BLAST FURNACE PRACTICE

The quality of the materials used in the manufacture of this book is governed by continued postwar shortages.

BLAST FURNACE PRACTICE

BY

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PREFACE

"Blast Furnace Practice" is a condensed story of the making of pig iron in the present-day iron blast furnace; it describes the raw materials, plants and equipment used, and the products and by-products manufactured. Operating practice, theories of the process, commercial aspects, and obsolescence are treated from a furnaceman's viewpoint.

This book is written for that increasing number of men engaged in the production and use of pig iron, in the mining and preparation of the raw materials, and in the building of blast furnace plants and equipment. It may be used as a reference book by students Although there has been a drastic reduction in the number of blast furnaces in this country since the World War, there has been a great increase in the number of technical men employed in the making and utilization of pig iron.

It is essential that the members of the operating organizations all along the line, from the working faces of the iron and coal mines through to the steel plants and foundries, should understand the effects of the quality of raw materials on the character of the final products Many of the qualities of pig iron in both its forms, liquid "hot metal" and solid "iron in pigs," even now are little understood; there are wide frontiers of blast furnace research still open for ambitious technical explorers.

For nearly a decade previous to 1938, no new blast furnace plants were built in this country, and there were some doubts as to whether the blast furnace was, after all, the best medium for getting metallic iron from its ores. That doubt is now past, and the blast furnace process with its American practice is recognized as the most efficient and economical method of producing pig iron. It is timely, therefore, to describe briefly the modern blast furnace and its solid, liquid, and gaseous products. This book is the result of many years of operating practice and research work and makes use of copious extracts from publications of contemporary furnacemen and research men who have helped to bring the art of making pig iron to its present advanced condition.

One aim of the author is to call attention to the need of further research in the fundamentals of ferrous metallurgy and to point the way to cooperative investigation of the reactions inside the blast furnace Although more of such work has been done in the past ten years than was done in the previous two generations, when the industry was striving for tonnage records, there is much still to be discovered.

High production is still demanded, but quality of product is becoming increasingly desirable.

To give proper acknowledgment to all those who have contributed to the writing of this book would be to make a very long list of all those men with whom the author has worked in all the many phases of the making of pig iron. The friendship of furnacemen is the greatest reward of the strenuous life around blast furnaces; the author is grateful to them all The author thanks the many contributors of text, photographs, and drawings reproduced in this book; as far as possible due credit is given in the text and in the legends

RALPH H SWEETSER.

NEW YORK, N Y,
October, 1938

CONTENTS

LIST OF TABLES

BLAST FURNACE PRACTICE

PART I

THE BLAST FURNACE PLANT

Introduction.—"Pig iron is the metallic product of an iron blast furnace." That is the definition officially announced by the Canadian Government about thirty years ago when there was a bonus on every ton of pig iron made in the province of Ontario. At first the iron made was all in pigs, but when molten iron was taken in ladles from the blast furnace over to the Bessemer department the Government inspector would not certify the weights because he claimed that the molten iron was not "pig iron"; hence the legal definition.

The United States Government, in the Tariff Commission makes a very clear distinction between "iron in pigs," and states that "molten iron is not an article of commerce," and says further that, "pig iron" applies to all iron produced in the iron blast furnace whether used in the molten condition or cast into pigs.[1]

Pig iron is the raw material for practically all iron and steel products. It has been made in this country for nearly three centuries, and for the first one hundred years Massachusetts produced more pig iron than any other colony. Then for two hundred years Pennsylvania led all other colonies and states up to 1932 and 1933 when Ohio produced a few tons more; in 1935 Pennsylvania took the lead again.

The first blast furnace built in Massachusetts on the Saugus River near Lynn nearly 300 years ago used charcoal for fuel in the smelting of the lean "bog" iron ores. It was a very small furnace making less than 1 ton of pig iron in 24 hr. The last blast furnace built in Pennsylvania uses by-product coke

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[1] *U. S. Tariff Commission Report on Iron in Pigs*, Feb. 2, 1927.

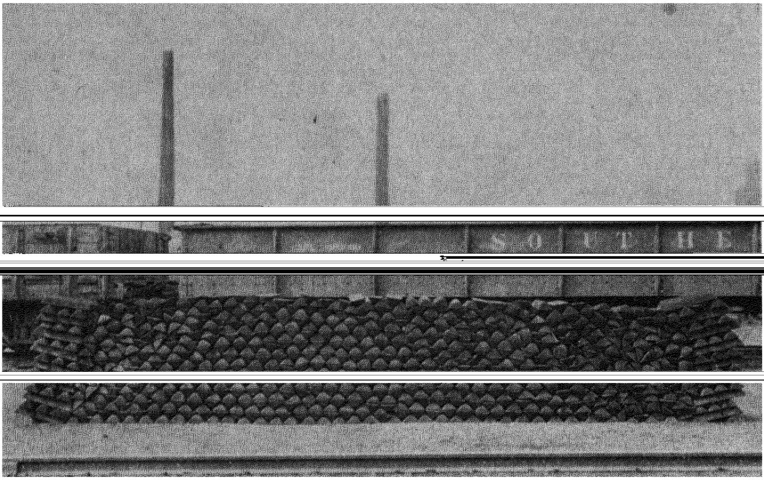

FIG. 1.—Iron in pigs. (*Courtesy of Woodward Iron Co.*)

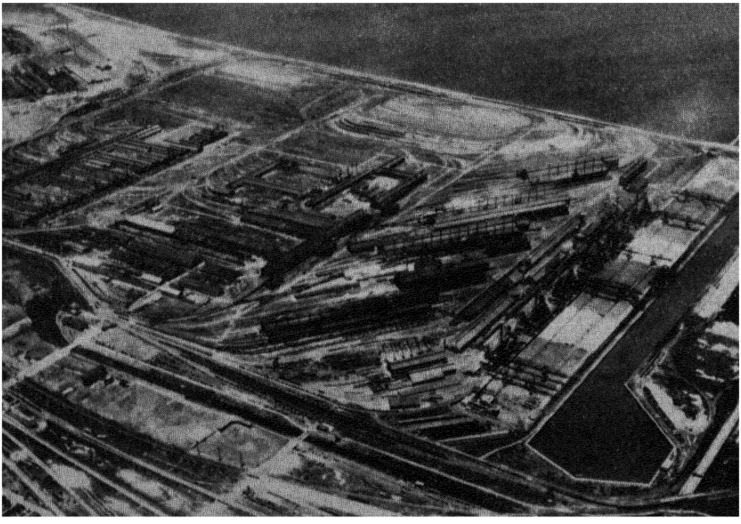

FIG. 2.—Pig iron is the raw material for steel. Gary Works, Gary, Ind. (*Courtesy of Carnegie-Illinois Steel Corp.*)

for fuel in the smelting of Lake Superior ores transported hundreds of miles on railroads and on ore boats on the Great Lakes. It is a very large furnace making 1,200 tons in 24 hr.

The blast furnace process in both these cases is practically the same; a column of solid iron ores (oxides of iron), fuel, and flux descends through the vertical shaft of the blast furnace, meeting a large volume of ascending hot gases containing about 34 per cent CO gas (carbon monoxide). The iron ores are reduced to metallic iron, which melts and is drawn off at intervals from the hearth of the furnace through the iron notch. The earthy constituents of the iron ores (the non-metallic elements) and of the ash in the coke combine with the lime and magnesia of the flux to form the blast furnace slag which passes out of the furnace through the cinder notch at intervals between the casts, and also at the casting time through the iron notch together with the molten iron.

THE IRON BLAST FURNACE

The modern iron blast furnace of the year 1938 is practically the same as the composite type of a 1,000-ton furnace selected by the Blast Furnace and Coke Oven Association of Chicago in 1930 with the exception that the top diameter is enlarged. It is the wonderful result of the development, through mechanical skill and cut and try methods in devising, of an apparatus strong enough to withstand the strain of a slowly moving descending column of solid materials gradually getting hotter and hotter till all are liquefied or gasified, meeting a voluminous column of swiftly ascending hot gases gradually getting cooler. The liquefied products, the molten iron and the molten slag, pass out of the furnace at the bottom intermittently, and the gasified products pass out at the top continuously.

Description.—A vertical cross section of such a blast furnace is shown in Fig. 3. The main parts of the iron blast furnace are the hearth or crucible, the bosh, the shaft, and the top; the usual dimensions given to designate the size of a furnace are: the height inside the lining from the level of the iron notch to the level of the top platform; the diameter of the bosh; the diameter of the hearth; the diameter of the stock line. The bosh angle is important and is now usually 80 to 81 deg. plus. Each part of the furnace has gradually been strengthened until for fuel in the smelting of Lake Superior ores transported hundreds of miles on railroads and on ore boats on the Great Lakes. It is a very large furnace making 1,200 tons in 24 hr.

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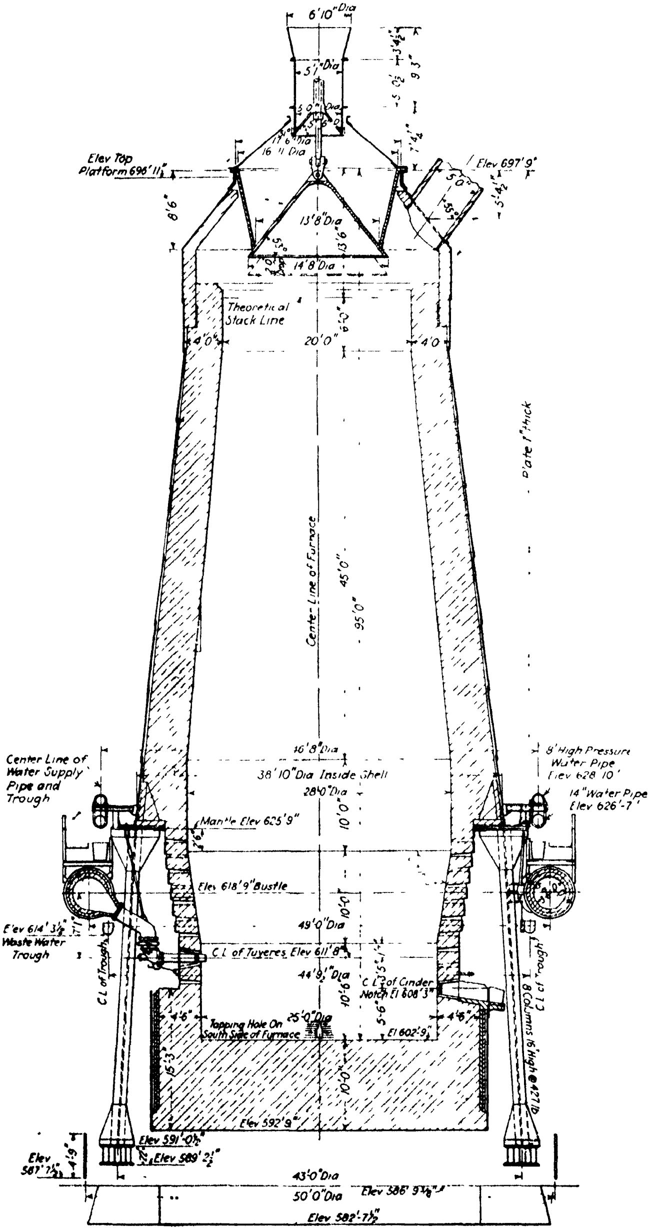

FIG. 3.—Large furnace with stock line 20 ft. in diameter. (*Trans. A I. M.E. vol.* 113, *Harlan.*)

now there is ample protection to the firebrick lining by means of strong steel hearth jackets, tuyere jackets, bosh bands and shells to hold the refractories in place, and water-cooled bronze bosh plates and water-cooled iron hearth plates to keep the refractories from melting out too fast.

The mechanical side of the blast furnace process has been brought to a high degree of efficiency, and the principles of heat exchange between the descending solids and ascending gases are correct in theory, though in most cases unevenly carried out in actual practice, but the chemical reactions are not yet satisfactorily solved because of the lack of enough research work to find out what really goes on inside the iron blast furnace, while it is in normal operation.

The Hearth.—The hearth, or crucible, of the furnace is the lowest part of the interior; it is the receptacle for the molten iron after it has melted and trickled down through the bath of molten hot slag that floats on the surface of the liquid iron. This bath of slag gradually rises until its upper surface is just below the level of the bottom of the tuyeres, when the slag is drawn off through the cinder notch down to a point where the blast begins to blow out a little with the flowing slag (see Fig. 3).

The level of the center of the cinder notch is 2½ to 3½ ft. below the level of the center line of the tuyeres, depending on the size of the furnace, and is 4½ to 5½ ft. above the level of the iron notch. The level of the iron notch when the furnace lining is new is usually about 18 in. above the inside bottom of the hearth, but after a while the firebrick bottom gradually cuts out and there is considerable depth of molten iron in the pool that remains in the furnace even after each cast (see Fig. 12).

The iron notch may seem to be a simple and an insignificant part of the blast furnace, but its proper care and upkeep are most important: through it, at intervals of 3 to 6 hr. depending on the practice and the requirements for hot metal, there will flow 50 to 200 tons of white-hot molten iron at a temperature of 2550 to 2750°F. When the level of the iron inside the furnace is down to the point when the blast begins to blow out the hot gases, the iron notch is shut by forcing a cylinder full of iron-notch clay from a powerful mud gun, which is truly an automatic breech loader operated by steam, compressed air, or electricity. The largest and latest types allow the iron notch to be shut without taking the blast off the furnace, and even without slacking the blast.

The Tuyeres.—Above the hearth are the tuyeres, regularly spaced around the circumference of the tuyere jacket through which the hot blast is blown into the furnace. They are 8 to 16 in number and are made of copper, or copper bronze, water cooled. They are easily removable and are fitted tightly into a tuyere cooler which helps to protect the firebrick lining at this very hot part of the furnace. The nose of the tuyere is usually circular, although tuyeres with oval openings have been used.

The Bosh.—Just above the tuyere jacket the lining of the furnace slopes outward till the maximum diameter of the interior of the furnace, called the "bosh diameter," is reached at a level about 10 or 11 ft. above the center line of the tuyeres. This section of the furnace is a truncated cone with its larger diameter at the top. In most furnaces there is a cylindrical part of the furnace, 4 to 10 ft. in height, of the same diameter as the bosh diameter, called the "straight part of the shaft," immediately above the bosh line.

The Shaft.—Above the bosh comes the shaft of the furnace which is another truncated cone, this time with its larger diameter the same as the bosh diameter, at the bottom, and its smaller diameter near the top of the inside of the furnace.

The Furnace Top.—All the solid materials used in making pig iron—the iron ore, the fuel, and the flux—are fed into the top of the furnace at more or less regular intervals and are delivered to the inside of the furnace without any serious interruption to the enormous and continuous stream of blast furnace gas that passes off the column of solid stock at the point where the cold fresh stock is delivered. The mechanical device that closes the top of the furnace so as to prevent the tons of hot gases from escaping into the air, and allows the raw materials to be delivered inside, is the double bell and hopper shown at the top of Fig. 3; the little bell is 5 ft. 6 in. in diameter and the big bell is 14 ft. 8 in. in diameter.

In order to deliver the "stock" (the mixture of the coke, ore, and flux) evenly around the circumference of the top of the stock inside the furnace, a revolving top, called the "McKee top" (invented by Arthur G. McKee), is almost universally used (see Figs. 14 and 15). By means of suitable mechanism the little hopper and little bell, together with whatever stock is on the bell, are revolved through the predetermined degrees of a circle, and then the stock is dropped onto the big bell until the big hopper is filled with its layers of ore, fuel, and flux. The little bell is then closed and the big bell lowered so that all the stock slides down into the furnace. The level of the top of the stock inside the furnace is kept at a few feet below the level of the big bell when closed; this level is called the "stock line." When the stock in the furnace is up to this level, the furnace is called "full."

The Downcomers.—The large annular space at the top of the furnace, around the big bell and hopper, is filled with the hot waste gas, called "blast furnace gas," which then passes out and down through one or more downcomers into the dustcatcher and through whatever cleaning devices there may be for removing the particles of fine dust from the gas. The off-takes for the gas are placed at equidistant points around the furnace top,as shown in the picture of the Warren, Ohio, furnace of the Republic Steel Corporation (see Fig. 4).

The weight of the waste gases passing off through the downcomers is at least 1½ to 1¾ times as great as the total weight of all the solid materials going into the furnace, and 3½ times greater than the combined weight of the molten iron and molten slag flowing from the furnace at the bottom. The volume of these gases is so great that the velocity at certain parts of the stream at the stock-line level has been found in some blast furnaces to be greater than the speed of Sir Malcolm Campbell's 2,500-hp. racing auto, "Bluebird," when he broke the world's record by driving at the rate of 301.3 miles per hour, which equals 5.02 miles per minute, or 4,419 ft. per second.

The Waste Gas.—The temperature of the waste gas as it comes off the top of the furnace is about 250 to 450°F., and consequently carries off much sensible heat. Its calorific value varies from about 90 to 105 B.t.u., according to the materials used and the blast furnace practice. Blast furnace gas is a valuable by-product, and when properly cleaned is cleaner than the air we breathe; it is used for heating the blast for the blast furnace plant and often for surplus power, for gas engines, for underfiring coke ovens, and for various uses around the steel plant and sintering plant.

Hot-blast Stoves.—About 20 per cent of the waste gas is burned in the hot-blast stoves for heating the blast to a temperature of 1250 to 1600°F., thus recovering a considerable amount of heat removed from the furnaces by the waste gases. The checker brick of the stoves absorbs the heat from the burning of the waste gas in the combustion chamber of the stove; then, when the cold-air blast from the blowing engines is blown through the checker brick in the stoves, it takes on much of the heat that has been stored up (see Figs. 4 and 5).

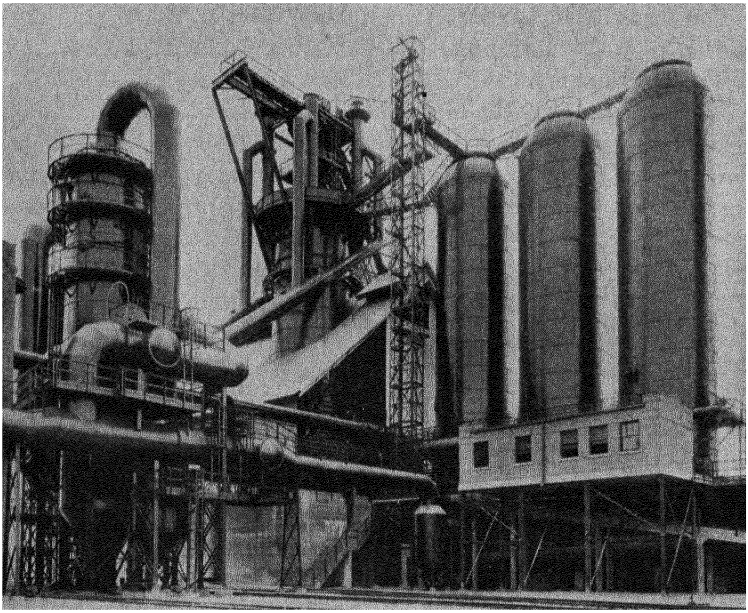

FIG. 4—Blast furnace, stoves, gas washer. (*Courtesy of The William B. Pollock Co.*)

Blowing Engines. The air blast is greater by weight than all the solid materials put together for the production of a ton of pig iron, being over 4 tons (8,960 lb.) per 2,240 lb. of iron. All this air is taken from the atmosphere and pumped by reciprocating engines or else rotary compressors and forced through the hot-blast stoves on into the blast furnace. This takes much power which is generated from the waste gases, either directly or indirectly, so that a large part of the energy in the surplus fuel used in the blast furnace process is recovered and utilized in the process itself. Formerly all this surplus energy was consumed in heating the blast and in raising steam to furnish power for operating the whole blast furnace plant.

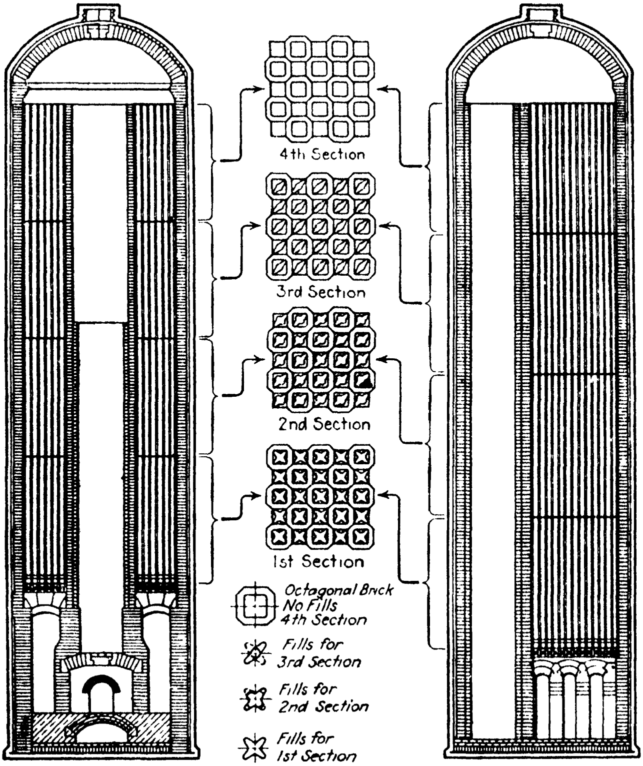

FIG. 5.—Vertical cross section of hot-blast stove. (*Trans. A.I.M.E.*, *vol.* 113, *Harlan.*)

The Raw Materials.—The whole iron and steel industry is based on units of iron and units of fuel (usually carbon). The element iron, Fe, makes up about 94 per cent of the product pig iron, the balance being other metals and metalloids. The carbon not only furnishes the heat and forms the reducing agent for smelting the iron from its ores, but a certain percentage (3.50 to 4.50 per cent) of carbon enters into the chemical and physical composition of the pig iron itself.

In a typical case it required the following materials to make a ton of pig iron:

Iron ore	4,333 lb.	1 934 gross tons
Coke	2,162 lb	0 965 gross ton
Limestone	1,078 lb.	0 481 gross ton
Solid materials	7,573 lb.	3 380 gross tons
Air blast	8,885 lb.	3 966 gross tons
Total materials	16,458 lb	7 346 gross tons

This statement shows the importance of the blast furnace in reference to freight tonnage; to produce 1 gross ton of pig iron it requires about 3½ gross tons of solid materials besides the miscellaneous supplies and repair materials.

The products of the blast furnace are

Pig iron	2,240 lb.	1 000 gross ton
Slag	1,222 lb	0 545 gross ton
Gas	12,721 lb	5 679 gross tons
Flue dust	200 lb	0 088 gross ton
Total		7 312 gross tons

Roughly speaking this means about 2 tons of ore, 1 ton of coke, and half a ton of limestone to make 1 ton of pig iron and a little more than half a ton of slag. This means that a blast furnace plant making 1,000 tons of pig iron in 24 hr. would require:

Inbound	about 2,000 tons of iron ore	=	40 carloads
	about 1,000 tons of coke	=	25 carloads
	about 500 tons of limestone	=	10 carloads
	3,500 tons		75 carloads
Outbound	about 1,000 tons of pig iron	20	
	about 500 tons of slag	11	31 carloads
To the atmosphere	about 5,700 tons	Waste gas	114 carloads

The Process.—It is a strange metallurgical process that requires 75 carloads of inbound freight and produces only 31 carloads of outbound freight, sending the equivalent of 114 50-ton carloads of waste gases into the atmosphere.

Here again, the mechanical equipment and the mechanical practice have reached such perfection that waste gases are now so thoroughly cleaned that when they are finally wasted into the atmosphere there is less solid pollution than there is in the air in any room.

But the strangest part of the blast furnace process is the immense success in its manufacture in spite of the rather meager knowledge of the fundamentals pertaining to the reduction of iron oxides by means of carbon monoxide in the presence of carbon and carbon dioxide. According to the theories of the scientists and physiochemists, there are reactions of reduction and of reoxidation continually taking place within the shaft and the bosh of the furnace From the samples of iron and slag withdrawn through the tuyeres, we know positively that these reactions are not complete even when the molten iron and the molten slag pass down through the combustion zones in front of the tuyeres where the solid incandescent coke meets the hot blast and is converted into a mixture of carbon monoxide and nitrogen having a temperature of about 3500°F.

The molten iron passes down through a layer of molten slag and is instantaneously purified from nearly all the sulphur which had combined with it shortly after being reduced from the oxide. The character of the slag must be such in chemical composition and temperature as to cause the sulphur in the molten iron to be changed into calcium sulphide which in turn is dissolved in the molten slag which floats on the surface of the molten iron like cream on top of milk.

THE 1,000-TON FURNACE

When a group of blast furnacemen, actively engaged in the operation of or in the designing and building of blast furnaces, work together for several months studying the designs and performances of large blast furnaces, with the aim of agreeing on a composite plan for a blast furnace that would make 1,000 tons of pig iron per day, it is certain that the consensus of opinion will be a design sound in principle and capable of the desired performance. Such was the case with the committee of the Blast Furnace and Coke Association of the Chicago District which presented its classic report, entitled "The Modern Blast Furnace and Auxiliaries," on Apr. 1, 1930, in Chicago.

The conclusions, designs, and dimensions agreed upon were so conservative that many blast furnaces of similar form and size have produced more than 1,000 tons per day; some as much as

1,400 tons. The author's own remarks on the design, published in the annual number of *Blast Furnace & Steel Plant*, January, 1931, were as follows:

> I know that blast furnaces approximately of these dimensions are already making 1000 tons, or more, pig iron per 24 hours. Naturally, I will apply the rule of the Southern Ohio Pig Iron and Coke Association to determine the capacity of this furnace computed at the rate of burning 60 lbs. of coke per cubic foot of working volume per 24 hours, the "working volume" being the cubical contents of the furnace from the level of the center line of the tuyeres to 2 feet below the bell when closed. According to the dimensions of Fig. 9 of the report [Fig. 6] the furnace has a working volume of 34,906 cu. ft. from center line of tuyeres up to the stockline, at 60 lb. of coke per cubic foot the furnace should burn 2,094,363 lbs. of coke, which at 1900 lbs. coke per ton of pig iron means 1102 tons of pig iron per 24 hours. There is no doubt but the furnace can do it if the coke ash is not over 10 per cent and if the ore mixture contains as much as 51½ per cent iron natural.
>
> If the furnace should be filled to within 2 feet of the bell when closed, the calculated capacity of the furnace would be increased about 35 tons to a total of 1137 tons per day.
>
> Weirton No. 1 blast furnace is similar to the proposed furnace in most dimensions, but is only 91 ft. 6 in. high; its hearth diameter is 25 ft. 6 in. and bosh diameter 28 ft. 6 in. This furnace makes comfortably over 1000 tons per day.

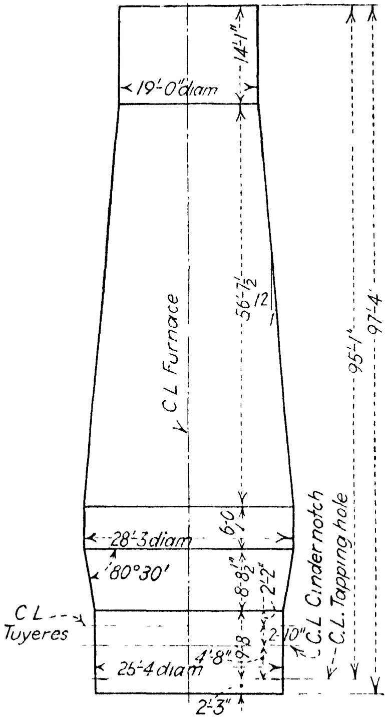

FIG 6 —Lines of 1,000-ton furnace. (*Courtesy of Blast Furnace & Coke Oven Assoc., Chicago.*)

In the same January, 1931, issue of *Blast Furnace & Steel Plant*, H. A. Brassert called attention to the fact that

The 1000-ton furnaces of today have hearths more than twice the area of their stock lines. The outcome of this development is an ill-proportioned furnace approximately the shape of a bottle. It has given the desired tonnage, but the increased production has been generally accompanied by high ore losses and a relatively high coke consumption,

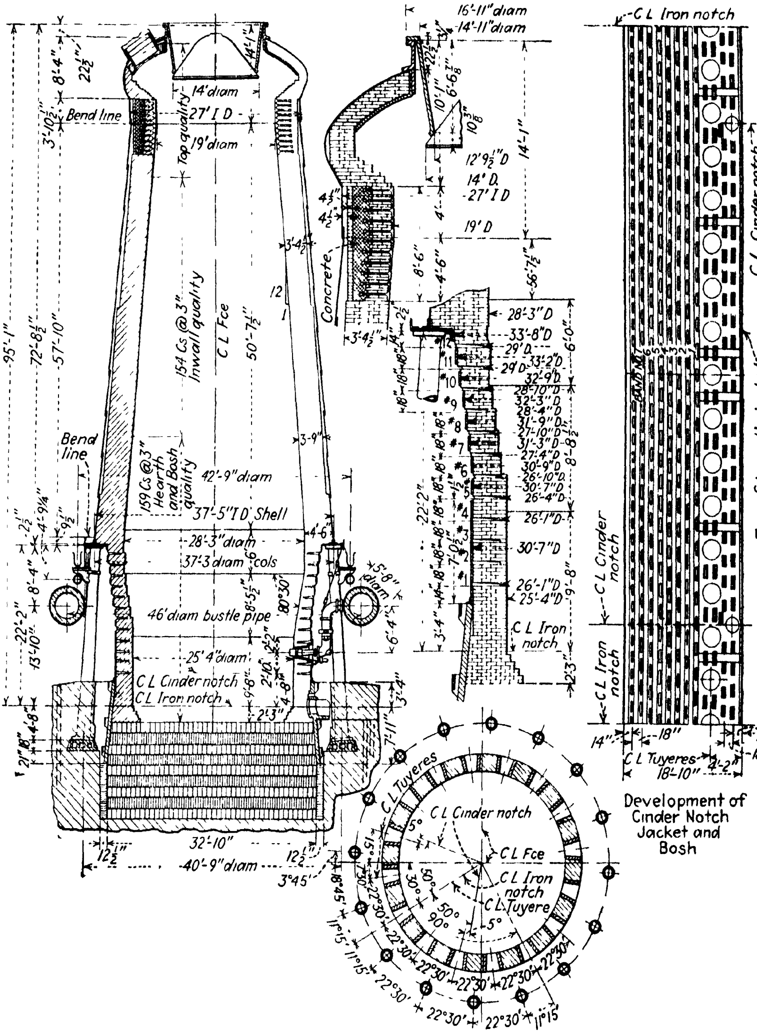

FIG. 7.—Brick lining, shell, and jackets of 1,000-ton furnace. (*Courtesy of Blast Furnace & Coke Oven Assoc., Chicago.*)

> items which in some cases have more than offset the saving in labor and general expense. If the furnace were blown in proportion to the size of its hearth, all the fine ore would be blown over into the dust catcher. . . .
>
> I am of the opinion that more attention should be given to increasing the heights of the stacks in proportion to the great increases below.

The correctness of these comments of Mr. Brassert has been demonstrated during the past seven years, and about the only changes in blast furnace design have been the widening of the top of the furnace and some increase in height.

The dimensions of this 1,000-ton furnace were as follows:

Hearth diameter	25 ft 1 in
Bosh diameter,	28 ft 3 in
Stock line diameter	19 ft. 0 in.
Bosh height, slope	8 ft. 8½ in
Tunnel head at top of bosh height	6 ft.
Height of inwall	56 ft. 7½ in
Height of throat at stock line	14 ft 1 in
Height of furnace overall	97 ft 4 in
Height of furnace center line of tapping hole to deck ring	95 ft. 1 in
Diameter of bell	14 ft.
Angle of bell	50 deg.

A thickness of brick of 31½ in. in the hearth and bosh walls, and an average of approximately 45 in. in the remainder of the stack makes it possible at some future time, without change of shell or hearth sections, to increase the size of the furnace by an additional 18 in. No cooling plates have been proposed above the mantle. Sixteen tuyeres and columns are proposed. A stock line armor embedded in a reinforced band has been included.

The lines of this proposed furnace are shown in Fig. 6. The details of the brick-lining, construction of shell and hearth jacket and cooling plates are shown in Fig. 7.

The stocking and charging equipment consisted of the following:

Ore bridge and unloader:

Two 10-ton bucket-man trolley unloaders, 550 tons per hour

Ore bridge rated at 15 tons with free stocking capacity of 750 tons per hour

Ore Bins:

Number and material	Capacity per bin, tons	Total capacity, tons
9 ore	230	2,070
3 limestone	157	471
2 scrap	500	1,000
1 open-hearth slag	250	250
1 roll scale	350	350
1 sinter	320	320
1 coke, center bin		230
3 unit coke	40	120
21 bins total		

The bins are served with double-compartment scale car, each hopper having 250 cu. ft. capacity; rated at 25 tons. It would have a speed of 600 ft. per minute.

> The coke from the central coke bin chutes, with no provision for coke breeze screening, into an automatic weigh hopper of 200 cu. ft. capacity. . . . When desired, coke may be charged in weigh hoppers on volumetric basis.
>
> The operation of skip, bells, distributor and stockline recorder is effected by automatic sequence control.

Only two men per turn are employed.

The double-skip hoist is of cantilever type; "each skip is of 200 cu. ft. effective volume, bail type, and provided with roller bearings and discharges into a McKee distributor having an effective volume of 230 cu. ft. Skip hoist, bell hoist, McKee distributor and stock-line recorder all are tied into one synchronized control." (See Fig. 8.)

CONSTRUCTION OF THE SHELL

The shell of the blast furnace is that part of the steel jacket extending from the mantle upward to the top platform, and enclosing the brick lining of that part of the furnace called the "shaft" where the preheating of the charge and most of the reduction of the iron ore take place. It is essential that the shell be strong enough to hold the brick lining firmly in place when it is subjected to the expansive force of heat and, sometimes, to the more powerful expansive force of the reactions of certain nonferrous metallic oxides, such as zinc and lead. The shell usually supports the top platform and all the bells and operating mechanism of the furnace top, as shown in Figs. 4 and 13. Sometimes the top platform and superstructure are supported on structural-steel columns resting on the mantel. The plates at the mantel are heaviest, $1\frac{1}{8}$ in. thick on big blast furnaces for at least two rows of sheets above the mantel; then come $\frac{3}{4}$-in. plates, or at least $\frac{5}{8}$-in. plates, up to the top plates, which are a little heavier. The butt straps for the riveted shells are of heavy construction. Recently some furnace shells have been welded throughout.

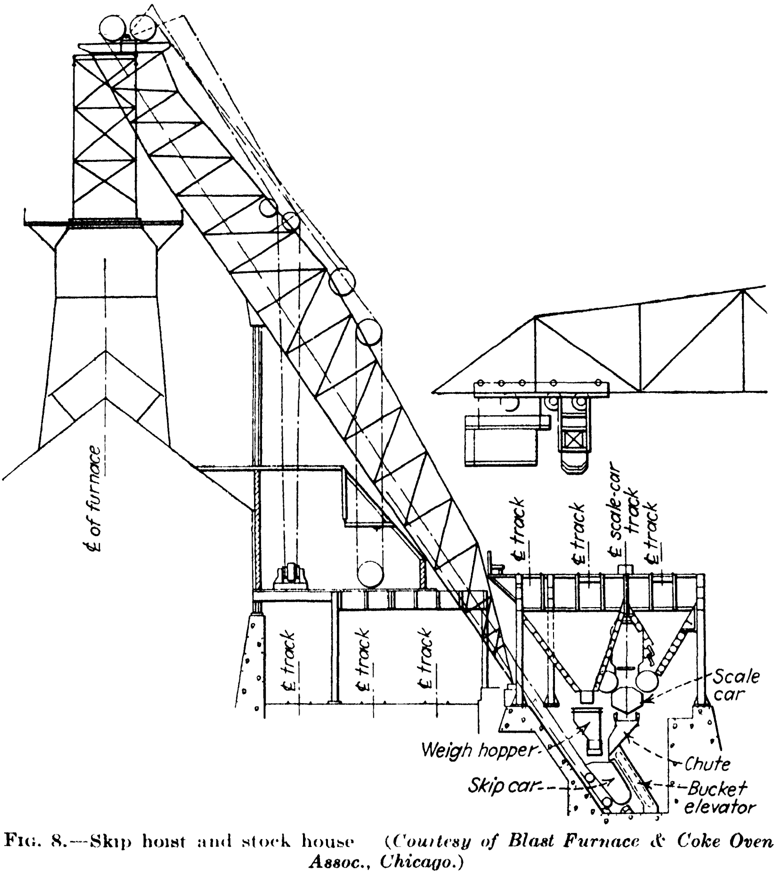

FIG. 8.—Skip hoist and stock house (*Courtesy of Blast Furnace & Coke Oven Assoc., Chicago.*)

Construction of the Bosh.—The bosh of the blast furnace, the part sloping a little more or a little less than 10 deg. from the perpendicular and extending upward from just above the tuyeres to the mantel, is subjected to the highest temperatures inside the furnace, and the firebrick used must be especially protected and supported; this part of the furnace does not support anything but is itself supported by the hearth jacket, or, in some cases where there is a steel-plate bosh jacket or a "petticoat" jacket, is suspended from the mantel.

The fire-clay bricks of the lining are protected more in this part of the furnace than in any other, chiefly by bronze bosh plates through which clean water circulates, it is not necessary that this water be very cold but it must not reach a temperature too hot for the furnacemen to handle in case of changing a leaking plate. Usually this water is recirculated after being cooled in a spray pond. The bronze cooling plates are kept in position by cast-iron or steel bosh-plate frames such as shown in Fig. 10, which are held in place either by what is described[1] as "practically a permanent bosh," or by strong, wide, steel bosh bands supported from the mantel by strap hangers fastened to

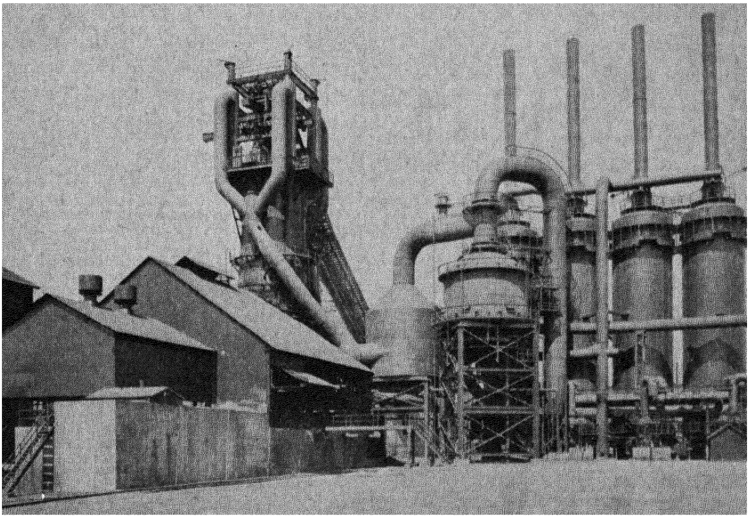

FIG. 9. A Southern merchant furnace. (*Trans. A.I.M.E., vol.* 120, *Crockard.*)

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[1] By Francis H. Crockard in his paper "Progress in Southern Blast-Furnace Practice" (*Trans. A.I.M.E.*, vol. 120).

each succeeding bosh band (see Fig. 11). The angle of the bosh shown in Fig. 10 can be changed by changing the position of the nose of bosh plates.

Construction of the Hearth.—The hearth of a blast furnace requires the heaviest and strongest construction, not only because of the weight and pressure of the tons of molten iron and slag, but because of the danger resulting from the slightest crack in the brickwork through which iron might trickle and eventually cause a breakout in the hearth, formerly one of the most disastrous accidents around a blast furnace, but now seldom experienced.

Figure 11 shows the design of a 25-ft. hearth as built by Arthur G. McKee & Co. The hearth jacket of 1½-in. steel plate is 14 ft. deep with cast-iron water-cooled plates between the jacket and the brickwork; the total depth of 15 ft. of bottom brick laid as indicated should prevent the formation of any sizable salamander.

The outline of a salamander weighing only 77 tons is shown in Fig. 12. It is remarkable for its small weight and for the very distinct cleavage plane at the top of the bottom course of 13½-in. brick inside the hearth jacket. These bottom "blocks" (13½ by 6 by 3 in.) were hard burned, carefully made and sized, and most carefully laid.

Big-hearth Furnaces.—Each decade of blast furnace practice has some particular dimension that is emphasized, such as the angle of the bosh, the diameter of the bosh; beginning about 1927, it was the big-hearth furnace. Several furnaces with hearth diameters of 25 ft. were built, and at the Aliquippa Works of Jones & Laughlin one furnace, No. 4, 90 ft. high, had a hearth diameter of 27 ft., and the biggest hearth diameter (No. 3 furnace) at the same plant was 28 ft. 6 in. This furnace was 90 ft. high, with 30-ft. bosh diameter and 86-deg. bosh angle. The stock line was only 19 ft., which was out of proportion. Both furnaces had 12 columns and 18 tuyeres. In No. 4 furnace have been made over 2,100,000 tons on the original lining with only minor repairs to the stock line.

The big-hearth furnaces at Weirton, W. Va., are 91 ft. 6 in. high with 25 ft. 6 in. hearth diameter and 19 ft. 4 in. stock line; 16 columns and 16 tuyeres on one furnace and 12 columns and 12 tuyeres on the other.

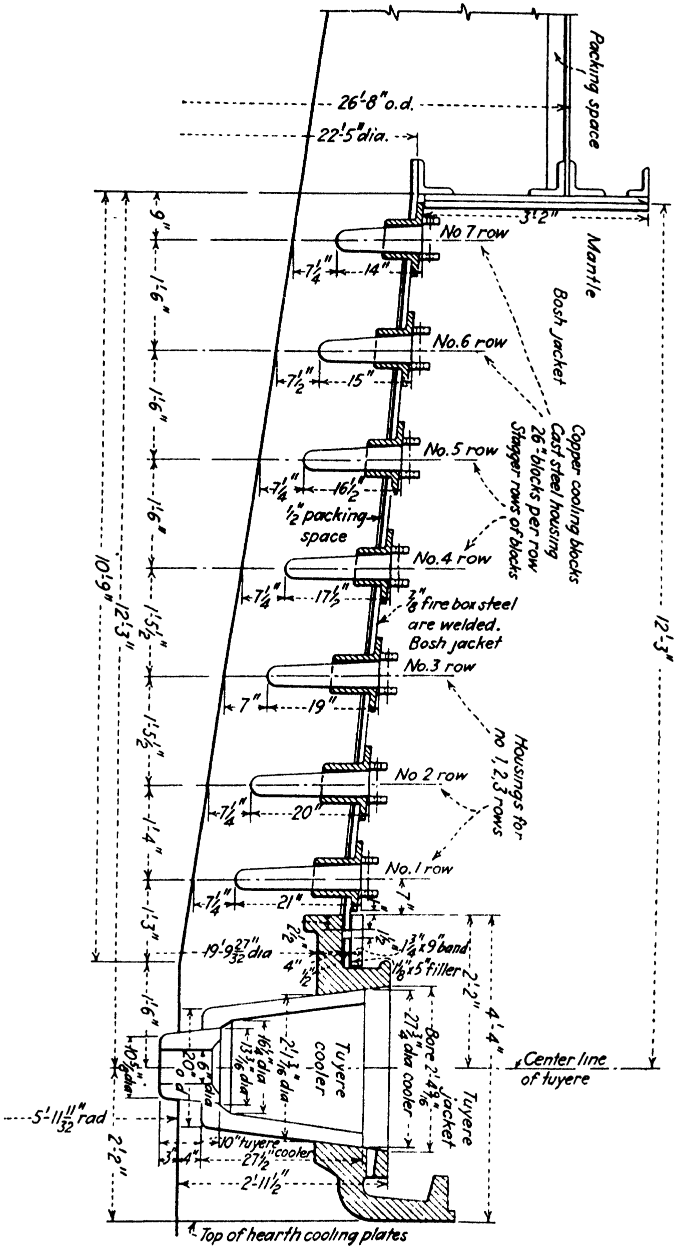


FIG. 10.—Arrangement of new bosh. (*Trans. A.I.M.E., vol.* 120, *Crockard.*)

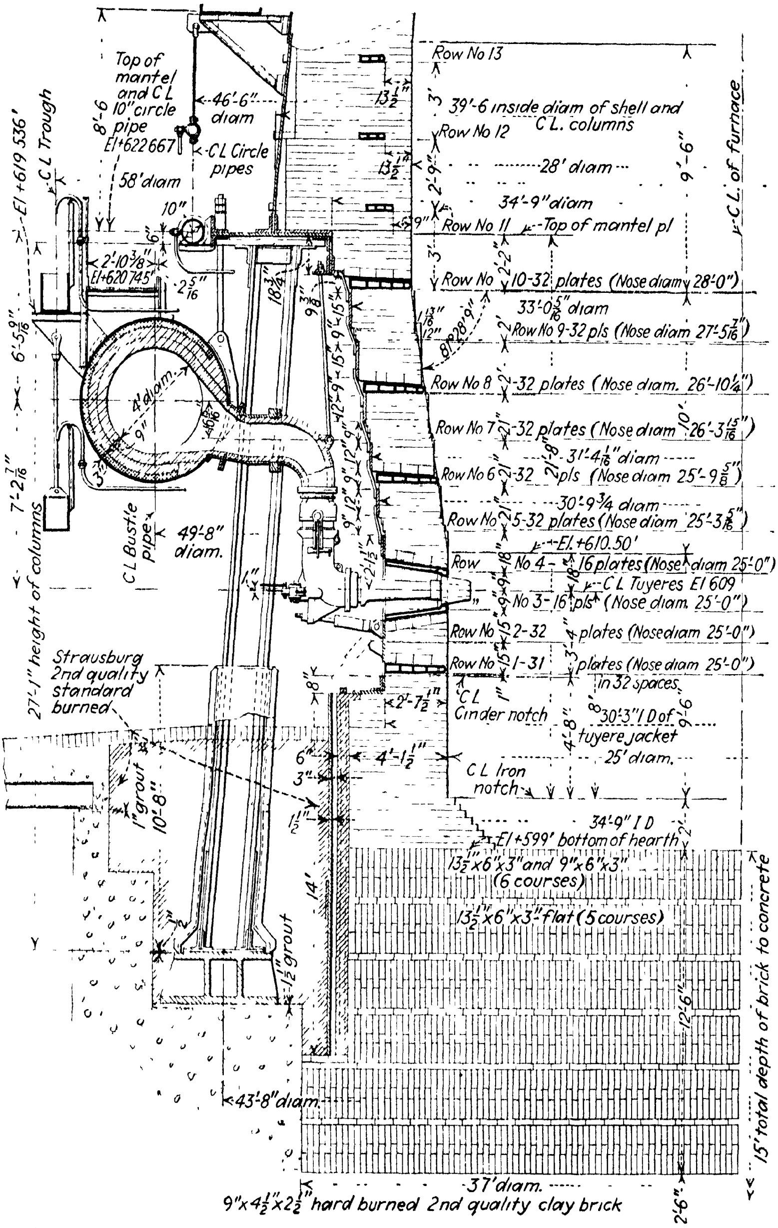


FIG. 11.—Construction of hearth of modern blast furnace. (*Courtesy of Arthur G. McKee & Co.*)

Some of these big furnaces are as easily handled as those much smaller, but apparently the only advantage they have is the large tonnage of hot metal that can be held in the hearth and cast at one time. All the above furnaces make over 1,000 tons per day, some over 1,200 tons, but apparently there is no saving in coke consumption.

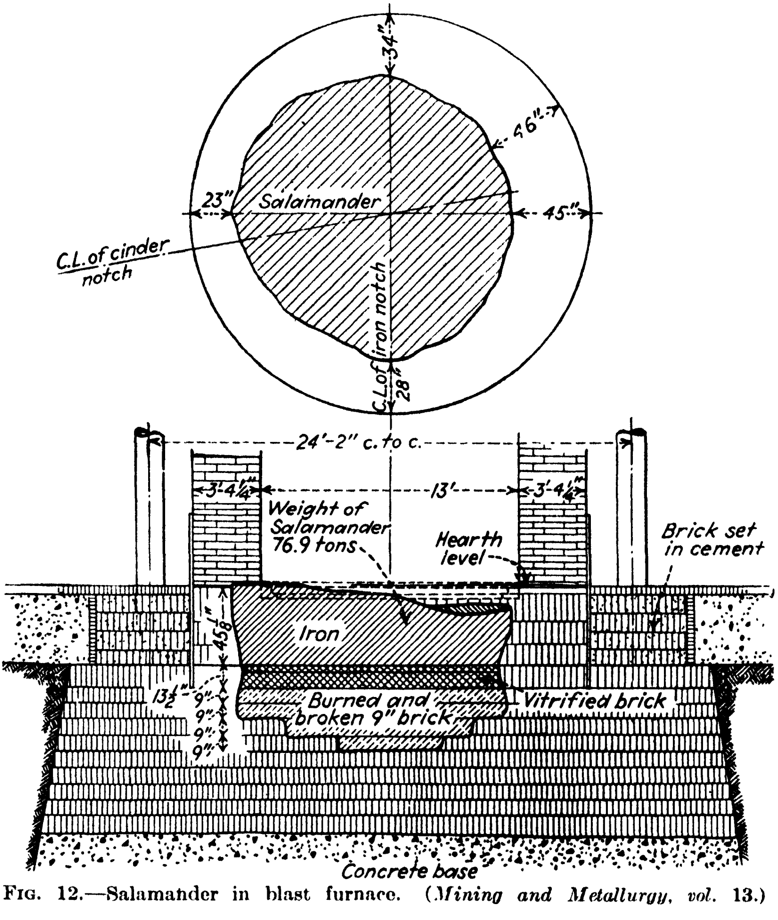


FIG. 12.—Salamander in blast furnace. (*Mining and Metallurgy, vol.* 13.)

Construction of the Top.—The top of a modern blast furnace must provide adequate, automatic, and accurate means for the two-way travel of all the descending solids that enter the furnace and all the ascending gases that leave the furnace. In the cross-section view of a blast furnace (Fig. 3) is shown the double-bell and double-hopper arrangement for lowering the charges of ore, coke, limestone, and scrap into the top of the furnace, and at the same time preventing the escape of the waste gases except through the off-takes and downcomer such as shown in Fig. 13.

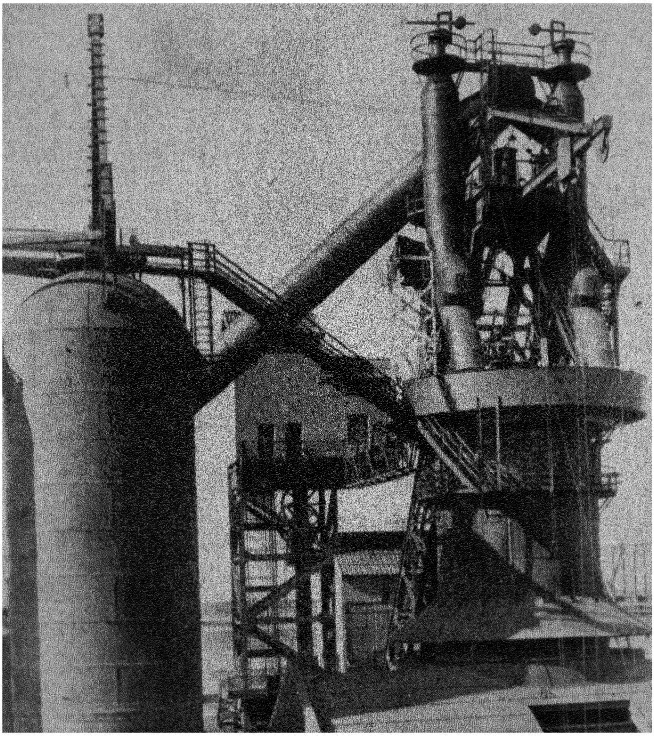


FIG. 13.—Construction of furnace top (*Courtesy of Arthur G. McKee & Co*)

There must be room enough on the top platform for men to work in changing bells and hoppers and making any necessary repairs to the revolving top or charging apparatus. The bells and hoppers, downcomers, gages, etc., will be described in later chapters.

The McKee Revolving Top.—After double bells and skip hoists replaced "top fillers" (men on top who dumped the buggies of ore, coke, and limestone into the single big hopper) and the vertical platform elevators, it was found that it was impossible to distribute satisfactorily the stock on the big bell so that successive charges of ore, coke, and limestone were evenly lowered into the furnace Many devices were designed and installed with varying degrees of improvement, but the most successful was the McKee revolving top invented by Arthur G McKee.

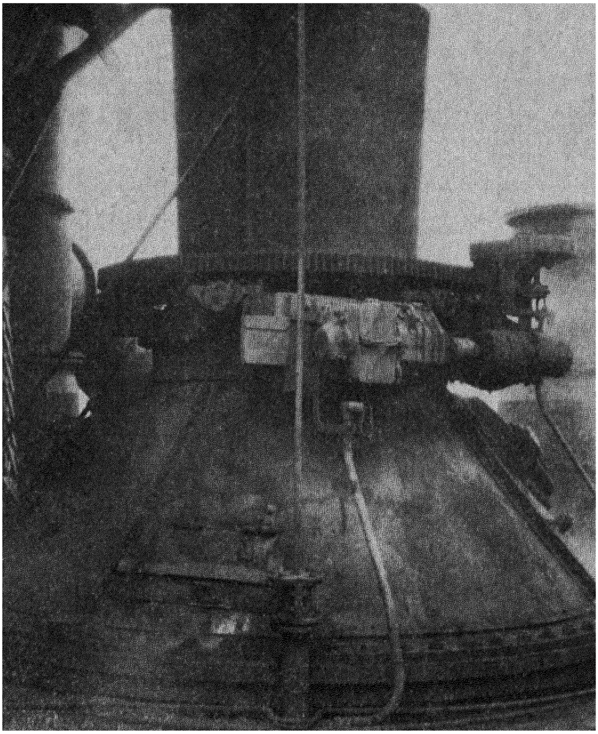


FIG 14 — McKee revolving top (*Courtesy of Arthur G McKee & Co*)

A photograph of the exterior of the McKee revolving top is shown in Fig. 14, and a cross section of the revolving hopper and the small bell is shown in Fig 15 An electric motor, automatically controlled, revolves the hopper and small bell through a predetermined part of a circle so that each skipload of the stock is dumped onto the big bell at a spot different from the preceding skipload, thus distributing the stock regularly inside the furnace when the big bell is lowered This arrangement prevents the

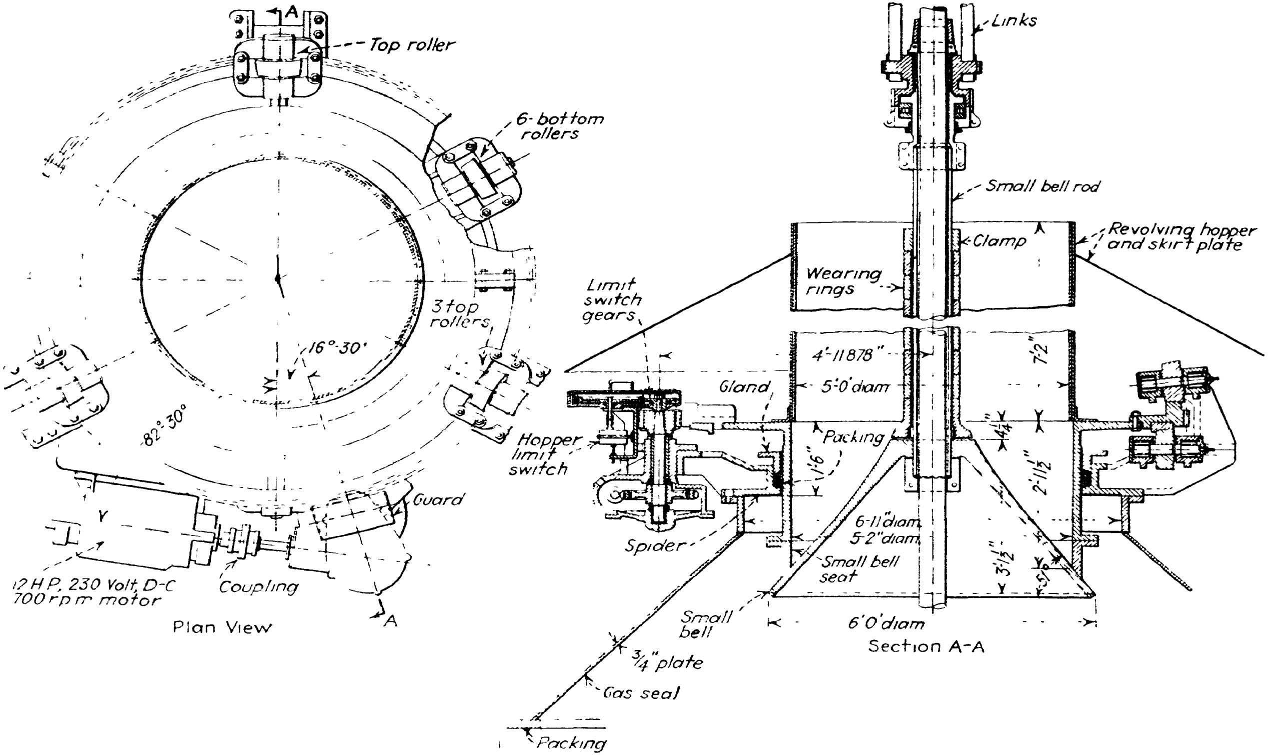


FIG. 15 — Cross section of McKee revolving top. (*Courtesy of Arthur G. McKee & Co.*)

segregation of the big lumps of materials all going to one side of the furnace, which would be opposite the skip hoist if it were not for the revolving top.

LINES OF BLAST FURNACES

Of all the 1,870 blast furnaces built in this country from the days of the Massachusetts colony to the time of the new Ford Motor Co furnace now in construction, it is safe to say that very few have had properly proportioned "lines," as the inside dimensions of heights and diameters are called. Fashions in furnace lines in these three centuries (from 1645 to 1938) have changed as often and as radically as the fashions in women's dresses, especially in reference to the size and the height of the bosh or waist line. These changes were due chiefly to the lack of the knowledge of the fundamentals of smelting iron ores

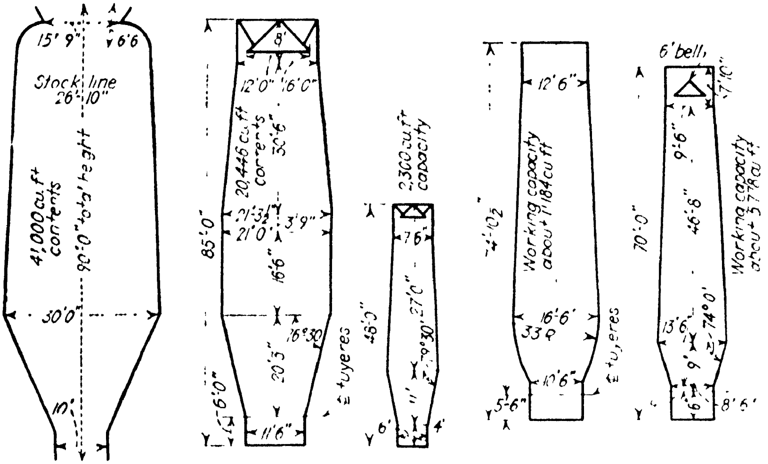
In a later section, Theories and Lack of Theories, mention is made of the fact that false theories, based on incomplete data, have been responsible for many queer and uneconomical designs of blast furnaces. One notable monstrosity was the famous Ormesby furnace, built in England about 1869, as a trial to lower the temperature of the waste gases by enormous capacity (41,000 cu. ft.); but it made only 79 tons per day and failed to gain anything over the other furnaces (see *A* in Fig. 16)

In Fig. 16 are the lines of five furnaces built at different times and places. Three, *C*, *D*, and *E*, had certain proportions conducive to good practice and obtained excellent results compared with the records of that period. The recorded data of these furnaces follow:

Furnace	Location	Year	Fuel	Tons of pig per day	Fuel per ton of pig	Total cu ft capacity	Pounds fuel, 24 hrs.
A	England	1869	Coke	79	2,205	41,000	171,195
B	Maryland	1893	Coke	236	2,396	20,446	565,456
C	Michigan	1894	Charcoal	73	2,060	2,300	150,380
D	Ohio	1895	Coke	207	1,664	11,184	344,000
E	Ontario	1905	Coke	200	2,400	6,119	480,000
E	Ontario	1905	Charcoal	124	2,000	6,119	248,000

There was something out of balance in all the above furnaces; *C* came nearer being right than any of them. Furnace *E* was blown too hard when using coke and not enough when using charcoal; it should have made 200 tons of coke iron on less fuel; it did make 160 tons of charcoal iron per day when there was enough charcoal.

In the gradual enlargement of the hearth diameter, there had not been, until recently, a corresponding increase in the stock line; this has been due largely in recent years to the fact that furnace shells, lasting through several relinings, are not large enough to allow for the requisite increase in stock-line diameter; and, moreover, the present forms of bells and hoppers would not give what is supposed to be the proper distribution of the stock.



Coke 1869
79-tons
England
"A"

Coke 1893
Maryland
"B"

Charcoal-1894
Michigan
"C"

Coke 1895
207-tons
Ohio
"D"

Coke-1905
200-tons
Ontario
"E"

FIG. 16. Lines of furnaces.

Very few blast furnaces have lines exactly alike, and in the few cases where this has happened the furnaces do not perform exactly alike; there seems to be a certain personality about a blast furnace that persists throughout its lifetime.

As long as there are succeeding generations of blast furnacemen, and as long as there are changes in the character of iron ores and fuels, there will be changes in the lines of blast furnaces.

THE BRICK LINING

The present practice in blast furnace linings is to use 9- and $13\frac{1}{2}$-in. brick made of various mixtures of fire clay, finely ground, machine pressed, and burned hard at temperatures higher than those to which the brick will be subjected inside the blast furnace. In Figs. 7 and 11 can be seen the methods of laying the firebrick in different parts of the furnace

The requirements for firebrick for the different parts of the furnace vary greatly. The hearth and bosh brick must be highly refractory (70 per cent flint clay, 15 per cent calcine, 15 per cent plastic) to withstand the high temperatures and the slagging action of molten slag and iron. The brick for the hearth bottom must be burned at high temperatures so that there will be no "secondary shrinkage" when the brick are subjected to the high temperatures of molten pig iron, otherwise the bottom brick would "float" and the hearth lining would be ruined Such cases have happened.

The firebrick for the lining of the tuyere jacket and of the bosh must also be highly refractory and tightly laid. These bricks, because of very high temperatures, must be held in place and kept from supporting much weight since their strength greatly diminishes when approaching the softening temperature of the clay mixture from which the brick were made. The brick in this part of the furnace are further protected by water-cooling devices to be described later.

The inwall brick for lining the shaft of the furnace have to withstand abrasion, pressure, chemical reactions from the gases and considerable temperature but not so high as the brick below the mantel.

The "top" brick must be the hardest and densest so as to withstand the shocks and abrasion of the stock as it is dumped off the big bell into the furnace A larger percentage of plastic (30 per cent plastic, 50 per cent flint, 20 per cent calcine) fire clay is used in the top brick which should be hard burned

One of the most necessary requirements for firebrick in a blast furnace lining is that all the sizes and shapes should be accurate with regard to dimensions, especially thickness. This accuracy can be obtained by the proper selection, grinding, mixing, pressing, and burning at the brick plant Power presses (electrohydraulic or toggle) are now generally used; hand molding and auger presses cause laminations in the brick; grain sizing and deairing are recent improvements.

The life of a blast furnace lining is usually measured in hundreds of thousands of tons of pig iron made; several records of over 1,000,000 tons, some over 1,500,000 tons, and a few of 2,000,000 tons have been made

The chemical analysis of a deaired brick for a blast furnace lining made from Kentucky fire clays was as follows:

AVERAGE OF 2 DETERMINATIONS (A.S.T.M. C-18-21)

Element	Per Cent
Silica	55.41
Alumina	37.09
Iron oxide	1.85
Titania	2.18
Lime	0.30
Magnesia	0.63
Alkalies ..	2.29
Total	99.75

Pyrometric Cone Equivalent $32\frac{1}{2}$-33 (A.S.T.M. C-24-31)

Subsidence in load test at 1350°C = 1.0% (2462°F.) under 25 lb. pressure per square inch (A.S.T.M. C-16-20) avg

Comparative abrasion test = 0.261 cu. in. per minute, and cold crushing on 9 by 6 by 3 in., per square inch = above 5,723 lb. (*Courtesy of North American Refractories Co., Cleveland, Ohio.*)

Cyanonitride of Titanium.—In the salamander (see Fig. 12) of a blast furnace there are often found clusters of beautiful copper-colored crystals of cyanonitride of titanium, which erroneously were believed to be caused by magnetic iron ores containing titanium. On finding such crystals in the salamander of a furnace that had not used magnetite, the author had a sample analyzed; the result was titanium 12.0 per cent and nitrogen 2.0 per cent. There were flecks of the copper-colored crystals in the vitrified brick shown in Fig. 12.

Roy A. Lindgren gives some excellent illustrations of the behavior of firebrick in blast furnace linings in his paper[1] "Some Observations Regarding Refractories for Iron Blast Furnaces."

The firebrick lining of the bosh of a furnace, and also that part of the brickwork extending from the top of the hearth

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[1] *Trans. A.I.M.E.*, vol. 125.

jacket to the top of the tuyere coolers, is protected by bronze, or copper, cooling plates as shown in Figs. 7, 10, and 11. These bronze bosh plates, cast with a taper on top and on both sides so as to be withdrawn from the furnace wall in case of a leak, are put in place as the brick are laid. Sometimes a layer of "chicken feed" (a mixture of crushed firebrick and fire clay) is laid over the bosh plate, and the brick laid flat, but it is better to build arches over each plate with side arch brick as shown in Fig. 99.

Cold water circulates through the bosh plate, each plate being connected so that the feed water goes directly to the nose of the plate which is sometimes placed flush with the inside face of the brickwork, as in Fig. 11, and sometimes set back a few inches, as in Fig 10.

Although most furnaces have no bronze cooling plates above the mantel, there are several furnaces that have the Dovel bronze cooling plates all the way from the mantel to the top In the case of an inwall that is badly worn, these plates can be inserted from outside the furnace through holes cut in the shell A bosh-plate frame bolted to the shell holds the bosh plate in place.

Stock-line Plates; Sprays; Castings. To protect the top brick, especially near the stock line where the stock falling off the big bell strikes the walls, many designs of cast-iron and cast-steel plates have been used; solid blocks of cast iron, the thickness of one course of brick; angle plates extending back into the furnace wall and set in concrete; heavy steel protection rings, or "thimbles," suspended on rods hanging down from the brackets that support the big hopper; and, in a few cases, the Dovel top of solid steel jackets bolted together and with no brickwork inside.

A few bosh jackets, usually on small blast furnaces, have a sloping steel plate and a very thin brick lining (9 in or less), with many water sprays on the outside

The several ways of protecting the inwall and the top are shown in Fig. 17.

TUYERES; TUYERE STOCKS; BUSTLE PIPE

The hot blast enters the furnace from the hot-blast stoves through hot-blast main bustle pipe, tuyere stocks, blow pipes, and tuyeres as shown in Figs. 18 and 19. The tuyeres and tuyere coolers are bronze and water cooled; the blow pipes are

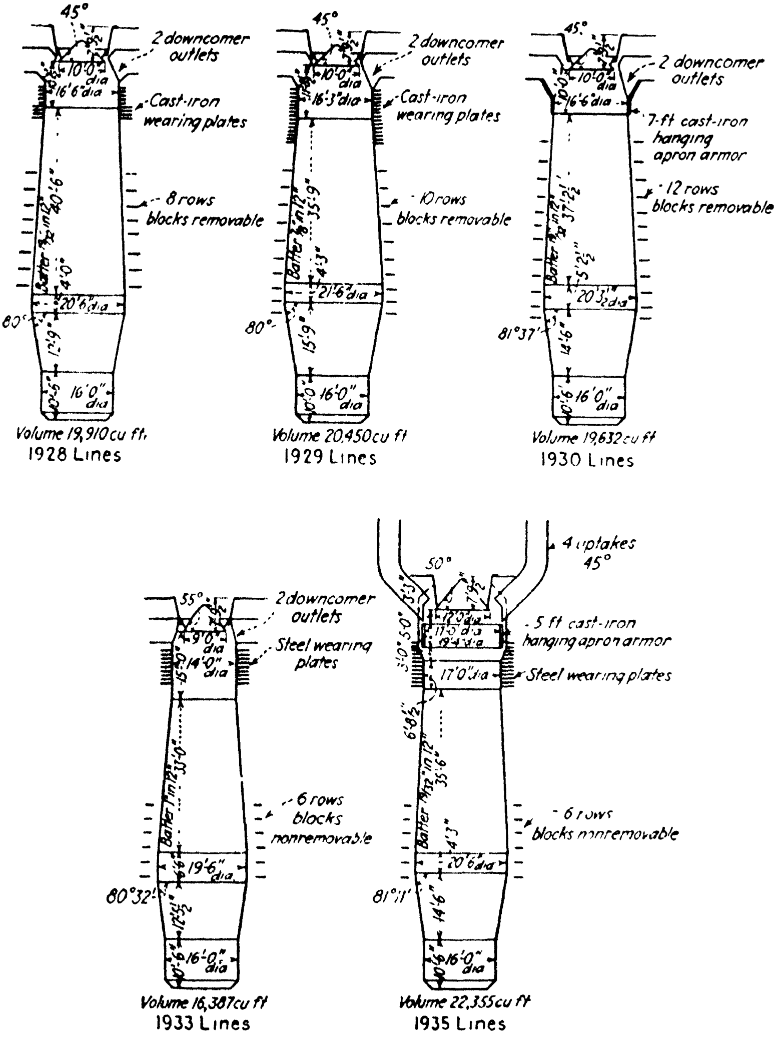

FIG. 17. - Protection of brick lining (*Trans. A.I.M.E.*, *vol* 120, *Crockard.*)

cast iron, sometimes covered with insulating material; the rest of the connections are lined with firebrick.

Figure 18 shows the essential parts of the tuyere connections in detail; the cast-steel saddle is riveted to the bustle pipe and

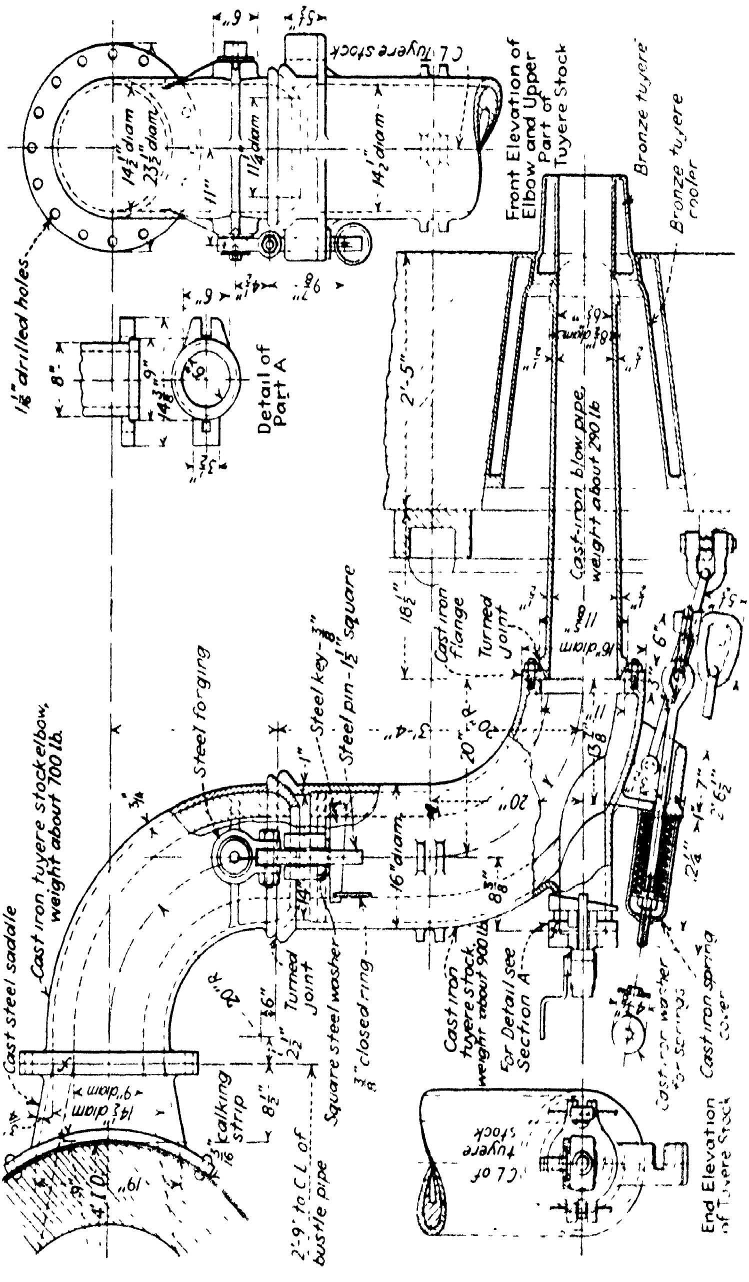

Fig. 18. Details of tuyere stock and blow-pipe equipment. (U. S. Bureau of Mines Bull. 130.)

the goose neck, as the tuyere-stock elbow is called, is bolted to the saddle. The tuyere stock is adjustable and can be keyed tightly to the goose neck by means of the wedged keys in the slotted hangers, and the ball-and-socket turned joint. The blow pipe has a turned joint at each end and fits into the ball-and-socket joint on the face plate of the tuyere stock. All these parts are held tightly in place by the keys at the top of the tuyere stock, and the "bridle," with its heavy double-coil spring, at the lower end. The bridle is usually protected by a steel-plate shield; a plate curved to fit the surface of the bronze tuyere cooler under the blow pipe is a good protection against being burned by a rush of slag or iron coming through the blow pipe during a heavy slip. All these parts must be strongly built and accurately fitted in order to prevent any blast leaks.

Number of Tuyeres.—The number of tuyeres is from 8 to 18, usually an even number according to the number of columns supporting the mantel. In the Arthur G. McKee design in Fig. 19 there are 8 furnace columns and 16 tuyeres. A big-hearth furnace may have 20 tuyeres. One of the Aliquippa furnaces has a hearth 28 ft. 6 in. in diameter, 12 columns, and 18 tuyeres.

Although many special designs of tuyeres have been used, the almost universal shape is shown in Figs. 11 and 18; the length varies from 9 to 15 in. and the inside diameter of the nose from 4 to 7 in. The shoulder is about 3 in. long and makes a snug fit with the machined bevel of the tuyere cooler. In a smoothly working furnace the tuyeres will wear thin on the nose from abrasion of the hot coke before they get burned by slugs of molten iron. The butt of the tuyere is tapped for the feed-water pipe, which should be at the lowest part of the tuyere, and for the discharge pipe which should be at the highest point of the butt. A recent innovation in tuyeres is the angle tuyere which has the nose turned sideways about 22 deg. with the idea of having no "dead" spaces between the tuyeres. The theory of tuyere zones will be treated later.

The function of the bustle pipe is to distribute the hot blast to each of the tuyeres as evenly as possible. The bustle pipe is shown in elevation in Figs. 3, 7, 11, and 18, and in plan in Fig. 19. A method of suspension from the mantel plate is shown in Fig. 11. The bustle pipe is lined throughout with firebrick, usually a double course of circle brick. Adequate manholes and cleaning holes with bolted covers are provided. Dust from the stoves may accumulate and obstruct the free passage of the blast A serious slip in the furnace—a bottom slip—has been known to force slag all the way back and up into the bustle pipe.

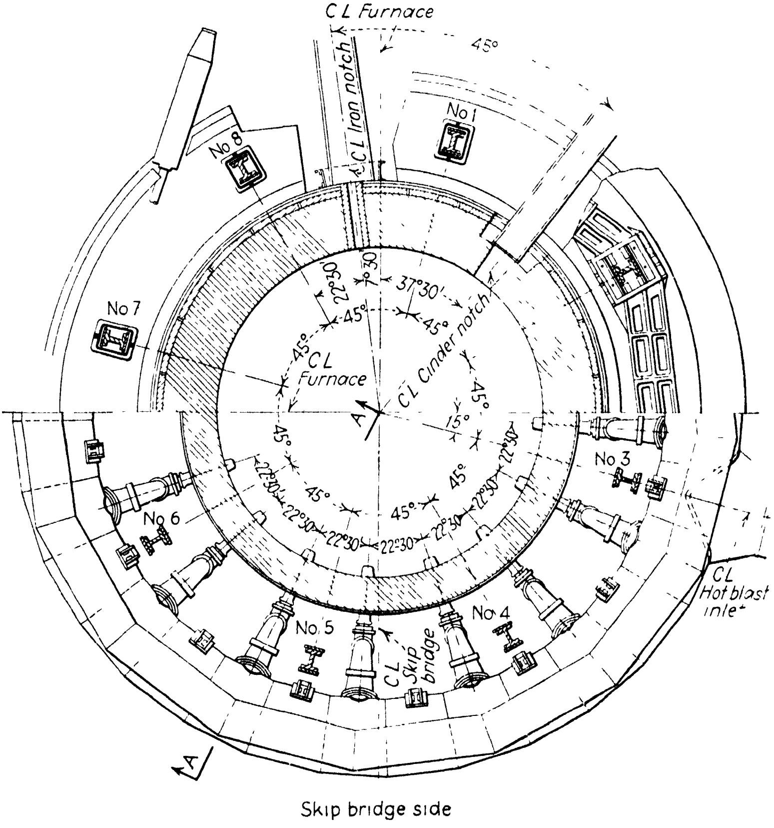

FIG. 19—Plan of bustle pipe and tuyere stocks. (*Courtesy of Arthur G. McKee & Co*)

IRON NOTCH

The iron notch of a blast furnace, the hole in the brickwork through which every cast of iron must flow, is not even a piece of apparatus, but is one of the essential parts of the iron blast furnace, and, if it is not properly cared for, the whole operation of the furnace is interrupted. A cross section of the iron notch is shown in Figs. 7 and 20; and a front view in Fig. 21 shows the

The fire clay in the iron notch burns hard for the entire 3 to 5 ft. of the depth of the hole, which is more than the thickness of the brickwork because the hole is gradually worked down to a considerable angle from the horizontal.

Power Drills and Mud Guns.—To open the iron notch when ready to run a cast of iron, an electric rotary drill is used by the keeper and his helper. The bit of this drill makes a hole about 3 in. in diameter. When the hole is almost through into the molten iron, a square tapping bar is driven in with sledges and pulled out with ring and wedge driven with sledges. Sometimes, an oxygen lance is used, by releasing oxygen from a regular oxygen tank through a ⅛-in. pipe.

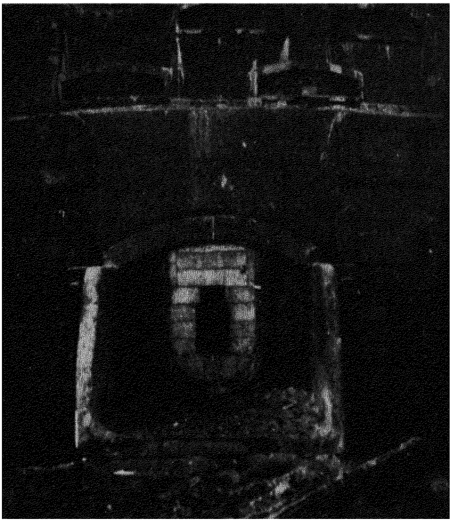

Fig. 21.—Front view of iron notch.

After the cast is over and most of the iron is out of the furnace, the iron notch is shut tight and filled up with stopping clay by means of an electrically operated iron-notch gun, shown in **Figs.** 22 and 23. Such a gun can be operated by push buttons placed at the side of the cast house behind a shelter of sheet iron and fireproof glass. The gun is swung into place and held there by a powerful motor. No splash plates over the iron trough are necessary, and no "dogs" are now needed to clamp the gun into place. The modern iron-notch gun is an expensive accessory.

but it soon pays for itself because it is no longer necessary to slack the blast when shutting the iron notch, thus preventing the settling of the stock after the cast with its consequent slowing up of the normal reactions in the smelting of the iron ores; and there is no interruption of the flow of waste gas out of the top of the furnace. As a safety device, its great advantages are obvious.

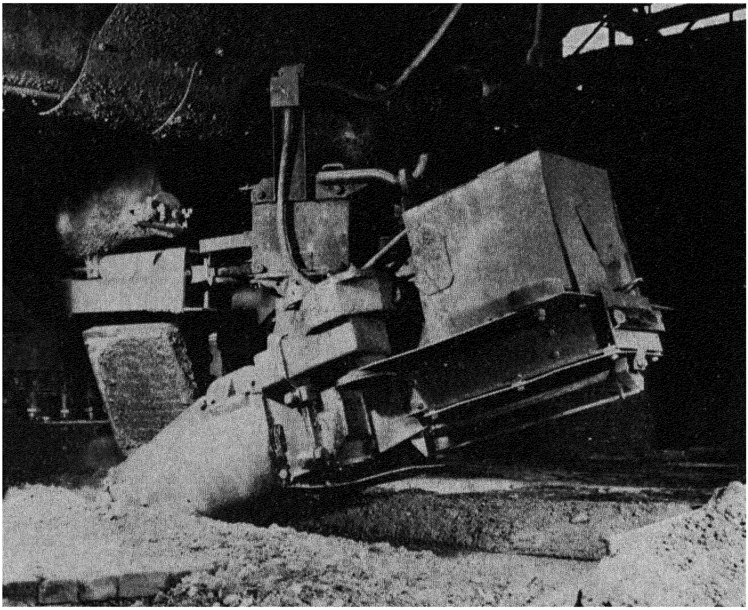

FIG. 22.—**Iron notch shut with electric gun.** *(Courtesy of Edgar E. Brosius, Inc.)*

CINDER NOTCH

The cinder notch (Fig. 20) is for the purpose of removing the slag at intervals between the casts. The slag, or cinder, is allowed to accumulate in the hearth until it nearly reaches the tuyeres and is then drawn off through the cinder notch located 3 to 4 ft. below the center line of the tuyeres (see Fig. 98) The cinder notch is made up of several parts; the *bronze monkey*, the *bronze intermediate cooler*, and the cast-iron, water-coil, *cinder-notch cooler* all set in the cinder-notch arch built in the brickwork as shown in Fig. 20. The separate feed- and discharge-water pipes for each part are not shown. All are held in place by

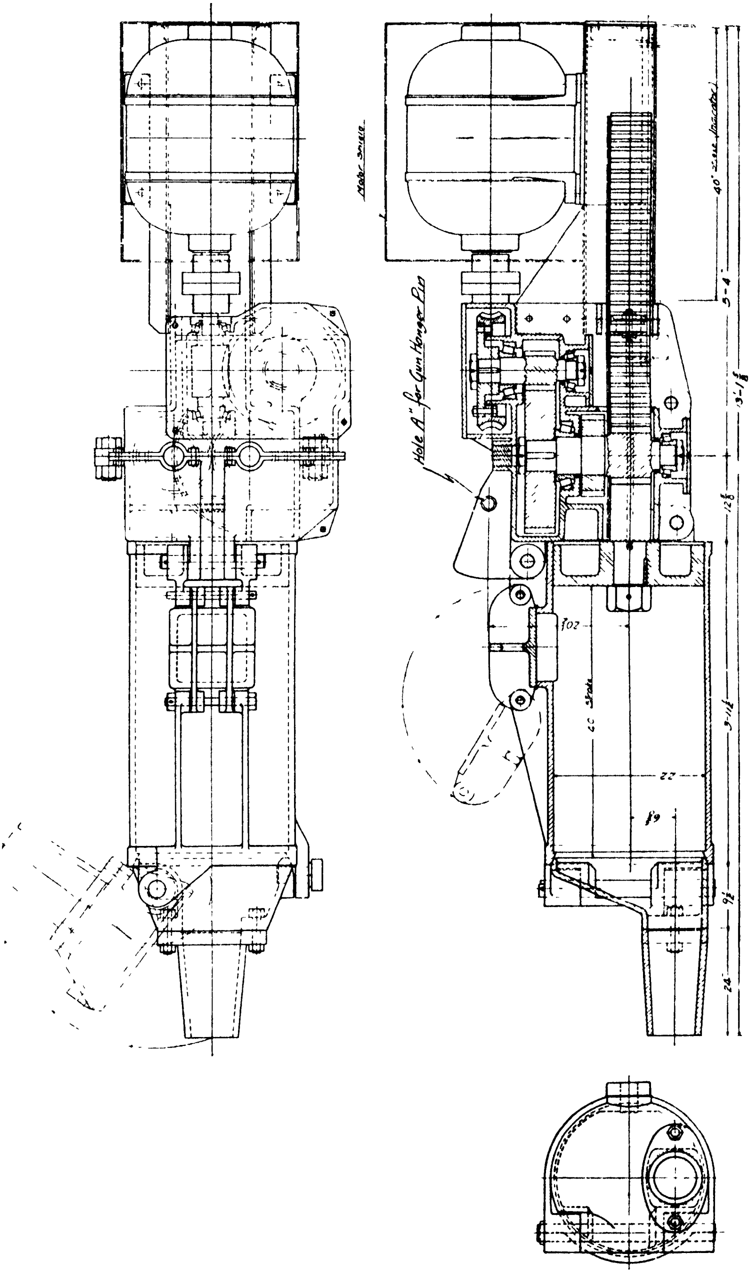

FIG. 23.—Assembly of electric clay gun (Courtesy of Edgar E. Brosius, Inc.)

suitable bridles and wedges. The monkey, which is more easily burned by a flow of molten iron, is quickly removable. It is kept shut by the monkey "bott," or stopper, which is an iron plug on the end of a long handle. The larger furnaces have a mechanical stopper that throws the bott into place by movement of levers without exposing the keeper to flying drops of slag and gas flames. A sheet-iron shield is alongside the cinder "fall," as the trough or runner is called, so as to protect the men The inside surface of the cinder-notch cooler is protected with a mixture of mud and soft coal or coke breeze.

In the event of furnace trouble and cold slag, the monkey and intermediate are pulled out and slag is run through the big opening and then stopped up with clay balls.

CAST HOUSE

The cast house of a modern blast furnace, whether a merchant or a steel-plant furnace, is a rather small affair compared with the long, covered shelter formerly used to protect the sand pig bed or the chill bed now fortunately obsolete. The short, steep-roofed, steel-frame structure shown in Fig. 4 is a typical cast house. Troughs and spouts for the iron are on one side, and for the slag on the other side. This trough and the runners must be kept warm and dry. The cast house shelters the sand and clay and tools, and at most furnaces there is enough floor space in the cast house for a small foundry making a great variety of castings direct from the molten iron, especially pig molds for the pig machine.

Runners.—The big iron trough, or casting trough, that fits close up to the iron notch at the upper end has the dam, skimmer, and "punch-out" at the lower end. The molten iron flows through the iron notch into the trough and is separated from the slag by the dam and skimmer which force the iron under the skimmer and over the dam into the runners that carry the stream of iron to the casting spouts and into the hot-metal ladles. The slag is skimmed off the top of the iron like cream and flows off at one side into the slag runners which carry it either to cinder ladles or into cinder pits just outside the cast house. These pits are either dry or filled with water for making granulated slag.

Skimmer: Slag Pit: Granulating Devices.—The skimmer is made of firebrick fastened in a steel frame so as to reach across the iron trough; the brick are easily replaced when burned away too much.

Since the blast furnace slag has become a valuable by-product, the method of handling at the furnace depends largely on the use to which it will be put The dry pits just outside the cast house are the least expensive method; one pit is being filled up with hot slag while the cold solid slag is being dug out of the alternate pit.

Hot slag can be granulated by running it directly into a deep pit filled with water; often there is a jet of water under the end of the cinder spout that helps to granulate the slag. Special granulating spouts are used to prepare the slag for making cement and the slag can be carried a long distance in sluices.

A new method for granulating slag has recently been installed at the Thomas blast furnace plant of the Republic Steel Corporation in Birmingham, Ala., and described by J. M. Hassler in his paper "Offsetting Increased Labor Cost in Southern Blast Furnace Operation."[1] The slag is taken from the blast furnace in cinder ladles and poured "into a rotating machine which whips and cools it and breaks up the lumps. A small amount of water is used at the entrance spout which literally explodes the molten hot slag."

The various uses of granulated slag and dry crushed slag will be described later.

Cinder Ladles: Cinder Dumps.—Cinder ladles of large capacity and of very strong construction are used to take the molten slag from the blast furnaces to a central slag dump. Many types of ladles have been used—side dumps, end dumps, brick lined, cast-iron pots, and cast-steel pots. The approved types have standard railroad trucks and air brakes and are dumped by air pressure applied from the cab of the locomotive. They are fully equipped with safety devices as shown in the photograph of a Pollock cast-steel, ribbed pot, 330-cu. ft. capacity cinder car (Fig. 25). These ladles, when filled at the furnaces of a steel plant, are hauled in trains to the cinder dump (see Fig. 24).

The modern cinder dump is scientifically arranged so that the slag when cold and solidified will easily break up into the sizes

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[1] *Trans A.I M.E*, vol 125

required in the market. This will be discussed in the section on Blast Furnace Slag in Part V.

Unless greatly restricted in space, the modern slag dump is long and fairly level with slag pits on either side of an elevated track, one side being filled as the other side is being dug up and sent to the crushing and screening plant.

Slag dumps for a single blast furnace or a group of merchant furnaces are not economical because of switching costs and ladle expense.

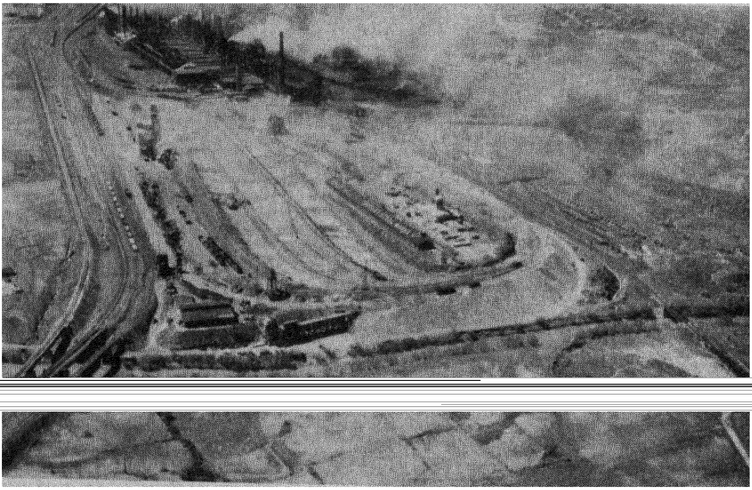

FIG. 24.—Dry slag pits at Ensley blast furnaces. (*Courtesy of Birmingham Slag Co.*)

HOT METAL

Ladles.—Hot-metal ladles are universally used in this country, whether making hot metal for a steel plant or cold pig for the market, for conveying the molten iron from the blast furnace to the open-hearth furnaces or to the pig-casting machine. Sand pig beds and "chill" pig beds are, fortunately, obsolete, and men are no longer obliged to break hot iron and carry it out of pig beds. Only the name—"pig iron" remains; the backbreaking drudgery is gone forever.

The hot-metal ladles are of two general types: the stationary ladle mounted on a pouring stand in the cast house and receiving the iron from the furnace and then pouring it out the other side into a runner leading to a pig-casting machine; and the mounted ladle on railroad trucks that is hauled to the open-hearth furnaces, Bessemer plant, or to the pig machine

The stationary ladle, with trunnions resting on a pouring stand similar to those shown in Fig 26, usually has a removable cover with a hole through which the molten iron pours from the spout at the end of the cast-house runners The ladle is tilted by a hook from an overhead crane. Such an arrangement eliminates the need of a shifting engine.

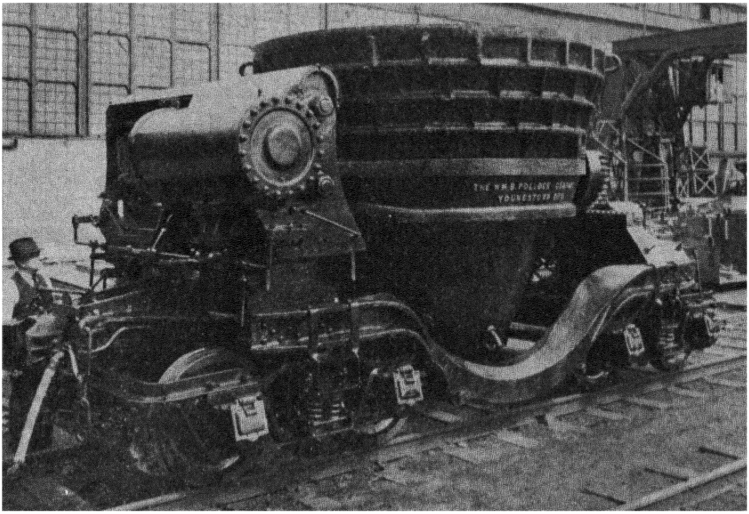

Fig 25.—Cinder car with cast-steel ribbed po [illegible] *of The William B. Pollock Co*)

The ladle shown in Fig. 26 is used also for conveying hot metal to the steel plant or to the pig machine and is shown in Fig. 30 where the molten iron is being poured into the double-strand pig machine of the Woodward Iron Company at Woodward, Ala The big hook suspended from the overhead crane can be seen in the background

Where the casts are very large and the distance to the steel plant is several miles, the Pugh mixer-type ladle shown in Fig. 27 is now used; this particular ladle holds 150 tons and is used to haul hot metal from the blast furnaces at Hamilton, Ohio, to the

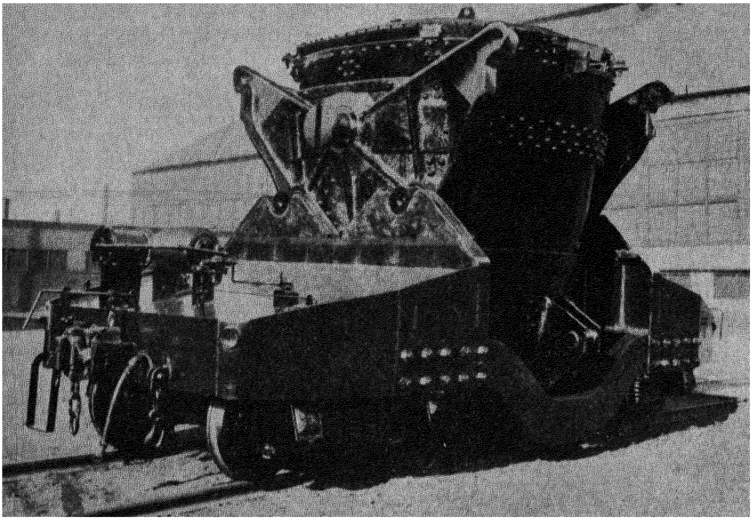

FIG. 26.—Seventy-five-ton short-pour hot-metal car. (*Courtesy of The William B. Pollock Co.*)

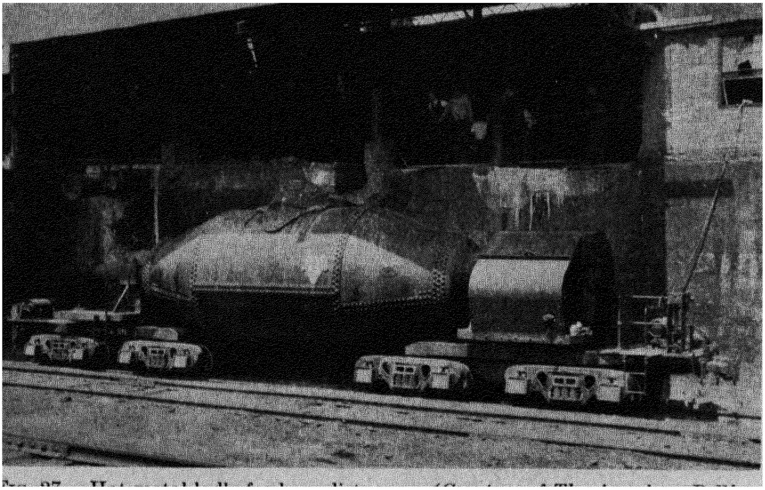

FIG. 27.—Hot-metal ladle for long distance. (*Courtesy of The American Rolling Mill Co.*)

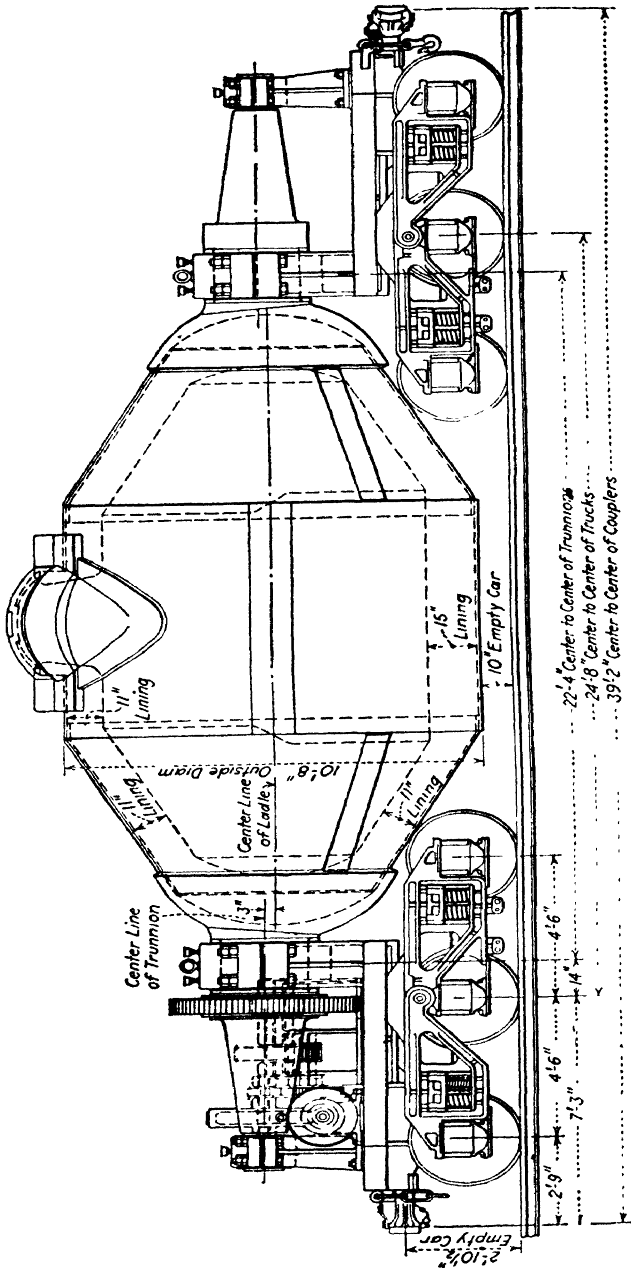

FIG. 28.—Iron ladle of the mixer type. (*Trans. A.I.M.E.*, vol. 113, *Harlan.*)

open-hearth plant of The American Rolling Mill Company at Middletown, a distance of 11 miles. The motor for tilting the ladle for pouring is mounted on the 16-wheel ladle car.

The ladles are hauled over standard gage railroad tracks and bridges of heavy construction and with special safety guards.

Hot-metal ladles are lined with firebrick, as indicated in Fig. 28[1], or with silica "firestone," a natural silica rock quarried by The Cleveland Quarries Company (Ohio), as shown in Fig. 29.

PIG-CASTING MACHINES

The pig-casting machine, now universally used for molding merchant pig iron and for taking care of the cold pig at the steel plant, is an endless chain of cast-iron molds mounted on small wheels traveling upward on an inclined track to the discharge end where the pigs, which have solidified on the way up, are dropped into a railroad car. The rate of pouring and the speed of the pig machine can be so simultaneously regulated by the "pourer" from his protected pouring stand that the molds are filled evenly to the desired size of pigs.

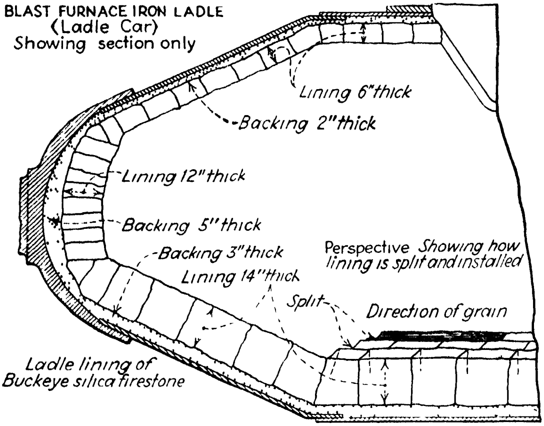

FIG. 29.—Firestone lining for hot-metal ladles (*Courtesy of The Cleveland Quarries Co.*)

Although the iron is skimmed at the blast furnace it is necessary to skim it again at the pig machine, as shown in Fig. 30, so as to remove any kish, slag, or scurf that may have gathered on the surface of the metal in the ladle during transit.

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[1] *Trans. A.I.M.E.*, vol 113, p 39, 1934.

Francis Crockard, in his paper "Progress in Southern Blast Furnace Practice"[1] describes the method of "double skimming", he also shows how the molten iron is gradually cooled by water sprays on the bottom side of the molds (Fig. 31) so as to "give the pigs time to deposit graphite and form the usual fracture"

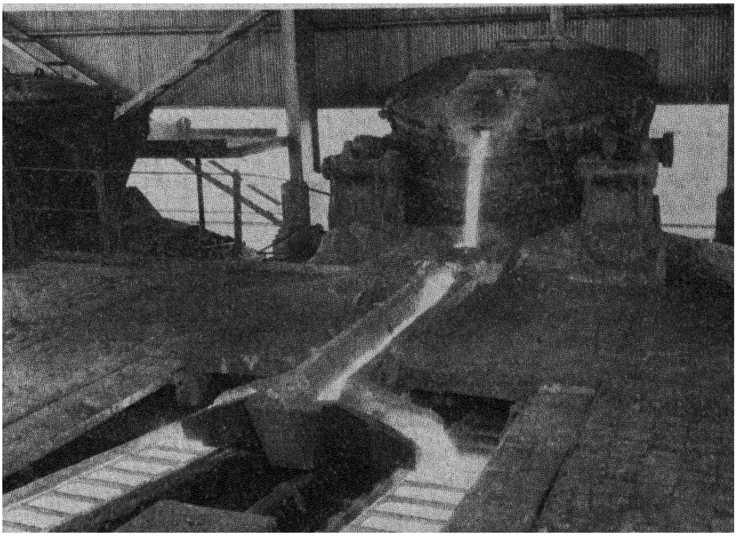

FIG. 30.—Hot-metal ladle pouring at pig **machine.** (*Courtesy of Woodward Iron Co.*)

The pigs weigh from 40 to 80 lb., according to the requirements of the consumers; the usual shape is seen in Fig 1.

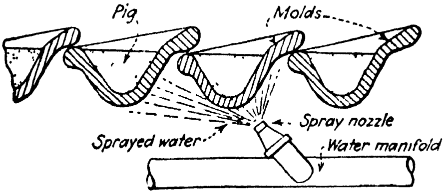

FIG. 31.—Water-spray cooling mold on pig machine. (*Trans. A.I.M.E.*, *vol* 120, *Crockard.*)

To protect the heavy cast-iron molds from being cut by the molten iron and to prevent the pigs from sticking at the delivery end, it is necessary to give them a coating or a "wash" that

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[1] *Trans. A.I.M.E.*, vol. 120.

will be dried by the heat of the molds. At the Alabama merchant furnaces a mixture of half lime and half pulverized coal is blown on with an air-jet aspirator. In the Chicago District a coating of burnt dolomite wash, called "Mag-li-kote" is applied as shown in Fig. 32; the results are very satisfactory.

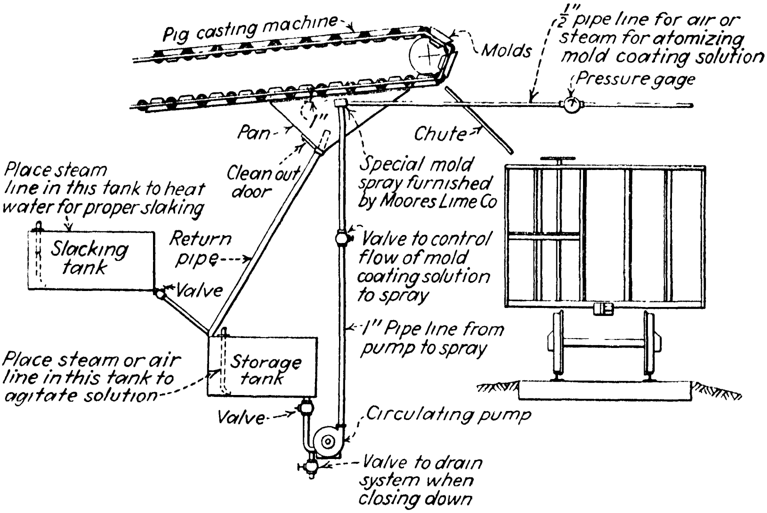

FIG. 32.—Arrangement for applying Mag-li-kote on pig machine. (*Courtesy of The Moores Lime Co.*)

DOWNCOMER AND GAS MAINS

The waste gases rushing off the top of the stock inside the blast furnace are prevented from escaping into the air by the double bell and hopper arrangements, and are passed upward through the uptakes (four separate, as in Figs. 4 and 9, or two double uptakes, as in Figs 13 and 33) which then deliver to one or more downcomers and thence into the primary dustcatcher at a tangent so as to give a swirling motion as shown in Fig. 9. The dry primary dustcatcher takes out most of the coarser flue dust, and the pieces of coke and coke breeze carried over by the velocity of the large volume of gas A further dry cleaning of the blast furnace gas is done in "dry whirlers" which remove much of the fine dust, but even this extra cleaning is not satisfactory for two reasons; first, there is still too much fine flue dust left in the gas and, second, there is too much moisture.

Wet gas, like some wet iron ores, must be washed with cold water in order to reduce the moisture.

Gas Washers.—In a report[1] on gas cleaning and stove equipment, A. J. Boynton said, in part:

> Any system of gas cleaning which fails to reduce the temperature of the gas to the lowest possible point fails to accomplish its purpose completely and results in a clean gas which is completely unsuited for certain technical requirements, while under all conditions it is less desirable than a gas more thoroughly cooled. Until very recently, electric precipitation has been applied to uncooled gases. . . . Up to the present

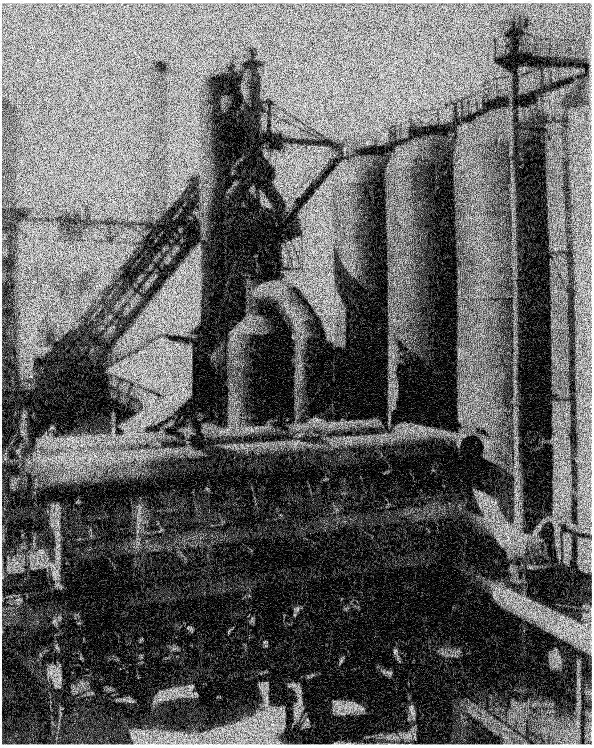

FIG. 33.—Single downcomer and off-takes. *(Courtesy of Arthur G. McKee & Co.)*

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[1] "Gas Cleaning and Stove Equipment," report to the 1,000-ton Blast Furnace Committee of the Blast Furnace and Coke Association of the Chicago District, April, 1930.

time, therefore, the wet washing system may be considered as the most reliable and the cheapest.

The plan for the cleaning of blast furnace gas finally approved consisted of a primary dustcatcher which delivers the flue dust direct into railroad cars; a pair of secondary dry centrifugal dust (vortex) collectors; a cooling and scrubbing tower (wet washer); and a group of disintegrators. It was estimated that the requirements would be 5 gal. of water and 8 hp. per 1,000 cu. ft. of gas per minute, or .0994 kw.-hr. per 1,000 cu. ft. of gas washed to a sufficient degree of cleanliness for use in hot-blast stoves. Figure 4 shows a tower washer; Fig. 9, a Mullen washer.

Cottrell Electric Precipitator.—The first Cottrell electric precipitator the author ever saw was at a Dunbar, Pa., furnace shortly after the World War; the fact that men were sledging fused flue dust out of the combustion chambers of the stoves proved that the precipitator was not functioning properly. Later, it was found that no gas cleaning system gets good results until the temperature is reduced to the lowest possible point. In 1935 Boynton and Kinney said in their paper,[1] "Notes on the Development of the Iron Blast Furnace," that

> . . . the chief difference between the furnace plant as conceived today and that of 1930 is the substitution of the Cottrell precipitator for the methods previously in use. . . . Since that time the development of a thoroughly practical tube-type precipitator has been accomplished, largely by experiments and development work at the South Works of the Illinois Steel Co. [now the Carnegie-Illinois Steel Corp.]. . . . It has, in addition to the advantages of low cost of operation, including low power consumption and low water consumption, three decided advantages over other forms of washers . . . ability to handle a primary washed gas containing considerable quantities of dust, . . . second, low drop in pressure, . . . third, the gas as cleaned is clear of entrained water.

"The wet electric precipitator will clean primary washed gas to 0.01 grain per cu. ft. or less." (Harlan.)

Gas Mains.—The gas mains for conveying the blast furnace gas from the dustcatchers to gas washers and other cleaning devices are of ample diameter and strength to carry the gas without leakage. Sometimes, to protect the elbows and turns against abrasion by the hot dusty gas, there will be some sort

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[1] *A.I.M.E., Tech. Paper*, 652.

of armor plate inside the gas mains (as shown in Fig. 4 just to the left of the closed goggle valve).

Gas Seal.—In order to shut off completely the gas from the blast furnace between the primary dustcatcher and the other parts of the gas system, or from the gas connections of another furnace, it is necessary to have some sort of a gas seal. This may be a U pipe, filled with water up both sides far enough to more than balance any gas pressure that might come from the furnace.

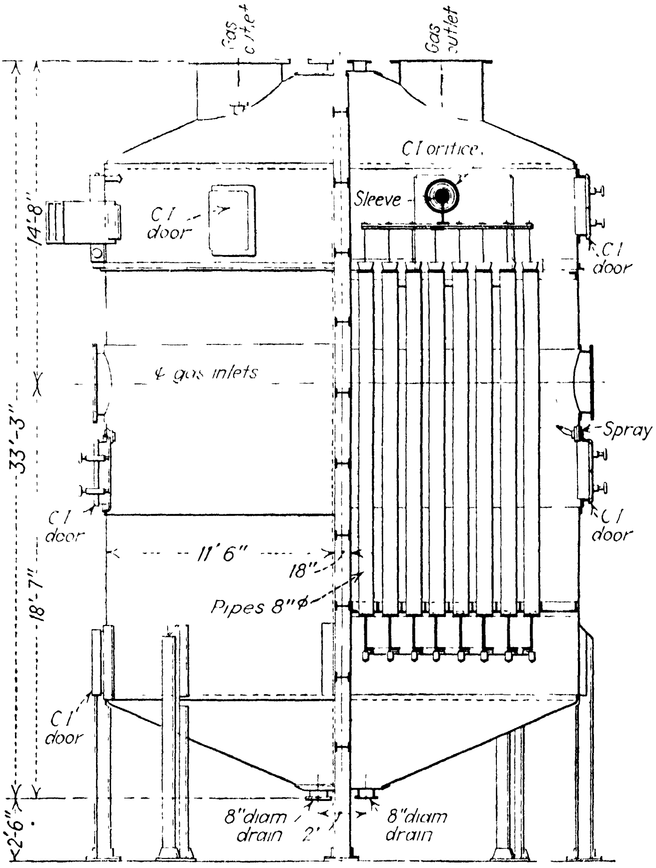

FIG. 34.—Cottrell divided precipitator (*Courtesy of Research Corporation.*)

Gas Valves.—Gas valves in the gas mains are of several different types, including the goggle valve (seen in Fig. 4), the gate valves, and the mushroom valve. Some of the latest valves have devices to prevent the accumulation of flue dust in the grooves, and are actuated by gears.

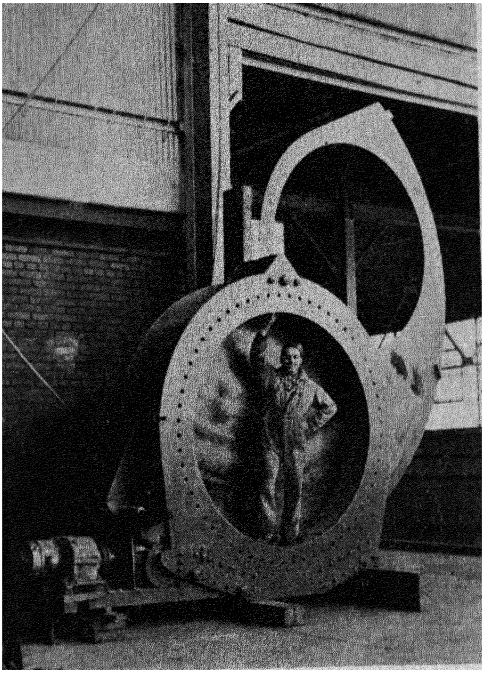

FIG. 35.—Automatic motor driven goggle valve (Courtesy of Edgar E. Brosius, Inc.)

COOLING-WATER SYSTEM

Several million gallons of water per 24 hr. are required for circulation through the many cooling bronzes of a modern blast furnace—the bosh plates, the tuyeres and tuyere coolers, monkey and coolers, and the pipe coils in hearth jackets. This water *must* be clean, and should be soft, or there will be too much lime scale formed in the pipes and in the bronzes. Sometimes the water supply carries so much lime that it is necessary to put in a water-softening plant, such as the Scaife system for boiler water. In such cases, it is necessary to recirculate the water through some sort of a cooling pond and cool the water either by cooling racks or by sprays. Racks cost less and cool the water without much loss by mist. The make-up water is only a very small part of the total water circulated.

In all cases care should be taken that the vapors, and mists from the spray ponds do not enter the intakes of the blowing engines.

BELLS AND HOPPERS

In Fig. 3 is shown the conventional double-bell and hopper arrangement of the closed-top furnace of today, a device whereby the ore, coke, and limestone can be lowered into the furnace every few minutes without letting the waste gases escape into the air. The raw materials are dumped into the little hopper, which is rotated so as to give the proper distribution; the little bell is lowered while the big bell remains closed. When the big hopper is filled, the big bell is lowered while the little bell remains closed.

The big bell in Fig. 3 has a diameter of 14 ft. 8 in.; and the stock-line diameter is 20 ft.; this leaves a distance of 32 in. between the lip of the bell and the walls of the furnace all around. This is a large bell, and it is questionable if the same type of bell can be used if the stock-line diameters should be much increased. The immense size of the bell-operating rigging for such a big bell can be seen in Fig. 36 which was welded for a 1,000-ton furnace. Various devices for annular bells in two sections have been tried at intervals from the days of the anthracite furnaces in the Lehigh Valley. The author used one in Tennessee long ago, where most of the furnace troubles would have disappeared with proper preparation of the raw materials and an ordinary bell.

HOT-BLAST STOVES

The blast for a modern blast furnace, in volume up to 86,000 cu. ft. per minute, is heated in regenerative hot-blast stoves made of firebrick checkerwork incased in steel shells 20 to 25 ft. in diameter and 80 to 100 ft., or more, high.

In the search for lower costs and higher efficiencies all operators are adopting stoves that will maintain maximum hot-blast temperatures with a minimum gas consumption. To meet these requirements, stove capacity of approximately 7 sq. ft. of heating surface and 1.8 cu. ft. of brick volume is required per cubic foot of wind blown per minute. Two types of stoves meet these specifications, one maintains a small checker opening of uniform cross section throughout the stove and the other uses a graduated checker opening from the top to the bottom of the stove. The larger open area is in the top of the stove, the area decreasing in zones to the bottom. Each type has its advantages and its disadvantages. The stoves having uniform checker openings are perhaps of stronger construction, but those having graduated checker openings give a more efficient heat transfer.[1]

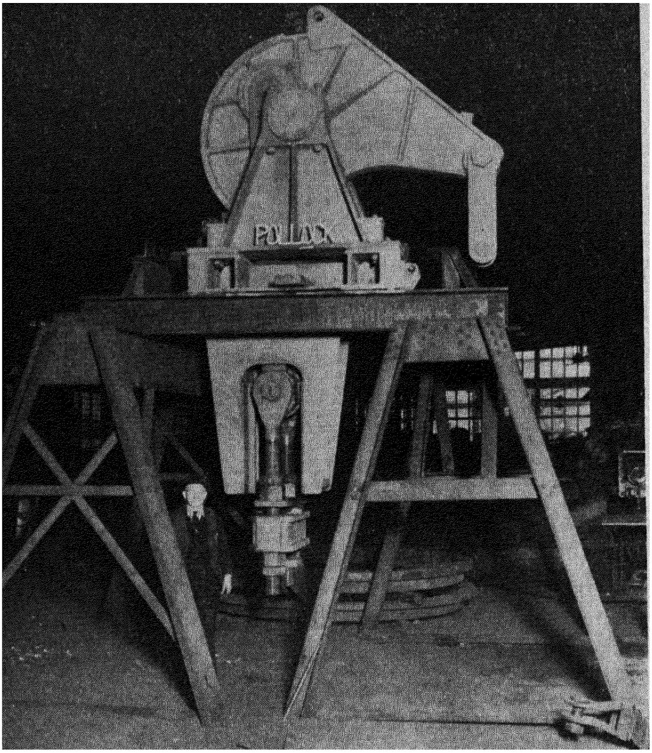

FIG. 36.—Welded bell-operating rigging for 1,000-ton furnace. (*Courtesy of The William B. Pollock Co.*)

Figure 5, from Harlan's paper, shows cross sections of a modern stove; Figs. 4, 9, 13, and 33 show the exteriors of various types

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[1] From B. J. Harlan's paper, "Recent Trends in Blast Furnace Operation and Design," *Trans. A.I.M.E*, vol. 113, 1934.

of stoves. In Fig. 37 is seen the cross section of checkers of straight brick with a very practical method of laying the ring wall in a side-combustion stove; there is a $4\frac{1}{2}$-in. wall of insulating brick next to the shell.[1]

Gas Burners.—The hot-blast stoves require about 20 per cent of the total blast furnace gas, and the more efficiently this gas is burned the higher the blast temperature obtained. Gas for the stoves should be cleaned to 0.02 grain of dust per cubic foot, and as much of the moisture as is possible should be removed. The Steinbart pressure burner is much used; it provides a forced draft of air in the right proportion for the burning of the gas.

Hot-blast Valves.—The cold blast from the blowing engines flows through the checkerwork of the hot-blast stove in the reverse direction of the passage of the hot gases which heated the checkers. The stoves are connected to the cold-blast main on one side and to the hot-blast main on the other The hot-blast valve, which is closed while the stove is "on gas" and open while the stove is "on the furnace," is a water-cooled mushroom valve accurately machined so as to fit into the bronze hot-blast valve seat which is also water cooled.

Chimney Valves.—The chimney valve (or valves) is at the back of the stove and connects the back of the stove with the waste-gas main when the stove is on gas, except in the case of the Massicks and Crooke type of stove shown in Fig. 9, which has an individual stack for the waste gases, and the cold blast enters the top of the stove at the same place that the products of combustion enter the bottom of the stove stack. Some stoves have individual draft stacks with the chimney valve at the bottom of the stoves.

Equalizer.—At some furnaces there is an "equalizer" between the hot-blast stoves and the blast furnace through which the hot blast passes so that it stores up heat and prevents the too rapid cooling of the blast. It is like a hot-blast stove without a combustion chamber.

Cold-air Mixer.—In order to maintain "straight-line heat" at some certain temperature, say 1450°F., on a blast furnace, it is necessary to have a source of heat greater than the 1450°F. and a source of heat less than the 1450°F. Sometimes this can be accomplished by blowing through two stoves at a time and

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[1] BOYNTON, A. J. and S. P. KINNEY: *A I.M.E., Tech. Paper* 652.

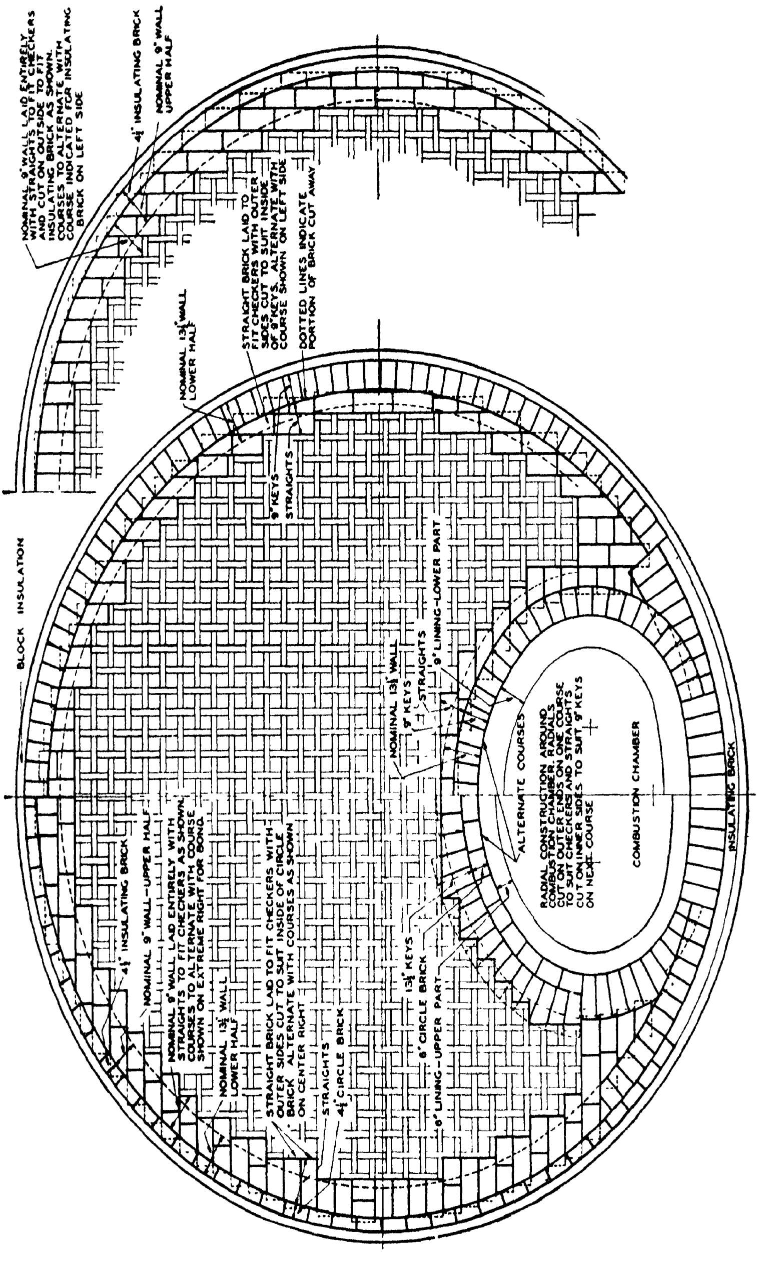

FIG. 37.—Cross section through checkers of hot-blast stove. (*A I M E , T P* No 652, *Oct.*, 1935, *Boynton & Kinney.*)

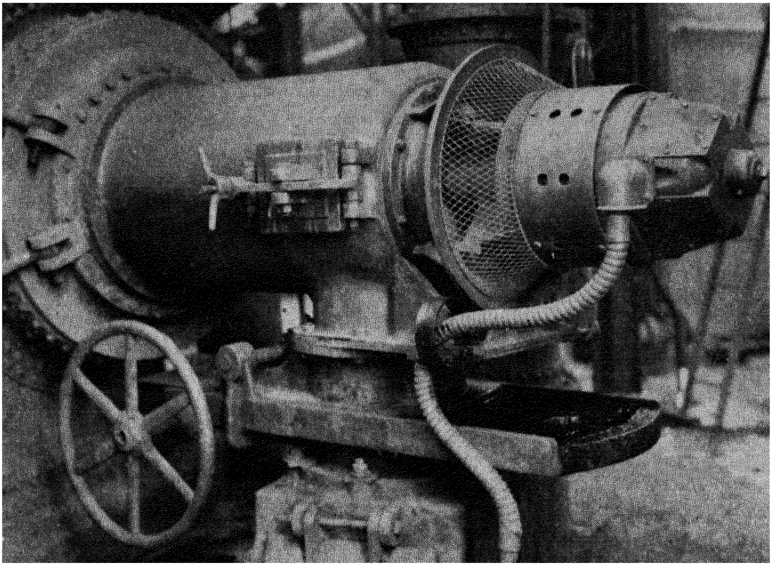

Fig. 38.—Pressure gas burner for stoves. (*Courtesy of Freyn Engineering Co.*

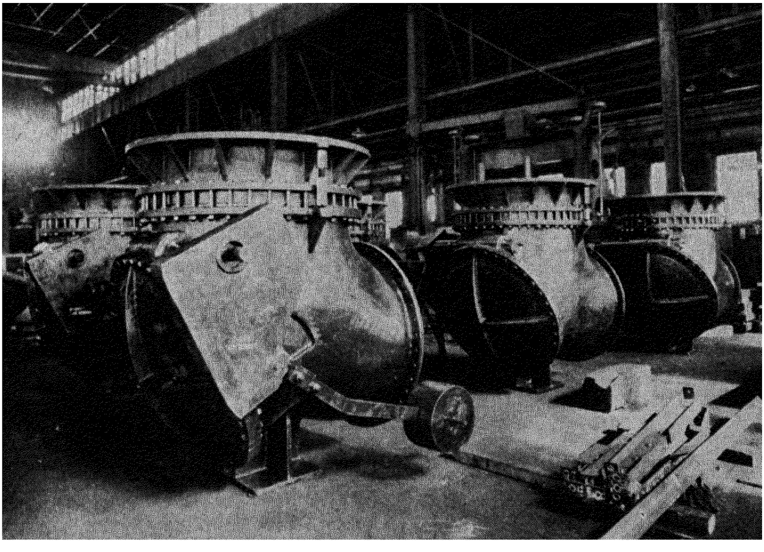

Fig. 39.—Chimney valve, gas flue located above stove platform. (*Courtesy o*
Freyn Engineering Co.)

regulating the valves of each until the cold stove and the hot stove can no longer maintain the desired temperature; then another hot stove is put on the furnace.

The usual way is to have a connection from the cold-blast main to the far end of the hot-blast main, with a gate valve or a butterfly valve, through which just enough cold air is allowed to flow so that the mixture of cold air and the hot blast from the stove will give the desired temperature of the blast entering the furnace. This "cold gate" may be operated by hand or may be automatically controlled by a thermostat.

Pyrometers.—The temperature of the blast is indicated and recorded by thermocouple electric pyrometers placed near the furnace in the pyrometer house or at a distance in the blower's office. The records are taken off each morning at the same hour and sent to the superintendent's office for observation and filing.

Checker Brick.—Before the general practice of cold and clean gas for hot-blast stoves much flue dust was carried over into the stoves and was either fused in the combustion chamber or clogged on the top courses of the checker brick which formed the vertical flues with areas 6 to 9 in. square. With gas cleaner than most of the air we breathe, these checkers have been greatly reduced in area and increased in number. Research has brought out the fact that checker brick should be as dense as hard burning and fine grinding can make them, so as to take in and give out as much heat as can be stored up while the stove is on gas.

All checker brick are machine pressed, true to dimensions, and hard burned. Many checker brick are made from deaired clay. The brick manufacturers have cooperated with the blast furnacemen in attaining the right kind of brick for the checkers of the modern hot-blast stove with its ever-increasing blast temperatures.

As to the shapes of checker brick, there are numerous designs which not only give much heating surface, but also considerable thickness of walls for heat storage and stability of construction. Intricate dies and electrohydraulic brick presses make it possible to press brick with as many as 19 vertical holes of small diameter in a sturdy hexagon checker.

Recording Instruments.—The recording instruments at a modern blast furnace are now so numerous that a permanent record is continuously made of pressures, temperatures, revolutions, weights. The clocks of these instruments must be regularly wound and cared for and the fresh charts put on daily in place of the previous 24 hours' record. A partial list of these daily records is as follows:

PRESSURES

Blast pressure at blowing engines
Blast pressure at furnace
Steam pressure at boilers
Steam pressure at blowing engines
Water pressure at pumps
Water pressure at furnace
Gas pressure at top of furnace
Gas pressure at gas washer

TEMPERATURES

Hot-blast temperature entering the bustle pipe
Hot-blast temperature at each stove
Top-gas temperature at downcomer
Waste-gas temperature at chimney valves of stoves
Hot-water temperature at boilers
Outdoor temperature at intake of blowing engines

MISCELLANEOUS

Number of charges put into furnace
Number of revolutions of blowing engines
Number of times big bell lowered
Number of feet down-top of stock in furnace

SINTER PLANT

The sintering process was first introduced into blast furnace practice in order to utilize the large amounts of flue dust blown out of the furnaces, especially when smelting Mesabi ores, and at a time when there was considerable fine coke and coke breeze in the flue dust. It was a cheap way to get a fairly rich iron-bearing by-product, and its use in the furnace helped to reduce the amount of flue dust made.

Three types of sinter plants were erected in this country, the Dwight-Lloyd, the Greenawalt, and the Plock, all based on the principle of down-draft suction, ignition on the top of a mixture of flue dust, and fine iron pyrites cinder ("Blue Billy" or purple ore).

The Dwight-Lloyd sintering machine is a continuous traveling grate (similar to a Coxe traveling stoker) passing over suction "wind boxes" at such a speed that all the carbon in the mixture is burned out by the time each section of the grates (called "pallets") reaches the dumping end of the machine where the cake of sinter is dumped into a railroad car or into the stock pile. A side view of the Dwight-Lloyd sintering plant[1] of the Republic Steel Corp., Thomas, Ala., is shown in Fig. 40. This plant is described by J. M. Hassler in his paper[2], from which Fig. 41 has been taken; this shows the general arrangement of the sinter plant, which has 98 pallets, 72 in. wide, and "a capacity of 60 tons of sinter per hour when operated at a speed of 112 in. per minute." This plant sinters red ore, fines, and flue dust.

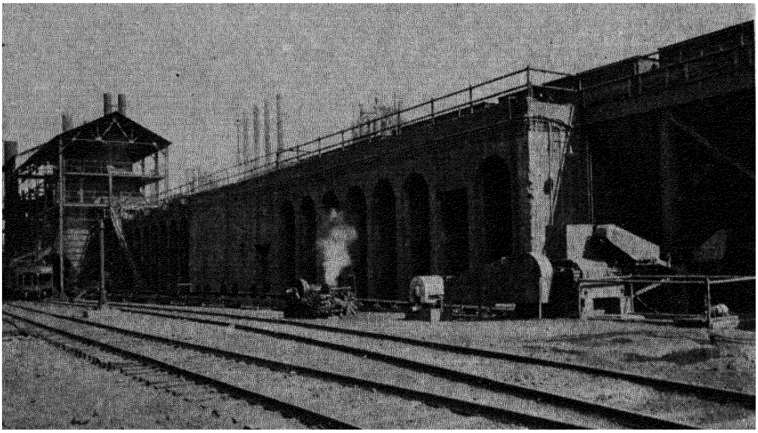

FIG. 40.—Sintering plant of Republic Steel Corp., Thomas, Ala. (*Courtesy of Republic Steel Corp.*)

The Greenawalt sintering plant, like the other two systems, was first used at blast furnace plants for sintering the flue dust, but now it is being used primarily at the iron-ore mines for sintering the fines produced in the beneficiation of iron ores, such as fine grinding and magnetic concentration, crushing and sizing or the sintering of pyrites fines after the sulphur has been burned off (at a new iron plant in Italy, the iron comes from a pyrites deposit).

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[1] CURRAN, W. E., "Trend of the Southern Pig-iron Business," *Trans A.I M E.*, vol 131.

[2] "Offsetting Increased Labor Cost in Southern Blast-furnace Operation," *Trans. A.I M E*, vol 125, 1937.

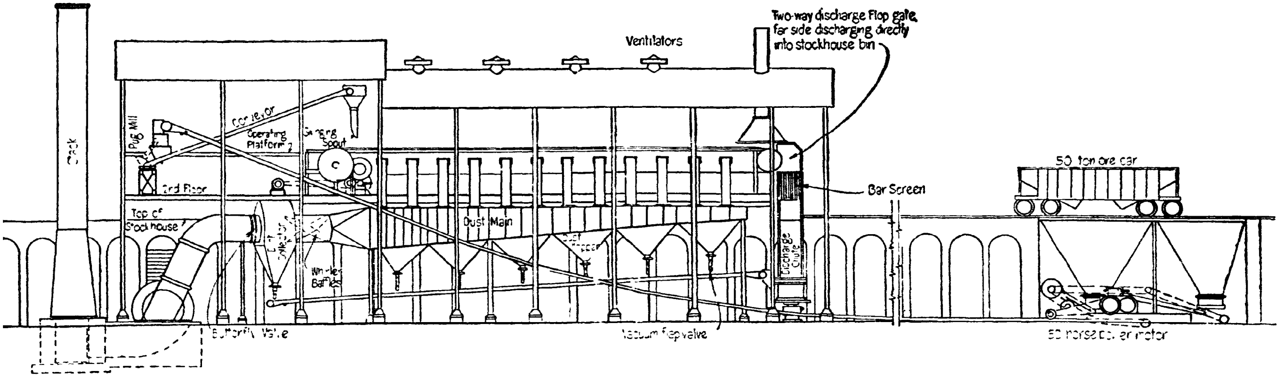
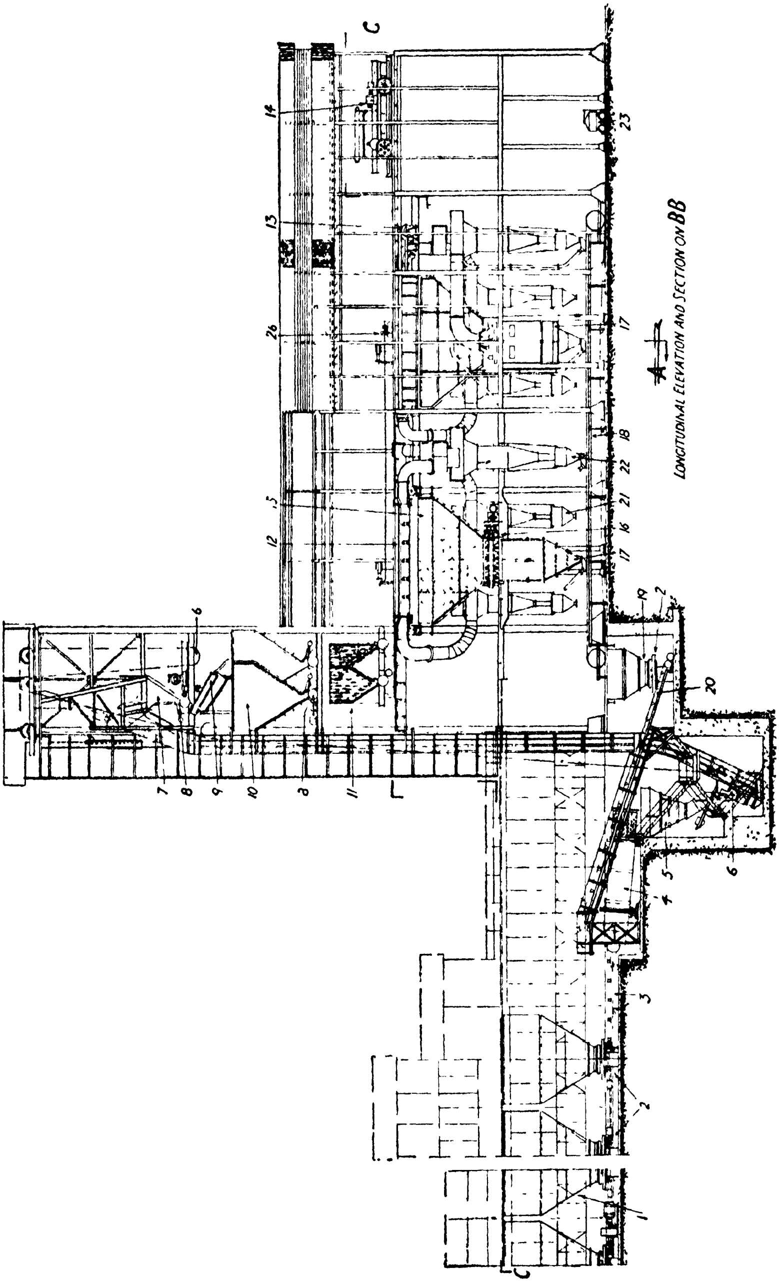


FIG. 41.—General arrangement Republic's sintering plant, Thomas, Ala. [*Courtesy of Steel, Feb.* 8, 1937, ***Hassler*** (*later in A.I.M.E.*).]



LONGITUDINAL ELEVATION AND SECTION ON BB

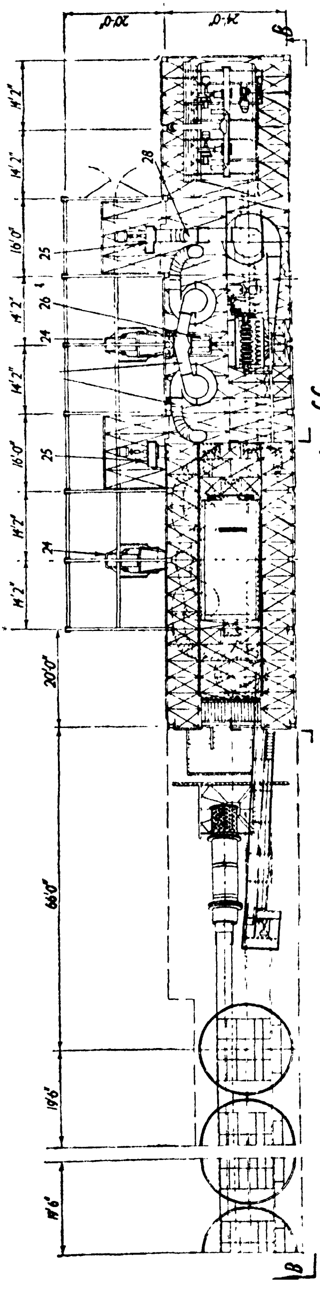


FIG. 43.—Greenawalt sintering plant at works of Appleby-Frodingham Steel Co., Ltd., England. (Courtesy of John E. Greenawalt.)

The Greenawalt pan is mounted on trunnions through which there is a strong suction (up to 50 in., water gauge); the pans, when in upright position are filled level full with the mixture of ore and fuel (either flue dust or fine coke breeze), and ignited on top with gas or fuel oil by means of an ignition hood which is moved into position over the pan. The pan is 30 by 10 ft. and 7 to 17 in. deep according to the character of the ores to be sintered. Where the ore is exceedingly fine, as in some magnetic concentrates, the depth of bed is less, but the pan is dumped oftener. It takes about 1 min. to sinter each inch of material in the pan.

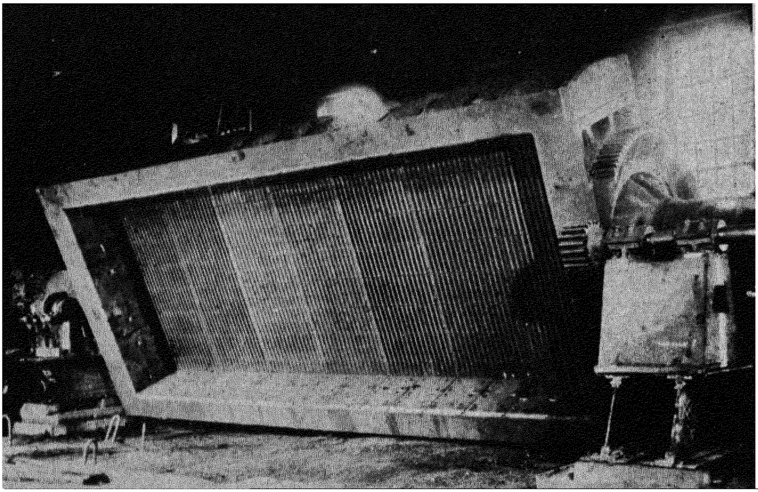


FIG. 42.—Greenawalt sintering pan, 25 by 10 ft. (*Courtesy of John E. Greenawalt.*)

The Plock system of sintering was a cross between the Dwight-Lloyd and the Greenawalt. The train of pans on wheels passed over a wind box and were dumped on a tipple, and then transferred to a return track and pulled to the charging end of the plant when another transfer started the cars under the loading chutes and forward under the natural gas ignition hood and over the wind box. The author knows of only two Plock plants ever built; one of these was scrapped soon after the World War.

POWER PLANT

The power required to operate a modern blast furnace plant —for blowing engines, pumps, electric power, hoisting, shops, lighting, pig machine, sinter plant, etc.—can all be supplied from the waste gas out of the top of the furnace, besides the gas required for the hot-blast stoves (20 to 22 per cent), and besides furnishing gas for other purposes. But, at integrated steel plants[1] it has been found that clean blast furnace gas (cleaned to 0.015 grain per cubic feet) has a greater value in underfiring coke ovens and in soaking pits and reheating furnaces than when used as boiler fuel to raise steam. Therefore, the boiler plant is equipped to use either blast furnace gas or powdered coal.

In the power plant recommended by the Committee on the 1,000-ton Furnace, the boilers operate at 650 lb. pressure and 750°F. total temperature; a cross section of this plant is shown in Fig. 44.

Steam Lines.—Steam lines to carry such high pressures and temperatures must be provided with adequate supports, expansion joints, and insulation covering.

Pumps.—Owing to large capacity and small space requirements, centrifugal pumps are largely used for the water supply at blast furnaces.

Blowing Engines.—At the present time there are four types of blowing engines in use at the blast furnace plants in this country: (1) the vertical reciprocating steam engine; (2) the horizontal reciprocating steam engine; (3) the blast furnace gas blowing engine; (4) and the turboblower, which has been found to be the most economical. A good steam-reciprocating blowing engine will last many years and there are still many in use, but new installations are turboblowers.

The air intakes for air going to the air cylinders, or "blowing tubs," should be located outside the engine house where the atmospheric air is the coolest, dryest, and cleanest; air from inside the engine house is too hot and humid to be blown into a blast furnace, but the author saw such installations in this year, 1938.

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[1] An integrated steel plant includes by-product coke ovens, blast furnaces, steel furnaces, and rolling mills.

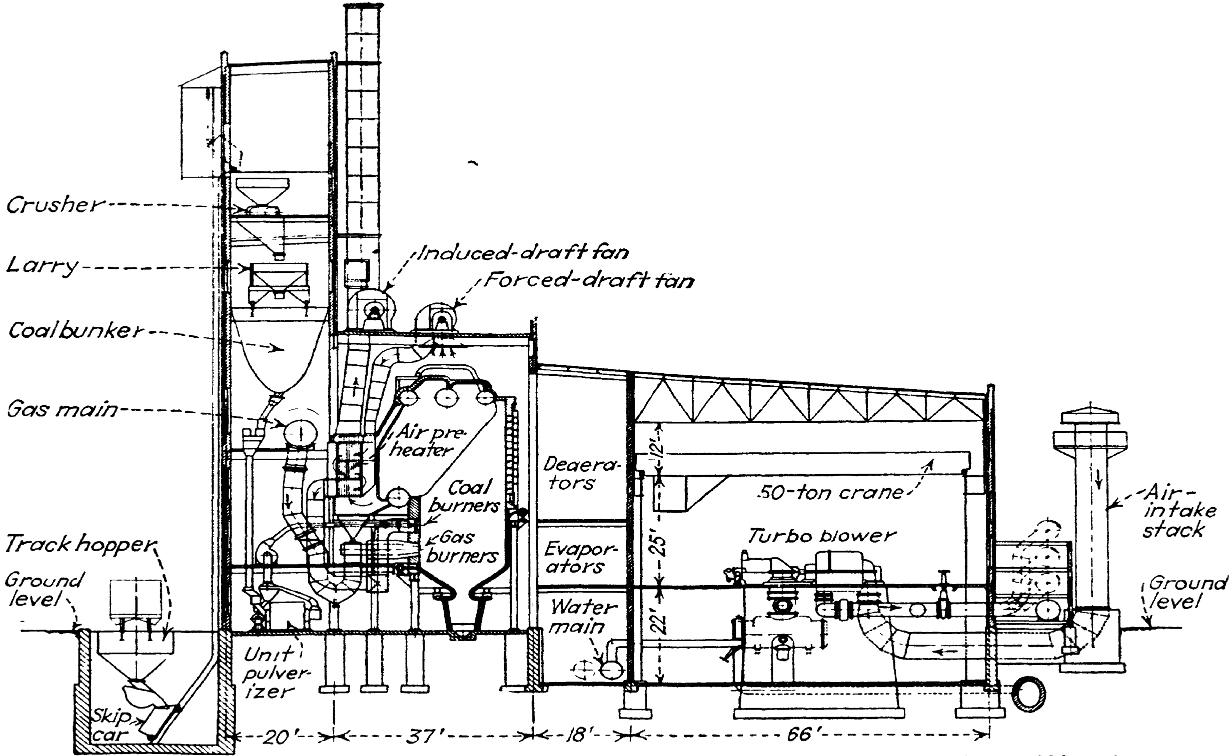

FIG. 44.—Cross section of power house. (*Courtesy of Blast Furnace & Coke Oven Assoc., Chicago*)

BLAST FURNACE CAPACITY

The capacity of a blast furnace measured in tons of pig iron per 24 hr. depends upon the richness of the iron-ore mixture and the number of pounds of coke required per ton of pig iron. The rule for calculating the capacity of a blast furnace of given dimensions, now generally accepted, is that adopted by the Southern Ohio Pig Iron & Coke Association in October, 1920, after two years of work by a special committee. The rule is as follows:

> Regardless of grade of pig iron produced blast furnaces of modern construction should burn about the same amount of fuel daily under same operating conditions. For each grade of pig iron the tonnage which can be produced will depend upon the quality of fuel used, yield of ore mixture and blast temperature. The tonnage of coke which can be burned in a unit of time has a certain ratio to the working volume of the furnace.
>
> From figures prepared on a number of different size furnaces, it has been found that with good practice 60 pounds of coke can be burnt each 24 hours per cubic foot working volume. The working volume is taken as volume from center line of tuyeres to two feet below bell when closed.
>
> Therefore, the capacity of a blast furnace must be expressed in terms of pounds of coke which can be burned per day. And in order to cover variations which exist from time to time in operation, it is necessary to adopt a base coke, a base theoretical yield ore mixture and a base hot blast temperature and then make allowances for variations as encountered

The analysis of the "base" coke referred to is as follows.

	Per Cent
Fixed carbon	89
Sulphur	1 (maximum)
Ash	9 to 10
Volatile	1 to 2

The structure of the coke is tough, but not dense or fragile, and free from breeze.

PART II

RAW MATERIALS

NATURAL IRON-ORE MINERALS

Iron ores are usually classified by blast furnacemen mineralogically or geographically, such as magnetites, hematites, limonites, etc., or as Adirondack ores, Lake Superior ores, and Southern ores. It would be helpful to the blast furnace operator and to the student to consider the merchantable iron ores from the geologico-geographical standpoint, as was done by Prof. J. P Leslie in his "Iron Manufacturer's Guide," 1859, and by John C. Smock in his paper on the "Geologico-Geographical Distribution of the Iron Ores of the Eastern United States."[1]

It is seldom, if ever, that iron ores occur as pure iron minerals; but they are either chemical or physical combinations with other minerals which form the gangue of the iron ore. The composition and amount of the gangue have direct influences on the value of the iron ore. Often there are several forms of iron minerals in the same ore, due to the varying degrees of oxidation or of hydration of the iron, or due to the weathering of bedded deposits of primary iron ores. Geologists tell us that iron ores are continually being formed and transformed by the action of

Name	Classification	Formula	Fe content, %	Sp. gr
Hematite	Oxide (hexagonal)	Fe_2O_3	70 0	4 9 to 5 3
Magnetite	Magnetic oxide	Fe_3O_4	72 4	4 9 to 5 2
Martite	Oxide (octahedrons)	Fe_2O_3	70 0	4 9 to 5 3
Limonite	Hydroxide	$2Fe_2O_3.3H_2O$	59 8	3 6 to 4 0
Turgite	Hydroxide	$2Fe_2O_3.H_2O$	66 2	4 3 to 4 7
Goethite .	Hydroxide	$F_2O_3.H_2O$	62 9	4 0 to 4 4
Siderite .. .	Carbonate	$FeCO_3$	48 2	3 8 to 3 9

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[1] *Trans. A.I.M.E.*, vol. 12, p. 130, 1883–1884.

water, air, and carbon dioxide. In less than a generation a "fossil" iron ore may be changed to a hematite.

The iron minerals occurring as merchantable iron ores are as shown in the table at the bottom of page 66.

There are other natural iron minerals in which the iron is combined with sulphur or with other metals, to such an extent that they are removed separately, as in the case of the sulphur in the sulphides and the zinc in Franklinite, or else used for alloy steel making as in the case of chromite. The more important of these iron-bearing minerals are as follows:

COMBINED IRON ORES

Name	Classification	Formula	Fe content, %	Sp. gr.
Franklinite	Oxides	$(Fe,Zn,Mn)(Fe,Mn)O_4$	21.0	5.1
Ilmenite	Oxides	$(FeTi)_2O_3$	Variable	4.5 to 5.0
Chromite	Oxides	$FeCrO_4$	Variable	4.3
Wolframite	Oxides	$(FeO.MnO)WO_3$	Variable	7.3
Pyrite. ...	Sulphide	FeS_2	46.7	4.9 to 5.2
Pyrrhotite..	Sulphide	Fe_6S_7	Variable	4.5 to 4.6
Chalcopyrite	Copper-iron sulphide	$CuFeS_2$	30.4	4.3
Marcasite	Sulphide	FeS_2	46.7	4.6 to 4.9

There is also another class of iron ores which are not now used in this country, although they once were the main source of supply for the early charcoal-iron and the raw-coal blast furnaces in many sections of the United States. In England, they have been used for many years, and recently have become the main supply of steel plants on a very large scale. These iron ores are as follows:

IMPURE CARBONATES

Blackband—formerly smelted in the Mahoning and Hocking Valleys of Ohio; practically exhausted

Clay ironstone—a carbonate iron ore mixed with clay, abundant in England

Cleveland ironstone—contains about 33 per cent iron and 0.75 per cent phosphorus (England).

The usual impurities, or gangue, occurring with the natural iron ores are silica in various forms of free silica, quartz, chert and silicates; clay; taconite; sulphur as sulphides and sulphates; phosphorus, as apatite; sometimes zinc, as carbonate or sulphide; seldom, barium, as sulphate; frequently, lime and magnesia, as carbonates which are beneficial as fluxes, these two carbonates (calcite predominating) forming a fifth to a third of the famous red ores of Alabama.

The general location of the iron ores of the United States is shown in Fig. 45.

LAKE SUPERIOR IRON ORES

The iron ores of the Lake Superior region, that part of Minnesota, Michigan, Wisconsin, and the province of Ontario bordering on Lake Superior and comprising around 181,000 square miles, supply about 85 per cent of all the ores smelted in the United States and about half in the Dominion of Canada. The predominance of Lake Superior iron ores was coincident with the passing of the anthracite blast furnaces of the Eastern states, which had depended largely on the magnetites and other local and imported ores. Most of the present day American blast furnace practice has been built up around the smelting of Lake Superior ores using by-product coke as the fuel.

Lake Superior iron ores are separated into Bessemer and non-Bessemer ores according to the phosphorus content; and further classified according to the range in which they are found. According to the *Directory* (July, 1935) of The Lake Superior Iron Ore Association, these ranges and the dates of first shipments are as follows:[1]

Range	Location	Began shipments
Marquette.	Michigan, Northern Peninsular	Previous to 1854
Menominee	Michigan (mostly) and Wisconsin	1877
Gogebic..	Michigan and Wisconsin	1884
Vermilion	Minnesota (northwest)	1884
Mesaba .	Minnesota (northeast)	1892
Mayville	Wisconsin (southeast)	1892
Baraboo ..	Wisconsin (south central)	1904
Michipicoten	Northern Ontario	1900
Moose Mountain	Sudbury District, Ontario	1908
Cuyuna...... .	Minnesota (east central)	1911

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[1] (See Fig. 46.)

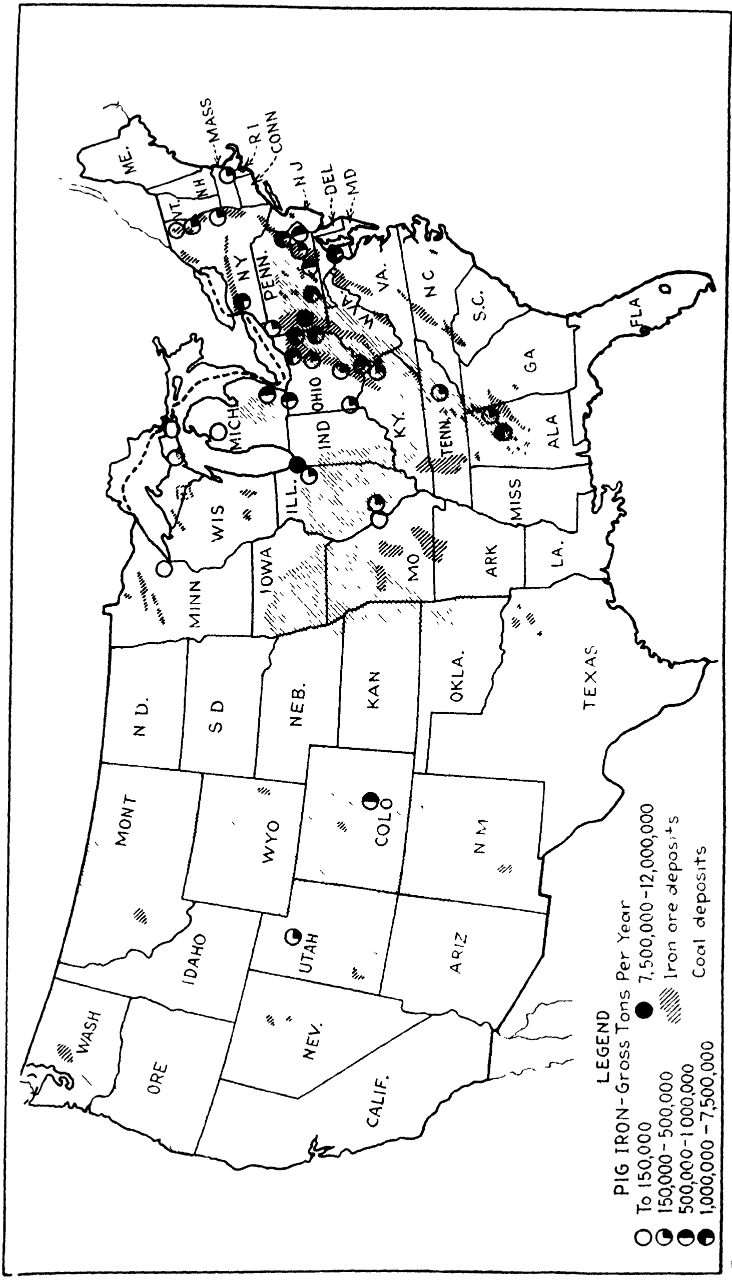

FIG. 45.—General location of iron ores, coal, and pig-iron capacity of the United States. (*Courtesy of American Iron and Steel Institute*, 1937.)

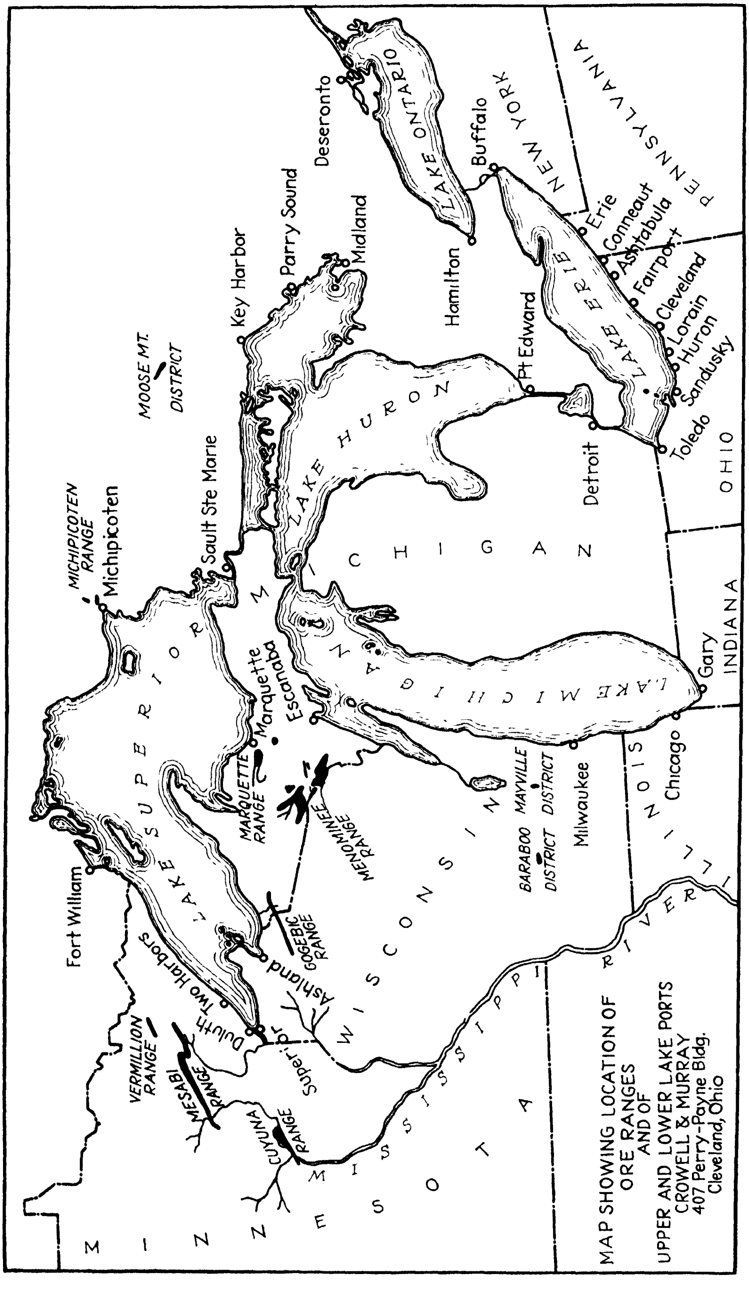

FIG. 46. - Map showing location of ore ranges and Lake ports (*Courtesy of Crowell & Murray, Inc*)

Until the discovery of, and shipments from, the Mesabi Range in 1892, all the Lake Superior ore was "old range" ore from Michigan, Wisconsin and Minnesota, and chiefly from underground mines with costs that prevented serious competition with the iron ores smelted in the Eastern blast furnaces. With the rapid increase of production of the rich open-cut "soft" ore from the Mesaba range—614,000 tons in 1893 and 6,614,000 in 1899—and with the remarkable decrease in prices of Bessemer and non-Bessemer ores delivered at lower Lake Erie ports down to as low as $2.15 and $1.90 per ton (the lowest prices for Lake Superior ores ever reached) respectively, there was a gradual abandonment of the hard ores of New York, New Jersey, and eastern Pennsylvania, and a corresponding shifting of the center of iron and steel production towards western Pennsylvania and the Great Lakes.

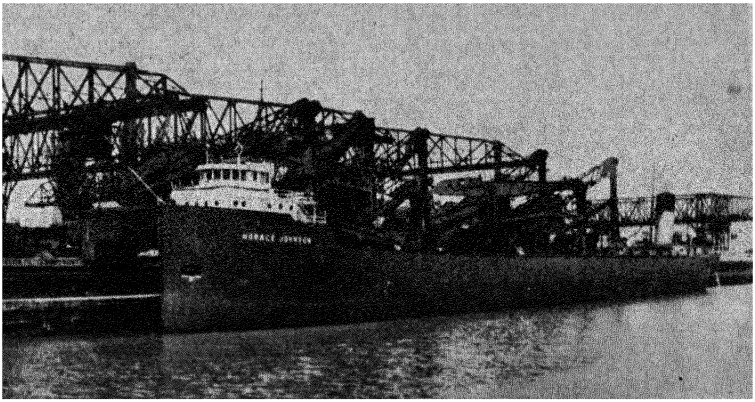

Fig. 47.—Unloading ore boat at Gary Works—12,300 tons in four hours
(Courtesy of Carnegie-Illinois Steel Corp.)

Blast furnace practice and blast furnace construction had to be revised in this country to meet the requirements of the soft and easily smelted ores of the Mesabi range; vast transportation systems of railroads, loading docks, huge ore boats, and rapid unloading docks (see Fig. 47), were built up to handle a whole year's supply of iron ore in the 7 months of the ore season. Naturally, the richest and cheapest ores were used first, with consequences that will be described later (see Fig. 48).

The Lake Superior ores include all the different ores in the older geological formations of the North American continent, but the hematites predominate. Some of the hematites are very hard and dense, in color, red and blue and black; some hematites and the limonites are soft ores; the magnetites are mostly so low in iron that they have to be crushed fine and magnetically concentrated.

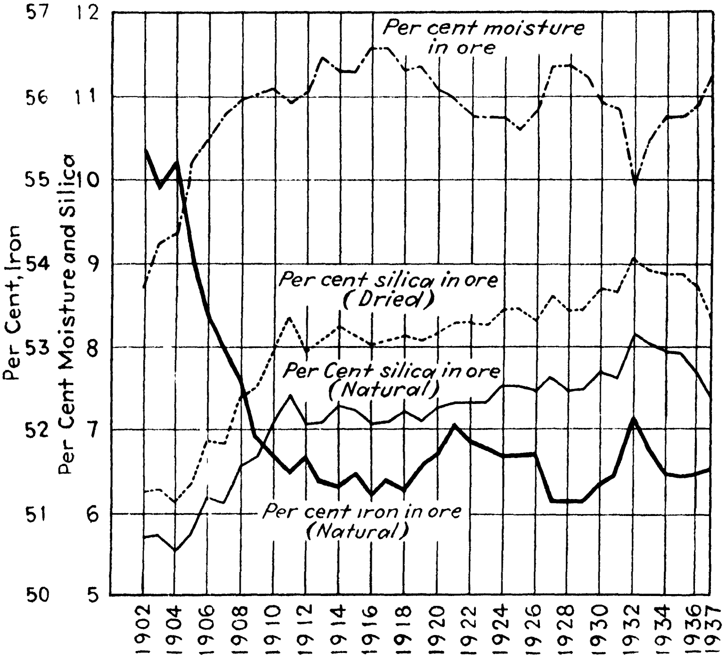

FIG. 48.—Decrease in average iron contents of Lake Superior iron ores.

The commercial classification[1] of Lake Superior iron ores is as follows:

Bessemer—Old Range, Mesaba	P, 0.045% or less, dry; Fe, 51.50%
Low phosphorus	P low enough to make 0.035% phosphorus in pig
High phosphorus	Ores containing over 0.180% P
Manganiferous	Ores containing over 2% Mn
Silicious	Ores containing 18 to 20% SiO_2, or more

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[1] "The Iron Ores of Lake Superior," 7th ed., 1930, Crowell & Murray, Inc.

The total recorded shipments of Lake Superior ores up to date amount to nearly a billion and three quarters gross tons (1,725,168,731 tons up to Dec. 31, 1937), and the known tonnage remaining is roughly estimated to be about the same amount; in other words, about half the known Lake Superior deposit has been consumed in the past 85 years. The extent and quality of these ore reserves will be further discussed in later chapters.

Some of the Lake Superior ore mines have produced enormous tonnages, especially in the Mesaba region where at least fourteen mines have shipped a total of more than ten million tons each. The Hull-Rust mine, in St. Louis County, Minn , has shipped over 100,000,000 tons of ore since it was opened in 1896; the record tonnage was 8,823,879 tons in 1923. In the Gogebic, Menominee, and Marquette Ranges only a few mines have produced more than 1,000,000 tons per year, but they have been shipping for many years.

With the movement ot such large tonnages of a basic raw material (frequently over 50,000,000 tons in a season) there has been developed gradually a system of sampling and analyzing that is fair to all concerned, and is the basis of payment for all the Lake Superior ores shipped. The ores are sampled at the mines from the ore in place and then each carload is sampled before it goes to the loading dock at upper lake ports. The separate carloads are then assigned to numbered orebins in such a way that the whole cargo in the ore vessel is comparatively homogeneous.

Usually the ore is sampled again as it is being unloaded at lower lake ports; this is done by the Lake Erie chemists according to specifications adopted by The Lake Superior Iron Ore Association and other groups of technical men and approved by the shippers and users of Lake ores. The methods of pricing the ores will be explained in a later chapter.

EASTERN MAGNETITES AND CLINTON ORE

There has always been in this country a strong prejudice against magnetic iron ores, founded half on facts and half on ignorance; it was a fact that big lumps of magnetite would chill the furnace hearth unless the furnace were blown very slowly; it was a fact that fine magnetic concentrates would "run ahead" of the rest of the ores and chill the furnace hearth. On the other hand, the laws of reduction of lumps of iron ore within the blast furnace were not known, nor had the process of sintering fine concentrates been established. Although some authorities say that the magnetites are harder to reduce than the hematites, no one has satisfactorily explained why, if that is true, it is a fact that the hematite ores in the top of a blast furnace are first reduced to the magnetic oxide, whereas the magnetites are already reduced to the magnetic oxide when charged into the furnace.

The reason that so many blast furnacemen in the past had difficulties in smelting magnetic iron ores was that the ores were not properly prepared. The richness of the commercial sintered concentrates not only reduces the freight paid per ton of iron, but increases the pig-iron production per furnace, decreases the coke consumption, and by "the cumulative effect of a good thing," decreases the cost of a ton of pig iron.

The early practice in the smelting of magnetic iron ores was to put lumps as big as one man could lift into the furnace—big lumps of limestone, big lumps of coke, and big lumps of ore. Such practice caused all sorts of furnace troubles, especially when some fine magnetic concentrates or some fine hematite ore would be mixed with the big lumps of magnetite. Some of the crude magnetite used to be very rich in iron; there are records of regular shipments of magnetite shipped from the Barton Hill mine where the crude ore ran 70 per cent in iron.

With the advantage of the new methods of mining, concentrating and sintering, there are now four mining districts in the Eastern part of the United States that are producing high-grade magnetic concentrates, either sintered or as concentrates. These districts are Mineville and Chateaugay (Lyon Mt.) in the Adirondack region of New York; the Wharton district in northern New Jersey; and the old Cornwall mines in eastern Pennsylvania.

These magnetic iron ores of New York, New Jersey, and eastern Pennsylvania once formed the basis of the iron and steel industry of that section of the country, and especially throughout the period when anthracite coal was the chief blast furnace fuel. The coming of cheap Mesaba ores in the early nineties caused the use of crude magnetic ores to decrease rapidly. Now that improved mining methods are used, fine grinding and efficient magnetic-concentration machines installed, and the sintering process established, there has been a gradual return to the use of sintered magnetic concentrates not only in New York blast furnaces, but also in the Pennsylvania furnaces as far west as the Pittsburgh region (the 47 blast furnaces built in New Jersey, beginning in 1674, have all been abandoned and scrapped).

The Adirondack region in the northeast part of New York State has the most extensive deposits of magnetite so far known in this country. The area contains about 12,500 square miles; no complete survey of the ore reserves in this area has ever been made, but enough drilling has been done to make sure that the region can be a dependable source of supply for many years to come. In his paper "The Iron Ores of the Adirondack Region," before the American Iron and Steel Institute in October, 1916, the late Frank S. Witherbee put the estimate at 1,100,000,000 tons of ore that could be concentrated to produce 5,000,000 tons of concentrates higher than 63 per cent iron for over 100 years.

The most notable straight magnetite deposits now being worked on a large scale are those of Witherbee, Sherman and Co. at Mineville, near Port Henry on Lake Champlain, and Chateaugay Ore and Iron Company at Lyon Mountain. The first company can produce low-phosphorus and high-phosphorus ore. The magnetic concentrates from the mines at Mineville are sintered in Greenawalt pans at Port Henry.

At Lyon Mountain, Clinton County, about 37 miles west of Plattsburg, N. Y., the magnetite is exceptionally low in phosphorus and is used for making special low-phosphorus pig iron. The concentrates contain 66 per cent iron and 0.005 per cent phosphorus.

The titaniferous magnetic iron ores of the Adirondack region occur in great abundance (the Sanford Lake deposit is estimated to contain 70,000,000 to 100,000,000 tons), but the titanium content has hitherto prevented the commercial use of these ores Iron ores with high titanium have been successfully smelted in the iron blast furnace[1] but, here again a deep-set prejudice against titanium in the blast furnace (based partly on fact and partly on ignorance) has prevented the general use of titaniferous ores.

The ores of the Adirondack region are concentrated by the *dry* magnetic processes.

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[1] FRANK E BACHMAN, *Yearbook, Am. Iron Steel Institute*, 1916

In northern New Jersey are important magnetic iron-ore deposits extending northeasterly from the Delaware River near Easton, Pa., to the New York State boundary line near Greenwood Lake. These deposits also extend through the Highlands to the Hudson River, and beyond, in New York State, but the several mines of that region are now idle.

These ores have been mined for over two centuries, and at one time were extensively smelted in New Jersey and in the Lehigh Valley of Pennsylvania. For many years the crude ore, hand cobbed, was shipped direct to the furnaces; over 3,000,000 tons of such ore averaging about 56 per cent in iron was shipped from the Richard mine near Wharton, N. J., from an area of only 84 acres, up to 1913. Gradually crushers were installed, then magnetic cobbing, but the mines were generally owned and operated by iron companies that produced only enough ore for their own use. There was no large-scale mining and no economical concentration methods until recent years; meanwhile most of the blast furnaces of the region have been scrapped.

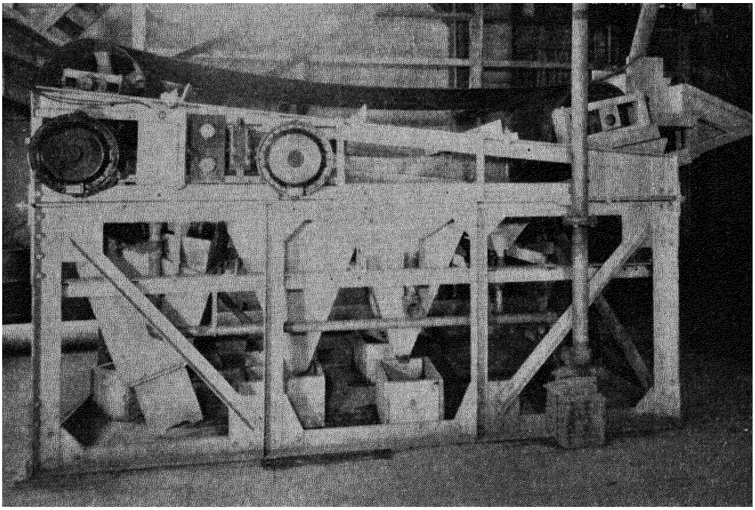

Fig. 49.—Crocket-Dings magnetic separator. *(Courtesy of Dings Magnetic Separator Co.)*

The present status of the magnetites of New Jersey and their future possibilities are well described by H. M. Roche, in his paper[1]

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[1] "The Iron Ores of New Jersey," *The Iron Age*, Feb. 4 and 18, 1937.

which gives much information on the character, beneficiation, and extent of these ores. His estimates show reserves of minable ores that would produce 400,000,000 tons of concentrates containing 67 per cent iron. The new wet magnetic concentrating machines can reduce the phosphorus contents of the ore down below the Bessemer limits, and will keep the iron contents within very close controllable limits. The Crockett-Dings wet magnetic separator is shown in Fig. 49.

The third important Eastern magnetite district is the famous Cornwall deposit now owned and operated by the Bethlehem Steel Company. Here the ore is crushed and ground fine before wet magnetic concentration; the concentrates are sintered in Greenawalt pans and shipped to the blast furnaces at Steelton and Bethlehem.

"Southern ores" include the red ores and the brown ores of the Southern states, particularly of Alabama, where the Clinton ores of the Appalachian region are found in thicker veins than in any other section, and where there are many brown ore (limonite) deposits with ores almost as rich in iron as the average Lake Superior ores, that can be mined on a commercial scale.

Southern blast furnace practice has been built around the great deposits of iron ore in Red Mountain at Birmingham, Ala., where the Clinton ore outcrop is 20 ft. thick and is within switching distance of great beds of coking coals. Just as in the case of Lake Superior iron ores, where the best and easiest to mine ores were used first, so, with the red ore, the richest parts of the vein near the outcrop were mined first; now the ore is not so rich in iron but costs more to mine, and it takes 2½ to 3 tons of ore to make a ton of pig iron.

Ernest F Burchard, mining engineer, U. S. Geologic Survey, who has made special studies of the Clinton ores, says of the Red Mountain deposits,

> The structure and mineralogy of the Clinton ores are closely related features of the deposits. The ore with its associated minerals occurs in lenticular beds analogous to strata of sandstone, shale, and limestone, and interbedded with such rocks. The fossil ore consists of aggregates of fossil organic forms. . . .[1]

The red ore is almost as dense as magnetite, and the same erroneous practice of the Lehigh Valley furnacemen in using

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[1] (*U. S. Geol. Survey, Bull.* 400, p. 26, 1910.)

The brown ores originally comprised the entire ore mixture of the Southern blast furnaces, but in some cases they have been almost replaced by red ores, on account of cost and irregularity of supply and analysis. With improved methods of locating, mining, and beneficiating, brown ores are being used in larger proportions of the burden. Some of the brown ore is not only much richer in iron and in manganese but is much lower in phosphorus than the red ores.

Actual analyses of brown ores used in blast furnaces in 1937 were as follows:

Type	Fe, %	P, %	Mn, %	SiO_2, %	Al_2O_3, %
Russellville ore	47.74	0.65	0.47	6.67	3.25
Tait's Gap ore	48.27	0.16	0.70	9.87	2.75
Champion ore	50.00	0.25	0.50	8.00	2.93

In his book, "Iron Making in Alabama,"[1] William B. Phillips says,

> As a rule the limonites, or so-called Brown ores constitute the best material for iron making in the State. . . . under ordinary weather conditions well washed Brown ore will contain 7% moisture when delivered at furnace . . . normal limonite, when pure, contains 14.44% of combined water and 85.5% oxide of iron (= 59.89% Fe). . . . An average analysis of a good quality of Brown ore, as delivered to the furnaces in Alabama, is as follows:

Contents	Percentage
Hydroscopic water—moisture. . . .	7.00
Combined water. . . .	6.00
Metallic iron. . . .	48.54
Silica	11.22
Alumina	3.61
Lime	0.84
Phosphorus	0.38
Sulphur	0.09

FOREIGN IRON ORES USED IN THE UNITED STATES

In spite of the abundance of rich and cheap iron ores in the United States, large quantities of foreign ores have been, and still are, imported for smelting in the blast furnaces near the

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[1] 3d ed., 1912.

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Metallic iron.	48 54
Silica. . . .	11 22
Alumina	3 61
Lime .	0 84
Phosphorus	0 38
Sulphur	0 09

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Atlantic seaboard; a few blast furnace plants, especially at Sparrows Point, Md., Chester, Pa., and at Boston, Mass. were built on tidewater so as to get foreign ores imported at low ocean freight rates. The author's own early blast furnace experience was entirely with foreign iron ores from Cuba, Spain, North Africa, islands of the Mediterranean, and Newfoundland.

Recently, much ore has been imported from Chile, Russia, Norway, and Sweden, and even from Australia. New York, Boston, Philadelphia, and Baltimore (including Sparrows Point) are other ports of entry.

As a rule, the foreign ores are not so well prepared, especially as to sizing, as are our domestic ores; in many cases, there are objectionable constituents, such as zinc, lead, and arsenic, which give trouble in smelting. Zinc and lead do not go into the pig iron, but part of the arsenic will remain in the iron giving certain effects in the steel or castings. Some foreign ores contain small amounts of copper, most of which will enter the pig iron, which is helpful in some cases and harmful in others.

Since 1913, foreign iron ores have been admitted free of duty. The ocean freight rates vary greatly, affected by international economic conditions and political disturbances. The labor costs in most of the foreign countries are very much lower than in this country, making low mining costs, which, combined with low ocean freights, would ordinarily result in low-priced ores along the Atlantic seaboard. But another factor has caused an increase in the price of foreign ores, and that is the greatly increased demand for iron ores in those countries which do not have an adequate supply of their own, such as Japan, Italy, Belgium, Germany, and even England. From what has been said in previous chapters about the enormous iron-ore reserves in the Adirondacks, in northern New Jersey, and in Alabama, and from what will be said in succeeding chapters on the beneficiation of iron ores, it is not likely that there will be much of an increase in the importation of foreign iron ores. Most of the imported ores in recent years have come from Chile and Cuba to the furnaces of the Bethlehem Steel Company.

The richest of the foreign ores are the magnetites from Sweden and Chile, containing 66 and 65 per cent iron respectively; sintered concentrates from the Adirondacks and New Jersey are as rich and, in many cases, even richer in iron.

TREND OF ANALYSIS OF LAKE SUPERIOR IRON ORES

As long as the annual shipments of Lake Superior ores were not over 10,000,000 tons, the average iron contents could be kept high, and it was not difficult to purchase lake ores that would average over 60 per cent iron in the natural state. In 1895, when shipments were 10,441,462 tons, it was possible to get Mesaba ore running 64.44 per cent in iron and only 2.85 per cent in silica.[1] Six years from then the shipments were doubled, and in another six years again doubled to a total of 42,401,588 tons; six years later the tonnage reached 50,114,927. In order to produce such huge tonnages, it became necessary to include ores of much lower grade which meant a decrease in iron contents and almost double as much moisture as well as silica.

Figure 48, giving the average annual analysis of all Lake Superior iron-ore shipments, beginning with 1902, shows the drastic changes in the average analysis of the ores in the 10 years immediately following 1901, the first year to exceed 20,000,000 tons. The lowest point was 51.15 per cent in 1928; only twice in the past 25 years has the iron content gone above 52 per cent—in 1921 when shipments were only 22,851,805 tons (lowest since 1904), and again in 1932 when shipments dropped to 3,588,608, the lowest tonnage since 1886.

These records indicate that the high-grade Lake Superior iron ores have been greatly depleted, a fact that has far-reaching effects on the iron and steel industry of the United States. The decrease in iron and the considerable increase of the useless, inert matter, silica and moisture, have a direct influence, metallurgically, geographically, financially, sociologically, on the manufacture of iron and steel and on all the allied iron and steel industries and have so adversely affected transportation costs that vigorous steps are being taken to prevent further decline and possibly restore the former high quality of lake ores.

With decreased iron content and increased silica and moisture, blast furnace practice must be metallurgically adjusted to meet the changes in character of the basic raw material. The geographical location of steel plants will be shifted to take advantage of higher grade raw materials. Financially, the adverse effects

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[1] Reese, Arnold K., "Notes on Six Months' Working of Dover Furnace, Canal Dover, Ohio." *Trans. A I.M.E.*, vol. 28, p. 481, 1897.

TABLE I.—ANNUAL SHIPMENTS OF LAKE SUPERIOR IRON ORES BY RANGES
(In thousands of tons)

Year	Range										
	Marquette	Menominee	Gogebic	Vermilion	Mesaba	Mayville	Baraboo	Cuyuna	Total U. S. mines	Canadian mines	Grand total
Unknown	74								74		74
1854	3								3		3
1855	1								1		1
1856	7								7		7
1857	26								26		26
1858	23								23		23
1859	69								69		69
1860	114								114		114
1861	50								50		50
1862	124								124		124
1863	203								203		203
1864	247								247		247
1865	199								199		199
1866	297								297		297
1867	466								466		466
1868	507								507		507
1869	649								649		649
1870	856								856		856
1871	819								819		819
1872	949								949		949
1873	1,175								1,175		1,175
1874	936								936		936
1875	899								899		899
1876	995								995		995
1877	1,013	10							1,024		1,024
1878	1,039	83							1,122		1,122
1879	1,135	247							1,383		1,383
1880	1,384	561							1,945		1,945
1881	1,580	739							2,319		2,319
1882	1,829	1,171							3,000		3,000
1883	1,305	1,079							2,384		2,384
1884	1,558	896	1	62					2,517		2,517
1885	1,430	693	120	225					2,468		2,468
1886	1,627	892	753	304					3,577		3,577
1887	1,851	1,196	1,323	394					4,765		4,765
1888	1,924	1,191	1,437	512					5,064		5,064
1889	2,643	1,797	1,988	845					7,273		7,273
1890	3,001	2,282	2,848	880					9,011		9,011
1891	2,512	1,825	1,842	895					7,073		7,073

1892	2,665	2,261	2,973	1,168	4	9			9,081		9,081
1893	1,837	1,466	1,329	821	614	8			6,075		6,075
1894	2,060	1,138	1,809	949	1,793	11			7,760		7,760
1895	2,094	1,924	2,548	1,078	2,782	16			10,441		10,441
1896	2,607	1,560	1,800	1,088	2,882	13			9,951		9,951
1897	2,713	1,937	2,258	1,278	4,277	11			12,474		12,474
1898	3,119	2,522	2,498	1,265	4,614	18			14,038		14,038
1899	3,738	3,301	2,796	1,772	6,614	20			18,241		18,241
1900	3,479	3,261	2,877	1 656	7,810	21			19,104	65	19,169
1901	3,247	3,619	2,938	1,786	9,005	22			20,617	233	20,850
1902	3,865	4,613	3,659	2,084	13,331	30			27,582	303	27,885
1903	3,040	3,750	2,939	1,677	12,894	28			24,327	203	24,530
1904	2,852	3,075	2,399	1,283	12,157	46	48		21,859	118	21,978
1905	4,236	4,495	3,706	1,677	20,159	61	71		34,405	170	34,575
1906	4,057	5,110	3 642	1,793	23,821	77	67		38,567	122	38,689
1907	4,388	4 965	3,633	1,685	27,492	24	72		42,259	143	42,402
1908	2,414	2,679	2,700	842	17,258	71	51		26,015	151	26,166
1909	4,253	4,875	4,088	1,109	28,178	83			42,586	196	42,782
1910	4 393	4 238	4,316	1,203	29,200	92			43,442	188	43,630
1911	2 836	3 911	2,603	1,089	22,099	116		148	32,802	155	32,958
1912	4,203	4,711	5,006	1,845	32,045	104		305	48,220	88	48,308
1913	3 968	4,967	4,532	1,567	34,040	145		733	49,952	165	50,117
1914	2,492	3,222	3,569	1,017	21,468	106		868	32,741	208	32,949
1915	4,106	4,983	5,478	1,734	29,757	81		1,128	47,266	369	47,635
1916	5,410	6,365	8,490	1,947	42,526	126	93	1,716	66,673	230	66,903
1917	4,874	6,046	7,980	1,531	41,441	94	43	2,422	64,430	265	64,695
1918	4,354	6,379	7,937	1,193	40,399	89	9	2,479	62,839	188	63,027
1919	2,992	4 447	6,230	929	32,004	93		1,859	48,553	168	48,721
1920	4,608	6,569	8,763	1,007	37,150	79	51	2,192	60,419	114	60,533
1921	1,117	1,584	2,337	869	16,350	52		490	22,799	53	22,852
1922	2,818	4,079	6,221	1,212	28,064	87	23	1,496	44,001	14	44,016
1923	3,892	4,855	6,580	1,279	41,806	111	27	2,221	60,771	27	60,799
1924	3,175	3,837	5,160	978	29,142	99	36	1,469	43,896	*	43,896
1925	4,198	5,270	7,068	1,438	35,890	106	51	1,514	55,535		55,535
1926	4,435	5,946	7,537	1,586	38,251	132		2,083	59,970		59,970
1927	4,148	5,213	6,386	1 548	32,976	93		1,982	52,344		52,344
1928	4,299	4 842	6,540	1,671	35,399	7		2,098	54,856		54,856
1929	5,410	5,645	7,624	1,874	43,008			2,596	66,157		66,157
1930	3,634	3,609	5,064	1,885	31,067			1,929	47,188		47,188
1931	1,809	1,469	2,908	1,141	15,270			898	23,496		23,496
1932	357	308	673	217	1,935			99	3,587		3,587
1933	2 807	1,511	2,401	740	13,472			741	21,672		21,672
1934	2,474	1,335	2,287	785	14,650			533	22,064		22,064
1935 ...	3,111	1,628	3,038	842	18,695			763	28,078		28,078
1936	4,460	2,150	4,577	1,019	30,909			1,257	44,373		44,373
1937	5,747	2,649	5,661	1,453	45,823			1,775	63,110		63,110
Totals	194,310	182,984	207,372	64,726	1,030,521			37,792	1,721,232		1,725,167

* Less than 500 tons.

are twofold—increased operating costs and increased capital investment to obtain the same results. The sociological effects include the problems of taxation on low-grade iron ores and the abandonment of mining communities when costs get prohibitive.

The cost of transporting a ton of ore with only 49 per cent iron and 11 per cent moisture is the same as for a ton of ore with 67 per cent iron and 2 per cent moisture, but the freight per unit of iron varies greatly, being 6.12 cents per ton per unit and 4.47 cents respectively, which is equivalent to $6 per ton of pig iron and $4.38 per ton.

The steps taken to correct this situation will be described in another chapter.

TABLES OF TONNAGE OF IRON-ORE PRODUCTION

Because the Lake Superior ores have so long predominated the iron industry in this country, the record of annual shipments is here given. These figures are from the records of The Lake Superior Iron Ore Association, Hanna Building, Cleveland, Ohio; up to the end of 1934 from their "statistical data" of July, 1935, and for the last three years from annual reports kindly sent to the author by Secretary Harbaugh (see Table I).

The map (Fig. 45) on page 69 is from the American Iron and Steel Institute (1937). Although the intensity of the ore deposits shown on the map seems to indicate greater tonnages in Ohio and West Virginia than in Minnesota, the author doubts it very much, in spite of the fact that he was assured that the map conformed to the authoritative reports.

CHEMICAL AND PHYSICAL CHARACTERISTICS OF IRON ORES

Although the market value of an iron ore can be accurately determined by the percentage of iron content, modified by the presence or absence of other elements (some beneficial, some deleterious), there are other constituents, chemically or mechanically combined, and other physical qualities, which either enhance or detract from the value of the ore in the mind of the blast furnace operator. Some of these characteristics cannot be evaluated in terms of the price; it is by practical experience that a blast furnaceman learns how to select his ore or, if he has no choice in the matter, how to get the best results with the ores at hand.

In the present American practice it is seldom, if ever, that a blast furnace is run exclusively on a single iron ore; the usual exception is in making low-phosphorus pig where it is possible to smelt magnetites with very low phosphorus, such as Chateaugay ore, or the now exhausted Cranberry ore from North Carolina. The varying demands for phosphorus and manganese necessitate the control of these two metalloids by varying the amounts present in the ore mixture.

Some natural iron ores, especially foreign ores, contain objectionable amounts of zinc and lead, which are volatilized in the shaft of the furnace and pass off with the waste gases or else impregnate the brick of the furnace lining; in either case, they are sources of cumulative operating troubles.

One constituent of the gangue of iron ores gives trouble if it is present in too small percentages, and that is alumina, which is one of the ingredients of the blast furnace slag. Its influence will be shown in the chapters on slags.

Of the physical characteristics of iron ores, density is one of the most important, because, even though it may be properly crushed and sized, the density of an ore directly affects its porosity and reducibility.

Some iron ores are naturally so fine, especially the Mesabas, that there are difficulties in smelting them in the crude state. Some few ores decrepitate when heated in the furnace, giving dust troubles.

In certain ores, the silica is present as pure quartz, making it difficult to sample accurately and to distribute evenly the flux. If the ratio of silica to alumina in an ore is too high, there will be smelting difficulties.

An example of an ore that combined many of the above physical, and some of the chemical, troubles was that of a Mesaba ore

Analysis	Iron (natural), %	Silica (natural), %	Alumina (natural), %	Moisture, %
One Lake chemist	50.49			13.94
Second Lake chemist .	44.94			12.14
Furnace chemist	45.09	18.20	0.18	13.95
Crest of pile at furnace	51.67	12.75	0.07	9.60
Lumps that rolled down	32.76	47.24	0.50	2.00

named "Medina," before anything was done to prepare it properly for the blast furnace. Its irregularity in every particular got so bad that reforms in preparation and cargo sampling started to improve that year. An example of the irregularity is shown in *the table on page 85.*

BENEFICIATION OF IRON ORES

In previous sections are given some of the reasons for making iron ores more regular as to size and chemical analysis before charging into the blast furnace. Such improvement as to quality is called "beneficiation," whether it increases the iron content by some concentration method or simply improves the physical condition by crushing or by screening and sizing.[1]

The late John L. W. Birkinbine[2] said that his father's motto was, "The blast furnace is a very economical metallurgical apparatus, but it is a most expensive place in which to prepare your raw materials."

The various processes for the beneficiation of iron ores include:

Crushing	to break up big lumps
Screening	to separate lumps, or to size
Washing	to remove clay, sand or excessive moisture
Drying	to remove moisture
Magnetic concentration	to concentrate magnetites
Sintering	to agglomerate fine ores and flue dust
Nodulizing	to agglomerate fine ores and flue dust
Briquetting	to agglomerate fine ores and flue dust
Roasting	to eliminate wholly or partially some objectionable ingredient; also to make magnetic

There was a time in blast furnace practice when big lumps of ore were erroneously desirable, but, when the principles governing the reduction of iron ores in the furnace became better known, it was found imperative that no big lumps should be charged into the furnace and, further, that it was desirable that lumps of different sizes should be charged separately. One of the objections to crushing was that it necessarily made more

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[1] See "Beneficiation of Iron Ores from the Blast-Furnace Viewpoint," *Mining and Metallurgy*, September, 1930, p. 423, which the author presented at the Chicago meeting of the Iron and Steel Division, A.I.M.E., September, 1930. For discussions on the needs of beneficiation of iron ores see *Trans A.I.M.E.*, Iron and Steel vol., 1930, pp 407–431.

[2] *Yearbook, Am. Iron Steel Inst.*, 1916.

fines which were thought to make trouble. Crushing was one of the first steps in the preparation of iron ores for the furnace; breaking big lumps that passed over a grizzly screen was the first method at the mines, followed by rotary crushers or jaw crushers.

Where fine grinding is necessary for concentration, such as minus 100 mesh or even minus 200 mesh, as in some magnetic concentration, rolls, ball mills and rod mills are used. In concentrating the New Jersey magnetites, the ores are crushed to minus 6-mesh size when they are to be sintered, and to minus 2-in. size when shipped as direct furnace ore.[1]

The red ores of the Birmingham district are now being crushed to three sizes which are filled separately into the blast furnace—lump, medium, and fines (see Fig. 50). Lump ore is supposed to be through 3-in. round hole and on 1 in.; the medium, through 1-in. and on $\frac{1}{4}$ in.; the fines through $\frac{1}{4}$-in. hole. At one plant using red ore, the minus $\frac{3}{8}$-in. ore is sintered together with flue dust (see Fig. 40).

SCREENING; WASHING; MAGNETIC CONCENTRATION

The simplest form of screening iron ore is to dump it over a grizzly with bars set to the desired width, usually 3 to 4 in. wide. The oversize is either broken up with sledges or passes to a crusher. The minus size goes direct to shipping ore, to other screens, or to the next step in concentration. At brown ore mines in the South and at some ore mines in the Lake Superior region, the grizzly does the primary screening. These stationary screens are set at an angle that allows the ore to slide down easily, usually 45 deg. At brown-ore mines a high-pressure stream of water is played on the ore on the grizzly so as to help the fine sticky ores to pass through the bars and to clean the clay off the big lumps.

Revolving screens, or trommels, are used to divide the ore into different sizes, some of which will be direct-shipping ore and some of which will go to other machines for further treatment. Many plants in the Lake Superior region are simply crushing and screening plants for the purpose of more thoroughly mixing the ores and providing a more homogeneous raw material, both

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[1] ROCHE, H. M.: "The Iron Ores of New Jersey," *The Iron Age*, Feb. 4 and 18, 1937.

chemically and physically; sometimes the oversize is recrushed in secondary crushers. In some cases with lake ore and also with red ore in the Birmingham district, the fines are screened out and sintered, thus reducing the furnace loss through excessive flue dust.

Vibrating screens are much used in the screening and sizing of magnetic iron ores; Hummer screens have been used at the Babbitt plant of the Mesabi Iron Company in Minnesota and at plants in New Jersey.

Washing.—Some iron ores are concentrated in log washers which remove the clay and sand, and in some cases, where there is excessive moisture, as in certain Mesabi ores on account of much clay, moisture is reduced. In recent years, many washing plants have been installed on the Mesabi range; most of the brown ores in the South are washed before shipment to the furnace; and log washers have been used getting rid of some of the waste in the wet magnetic-concentration process.

The principle of the old-fashioned log washer, where cast iron blades were stuck into a log that revolved in a trough of water, was the same as for the modern double-log washers now being extensively used. The two revolving shafts fitted with steel blades set at oblique angle, revolving in opposite directions in an inclined trough, receive the ore at the lower end of the washer. Water is fed in at the higher end of the trough where the lumps of ore are discharged by the upward thrust of the blades of the log washer; dirty water, clay, and sand overflow at the lower end of the trough. In the washing of brown ores, the sandy fine ore is screened out and jigged. The McLanahan steel-log washer (Fig. 51) is now much used for washing iron ores

In cases where lumpy ores carrying most of the iron are mixed with clay and fine sand that carry very little iron, the ore is fed into a trommel fitted with several sizes of screens and with many jets of water. The lumps are washed clean and discharged in separate sizes or all mixed together; the clay and sand are carried off in the waste water.

Drying.—Some lake ores carry so much moisture (15 per cent or more), especially in the Mesabi and Cuyuna ranges, that it is necessary to remove some of the moisture before shipment from the mines. This is done either in big revolving driers, or by mixing the fine wet ore with the hot sintered ore as it comes

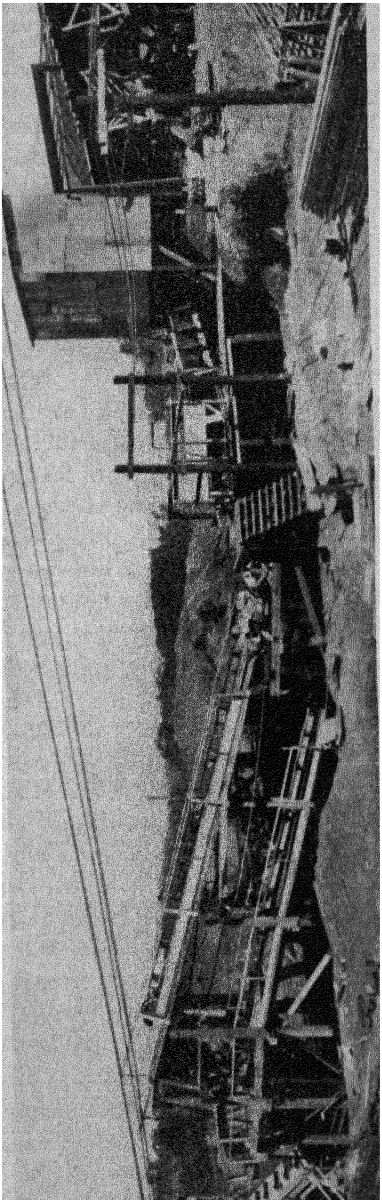

FIG. 51.—**Brown-ore washer,** Russellville District, Ala. (McLanahan double **steel-log washer).** (*Courtesy of E. F. Burchard.*)

from the sinter plant, thus reducing moisture in part of the ore and at the same time cooling down the hot sinter.

Magnetic Concentration.—Of all the low-grade iron ores that can be concentrated, the magnetites are the most amenable to treatment, not only because they are the richest in iron of all the iron compounds in the pure state but because the grains of iron ore and the grains of gangue are usually so distinct when crushed to the requisite size, that they can readily be separated with electromagnets in either the dry or wet condition.

Magnetic concentration is so effective that in some of the processes for enriching hematite ores, the ore is first changed to the magnetic ore by heating, or by partial reduction, or by a combination of the two steps.

Although there are deposits of magnetite rich enough that the crude ore could be shipped direct to the furnace, yet it is usually more economical to mine the low-grade ore along with the high-grade and to crush, size, and concentrate all the ore into a homogeneous shipping product that is kept under control as to the richness of iron. Moreover, it is now possible to remove the phosphorus along with the other gangue material.

EVALUATION AND PRICING OF IRON ORES

During the years in which there have been bought and sold over one and a half billion tons of Lake Superior iron ores, and especially in the last twenty-five years, there has been evolved and universally accepted a system of sampling, analyzing, and evaluating lake ores that is commercially accurate. Lake ores are bought and sold on the "natural"- or "wet"-analysis basis, *viz.*, the percentage of iron in the ore in its natural, or moist, condition as it is unloaded from the ore boats at lower Lake Erie ports governs the price of the ore delivered at the rail of the ore boat.

The ore is sampled by experienced samplers, as the ore is being unloaded, according to well-tried, scientific rules of The Lake Superior Iron Ore Association. The percentage of moisture is determined from a moisture sample especially protected. The large sample of the whole cargo is quartered down and one portion sent to the buyer and one portion analyzed by the custom chemist.

ores are divided into Bessemer and non-Bessemer according to whether they contain not over 0.045 per cent phosphorus dry, in which case they are Bessemer ores and command a differential in price over the non-Bessemer ores, which amounts to at least 15 cents per ton, and is increased according to the "phosphorus table" for each thousandth of a per cent below 0.045 per cent phosphorus.

Lake ores are further classified into "old range" and "Mesaba," with another 15 cents per ton differential in favor of old range. High phosphorus ores (over 0.18 per cent phosphorus) have a still lower base rate of 10 cents per ton under the Mesaba non-Bessemer.

After the price of a Bessemer ore containing 51.50 per cent iron and 0.045 per cent phosphorus at Lake Erie ports has been decided each season, it is then possible to evaluate any lake iron ore according to its analysis; the method of adjustment being based on a "base unit." This base unit is found by "dividing the selling price at Lower Lake Ports by the natural iron of the guarantee, namely 51.50%." For instance, the price for old range Bessemer ore in 1937 was $5.25 lower lake ports, and the unit value was 10.194 cents; for Bessemer Mesaba and non-Bessemer old range, it was $5.10, and the unit value was 9.903 cents. For ores with less than 51.50 per cent iron, the adjustments are as follows:

51.50 to 50 per cent, value of each unit is the base unit.
50.00 to 49 per cent, value is the base unit increased 50 per cent.
Less than 49 per cent, value is the base unit increased 100 per cent.

Silicious lake ores are low in iron and contain 18 per cent or more silica; they are sold at special prices agreed upon.

The brown ores in the South are bought and sold on the "dry" basis, delivered f.o.b. blast furnace, at so much per unit of iron as analyzed at 212°F. No such accurate rules as govern the lake ores have been worked out for the brown ores. In the few cases where red ores are bought and sold in Alabama, special prices are agreed upon by the seller and buyer.

Eastern magnetites, as concentrates and usually sintered, are sold at so much a unit delivered at furnace. The prices are a little less than lake ores delivered at Eastern furnaces.

Foreign ores have no fixed prices but are sold on the unit basis, f.a.s. Atlantic ports.[1]

SECONDARY IRON-BEARING MATERIALS

Besides the natural iron ores, which really are the original source of all iron and steel (except the very few meteorites that have been found and worked), there are now many secondary sources for the iron-bearing materials smelted in the iron blast furnace. Materials that were formerly wasted on the slag dump, and many by-products of other processes are now put through the blast furnace providing they contain iron, manganese, phosphorus, or some other element desired in the pig iron.

In the days of much wrought iron, it was customary to put the mill cinder into the blast furnace burden mixed with the ores, but for the best grades of foundry pig iron this practice was not allowable. Roll scale from all the various iron and steel rolling mills has been a standard raw material for the blast furnace. In the case of merchant blast furnaces there has always been a preference among the users of pig iron for "virgin iron," *i.e.*, pig iron made from an all-ore burden, and a prejudice against mill cinder and even against roll scale. It is likely that the prejudice against mill cinder was well founded.

As the new steel processes came into use there were new waste materials, or by-products, containing considerable iron, which could not be used in the steel furnaces, and, at first, were thrown on the dump. At integrated steel plants these materials are regularly sent to the blast furnaces and smelted as part of the burden, in some cases making up a third of the ore mixture.

Gradually the use of scrap in the blast furnace has extended from the melting of the "return scrap" from the cast house and hot-metal ladles to include all sorts and kinds of iron scrap and steel scrap, some of it of questionable value, bought from scrap dealers who have now developed a regular scrap industry with standard grades of scrap bought and sold on a scale of prices similar to prices for iron ores.

The secondary iron-bearing materials smelted in the blast furnace are as follows:

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[1] For a thorough explanation of the methods, present and past, of buying and selling Lake Superior iron ores, see "The Iron Ores of Lake Superior," 7th ed., Cleveland, 1930, Crowell & Murray, Inc.

- Blue Billy:
  - Raw
  - Briquetted
  - Nodulized
  - Sintered
- Flue dust:
  - Raw
  - Briquetted
  - Nodulized
  - Sintered
- Roll scale:
  - Blooming mill
  - Rod mill
  - Bar mill
  - Rail mill
  - Sheet mill
  - Wire mill
- Mill cinder:
  - Puddle cinder
  - Tap cinder
  - Finishing mill cinder
- Slag:
  - Open hearth
  - Ingot iron
  - Bessemer spittings
  - Spiegel-residuum
- Scrap:
  - Borings
  - Turnings
  - Stove plate
  - Slag scrap
  - Shot scrap
  - Shovel scrap
  - Crop ends
  - Annealing pots
  - Ladle kish

BLUE BILLY, OR PURPLE ORE

Blue Billy is the residue from iron pyrites (FeS_2) and from chalcopyrite ($CuFeS_2$) after the sulphur has been burned off for the manufacture of sulphuric acid and the copper extracted from the chalcopyrite. The residue is ferric oxide mixed with whatever gangue material was in the original sulphide ore, plus a varying percentage of sulphur which cannot all be removed in the sulphur burners The Blue Billy as it comes from the burners is purplish in color (sometimes called "purple ore") and is physically fine (hence sometimes called "pyrites fines"). Some of the foreign copper-bearing iron sulphides carry many other elements besides iron, copper, and sulphide, and these remain in the Blue Billy except what lead, zinc, and arsenic might be volatilized in the burning process.

Although it is possible to charge raw Blue Billy into the blast furnace, it is common practice in this country to sinter it, usually with flue dust. Briquetted Blue Billy has been used, but the material is too dense for satisfactory working in the furnace. Nodulized Blue Billy has been frequently used, but sintered Blue Billy is now found to be the most desirable form for the blast furnace.

The main thing in using Blue Billy is to have the sulphur as completely removed as is practically possible. A large pile of pyrites fines at a chemical plant where the burning was poorly done varied from 3.28 to 5.31 per cent sulphur, which was entirely too high for blast furnace use. The next thing to avoid is the presence of zinc and lead because of their damaging effects on the furnace lining.

Analyses of Blue Billy

	Fe, %	SiO_2, %	Al_2O_3 %	P, %	Mn, %	S, %	CaO, %	MgO, %	BaO, %	PbO, %	Zn, %	Cu, %	Moist, %
Nodulized Blue Billy	59.65	5.75	1.84	0.017	0.075	0.25	trace	trace	3.15	0.10	1.82	0.72	
Pyrites fines to be sintered	46.58	10.56	2.75	0.041		0.53							14.84

The nodulized Blue Billy made excellent Bessemer pig iron but the presence of 0.72 per cent copper made the iron unfit for certain uses, especially for making soft-center steel for agricultural implements. The presence of lead and zinc caused the bursting of the shell of the furnace and the disintegrating of the brick lining. The barium monoxide present helped to make a very hot fluid slag.

FLUE DUST

With the increasing use of coke as a blast furnace fuel it became necessary to remove the flue dust from the blast furnace gas; and with the coming of Mesaba ores, the flue dust became a serious problem, both in preventing excessive amounts and in its removal from the furnace gas. For many years, it was wasted on the dump or else piled with the hope it might be utilized later. Attempts to use the flue dust raw, especially dust containing much carbon from the coke breeze, generally resulted in furnace troubles. Flue dust from modern wet washers which contains very little carbon can be filled back into the furnace. Flue dust mixed with 5 per cent plastic clay and ground in a wet pan has been returned to the furnace with satisfactory results.

The ideal utilization of flue dust is to mix it with fine iron ore and sinter it. The carbon of the fine coke breeze in the dust is generally too much for sintering the dust by itself, but by adding fine ore, Blue Billy, roll scale, or other fine iron-bearing material, the right amount of carbon (about 3 to 5 per cent) for sintering is obtained.

Certain kinds of blast furnace flue dust contain potash and soda which are recovered for fertilizers; this special use will be described in Part V, By-products of the Blast Furnace.

SINTER

The sintering process has now been developed to the point where it is an essential part of American blast furnace practice; coincident with this development has come the advancement of the art of blast furnace practice to the point where it is possible to successfully operate a blast furnace with a 100 per cent sinter burden.[1] Blast furnacemen had to learn to use sinter in the mixture, just as they had to learn to use Mesaba ores; the first sinter plants were small and used only flue dust, so that the sinter in the burden amounted to less than 30 per cent. Blast furnace superintendents are responsible for their furnaces and equipment, and are reluctant to push untried methods and materials too far or too fast, but if the executives are willing and cooperative much progress can be made in blast furnace practice Meanwhile, all those concerned are mindful of the fact that the modern blast furnace is a very expensive piece of apparatus with which to experiment. The pioneering work in the use of sinter done at The Bethlehem Steel Company's Lackawanna plant by B. J. Harlan, superintendent of the blast furnace department, and by Robert McClurkin, manager of Tonawanda Iron Corporation, at the Tonawanda furnaces, did much to advance the use of this ideal raw material for blast furnace. Robert McClurkin presented his paper[2] "Sinter in Blast Furnace Burdens," at the annual meeting of the A.I.M.E., February, 1932; B. J. Harlan's paper[3] shows that "other plants have sintered a mixture of stock flue dust, current dust, and Mesabi ore screenings and used the sinter produced from this mixture in quantities as great as 100 per cent of the burden, with excellent results."

The sintering of magnetic iron-ore concentrates has been successfully carried on at Port Henry, N. Y., by Witherbee

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[1] HARLAN, B. J., "Recent Trends in Blast Furnace Operation and Design," *Trans. A.I.M.E.*, vol. 113, p. 40, 1934.

[2] *Trans. A.I.M.E.*, Iron and Steel, vol. 100, p. 47, 1932.

[3] HARLAN, *loc. cit*

Sherman & Company since 1923; the Greenawalt sintering plant is now capable of producing 3,400 tons of sinter in 24 hr.

The sintering of limonitic iron ores at Ironton, Minnesota,[1] was described by Perry G. Harrison in his paper by that title. Not only is the moisture eliminated from the Cuyuna manganiferous iron ores, thus reducing freight rates, but the fines are agglomerated into the most desirable condition for smelting in the blast furnace.

The character of iron-ore sinter as it was at first produced is well described by G. M. Schwartz.[2] He says that the porous cellular structure extends throughout the entire mass thus increasing the efficiency of the gas-solid contact in the reducing zone of the blast furnace.

Fundamentals of Sintering Iron Ores.—In a paper[3] presented at the Buffalo meeting of A.I.M.E., Apr. 22, 1938, John E. Greenawalt described the fundamentals of sintering iron ores and showed, by photomicrographs, how the minerals in the original ore are changed into different minerals in the sinter or else to different crystallizations of the same mineral. The following quotations are from his paper:

> Sintering may be defined as the agglomeration of fine mineral particles into a porous mass by incipient fusion caused by heat produced by combustion within the mass itself. . . . The application of down draft brought about tremendous results; the principal one of which was that an air blast of high pressure could be passed through a layer of ore deposited on a grate, or on a grate covered by a layer of coarse material, without disturbing the particles of which the layer is composed. The air current is compelled to filter through the pores of the charge, whereas if the same pressure we apply to the top surface of the charge with down draft were applied to the bottom of the charge with up draft, the charge would be blown completely off the grate. Another result of reversing the draft was that a flame could readily be applied to the top surface of the charge for igniting purposes.
>
> Broadly speaking, sintering is an oxidizing or burning process, and therefore, the volume of air passing through the charge is the all-important factor. The air must pass through with sufficient rapidity to

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[1] HARRISON, PERRY G., "Sintering of Limonitic Iron Ores at Ironton, Minnesota," *A.I.M.E.*, vol. 90, p. 346, 1930.

[2] "Iron Ore Sinter," *A.I.M.E.*, Iron and Steel Division, vol. 84, p. 39, 1929.

[3] "The Sintering Process and Some Recent Developments," *Trans. A.I.M.E.*, Iron and Steel Division, vol 131, 1938.

produce the necessary heat and if sufficiently rapid, the combustion will take place with a blow pipe action that will quickly generate a sintering temperature, whereas if the flow of air is insufficient, the burning will be like that of burning punk and will not generate sufficient heat to form sinter.

The first condition confronting us is to pass the air through the charge in sufficient volume to produce a sintering temperature in the mass and this is greatly influenced by two important factors; one of which is the porosity of the charge itself and the other is the pressure applied to force the air current through the pores of the charge by means of suction.

The porosity of the charge is influenced by the following three important factors:

First: Moisture. Were it not for the fact that moisture added to fine ores increases the porosity of the charge enormously, the sintering process as applied today would be a complete failure. The porosity of fine, dry ore is so small that it becomes impracticable to pass air through the charge in sufficient volume to produce a sintering temperature. Fortunately, however, we find that if we add say 4% of water to this same charge and mix it thoroughly, the porosity has been greatly increased and if we continue to add water one per cent at a time and test the porosity after each addition, we will find the porosity of the charge progressively increasing until a maximum has been reached and then if we continue to add water, we will find the porosity decreasing until it has been completely destroyed. The amount of moisture used to obtain maximum porosity is usually the best percentage of water to use in preparing the charge for sintering. In actual practice, this depends upon the character of the ore and may vary from 5% to 12% not including combined moisture. Magnetite ores require the least and clayey ores the most to produce the best physical condition for sintering. The character of the sinter can be slightly influenced by the moisture content of the charge; the drier charges tend to produce a more fragile sinter and wetter charges a stronger and denser sinter. High moisture in the charge decreases its combustibility and increases ignition difficulties.

Second. Returning part of the previously sintered charge in the form of "returned fines." It is impracticable to produce 100% sinter in one operation except under unusual conditions, so that the sintered charge is passed over a screen and all the fine material below a fixed size is returned and resintered. The size of this screen may vary from ¼″ to ¾″ and the amount returned may vary from 20% to as much as 50%, although in the intermittent system, this is rarely more than 25%. Much of this material has been sintered so the addition of it to the charge greatly increases its porosity and sintering qualities and thereby increases the capacity of the sintering unit. It improves the sintering charge the same as sinter improves the blast furnace charge. This practice, however, has the disadvantage of double sintering, requiring additional fuel, which adds considerably to the cost of sintering low grade ores. This re-sintering of part of the charge which has previously been partially sintered and which fuses far more readily than the original charge strongly tends to the formation of the undesirable iron silicates in the finished sinter, so that the modern tendency is to reduce the "returns" to a minimum.

Third: Preparing the charge so it will consist of a mixture of materials, some of which are coarse and of great permeability. This method of increasing the porosity of the sintering charge is very desirable whenever it can be applied, as for example, mixing fine ores with flue dust, roll scale, etc. It is also advantageous to mix fine magnetic concentrate with coarser ores in the preparation of the sintering charge. Obviously, this method of increasing the porosity of the charge has its limitations in the materials available. Having prepared the charge so as to obtain the maximum porosity, we find a definite resistance to the flow of air through the charge. The amount of air that will flow through the charge is proportional to the thickness of the charge and to the suction applied to the lower side of the charge. The thickness of the charge treated is very important. In plants using the intermittent system, the depth of the charge varies from 7 inches with a fine magnetic concentrate to 18 inches with the fines below $\frac{3}{8}''$ of a hematite ore. Economically, a thick charge has many advantages over a thin layer. The cost of igniting and charging a thick layer is the same as a thin layer and it also requires less sintering fuel. The time of sintering, that is the time required for the sintering zone to travel from the top surface of the charge to the grate, varies from 10 to 18 minutes. Experience has shown that 18 minutes should be the maximum for the reason that, if a charge requires more time than this to sinter, the portion of the charge near the grate dries out and greatly slows up the travel of the sintering zone through the charge. The sintering zone should travel through the charge at the rate of about 1" per minute.

Suction. The thickness of the charge is also dependent upon the suction available. We have for some years in connection with the intermittent system been advocating and using powerful fan exhausters capable of giving a suction of 50" of water and from the results obtained, the writer is convinced that the use of high suction in the future will become more and more pronounced and this is especially true for sintering at a low cost large tonnages of ores with reduced fuel consumption and thereby eliminating almost completely the possibility of forming iron silicates in the finished sinter.

Figure 1 [Fig. 52] is a chart based upon the tests made by A. K. Walter and illustrates clearly the positive results that can be obtained by applying increased suction to a sintering apparatus. Here are represented the results obtained with a series of tests made from a large amount of ore prepared for this purpose, so as to have uniformity in fuel and moisture. The charge was thoroughly mixed so that the charges were as nearly alike as possible except for the suction applied to the charge. Vertical distance on the chart represents the suction and the horizontal distance the number of pounds of sinter produced. Line A represents the sinter produced by shoveling the charge directly into the pan with more or less irregular packing, the line B represents the production obtained by carefully fluffing the charge so as to give it the greatest amount of porosity possible and the greatest amount of uniformity. Notice that with 17″ of suction, the increase in sinter production due to proper charging was 18% while with 40″ suction, the

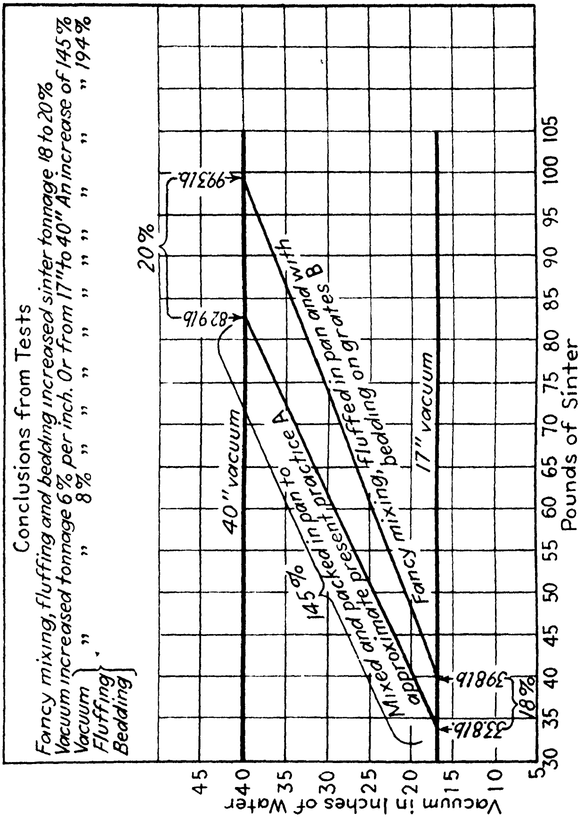

FIG. 52.—Results obtained by applying increased suction to sintering apparatus. (*Courtesy of John E. Greenawalt, based on tests by A. K. Walter.*)

increase was 20%. By increasing the suction from 17″ to 40″, the capacity was increased 145% and by increasing the suction from 17″ to 40″ and at the same time depositing the charge into the sintering apparatus with the greatest amount of uniformity and porosity, the capacity was increased 194%.

To apply high suction, it is obvious that the sintering apparatus must be air tight from the top surface of the charge to the fan exhauster and that exhaust fans of superior design are required. High suction fans when carefully designed and properly constructed are capable of operating over long periods of time without attention except lubrication. . . . This is a real accomplishment when we consider that the top speed of the impellers is over 26,000 ft. per minute. . . .

Proper *ignition* of the charge is important and the time required to accomplish this should not exceed 30 seconds. Every square inch of the charge surface must be evenly and fully ignited. Long exposure of the igniting surface to flame dries out the charge and produces uneven sintering. A clean, high temperature and highly oxidizing flame applied instantaneously to every square inch of surface produces the best results. For this reason, it is preferable to use high grade fuel such as oil, natural or coke oven gas instead of blast furnace or produced gas.

Grate bars. In any down draft sintering apparatus, the grate receives severe punishment. It should be self-cleaning and have an opening amounting to at least 20% of the total grate area. The amount of grate opening, however, depends upon the character of the material being sintered. Fine ores lacking in cohesiveness are readily drawn through the grate by the air blast. Whenever possible, it is advisable to place a thin layer of coarse material upon the grate, and when sintering fine ores, it is excellent practice to deposit a layer of the ore upon the grate without the admixture of fuel or very little fuel as this prevents the formation of highly fused sinter which frequently forms next to the grate.

Sinter should be air cooled for the reason that if red hot sinter is doused with water, it becomes very brittle and breaks up easily when handled. Air-cooled sinter is much stronger than water-cooled sinter and sinter made from a charge containing lime should not be moistened

Sulphur elimination is of vital importance in the preparation of certain sulphur-bearing iron ores, and this element should be reduced to .10% or less for use in the blast furnace. The all-important point to remember in sulphur elimination is to reduce the carbon content of the charge to a minimum, so that the heat released by the combined burning of the carbon and sulphur is just sufficient to produce a sintering temperature. If more carbon is present, the oxygen combines with the carbon in preference to the sulphur, thus fusing some of the sulphur compounds from which it is extremely difficult to remove the sulphur. . . .

Coke breeze crushed to pass a 10 mesh screen is an excellent fuel for mixing with the charge to be sintered and another satisfactory fuel is anthracite culm. Bituminous coal is not satisfactory due to its volatile constituents which are not only wasted but tarry compounds are condensed and clog the pores of the charge, greatly interfering with the flow of air through the charge. To obtain uniform distribution throughout the charge and avoid intense local temperatures, the fuel must be finely divided. There is not sufficient time to burn large particles of fuel and, therefore, the unburned fuel is wasted so far as the sintering operation is concerned. Ores containing 6% sulphur have sufficient fuel to produce a sintering temperature. Blast furnace flue dust always has an excess of fuel for sintering; in fact, a ton of dust with 15% of carbon has sufficient fuel to sinter 3½ tons additional of fine ore or concentrate providing the charge is properly arranged and treated with high suction.

The object of sintering material is to prepare it for treatment in the blast furnace and, therefore, the chemical and physical qualities of the sinter are of major importance. It is only during the last few years that the full significance of the fact that sinter may be good, bad or indifferent in the blast furnace has been fully appreciated. . . . In the early days of sintering, the sole object was agglomeration and very little attention was given to the chemical reactions taking place during sintering. In fact, many authorities considered it necessary and desirable to form iron silicates in order to make a sufficiently strong sinter. For example, Schwartz in his paper on Iron Ore Sinter* contends that the strength of sinter was increased by the presence of silica which was converted into iron silicate and that iron silicate was not detrimental in the blast furnace charge. In recent years, the opinion has been gaining ground that a highly fused sinter charged with iron silicates is not the best sinter for blast furnace purposes, and this was conclusively demonstrated in the very excellent paper by Mr. Charles E. Agnew which was presented at the last session of the Institute. The solution presented was the elimination of the silica before sintering but obviously this can be accomplished only with a limited class of materials.

The problem then becomes one of converting all kinds of ores into a sufficiently strong sinter for blast furnace use without the formation of iron silicates. The factors involved in the avoidance of iron silicates are the control of the temperature at which sintering occurs and the time the charge is exposed to this temperature, the amount of returned fines in the charge and probably the presence of small quantities of basic materials in the charge.

By means of high suction and an improved arrangement of the charge to be referred to later, the writer has obtained some rather remarkable

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* *Trans. A.I.M.E.*, Iron and Steel, vol. 84, 1929.

results in sintering fine red hematite ore. Sinter sufficiently strong for blast furnace purposes was repeatedly produced with 3½ per cent coke in the charge and excellent sinter was made by adding 15.41% flue dust so that the charge sintered contained only 2.84% carbon. This is considerably less than one half the amount of fuel required heretofore for sintering this ore. The fines below ¼″ amounted to 20 per cent and were returned to the succeeding charge, and a 16″ charge sintered in 15 minutes

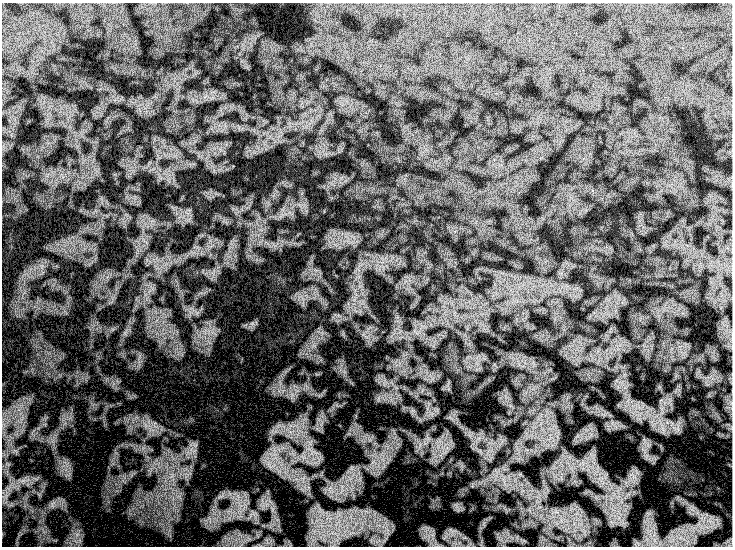

FIG. 53.—Crystals of hematite and magnetite embedded in glass, as they appear on a polished surface. Large, light gray angular areas represent hematite crystals in reflected light. A few dendritic groups of magnetic crystals are shown at the side. (*Courtesy of John E. Greenawalt.*)

The following is the analysis of the ore from which sinter was made, with 3½% coke breeze for the microscopic investigation.

	Fines, Per Cent
Silica	12 32
Al_2O_3	3 47
CaO	16 75
MgO	51
Fe	36 35
P	30
Mn	17
H_2O	2 74
	72 61

The microscopic examination of this sinter was made by Professor Paul F. Kerr of Columbia University to whom the writer is indebted for this very interesting study.

Figure 2 [Fig. 53] is a photomicrograph showing crystals of both hematite and magnetite embedded in glass, as they appear on a polished surface. The large light gray angular areas represent hematite crystals as they appear in reflected light. A few dendritic groups of magnetite crystals are shown at the side of the view.

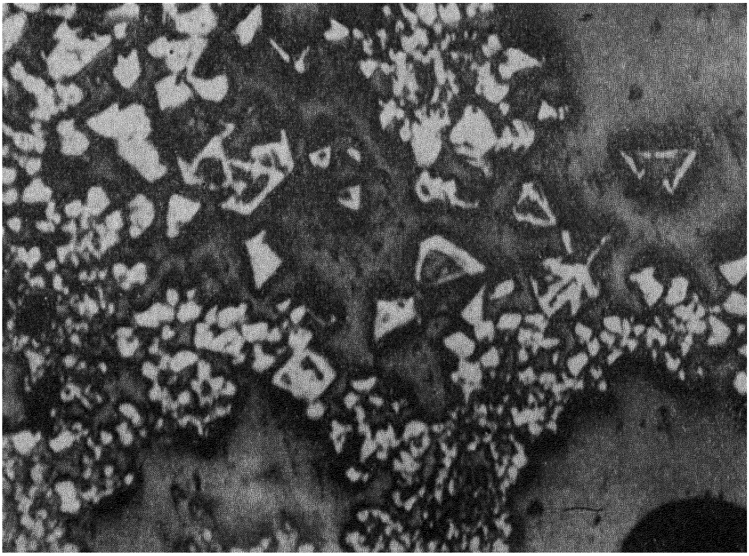

Fig. 54.—Skeleton crystals of magnetite embedded in glass. (*Courtesy of John E. Greenawalt.*)

The metallic constituents of the sinter occur either as magnetite or hematite. The magnetite occurs as a recrystallization product of the original hematite in clusters of minute octahedral crystals.

The original fine hematite powder has been recrystallized in clusters of minute, sharply defined, hexagonal crystals of the same mineral.

The principal non-metallic constituent of the sinter, produced during the heat treatment, is glass. Apparently the fine quartz particles in the original ore, together with a considerable proportion of the calcite, forms glass. The brownish color would indicate a contamination with iron. This glass formation is clearly shown in Figure 3 [Fig. 54].

Figure 3 [Fig. 54] also shows skeleton crystals of magnetite as they appear on a polished surface. The edges of the crystals are much more prominently developed than the crystal faces or the interiors. The skeleton outlines are embedded in glass and glass even fills the interior of some of the crystals.

This excellent paper by Mr. Greenawalt is a valuable contribution to the sintering practice in this country and calls our attention to new possibilities in the improvement of our present-day blast furnace practice. His paper brings out some facts contrary to much of the previously published data, which is not surprising when we consider that the sintering of iron ores has as many variations as there are different iron ores and each operator has observed a different set of phenomena.

The author's first personal experiences with a sintering plant and with the use of sinter were so distasteful that he can appreciate the apparent lag in the general adoption of the sinter plant "as an adjunct to the blast furnace," as Mr. Greenawalt says in his conclusions regarding the future of sintering.

There is as much difference between the sinter plants and sinter of the postwar period and the plants and sinter of today, as there was between the by-product coke plants and coke of the early Otto-Hofman plants and the new coke ovens and by-product coke of today. The author sees such a great similarity between the introduction of by-product coke into blast furnace practice some twenty years ago and the rather slow adoption of sintered iron ores (outside the almost universal practice of sintering fine magnetic concentrates), that he approaches the discussion of Greenawalt's paper from a background of blast furnace and coke-oven experience during the development of by-product coke as the almost universal blast furnace fuel in this country.

The beginnings of the making and use of by-product coke for blast furnace fuel were as crude and nerve-racking as the initial steps in the production and the introduction of sintered ores as a major part of the blast furnace burden.

As in coke, so in sinter, no attention was paid to the hardness, size, porosity, density, or moisture contents. In those days by-product coke was truly the "by-product" of a gas plant or a chemical works, and no consideration was given to the many troubles of the blast furnaceman.

In the above paper Mr. Greenawalt describes the sintering of a ferruginous sandstone using flue dust and high suction, without the formation of iron silicate (see Fig. 55).

The same fallacies that used to prevail among blast furnace and coke men seemed to prevail in the use of sinter. One exploded theory, that high ash made a "stronger coke that would carry the burden better," had its counterpart in thinking that a hard firm sinter was necessary. But Schwartz[1] recognized the fact that "iron silicates are difficult to reduce"; and said, further, that "since we have definitely identified these silicates in practically all samples of sinter examined and since ordinary iron ore contains only a small amount of iron silicate, it appears that the increased porosity of the charge when using sinter is of such value to the blast furnace that the increase in the percentage of the iron silicate minerals in the sinter is far overshadowed by the increase in porosity. If good sinter could be produced containing no iron silicate this sinter would undoubtedly be better for blast furnace use."

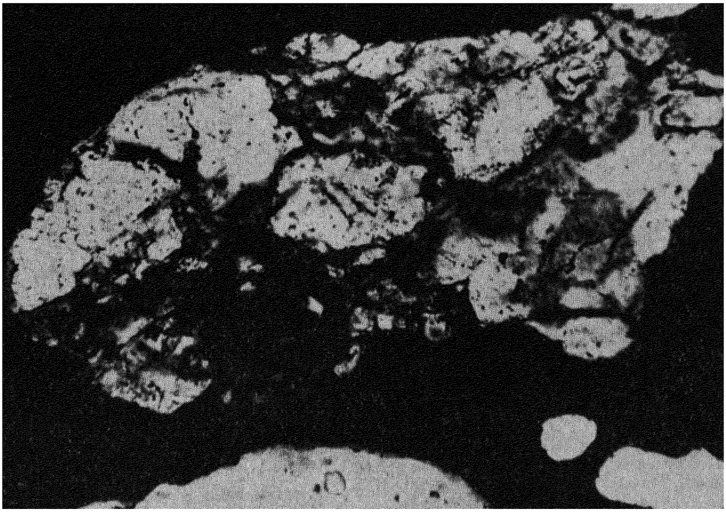

FIG. 55.—Quartz and unaltered iron ore. (*Courtesy of John E. Greenawalt.*)

That this desirable practice in the art of sintering iron ores has already been attained is attested in the papers of Agnew and

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[1] SCHWARTZ, G. M., "Iron-Ore Sinter," *Trans. A.I.M.E.*, vol. 84, Iron and Steel Division, 1929.

Greenawalt; one accomplished it by removing the excess silica previous to sintering, and the other removed the cause for excess temperature and increased the suction of the air.

Control of Porosity.—It was an agreeable surprise to the author to observe that it is possible to control the porosity and cell structure of iron-ore sinter much in the same way as the porosity and cell structure of by-product coke is controlled. When blast furnacemen went from beehive Connellsville coke to by-product coke, it was generally agreed and understood by the furnacemen and the coke men that the by-product coke should be hard burned and in big lumps. But it was different with the blast furnacemen who had been using Pocahontas beehive coke; and they demanded a more open coke, pushed on the "green side."

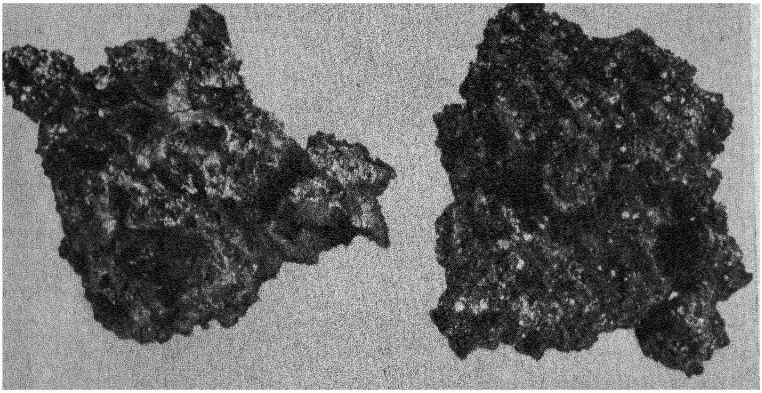

FIG. 56. Two sinters made from same ore with suction of 50 inches of water. The sinter to the right was made with 3.5 per cent coke, completely free from iron silicates. The sinter to the left had more return fines and 4.5 per cent coke. Here a pronounced smelting or slagging action is observable. This sinter is fused entirely too much for the most economical results in the blast furnace. (*Courtesy of John E. Greenawalt.*)

Sizing the Sinter.—Just as by-product coke was first used as run-of-oven coke after screening out the coke breeze, so has sintered ore been used after screening out the fines which have been used as "returns" in the sintering mixture. It has become standard practice to size the by-product coke and to crush the oversize. The author believes it will be necessary to size sintered ore in order to get the best results.

ROLL SCALE; MILL CINDER; OPEN-HEARTH SLAG; RESIDUUM

Roll Scale.—Roll scale is oxidized flakes of almost pure iron formed during the rolling of hot steel in its various forms from the big steel ingots down to thin sheets or threadlike wire. Clean roll scale is almost pure ferric oxide, but the commercial roll scale will have the chemically combined elements of the steel that was rolled, plus the sand, grease, and dirt of the rolling mill. A good roll scale, throughout a year's shipments, actually contained 70.44 per cent iron (dried at 212°F.) and 4.60 per cent silica; the iron in natural state was 67.25 per cent.

The coarser roll scales, such as blooming mill, bar mill, and rail mill, can be charged direct into the furnace, but the fine scales, especially from wire and sheet mills, should be sintered first.

Mill Cinder.—Mill cinder is still produced in this country but in much less quantities than before the World War. Although it is fairly high in iron (53 to 54 per cent iron), it is very high in silica (24 to 28 per cent silica). The average analysis of a year's shipments was as follows:

Element	Percentage
Fe	53 370
SiO_2	24 700
P	0 118
Mn	0 33
Al_2O_3	2 22
CaO	0.45
MgO	0.10
S	0 09

The late E. A. Uehling once said that mill cinder melted before it was reduced, and then it was reduced by the incandescent coke. It used to be charged into the furnace in big blocks the size of the little slag pots into which it was tapped at the puddling furnaces. At one furnace plant the author installed a jaw crusher which crushed the mill cinder to 1¼-in. size.

Open-hearth Slag.—For several reasons, open-hearth slag is a desirable and profitable material for the blast furnace, not only for its iron content, but also for its manganese and its fluxing value. This is particularly true of the slag when making ingot iron in the open-hearth furnace.

The analysis of open-hearth slag varies somewhat with the materials used, with the kind of steel being made, and with the practice. The usual contents are as follows:

Element	Percentage
Fe	10 to 16
Mn	4 to 7
CaO	43 to 48
MgO	6 to 8
SiO_2	12 to 20
Al_2O_3	2 to 8
S	0.16 to 0.22
P	1.50 to 2.35

In the making of ingot iron, which requires a hotter furnace and a "yield factor" of 99.84 per cent iron, the slag is richer in iron, varying in certain grades of ingot iron from a minimum of 22.78 iron up to 42.75 per cent iron with an average of 32.04 per cent iron. An actual analysis of slag from an ingot iron heat was:

Element	Percentage
CaO	33.20
MgO	7.20
Al_2O_3	0.92
FeO	46.50
MnO	3.68
S	0.065
Fe	36.13
P_2O_5	0.88

At another plant making ingot iron, where the slag was granulated, the analysis was as follows:

Element	Percentage
CaO	34.01
MgO	8.51
S	0.093
FeO	40.25
MnO	4.26
Fe	31.27
P_2O_5	1.07

The actual value of open-hearth slag can be calculated by finding the value of the total units of iron and of the total units of manganese and adding these values to the value of the total available lime in terms of limestone based on the prices of these materials delivered at the furnace. Although some furnaces will use the crude-lump open-hearth slag, it is much better in every way to granulate the slag as it is poured from the slag ladles at the open-hearth plant.

The amount of open-hearth slag that can be used in the burden varies, but 8 per cent has been found to work satisfactorily.

Residuum.—In the treatment of Franklinite for the extraction of the zinc there is a residue of iron and manganese which is smelted in a blast furnace for the production of spiegel. The slag from the spiegel furnace contains enough manganese to make it a source of manganese, for those are mixtures which contain only, or chiefly, the sintered magnetic concentrates. One difficulty is that there is still a small amount of zinc left in the slag, and zinc inside the iron blast furnace always gives more or less trouble. A typical analysis of this manganese residuum is as follows:

Element	Percentage
Fe	17 15
Mn	12 20
ZnO	4 10
SiO_2	24 58
Al_2O_3	7 25
CaO	11 99
MgO	1.36

It is usually sold at so much per ton delivered at the blast furnace.

STEEL SCRAP; IRON SCRAP

It has always been customary to charge back into the blast furnace all the scrap that was produced in the manufacture of pig iron, such as the runner scrap, the pig-bed scrap (now obsolete except at the few charcoal blast furnaces), the pig-machine scrap, the ladle scrap, scrap from "messes," iron-yard scrap, and "off" iron. In many cases this kind of scrap is excessive and thoughtlessly wasteful; it can largely be prevented by thoughtful practice.

At integrated steel plants there is considerable scrap that can best be utilized in the blast furnace. For instance, the "clinker" from the soaking pit of a steel plant was found to contain 84 per cent iron, and it was 1.6 per cent of the total weight of ingots put through the soaking pit; formerly thrown on the slag dump, this is now recovered and sent to the blast furnace.

Old annealing pots and annealing-pot scale are sent to the blast furnace; the solid part contains about 96 per cent iron and the thoroughly "burnt" scale about 73 per cent iron.

"Slag scrap" is the iron scrap recovered at slag-crushing plants by the magnetic belt and pulley; it runs about 90 per cent, or less, in iron. Some old slag dumps yield much of this kind of scrap.

Ladle scrap dug out of the direct-metal ladles as they skull up and the ladle kish that is rabbled out of the ladles after every cast or two are remelted in the blast furnace; sometimes the clean pieces are thrown back into the hot ladle and melted when the next cast is poured. The use of much of the kish containing shots is questionable on account of the large amount of inert carbon in the form of kish; it is likely that it produces dirt troubles in the furnace.

Crop ends, mainly rail ends and bloom crops of basic open-hearth steel have made up the furnace burden, with gravel, dolomite and a small quantity of manganese ore, at one of the blast furnaces of the Tennessee Coal, Iron & Railroad Company in the Birmingham district for the manufacture of Bessemer pig iron. There are no Bessemer iron ores available in Alabama. This case of practically 100 per cent scrap for the burden is described by R. H. Ledbetter in his paper "Blast Furnace Practice in the Birmingham District."[1]

Besides the plant scrap that makes up part of the blast furnace burden, miscellaneous scrap bought through regular scrap dealers is used to enrich the ore mixture thus increasing the output of the furnace. The usual grades of scrap sold to blast furnaces are stove plate, borings, turnings, shovel scrap, busheling, alley scrap, and all sorts of iron and steel scrap from rust up to clean iron.

The prices of the different grades of scrap vary greatly, and sometimes are higher than the market prices of pig iron. The spread between the price of scrap and the price of pig iron has a direct effect on the proportions of scrap and of pig iron used in the open-hearth charge. When scrap for the open hearth is high in price, scrap that is worth while for the blast furnace is also high. The top price that can profitably be paid for scrap for the blast furnace mixture is about $4 per ton below the price

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[1] *Yearbook, Am. Iron Steel Inst.*, 1924.

obtained for the pig iron. In the first place, scrap is not all iron; for instance, rusty borings contain 66 per cent iron and clean borings 90 per cent iron; in the second place, scrap is not *melted* in the blast furnace, but is *smelted*, and the product is regular pig iron regardless of the class of scrap that is smelted. Ledbetter[1] said

> . . . this operation should not be confused with that of the cupola. Besides melting the scrap and slag forming constituents, it returns to the metal all that was removed in the converter and the open-hearth except the phosphorus. . . . From 900 to 1200 pounds of coke are required to produce a ton of this iron.

Clyde E. Williams said[2]

> . . . most cast iron scrap is lower in carbon, silicon and manganese and higher in sulphur and phosphorus than normal basic pig iron and so must sell for a lower price. So-called "burnt" iron scrap, grate bars and castings of thin section, either are higher in sulphur or undesirable in other ways and are still lower in price. Such scrap usually is not taken for open hearth charges but goes to the blast furnace. Iron borings are a still lower grade, difficult to handle and readily oxidized.

The blast furnaces of this country consumed 2,086,000 tons of scrap in 1936, of which 903,000 tons was purchased.[3]

BLAST FURNACE FUELS

Influences of Blast Furnace Fuels on Plant and Practice.—Blast furnace fuels, charcoal, anthracite, raw coal, beehive coke, and by-product coke, each in their turn, have had controlling influences, not only on the art of smelting iron ores, but also on the choice of the location of the iron blast furnaces themselves; and also on the building up of the subsequent iron and steel centers of this country. The influence of fuel in determining the location of blast furnaces has been greater than that of the iron ore itself, which is *the* essential foundation of the iron and steel industry. It is a dual foundation, however—units of iron and units of carbon.

It is obvious that there can be no iron smelting without iron ores, whatever fuel may be used; but it has been a fact in the

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[1] *Yearbook, Am. Iron Steel Inst.*, 1924.

[2] "The New Technical and Economic Importance of Iron and Steel Scrap," *Am. Iron Steel Inst.*, May, 1936.

[3] *Bur. Mines Pub. M.M.S.* 550, May 28, 1937.

history of iron making that the iron ore was either located at or near the source of fuel supply or else the ore was transported to, or toward the fuel.

The present modern blast furnace practice in America is built up almost entirely around by-product coke as the fuel, and not much remains of the influences of charcoal, anthracite, and raw coal on the art of smelting iron ores, except some traces of the old operating customs. In some cases, like the Sunday shutdown for instance, old customs have been put into present practice and considered as something new. On the other hand, however, the effects of the regional influences of these fuels still persist, and, together with the influences incident to the making of by-product coke, are the predominating factors in maintaining the centers of the iron and steel industry where they now are. And fuel will be the controlling factor in any future shifting of these centers, even if the source of heat should be electricity.

In view of the present evident trend toward regional operations, it seems appropriate to take a look at the record of blast furnace fuels in this country from the early days of the colonies down to the present time of the New Deal. Like many other industrial developments, the centers of pig-iron manufacture have moved inland and westward from the Atlantic Coast The first continuing blast furnaces were built along the coast of eastern Massachusetts and Rhode Island, and from there they spread across to the Salisbury district in southwestern Massachusetts and northwestern Connecticut, to the magnetic iron ores of the Hudson Valley of New York and northern New Jersey, and then to the valleys of eastern Pennsylvania.

For the first one hundred years after the settling of Massachusetts, that colony led in the production of iron. For the next two centuries, Pennsylvania held the leadership continuously, up to the year 1932, when the state of Ohio made more pig iron than any other state. Pennsylvania, because of its abundance of charcoal, of anthracite, of block coal, and of coking coals, and *not* because of its iron ores, important as they are, has led the country in the production of pig iron throughout the successive eras of these fuels; only in the production of pig iron made with raw coal has any other state—Ohio—exceeded Pennsylvania.

Whether or not this leadership of Pennsylvania as a producer of pig iron, held for nearly two centuries, has passed to Ohio only temporarily is a question that will be settled soon, probably in favor of Pennsylvania, because Pennsylvania alone of all the states has within its borders all five of the blast furnace fuels that have so far predominated in the smelting of iron ores.

In the making of pig iron, as in many other things, we are now in a transition period that may bring about as momentous changes as in that period nearly one hundred years ago when anthracite, raw coal, and coke were introduced as blast furnace fuels all within the same decade. These three mineral fuels (two of them being natural fuels) threatened the supremacy of charcoal, which had been the only blast furnace fuel for two hundred years; no other fuel predominated until 1855, when anthracite took the lead for the next twenty years.

Four Periods of Blast Furnace Fuels.—There have been four distinct blast furnace fuel eras in this country from the days of the first colonial blast furnace down to the present time, as follows:

The charcoal period from 1645 to 1855
The anthracite period from 1855 to 1875
The beehive coke period from 1875 to 1919
The by-product coke period from 1919 on

The periods are divided according to the annual tonnage of pig iron made with each fuel. Swank (U. S. Census, 1880) designates the total period previous to 1840 as "the charcoal iron era," but inasmuch as charcoal iron predominated till 1855 it seems to be more fitting to extend the charcoal period up to the year when anthracite pig iron surpassed charcoal pig iron in tonnage made, *i.e.*, the year 1855. The fuels overlap and it is interesting to note that charcoal pig iron has persisted throughout all four periods.

No separate period is designated for raw coal, which began a little later than the other "natural" fuel (anthracite) and the building of strictly raw-coal blast furnaces ended sooner (in 1887). For a while it was possible to keep the records of raw-coal furnaces separate from the coke furnaces, but for over half a century the statistical reports have listed all bituminous coal (raw coal) furnaces under the same heading as the coke furnaces. Except in rare cases, such as in Jackson County, Ohio, where there is still some of the Sharon No. 1 coal, no raw coal (either hard or soft) is used as blast furnace fuel, in spite of the excellence of the pig iron made with it.

Characteristic Effects of Fuels on Pig Iron.—The fuel used in a blast furnace to make pig iron imparts to that pig iron certain characteristics and qualities that seemingly are outside the effects from the chemical constituents of the other raw materials used and independent of the practice in handling the operations of the furnace. There have been many attempts to discover just what this "it" in pig iron really is, but so far there have been no published reports of success. This is particularly true of charcoal pig iron.

Statements have been made at sundry times, especially by the late Dr. Richard Moldenke, that the quality of pig iron has been deteriorating with the successive changes in the fuels used, and in the order as on page 113. This decline in quality was accompanied by increasing tonnage as the fuels changed from charcoal to the natural fuels (anthracite and bituminous coal), and then to beehive coke and by-product coke. There were also several other changes in blast furnace practice that affected tonnage and possibly the quality of the pig iron, especially the big increase in hot-blast temperature and in the diameter of the furnace hearth.

Although the word "seemingly" is used above to modify the statement about the characteristic effects of the different blast furnace fuels, the author is strongly of the opinion that the fuel itself imparts a certain "personality" to the pig iron that appears to be hereditary and firmly fixed in the metal, a personality that remains in the iron even when it goes through the foundry or through the steel plant to its final product. It is realized that such a theory can exist only until the positive facts are made known. Morgan[1] says, "Although the production of pig iron is very simple in principle, the changes, chemical and physical, which the material undergoes in the blast furnace are many and complicated, and not altogether understood. Many can only be guessed at."

The art of making pig iron has undergone many changes in the past hundred years, and most of these changes were brought about by changes in the theories of the smelting of iron ores.

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[1] MORGAN, J. J., "Blast Furnace Practice," C. Griffin & Co., Ltd., London; J. B. Lippincott Company, Philadelphia, 1910.

It is surprising to see how far the manufacture of pig iron progressed in the pioneer days in this country, before the chemist became a part of the blast furnace organization and before the combustion of fuels in the hearth of the furnace had been studied.

At the early charcoal furnaces, and even when anthracite was first used, the steam plant and the hot-blast stoves were erected on top of the furnaces because no one believed that the hot waste gases could be brought down to the ground.

Charcoal.—"No other fuel than charcoal was used in United States blast furnaces until about 1840,"[1] and many small charcoal blast furnaces were built throughout New England and in all the other colonies, and later in every state east of the Mississippi River. with the single exception of Florida. The total production was not great, even for all of the first hundred years, throughout which Massachusetts was the greatest pig-iron producer, and even as late as 1810 the annual production for the whole country was only 53,808 tons of charcoal pig iron.

Throughout the period which Swank called the "charcoal era," previous to 1840, it is certain that the making of iron was confined to those regions that had enough timber to supply wood for the charcoal used in the little blast furnaces. The records show that these furnaces were near enough to the charcoal pits so that all the fuel could be hauled in oxcarts. In modern times there have been cases where the wood, and even the charcoal, was transported considerable distances in railroad cars. At the largest charcoal blast furnace in the world, operated by the Algoma Steel Co., Sault Ste. Marie, Ont., in 1905, a part of the charcoal was hauled over the Algoma Central Railroad from the brick charcoal kilns erected in the forest 25 to 30 miles away. The wood supply could not keep up with the furnace when it demanded a cordwood pile half a mile long every 24 hr.

The regional influence of charcoal as a blast furnace fuel was positively decentralizing; for nearly two centuries it was a frontier industry supplying the local market with "hollow ware" and blooms for the blacksmiths and nailers. Lewis Mumford in his "Technics and Civilization," calls it the "Eotechnic Era." Usually the furnaces were built along the ridges and "coves" of the Blue Ridge and Allegheny Mountains, far away from the centers of population.

[1] James M. Swank, 10th Census of United States, 1880, Part II, p. 59.

Charcoal is unique in that it is the only fuel that can perpetuate itself (by reforestation and cutting in rotation every 15 to 20 years); it makes the highest quality and purest pig iron; it requires the greatest amount of labor, all of which is above ground.

Charcoal for blast furnace fuel is made from cordwood by low-temperature distillation in by-product retorts, in brick kilns, and formerly in heaps covered with earth called "meilers." Hardwoods, such as maple and birch, make the best charcoal for blast furnaces, but softer woods can be used. The best charcoal is made when the trees are cut before the sap comes up and the wood is stacked in cordwood piles to dry out. Charcoal is an ideal fuel; its low combined carbon and high volatile matter make its reactivity the greatest of all the blast furnace fuels. Some actual analyses are as follows:

Kind	Moisture, %	Volatile, %	Fixed carbon, %	Ash, %	S, %	P, %
Maple—body wood	0 27	24 27	71 53	3 93	0 037	0 020
Maple—small limb	0 14	29 80	63.95	6 11	0 031	0 030
Maple—body wood—bottom of car	0 82	23 89	74 02	1 27	0 034	0 011
Elm—body wood	0 73	23.28	75 84	1 15	0 030	0 018
Birch—body wood—bottom of car	0 98	22 01	77 04	0 97	0 045	0 009
Maple—bark	1 00	25 59	62 49	10 92	0 160	0 056
Iron wood	0 58	27 50	70 33	1 59	0 027	0 015
Fine charcoal dust	20 35	13 69	54.77	11 19		0.078

The ash in a sample of charcoal from the stock-house bins was 2.90 per cent, and contained 0.55 per cent silica, 0.60 per cent alumina plus ferric oxide, 1.15 per cent calcium oxide, 0.50 per cent magnesium oxide, 0.07 per cent alkalies, 0.03 per cent phosphorus.

The largest charcoal blast furnace ever built and operated on 100 per cent charcoal was No. 1 furnace of the Algoma Steel Company at Sault Ste. Marie, Ont., which made the world's record of 173 tons of pig iron in 24 hr. The stock went through the furnace in 5 hr.; the Bessemer pig iron made that day averaged 1.49 per cent silicon and 0.014 per cent sulphur. This furnace is shown in Fig. 57.

In an article, "Charcoal and Coke as Blast Furnace Fuels"[1] the author gave a description of this furnace and a comparison of its performance with that of a coke furnace on the same ore mixtures; and also a comparison of the performance of No 1 furnace on charcoal and on coke and on part charcoal and part coke.

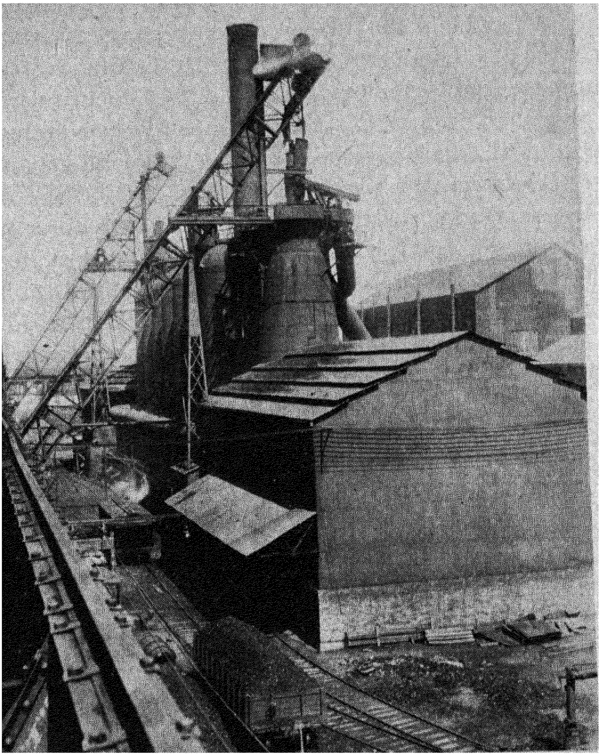

FIG. 57.—The world's largest charcoal blast furnace, Algoma No 1 (1905).

The advantages of charcoal over coke are:

1. The furnace consumes considerably less charcoal than coke per ton of pig iron.
2. Only one-third as much limestone per ton of pig iron is required in a charcoal furnace.
3. The amount of blast required for a charcoal furnace is only about 65 per cent of that for a coke furnace of the same productive capacity.

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[1] *Trans. A.I.M.E.*, vol. 39, 1909.

4. The "critical temperature" in a charcoal furnace may be lower than in a coke furnace.

The two serious disadvantages of charcoal are, first, the difficulty in getting a sufficient supply of good charcoal (it takes a cordwood pile half a mile long to make enough charcoal for 150 tons of pig iron in 24 hr.); second, the readiness with which charcoal catches fire; even in the upper part of the furnace there is danger of trouble if the furnace makes a heavy slip when using dirty charcoal. These two disadvantages can be overcome.

Anthracite Coal.—Although charcoal was plentiful in all the states that had iron ores, there were only two states having anthracite coal deposits, Rhode Island and Pennsylvania. An unsuccessful attempt to use Rhode Island anthracite in place of charcoal was made as early as 1827. Several other attempts were made in this country and abroad to use anthracite as blast furnace fuel, but they all failed, till Dr. F. W. Geissenhainer, a Lutheran minister, of New York City, successfully used anthracite in his valley furnace on Silver Creek, near Pottsville, Pa., in 1836.

This first practical use of anthracite was in a region where iron ore was found near anthracite coal that could be satisfactorily used as blast furnace fuel; some other attempts failed because the anthracite was not the right sort for blast furnaces.

The use of anthracite as a blast furnace fuel progressed rapidly, but the use of bituminous coal and coke went ahead so slowly that Frederick Overman said,[1] "But few blast furnaces work coke in this country . . . as there is but little prospect of an addition to the number of coke furnaces which now exist, we shall devote but a limited space to this subject."

The valley of eastern Pennsylvania, tapping the anthracite region, became the center of the iron industry, and Pennsylvania continued to hold the leadership which has been maintained ever since until the year 1933. With anthracite, however, its regional development was not so restricted as with charcoal, because it could stand transportation by canal boats away from the coal mines. This enabled the iron industry of New England, New Jersey, and New York to use anthracite; some anthracite was shipped as far west as Wisconsin and Michigan, but the domi-

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[1] "The Manufacture of Iron," Philadelphia, p. 174, 1854.

nance in the iron industry remained in the Lehigh, Schuylkill, and Susquehanna valleys, close to the supply of anthracite.

This regional supremacy of anthracite coal in the iron industry continued until the year 1875 when the tonnage of pig iron made with bituminous coal and coke surpassed that made with anthracite. The regional strength of the Pittsburgh vein of coking coal was too strong, and the center of the iron and steel industry gradually passed over the Allegheny Mountains to western Pennsylvania.

The influence of anthracite furnace practice was carried to other sections of the country by men brought up and trained in the valleys of eastern Pennsylvania and was felt in the South at Birmingham and Johnson City, and in Ohio and Wisconsin. But anthracite practice was "too slow" and soon gave way to the faster driving practice with beehive coke.

The last furnace to use 100 per cent anthracite was Alburtis furnace, of the Thomas Iron Co., in January, 1914. Carbon Iron Co.'s Parryville furnace used a little anthracite mixed with coke in 1923.

Atavism in blast furnace practice has always prevailed, and in passing from charcoal to anthracite, the blast furnacemen of 1840 were confronted with a much greater problem than were the blast furnacemen of the first decade of the twentieth century when they passed from bee-hive coke to by-product coke. Anthracite for blast furnace fuel made great gains in tonnage and within fifteen years from its introduction it outstripped charcoal in the production of pig iron. It took by-product coke about twice as long to gain predominance as a blast furnace fuel.

One great advantage of anthracite was the fact that it is a "natural" fuel, whereas charcoal and coke are the products of a distillation process and, consequently, require a more or less extensive plant. Only a part of this advantage of anthracite was recognized during the era in which anthracite played such an important part in the development of the iron and steel industry of this country. Even today, after years of depression and research, the characteristics of anthracite as a metallurgical fuel are not fully recognized.[1]

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[1] See author's paper, "Blast Furnace Fuels-Anthracite Coal," *Trans. A.I.M.E.*, vol. 116, p. 53.

Anthracite was filled into the furnace in big lumps without sizing; later steamboat-size and broken-size coals were used. Although "broken" anthracite (4⅜ by 3¼ in.) was the recognized blast furnace fuel, the author believes that egg anthracite would give excellent results.

Some broken anthracite used in a blast furnace mixed with coke in 1933 had the following dry analysis (St. Nicholas breaker, sample of 7 cars):

Item	Percentage
Volatile	2.54
Fixed carbon	88.05
Ash	9.27
Sulphur	0.70
Phosphorus	0.044
Iron	0.50

Block or Raw-coal Furnaces.—Block coal, the other "natural" blast furnace fuel, was more scattered in its sources than anthracite, and during the early years of its use raw-coal blast furnaces were erected in nine different states. In nearly every case, the furnace was adjacent to the coal mine. The 70 strictly raw-coal blast furnaces were built during the 43 years beginning with 1845, when three small furnaces, two in Mercer County, Pa., and one in Mahoning County, Ohio, were built to smelt the local iron ores with the local block coal.

The most important regions using raw coal were the Hocking Valley and Jackson County regions of Ohio where the No. 1 Sharon seam of coal was most abundant. More than a third of the 70 raw-coal furnaces erected in the country were built in that part of Ohio during the 30-year period beginning with 1858.

With the exception of two furnaces in Jackson, Ohio, making Jackson County silvery iron, there are no blast furnaces now using raw coal, and these two use it mixed with coke.

On the whole, the influence of raw coal was the least of all the blast furnace fuels, and its use was gradually abandoned in favor of beehive coke.

Pig iron made with raw coal has always been considered to be of very high quality, as is shown by the quality prices now obtained for such irons made in Scotland.

Beehive Coke.—It was beehive coke and the railroads that made possible the great expansion of the iron industry in the decade beginning 1870. During the 10-year period of 1870 to 1879 inclusive, more blast furnaces were built in this country than in any other decade; it is true that the capacity of the blast furnaces was small compared with those of a later period, but it is the *numbers* of separate new blast furnaces built that is significant. The new furnaces built in this decade are here tabulated.

NUMBER OF BLAST FURNACES BUILT IN 1870–1879 DECADE	
Charcoal	68
Anthracite	75
Raw coal	24
Coke	79
Total	246

Much time was devoted to attempt to use coke in the blast furnace, and much money was spent a hundred years ago before the right kind of coal and the right kind of treatment were found, and it was not until 1875 that beehive coke became the standard blast furnace fuel in this country. The Pittsburgh seam of coal in western Pennsylvania is one of the largest and best bodies of coking coal in the world, and Connellsville coke for many years was the standard blast furnace fuel.

The Connellsville ovens were built in double blocks from 100 ft. to a quarter of a mile in length with a loading wharf on either side; a single block in West Virginia is shown in Fig. 58. The ovens were shaped like a beehive about 5 ft. inside height and 11 to 12 ft. inside diameter at the bottom. The coal was charged through the round door at the top, and the coke drawn out by hand through the door on the side. The ovens were first heated red hot with wood fires, and then the raw coal (usually slack size) was fed in at the top and allowed to coke for 24 hr., during which time practically all the volatile matter was driven off. The door was closed up with loose firebrick and the rate of burning controlled by the draft. The volatile matter made a very dense smoke over the whole region and all the valuable by-products were wasted.

An oven held 3 to 4 tons of coal, and the yield was 62 to 66 per cent, according to the amount of volatile matter in the coal. The charge of coal was 3 ft. deep for 48-hr. coke and 4½ ft. deep for 72-hr. coke (foundry coke).

The Old Basin coal of the Connellsville region made coke that analyzed as follows:

Item	Percentage
Moisture	0.30
Volatile matter	0.46
Fixed carbon	89.57
Ash	9.11
Sulphur	0.82
Phosphorus	0.014

Such coke was strong and hard, with well-developed cell structure, silvery in color, and with a metallic ring. In those days the large columnar structure was desired, and "sized" coke was unheard of.

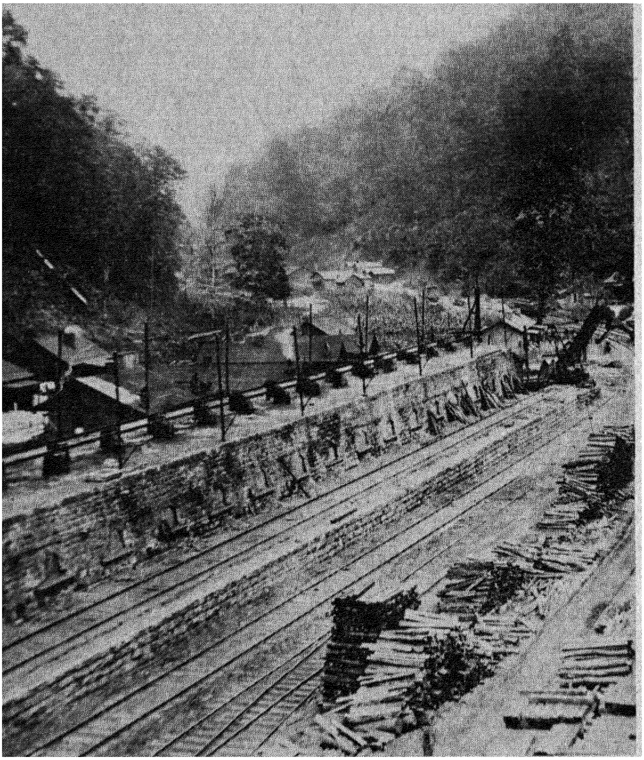

Fig. 58. Beehive coke ovens, West Virginia.

Gradually, the low-ash coking coals in the Connellsville region, like the high-grade lake ores, were used up and the ash in the "standard Connellsville" coke went up to 12.50 per cent and the fixed carbon correspondingly lower, and the sulphur over 1.00 per cent.

Pocahontas coke was softer, dull in color, and much lighter in weight, but the ash and sulphur were much lower. Good Pocahontas·coke would have 90.87 per cent fixed carbon, 6.67 per cent ash and 0.62 per cent sulphur; very poor Pocahontas coke would have only 80.79 per cent fixed carbon and up to 16.54 per cent ash. Some Pocahontas coke would have only 0.0050 per cent phosphorus, and such coke was desirable for making low-phosphorus pig iron.

East Broad Top beehive coke ran about 85 per cent fixed carbon, 12.50 per cent ash, 1.40 per cent sulphur, and 1 per cent volatile matter.

It was thought that beehive coke, like anthracite, was an obsolete fuel, but much was made for blast furnaces in 1937.

By-product Coke.—By-product coke's present supremacy as the blast furnace fuel of modern practice is almost complete, but it has been a harder fought battle than any of its predecessors, and it took a longer time to bring it about. Its regional influence in the location of new blast furnace plants and in the creation of new steel centers, and in maintaining old ones, has probably been greater thanthat of any of the other blast furnace fuels.

Charcoal, raw coal and anthracite were decidedly local in their regional influence and the blast furnaces using them were generally restricted to the vicinity of the supply, only less so in the case of anthracite. With beehive coke, there were metallurgical and freight obstacles to having too great a distance between the coke ovens and the blast furnaces.

In the case of by-product coke most of the freight haul is on the coal, often by water transportation, and there is such a division of costs apportioned to gas, by-products and coke that it can be advantageously used where beehive coke would be prohibitive. The economic and metallurgical advantages of by-product coke over beehive coke have brought about the gradual extinction of the beehive ovens, although a few are still in operation. It is hardly possible that our present civilization will again tolerate the wholesale pollution of the atmosphere of a whole region with the wasteful smoke of banks of beehive coke ovens.

There were many strange happenings among the blast furnacemen during the long period of acquiring the technique of by-product coke. The coke-oven men knew nothing about the requirements for blast furnace coke, and the furnacemen could not give specifications in terms that the coke-oven men could interpret. Those troubles are past, and other things being equal, it is probable that the advantage of location will be with those steel plants having the lowest transportation costs on their coking coals. Thus it will be possible for Pennsylvania to hold the two-century leadership as the premier iron and steel producer, because in Pennsylvania are the greatest supplies of anthracite, or coking coals, or steam-made electricity.

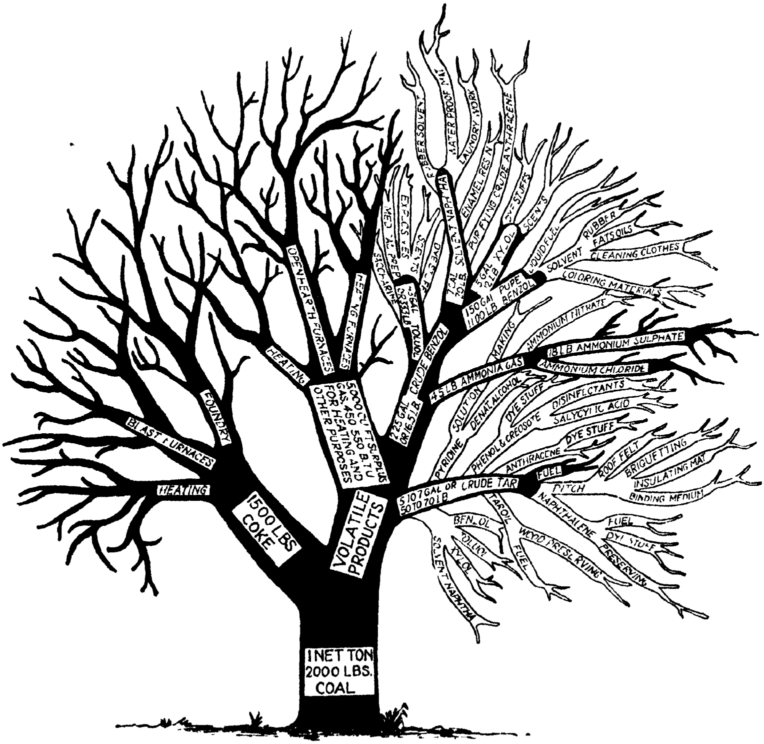

FIG. 59.—Products from the by-product coking of a ton of coal (*Central Research Bureau*, 1915.)

At the present time by-product coke for blast furnace fuel is made in high temperature ovens; the principal types used in this country are Koppers, Semet-Solvay, Wilputte, which vary in the design for heating the ovens with the gas from the coal charged into the long rectangular retorts, or ovens which are heated to a temperature of about 2000°F. The kinds and amounts of the many by-products which are recovered from the volatile portion of the coking coals are shown in Fig. 59. The general arrangement of a modern by-product coke plant is shown in Fig. 60.

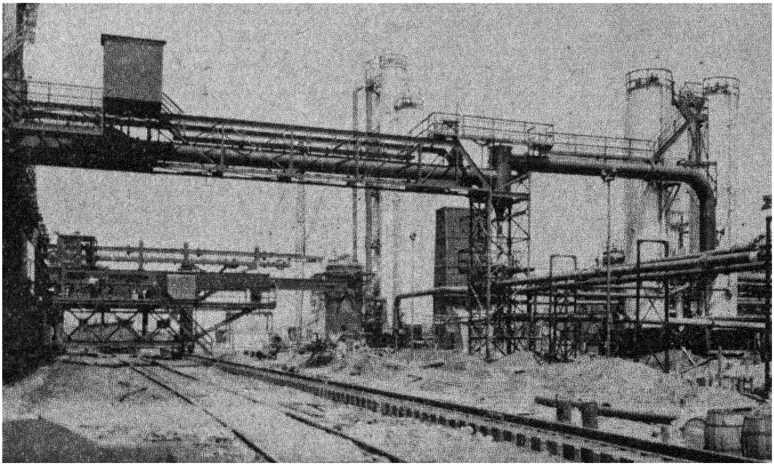

Fig. 60.—By-product coke plant under construction (*Courtesy of The American Rolling Mill Co.*)

It is seldom that any single coking coal is used by itself to make by-product coke; usually two or more kinds of coal are mixed in definite proportions, for economical and metallurgical reasons, in order to give the desired characteristics to the furnace coke. Not only do the coals themselves influence the character of the coke, but each detail of operation has its own effect; the degree of pulverization (*i.e.*, the percentage of coal passing through $\frac{1}{8}$-in. screen), the amount of moisture in the coal, the temperature of the oven, the length of the coking time, the regularity of the pushing schedule, the manner of quenching and the amount of water used, the carefulness of the sizing and screening, and the way in which the coke is handled from the time it leaves the coke plant until it is dumped into the top of the blast furnace

—all these and other little details affect the quality and character of by-product coke.

In going from beehive coke to by-product coke, it was natural that blast furnacemen would specify similar qualities such as hardness, low sulphur, and firm cell structure, and large pieces like the Connellsville coke. At first the coke-oven men took the stand that by-product coke was something new and that blast furnacemen should learn to use just what was given to them by the coke-oven men. The many troubles incident to such an attitude brought about the formation of the Southern Ohio Pig Iron & Coke Association during the World War, and the blast furnacemen and coke-oven men cooperated so successfully that the technique of making satisfactory furnace coke in by-product ovens was worked out with mutual benefits. By-product coke has been the predominant blast furnace fuel since 1919.

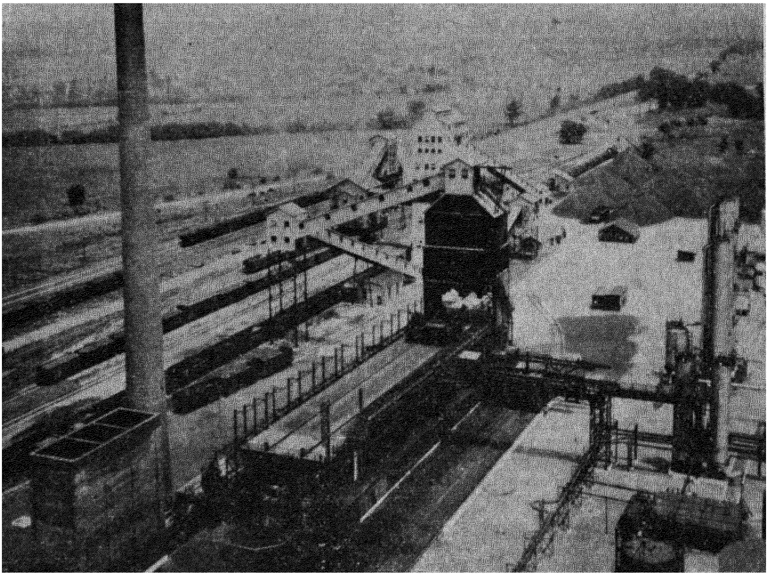

Fig. 61.—Koppers coke-oven plant, Hamilton, Ohio (*Courtesy of The American Rolling Mill Co.*)

Beehive coke predominated for 44 years. How long by-product coke will prevail is not wise to predict.

Only under special conditions is it now possible for a blast furnace to be profitably operated unless it is directly connected with a by-product coke plant having a satisfactory market for all its coke-oven gas. The few blast furnaces now in active condition in this country not so connected are only "marginal" plants and can run only in prosperous times.

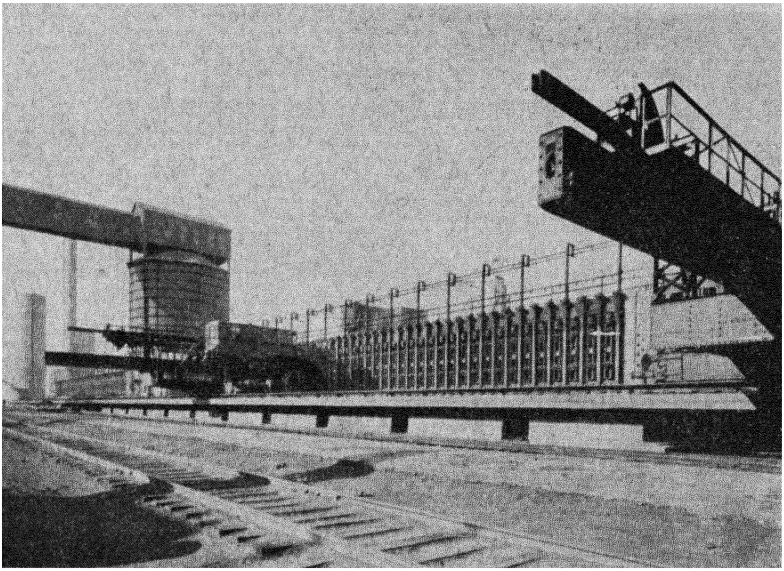

FIG. 62.—Koppers-Becker underjet coke-oven plant. (*Courtesy of Koppers Company.*)

The products from 1 ton of coking coal coked in a by-product coke plant making blast furnace coke and selling domestic coke are as follows:

Product	Amount
Furnace coke	0.38 ton (2000)
Domestic coke	0.32 ton (2000)
Coke breeze	0.05 ton (2000)
Tar	10 gal.
Motor benzol	2.8 gal.
Ammonium sulphate	24 lb.
Surplus gas	6,500 cu. ft.

In cases where blast furnace gas is used for underfiring the coke ovens (to be described in a later chapter), there is released for sale all the coke-oven gas ordinarily used for heating the coke ovens about 4,500 cu. ft., making a total of about 11,000 cu. ft. of coke-oven gas with a calorific value of about 540 B.t.u.

The present practice of sizing coke for blast furnace fuel includes the following classification:

Furnace coke through 4 in. to 3 in. on 1¼ in. to 1 in.
Egg coke Domestic through 3½ in. on 1½ in.
Nut coke Domestic through 1½ in. on 1 in.
Pea coke Domestic through 1 in. on ½ in.
Breeze through ½ in.

Analyses, Sampling, Testing Coke.—The analysis of by-product coke for blast furnace fuel varies greatly in the percentages of ash and sulphur according to the coking coals used and according to the extent to which the responsible management is cognizant of the wastefulness of each excess percentage of ash in the coking coals, as will be shown in the next section. A high-grade by-product coke will have the following anlysis:

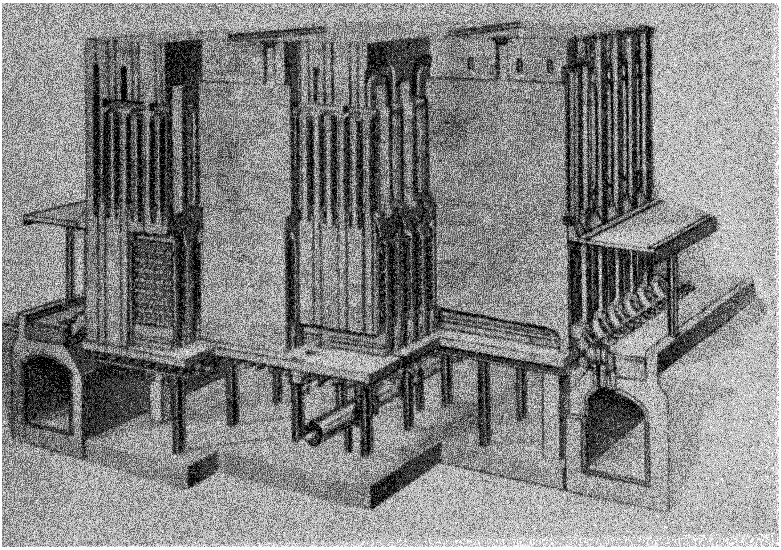

Fig. 63.—Cross section of Koppers-Becker underjet coke oven *(Courtesy of Koppers Company.)*

Contents	Percentage
Moisture	1 to 2
Fixed carbon	90 to 92
Volatile matter	1.50 to 2
Ash	7 to 4.5
Sulphur	0.6 to 0.45

Some blast furnace managers believe in hard-burned coke with the volatile matter under 1 per cent; but the majority of furnace men have found that coke pushed on the "green side," *i.e.*, with volatile matter between 1.50 and 2 per cent, gives better results in the blast furnace. Coke with black ends and "spongy" coke are not desirable as they are conducive to coke breeze inside the furnace and to solution losses in the upper part of the furnace.

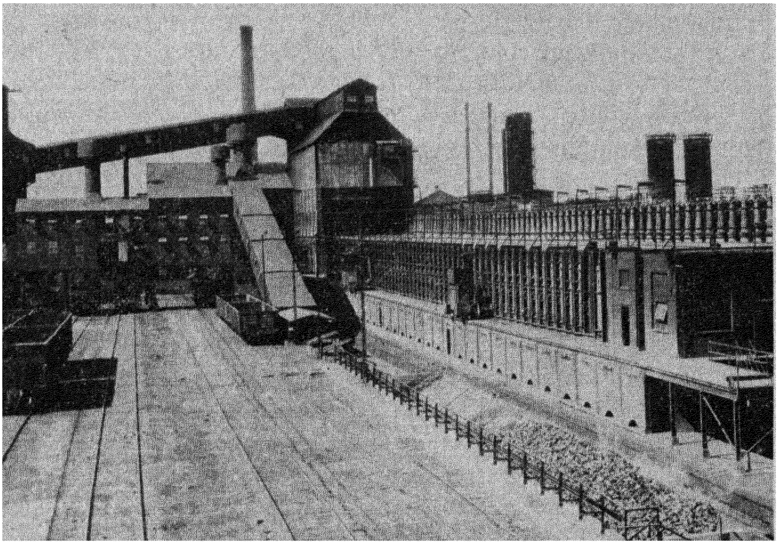

FIG 64.—Semet-Solvay coke-oven plant. (*Courtesy of Semet-Solvay Engineering Corp.*)

Many by-product cokes are much higher in ash and sulphur than the example above; some actual analyses follow:

Type	Moisture, %	Fixed carbon, %	Volatile matter, %	Ash, %	Sulphur, %
Birmingham . . .	3.90	88.70	1.00	8.76	1.01
Birmingham .		85.43	1.61	12.96	0.80
Klondike coke . . .	4.08	86.78	1.31	11.80	1.12
Freeport coke	3.83	86.52	1.41	11.96	1.10

The best place to sample furnace coke is off the loading belt as the coke goes from the screening plant to the railroad cars.

A box or big scoop on a long handle is passed through the stream of coke at intervals throughout each 8-hr. shift, collecting about 15 lb. at a time. The samples are accumulated in a covered metal can and broken down and quartered at the laboratory. Moisture is determined in one portion of the sample by heating in a drying oven kept at 105°C. The standard moisture content is "not over 3 per cent," and in some cases the weights of coke shipped to the blast furnace are adjusted to 3 per cent moisture, by deducting the weight of all moisture above that amount.

The sampling of coke already loaded on cars has to be done sometimes, but it is not so satisfactory as sampling from a stream of flowing coke. The cars are sampled on top in the usual manner of sampling coal and ores in cars.

If coke samples are ground down too fine on a "bucking board," there is danger of getting some metal from the muller and the plate which will increase the percentage of ash and phosphorus falsely.

At many blast furnace and coke-oven plants it is the practice to make daily tests of the porosity and combustibility and to make shatter tests for toughness and sizing. Some furnacemen dispense with these tests and specify certain screen size for the furnace coke and freedom from all coke breeze, and then depend on "what the furnace says" as to whether it is the right kind of coke. There are not yet enough data concerning the combustion of coke inside the blast furnace to justify hard and fast rules as to the specifications for blast furnace coke.

BENEFICIATION OF COKING COALS

Some coking coals are so clean that they can be charged into by-product coke ovens without any cleaning, but most of the coals that have good coking qualities must be beneficiated by some cleaning process, either wet washing or pneumatic cleaning, so as to reduce the ash and sulphur. Every coal has a certain amount of inherent ash and a certain amount of organic sulphur that cannot be removed by any cleaning process. Slate partings in the coal seam, bone, sand rock, and pyritic sulphur can be removed from the coal by proper crushing and cleaning.

Wet washing of coal is done with jigs; launder washers; wet concentrating tables; tubs and cones; thickeners and classifiers;

flotation systems and dryers. The dry methods of cleaning include hand-picking; Bradford breakers; Sutton, Steele and Steele dry tables; the St. Benedict dry cleaner of Peale, Peacock & Kerr; and the dry table of Roberts & Schaeffer Company.

In Alabama the wet jigs are the usual equipment followed by natural drainage of the water from the wet coal loaded on cars. Figure 65 shows the coal-washing plant at Woodward, Alabama. There is considerable moisture in the coals charged into the ovens, unless driers are used. The Rheolaveur washer is the best known of the launder type washers (current washers), and has large capacity; the very fine coal from this system is dried in revolving driers.

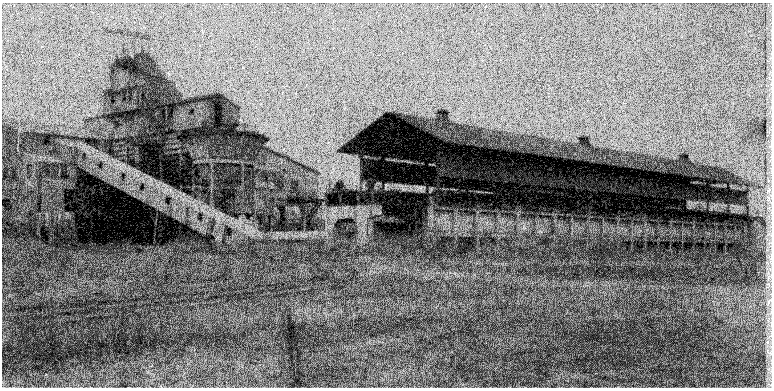

FIG. 65. Coal-washing plant at Woodward, Ala. (*Courtesy of Woodward Iron Company*)

No one coal-cleaning process is adaptable to every coal, and the right system must be found by studies and by applying the washability-test procedure to the coal to be beneficiated.

Evaluation of Coking Coals.—All the ash in the coal coked remains in the coke; a part of the sulphur in the coking coal passes off in the by-products, and only a certain amount remains in the coke. Inasmuch as coke with low ash and low sulphur is better for the blast furnace than high-ash, high-sulphur coke, it is evident that the value of the coking coals will vary in proportion to their ash and sulphur contents. The author found that 1 per cent of ash in a ton of coking coal will increase the cost of pig iron by 30 cents a ton when conditions are as shown in the comparison, Table II, which is from actual operation data where it took 1.45 tons of coal to make a ton of coke.

Table II.—Comparison of Pig-iron Costs

Ash in coal, %	Ash in coke, %	Fixed carbon in coke, %	Coke per ton of pig, lb.	Pig iron per day, tons
6.00	8.70	89.80	1,800	365.0
7.00	10.15	88.35	1,860	353.2

Coke with 8.70 per cent ash:

	Cost per Ton of Pig
Ore mixture—4,144 lb.—1.85 tons at $5.50	$10.17
Coke—1,800 lb.—0.90 ton at $6.50	5.85
Limestone—1,000 lb.—0.50 ton at $1.50	0.75
Labor—$365 per day for 365 tons	1.00
Supplies and service—$250 per day	0.68
Overhead—$200 per day	0.55
Reserve for relining and depreciation	1.00
Total cost	$20.00

Coke with 10.15 per cent ash:

Ore mixture—4,144 lb.—1.85 tons at $5.50	$10.17
Coke—1,860 lb.—0.93 ton at $6.50	6.05
Limestone—1,034 lb.—0.517 ton at $1.50	0.77
Labor—$365 per day for 353.2 tons	1.03
Supplies and service—$250 per day	0.71
Overhead—$200 per day	0.57
Reserves for relining and depreciation	1.00
Total cost with 10.15 per cent ash	$20.30
Total cost with 8.70 per cent ash	20.00
Increased cost	$ 0.30

In both cases it took 1.45 tons coal per ton furnace coke.

Note. This was first published in *Iron Trade Review*, June 4, 1925, p 1446, and later Ralph Hayes Sweetser, "Clean Coal," Penton Publishing Co , Cleveland, Ohio, 1927

This table has become the basis for evaluating the prices of coking coals and for estimating the economics of the cleaning of coal.

BLAST FURNACES FLUXES

The blast furnace process requires a slag which removes all the earthy materials in the ore and fuel and which forms a molten magma for dissolving the calcium sulphide in which sulphur leaves the iron and goes off in the slag. Lime (calcium oxide, CaO) is essential in a blast furnace flux, and it is usually provided in limestone, dolomite, or seashells (obsolete).

Flux stone is so widely scattered over the country that it has been usual to select the nearest quarry, whether it be calcite ($CaCO_3$) or dolomite [(Ca Mg) CO_3], or, as formerly, near Baltimore, oyster shells, as the source of supply providing it was pure enough; but as blast furnace practice has become more refined, it has been profitable to obtain the right kind of flux stone, even if it meant a higher cost and a longer freight haul.

Blast furnace flux will not remove phosphorus from the pig iron; it takes out at least 15 per cent of the manganese and only that part of the silica that is over the amount desired in the pig iron.

At one time the flux at Sparrows Point, Md., was half calcite and half oyster shells which was a poor combination because the shells contained no magnesia. Oyster shells could be bought for half the cost of limestone but made an unsatisfactory slag, even though they were almost pure calcium carbonate. Oyster shells were used at the small blast furnaces near Chesapeake Bay, especially the charcoal furnaces.

An analysis of shells used at Muirkirk furnaces was as follows:[1]

Contents	Percentage
Carbonate of lime	94 48
Carbonate of magnesia	0 94
Insoluble	2 54
Sulphuric acid	0 80
Phosphoric acid	0 06
Alumina and ferric oxide	0 53
Soda	0 65
Total . .	100 00

CALCITE

Calcite limestone is the usual and also the most effective of the blast furnace fluxes; it varies greatly in its purity and its physical structure. The crystalline calcite, although very pure, is not desirable because it crumbles too easily and the fine dust is carried over in the waste gas.

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[1] *Trans. A.I.M E.*, vol. 17, p 471.

The usual impurities in limestone are silica and alumina; sometimes a little sulphur in the form of sulphate; in some sections of the country zinc is present in troublesome amounts. In the making of low-phosphorus pig iron, it is essential that the phosphorus in the flux stone be very low; some calcite (northern Michigan) has only 0.001 per cent phosphorus.

It has been thought that barium would be advantageous in blast furnace flux, but, pound for pound, the carbonate of calcium is the better flux. The atomic weight of calcium is 40, of barium, 137. Wood and Joseph found that "BaO is about one-third as effective as an equal weight of CaO in removing S and in fluxing SiO_2 and Al_2O_3."[1] If barium is present in the ore it is helpful, but barium in a flux stone is not worth the cost. In using a limestone for the first time it is necessary to make a complete analysis; it may contain deleterious minerals.

The "available lime" in a flux stone, whether it be a calcite or a dolomite, is the percentage of CaO + MgO that is left after satisfying the $SiO_2 + Al_2O_3$ in the limestone itself. Blast furnace slags usually have a ratio of 1:1 of $SiO_2 + Al_2O_3$ to CaO + MgO, and for every pound of $SiO_2 + Al_2O_3$ in the flux stone, there is required a pound of CaO + MgO to flux it. Therefore, the less SiO_2 and Al_2O_3 in a flux stone the better it is.

Actual analyses of calcite limestone are as follows:

Location	SiO_2, %	Fe, %	P, %	Al_2O_3, %	CaO, %	Mg, %	CO_2, %	S, %	$Al_2O_3 + Fe_2O_3$
Marble Cliff, Ohio	1.76	0.20	0.006	0.45	50.59	3.43	43.45	0.05	
Northern Michigan	0.57		0.001	....	($CaCO_3$) 96.79	($MgCO_3$) 1.60	..	0.013	0.46
East Tennessee	2.56		0.005		91.69	4.77			0.84
Western Pennsylvania	4.44	0.59	0.023	3.00	90.02				

The controversy among blast furnacemen and chemists as to whether calcite or dolomite is the more efficient flux stone has been going on for many years. It is natural for the furnaceman to make the best of the flux stone nearest at hand and lowest in cost. The chemical phases of this question will be discussed in later chapters.

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[1] *Trans. A.I.M.E.*, vol. 84, p. 126, 1929.

It has been found that a pure calcite is not satisfactory; sometimes the addition of a true dolomite has helped to solve serious blast furnace troubles. It is better to have a flux stone with a small amount of carbonate of magnesia already a natural part of the calcite stone; the Columbus limestone from Marble Cliff, Ohio, is such a limestone and has been found to be a most satisfactory flux, especially when prepared as described under "beneficiation."

Dolomite.—Dolomite was the favorite flux stone in the Lehigh Valley, probably because it was easiest and cheapest to get. Technical papers proving the superiority of dolomite over calcite have been published ever since the days of Ledebur. Advocates of calcite limestone point to the dangers of spinel, an almost infusible combination of magnesia and alumina, according to the formula $MgO.Al_2O_3$, which is apt to form in slags where magnesia and alumina are both high. Firmstone[1] said that "it seems that when the magnesia in the cinder is high—say 20 per cent or more—then, in the absence of further data, any increase in the alumina above 10% should be made cautiously."

In *The Iron Age*, June 27, 1918, there is a short article "Spinel in Blast Furnace Slags," which quotes A. Marshall Le Tellier, chief chemist, Wickwire Steel Company, who said in part:

> This impurity occurring with the silica from the slag (when analyzing a slag) is a definite compound of magnesium and aluminum called spinel, and known to the chemists as magnesium aluminate, having the formula $Mg(AlO_2)_2$. This compound or substance theoretically contains 28.29 per cent magnesia and 71.71 per cent alumina, and by actual analysis covering months of blast furnace practice the substance was found to always occur in this proportion . . . the conditions favoring the formation of spinel in blast furnace slags are three, as follows:— The magnesia content must be over 10 per cent, the alumina content must be over 12 per cent and the silica content must be not more than 33 per cent.

As will be explained later on it is the calcium, and not the magnesium, that combines with the sulphur when the slag and the iron are in the molten state inside the blast furnace and forms calcium sulphide (CaS). The function of magnesium oxide is to lower the melting temperature of very basic slags, and "to

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[1] *Trans. A.I.M.E.*, vol. 24, p. 505, 1894.

permit the use of higher basicity than would otherwise be possible."[1] These authors say further in their excellent paper "Relative Desulphurizing Powers of Blast Furnace Slags" that "MgO has been found to be slightly deleterious to desulphurization of acid slags. The effect becomes increasingly undesirable as basicity is increased to that of slags of average composition. The presence of MgO, however, is decidedly favorable to desulphurization in the more basic slags."

ANALYSIS OF DOLOMITE FLUX

Location	Insoluble	CaO, %	$CaCO_3$, %	MgO, %	$MgCO_3$, %	S, %	P, %
East Tennessee .	1 46	30 27	54.02	21 05	44 04	0 05	0.0034

Beneficiation: Sizing.—The beneficiation of blast furnace flux, outside of picking out the "clay balls" and screening out the fines, is rather recent practice, but as the cleaning of coking coals and iron ores, and the sizing of ores and cokes progressed, it became necessary to pay more attention to the preparation of the flux stone. To produce the right size and quality of flux stone it has been necessary to build up a market to take all those sizes above and below the sizes of stone acceptable for blast furnace flux.

The first paper[2] published on this subject described the quarrying, crushing, screening, and washing of the Columbus limestone which is so satisfactory in analysis for blast furnace flux, at the big Marble Cliff quarries near Columbus, Ohio.

The standard flux stone size at Marble Cliff is through 4 in. and over 1½ in.; but a top size of 6-, 8-, or 10-in. ring and over a 2½-in. screen. One Chicago plant has tried stone that will range between 2 and 3 in.

Whatever size is selected for the blast furnace flux it is certain that all the fines and limestone dust should be screened or washed out. In some limestone quarries there are crevices through which clay has percolated from the surface; this clay is loaded with the

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[1] HOLBROOK, W. F., and T. L. JOSEPH, *Trans. A.I.M.E.*, vol. 120, p. 115, 1936.

[2] HODGES, PAUL C., "Production and Preparation of Blast Furnace Flux," *Trans. A.I.M.E.*, vol. 120, 1936.

broken stone and sent to the crushing plant where it forms into clay balls in the rotating screens and is removed.

The burning of limestone to remove the carbon dioxide gas before charging into the blast furnace has been tried, but not enough benefit has been found to make it practicable. It is possible that fine limestone could be sintered with coke breeze and fine ores and thus burned with good results before charging into the blast furnace.

THE ATMOSPHERIC BLAST; QUANTITY

Of all the raw materials required to make a ton of pig iron in the iron blast furnace, the atmospheric air is greater in weight than all the rest of the materials put together, as is shown by the following table:

RAW MATERIALS TO MAKE A TON OF PIG IRON

Material	Amount
Iron ore	4,333 lb.—1 934 gross tons
Coke	2,162 lb.—0 965 gross tons
Limestone	1,078 lb.—0 481 gross tons
Solid materials	7,573 lb.—3 380 gross tons
Air blast	8,885 lb —3 966 gross tons
Total materials	16,458 lb —7 346 gross tons

A consulting engineer versed in coal and coke remarked that it was a strange metallurgical process that used the oxygen of the air to remove the oxygen from the oxides of iron; but such is the case. It is the oxygen of the atmosphere that is necessary for the combustion of the fuel at the tuyeres to form the carbon monoxide gas—"bosh gas"—that reduces the oxides of iron to metallic iron, and to furnish the heat required for smelting and for melting the iron and the slag.

For a given amount of carbon in the fuel that is burned at the tuyeres there is a certain definite *weight* of oxygen required, but the volume of atmosphere needed to furnish that weight of air varies greatly, according to the weather conditions, to the conditions under which the air enters the blowing engines, and to the kind and amount of beneficiation done to the atmospheric air. The volume of air blown into a blast furnace is measured as the atmospheric air enters the blowing engines, and before compression and before heating in the hot-blast stoves.

This measurement of the volume of blast is fairly accurate for reciprocating engines if the revolutions are counted and multiplied by the cubic contents of the air cylinder. The "slippage" at any pressure may be found by shutting tight the valves on the cold-blast main at the stoves and turning over the engines until the desired pressure is reached. The number of revolutions needed to maintain this pressure is the amount of leakage.

For turbo engines the volume of blast is measured with a venturi meter.

If we calculate on the air being at 62°F. and containing approximately 76.8 per cent nitrogen and 23.2 per cent oxygen and weighing 532.5 grains (0.076085 lb.) per cubic foot of dry air at 30 in. mercury, at sea level, according to the chemical reaction at the tuyeres:

$$C + O_2 = CO_2$$
$$CO_2 + C = 2CO$$

Then for each 12 lb. of carbon, it will require 16 lb. of oxygen, or 1 lb. of carbon requires 1.333 lb. of oxygen, or 5.74 lb. of air, equal to 75.45 cu. ft. of air at 62°F. and at 30 in. of mercury ("75.45 cu. ft. air at 62°F. and 30 inches of mercury are required to burn one pound of carbon"[1]). It must be remembered that all the coke is not burned at the tuyeres and that coke of the higher grades will contain 90 to 92 per cent fixed carbon and the lower grades down as low as 82 per cent fixed carbon.

The actual volume of air blast blown per pound of coke varies considerably at different furnaces and under different conditions. As a rule furnaces are blown on a certain number of revolutions in the case of reciprocating blowing engines and by so many thousand cubic feet in the case of turbo engines. Furnace records show in practice that the volume of blast per pound of coke varies from 54 to 70 cu. ft.

In regard to the influence of the weather, a blast furnace is more sensitive than a fine watch to sudden changes in weather conditions. For each 10° rise in temperature of the outdoor air

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[1] JOSEPH, T. L., P. H. ROYSTER, and S. P. KINNEY, *Proc. Eng. Soc. Western Pa.*, p. 435, January, 1926.

it is necessary to increase the volume of blast blown by 2 per cent in order to get the same weight of oxygen. In addition to the temperature of the atmosphere, the humidity has a decided effect on the furnace, and the barometer at times has some effect. The author saw a remarkable demonstration of these effects of temperature, barometer, and moisture back in 1908 when furnace practice was different from what it is now, but the

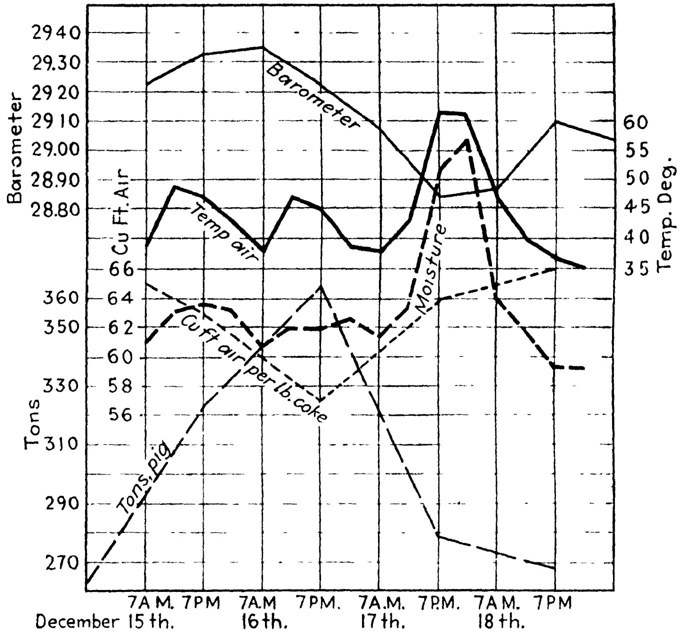

FIG 66—Effects of changes in weather.

laws of nature were the same. When such sudden changes in the weight of oxygen and moisture take place it is necessary to vary the volume of blast blown per minute. This was not done during the four days recorded in Fig. 66.

The weather conditions should be so closely watched that sudden changes may be met in time to prevent serious changes in the quality or the tonnage of the pig iron. If the temperature goes up, the volume of the blast should be increased correspondingly. The falling off in tonnage during the summer months can be largely offset by increasing the volume of the blast.

CHEMICAL AND PHYSICAL CHARACTERISTICS

Moisture.—The uncontrollable changes in the weather, bringing about only slight variations in the chemical and physical characteristics in the air blast, have pyramiding effects on the working of the blast furnace because of the enormous volumes of blast per minute being pumped into the furnace. The difference between 50°F. temperature of the atmosphere at midnight and 70°F. at noon is only 20°, but to a blast furnace being blown at the rate of 50,000 cu. ft. per minute, it means a difference of 35 lb. of oxygen per minute. It is good practice to change the volume of blast 2 per cent for each change of 10°F. in the temperature of the atmosphere.

The other constituent of the atmosphere, besides oxygen, that has a direct effect on the working of the blast furnace is the relative humidity and the weight of vapor present in a cubic foot of the atmosphere. In an outdoor temperature up to 40°F., it is impossible to get very much moisture in a cubic foot of air; even at 100 per cent humidity, it would be only about 2.8 grains per cubic foot, which is equal to 20 lb. of water when blowing 50,000 cu. ft. of air per minute. But if the temperature should go up to 90°F. and 100 per cent humidity, there would be 105 lb. of water per minute, or 151,200 lb. in 24 hr., pumped into the furnace through the tuyeres.

The rapid rise of moisture contents with increase of temperature of the atmosphere is shown in the relative humidity and psychrometric chart in Fig. 67.

Beneficiation of the Blast.—Because air was free, but in spite of the fact that air weighed more than all the materials used in making a ton of pig iron, not much attention was paid to its quality for a long time, and the intakes of the "blowing tubs" or air cylinders of the blowing engines took air from inside the engine room where it was nice and hot and full of moisture. (Even in 1937 the author found just such blowing engines) As far back as 1793, the English ironmasters were experimenting to improve the quality of the air blast. Joseph Dawson, one of the founders of Lowmoor Ironworks, England, said at a meeting of blast furnacemen in June, 1800, "In the summer season we all know that the furnaces never work quite so well as at any other time." He asked "leave to enquire how these

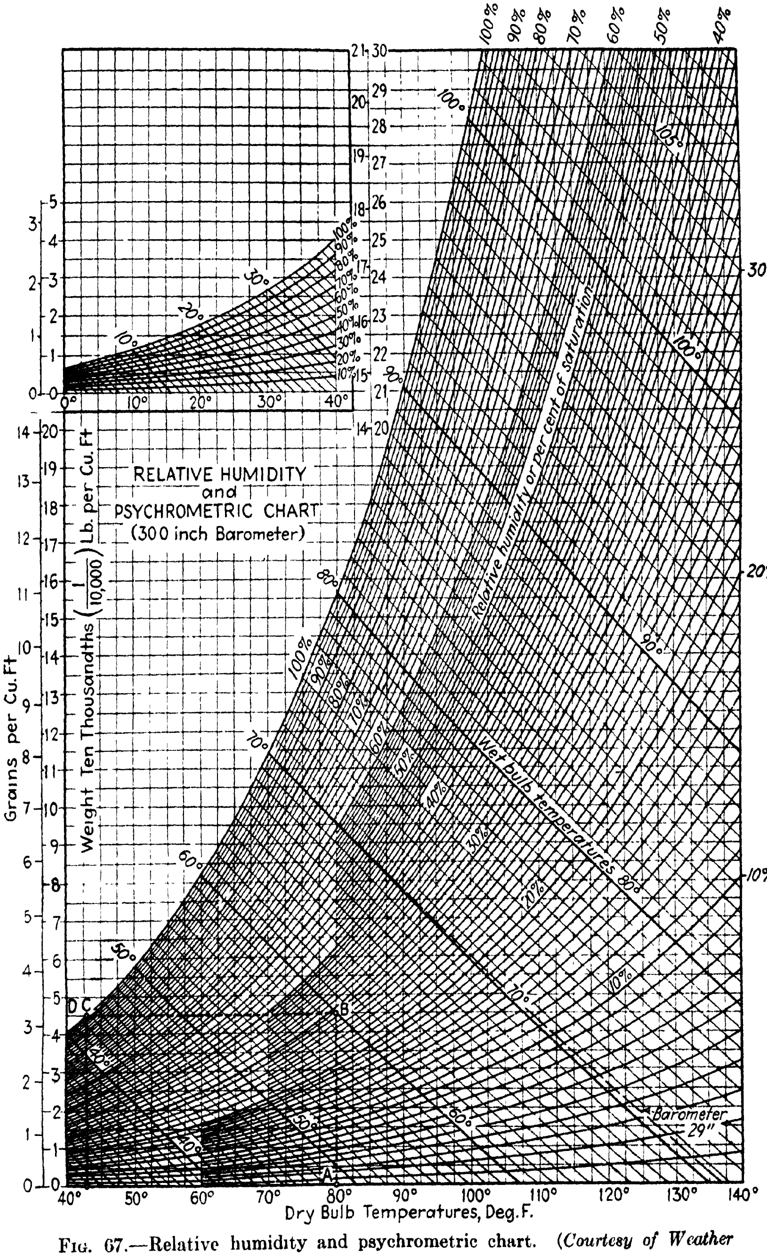

FIG. 67.—Relative humidity and psychrometric chart. (*Courtesy of Weather Bureau, Department of Agriculture.*)

principles respecting air and moisture will explain the several appearances that take place in our blast furnaces."

Not much was done, however, until about a hundred years later when James Gayley and David Baker experimented on reducing the temperature of the air and thus eliminating much, and even all but a trace, of the moisture in the blast.

The most successful of all the processes for eliminating moisture was the Gayley dry-blast process, invented by the eminent blast furnace engineer James Gayley and put into operation at the Isabella furnaces of Carnegie Steel Company, Pittsburgh, Pa., in August, 1904. The immediate increase in production of pig iron and decrease in coke per ton of pig iron caused much wonder and discussion throughout blast furnace centers in this country and in Europe. This process consists of passing air through refrigerating chambers cooled by ammonia-machines so that the air delivered to the intake valves of the blowing engines was cooled down to about 22°F., thus "freezing" out the moisture to the saturation point at that temperature. By looking at the psychrometric chart (Fig. 67), it will be seen that even if the humidity is at 100 per cent, the total moisture at, say, 24°F. can be only about 1.5 grains. Gayley first presented his paper at the New York meeting of the Iron and Steel Institute (Great Britain) in October, 1904, but it was read by title at the September, 1904, meeting of A.I.M.E. and published[1] under the title "Application of Dry-blast to Manufacture of Iron."

The British and French ironmasters were not all in agreement as to the advantages of the Gayley dry-blast process, and some even suggested that the economies obtained by dry blast at Isabella might have been obtained in a large degree by other improvements in blast furnace practice. And such has proved to be the case. Mr. Gayley's dry blast helped to increase the tonnage of his 90-ft. blast furnace (18,090 cu. ft. contents) from 358 to 447 tons per day, an increase of 24.8 per cent; it decreased the coke consumption from 2,147 to 1,726 lb. per ton of pig, reduction of 19.6 per cent; these were tremendous improvements at one jump. The advantages were the "cumulative effect of a good thing"; practically the same amount of oxygen was blown into the furnace to burn almost exactly the same weight of coke with dry blast (771,522 lb.) as with the natural blast (768,626 lb.)

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[1] *Trans. A.I.M.E.*, vol. 35, pp. 746–771, 1905.

in 24 hr., but it was done with 15 per cent less engine revolutions, less volume of blast, with same weight of oxygen; it helped to reduce the flue dust loss from 5 per cent of the ore charged down "to less than 1 per cent"; it resulted in greater regularity of the quality of the pig iron and greater control of the working of the furnace.

James Gayley was a bold and ingenious blast furnaceman and accomplished almost overnight what it has taken thirty years to accomplish in other ways—by little changes in dimensions of the furnace, by little changes in the preparation of coking coals and the sizing of coke, by little changes in the preparation of the iron ores, and by sizing and cleaning the limestone flux.

PART III

THEORY AND CHEMISTRY OF BLAST FURNACE PROCESS

THEORIES—AND LACK OF THEORIES

The different theories as to what goes on inside a blast furnace remind us of the ancient maps of the world made by the explorers of the fifteenth century. When they did not know by actual experience what was in the interior of an island or a continent whose shores they had explored, they drew a picture of some fantastic monster, and gave it a name based on some legendary half-truth or on some pure misinformation. Even today there are some parts of the interior of the blast furnace which are still unexplored, but which are the subjects of thermodynamical calculations and theories based chiefly on the knowledge of what is going on outside the furnace, and at several points inside the hearth of the tuyere level, the bosh, and the shaft.

The remaining unexplored territory of the iron blast furnace, that part between the tuyere level and the level of the inside end of the iron notch, known sometimes as "the crucible" of the furnace, is perhaps the most important section of the furnace because it is here that the final chemical and physical characteristics are imparted to the iron. The author has withdrawn samples of iron and slag at the tuyere level all along the radius from the center to the nose of a tuyere in a furnace in full blast and has found all sorts and conditions of iron from low carbon to high carbon; iron that was like "sponge" iron, and white iron so hard that it would cut a file. The slag at the tuyere level is in many phases of basicity and is often intimately imbedded in the coke. The coke, or any other fuel, at this level is still solid, but most of it in the stage of imminent gasification. The reason for certain approximately regular amounts of the carbon of the coke, or other fuel, passing into the liquid iron is not yet definitely known.

With such an important region of the blast furnace as is the hearth, or crucible, still unexplored it is impossible to formulate complete theories for the reactions that govern the smelting of iron ores in the blast furnace. Back in 1912, the late J. E. Johnson, Jr.,[1] said that "we may as well admit frankly that experiment on the furnace itself is the only safe foundation for practice or for a useful theory." It has been by bold experiments made by practical and adventurous blast furnacemen that we have developed blast furnace practice to the present state of the art of smelting iron ores, in spite of many erroneous theories and, in some cases, in spite of the lack of any theories at all. The iron blast furnace is still an enticing field for research for those young metallurgists who wish for the thrill and adventure of discovering facts now unknown to the iron and steel industry.

Much of the construction of blast furnaces in the past has been based on false theories; the same can be said for much of the practice. It is a marvel that we have advanced as far as we have in the art of iron smelting "hampered by the lack of explanation and data regarding the fundamentals," as Dr. Saklatwalla said.[2]

In recent years, the greatest advances in blast furnace practice have been due to causes other than mechanical enlargement of the furnace itself, as was unsuccessfully attempted in the days of Sir Lowthian Bell, but have come about through the scientific research of the fundamentals underlying the exchange of heat between hot gases and cold solids, and the phenomena attending the reduction of iron ores. These problems will be discussed in the pages following. Important as such research work is for the guidance of the practical furnaceman, there still remains the need for explorations inside the hearth of the furnace and further examination of the interiors of the bosh and of the shaft.

False theories, based on incomplete data, isolated facts and fragmentary observations have been responsible for many queer and uneconomical designs of blast furnaces. In many cases the changes in design have been gradual because it takes time and often much money to change the inside shape or dimensions of a blast furnace lining. At the present time, for instance, many blast furnaces cannot have so large a stock-line diameter as should go with their big hearths because it would be necessary to replace completely the steelwork above the mantel.

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[1] In his paper "The Effect of Alumina in Blast-furnace Slags," *Trans. A.I.M.E.*, vol. 54, p 124, 1912.

[2] In his address, "Fundamentalism in Ferrous Metallurgy," Dec. 5, 1924.

The false theories about "the penetration of the blast" have been responsible for much trouble in the past and for many queer sizes and designs of tuyeres. Some of the faulty practice still exists. The incomplete data about the combustion of fuel at the tuyere level led to the great increase of the number of tuyeres in furnaces, even of small hearth diameter, at the turn of the present century. Not until the physiochemists and research men of the U. S. Bureau of Mines (Joseph, Kinney, Perrott, and Royster) discovered the combustion zones of the blast furnace, did we have an adequate theory on which to base furnace design and practice, and even now we have not taken full advantage of their discoveries. There is still need for further investigation of the region in front of the tuyeres of a blast furnace, and we are now much better equipped with pyrometers than were those young men fifteen years ago.

As was shown in a previous chapter, it may take a century for an idea to be fully developed, because of the lack of two important things, *viz.*, the lack of money and opportunity with those who have the inventive imagination and the lack of courage and imagination with those who have the money and the plants. Charles F. Ramseyer, said,[1] in speaking of the causes for lack of development in the steel industry, "The non-technical bankers, lawyers and financiers at the heads of the larger companies, were against spending large sums on dubious experiments, and when they did attempt some experimentation they were frequently ill-advised and unsuccessful. . . . Perhaps, too, the tremendous investment in plant made them apprehensive of the financial dangers of sudden obsolescence."

False Theory in Use of Anthracite.—The use of anthracite as a blast furnace fuel is a striking illustration of the cumulative grief that comes from false theories and lack of scientific facts. All honor is due those adventurous ironmasters who jumped from charcoal, the perfect blast furnace fuel, to anthracite, the hardest of fuels and one that had baffled the European ironmasters for many years. It is not to the credit of the ironmasters of today that we still lack knowledge of some of the fundamentals of blast furnace practice. In the original patent granted to Friederich W. Geissenhainer, Dec. 19, 1833, for his "new and useful improve-

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[1] "A Chemical Engineer Views the Steel Industry," *Trans. A.I.M.E.*, vol. 116, p. 159, 1935.

ment in the manufacture of iron and steel by the application of anthracite coal," is the foundation of the erroneous belief that anthracite requires three and a half times "the quantity, velocity and density or compression of a blast necessary and proper for charcoal, and as much greater than for coke in the proportion of three and a half to two and a half."

Whatever data are available and what actual experience the author has had with charcoal and coke in the same blast furnace with the same equipment point to the fact that coke does not require 2½ times as much volume and pressure of blast as does charcoal, and that neither does anthracite require 3½ times as much.

Charcoal used to be considered to contain about 95 per cent fixed carbon, but such is not the fact. It is safe to consider that charcoal is about 70 per cent fixed carbon.

In the author's own blast furnace experience he found that in the same blast furnace, smelting the same ores to make the same kind of Bessemer pig iron, and using the same blowing engines, that it took about 1.44 times as much air blast by volume to burn a pound of beehive coke as it did to burn a pound of charcoal.[1] That was at Sault Ste. Marie, Ont., in 1905.

Kreisinger[2] found that anthracite required only 95.6 per cent as much air for combustion as coke.

The author has found in practice that it requires approximately the same volume of air to burn anthracite as to burn coke in the same blast furnace.

The greatest advances in blast furnace practice have been due to causes other than mechanical and have been brought about more by changes in our attitude of mind than by changes in design and equipment.

Present blast furnace practice is based on the theory that the iron oxides of the solid ore are "reduced" to metallic iron by means of hot carbon monoxide gas according to a complex series of chemical reactions and reversed reactions whereby the iron becomes a spongy solid and the oxygen becomes a gas and passes out of the top of the furnace; the iron melts and passes out of the bottom of the furnace in its liquid form. The hot carbon monoxide gas comes from another series of reactions at the

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[1] *Trans. A.I.M.E.*, vol. 39, p. 228, 1909.

[2] *Bur. Mines Tech. Paper* 137, p. 54.

tuyeres, where solid coke which has come down the whole length of the furnace from top to tuyeres as a solid and returned upward as a hot gas, is instantly gasified at the tuyeres on meeting the oxygen of the preheated air blast. Limestone, like the iron ore, comes into the top of the furnace as a solid and goes out half as a gas at the top and half as a liquid at the bottom.

The theory is that the combustion of the fuel at the tuyeres is sufficient to furnish all the heat necessary for the chemical reactions inside the furnace and to liquefy all the iron and slag leaving the furnace at the bottom, and yet there are no two technical men who agree with each other in calculating the heat balance of the same blast furnace.

The law of gravitation takes the solids downward in the furnace, but considerable solid matter is carried out of the top in the waste gases. The furnace is filled with cold stock when it is first blown in, and in regular operation it takes eight to twelve hours for the stock to go completely through the furnace. Even with the furnace full of solid and liquid materials, there is enough air blown in every minute equal in volume to 2¼ times the cubical contents of the furnace when empty.

Such a countless number of laws of chemistry, of physics, of thermodynamics, of the flow of gases through a column of irregular solids, of vapor pressure, of expansion of gases, of the interchange of heat, of expansion of solids, of expansion of liquids, of expansion and density of gases, of conductivity of solids, liquids and gases, of equilibrium and motion—all these and many other laws, are involved in blast furnace practice so that it is no wonder that many erroneous theories can be based on some one or more actual observations of blast furnace phenomena.

This long list of the laws governing blast furnace practice is given here to show that it is humanly impossible for any one man to know all the theories, principles, and natural laws governing the operations of the blast furnace and at the same time handle a blast furnace in the best possible manner, according to those theories.

COMBUSTION ZONES

The discovery of the combustion zones in front of the tuyeres of a coke blast furnace by the young men of the U. S. Bureau of Mines beginning in 1922 was one of the greatest discoveries in blast furnace practice since the research work of Sir Lowthian Bell; it ranks with the announcement of the critical temperature of the hearth by J. E. Johnson, Jr. Like many other discoveries, it came as an indirect result of the study of the properties of metallurgical coke, during which study Perrott and Kinney "explored the hearth combustion zone in a number of blast furnaces," and presented a paper at the February, 1923, meeting of A.I.M.E., entitled "Combustion of Coke in Blast-furnace Hearth."[1] This paper was the first of a series of reports on the research work to determine "the exact nature of the combustion of coke in the neighborhood of the tuyeres."

The following year, Royster and Joseph presented their paper "Effect of Coke Combustibility on Stock Descent in Blast Furnaces,"[2] in which was a diagram showing the flow of stock when combustion takes place near the tuyeres. In discussing that paper, the author said, in part, "That figure [Fig. 2] is one of the most important diagrams of blast furnace practice." The author still thinks so much of it that it is herewith reproduced as Fig. 68, even though the extent and shape of the combustion zones were not so well known and defined as in the paper of Kinney, Royster, and Joseph,[3] entitled "Iron Blast-furnace Reactions." Figure 69, from this article, shows the probable size of the combustion zones in a vertical plane and gives a plan of the probable arrangement of the zones of combustion in a 12-tuyere furnace.

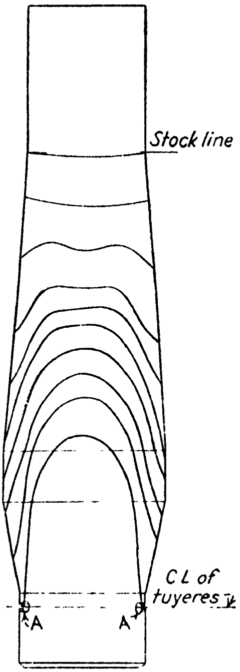

Fig. 68.—Flow of stock when combustion takes place near the tuyeres. (*From Royster and Joseph, Trans. A.I.M.E., vol.* 70.)

The water-cooled gas-sampling tube used for taking the gas samples had a total length of about 17 ft. and was well protected by cold water circulating under pressure; compressed air was blown through the 3/8-in. gas pipe until the sampling tube had

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[1] *Trans. A.I.M.E.*, vol. 69, pp. 543–584, 1923.

[2] *Trans. A.I.M.E.*, vol. 70, p. 229, 1924.

[3] *Bur. Mines Tech. Paper* 391, 1927.

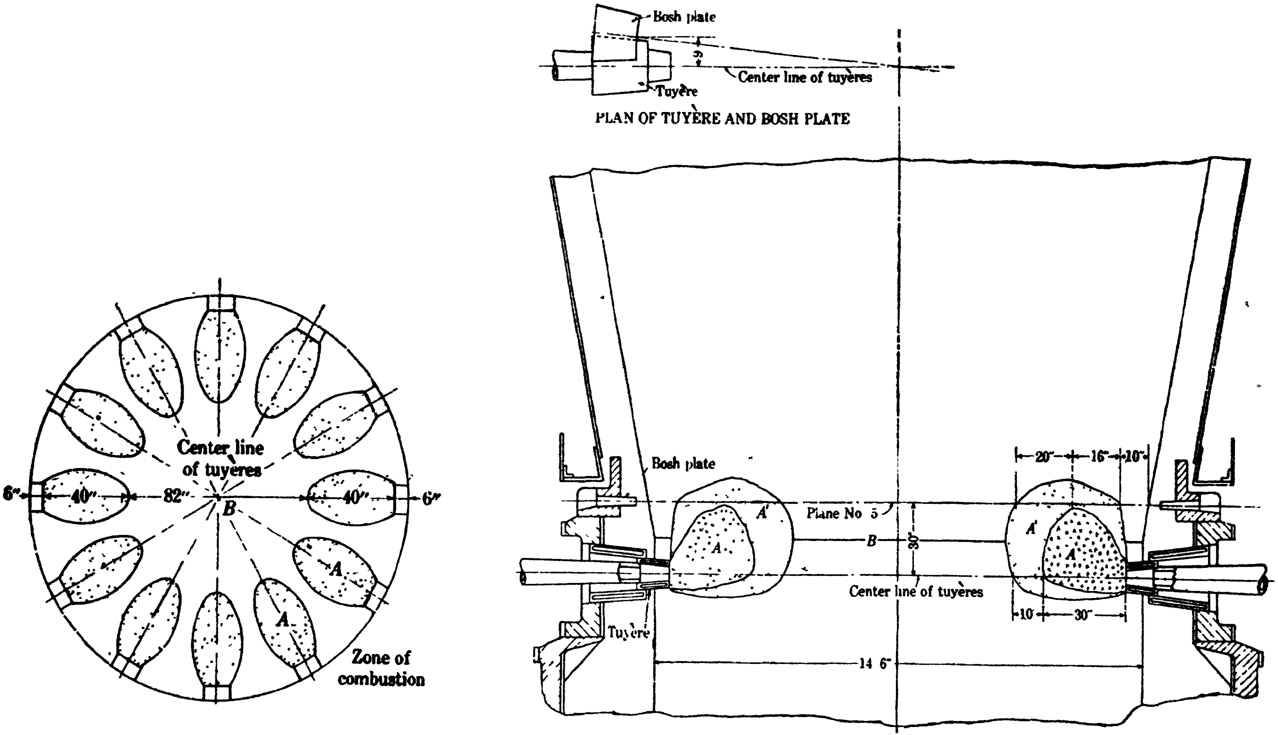

FIG. 69.—Approximate size and shape of combustion zone. (*From Bur. Mines Tech. Paper* 391.)

been pushed through the tuyere to the point where the gas was to be sampled.

In May, 1923, S. P. Kinney and the author took a sample of gas, through such a sampling tube, from the very center of the hearth of East furnace, Columbus, Ohio, and thought they had a sample of cyanogen (from its peculiar odor) which was sent to the Bureau of Mines laboratory for analysis. There was a long delay before analysis, and no cyanogen was found.

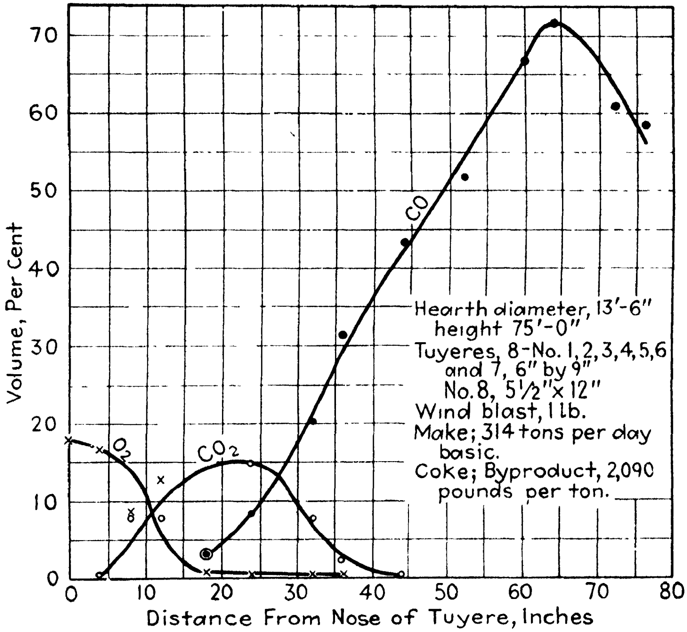

FIG. 70.—Combustion zone under slack blast. (*Courtesy of Kinney, Blast Furnace & Steel Plant, June,* 1925.)

At the same furnace, and during the tests for temperatures of iron and slag and carbon contents described under the heading Carbon in Pig Iron, Kinney took gas samples from the interior of the blast furnace at the tuyere level, and at other levels of the Columbus blast furnaces of The American Rolling Mill Company. Most of the tests were made while the full blast was on the furnace. In order to find out the size of the combustion zone in front of the tuyere when very little wind was blown, we slacked the blast to only 1 lb. pressure and took gas samples as rapidly as possible over a period of 19 min. The results are shown in Table III and are plotted in Fig. 70. This table shows that

TABLE III.—ANALYSES OF TUYERE GAS SAMPLES TAKEN AT THE TUYERE LEVEL OF NO. 2 FURNACE[1]
(Blast pressure, 1 lb.)

Distance from nose of tuyere, inches	CO_2 %	O_2 %	CO %	H_2 %	N_2 %	Time on April 5, 1923
−8	0 0	20 8	0 0	0 0	79 2	9:39 A.M.
−4	0 0	20 9	0 0	0 0	79 1	9:39 A.M.
0	0 0	18 1	0 0	0 0	81 9	9:36 A.M
4	0 3	16 9	0 0	0 0	82 9	9:35 A.M
8	8 0	8 9	0 0	0.0	83 1	9:34 A.M.
12	7 8	13 0	0 0	0 1	79 1	9:32 A.M.
18	3 2	0 9	3 2	0 0	92 7	9:30 A.M.
24	15 0	0 8	8 3	0 0	75 9	9:29 A.M
32	7 8	0 3	20 2	0 4	71 3	9:27 A.M.
36	2 2	0 3	31 4	0 4	65 7	9:26 A.M.
44	0 3	0 0	43 5	0 4	55 8	9:24 A.M.
52	0 0	0 0	52 0	0 0	48 0	9:23 A.M.
60	0 0	0 0	67 0	0 0	33 0	9:22 A.M.
64	0 0	0 0	72 0	0 0	28 0	9:21 A.M.
72	0 0	0.0	61 0	0 6	38 4	9:20 A.M
76	0 0	0 0	58 5	0 0	41 5	9:20 A.M.

[1] From S P. Kinney, *Blast Furnace & Steel Plant*, June, 1925

two samples were taken inside the tuyere and one at the nose of the tuyere in which there was only atmospheric air. Two samples were taken from the far side of the center of the furnace, and these show a decrease in the percentage of carbon monoxide in the gas.

In commenting on these results and charts Kinney says[1] that "an examination of the curves representing the results of gas sampling in No. 2 furnace at normal working and No. 2 furnace at 1-pound pressure, will result in the conclusion that the general form of the curves is quite similar. . . . The extent of penetration of the combustion zone in all cases is approximately 40 inches, regardless of whether the furnace is operating on 1-pound or 14-pound pressure." Kinney reported variations in analysis of the

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[1] *Blast Furnace & Steel Plant*, June, 1927.

gas sampled at the same distance in front of the tuyere but taken at different times of the day, as shown by the following table:

Distance from nose of tuyere	CO_2, %	O_2, %	CO, %	H_2, %	N_2, %	Time	Date
12 in	9.6	1.1	2.7	0.0	86.6	10:47 A.M.[1]	4-2-23
	7.0	1.4	0.6	0.0	91.0	10:14 A.M.	4-2-23
	6.1	10.6	0.0	0.0	83.3	10:12 A.M.	4-4-23
Average . .	7.4	4.3	1.1	0.0	87.2		

[1] At 10:47 A.M. on Apr. 2, a sample of gas was taken at the tuyeres, which is shown to be much different from the sample taken at 10:14 A.M. the same day, and quite different from the one taken 2 days later at the same distance in front of the tuyere.

The results of sampling in the combustion zones of 10 other blast furnaces by the Bureau of Mines are shown in Fig. 71, which reveals that combustion is practically complete within 40 in. of the nose of the tuyere.

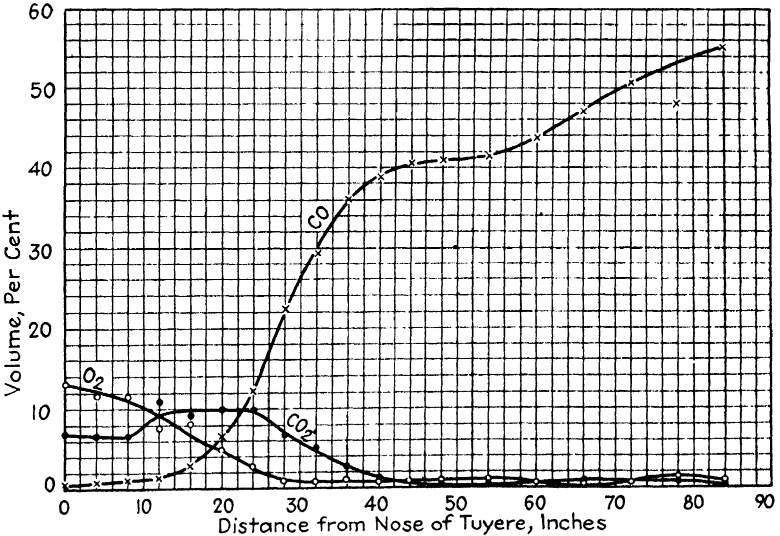


FIG. 71.—Average combustion zone in ten furnaces. (*From Perrott & Kinney, Trans. A.I.M.E., vol. 69.*)

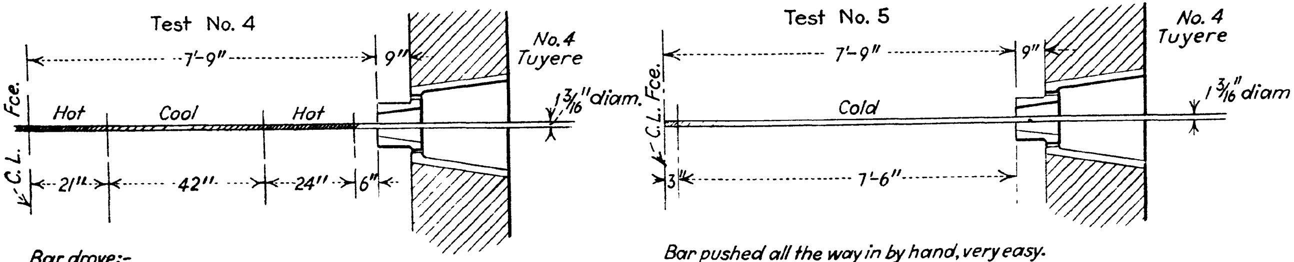
The Rod Test.—There is a very simple way of testing the extent and relative temperature of the combustion zone in front of each tuyere and that is to push a long round steel rod through the tuyere cap and blowpipe into the very center of the hearth. The rod should be 1$^3/_{16}$ in. round and coated with "clay wash," put on the rod while hot and allowed to cool; this gives it some protection, and rods thus protected can usually remain intact for an elapsed time of 20 to 35 sec. from the time of starting to push the rod through the tuyere until it is finally withdrawn.

Not only can the combustion zones be studied by this test, but the condition of the core in the center of the hearth at the tuyere level can be ascertained. This floating core is the lower end of the stock column of solid coke that rests upon the bath of slag just as soon as the normal blast pressure is taken off the furnace.

In such tests at the Ashland, Ky., furnace of The American Rolling Mill Company, it was found that there was a very hot section of the combustion zone beginning about 6 in. from the nose of the tuyere and extending for about 24 in.; then there was a cooler section 2 or 3 ft. long, varying, apparently, according to the time elapsed since the previous cast. There is much evidence to show that the conditions of combustion in the tuyere zones, and the character of the floating core at the tuyere level are much influenced adversely by taking off the blast after casting in order to shut the iron notch. This subject will be discussed further in the chapter on iron notch and iron-notch guns.

Out of a series of 10 rod tests made by Ora E. Clark, blast furnace superintendent of the Hamilton Coke and Iron Company, Hamilton, Ohio, the author has selected two sketches illustrating the difference in the physical conditions at the tuyere level just before and just after a cast. Figure 72*a* shows that the bar had to be driven into the furnace, and then it took 15 sec. to pull it out by "ring and wedge" and sledge hammers. The rod passed through a nondescript slag, as shown by the analysis of slag adhering to the rod. Figure 72*b* shows that 14 min. after cast, the rod was easily pushed by hand all the way into the center of the furnace, and that it took only 6 sec. to pull it out. The blast pressure on the furnace was 1 lb. higher than just before cast.

Although this theory of the combustion zones in front of the tuyeres clears up much of the uncertainty as to how and where most of the coke is consumed, there is still unsolved the question



Bar drove:-
¼ easy, ½ easy, ¾ hard, 4" past center
Time in 22 sec. Out 15 sec.
Elapsed time 37 sec.
All of bar recovered, had some particles of slag which analyized as follows:-
SiO_2 17.40, Al_2O_3 6.90, CaO 28.00, MgO trace Fe. 33.92
Test just before casting. B. P. 16-½ lb., B.T. 1300°

a

Bar pushed all the way in by hand, very easy.
Time in 8 sec. Time out 6 sec.
Elapsed time 14 sec.
Bar cold except 3" at end glowing
Test 14 min. after cast. B. P. 17-½ lb., B.T. 1300°

b

FIG. 72.—Temperature at tuyeres by rod test. (*Courtesy of Ora E. Clark.*)

of how the coke that drops below the tuyere level is consumed, since all the oxygen of the blast is combined with solid coke within about 40 in. of the nose of the tuyere. The amount of coke within the hearth and between the tuyere level and the level of the iron notch varies considerably during the time between casts. The physical and the chemical character of this coke is quite different from that of the coke that comes down to the tuyeres.

It is probable that some of this coke obtains its oxygen for combustion from the oxides of the metalloids that come down into the hearth, and some of the carbon of the coke unites with molten iron in the form of graphite and of combined carbon.

This theory of the combustion zone with its length of about 40 in. explains why the oldtime charcoal blast furnaces with hearths only 36 in. in diameter could be operated with only one tuyere; the whole hearth at the tuyere level was a combustion zone. Of course, this remark is predicated on the assumption that the combustion zone for charcoal is the same as for coke, and this has not yet been determined.

High Carbon Monoxide Content.—Some of the gas analyses reported by Kinney show as high as 67 and 69.4 per cent of carbon monoxide in the center of the furnace at the tuyere level, and only 32.3 and 29.4 per cent nitrogen respectively, and with no carbon dioxide. Bosh gas, the final gas after combustion of the coke is complete and before reduction of the iron ore begins, is considered to contain 34 per cent carbon monoxide and 66 per cent nitrogen. This is the zone marked *B* in Fig. 69, and this zone would be lacking in the one-tuyere charcoal blast furnace mentioned above and was found to be lacking in the experimental furnace at the North Central Bureau of Mines station in Minneapolis, which had a hearth diameter of only 36 in.

Zone *B* is rather inactive and is sometimes cooler than other parts of the plane at the tuyere level; again, it has been found to be hotter than the carbon dioxide section of the combustion zone in front of the tuyeres, as is shown by Figs. 72*a* and *b*. This sluggish zone (*B*) is greatly increased in size in the so-called "big-hearth" furnaces, and this may be one of the reasons that the coke consumption in these big furnaces is not lower than in the furnaces with smaller hearths. It has been found that the bigger hearth diameter furnaces tend to make pig iron with higher contents of total carbon.

Not enough information regarding this center zone has yet been obtained to formulate a satisfactory theory as to the cause for the present of so great a percentage of carbon monoxide and so little nitrogen. Some conflicting conclusions have been published, all of which may be correct as to the condition existing at the time of the observations, but we know that the conditions at the center of the plane of the tuyeres vary greatly in the same furnace and in different furnaces.

There are enough data, however, to support the suggestion of the Bureau of Mines men[1] to eliminate the inactive zone *B* and build a long rectangular hearth with a width of twice the length of the combustion zones, or 80 in. Such a furnace would probably allow the stock column to settle more evenly and would provide a more regular distribution of the ascending gas column.

REDUCTION OF IRON ORES

Iron ores are chiefly oxides of iron mixed with varying amounts of earthy materials, such as silica in the form of sand and silicates and alumina in the form of clay and other alumina minerals. The iron oxides are often compounded with water to form the hydrated oxides of iron. The different forms of iron ores are described in the section on Natural Iron-ore Minerals.

The smelting of iron ores to make pig iron is simply to remove the oxygen from the iron oxides by the use of suitable reducing agents. The blast furnace process, in spite of the fact that it uses approximately a short ton of oxygen in the air blast per ton of pig iron produced, is still practically the only commercial method used for the reduction of iron ores. Chemically it is an indirect reduction effected by, first, oxidizing the carbon in the coke completely to CO_2, and then instantly reducing the CO_2 to 2CO and finally using about a third of that CO gas to reduce according to the simple formula

$$Fe_2O_3 + 3CO = 3CO_2 + Fe_2$$

and the balance of the CO gas goes out of the top of the furnace without having done any work of reduction at all.

As the student of ferrous metallurgy studies the phenomena of the iron blast furnace, he will see how it has been possible

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[1] Kinney, S. P. P., H. Royster, and T. L. Joseph, *Bur. Mines Tech. Paper* 391, 1927.

for a great many different, and sometimes contradictory, chemical equations and thermodynamical calculations to be used to explain the smelting process which transforms the solid oxide of iron and the solid carbon of the coke into metallic iron that melts and leaves the furnace as a liquid and into a mixture of carbon compounds that leaves the furnace as a gas.

Two good illustrations of the many steps in reduction of iron ores and the final formation of pig iron (see definition on page 1) are given in Figs. 73 and 74. Both these diagrams deal with straight iron-ore burdens; the author does not know of a similar chart showing the reactions when scrap is mixed in the burden, but the end results are practically the same, and pig iron, slag, and furnace gas are the products.

In Stout's diagram are the following reactions:

$$\mathrm{Fe_2O_3 + 3CO = 2Fe + 3CO_2} \tag{1}$$
$$\mathrm{2Fe_2O_3 + 8CO = 7CO_2 + 4Fe + C} \tag{2}$$
$$\mathrm{2Fe_2O_3 + CO = 2FeO + CO_2 + Fe_2O_3} \tag{3}$$
$$\mathrm{Fe_2O_3 + 3C = 2Fe + 3CO} \tag{4}$$
$$\mathrm{Fe_3O_4 + 4CO = 3Fe + 4CO_2} \tag{5}$$
$$\mathrm{FeO + CO = Fe + CO_2} \tag{6}$$
$$\mathrm{Fe_3 + C = Fe_3C} \tag{7}$$

In the Carnegie diagram are the following reactions:

$$\mathrm{2Fe_2O_3 + 8CO = 4Fe + C + 7CO_2} \tag{1}$$
$$\mathrm{3Fe_2O_3} + \left\{\begin{matrix}\mathrm{C}\\ \mathrm{CO}\end{matrix}\right. = \mathrm{2Fe_3O_4} + \left\{\begin{matrix}\mathrm{CO}\\ \mathrm{CO_2}\end{matrix}\right. \tag{2}$$
$$\mathrm{Fe_3O_4} + \left\{\begin{matrix}\mathrm{C}\\ \mathrm{CO}\end{matrix}\right. = \mathrm{3FeO} + \left\{\begin{matrix}\mathrm{CO}\\ \mathrm{CO_2}\end{matrix}\right. \tag{3}$$
$$\mathrm{FeO} + \left\{\begin{matrix}\mathrm{C}\\ \mathrm{CO}\end{matrix}\right. = \mathrm{Fe} + \left\{\begin{matrix}\mathrm{CO}\\ \mathrm{CO_2}\end{matrix}\right. \tag{4}$$
$$\mathrm{3FeO + CO_2 = Fe_3O_4 + CO} \tag{5}$$
$$\mathrm{Fe + CO_2 = FeO + CO} \tag{6}$$
$$\mathrm{Fe_3O_4 + C = 3FeO + CO} \tag{7}$$
$$\mathrm{FeO + C = Fe + CO} \tag{8}$$
$$\mathrm{SiO_2 + 2C + Fe = FeSi + 2CO} \tag{9}$$

The first man to investigate and to explain the phenomena of the reduction of iron ores in the blast furnace was Sir Isaac Lowthian Bell, who based his theories and formulas on his extensive observations of the operations of his blast furnaces at Clarence Works, England, smelting the Cleveland calcined ironstone with a yield of about 41 per cent pig iron. His observations and conclusions were published, in his book *Chemical Phenomena of*

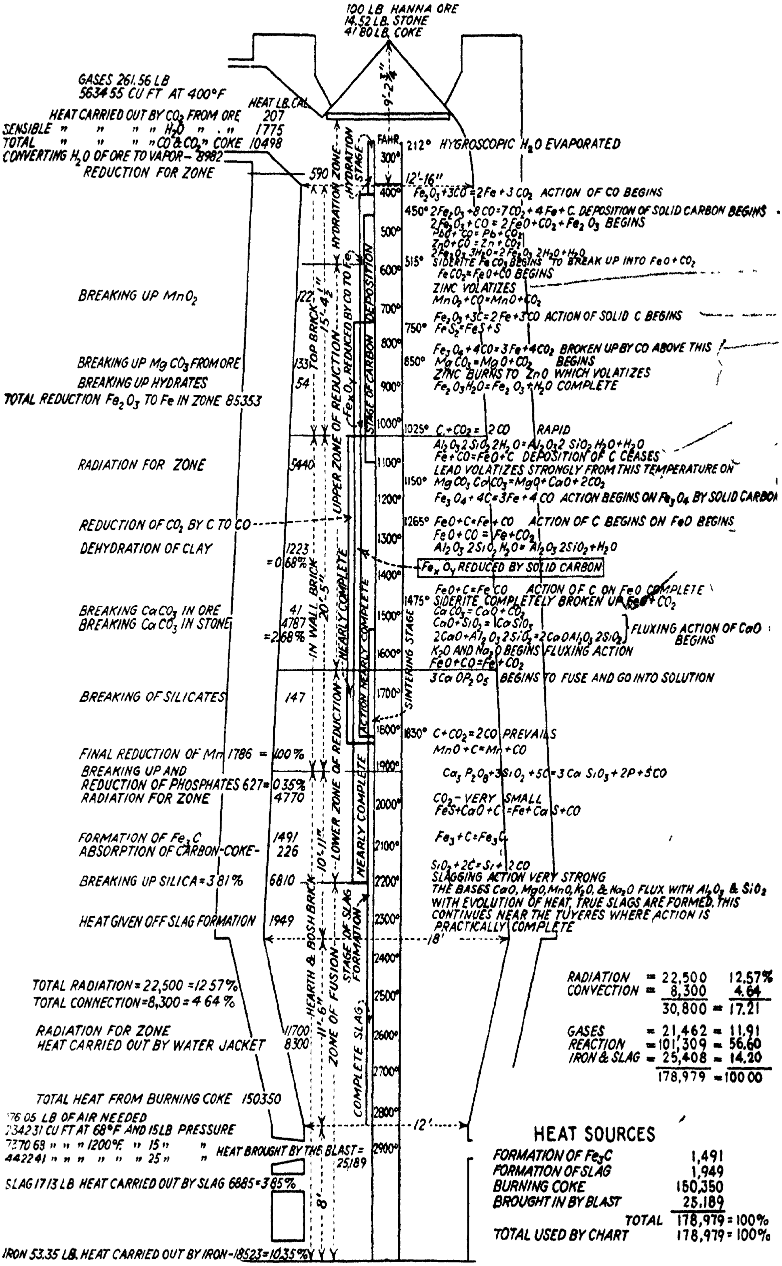

FIG. 73.—Graphic reactions of the iron blast furnace. (*Courtesy of Wilber Stout.*)

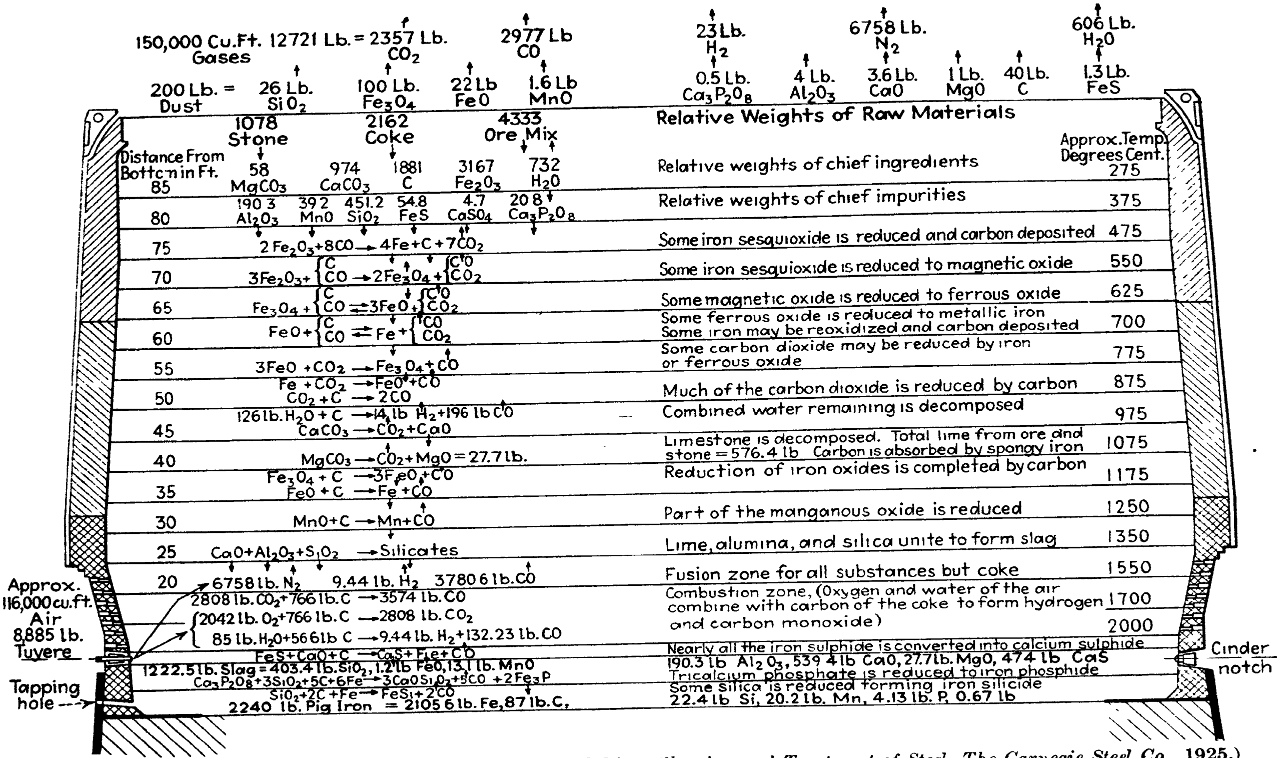

FIG. 74.—The making of a ton of pig iron. (*From The Making, Shaping and Treatment of Steel, The Carnegie Steel Co.*, 1925.)

Iron Smelting (1872), which remained the standard textbook for the fundamentals of blast furnace practice for many years. Bell concluded that the limit of economical reduction of iron oxide was reached when the ratio of CO to CO_2 in the waste gases was 2:1. This conclusion was based on the equation

$$Fe_2O_3 + 9CO = Fe_2 + 3CO_2 + 6CO$$

in which the CO is twice the CO_2. He figured that "any more complete oxidation of the carbon would result in the carbon dioxide formed oxidizing the reduced iron to FeO."[1]

For many years blast furnacemen in England and the United States thought they were doing good work when their ratio of carbon monoxide to carbon dioxide, the waste gas, was 2:1 and began to doubt their analysis if it fell below that ratio. In this country the ratio has been as low as 1.4.[2] This shows how a false theory may retard progress. Joseph now says that "blast furnaces are most efficient thermally when the CO_2 in the top gas is highest."[3]

All the above chemical equations are probably right, and probably they are all taking place in some part of the furnace at the same time. Samples of the gases, solids, and liquids removed from the different levels of a blast furnace in operation give proof of the strange conglomeration of chemical and physical conditions existing in the different zones of the blast furnace at the same instant; nothing is complete, nothing is static; everything is in action and in seeming confusion; if anything ceases to move inside the furnace, it becomes a source of trouble. Even at the tuyere level, the iron is not in its final condition, though practically every bit of iron oxide has been reduced to metal by the time it reaches the tuyeres, but the composition of the iron is not completed with respect to its contents of carbon, silicon, sulphur, manganese, and phosphorus.

Not all the iron oxide is reduced by carbon monoxide gas; some of it is reduced by solid carbon according to equation (4) of Stout's diagram, or according to the formula[4]

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[1] Sillars, Daniel, February, 1925, West of Scotland Iron & Steel Institute.

[2] Ramsay, G. D., *Trans. A.I.M.E.*, vol. 120, 1936.

[3] *Trans. A.I.M.E.*, vol. 120, p. 72, 1936.

[4] Morfit, C. C., and Ralph H. Sweetser, U. S. Patent 2121160, issued June 21, 1938.

$$2Fe_3O_4 + 4C = 6Fe + 4CO_2$$

Not all the carbon of the coke is burned to carbon monoxide at the tuyeres (perhaps 80 to 85 per cent), but some of it is consumed in the direct reduction of iron oxide as shown above and some of it is "dissolved" by carbon dioxide gas in the top of the furnace according to the equation

$$C + CO_2 = 2CO$$

Reduction Influenced by Size.—It takes time and the right temperature for the reduction of iron oxides by the action of carbon monoxide gas in the blast furnace. Blast furnacemen have known that the reducibility of iron ores varied greatly, and that the soft "local" ores (limonites) would "melt like butter" in the furnace, and that other ores, like raw magnetites and lumpy, dense hematites, would "chill" the furnace and require slow driving. The problems of reducibility and the sizing of iron ores were studied by T. L. Joseph, then supervising engineer, U. S. Bureau of Mines, and the results published in the 1936 Iron & Steel volume.[1] His aim was quantitative information that could be applied by furnace operators "in determining the size to which dense ores should be crushed to permit more complete reduction in the upper part of the furnace where low temperatures retard conversion of CO_2 to CO."

A wide variety of iron ores, 43 of them, were selected and analyzed chemically and physically as to contents of iron magnesia, silica, alumina, and loss on ignition; and as to weight of a cube, approximating $\frac{9}{16}$ in., volume in cubic centimeters, apparent density, true density, and porosity. These specimens were reduced in a stream of hydrogen at 800°C. after determining the porosity. Parts of Joseph's paper are herewith quoted:

> **Blast Furnace Conditions Cannot Be Duplicated in the Laboratory.**—However, relative rates of reduction can be determined more accurately by laboratory tests with hydrogen than with CO or mixtures of CO and nitrogen. As will be shown later, reducibility is closely related to the porosity of the ore. Actual rates determined by reduction with hydrogen would differ from those determined with CO, but the order of reducibility, which is all that can be readily established from a laboratory test, would be about the same.

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[1] "Porosity, Reducibility and Size Preparation of Iron Ores," *Trans. A.I.M.E.*, vol. 120.

The percentage of total water formed at 10-min. intervals was determined for 110 specimens prepared from 33 ores.

To express reducibility by a single numerical value, the time required for 90 per cent reduction was taken as an index of reducibility. This degree of reduction was selected rather than 100 per cent because in some cases the rate of reduction decreased sharply beyond about 90 per cent reduction. There was considerable uncertainty as to the exact moment for 100 per cent reduction, but by plotting the degree of reduction against time, the time for 90 per cent reduction shown by the vertical lines was established within ½ min. . . .

The present study shows the importance of porosity in reduction. It is intended primarily however for use in connection with hard, dense, coarse ores. To establish the relative reducibility of fine ore from the standpoint of its use in a blast furnace would involve consideration of its screen analysis and difficulties inherent in maintaining a uniformly permeable bed or column of stock.

With certain Lake Superior ores, particularly with the Alabama, Wyoming, New Mexico and Utah ores, it is difficult to determine how fine the ore should be crushed to permit reduction of the central area of coarse lumps. The present study was projected primarily to furnish information on this problem. . . .

POROSITY AND SIZE OF ORE LUMPS FOR BLAST-FURNACE USE

If large lumps of hard, dense ores are charged into blast furnaces, they will reach the top of the bosh and the fusion zone with unreduced centers. The size of such ores should be reduced according to the porosity, which has been shown to bear a direct relation to the time required for reduction. Finer crushing has improved furnace practice on Alabama ores and Utah ores. Some criteria for determining the size to which an ore should be crushed should stimulate further progress in this direction.

The size to which ores should be crushed can also be determined from the relation between porosity and reducibility expressed as the reciprocal of the time required for 90 per cent reduction.

RELATION BETWEEN POROSITY AND RELATIVE REDUCIBILITY OF IRON ORES

The reduction of iron oxides by CO or hydrogen is a heterogeneous reaction between a gas phase and a solid phase. Such reactions proceed at rates proportional to the solid surface exposed when other factors are constant. Fine ores present a large surface, but mechanical difficulties limit the quantity of reducing gases that can be applied to the surface of fine particles in the blast-furnace and similar processes that involve a *countercurrent circulation of gases and solids. The relative reducibility* of fine ore is not important. Such material should be converted in a porous agglomerate for effective mass reduction. The Bureau of Mines, accordingly, has recommended sintering or other methods of agglomeration for preparing fine ores for use in the blast furnace.[1] Sintering of fines and segregation of plus 3/8-in. particles into several sizes provide conditions favorable to mass reduction.

Joseph's article gives tables and graphs for determining the reducibility and the size to which ores should be crushed to get the best results. These tables are being put into practical use, especially in the smelting of the red ores of Alabama. Already it has been found profitable to crush the ores finer and to screen out the minus 3/8-in. ore and sinter it.

In the application of the above data, the character of the ore, particularly the way it breaks on crushing, should be considered. Laminated ores that tend to break in flat, elongated pieces would not require such fine crushing as ores that tend to break into pieces more spherical in shape. Such ore should be crushed according to its width. The amount of fines produced and the tendency of the ore to break up under mechanical action should also be considered. Operators using coarse ores or burdens containing substantial amounts of coarse ores can obtain satisfactory indications from porosity measurements as to whether or not particular ores should be crushed finer and, if so, how much finer. Crockard recently reported that crushing hard Alabama ores to 1 in. has greatly improved practice.[2] He also stated that by crushing the ore to 3/4 in. it is possible to use as much as 25 per cent of an ore that is difficult to reduce and contains more silica than lime. The high-lime Alabama ores, according to practice, are easier to reduce than those containing more silica than lime. This difference was not shown by the laboratory tests and is attributed to the retarding action of the lime in the formation of iron silicate under actual furnace conditions. These practical results, reported by Crockard, justify the position of the low part of the curve in Fig. 75, which indicates that ores approaching zero porosity should be crushed as small as 0.75 in.

REDUCIBILITY OF ALTERED AND UNALTERED MAGNETITES

As eastern magnetites are largely concentrated and sintered, the reducibility of the crude ore assumes less importance. Preliminary reduction tests on crude, unaltered magnetite indicated slow reduction

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[1] FURNAS, C. C., and T. L. JOSEPH, "Stock Distribution and Gas-solid Contact in the Blast Furnace," *U. S. Bur. Mines Tech. Paper* 476, 1930.

[2] CROCKARD, F. H., "Five Years of Progress in Southern Merchant Iron, Production," *Trans. A.I.M.E.*, vol. 120.

rates, 380 min. being required for 90 per cent reduction compared to 40 min. on Desert Mound ore from Utah. According to Ramsay,[1] the iron in the Utah ore is principally hematite but contains 12 to 20 per cent of magnetite. It seems therefore that weathered or altered magnetites reduce much more rapidly than the unaltered type in New York and New Jersey.

The conclusions drawn from the tests of Joseph as described in the above paper corroborate the practical experience of furnacemen in the smelting of hard iron ores, especially the magnetites. Big lumps of ore mixed with fines cut down production and increase the coke consumption. Again we see how delicately balanced is the operation of a modern blast furnace, huge as it is.

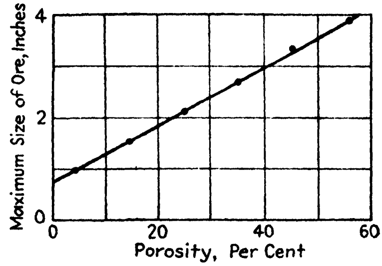

FIG. 75.—Relation between porosity of iron ore and maximum size for blast furnace use. (*From Joseph, Trans. A I.M.E., vol.* 120.)

Bosh Gas ($CO + N_2$).—Bosh gas is that hot mixture of carbon monoxide gas, nitrogen, and small amounts of hydrogen and traces of oxygen that exists inside the bosh of the blast furnace from the level just above the tuyeres up to the level of the greatest diameter of the bosh of the furnace. This gas contains about 34 per cent carbon monoxide and about 66 per cent nitrogen. This gas is the product of the combustion of the coke and hot blast in the combustion zones at the tuyere level.

In the very illuminating technical paper[2] by Kinney, Royster, and Joseph, entitled "Iron Blast Furnace Reactions," there is a summary of the gas analyses from plane 4 (see Fig. 76) which in the Holt furnace (Central Iron & Coal Company's furnace at Holt, Ala.) was 19 ft. 6 in. above the tuyere level. This summary of analyses is graphically shown in Fig. 77, and the text says that "the CO content of the gas is about that of bosh gas—34 per cent CO and 60 per cent N_2." It is evident, however, that there will be some variations in the complete analysis of the bosh gas, not only from furnace to furnace, but also from hour to hour in the same furnace, owing to the slight variations in the

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[1] RAMSAY, G. D., "Sintering Adds Greatly to Efficiency of Ironton (Utah) Plant, Columbia Steel Co.," *Min. & Met.*, September, 1935.

[2] *Bur. Mines Tech. Paper* 391, 1927.

amount of water vapor in the hot blast and to differences in the amounts of reactions of cyanogen and variations in the reduction of oxides of iron, manganese, and other metals at the tuyere level. The evidence of the reported observations points to the fact that the gas in this region of the furnace is chiefly nitrogen and carbon monoxide.

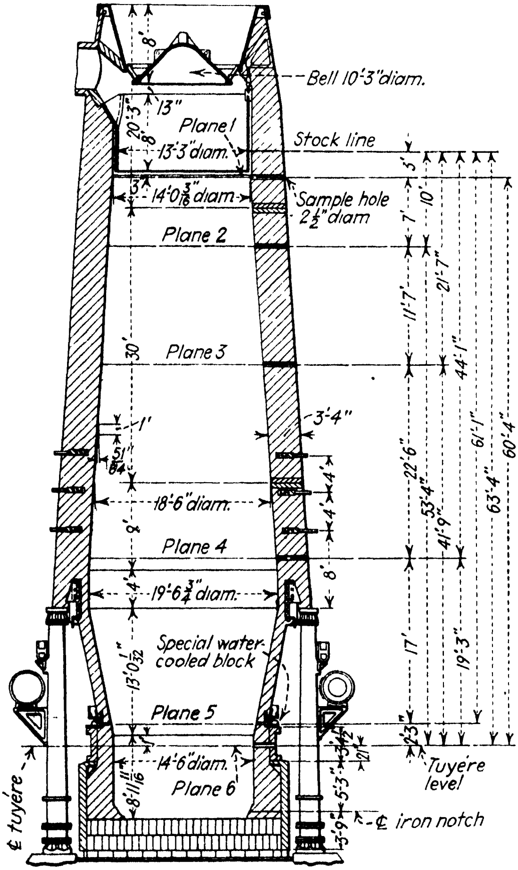

Fig. 76.—Section of Holt furnace showing holes for sampling. (*From Bur Mines Tech. Paper* 391.)

As to the functions of the nitrogen, outside of being the main carrier of the heat that is generated at the tuyere level, there has been much discussion but no clear proof of what takes place within the interior of the furnace between the tuyere level and the level of the top of the bosh. In some furnaces which the author has personally explored, there is a sort of core in which there is a zone of greatly reduced movement of the solid materials and gases. Just what effect this will have on the analysis of the gases in the center column of ascending hot gases from the tuyere level upward is not known. In the section on Combustion Zones are some figures showing the relative temperatures at the tuyere level from the nose of the tuyere into the very center of the furnace. This simple rod test shows that it is misleading to take temperature tests at the tuyeres with an optical pyrometer.

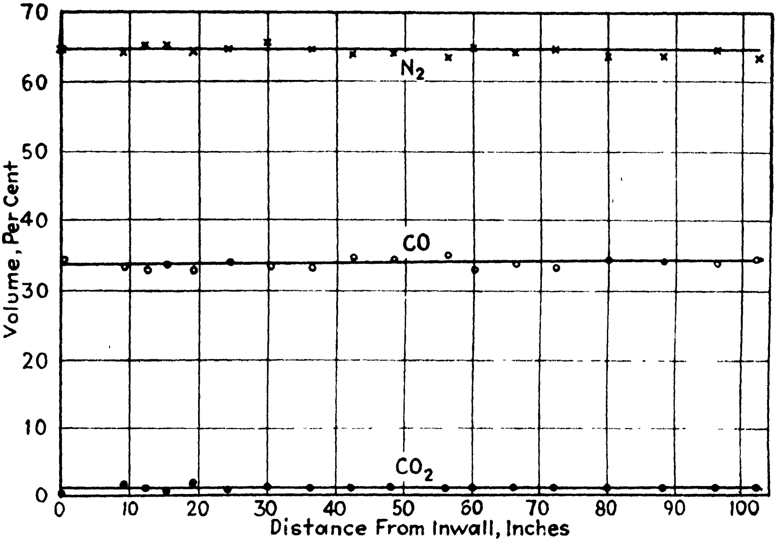

FIG. 77.—Summary curves of gas analyses—plane 4. (*From Bur. Mines Tech. Paper* 391.)

Just what is the temperature of bosh gas—this mixture of nitrogen and carbon monoxide—at any particular time in any particular furnace is not definitely known. In Fig. 74, from the "Carnegie Handbook," the temperature goes from 3600°F. at the tuyeres to 2462°F. at the bosh line. Stout, in Fig. 73, shows 2900°F. at the tuyeres and 2450°F. at the bosh line. Kinney reports 2804°F. at the tuyeres and 1661°F. at plane 4, about 5 ft. above the bosh line and at the center of the plane. We know, however, that the temperature of the bosh gas must be at least as high as the "critical temperature" of the hearth, as was enunciated by that blast furnace genius, the late J. E. Johnson, Jr., in his paper "The Physical Action of the Blast Furnace."[1] Johnson said, in that classic paper, in part,

> It may be said without reservation that for every set of furnace-conditions there is a certain critical temperature, *above which only*, certain necessary operations of the process can be carried out. It is not necessary to know what the operations are, and no attempt will be made to enumerate them here, further than to say that they probably comprise the removal of the final traces of oxygen from the ore, the formation and subsequent superheating of the cinder, and the melting, carbonization and superheating of the iron,—"superheating" being used in the sense of heating above the point of fusion.

Proceeding with this lucid explanation of what takes place within the hearth of a blast furnace, Johnson said further:

> It is obvious that the nearer the critical temperature is to the theoretical temperature of combustion, the smaller will be the quantity of such available heat. If the critical temperature is, say, four-fifths of the theoretical combustion-temperature, then the available heat is only one-fifth of the total; and while the other four-fifths are useful for other purposes, they are lost for those under consideration.
>
> The critical temperature varies in the same furnace with varying conditions, but for certain conditions it was determined to be about 2750° F., as a probable average, and results obtained from calculations made on this basis were in such close agreement with actual results, that the series was extended to cover other conditions.

In the author's own observations of the temperature of iron and slag as they ran from the iron notch and cinder notch, the temperature of the liquids leaving the bottom part of the hearth of a furnace making basic iron for the steel plant varied from 2450 to 2758°F., sometimes varying as much as 150°F. in the same cast.[2] In his paper[3] "Oxides in Basic Pig Iron and in Basic Open-Hearth Steel," Joseph found that most of the casts of basic iron had temperatures averaging between 2560 and 2660°F. In view of all these observations, it seems reasonable to assume that the bosh gas, by the time it is thoroughly mixed in the proportion of about 66 per cent nitrogen and 34 per cent

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[1] *Trans. A.I.M.E.*, vol. 36, p. 472, 1906:

[2] "Carbon in Pig Iron," *A.I.M.E. Tech. Paper* 11, 1927.

[3] *Trans. A.I.M.E.*, vol. 125, 1937.

carbon monoxide and starts on its work of heat exchange and reduction, has a temperature of about 2750°F. F. W. Davis[1] uses a temperature of 2800°F. for the bosh gas as it leaves the hearth.

Just as it is the *weight* of oxygen in the hot blast entering the tuyeres that counts in the combustion of the fuel, just so it is the *weight* of the carbon monoxide in the bosh gas that counts in the reduction of the iron oxides in the upper part of the furnace. There is, however, this great difference between the two gases—whereas all the oxygen of the air blast is consumed in the combustion zones, only a comparatively small part of the carbon monoxide gas in the bosh gas is consumed in the reduction of iron oxides in the upper part of the furnace, and all the rest passes out of the top of the furnace in the waste gases.

In Fig. 74 in the section on Reduction of Iron Ores, it will be seen that 1,562 lb. of carbon united with 2,042 lb. of oxygen to produce 3,574 lb. of carbon monoxide; there were other reactions in the hearth that added 206.6 lb. more of carbon monoxide, so that the total carbon monoxide going up in the bosh gas was 3,780.6 lb. per ton of pig iron. In addition to the 1,532 lb. of coke that reached the tuyeres to form carbon monoxide gas, there was also 349 lb. of carbon that entered into reactions above the bosh of the furnace in that multitude of reactions previously mentioned. The net result in the weight of carbon monoxide gas passing out of the top of the furnace was 2,977 lb. of carbon monoxide, which does not seem to be a very efficient use of the combustion of carbon at the tuyeres. Only 1,585 lb. of carbon monoxide gas was required to reduce the 3,167 lb. of ferric oxide.

Nitrogen in Bosh Gas.—The nitrogen in the bosh gas is 1 8 more by weight than the carbon monoxide and consequently, carries more heat out of each zone into the next zone and finally out of the top of the furnace than does the carbon monoxide, in the ratio of 1.8:1.0. Moreover, there is apparently no chemical reaction with the nitrogen whereas there is actually the combustion of carbon monoxide gas to carbon dioxide when the oxygen of the ferric oxide unites with the CO of the bosh gas. This is an exothermic reaction and completes the total combustion of the carbon that was formed into carbon monoxide at

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[1] In *Mining and Metallurgy*, July, 1935.

the tuyeres by the breaking up of carbon dioxide when in contact with incandescent coke in the combustion zone.

HEAT BALANCE

The heat balance of a blast furnace is a balance sheet showing the input of units of heat and the outgo of those same units. Usually the values are expressed in B.t.u. per ton of pig iron produced. It shows in detail the source of all the units of heat introduced into and generated inside the blast furnace, which calls for a keen knowledge of thermodynamics and an intimate familiarity with blast furnace operations.

In addition to "those same units" of heat mentioned above and put into the furnace by hot blast and combustion of the fuel, there are many units of heat "generated inside the blast furnace" by the combustion of the carbon monoxide gas and the oxygen of the iron ores. There is also the heat generated by the combustion of carbon and carbon monoxide and the oxygen of metalloids. The net results for any one furnace are constantly changing as is observed in the rapid changes in the temperature of the molten iron and slag as they leave the hearth of the furnace and in the changes of temperature and composition of the waste gases as they leave the top of the furnace.

Only those who have made tests on blast furnaces while in normal operation can appreciate the countless variations that must be taken into consideration when gathering data for calculating the heat balance of a blast furnace. For instance, the heat balance shown on page 56 of "Iron Blast-Furnace Reactions,"[1] by Kinney, Royster, and Joseph, was constructed from operating data gathered (according to the tables published) from Oct. 13, to Feb. 16 of the following year, and "the balance sheet of materials covers a 10-day period of operation." The author was told by an engineer who has the patience and the ability to work out thermodynamic problems that it takes 200 hr. of close application to calculate every detail of the heat balance, balance sheet of materials and distribution of heat in a modern blast furnace. "The blast-furnace problem is principally a thermal problem, and must be faced as such . . . the governing factor in fuel economy is not, in the main, chemical, but depends upon the thermal side of blast furnace work. Generally speaking, the

[1] *Bur. Mines Tech. Paper* 391, 1927.

necessity for thermal effects requires the combustion of fuel beyond any limitations prescribed by chemical considerations."[1]

The truth of this statement is clearly proved by the results obtained by crushing and sizing the raw materials put into a blast furnace. All raw materials must be brought to the temperature of each succeeding zone of the furnace before entering it, or else there will be irregularities of temperature and chemical reactions across the planes of each zone. So far, in actual blast furnace practice, it has been physically impossible to do this, but the nearer we approach to it, the lower is the coke consumption and the more economical is the whole blast furnace operation.

TABLE IV.—HEAT BALANCE

	B.t.u. per ton metal	Percentage
Heat produced:		
1. Combustion of C to CO	7,371,759	51 0
2. Combustion of C to CO_2	4,784,637	33 1
3. Heat in blast (including moisture)	2,316,539	15 9
Total	14,472,935	100 0
Heat consumed:		
1. Reduction of iron oxides	5,577,086	38 4
2. Reduction of MnO, P_2O_5, and SiO_2	825,832	5 7
3. Calcination of carbonates	1,176,470	8 1
4. Dissociation of moisture	1,030,464	7 2
5. Carried off with the iron	1,086,400	7 5
6. Carried off with the slag	1,500,632	10.4
7. Carried off with gases (dry)	1,083,650	7 5
8. Carried off with moisture in top gas	651,819	4 5
Total heat accounted for	12,932,353	89.3
Heat unaccounted for	1,540,582	10.7

In Fig. 73, in the section on Reduction of Iron Ores, Stout gives briefly the heat sources and the heat distribution in the smelting of a Mesaba iron ore that had just the right analysis for making the kind of pig iron desired, but in practice other ores were used in the mixture. The coke was Pocahontas beehive, the stone was Columbus limestone. The unit used in the chart

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[1] H. E. Wright, before Iron and Steel Institute (Great Britain), May, 1920.

was 100 lb. of Hanna ore. The temperatures are Fahrenheit, the weights in pounds.

Heat sources	Heat, lb cal
Formation of Fe_3C	1,491
Formation of slag	1,949
Burning coke	150,350
Brought in by blast	25,189
Total	178,979
Total used by chart	178,979

TABLE V.—MISCELLANEOUS OPERATING DATA[1]

Temperature of:

	°F.	°C
Blast	957	513.8
Top	335	168.2
Metal	2,525	1,385.0
Slag	2,568	1,409.0
Tuyere	2,793	1,534.0
Air at blowing engine, dry bulb	65	18.3
Air at blowing engine, wet bulb	56.5	13.6

Relative humidity, per cent	55
Moisture in air, grains per cubic foot	3.73
Barometer	29.64
Pressures (lb. per square inch):	
Blast	16.85
Steam	88.9
Blowing engine:	
Revolutions per minute	101.5
Air blown, calculated from engine speed, dry, cubic feet per minute at 65°F., and 30 in. of mercury	41,660
Air blown, calculated from carbon consumption and gas analysis—	
Dry, cubic feet per minute at 55°F and 30 in. of mercury	28,691
Wet, containing 3.73 grains of water per cubic foot	29,012
Coke:	
Shatter test, per cent[2]	69
True specific gravity	2.00
Apparent specific gravity	0.99
Furnace data:	
Volume of furnace, cubic feet	15,385
Number of tuyeres	12
Size of tuyeres, inches	6 by 12
Charges per day	71.4
Iron made, tons per day	324.7

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[1] Average values covering period represented by balance sheet of materials

[2] Percentage of coke remaining on a 2-inch square-mesh screen after 50-pound sample had been dropped four times from a height of 6 feet upon a steel plate

TABLE VI.—ANALYSES OF RAW MATERIAL, PER CENT[1]

Constituent	Brown ore	Attalla red ore	Estelle red ore	Nodules[2]	Limestone[3]	Coke[4]
H_2O	13 98	1 30	3 88	9 45	0 10	5 40
SiO_2	14.10	10.05	7.74	10 80	1 00	6 76
Al_2O_3	5 70	3 20	4 83	4 20	.60	4 10
Fe_2O_3	61 70	56 10	43 25	53 09	1 00	1 21
FeO	00	00	00	20.61	00	00
MnO	1 02	18	14	08	03	00
P_2O_5	1 56	42	21	07	01	04
CaO	22	14 80	20 91	.60	30 22	.27
MgO	.22	30	90	10	21 21	.16
K_2O	30	80	60	30	00	17
Na_2O	30	.30	50	20	00	.06
S	10	00	10	.30	10	1 02
CO_2	.80	12 10	16 93	20	45 73	00
Fixed carbon				. . .		80 35
Volatile matter		.	.			46
Total	100 00	100 00	100 00	100 00	100 00	100.00

[1] Analysis as reported by Bureau of Mines

[2] Nodules made from pyrite sinter

[3] Dolomite

[4] Coke made in Semet-Solvay ovens from washed coal Coal mined from Brookwood and Milldale beds, Kellerman, Ala

TABLE VII.—COMPOSITION OF MATERIALS CHARGED, POUNDS PER LONG TON OF METAL PRODUCED

Constituent	Scrap	Brown ore	Attalla ore	Estelle ore	Nodules	Limestone	Coke	Air	Total	Per cent
H_2O		296 01	8 52	16 98	94 74	1 22	141 65	67 92	627 04	3 47
SiO_2		298 99	68 68	33 85	108 05	12 51	177 76		699 84	3 86
Al_2O_3		121 23	20 85	21 09	42 00	7 54	107 68	. .	320 39	1 77
Fe	328 98	910 72	255 97	131 90	531 48	8 71	22 20		2,189 96	12 09
O_2		395 63	110 56	57 70	206 10	3 80	9 57	2,224 02	3,007 38	16 62
CaO		4 66	96 58	91 61	6 01	379 47	7 05		585 38	3 23
MgO		4 23	1 96	3 92	98	264 29	4 23	.	279 61	1 54
P_2O_5		33 03	2 70	92	74	.12	1 10		38 61	21
MnO		21 58	1 23	61	80	.37	00		24 50	14
K_2O		6 35	54	2 61	3 03	00	4 59		17 12	09
Na_2O	.	6 34	20	2 23	2 00	00	1 48	.	12 25	05
S	.	2 15	00	43	3 00	1 22	26 80		33 60	19
CO_2		16 92	79 10	74 07	2 02	573 86	00	.	745 97	4 12
C							2,110 66		2,110 66	11 65
H_2							12 08		12 08	06
N_2								7,403 86	7,403 86	40 89
Total	328 98	2,117 84	646 89	437 92	1,000 95	1,253 11	2,626 85	9,695 80	18,108 34	
Per cent	1 82	11 69	3 57	2 43	5 53	6 92	14 50	53 54	.	100.00

The heat balance constructed by Kinney, Royster, and Joseph, mentioned on page 170, is shown in Table IV.

A part of the minute details of the data necessary for constructing such a heat balance is shown in Tables V–X (beginning on page 172), from the U. S. Bureau of Mines.[1]

Calculation of Heat Balance.—Referring again to the section on Reduction of Iron Ores, and this time to Fig. 74, showing blast furnace reactions according to the "Carnegie Handbook," we have the basis for the heat balance of that furnace as calculated by Theodore Nagel (see Table XI).[2]

The exothermic reaction of the reduction of ferric oxide by carbon monoxide is slightly greater than the endothermic reaction of breaking up the ferric oxide, as is shown in sections III and IV of the heat requirements according to Nagel's balance sheet (pages 178*ff.*)

HEAT DISTRIBUTION

The distribution of heat in a blast furnace is so much a part of the heat and material balance sheet that the two go together like the two sides of a ledger. In talking with engineers who can make the calculations of a heat balance the author has found that if the balance does not come out right the first time, the chemical reactions must be readjusted and the heat required must be recalculated. For instance, in the U. S. Bureau of Mines heat balance shown in the previous section, there is an item of "Heat unaccounted for" amounting to 10.7 per cent of the total amount of heat produced. This amount of uncertain demand for heat is not surprising when all the numerous fluctuations are considered; the surprising thing about it all is the fact that blast furnace operators are able to get such uniform results of desired analysis as are obtained in modern practice, in spite of the uncertainty as to the actual conditions inside much of the interior of a blast furnace.

An experienced blast furnaceman can tell by the looks of his slag, his tuyeres, his iron as it runs out of the furnace and his gas as it burns whether or not enough heat is being generated in the hearth to meet properly the requirements of heat distri-

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[1] *Bur. Mines Tech. Paper* 391, Tables 3–8.

[2] NAGEL, THEODORE, "Blast Furnace Air-blast Beneficiation," *A.I.M.E*, manuscript mimeographed, 1935.

bution. Any lack of heat must be supplied by some adjustment of the hot blast or volume of blast or by a change in the burden; if the lack of heat is due to a water leak then the leak must be located and stopped.

The principles of the distribution of heat in a blast furnace—so much for chemical reactions, so much for the molten iron and slag, so much going out of the top of the furnace in waste gas and flue dust, and so much for radiation and cooling losses—may be the same in all cases, but the amounts and the percentages for each item vary greatly in different parts of the world according to the raw materials and the practice used. It is difficult to make clear comparisons of the balance sheets of different authors, partly because their observations and data are chosen from different furnaces working under different conditions, and partly because the authors choose different units for their calculations. For instance, Stout uses 100 lb. of ore in his "graphic reactions of the iron blast furnace" (Fig. 73); Clements bases his calcula-

TABLE VIII.—COMPOSITION OF MATERIALS DISCHARGED, POUNDS PER LONG TON OF METAL PRODUCED

Constituent	Flue dust	Metal	Slag	Gas	Water	Total	Per cent
H_2O					559.12	559.12	3.09
SiO_2	34.48		569.26			603.74	3.33
Al_2O_3	18.70		301.69			320.39	1.77
Fe	92.47	2,084.25	13.24			2,189.96	12.10
O_2	39.67		1.89			41.56	.23
CaO	13.67		571.71			585.38	3.23
MgO	4.17		275.44			279.61	1.54
P_2O_5	.92		6.79			7.71	.04
MnO	1.29		2.44			3.73	.02
K_2O	5.62		11.50			20.83	.11
Na_2O	4.19		8.06			8.54	.05
S	8.16	.99	24.45			33.60	.19
CO_2	13.37			1,952.30		1,965.67	10.86
C	40.35	80.06				120.41	.66
Si		45.02				45.02	.25
Mn		16.17				16.17	.09
P		13.51				13.51	.076
H_2				19.88		19.88	.11
N_2				7,403.86		7,403.86	40.89
CO				3,868.85		3,868.85	21.37
Volatile matter	.80			.	. .	.80	.004
Total	277.86	2,240.00	1,786.47	13,244.89	559.12	18,108.34	. .
Per cent	1.53	12.37	9.86	73.15	3.09		100.00

tions on "20 pounds pig iron produced, sheet IV" (Table XIII); Kinney, Royster, and Joseph based their calculations on 1 ton of metal produced; Shadgen uses 100 lb. of pig iron as the basis of his calculations.

TABLE IX.—CALCULATED ANALYSES OF MATERIALS DISCHARGED, PER CENT

Constituent	Flue dust	Metal	Slag	Gas, per cent by weight	Gas, per cent by volume
SiO_2	12.41		31.86		
Al_2O_3	6.72		16.88		
Fe	33.30	93.021	74		
O_2	14.30		11		
CaO	4.93		32.01		
MgO	1.50		15.42		
P_2O_5	33		38		
MnO	45		14		
K_2O	2.02		64		
Na_2O	1.51		45		
S	2.94	044	1.37		
CO_2	4.81			14.75	9.73
C	14.49	3.60			
Si		2.01			
Mn		722			
P		603			
H_2				15	2.16
N_2				56.00	57.90
CO				29.15	30.30
Volatile matter	.29				
Total	100.00	100.00	100.00	100.00	100.00

It is the author's opinion that no one yet knows just what takes place inside the iron blast furnace; we know what goes in at the top and at the bottom and what comes out at the top and at the bottom, and, vaguely, what radiates into the air and what goes off with cooling water between the top and the bottom of the blast furnace. But we know positively that the temperature of the iron and slag flowing from the furnace is never constant, neither is the temperature of the top gases the same for long; and we know that the composition of the gases, the iron, and the slag is never constant; we must strike averages of all these changing conditions.

In *The Iron Age* of July 5, 1934 (page 31), are "Graphical Balances Applied to Blast Furnace Operation," by Joseph F. Shadgen, which were based on the "actual performance data of a Midwestern blast furnace, making a standard basic pig iron out of Lake Superior ores, Michigan limestone of unusual purity and by-product coke." The illustrations of this article present graphically the input and outgo of heat and materials in a clear manner and are herewith reproduced. "Figure 145 [78] shows the heat balance in form of a rectangle in which the heat input is shown to equal the heat outgo . . . the sensible heat items are relatively small (some 13 per cent) and the reaction of the reduction process itself accounts for about 24 per cent or one-

TABLE X.—ACTUAL ANALYSES OF MATERIALS DISCHARGED, PER CENT

Constituent	Flue dust	Metal	Slag	Gas, by volume
SiO_2	12.9		32.15	
Al_2O_3	7.1		16.23	
Fe	34.2	93.021	[1] 28	
O_2	14.8		13	
CaO	5.2		32.29	
MgO	1.6		15.88	
P_2O_5	35		33	
MnO	49		21	
K_2O	[2]1.20		64	
Na_2O	1.43		45	
S	[3] 30	044	1.41	
CO_2	5.06	....	....	9.78
C	15.07	3.60		
Si		2.01		
Mn		722		
P		.603		
H_2	30			2.17
N_2		......		58.01
CO				30.04
Volatile matter				
Total	100.00	100.00	100.00	100.00

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[1] Analysis of slag made after removal of iron shot. Including shot, the slag contained 0.74 per cent Fe; 0.46 per cent of this was in the metallic form in shot, which is equal to approximately 82 pounds of iron per ton of metal.

[2] 2.29 pounds of K_2O and 0.23 pound of Na_2O carried to stoves and boilers; actual analysis flue dust therefore lower than calculated analysis.

[3] Approximately 25 per cent of sulphur charged was volatilized, therefore not shown in actual analysis.

TABLE XI

Oxygen from $Fe_2O_3 + CO$ = 6,922,000 B.t.u.
Fe_2O_3 to 2106 lb. Fe = 6,505,000 B.t.u.
417,000 B.t.u.

HEAT BALANCE[1]

A. Furnace Burden per 2,240 Pounds Pig Iron

4,333 lbs. ore (3167# Fe_2O_3) 51.2% Fe
1,078 " limestone (475# CO_2) } 732 lbs. H_2O
2,162 " coke (1881# C) 87% C
8,885 " Air blast containing 85# H_2O (116,000 CF)
16,458 lbs.

Furnace Products

2,240 lbs. pig iron (2105.6# Fe, 87# C, 22.4# Si, 20.2# Mn, 4.13# P, 0.67# S)
1,223 " slag (404# SiO_2)
200 " dust (100# Fe_3O_4, 22# FeO, 26# SiO_2, 40# C, etc.)
12,788 " gases[2] (2745# CO_2, 2647# CO, 6767# N_2, 23# H_2) + 606# H_2O
16,451 lbs.

Oxygen in Blast, Reaction to CO in Bosh

Air 8800# × 0.231 = 2033#
H_2O 85# × $8/9$ = 76# 2109# O_2

Oxygen from Burden Entering into Reactions

Ore 2105.6# × $48/112$ = 905#
H_2O (732 − 606) × $8/9$ = 112#
SiO_2 to 22.4# Si = 25.6# O_2
MnO to 20.2# Mn = 5.9 O_2
P_2O_5 to 4.13# P = 5.5 O_2
37# 1054# O_2

Total oxygen for reactions 3163# O_2
Nitrogen 8800 × 0.769 6767# N_2
Hydrogen (732 − 606 ÷ 85)/9 23# H_2
Carbon for reactions 1881 − (40 + 87) 1754# C
2109# O_2 blast to 3691# CO in bosh— 1582# C
(C for CO_2 reversion to CO and O_2 from H_2O to CO) 172# C

112# O_2 + 84# C = 196# CO
332# CO_2 + 88# C = 410# CO
942# O_2 + 1650# CO = 2592# CO_2 (reduction of burden)
2592# CO_2 + 475# CO_2 − 322# CO_2 = 2745# CO_2 Top gas
3691# CO + 606# CO − 1650# CO = 2647# CO " "
(475# CO_2 from stone + 2270# CO_2 + 2647# CO) = 1754# C + 3163# O_2 +475# CO_2

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[1] Nagel, Theodore, "Blast Furnace Air-blast Beneficiation," *A.I.M.E.*, 1935.

[2] Analysis as per calculations below 154,700 CF 84 BTU/CF.

TABLE XI.—(*Continued*)

***B.* Heat Requirements and Heat Distribution per 2240 Lbs. Pig Iron**
(Gas volumes at 60°F. and 30" Hg)

I. Sensible heat taken from hearth at 2750°F.

Pig iron	2240# × 522	1,170,000 B.t.u.	
Slag	1223# × 833	1,020,000 "	−2,190,000 B.t.u

II. Sensible heat in top gas at 400°F.

H_2O	606#	× 1192	723,000 B.t.u.	
CO_2	2745	87	239,000 "	
CO	2647	97	257,000 "	
H_2	23	1365	31,400 "	
N_2	6767	97	656,000 "	
Dust	200	100	20,000 "	−1,926,000 "

III. Exothermic reactions of burden and bosh gas

Oxygen from ore 905# + 1585# CO = 2490# CO_2, 680# C (14140 − 3960)	6,922,000 B.t.u.	
Slag formation 404# SiO_2 × 666 =	267,000 "	
O_2 from H_2O, 112# O_2 + 84# C = 196# CO 84# C × 3960	333,000 "	+7,522,000 "

IV. Endothermic reactions of burden and bosh gas

Limestone calcined 1078# × 718	770,000 B.t.u.	
Fe_2O_3 to 2106# Fe × 3,089	6,505,000 "	
SiO_2 to 22.4# Si × 12,890	290,000 "	
MnO to 20.2# Mn × 3,925	80,000 "	
P_2O_5 to 4.13# P × 10,640	44,000 "	
Fe_3C 87# C × 690	60,000 "	
Fe_3Si 22.4# Si × 1220	27,000 "	
H_2O to 14# H_2 × 51,643	723,000 "	
Pig iron fusion 2106# Fe × 126	265,000 "	
Slag fusion 1223# × (945 − 833)	137,000 "	
88# C + 322# CO_2 to 410# CO 88 × 6220	547,000 "	−9,448,000 "

V. Shaft and hearth heat losses

Water cooling 800 gal. + 100°F. per 2240# Pig =	668,000 B.t.u.	
Radiation and Hearth conduction 250 B.t.u./# × 2240 =	560,000 B.t.u.	−1,228,000 "

VI. Net heat required by CO production in bosh gas

I, II, III, IV, V	+7,270,000 "

TABLE XI —(*Continued*)

C. VII. Net heat produced by CO in bosh gas with 1250°F. hot blast

8800# Air + 85# H_2O = (2109# O_2 + 1582# C) 3691# CO + 9 44# H_2

C to CO 1582# × 3960	-6,265,000 B.t.u	
H_2O to H_2 85#/9 × 51,643	−488,000 "	
Air 116,000 CF (at 1250°F.) × 22.8	2,650,000 "	
		+8,427,000 B.t u.

VIII. Reaction temperature of bosh gas

Heat produced	8,427,000 B.t.u.
" 1582# C at 2850°F. × 0.376	1,700,000 "
10,467# bosh gas (117 B.t.u./CF)	10,127,000 "

91,000 CF N_2
50,000 " CO
1,800 " H_2
142,800 CF × 70.8 B.t.u./CF = 10,127,000 = 3500°F.

fourth of the heat supply." Figure 146 [79] shows the graphical balance of the material flow through a blast furnace. The author says that "this picture makes the observer aid-gas conscious; it

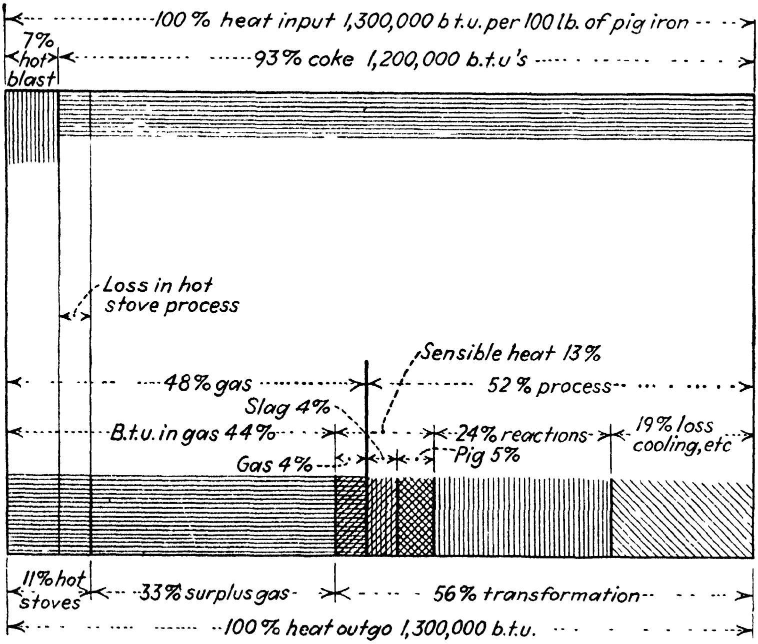

FIG. 78.—Graphic heat balance. (*Courtesy of J. F. Shadgen, The Iron Age, July 5, 1934.*)

shows the enormous proportions of the weights and volumes of gases handled . . . over 50 per cent of the weight that goes into the blast furnace is wind and over 75 per cent of the output by weight is gas."

The distribution of heat shown by Kinney, Royster, and Joseph[1] was "compiled on the basis of the available heat, on the assumption that all the C is burned to CO_2 and all the H_2 to H_2O. From the gas samples it is assumed that 80.5 per cent of the work of reduction of the iron oxides is done above the level of plane 4" (see Fig. 76). Their data are given in Table XII.

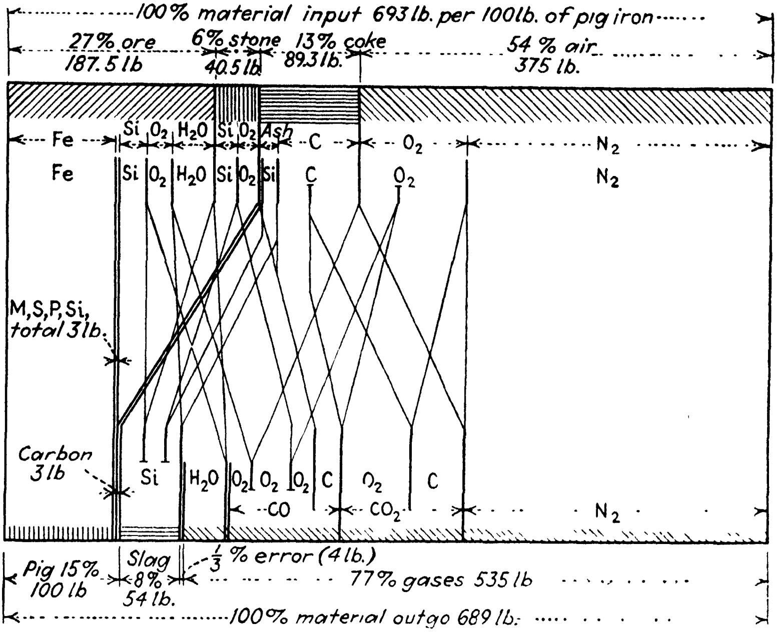

FIG. 79.—Graphic materials balance. (*Courtesy of J. F. Shadgen, The Iron Age, July 5, 1934.*)

The authors say that "more work is done in the stack above plane 4 than in the bosh and hearth. It is indicated that 18.6 per cent of the heat is consumed in the stack, and 16.5 per cent is consumed in the hearth and bosh."

In England, in recent years, Frederick Clements of The Park Gate Iron & Steel Co., Ltd., Rotherham, has published much of his keen observation of blast furnace phenomena, including

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[1] In *Bur. Mines Tech. Paper* **391, 1927.**

TABLE XII.—DISTRIBUTION OF HEAT[1]

	B.t.u. per long ton of metal	Total	
Available heat:		Per cent	Per cent
Combustion of C to CO_2	30,695,328	91.10	
Combustion of H to H_2O	685,860	2.04	
Heat carried in with blast	2,316,539	6.86	100.0
Total available heat	33,697,727	100.00	100.0
Heat consumed in stack, above plane 4:			
Calcination of stone	1,176,470	3.4	
Reduction of 80.4 per cent of iron oxides	4,473,454	13.3	
Drying charge	651,819	1.9	18.6
Heat consumed in bosh and hearth:			
Reduction of 19.5 per cent of iron oxides	1,083,632	3.2	
Reduction of MnO, P_2O_5, SiO_2	825,832	2.5	
Dissociation of moisture	1,030,464	3.1	
Sensible heat:			
In iron	1,086,400	3.2	
In slag	1,500,632	4.5	16.5
Heat lost via top gases, heat loss, etc.:			
Sensible heat in top gas	1,083,650	3.2	
Heat value of top gases	17,473,670	51.9	
Heat loss	1,560,582	4.6	
Carbon in flue dust	586,810	1.7	
Carbon in metal	1,164,312	3.5	64.9
	33,697,727		100.0

Table XII indicates that 18.6 per cent of the available heat is consumed above plane 4; of this, 13.3 per cent is used in reducing 80.5 per cent of the iron oxides, 3.4 per cent in calcination, and 1.9 in drying the charge. In the bosh and hearth 3.2 per cent is consumed in reducing iron oxides; 2.5 in reducing MnO, P_2O_5, and SiO_2; 3.1 per cent in dissociating moisture, etc. The table also shows that even though approximately 85 per cent of the carbon is burned at the tuyere level, more work is done in the stack above plane 4 than in the bosh and hearth. It is indicated that 18.6 per cent of the heat is consumed in the stack, and 16.5 per cent is consumed in the hearth and bosh.

[1] *Bur. Mines Tech. Paper* 391, p. 57.

several thermal-balance sheets. A part of one of these balance sheets[1] of a furnace making basic iron is reproduced in Table XIII.

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[1] From Frederick Clements, "British Blast-furnace Practice," Iron and Steel Institute (Great Britain), May, 1920.

TABLE XIII.—PART OF THERMAL-BALANCE SHEET[1]

Heat Generated: Thermo-chemical Changes

Heat Generated in Combustion of Carbon

Total weight of carbon = 25.67 lb.
Total weight of exit gases = 164.05 lb.

Analysis of gases by weight, per cent		Weight of carbon contained in 164.05 lb. of gas
CO^2	= 13.30	5.95 lb.
CO	= 28.05	19.71 lb.
H^2	= 0.21	
N	= 58.44	

Therefore, heat generated by combustion of 5.95 lb. of C into CO^2 = 5.95 × 14,580 = 86,751 B.t.u.
Also heat generated by combustion of 19.71 lb. of C into CO = 19.71 × 4374 = 86,211 B.t.u.

Heat Generated in Formation of Silicates in Slag

Weight of slag involved = 22.45 lb.
Weight of $SiO_2 + Al_2O_3$ = 10.72 lb.
Heat generated on combination with lime = 270 B.t.u. per pound $SiO_2 + Al_2O_3$
Therefore, total heat generated = 10.72 × 270 = 2894 B.t.u.

Formation of Carbide of Iron

The carbon in the liquid iron is taken as in the form of carbide of iron. Weight of carbon involved = 0.6 lb.
Heat of formation = 1270 B.t.u per pound of carbon
Therefore, heat absorbed = 1270 × 0.6 = 762 B.t.u.

Reduction of Sulphur

The amount of sulphur appearing in pig iron as MnS is very small and can be neglected.

The sulphur in slag is assumed to have been reduced according to equation FeS + CaO + C = Fe + CaS + CO. The thermal effect of CO formed is allowed for elsewhere. The heat of formation of CaS = 5301 B.t.u. per pound of sulphur.

Therefore, heat generated = 0.418 × 5301 = 2215 B.t.u.

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[1] **Based on work of No. 3 furnace from Jan. 4 to Apr 5, 1919; The Park Gate Iron and Steel Co., Ltd , Rotherham, April, 1919**

TABLE XIII.—PART OF THERMAL-BALANCE SHEET[1].—(*Continued*)

Heat Generated: Thermo-physical Changes

Heat Carried in by Blast

Weight of blast = 124.5 lb.
Temperature (average) = 1020°F.
Therefore, heat carried = (1020 − 60) × 0.237 × 124.5 = 28,320 B.t.u.

Heat Carried in by Moisture in Blast

Weight involved = 1.0 lb.
Temperature = 1020°F.
The initial air is at 60°F. and the moisture exists as water vapour The heat carried will be that required to superheat from 60°F. to 1020°F.
Specific heat (mean) = 0.42 × 0.000103t = 0.54.
Total heat carried by 1 lb. = 1.0 × (1020° − 60°) × 0.54 = 518 B.t.u.

Thermal Balance-sheet

Heat absorbed	B t u	Per cent	Heat generated	B t u.	Per cent
1 Reduction of silica	3,150	1.51	1. Combustion of C to CO_2	86,751	41.79
2. Reduction of Fe_2O_3	36,804	17.71	2. Combustion of C to CO	86,211	41.51
3 Reduction of FeO	15,291	7.04	3 Heat generated in formation of silicates in slag	2,894	1.39
4 Reduction of MnO	928	0.46	4 Heat generated in formation of carbide of iron	762	0.36
5. Reduction of P_2O_5	3,710	1.82	5 Formation of calcium sulphide	2,215	1.06
6. Reduction of iron silicate	820	0.42	6 Heat carried in by blast	28,320	13.64
7. Decomposition of $CaCO_3$	12,586	6.08	7 Heat carried by moisture in blast	518	0.25
8. Decomposition of CO_2	26,878	12.96			
9. Decomposition of ferric hydrate	2,704	1.32			
10. Decomposition of vapour in blast, etc	10,816	5.28			
11 Total heat in molten iron	11,320	5.45			
12 Total heat in molten slag	21,465	10.36			
13. Sensible heat in exit gases	11,637	5.63			
14. Heat carried in vapour in gases .	11,062	5.43			
15. Heat carried in dust .	103	0.05			
16 Heat absorbed in blast expansion .	649	0.31			
17. Heat carried with cooling water	18,700	9.02			
18 Balance—radiation loss, etc	19,048	9.15			
Total	207,671	100.00	Total	207,671	100.00

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[1] Based on work of No. 3 furnace from Jan. 4 to Apr 5 1919; The Park Gate Iron and Steel Co, Ltd, Rotherham, April, 1919

The calculations are based on 20 lb. of pig iron produced from the low-iron English ores that contained only 19.66 to 26.42 per cent iron, but 11.00 to 24.03 per cent lime (CaO); plus about 27.3 per cent of the burden made up of tap cinder, roll scale, etc., containing 53.82 to 70.1 per cent iron. The coke had only 83.86 per cent carbon in it, and it required 3,267 lb. of air per ton of pig iron (6.22 gross tons!) including 10,737 lb of nitrogen. The slag was very basic, only 32.8 per cent silica, with 14.8 per cent alumina, 43.86 per cent lime, and 1.59 per cent magnesia. This gave a very large volume of slag, 2,514 lb. per ton of pig iron. The blast temperature was 1020°F. and the top temperature 350°F.

The above examples show clearly that economies can be obtained by having a minimum of slag and a minimum of nitrogen consistent with the proper operation of the blast furnace.

MOVEMENT OF THE STOCK COLUMN

In the introduction of this book it is said that in the blast furnace process "a column of solid iron ores (oxides of iron), fuel, and flux descends through the vertical shaft of the blast furnace, meeting a large volume of ascending hot gases containing about 34 per cent CO gas (carbon monoxide)." The descent of that column of solids is accompanied by a remarkable series of phenomena, both physical and chemical. One striking fact is that of all the solids put into the furnace at the top only about 45% will go out at the bottom of the furnace and then as liquids (molten iron and slag), all the rest being gasified and returning upward in the column of hot ascending gases and passing out of the top of the furnace; the only exception being the very small weight of flue dust that went into the furnace and came out again at the top in the solid state.

The gasification of the solids—the removal of moisture and oxygen from the iron ores and the carbonic acid gas from the limestone, and the gasification of solid carbon of the coke—takes place in different parts of the furnace, at different temperatures and under rapidly changing conditions. The process continues from the time that the solid stock is lowered from the big bell into the furnace until the last bit of coke is consumed at the tuyeres.

In good furnace practice, solid coke will not be allowed to come out at the iron notch nor out of the bleeders at the top; with modern iron-notch mud guns and cinder stoppers, no hot gases are allowed to escape at the iron and cinder notches.

The descending column takes heat from the ascending column of gases, which exchange of heat is subject to laws governing the flow of gases through beds of broken solids as set forth by C. C. Furnas.[1]

A very thorough investigation of the movement of the descending-stock column in a 700-ton blast furnace was undertaken by the U. S. Bureau of Mines under the direct supervision of S. P. Kinney.[2] The investigation was conducted in 1926 on No. 4 blast furnace of the Illinois Steel Co. at its South Works, South Chicago, Ill.

> The data collected in the shaft of the furnace were obtained from 4 planes above the mantel, numbered 1 to 4. They were 3 feet, 11 feet, 21 feet 7 inches, and 44 feet 1 inch below the top of the stock column. . . . As to the conditions existing on each plane, it was shown in *Technical Paper* 391 (Iron Blast Furnace Reactions, 1927) already referred to, that the rate of gas and stock flow is not uniform across any plane parallel to the hearth. It is probable that the flow of stock in the vicinity of the inwall is more rapid than at the center of the column.
>
> **Summary of Tests of Flow of Stock.**
>
> In seven tests the average rate of flow of stock at the stock line was found to be 2.78 inches per minute. Individual rates, measured at the same time, over the iron notch, the cinder notch, and opposite the iron notch were 3.16, 2.92, and 2.93 inches per minute, respectively. The rate measured at a point at or near the center of the top of the column was 2.10 inches per minute; during the same period the rate measured at a point 9 inches from the inwall gave 2.46 inches per minute. The calculated average rate of flow in the straight section at the top of the furnace was found to be 1.99 inches per minute.
>
> The flow of stock in the blast furnace is not uniform. The flow directly over the tuyeres is faster than the flow in the center of the column, whereas the flow over the iron notch was found to be slightly faster than that on the sides or in the center of the column. Substantiation of the belief that the column of stock is partly submerged

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[1] "Flow of Gases through Beds of Broken Solids," *Bur. Mines Bull.* 307, 1929.

[2] KINNEY, S. P., "The Blast-furnace Stock Column," *Bur. Mines Tech. Paper* 442, 1929.

in and floating on a bath of slag and metal is obtained from the pendulumlike motion of the stock column at the reception of each charge.

For description of the furnace and operation the following figures and text are taken from *Bur. Mines Tech. Paper* 442 (see Fig. 80).

TYPE OF DATA COLLECTED

Observations on the Four Planes.—The gas samples and temperature and pressure observations obtained along a radius were taken from a point on the inwall at the back side of the furnace to the center. It is believed that in a furnace working normally observations taken on any radius are actually representative of any other. Certain proof of this was obtained in the study on the southern furnace previously mentioned, where the composition of gas on a diameter was taken to comprise that shown by the observed radius and one similar thereto. Upon integration of the curve thus formed a close approximation of the actual top-gas composition could be obtained, which is fairly good evidence of uniformity of the composition of gas at points equidistant from the inwall. Other evidence of uniformity at points equidistant from the inwall on No. 4 furnace was found by means of certain tests in which the rate of flow of stock was measured through try-rod holes. The results obtained for these holes were compared with an observation made when a cable was allowed to descend from a point at the center of the top of the stock.

Composition of Gas. *Uniformity of Gas Samples at Furnace Top.*—These stock-flow experiments were used to determine uniformity, and they were augmented by a series of gas samples collected from three try-rod holes. The samples were taken at points just below the level of the stock, on top of the stock, and at the deck ring.

Gas Temperature, Pressure, and Velocity on Each Plane.—Gas samples, temperature observations, and static and velocity pressure readings were taken on each of the four planes from a point on the inwall, on the back of the furnace, to the center. The readings were taken at intervals of 3 to 6 inches along the radius. Duplicate samples of gas were taken on each day of sampling, and each set of gas-sampling data was repeated on one or more days. The temperature observations were taken in a similar manner and were duplicated on each plane a number of times until fairly uniform results were obtained. Pressure readings were duplicated on each plane at each observed point on each day's observation and repeated.

MEASUREMENT OF FLOW OF STOCK

Method.—The rate of flow of stock in the furnace was measured with a cable to which was attached an iron rod 1 inch by 4 feet. The rod

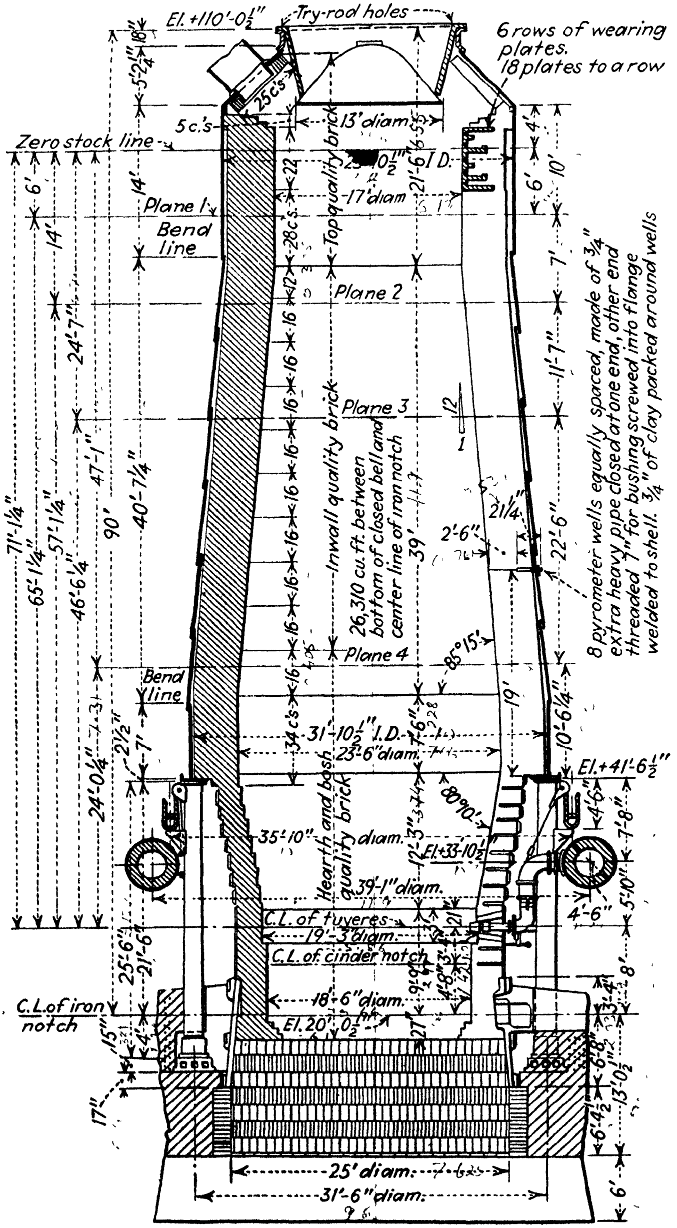

Fig. 80.—Section of No. 4 furnace, Illinois Steel Co., South Works. (*From Kinney, Bur. Mines Tech. Paper 442.*)

was lowered through a try-rod hole until the end of the rod just rested on the top of the stock. When the big bell of the furnace was lowered, the rod was caught by the incoming charge. The cable was then drawn tight, and the rate of movement of the cable against a stationary bench mark was recorded. This method was employed on all tests except one, when a one-half-inch iron pipe was employed; as the pipe descended, the time and distance were recorded. In a number of trials two or three cables were employed at the same time at different sides of the furnace. Each cable was held tight throughout the test, and the time and distance were recorded at short intervals.

For the sake of comparison of rates of flow an attempt was made to measure the rate of flow through the center of the stock column. In this test a 1-inch double-extra strong pipe was bent and clamped to the lip ring. At the start of the test the weight was placed in the stock at a point 42 inches below a 3-foot stock line at the center of the column. The cable was fed through the curved pipe, and the movement of the cable was recorded as the weight was carried down with the stock.

The Bureau of Mines pointed out in Technical Paper 391 that combustion in the iron blast furnace takes place in restricted zones at the hearth level and directly in front of the nose of each tuyere. The investigation in Alabama indicated that the zone of combustion in all cases is not more than 32 to 40 inches long. Later, the author showed that this zone extended upward approximately a like distance. Virtually all of the carbon, charged as coke, reaches the tuyeres before combustion takes place, and this combustion occurs in a relatively restricted zone, where the solid carbon is converted to the gaseous phase in a brief period. During this conversion a void is created, which in turn has an effect on flow of stock in the column.

The author believes that uniform flow of stock across any plane parallel to the hearth can not exist in the presence of these localized combustion zones. The effect of the combustion zones must be transmitted to the stock column. Certainly it is correct to assume that at a point—say, 6 inches above the top of the combustion zone—the effect of this transformation of carbon is reflected in the movement of stock. This effect is therefore transmitted to some point higher in the column, probably to the top of the column. With these points in mind the experiments to be described were attempted. The results would seem to indicate that the flow of stock in the furnace is not uniform.

Comparison of Flow of Stock at Three Points.—As it seemed desirable to know whether the rate of flow was the same on all sides of the furnace at any one time, it was arranged to let the cables down through three different try-rod holes. This was done on July 6 at the try-rod holes over the cinder notch, the iron notch, and the back. The rate to cast time was taken as a measure of the average rate. Examination of the curves shows a change in the rate of flow of the stock at the time the metal started flowing. It was found that up to the time of cast the rates over the cinder notch and the back of the furnace were almost constant at 2.92 and 2.93 inches a minute, respectively, whereas over the iron notch the rate was faster, 3.16 inches a minute.

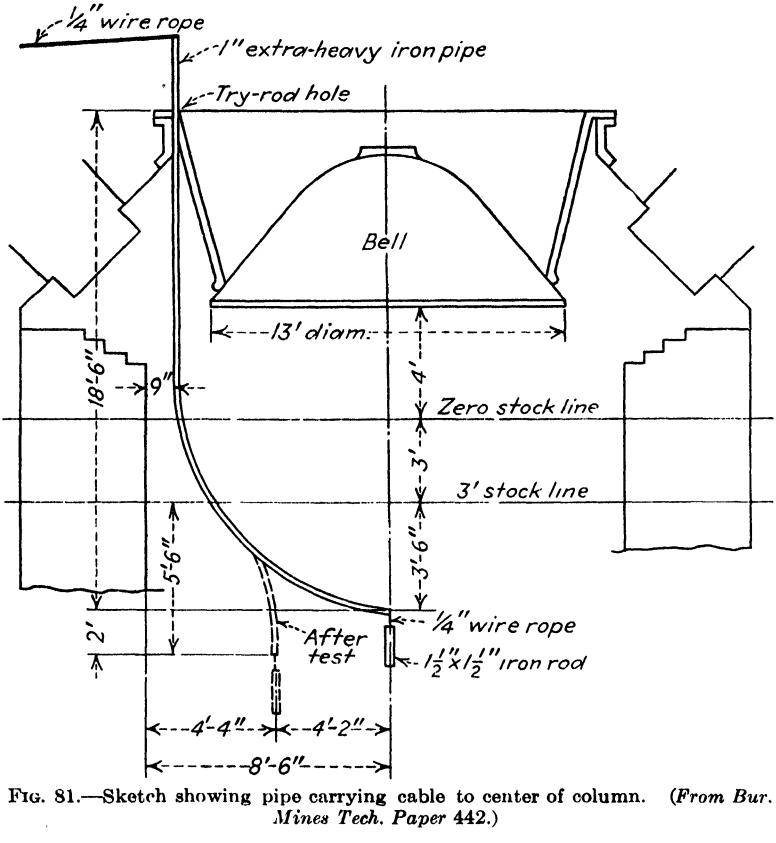

FIG. 81.—Sketch showing pipe carrying cable to center of column. (*From Bur. Mines Tech. Paper* 442.)

Flow of Stock at Edge Compared with Flow at Center.—An attempt was made to determine the rate of flow at the center of the stock column, but as there is no access to the center of the top of the stock column an attempt was made to convey a cable and weight through a double-extra strong pipe from one of the try-rod holes to a point 42 inches below a 3-foot stock line. Figure 81 shows the position of the weight and cable at the start of the test. It was hoped that the pipe bearing the cable to the center of the column would withstand the force of falling stock, and it did this fairly well considering the conditions under which it had to be maintained. The position of the end of the pipe after the test is shown, as determined by measurement, after withdrawing the pipe from the furnace. The end of the pipe had moved from a point 42 inches below the center of the top of the stock column to one 66 inches below the 3-foot stock line and 50 inches from the center line, which is 52 inches from the inwall. During the test the cable was descending from a moving pivot between the two points shown in Fig. 81.

TABLE XIV.*—RATE OF FLOW OF STOCK AT VARIOUS ELEVATIONS

Distance below zero stock line, feet 1	Diameter, feet 2	Area, square feet 3	Average rate of flow of stock, inches per minute[1] 4	Average rate for section, inches per minute 5	Period to travel section, minutes 6
0	17	227	1.99		
6½	17	227	1.99	1.99	39.2
9½	17½	240	1.89	1.94	18.5
12½	18	254	1.79	1.84	19.6
15½	18½	269	1.68	1.74	20.6
18½	19	284	1.59	1.64	22.0
21½	19½	299	1.52	1.55	23.2
24½	20	314	1.44	1.48	24.2
27½	20½	330	1.37	1.40	24.6
30½	21	346	1.31	1.34	26.8
33½	21½	363	1.28	1.30	27.7
36½	22	380	1.19	1.23	29.2
39½	22½	398	1.14	1.20	30.0
42½	23	415	1.09	1.11	32.1
45½	23½	436	1.04	1.07	33.6
53	23½	436	1.04	1.07	84.0
Total	....			.	457.6

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* This is Table 12, p. 34, of *Bur. Mines Tech. Paper* 442.

[1] With 3,610 pounds of stock charged per minute, the weight per cubic foot = 95.5 pounds, or 3,610/95.5 = 37.8 cubic feet move down each minute The average rate at the stock line, therefore, is (area of stock line) times X = 37.8 cubic feet. X = 0.166 foot = 1.99 inches a minute.

The rate from the stock line to the bend line is 1.99 inches a minute, and this rate decreases to 1.07 inches a minute at the point at which the inwall joins the mantle; through the mantle the rate would also be 1.07 inches a minute. The period required for the stock to pass through each section is shown in column 6 of Table 12. This has been calculated from the distance covered and the average rate for each section.

The table indicates that 7.6 hours would be required for stock to pass from the stock line to the top of the bosh if the flow of stock were uniform and there were no change in volume. A decrease in volume would, no doubt, increase the rate of flow, so that it is probably safe to assume that the rate is faster than that indicated.

Depth of Charge Layer.—In connection with the depth of the charge layer it might be of some interest to know the thickness of a layer of stock, assuming that it has been deposited in a uniform layer at the stock line. On July 6 the total charge weighed 37,400 pounds, with a calculated volume of 453.9 cubic feet. The area of the stock line is 227 square feet; therefore a charge would have a thickness of 1.99 feet or, say, 2.0 feet. Of this layer the coke occupies 9,000/35 = 257 cubic feet or a layer $^{257}/_{227}$ = 1.132 feet (13½ inches) thick; the limestone a layer $\frac{3,900}{97 \times 227}$ = 0.172 foot (2 inches) thick; and the remainder of the charge, consisting of ore, open-hearth slag, and flue dust, occupies 156.6 cubic feet, or a layer 156.6/227 = 0.69 foot (8⅓ inches) thick. If the stock were deposited in a uniform layer at the stock line, the layer would be 1.99 feet thick. Of this the coke would occupy a layer 1.132 feet, limestone 0.17 foot, and the ore 0.69 foot in thickness, or approximately 57.0, 8.5, and 34.9 per cent, respectively.

The same calculations may be made for the straight section at the top of the bosh, where the diameter is 23½ feet. Here the area is 436 square feet. If it be assumed that the layers remain uniform and there is no change in packing or volume, the charge layer would be 453.9/436 = 1.04 feet (12½ inches) thick, the coke $^{257}/_{436}$ = 0.59 foot (7 inches) thick, the limestone 40.3/436 = 0.09 foot (1 inch) thick, and the ore, open-hearth slag, and flue dust 156.6/436 = 0.36 foot (4⅓ inches) thick.

During the travel down the column to the straight section above the bosh the ideal stock layer has decreased in thickness from 1.99 to 1.04 feet or, say, by one-half. From this it is probably safe to assume that if the stock were charged in uniform layers these would not be maintained in layer form as the stock descended, first, because of the spreading caused by the batter, and, second, because of the irregular flow of stock in the column.

The conclusions regarding flow of stock were as follows:

1. The flow of stock in a blast furnace is not uniform.
2. The flow directly above the tuyeres is faster than that in the center of the column.
3. The observed rate of flow near the walls is approximately one-third faster than the calculated average rate. It might, therefore, be concluded that the center column is moving at a rate which is considerably lower than the average.

4. The flow of stock over the iron notch is faster than that on the sides or in the center of the column.

5. The pendulumlike movement of the stock column during charging would seem to substantiate the belief that the column of stock is submerged and floating in the bath of slag and metal.

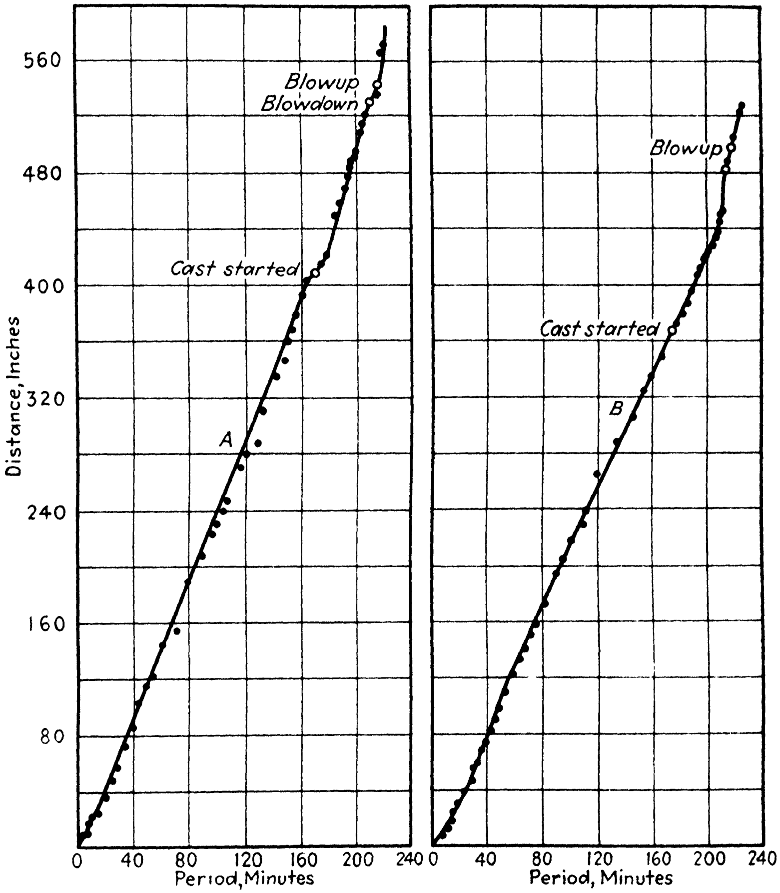

FIG. 82.—*A*, Rate of flow of stock as measured through try-rod hole No. 1 (over cinder notch); *B*, rate of flow of stock as measured at center of furnace (reached through try-rod hole No. 2). (*From U.S. Bur. Mines Tech. Paper* 442.)

GAS VELOCITIES

When one considers the enormous volume of air blast that is pumped into a blast furnace which is already filled with solids, knowing that this volume of air at 62°F. is enough to fill the furnace twice every minute even if the furnace were empty instead of filled to the stock line with solid materials, and then if one considers the voluminous additions of gases from the solid ore, flux, and fuel, then one can realize the speed at which these gases must pass through the stock-line area of the blast furnace.

The weight of the waste gases passing off through the downcomers is at least $1\frac{1}{2}$ to $1\frac{3}{4}$ times as great as the total weight of all the solid materials going into the furnace, and $3\frac{1}{2}$ times greater than the combined weight of the molten iron and molten slag flowing from the furnace at the bottom.

In the same investigation that Kinney made at No. 4 blast furnace, South Works (copiously quoted in the preceding section), he made many observations of the velocity of the gases at several planes inside the furnace. To get the data for calculating velocity and volume of gas in different planes of the furnace and at the different distances from the inwall toward the center of the furnace, it was necessary to take and analyze many samples of gas along the radius to the center and to determine the temperature at each point where gas samples had been taken and also to determine the static and dynamic pressures at the same points.

The method of calculating the velocity of the gas is described by Kinney, as follows:

> If the gas composition, temperature, and static and dynamic pressures at a series of points between the inwall and the center of the furnace on the four planes are known, it is possible to calculate the gas velocity at any point or series of points from the relation
>
> $$V = \sqrt{2gh}$$
>
> or gas velocity
>
> $$V = F\sqrt{2gh_x}$$
>
> where V = velocity in feet per second
> h_x = velocity head of medium flowing
> g = 32.2
> hw = velocity head, inches of water (see page 195)
> P = static pressure
> T = temperature, °F.
> W = weight of gas
> F = Pitot tube factor = 1.47 pounds per cubic foot, at temperature and pressure observed. 1 inch of water = $\frac{1}{12}$ foot of water = $\frac{1}{12} \times 62.4/144 = 0.03611$ pound per square inch.

The velocity at any point in the furnace at the temperature and pressure of said point in feet per second is as follows:

$$V = 1.47\sqrt{2gh_x}$$

$$V = 1.47\sqrt{\frac{2 \times 32.2 \times 144 \times 0.03611 \times hw}{W\left(\frac{29.9 + P}{29.9}\right)\left(\frac{459.2 + 32}{459.2 + T}\right)}}$$

$$V = 1.47\sqrt{\frac{334.869 \times hw}{W\left(\frac{29.9 + P}{29.9}\right)\left(\frac{459.2 + 32}{459.2 + T}\right)}}$$

$$V = 26.90\sqrt{\frac{hw}{W\left(\frac{29.9 + P}{29.9}\right)\left(\frac{459.2 + 32}{459.2 + T}\right)}}$$

From the observations made, the velocities and volumes of the gases were calculated, tabulated, and charted graphically. The estimated results were checked back through the observed nitrogen content of the gas at each plane and the estimated blast volume was compared with the actual volume of the blast blown at the time the observations were made. The average variation was only 2.8 per cent, with a maximum variation of 10.2 per cent. The article above quoted has figures showing carbon dioxide contents at various planes, temperatures, static pressure, and gas velocity. There are also figures showing the lines of equal carbon dioxide, isotherms, isobars, and lines of equal gas velocity in feet per second; the last of these figures is reproduced here[1] (Fig. 83).

The very high velocity of the gas in the center of plane 1 (450 ft. per second) is accompanied with high temperature (1350°F.) and low carbon dioxide content (7.4 per cent) showing that only a little work of heat transfer or of reduction had been done by the comparatively small volume of gas that goes up through the furnace at this point. This waste, however, was excessive and was corrected. Such high velocity is conducive to high flue-dust loss. Kinney says that "velocities of gas of 40 to 50 feet a second will lift a piece of three-quarter inch coke approximately 10 feet." Fine material would certainly ascend with the gas instead of descending with the stock column under such conditions.

[1] From Fig. 34, p. 108, *Bur. Mines Tech. Paper* 442.

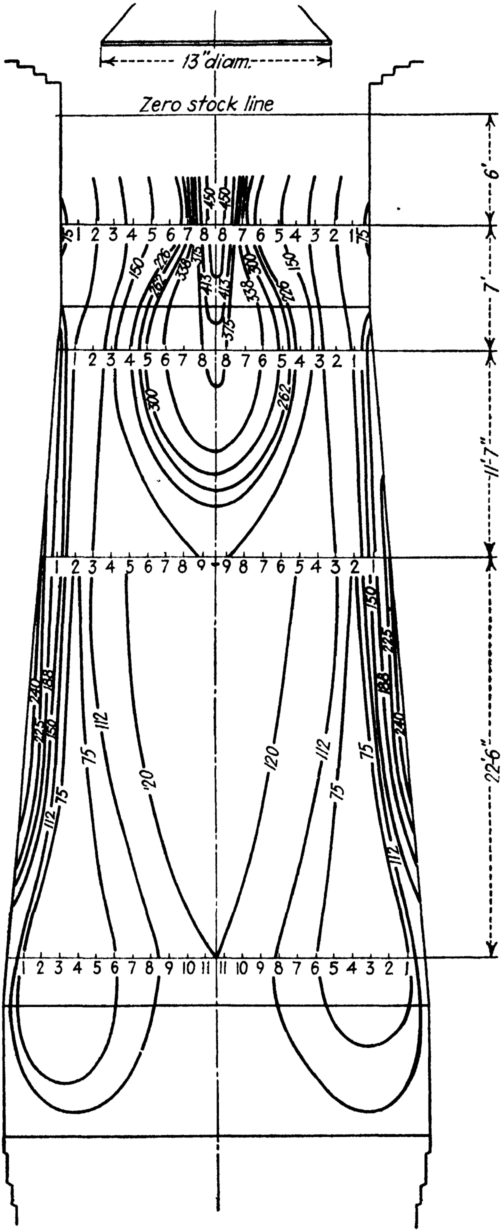

FIG. 83.—Lines of equal velocity, feet per second. (*From U.S. Bur. Mines Tech. Paper* 442.)

Another investigation of the conditions inside the blast furnace was undertaken by Kinney for the Bureau of Mines, at the West furnace of The American Rolling Mill Company, Columbus, Ohio, while the author was connected with that company. When the furnace was rebuilt after the World War, platforms were erected on the shell of the furnace at two planes with observation holes through the shell and lining similar to those at Holt furnace and No. 4 furnace at South Chicago. The detailed observations were published in the March and April, 1934, issues of *Blast Furnace and Steel Plant*.

Figure 84 shows the isotherms, the lines of equal carbon dioxide content, and lines of equal gas velocity, as observed in this investigation.

These results are far different from those obtained at Holt furnace and No. 4 furnace at South Chicago, so far different that some of the previous conclusions had to be modified. The published data of these three furnaces show, in part, the following comparison:

Item	Holt	Chicago	Columbus
Tons of pig iron per day	324 7	721	446.3
Coke per ton of pig iron	2,626	1,850	1,619
Temperature of blast, °F	957	1130	1239
Temperature of top gas, °F	335	350	384
Actual yield of ore mixture, %	49 42	.. ..	51 51
Flue dust per ton of pig iron, lb	.	.. ..	127 5
Blast pressure, lb	16.85	17 6	15.9
Volume of furnace in cubic feet	15,385	26,310	11,354
Air blown, 65°F., per pound of coke, cu. ft	70	57 6	59 5
Air blown per minute, engine revolutions	41,660	50,000	28,054

At Holt and Chicago, the greatest velocities were in the center; at Columbus it was at the inwall, where the carbon dioxide was lowest and the temperature highest, as will be seen in Fig. 84. In commenting on the Columbus results, Kinney said that they "show that certain excessive heat and flue-dust losses exist in the shaft of the furnace and that these losses take place at the top and near the inwall of the furnace. High gas velocity at the inwall is directly responsible for excessive wear and the ultimate deterioration of the stock-line section of the furnace shaft.

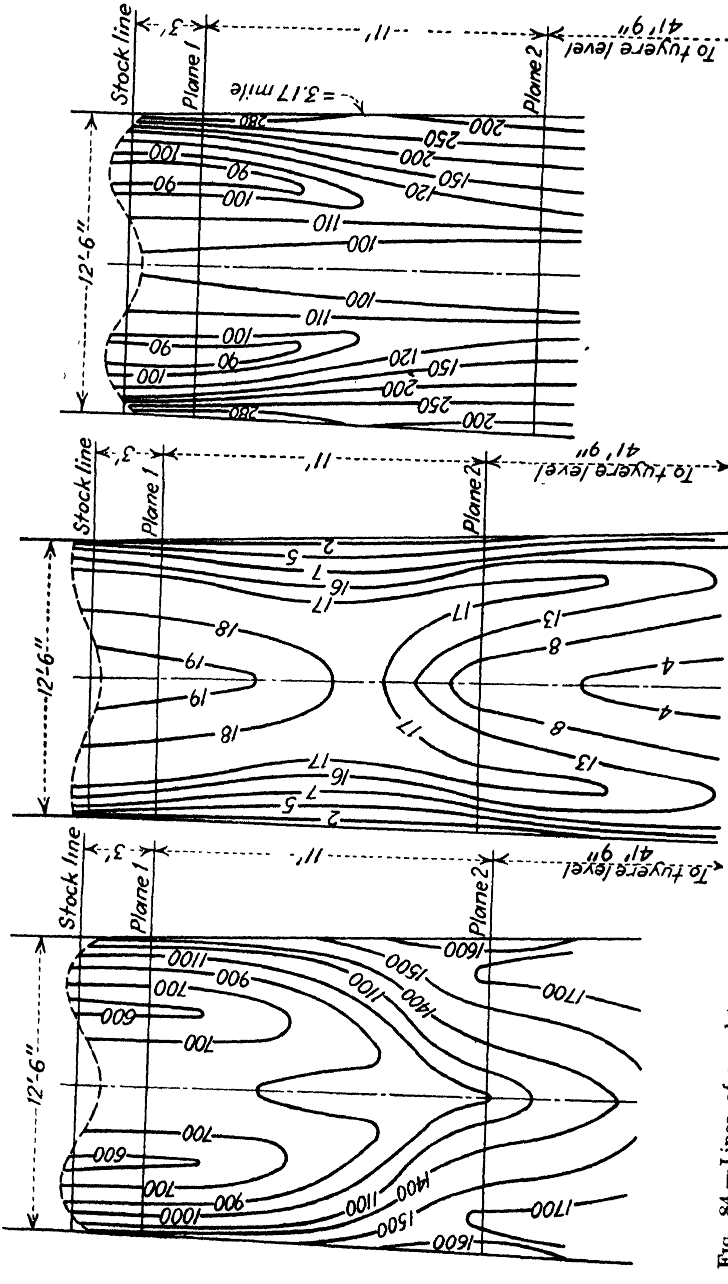

FIG. 84.—Lines of equal temperature (left); equal CO_2 content (center); equal velocity (right). (Courtesy of *Blast Furnace & Steel Plant*, *Apr.* 1934.)

Decreased velocities at the inwall, with a resultant lowering of flue-dust production, may be obtained by increasing the diameter of the shaft below the stock-line."

At the City furnaces of the Sloss-Sheffield Steel & Iron Company, Birmingham, Ala., there is the lowest flue-dust loss that has ever come to the author's attention (only 21 to 30 lb. per ton of pig iron in September, 1936). It was at this plant that the wide-top furnace was first installed by James P. Dovel, then Vice President of that company. In describing the large tops which had been gradually constructed at their blast furnace plants, Mr. Dovel said, in an article in *The Iron Age*, Sept. 22, 1927, that "the largest practical area in the upper section of the furnace is desirable; if the area is sufficient and the distribution of the stock uniform throughout, the upward passing gases will filter slowly through the stock and not be forced rapidly through openings or craters, picking up large quantities of dust. This slow and easy movement of the upward passing gases, filtering through the stock uniformly serves several very important functions: The gases are cooled, thereby retaining the maximum amount of heat units in the furnace; the gases reach the downcomer with very low dust content, which is a great saving in material; a longer and better contact is provided between the hot gases and the ore in the upper reduction zone, resulting in better preparation of the ore for final reduction, and better grade, more tonnage and lower coke consumption per ton produced."

Thus it is clearly seen that the gas velocities in different parts of the furnace can be controlled to a certain extent by changes in dimensions of the stock line, of the big bell, and of the batter of the inwall.

TEMPERATURES INSIDE THE FURNACE

The temperatures inside the iron blast furnace have been determined by actual observations with pyrometers in many investigations, but no series of temperature tests has been complete; there are still regions of the blast furnace which have not been explored with pyrometers and the temperatures of those regions have been only roughly estimated.

Temperature in Hearth.—Up to the present time, the usual way to get the temperatures of the hearth of a blast furnace is to use platinum-rhodium thermocouples, properly protected, placing them in the molten iron as it flows at the cast from the iron notch, and in the molten slag as it flows from the cinder notch at the flushes. This method was used at East furnace, Columbus, Ohio, in May, 1923.[1] The optical pyrometer can be used only part of the time because of the fumes that arise from the iron and the slag.

It is almost certain that the temperatures in the bath of metal inside the hearth of the furnace are a little lower than the temperatures of the bath of slag floating on top of the molten iron and through which the iron must drop in its downward path to the bottom of the hearth. We have found that the temperature of the slag governs the temperature of the iron. An instance of this is recorded in one of the author's previous articles,[2] "Carbon in Pig Iron," where a cast of iron was quite regular in temperature with an average of 2522°F.; the maximum temperatures of the slag in the two preceding flushes were 2623 and 2694°F., respectively. In another cast, where the maximum temperature of the iron was 2715°F., the temperature of the first flush was 2700 to 2758°F. for the last 5 min. of the flush that was running for 9 min. The second flush was above 2700°F., except for the first minute and the last minute of the flush.

Another investigation of the temperatures of the iron flowing from the hearth of the furnace was made at No. 1 furnace of The American Rolling Mill Co., Ashland, Ky., in August, 1924. The furnace was making basic pig iron for the open hearth. In the middle of this test, the hearth of the furnace was deliberately made colder so as to find out what effects the temperature *and the causes of the drop in temperature* had on the carbon in the pig iron. The results of this test are graphically shown in Fig. 85, giving maximum and minimum temperatures of the iron at cast over a period of 10 days. By reference to this chart of temperatures, it is evident that there are continual changes taking place in the molten metal and slag inside the furnace, both as to temperature and as to analysis.[3,4]

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[1] Described in *A.I.M.E. Tech. Paper* 11, 1927.

[2] *A.I.M.E. Tech. Paper* 11, 1927.

[3] See Ralph H. Sweetser, Combined Carbon—A Controlling Factor in Quality of Basic Pig Iron, *Trans. A.I.M E.*, vol. 131, 1938.

[4] Figure 85 was first published in Open Hearth Proceedings, *A.I.M.E.*, 1937.

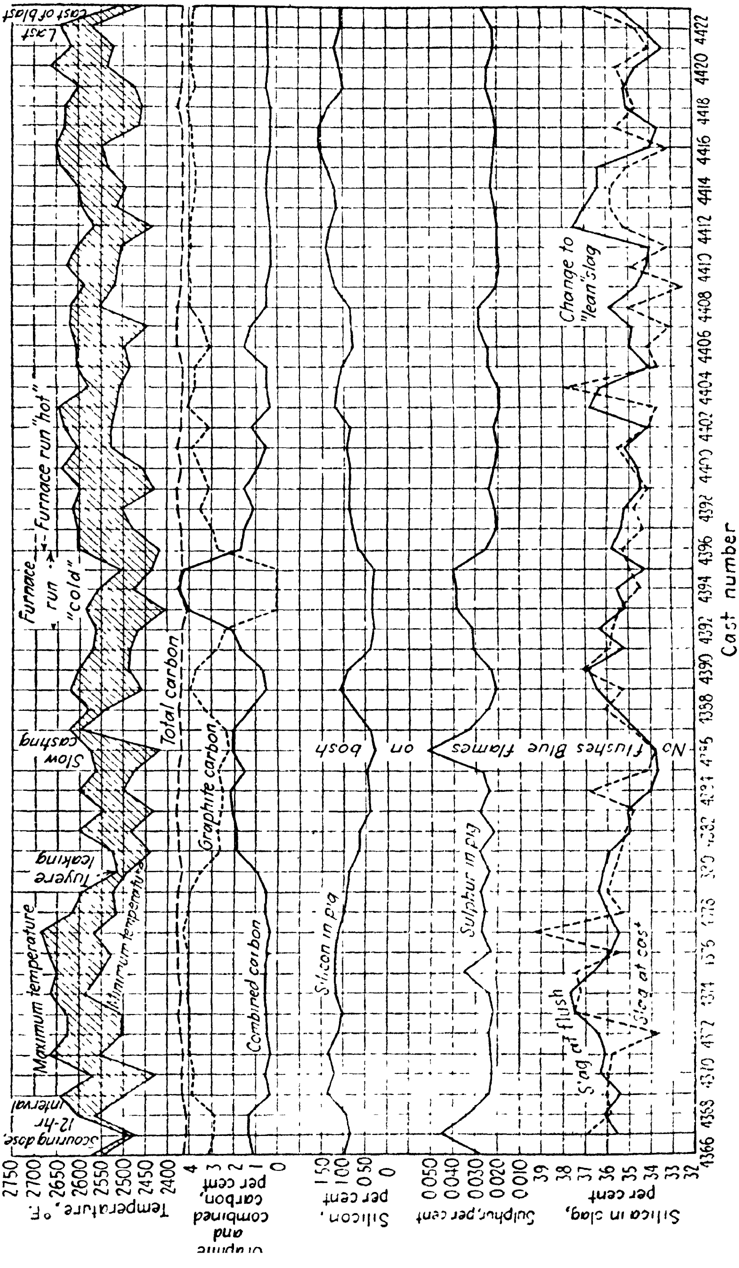

FIG. 85.—Temperature of iron at cast. (From *Open Hearth Proceedings, A I M E.*, 1937.)

All the above observations were made on furnaces producing basic iron; William E. Brewster mentions[1] pig iron with an initial temperature of 2800°F. as it came from the blast furnace while making malleable iron.

Temperature at the Tuyeres.—By referring to Figs. 73 and 74 in the section on Reduction of Iron Ores, it will be seen that Stout uses 2900°F. for the temperature opposite the tuyeres; and that the Carnegie chart shows 2000°C. (3632°F.) for the temperature just above the center line of the tuyeres. Neither temperature is from actual observations. By referring to Figs. 69 and 72*a* in the section on Combustion Zones, it will be seen that the temperatures inside the balloon-shaped combustion zones may be anything from the temperature of complete combustion of incandescent coke with oxygen at 1300 to 1600°F. (calculated to be 4049°F.) down to the temperature of red-hot iron. To attempt to get the temperature at the tuyeres of a blast furnace with an optical pyrometer is futile because of the constant flow of incandescent coke downward from the bosh walls with occasional fragments of ore, limestone, or slag, or a piece of coke not thoroughly heated. Moreover, according to the charts shown in the section on Combustion Zones, it would not be possible to see through about 20 in. of incandescent coke to the point of maximum combustion of carbon to carbon dioxide.

In their discussion[2] of temperature observations, Kinney, Royster, and Joseph say,

> The outstanding feature of the temperature observations in the interior of the furnace is the temperature at the center of the hearth level. The tuyere temperatures, as recorded by several hundred observations with an optical pyromenter, average 1534°C. (2793°F.) but this is probably many degrees below the actual temperature of the interior of the combustion zone. The temperature as measured by a couple at the center of the hearth is 1250°C. (2282°F.), or approximately 300°C. (572°F.) lower than the observed temperature of the tuyeres.

There are also tuyere temperatures recorded[3] as high as 1785°C. (3213°F.).

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[1] "Carbon in Pig Iron," *A.I.M.E.*, vol. 120, p. 136, 1936.

[2] "Iron Blast-furnace Reactions," *Bur. Mines Tech. Paper* 391, p. 52.

[3] "Production of High-alumina Slags in the Blast Furnace," *Bur. Mines Tech. Paper* 425, p. 17, 1928.

Temperatures in Shaft.—The temperatures across the several planes of the furnace above the tuyeres have been fairly accurately obtained at different furnaces. The illustrations in the preceding chapter show the great variations in temperature along the radius of a plane from inwall to center of the furnace. No set of observations so far reported shows that the same temperature persists across any plane of the furnace parallel to the hearth; the best that can be done is to take an average of observations made at some certain point on the radius—at the inwall and at the center—as is shown[1] in Fig. 86. The temperatures were recorded by base-metal and platinum-rhodium couples. On planes 1, 2, 3, and 4 the results are given for temperatures at the inwall, and on planes 3 and 4 for points in center of the plane.

Table XV gives the results of temperature observations in various parts of the furnace. The temperatures were recorded by base-metal and Pt-Rh couples. On planes 1, 2, 3, and 4 the results are given for temperatures at the inwall, and on planes 3 and 4 for points in center of the plane. The temperatures at the center of planes 4 and 6 (tuyere plane) were recorded with a Pt-Rh couple.

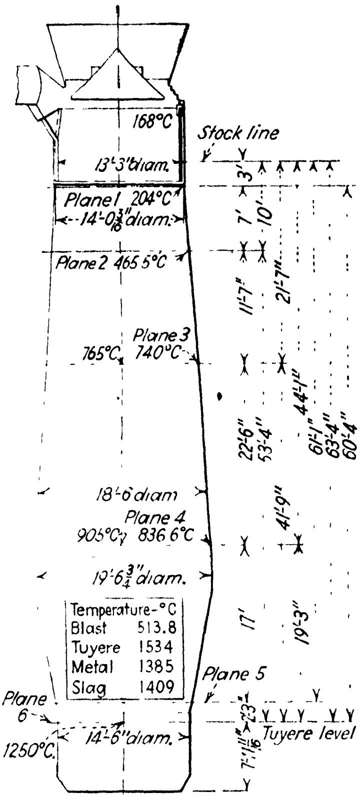

Fig. 86.—Temperature observations at various points in furnace. (*From U.S. Bur. Mines Tech. Paper* 391.)

Temperature of Top.—The temperature of the waste gases as they go into the downcomer is called the "top temperature," and this temperature is usually the temperature of a mixture of very hot gases from certain parts of the whole stock-line plane and

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[1] Reproduced from *Bur. Mines Tech. Paper* 391, p. 51.

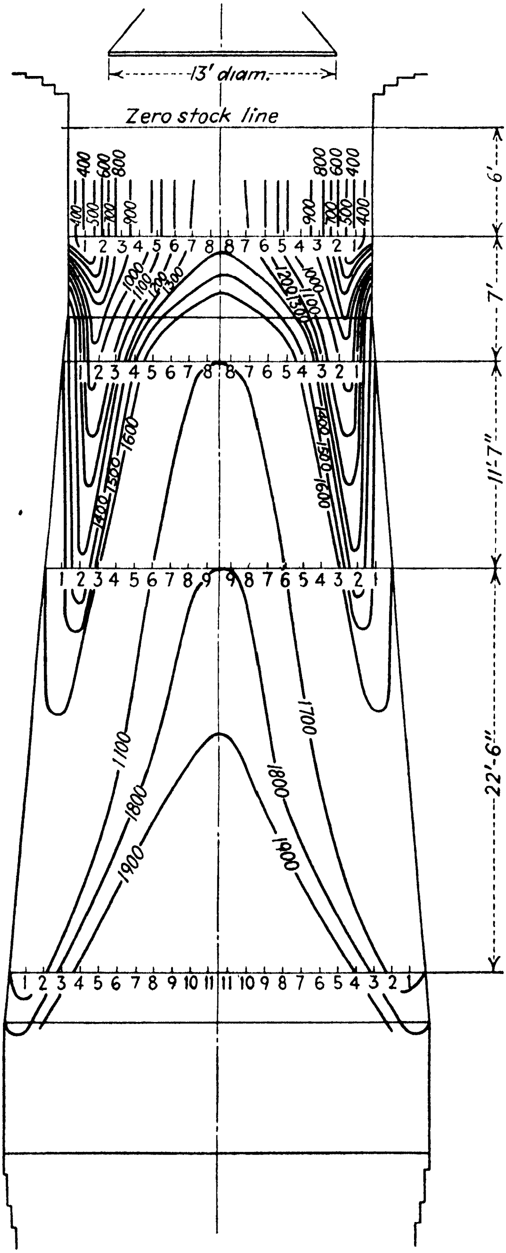

FIG. 87.—Isotherms inside the furnace. (*From U.S. Bur. Mines Tech. Paper* 442.)

much cooler gases from other parts of the same plane. Sometimes the gases from the center of the furnace have the highest temperature as shown in Fig. 87.[1] These temperatures, varying from 400 up to 1300°F. were found at plane 1, 6 ft. below the stock line in No. 4 furnace, South Chicago. The reverse condition was found at West furnace, Columbus, as shown in Fig. 84 in the section on Gas Velocities.

Table XV.—Temperature Readings at Various Points in the Furnace

Point of observation	Distance below stock line		Distance above center of tuyeres		Temperature at inwall, °F.	Temperature at center of plane, °F.
	ft.	in.	ft.	in.		
Top gas					334	
Plane 1	3	0	60	4	399	
Plane 2	10	0	53	4	870	
Plane 3	21	7	41	9	1364	1409
Plane 4	44	1	19	3	1538	1661
Plane 5	61	1	2	3		
Tuyere	63	4			2793	2282
Blast					957	
Slag					2668	
Metal					2525	

PRESSURES INSIDE THE FURNACE

The pressures of the gases inside the blast gradually decrease from the initial pressure of the blast as it enters the tuyeres down to the pressure of the waste gases as they leave the top of the furnace through the downcomer. The pressure at the tuyeres, measured in pounds per square inch, depends upon the volume blown and the conditions inside the furnace; the pressures of the top gases depend on the volume of blast blown, the conditions inside the furnace, and the back pressure of the gas-cleaning system.

Each blast furnace requires a certain volume of blast per minute in order to work properly; if too much wind is blown into the furnace, it will be "overblown," if not enough wind is blown, there may be irregularities and there will be less tonnage. There

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[1] Reproduced from *Bur. Mines Tech. Paper* 442, p. 106.

is no exact mathematical rule for knowing beforehand just what volume of wind is best for any particular furnace, it can be approximately estimated and then adjusted by practice. There must be enough oxygen pumped into the furnace to burn properly the amount of coke that is right and sufficient for that particular furnace. This amount is explained in the chapter on blast furnace capacity.

Although "the conditions inside the furnace" relate chiefly to the raw materials, Brassert[1] says that high blast pressures "can be lowered by changing the furnace lines . . . flatter boshes will decrease the blast pressure, but a flat bosh will eventually build up, throttle the descending column, and cause high pressure, hanging, and slipping. Therefore, flat boshes are not to be recommended as a means of maintaining low blast pressures, so we have looked in another direction to decrease the resistance in the stack and that is by lower gas velocities throughout. The lower gas velocities were obtained by means of wider stacks, larger inwall batters, and larger, but short and steep, boshes." Brassert, in the same discussion referred to the statement of the late J. E. Johnson, Jr., that "considerable of the weight of the charges is carried on the blast."

If the pressures get too high and are much above the normal pressure of that furnace, the stock will not move downward. In fact, the increased pressure is due to some condition inside the furnace that prevents the stock from descending continually and readily. In the author's own experience the worst condition causing high blast pressure was where the fuel had high ash and was charged into the furnace in large lumps (10 in. or more, in diameter); this was the case when using anthracite coal before the World War, and some of the poorly made by-product coke during the war. The author's comments on such conditions[2] were as follows:

> During the War, when we had very incombustible coke, we were obliged to cut down the volume of blast to about two-thirds of the nor-

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[1] *Trans. A.I.M.E.*, vol. 67, p. 620, 1922. Discussion on the paper of Ralph W. H. Atcherson, "Blast Furnace Flue Dust," *A.I.M.E.*, February, 1920.

[2] Presented in the discussion of the paper of Royster and Joseph, entitled "Effect of Coke Combustibility on Stock Descent in Blast Furnaces," *Trans. A.I.M.E.*, vol. 70, p. 237, 1924.

mal volume, in order to get the furnace to drive. We could not handle the furnace in any other way. Why? The coke was so hard that it would not burn properly before the tuyeres. It was blocky and high in ash; and as it was necessary to have so limy a slag there was an excess of lime above the tuyeres which united with the silica and alumina released by the burning of the coke at the tuyeres. This lime could not unite with the coke ash until the coke was burned. The coke would not burn under ordinary conditions; therefore, the combination between the volume of the blast and the combustibility of coke has to be found in each blast furnace.

Owen R. Rice[1] puts this question of blast volume and blast pressure into a formula which he calls the "blowing factor," and says,

> . . . the blowing factor is simply the ratio between the blast pressure and blast volume:
>
> $$\text{Blowing factor} = \frac{\text{average blast pressure, lb. per sq. in.}}{\text{average wind blown, cu. ft. per min.}} \times 1{,}000$$
>
> In no way is the physical well being of a furnace so truthfully indicated as by the blowing conditions. The blast is the pulse of the furnace. Pressure and volume conditions must be considered simultaneously, however, for the furnace may be driving well with pressures up to 18 or 20 lb. due merely to rapid blowing; or it may be hanging and slipping and may require slackening of the engines with but 14 or 15 lb. pressure. High pressure and low volume produce a high blowing factor and indicate poor working; low pressure and large volume yield a low blowing factor and show proper furnace conditions.

In 1908 the author made some tests to find the blast pressure at each tuyere and at different points along the radius to the center of the furnace at the tuyere level. There was an apparent drop of 2 lb. in pressure between the bustle pipe and the nose of the tuyere, and in two readings there was a drop of only 0.3 lb. between the pressure at the nose of the tuyere and at 5 ft. beyond the nose, near the center of a 12-ft. hearth.[2]

Pressures above the Tuyere Level.—The pressures inside the furnace at various levels have been determined at several furnaces by the investigators of the U. S. Bureau of Mines. The drop in average static pressure from the tuyere level to the top

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[1] In his article "Importance of Hardness of Blast Furnace Coke," *Trans. A.I.M.E.*, vol. 67, p. 599, 1922.

[2] *Trans. A.I.M.E.*, vol. 40, p. 247, 1909.

of the furnace when plotted against distance above the tuyeres is nearly a straight line, as is shown in Fig. 88, which has been reproduced from Fig. 48 of Kinney's classic report[1] "The Blast Furnace Column."

Figure 89, adapted from the same report, shows the isobars with pressures given in inches of mercury as in Fig. 88 mentioned above. It is clearly seen that across any plane inside the furnace there is considerable difference in static pressure. It is apparent that it is practically impossible to get an accurate "lifting value" of the static pressure of the ascending column of hot gases in supporting the descending column of solids. The pressures decrease with increase of distance above the tuyeres, but at the same time there is a corresponding decrease in the height of the column of stock to be supported.

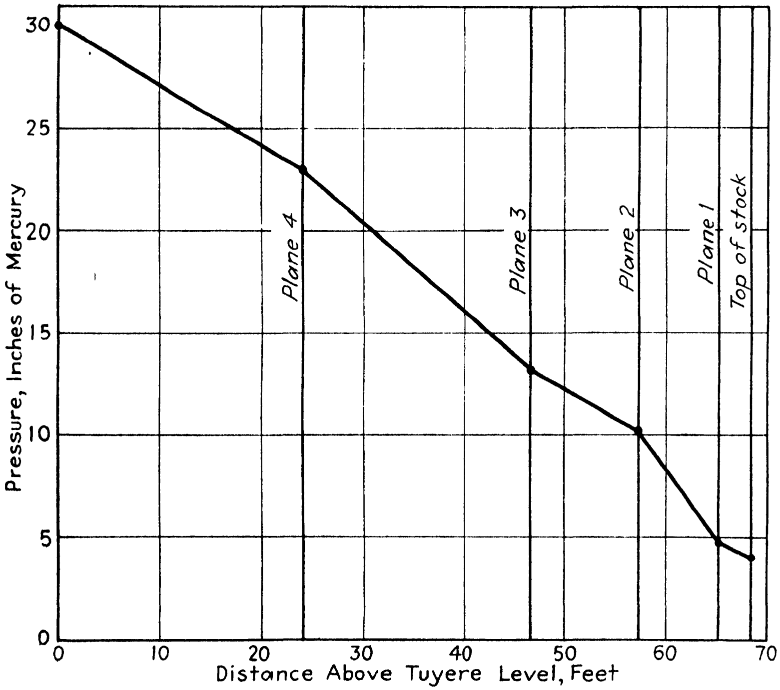

FIG. 88.—Static pressure at various elevations. (*From U.S. Bur. Mines Tech Paper* 442.)

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[1] *Bur. Mines Tech. Paper* 442, 1929.

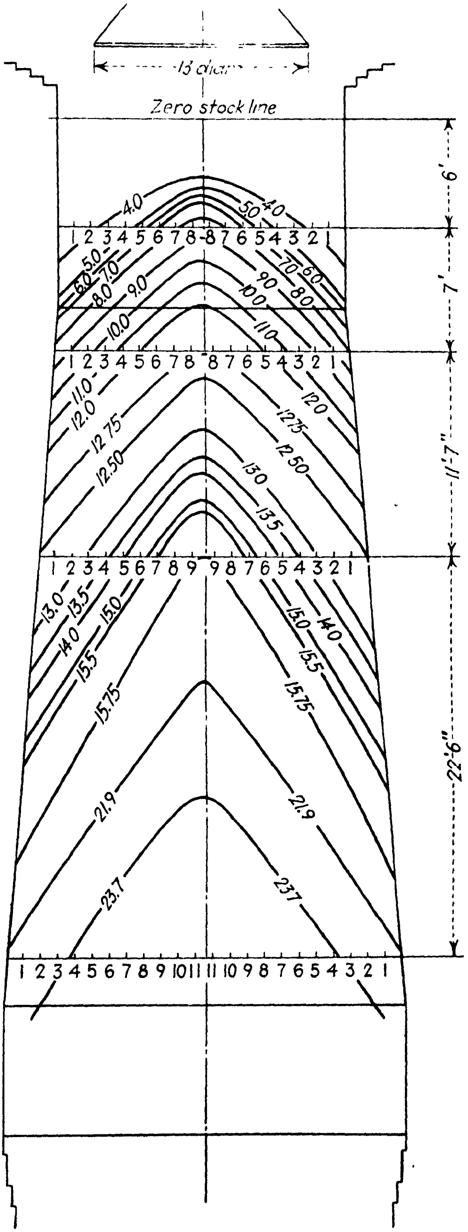

FIG. 89.—Pressures inside the furnace—isobars. (*From U.S. Bur. Mines Tech. Paper* 442.)

CARBON REACTIONS

The whole blast furnace process is based on a unit of iron (Fe) and a unit of carbon (C). These two essential units enter the top of the blast furnace as solids; with the exception of the small amounts of each leaving the top of the furnace as flue dust, the two essential units leave the furnace as liquids and as gases.

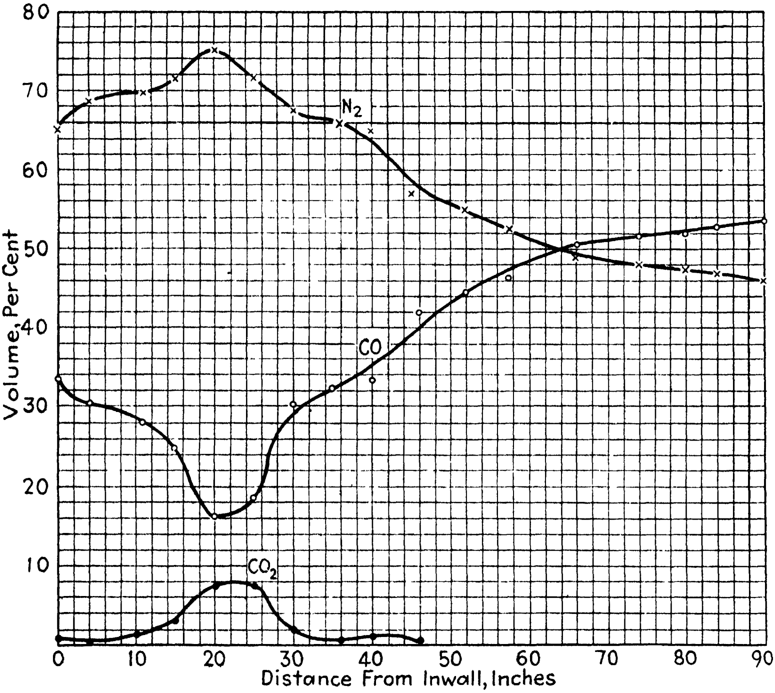

FIG. 90.—Summary curves of gas analyses from plane 5. (*From U S. Bur. Mines Tech. Paper* 391)

Practically all the iron, with some of the carbon dissolved in it leaves the furnace in its fluid state; a part of the carbon leaves the top of the furnace as carbon monoxide (CO) and a part as carbon dioxide (CO_2). There is also a small amount of carbon leaving the furnace compounded in the cyanides, either as gases out of the top and as fumes on the slag, or as a liquid in small traces in the slag.

Carbon reactions inside the furnace are continuous, vigorous, definite, and yet uncertain; they continue even after the molten iron runs out of the iron notch, when certain parts of the carbon dissolved in the liquid iron become solid and pass off into the air as kish or collect on the sides of the ladles into which the iron is poured.

The carbon reaction that is most important in the blast furnace process is that of the reduction of iron oxides by carbon monoxide gas, as has been described in the section on Reduction of Iron Ores. The carbon monoxide gas, as was explained in the section on Bosh Gas, is mixed with about 1.8 times its weight of nitrogen; some investigators say that nitrogen is inert and does not enter into any reactions inside the furnace but acts simply as a carrier of heat from the hot-blast stoves and then from the combustion zone upward through each succeeding zone of the furnace and out of the top with the waste gases. Other investigators, especially Richard Franchot[1] place much importance on the formation of cyanogen (CN) and concentration of cyanides (KCN) in the center of the furnace at the bosh level, but Kinney and Guernsey reported that "the amounts of cyanides which have thus far been found in circulation are too small to affect significantly the fuel economy of the furnace." This statement

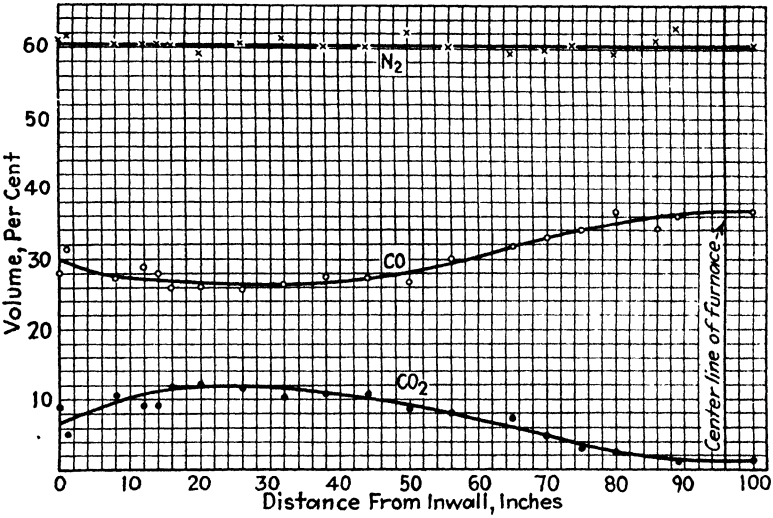

FIG. 91.—Summary curves of gas analyses from plane 3. (*From U.S. Bur. Mines Tech. Paper* 391.)

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[1] *A.I.M.E.*, 1470-C, February, 1926.

agrees with the author's own investigations. Therefore, we will not consider further the reactions of carbon and nitrogen.

We have seen that all the carbon in the coke is not converted into carbon monoxide in the combustion zones in front of each tuyere; only a majority of the solid coke reaches the tuyeres, and certain varying proportions of the solid coke filled into the furnace are gasified in the upper zones of the furnace. In discussing the paper[1] "Effect of Coke Combustibility on Stock Descent," Richard Franchot said, in part,

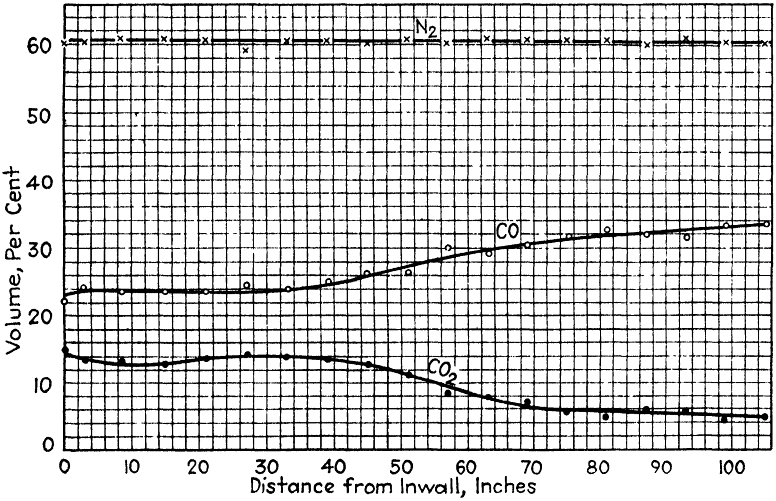

FIG. 92.—Summary curves of gas analyses from plane 2. (*From U S. Bur Mines Tech. Paper* 391.)

> The furnace acts differently with different cokes. To find out what it is in the coke that underlies this difference in action, it will be necessary to understand how any coke acts in the furnace. What are the factors that limit the burden-carrying capacity of the coke? This is a thermodynamic problem, solution of which is not to be found in the literature of the blast furnace in any terms approaching mathematical

The author agrees with the above statement of Franchot. There is still so much of the fundamentals of the blast furnace process to be discovered that there is some danger that, before any one can prove all that takes place inside the furnace, some one will have discovered a better way to extract the iron from iron ores. Engineers, chemists, physicists and laymen have criticized the apparently roundabout way of using the oxygen of the air to extract the oxygen of the iron ore, thereby getting only 4453 cal. out of the combustion of carbon to carbon monoxide when the combustion of carbon to carbon dioxide gives 14,450 cal. and the oxygen of iron oxides will satisfy the carbon of the coke in the same proportion as the oxygen of the air.

The problem of the carbon reactions inside the blast furnace presents a most interesting field for research, perhaps not so broad and deep as the field of carbon dioxide and nitrogen and water in the field of plant and animal life; but the addition of greater heat and pressure makes the problem complicated and mysterious enough to furnish a worth-while investigation

The downward path of solid carbon in the form of coke or of limestone begins at the temperature of the outdoor atmosphere, but the temperature rises and the atmosphere changes at once to one of a mixture of hot gases which not only raise the temperature of the coke and limestone but soon begin to react as shown on Figs. 73 and 74 in the section on Reduction of Iron Ores.

Carbon (C), carbon monoxide (CO), and carbon dioxide (CO_2) are in constant warfare with each other at the different temperatures in the several zones of the furnaces. As soon as CO_2 is formed in the complete combustion of coke and hot blast at the nose of the tuyeres, it is broken up into two volumes of CO immediately on coming in contact with more C in the incandescent coke:

$$O_2 + C = CO_2$$
$$CO_2 + C = 2CO$$

REACTIONS OF THE METALLOIDS

Besides the reactions that bring about the reduction of iron oxides to metallic iron and the subsequent formation of pig iron containing several metalloids, such as carbon, silicon, manganese, sulphur, phosphorus, vanadium, titanium, chromium, copper, nickel, etc., there are the reactions whereby these other elements are reduced from the minerals combined with which in various forms, they came into the furnace burden. Pig iron consists of 92 to 94 per cent iron and the balance of these metalloids, carbon usually predominating. In a later section Chemical Composition of Pig Iron, some of the usual, and unusual, percentages of these metalloids in pig iron will be shown.

ANALYSES OF METAL AND SLAG SAMPLES TAKEN AT TUYERE LEVEL WHEN GAS SAMPLES WERE TAKEN

Description	Si, %	Fe_2O_3, %	Si_2O_2, %	P, %	Mn, %	Al_2O_3, %	CaO, %	MgO, %	Total C, %	S, %
Slag from end of sampler No 3 tuyere, East furnace, May 4, 1923, 9:30 A.M	..	13 29	31 60		0.70	16 71	36 25	3 41	. .	0 250
Slag from No. 3 tuyere, West furnace, May 4, 1923, 1:30 P.M	.	31 77	23 00		0 88	9 23	30 23	3.19		0 200
Metal from end of sampler No. 3 tuyere, East furnace, May 4, 1923, 9:30 A.M	2.82	.....	. . .		0 34		. . ..		1 55	0 095
Metal from No. 3 tuyere, East furnace, May 5, 1923, 9:30 A.M. No 1 blast pres .	3 34	.		0 257	0 48		. .	. .	2.78	0 020
Metal from No. 3 tuyere, West furnace, May 4, 1923, 1:30 P.M	0 66			0 297	0 37		.		2 23	0 101

Carbon.—The carbon in pig iron, in its two forms of graphitic and "combined carbon," undoubtedly comes from the carbon in the coke, by contact of the soft, newly reduced iron and incandescent coke at points all the way from the bosh line to the iron notch. Just where the carbon goes into the iron for the final analysis is not definitely known. The following quotation, from the author's previous paper[1] "Carbon in Pig Iron," gives only a partial answer to the question, Where does

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[1] *Trans. A.I.M.E., Tech. Paper* 11, 1927.

the carbon enter the iron? At the tuyeres? Or below the tuyeres?

From the few samples taken at the tuyeres during this test, we believe that the reactions that determine the character of the slag and of the iron are only partially completed at the tuyere level, and that much chemical action takes place between the level of the combustion zones in front of the tuyeres and the molten iron that collects in the bottom of the furnace. The results shown in the table are indicative but not conclusive.

Silicon.—It has been generally thought that the silicon in pig iron came from the silica of the ash in the fuel as it was burned at the tuyeres. This cannot be entirely so because the ash in charcoal does not have enough silica for the silicon in the iron; and coke does not have enough silica for silvery iron. The silicon must come from the slag during the intimate contact of molten slag and molten iron, especially when the drops of iron pass down through the bath of slag below the tuyere level

Sulphur.—Sulphur has an affinity for solid iron from the minute it is reduced from the ore and will not part company until it joins with calcium in the high temperature near the tuyeres and below the tuyeres in the slag bath. If the slag bath is too low in temperature or too acid in its analysis, the sulphur will remain in the pig iron and very little will enter the slag.

Manganese.—From about 70 to 85 per cent of the manganese in the ore burden will be reduced and combine with the iron, beginning the contact of manganese oxide with solid incandescent carbon and continuing down into the hearth of the furnace; the balance passes off in the slag. The hotter the hearth and the more basic the slag, the more manganese will go into the pig iron.

Vanadium.—Neither vanadium nor titanium seems to be alloyed with the iron; both are probably present as carbides; at all events, they are found almost wholly, if not entirely, in the insoluble graphitic residue left after the iron has been dissolved . . . Apart from any cleansing action these elements may have by removing any nitrogen and oxygen that may be present, the suggestion is here ventured that they affect the structure by separating out earliest during the solidification of the iron as uniformly-distributed, finely-divided carbides, which furnish starting-points or nuclei for the rapid crystallization of the iron, in this way causing a finer grain—with its accompanying greater strength—than would be the case in the absence of these elements. That titanium carbide thus crystallizes out while the iron is still soft is proved by its perfect sharp-edged cubical crystals.[1]

The magnetic iron ores in northern New Jersey, particularly at Richard mine, contain some vanadium and titanium; a sample of Richard ore (February, 1914) had 0.07 per cent vanadium and 0.348 per cent titanium.

The author found that where there was 0.035 to 0.045 per cent vanadium in the pig iron there was no large amount of "kish" present when the iron ran from the furnace, even when making the higher silicon iron.

COMBUSTION OF THE FUEL

The combustion of the fuel in a blast furnace, whether it be coke, charcoal, raw bituminous coal or anthracite, takes place in the combustion zones in front of each tuyere, and this combustion has been shown in a previous section to be complete within a distance of about 42 in. from the nose of the tuyere.

The double function of the combustion of fuel in the hearth is, first, to provide heat required for high enough temperatures not only to fuse the slag and melt the iron but to have enough surplus heat above the "critical temperature" of the hearth (according to the late J. E. Johnson, Jr.) to preheat properly the materials coming down into the hearth of the furnace and to carry on the chemical reactions in the hearth, in the bosh, and in the upper part of the shaft of the furnace; and second, to provide the carbon monoxide gas of the bosh gas, and to keep it at the right temperature.

Up to the time of the decisive experiments of the U.S. Bureau of Mines "for the purpose of determining the exact nature of the combustion of coke in the neighborhood of the tuyeres," and the publication of the fundamental data discovered by Kinney, Royster, Joseph, Perrott, Blizzard, and Sherman in 1923 and 1924, the combustion of fuel was supposed to take place at the level of the tuyeres all the way across the hearth of the furnace. Brassert, in his very comprehensive and clear description[2] of prewar American blast furnace practice, says that "with slow-

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[1] SHIMER, PORTER W., "Vanadium in Pig Iron," *Trans. A.I.M.E.*, vol. 43, 1912.

[2] "Modern American Blast Furnace Practice," presented before the American Iron and Steel Institute in 1914.

burning coke, the molecules of oxygen are not all able to combine immediately with their molecules of carbon. The result is that the combustion is carried up in the furnace, the heat generated by combustion is spread over a larger area, and the top temperature increases."

Royster and Joseph[1] say that "Perrott and Kinney have verified the discovery of Ebelman, in 1841, that all of the coke burned by the blast is consumed within 30 to 40 in. from the tuyeres," and mentions Van Vloten's investigations in 1893 (see Fig. 69 in section on Combustion Zones).

It was a perfectly logical conclusion to believe that combustion of the fuel took place all the way across the hearth of the furnace, because that is exactly what took place in blast furnaces in this country for over two hundred years in all the charcoal furnaces and the early anthracite furnaces as long as the hearth diameter was not over about 8 ft. When the hearth diameter was greatly increased over twice the length of a combustion zone, which is about 42 in. beyond the nose of the tuyere (tuyeres usually project 6 to 9 in. beyond the wall of the hearth), there arose a different set of conditions inside the furnace, and observations and conclusions made then might not hold true now. However, each observation in blast furnace practice made and recorded, helps along the art of making iron, and gradually we learn the truth of what takes place. The saying of the late J. E. Johnson, Jr., is repeated here, *i.e.*, "experiment on the furnace itself is the only safe foundation for practice or for a useful theory."

In further discussion of the above paper of Royster and Joseph[2] (who at first did not realize the importance of the discovery of the combustion zones and drew such startling conclusions that the paper was once rejected), the present author quoted Brassert's definition of coke combustibility given several years before, "What principally concerns the blast furnace is the rate of progression of the combustion which depends not so much on the chemical analysis as on the physical qualities of the coke. It is this rate of progression that we term combustibility which is the speed at which the carbon molecules in the coke combine

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[1] In their paper "Effect of Coke Combustibility on Stock Descent in Blast Furnaces," *Trans. A.I.M.E.*, vol. 70, p. 225, 1924.

[2] *Ibid.*

with oxygen under given conditions." The author also suggested a modification of Brassert's definition to read as follows:

Combustibility of Coke.—"Combustibility of coke is the rate of complete gasification in front of the tuyeres of a blast furnace under standard conditions of blast temperature and of blast volume."

Although we do not yet have any accepted standards of blast volume and temperature, yet we must have them before we can properly measure the combustibility of cokes. The furnace always gives the final answer, and the place to test the combustibility (to date, at least) is in the combustion zones in front of the tuyeres.

SLAG FORMATION

The slag is one of the essentials of the blast furnace process; its formation begins in the middle regions of the shaft of the furnace and continues until the slag passes out of the cinder notch or out of the iron notch. The character of the slag is the final control of the character of the pig iron; the control of the slag will be discussed in a later section.

The statement of Oliver Bowles[1] is so concise that it is quoted herewith:

> The chief impurities in most iron ores are silica and alumina, and the addition of a basic flux is necessary to form a slag. If iron ore were reduced without flux, the siliceous and argillaceous gangue would unite with the iron oxides to form double silicates of iron and alumina, which would involve a heavy loss of iron. With the addition of limestone, the silica and alumina have a stronger affinity for the lime and magnesia than they have for the iron, and in consequence double silicates of lime and alumina or magnesia and alumina are formed—compounds which contain very little iron. Just as an acid and a base react to form a salt, so the siliceous impurities of the ore react with the basic flux to form a slag which corresponds to the salt of wet chemistry. Lime is infusible at the temperature of a blast furnace, but when it combines with the silica and alumina of the furnace charge it forms a liquid slag which floats on the molten iron. At the fusion zone, approximately 15% of the original iron exists as FeO, and this must be reduced in the lower part of the furnace. With insufficient flux a black slag containing iron is likely to be made during the reduction process. It is true, however,

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[1] In his article "Utilization of Metallurgical Limestone and Dolomite," *Trans. A.I.M.E., Tech. Paper* 62, 1928.

that a normal supply of lime will not in itself prevent loss of iron in the slag; other conditions must also be correct.

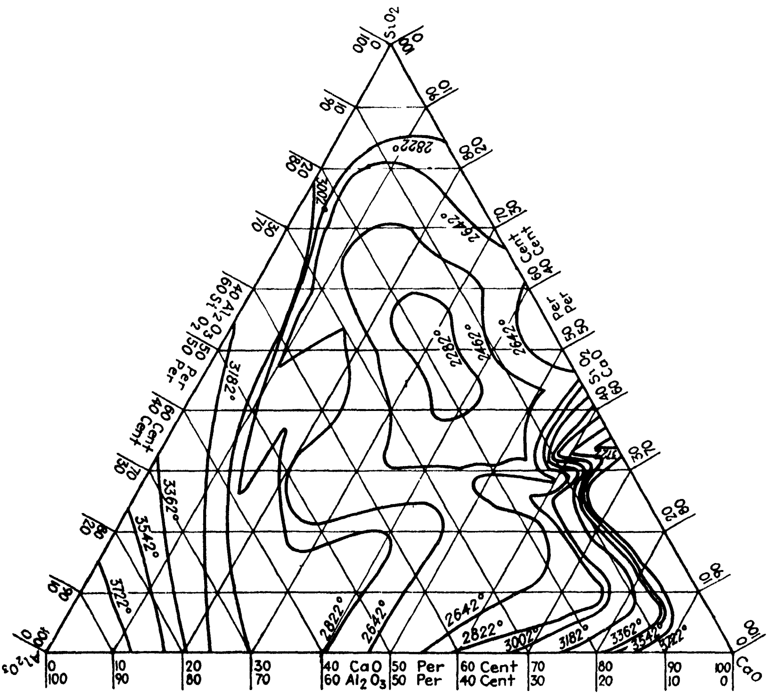
Coke is used as blast-furnace fuel, and when it burns varying amounts of ash are formed. The ash is composed largely of silica and alumina, which, like the similar impurities in the ore, must be removed. Therefore the formation of a slag with the ash is a secondary function of the limestone flux. The slag should pick up the coke ash in the combustion zone, for it is desirable to remove the ash which forms on the coke lumps in order that the coke surface shall be clean. Inasmuch as the combustion zone is the seat of life in a furnace, it is not only necessary to remove the ash but also to produce a slag which will pass freely through this part of the furnace. An improper slag adheres to the coke and is chilled by the blast. This results in a sluggish tuyere, and tuyere action must be carefully controlled by the furnace operator. The slag should have a melting point below the average tuyere temperature, and should be fluid enough to pour out readily through the cinder notch.

In some localities, iron ores are associated with sufficient lime carbonate to be self-fluxing. Ores are said to be self-fluxing when the sum of the calcium and magnesium oxides is approximately equal to the sum of the silica and alumina. Such ores occur in the iron district of Birmingham, Alabama. They smelt very readily, as the constituents are intimately mixed.

The formation of slag is an exothermic reaction contributing a rather small part of the total heat generated; in the graphic chart by Stout (see Fig. 73) the amount of heat generated by the formation of the slag is 1.08 per cent of the total. In the balance sheet by Clements (see Table XIII), the heat generated in the formation of silicates in slag, 2894 B.t.u., is 1.39 per cent of the total generated.

Melting Temperature of Slags.—The melting point of blast furnace slag is a very important factor; it depends upon the chemical composition, especially the percentage of silica, alumina, and lime. The most helpful guide for slag control that the author ever saw was a plaster model of the triaxial diagram of the melting points of varying percentages of silica, alumina, and lime made by Wilber Stout when he was chief chemist for The Columbus Iron & Steel Co., long before he became state geologist for Ohio. This model showed the necessity of burdening the furnace for a slag that has a safe margin of leeway in the variations of magnesia and alumina when working with certain iron ores, especially when the alumina is only about 5.6 per cent; each slight decrease in the percentage of alumina makes a slag of much higher melting point. A similar condition exists when there is very little magnesia in the slag.

The model referred to above was made from the Eutectic Chart of Blast Furnace Slags (Nov. 16, 1912) which is herewith reproduced in Fig. 93.



Note: Degrees Fahr. Temp.

FIG. 93.—Eutectic chart of blast furnace slags. (*Courtesy of Wilber Stout.*)

Although the temperature of the slag inside the furnace is higher than the temperature of the pig iron, it is not economical to have a slag with a free-running temperature so high that it takes excessive fuel to melt it.

With charcoal-furnace slags, the silica can be carried so high that the melting point of the slag is very low, and there is a large area of "safe" analysis. When basic iron was first made in this country it was thought necessary to carry a very limy slag so as to get low silicon and low sulphur in the pig iron. Nowadays, with low-sulphur coke and a rich iron mixture it is safe to run on a very "lean" slag without the danger of getting high-sulphur iron. Some open-hearth men say that basic iron from a furnace with a very hot hearth, which means a more refractory slag, is preferred.

In the preceding section it was stated that the formation of the slag began near the middle of the furnace, above the bosh line; the slag that melts at points above the tuyere level must combine with the silica and alumina of the coke ash. It is evident that the slag that runs from the cinder notch is different in composition and melting temperature from the slag that enters the combustion zone.

The questions of "free-running temperature" (as brought out by the late J. E. Johnson, Jr.) of viscosity as studied by Feild[1] and of the relative desulphurizing powers of blast furnace slags, reported by Holbrook and Joseph[2] can now be answered, and many hitherto mysterious actions of blast furnaces and diametrically opposite theories of blast furnace practice can be explained by the results of research of these men and of Dr. McCaffery and his associates.

CARBON IN PIG IRON

Carbon in pig iron is not only essential but, ordinarily, it is the most abundant metalloid present; iron without carbon could not be pig iron. Carbon in pig iron has been accepted, but seldom specified. How it gets into the pig iron as it is being smelted in the blast furnace and why just about so much of it enters into the pig iron in certain blast furnaces and more of it or less of it enters the pig iron in other blast furnaces or in the same blast furnace under varying conditions are problems that have not yet been satisfactorily solved.

During the author's own practical blast furnace experience, he collected analyses of pig iron, including the graphitic and combined carbon, and recorded them in reference to the percentage of silicon present, having in mind the generally accepted explanation that "silicon drove out the carbon." To this actual experience, the author has added some analyses by J. B. Rogers, who was superintendent of the blast furnaces of the Ashland

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[1] *Trans. A.I.M.E.*, vol. 56, 1917.

[2] *Trans. A.I.M.E.*, vol. 120, p. 99, 1936.

TABLE XVI.—EFFECTS OF FUELS AND SILICON ON AMOUNT OF TOTAL CARBON IN PIG IRON*

Analyses of Pig Iron Arranged according to Percentage of Silicon

Iron	Silicon, %	Sulphur, %	Phosphorus, %	Manganese, %	Graphitic carbon, %	Combined carbon, %	Total carbon, %	Total metalloids, %	Coke
Basic	0.36	0.022	0.153	0.80			4.40	5.74	Kanawha and Pocahontas
Low phosphorus	0.47	0.039	0.025	0.31	3.55	0.83	4.38	5.22	Pocahontas
Low phosphorus	0.78	0.020	0.028	0.49	4.27	0.46	4.73	6.05	Pocahontas
Low phosphorus	0.85	0.015	0.028	0.48	4.39	0.55	4.94	6.31	Pocahontas
Low phosphorus	1.03	0.010	0.029	0.55	4.30	0.40	4.70	6.32	Pocahontas
Malleable	1.04	0.028	0.169	0.69	3.60	0.90	4.50	6.43	Kanawha and Pocahontas
Malleable	1.10	0.013	0.163	0.87	3.64	0.88	4.52	6.66	Kanawha and Pocahontas
Low phosphorus	1.29	0.015	0.026	0.54	4.32	0.64	4.96	6.83	Pocahontas
Malleable	1.33	0.018	0.183	0.66	3.65	0.80	4.45	6.64	Kanawha and Pocahontas
Low phosphorus	1.58	0.008	0.028	0.54	4.25	0.35	4.60	6.76	Pocahontas
Low phosphorus	1.67	0.012	0.028	0.59	4.44	0.21	4.65	6.95	Pocahontas
Foundry 2x	1.79	0.028	0.201	0.176	3.10	0.19	3.29	5.49	Broadtop
Bessemer	1.85	0.021	0.058	0.38	3.50	0.75	4.25	6.56	Pocahontas
Low phosphorus	1.94	0.014	0.032	0.60	4.20	0.21	4.41	7.00	Pocahontas
Foundry —2x	1.98	0.015	0.144	0.173	3.23	1.15	4.38	6.69	Broadtop
Low phosphorus	2.00	0.010	0.029	0.60	4.43	0.15	4.58	7.22	Pocahontas
Low phosphorus	2.19	0.012	0.032	0.63	4.40	0.15	4.55	7.42	Pocahontas
Low phosphorus	2.46	0.011	0.030	0.69	4.32	0.12	4.44	7.64	Pocahontas
Foundry —2 Plain	2.49	0.050	0.425	0.115	3.40	0.12	3.52	6.60	Broadtop
Foundry 1 Scotch	2.79	0.017	0.559	0.173	3.14	0.74	3.88	7.42	Broadtop
Foundry 1 Scotch	3.09	0.006	0.473	0.216	3.83	0.24	4.07	7.92	Broadtop
Foundry 1 Scotch	4.01	0.053	0.227	0.241	3.29	0.41	3.70	8.23	Broadtop
Low phosphorus	4.69	0.005	0.024	0.70	3.73	0.09	3.82	9.34	Pocahontas
Silvery	5.12	0.034	0.534	0.315	3.22	0.14	3.36	9.36	Broadtop
Silvery	7.69	0.024	0.544	0.302	2.21	0.50	2.71	11.27	Broadtop
Silvery†	5.60	0.031	0.149	1.15	2.42	0.58	3.00	11.27	Unknown
Silvery	10.34	Trace	0.54	0.54	1.92	0.07	1.97	13.41	Unknown
Silvery†	11.26	0.020	0.84	0.84	1.52	0.03	1.55	14.51	Unknown
Silvery†	12.19	Trace	0.48	0.76	1.52	0.06	1.58	15.01	Unknown

* *Trans. A.I M.E.*, vol. 75, 1927

† Ashland, Ky

Iron & Mining Co., Ashland, Ky., and was making "silvery iron" at the time. These analyses are shown in the accompanying table.

The analyses do not tell the whole story, but they show that with Pocahontas beehive coke, the total carbon was generally high. The data relating to the composition of the slag are lacking but the author's customary practice was to have a rather basic slag.

Carbon is present in pig iron in at least two forms, graphitic carbon and combined carbon. As a rule the total carbon is controlled by the character of the blast furnace fuel, but the proportion of graphitic and combined carbon is controlled by the temperature of the earth. The temperature of the iron as it flows from the iron notch has been found to determine the proportion of the two forms of carbon after the metal has gone through the pig machine and solidified into "iron in pigs." A cast of basic iron was sampled at the runner, in the 75-ton ladle and from a pig in the car; the total carbon was 4.35, 4.25 and 4.25 per cent respectively; the combined carbon was 0.89, 0.90 and 1.14 per cent.

Recent studies of the effect of carbon in pig iron, reported at the Chicago meeting of A.I.M.E., October, 1935, indicate that merchant pig iron from a certain furnace made with the same fuel has a characteristic "personality."

Table XVI shows the effects of fuels and percentages of silicon on the amount of total carbon in pig iron; Fig. 85, temperatures inside the furnace, shows how the combined carbon is increased by the lowering of the temperature of the hearth.

It has been found that the "big-hearth" furnaces make pig iron with higher total carbons than furnaces of less hearth diameter using the same raw materials.

DESULPHURIZATION

One of the chief functions of blast furnace slag is to act as the solvent for calcium sulphide which is the compound that removes the sulphur from the iron in the fusion zone. Most of the sulphur comes from the coke and at first it all goes into the iron as soon as it is reduced from the ore. The first thorough study of the relative desulphurizing powers of blast furnace slags to be made and reported was by W. F. Holbrook and T. L. Joseph (then, both with U.S. Bureau of Mines).[1] Their paper is the best record and explanation of how slag reacts to take the sulphur out of the iron inside a blast furnace, and some of the statements are herewith quoted:

> While it is generally known that high temperatures and more basic slags favor desulfurization, operators as a rule produce the most acid slag that will permit proper desulfurization. . . . Because slag and metallic iron are immiscible, the desulfurization reaction is heterogeneous, occurring only at the interfaces between slag and metal bodies. In the blast furnace the newly reduced iron, containing FeS, descends through the slag bath probably either as small drops or streams, at the interfaces of which desulfurization occurs. After its descent through the slag the iron collects to form a bath of metal, at the top surface of which desulfurization reaction probably occurs. These two steps have been thought to account for all desulfurization in the blast furnace.
>
> The desulfurization reaction
>
> $$FeS + CaO \rightleftarrows CaS + FeO \qquad (1)$$

Fig. 94.—Bubble of CO outlined by film of high-sulfide slag (*Holbrook and Joseph, Trans. A.I.M.E., vol. 120.*)

> is reversible, and the products, CaS and FeO, tend to accumulate in the reaction zone, thus retarding the rate of the reaction. The tendency is for a high-sulfide film to form at the interface between slag and metal. . . . Some of the FeO formed by the reaction of equation 1, however, is reduced immediately by the action of carbon dissolved in the iron:
>
> $$FeO + C \rightarrow Fe + CO$$
>
> The CO, formed at the interface, expands greatly at the prevailing temperature and readily assumed the form of bubbles, which, to escape, must cause configurations and movements in the metal and slag about them, particularly in the interfacial film. That this is true is illustrated by the sulfur print in [Fig. 94] which was made from a quickly chilled specimen. This print shows a bubble of CO leaving the interfacial zone The bubble is outlined by a part of the high-sulfide film in which it was formed The movement of the bubble had distorted the film and was removing some of the CaS at the moment of solidifica-

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[1] "Relative Desulfurizing Powers of Blast-Furnace Slags," *Trans. A.I.M.E.*, vol. 120, 1936.

tion to some point within the slag bath. As such a bubble rises through the slag bath probably it leaves a trail of CaS, which then spreads by diffusion and by the movement of other bubbles. Thus, it is evident that diffusion alone need not account for the removal of CaS from the interface between the slag and metal baths.

There is much more of vital interest in this clarifying paper by Holbrook and Joseph, but space does not permit full quotations.

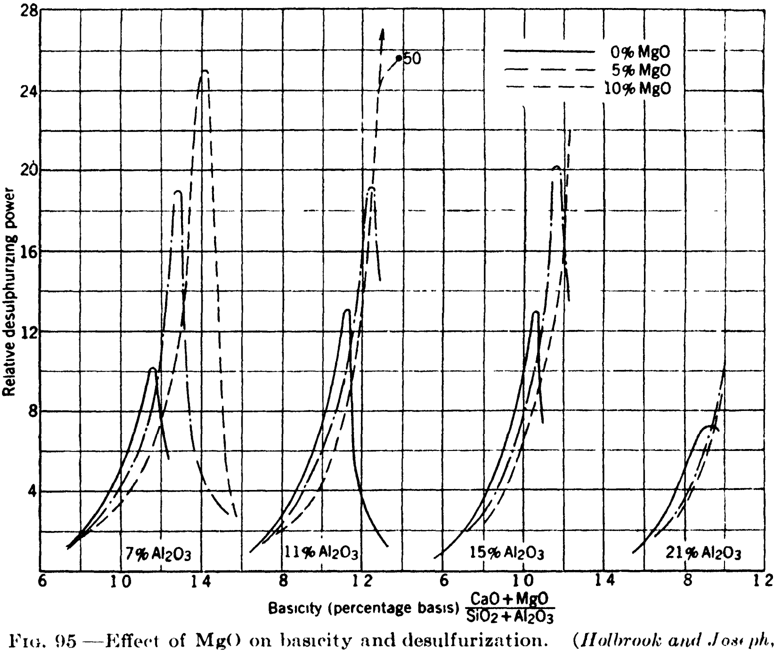

FIG. 95.—Effect of MgO on basicity and desulfurization. (*Holbrook and Joseph, Trans. A.I.M E., vol.* 120.)

The effect of MgO on basicity and desulphurization had special study, and it was found that "basicity does not fill all requirements as an index of desulfurization." [These effects are shown in Fig. 95.] From this figure it is evident that along the rising characteristic increasing MgO results in decreasing desulphurization but slags containing increasing amounts of MgO, owing to its thinning effect, attain higher basicities and therefore greater desulphurizing powers before the range of abrupt thickening is reached. Thus the most striking effect of MgO is to permit the use of higher basicity than would otherwise be possible. They also report that their test "tends to indicate that viscosity and desulfurization are not closely related."

Summary.—A laboratory method has been devised by which the relative desulfurizing powers of slags of varying composition may be determined. Data and diagrams are presented showing relative desulfurizing powers at 1500°C. (2732°F.) of all blast-furnace slags containing 10 per cent or less of MgO that are likely to occur. No simple relationship was found by which chemical composition as designated by the term "basicity" could be compared with desulfurization. It is shown that to relate basicity and desulfurization MgO cannot be combined with CaO as "total bases," nor can Al_2O_3 be combined with SiO_2 as "total acids." Moreover, Al_2O_3 cannot be ignored in computing basicity, as is frequently done. Each oxide has its own effect on desulfurization, and the degree of the effect is not constant for all ranges of composition.

MgO has been found to be slightly deleterious to desulfurization of acid slags. The effect becomes increasingly undesirable as basicity is increased to that of slags of average composition. The presence of MgO, however, is decidedly favorable to desulfurization in the more basic slags.

It is suggested that the evolution of CO accompanying desulfurization has an important role of the over-all process. It retards the descent of falling metal drops and carries CaS and globules of metal away from the bath interface and into the slag, in both instances contributing to the effectiveness of the reaction.

CHEMICAL COMPOSITION OF PIG IRON

"Pig iron is the metallic product of an iron blast furnace," so said the Canadian Government as explained in the opening sentences of this book. The United States Tariff Commission[1] said further that "pig iron" applies to all iron produced in the iron blast furnace whether used in the molten condition or cast into pigs.

Such definitions have sufficed for bounty and tariff purposes, but are inadequate for the intricate ramifications of the iron and steel industry. In the section on Carbon in Pig Iron is the statement that "carbon in pig iron is not only essential but, ordinarily, it is the most abundant metalloid present; iron without carbon could not be pig iron."

Carbon is present in steel, and nearly always there is more iron (Fe) in steel than there is in pig iron. When the truth of a matter is not clearly known, there is much ground for argument

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[1] *U. S. Tariff Commission Report on Iron in Pigs*, Feb. 2, 1927.

and theories. And such has been the case with that simple, yet mystifyingly complicated, metal that we call "pig iron." In *The Iron Age*, Nov. 7, 1935, is an article by A. L. Norbury, as published in the *Bulletin of the British Cast Iron Research Association*, entitled "Cast Iron and Steel Differentiated." He reviews the sets of definitions, as adopted by committees and commissions, beginning with the classification based on the amount of carbon contained in the metal, approved by an international commission at Philadelphia in 1878. He quotes Roberts-Austen (1898); Murray's *Dictionary* (1901); *Journal of the Iron and Steel Institute* (1902); Howe and Sauveur (1912); J. W. Mellor (1932); and makes the following remarks:

> The definition of the terms "cast iron" and "steel" has been the subject of a great deal of discussion. It has been discussed at international conferences, in the law courts and in numerous papers by metallurgists of all nationalities. The development of low-carbon alloyed cast irons has increased the need for some recognized dividing line. *The best method appears to be to fix this in terms of the presence or absence of eutectic.* Definitions of the terms in this manner, together with definitions of one or two other terms, are herein described as a basis for discussion. Some extracts from literature on the subject and a discussion of the limitations of some of the earlier definitions are also presented.
>
> The suggested definitions are as follows:
>
> *Steels.*—Alloys of iron and carbon (other than malleable cast iron) with or without other elements, which do not contain carbide eutectic or graphite eutectic in the microstructure.
>
> *Cast Irons.*—Alloys of iron and carbon with or without other elements, which contain carbide eutectic (white cast iron) or graphite eutectic (gray cast iron) or both carbide eutectic and graphite eutectic (mottled cast iron) in the microstructure.
>
> *Malleable Cast Iron.*—The product obtained by eliminating the carbide eutectic from solid white cast iron by decarburization (whiteheart) or by conversion into graphite by annealing (blackheart).
>
> *Pig Iron.*—Pigs of cast iron from the blast furnace.
>
> *Refined Pig Iron.*—Pigs of cast iron whose chemical analysis and structure have been modified either before solidification from the blast furnace or by treatment involving remelting.
>
> *Semi-steel.*—It is recommended that the use of the term "semi-steel" be abandoned.

In Table XVI, there are several kinds of pig iron given illustrating the variations in total carbon, graphitic carbon, and combined carbon. These analyses are all from actual practice—all but three from the author's own experience—yet they are far from complete. There are several other elements in pig iron besides the five usually reported, *i.e.*, silicon, sulphur, phosphorus, manganese, and carbon. Almost all such elements come from the iron ores smelted, whether they be the virgin iron ores or the miscellaneous iron-bearing by-products and scrap making up part of the burden. Usually the admixture of these elements is unavoidable; the results may be deleterious, but more often they are advantageous. Some of these metalloids are present as alloys of iron, and some probably as carbides, and the graphite is present as such, and is not chemically combined with the iron.

CHEMICAL COMPOSITION OF SLAGS

The clearest practical illustration of what a blast furnace slag really is was given to me by Wilber Stout, state geologist of Ohio, when he was chief chemist and the author was superintendent of The Columbus Iron & Steel Company. He said that a molten slag was like an igneous rock in its molten state with a lot of mineral compounds dissolved in a magma, and that when the slag was cooled to its solid condition the crystals of these various compounds could be discerned by the microscope. That was back in 1909 when very little research work in slags had been done, and each blast furnaceman had his own theory about silica-alumina ratios and the effects of magnesia.

Stout made a plaster model of the melting temperatures of the silica-alumina-lime compounds that in a very practical way showed the "safe" areas for slag composition expressed in terms of percentages of silica, alumina, and calcium oxide. The danger lines when only 4 to 6 per cent alumina is in the slag were clearly shown; also the reasons why a very limy slag will make a furnace run "cold," and, if there is no magnesia, as in slags with oyster shells or pure calcite, why a furnace goes into a "lime set" (appropriately called a "lime bum").

Since those days, much scientific research has been done by Rankin and Wright (1915), J. E. Johnson, Jr. (1918), Feild and Royster (1918), and McCaffery, Oesterle, and Schapiro (1926). This work covers viscosity of slags, temperatures of formation, "free-running" temperatures, the theory of the critical temperature (Johnson), and the theory of solid solutions in quaternary systems. The following quotations[1] give the results of their study of the general subject of slags:

> As blast furnace slags are included in the silica alumina-lime-magnesia system, which is a particular case of four-component solutions, we have determined that there are 22 components, Table XVII, which may enter into the silica-alumina-lime-magnesia system and that 10 or 12 of these components may be present in blast furnace slags which are within the ordinary range of composition. To have a very definite conception of the behavior of these components in a slag, we have developed the theory of the cooling of a four-component solution from the liquid state to the solid and the conclusions that we obtained have been made use of in this paper.

THE FOUR-COMPONENT SYSTEM, SILICA-ALUMINA-LIME-MAGNESIA

A blast furnace slag composed of silica, alumina, lime and magnesia generally will not contain any of the above four substances as such, but it will be composed of compounds of silica, alumina, lime and magnesia. The importance of this is that the properties of the slag are not the properties of silica, alumina, lime and magnesia, but the properties of the slag result from the properties of the compounds which may be present. Slags are solutions of these compounds in varying proportions and the properties of the slag depend, both in the liquid state and in the solid state, on the proportions of the compounds present and their mutual effect while liquid and also to a different degree while solid.

It then becomes necessary to study a four-component solution, for a silica-alumina-lime-magnesia slag is but a particular case of such a solution. Generally there are a fairly large number of types of solutions but in the particular four-component solution we are studying, it happens that the binary types composing it, that is the two-component types that are present in the system, are of only two kinds, first those two-component solutions or binaries which have components that are not mutually soluble, or, in other words, that form eutectics, and secondly those binaries, the components of which are soluble in each other in all proportions or that form an isomorphous series. The general discussion of four-component solutions which follows, takes up only those including these two types of binaries, which are alone needed in the discussion of blast furnace slags, and we do not attempt to discuss all the types which might possibly occur in a four-component system.

The names and composition of the oxides and compounds which may enter into the composition of slags are given in Table XVII. They

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[1] McCAFFERY, RICHARD S., JOSEPH E. OESTERLE, and LEO SCHAPIRO, "Composition of Iron Blast Furnace Slags," *A.I.M.E., Tech. Paper* 19, 1926; issued as *A.I.M.E.*, Pamphlet No. 1603-c, with *Mining and Metallurgy*, November, 1927.

number 22 in all and only about 12 would commonly occur in the range of composition of ordinary blast furnace slags. Of all the binary combinations that may occur, there are only two isomorphous series, the diopside-clino-enstatite or pyroxene series[1] and the akermanite-gehlenite or melilite series,[2] both of which may commonly occur in blast furnace slags, the first in charcoal furnace slags and the second in coke-furnace slags. All the other binary combinations form eutectics.

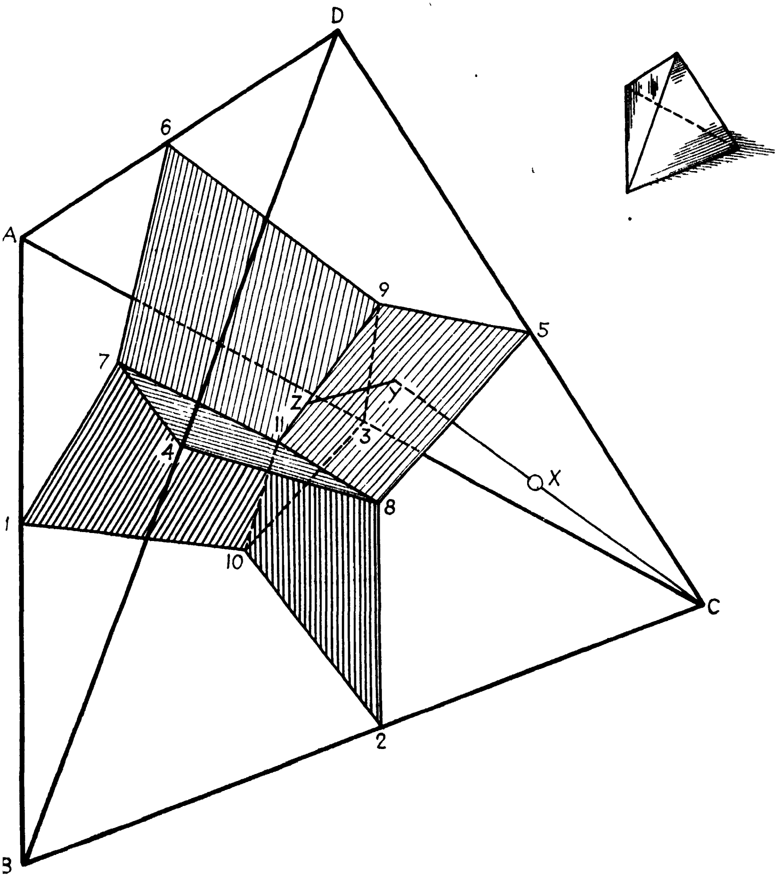

Fig. 96.—Diagram of four-component equilibrium when binaries form eutectics. (*A.I.M.E.*, *Tech. Paper* 19.)

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[1] N. L. Bowen: The Ternary System: Diopside-Forsterite Silica. *Am. Jnl. Sci.* (1914) **38**, 207.

[2] A. F. Buddington: On Some Natural and Synthetic Melilites. *Am. Jnl. Sci.* (1922) CC III, 35.

The equilateral tetrahedron, a symmetrical geometrical body, lends itself nicely to representation of systems of four variables as the sum of the perpendicular distances from each of the four faces to a common point within the body is a constant.[1] The four apices of the body represent respectively the four variables, each apex representing one individual variable. Any point selected within the body will represent the combined effect of the four variables. Any point selected on a face removed from facial intersection lines limits a perpendicular distance from this face to zero, and consequently excludes the presence and resulting effect of the variable represented by the apex opposite this face. Such a point thus includes but three variables in the system and is a point in the ternary system represented by that face of the tetrahedron. Any point on a facial intersection line by similar reasoning excludes two variables, includes the remaining two, the two connected by the line in question and consequently represents a point in the binary system composed of the two points connected by the line.

TABLE XVII.—NAMES AND COMPOSITION OF OXIDES AND COMPOUNDS WHICH MAY ENTER INTO COMPOSITION OF SLAGS

Reference letter	Mineral	Composition of oxides				Composition Cartesian co-ordinates		
		Al_2O_3	CaO	MgO	SiO_2	X	Y	Z
A	Akermanite		41.14	14.79	44.07	0.2943	0.4243	0.1208
B	Anorthite	36.65	20.16		43.19	.5824	.3741	.0000
C	Calcium aluminate	64.51	35.49			.6451	.0000	.0000
D	Calcium bisilicate		48.28		51.72	.2586	.4479	.0000
E	Calcium orthosilicate		65.12		34.88	.1744	.3021	.0000
F	Cordierite	34.86		13.79	51.35	.6743	.4845	.1127
G	Clino-enstatite			40.17	59.83	.5000	.6341	.3282
H	Corundum	100.00				1.0000	.0000	.0000
J	Cristobalite				100.00	.5000	.8660	.0000
K	Diopside		25.90	18.62	55.48	.3705	.5342	.1521
L	Forsterite			57.31	42.69	.5000	.5351	.4682
M	Gehlenite	37.18	40.91		21.91	.4813	.1897	.0000
N	Madisonite	21.46	23.61	16.98	37.94	.4892	.3777	.1387
O	Monticellite		35.84	25.77	38.39	.3208	.4068	.2105
P	Penta calcium trialuminate	52.17	47.83			.5217	.0000	.0000
Q	Periclase			100.00		.5000	.2887	.8170
R	Tricalcium aluminate	37.73	62.27			.3773	.0000	.0000
S	Tricalcium disilicate		58.34		41.66	.2083	.3608	.0000
T	Tricalcium pentaluminate	75.18	24.82			.7518	.0000	.0000
U	Sillimanite	62.92			37.08	.8146	.3211	.0000
W	Spinel	71.65		28.35		.8582	.0818	.2316
X	Lime		100.00			.0000	.0000	.0000

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[1] H. M. Howe: Note on the Use of the Tri-axial Diagram and Triangular Pyramid for Graphical Illustrations. *Trans.* (1898) **28,** 346.

With the ternary equilibrium established, giving the faces of the silica-alumina-lime-magnesia tetrahedron, and placing therein Madisonite, we constructed the space model for the four-component system and Fig. 97 illustrates such a model showing the volumes of primary crystallization.

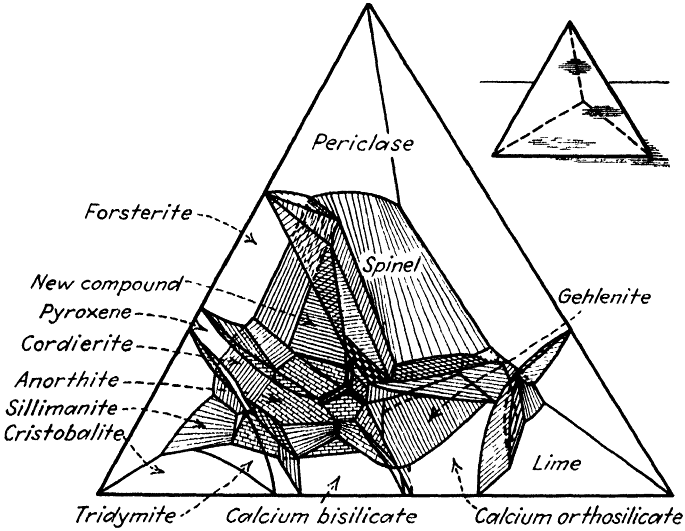

FIG. 97.—Equilibrium diagram of SiO_2-Al_2O_3-CaO-MgO system. (*A.I.M.E.*, *Tech. Paper* 19.)

To those who are mathematically minded in reference to the countless varieties and composition of blast furnace slags, the author cites the technical paper,[1] "Composition of Iron Blast Furnace Slags," by Dr. Richard S. McCaffery, Joseph F. Oesterle, and Leo Schapiro of Madison, Wis.

Other Variables.—There are so many other variables in blast furnace slags besides the four principal components (silica, alumina, lime, and magnesia) that it seems practically impossible to reduce the chemical composition of blast furnace slags to exact mathematical equations. These other variables are calcium sulphide (CaS); iron in some form or other besides the metallic iron present in small globules or "shot"; manganese oxide (MnO); alkalies nearly always in small quantities, and in large quantities in Southern practice; infrequently barium is

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[1] *A.I.M.E.*, Pamphlet No. 1603-c, Oct. 1926; *Tech. Paper* 19.

present[1] as BaO; once a trace of leadmonoxide was found in the slag of a furnace using an ore that had only 0.10 per cent leadmonoxide in it. Practically no phosphorus goes into the slag, but in making low-phosphorus pig iron with a large slag volume the author has found as much as 0.0023 and 0.0024 per cent phosphorus in the slag, which was an item of importance when the guarantee was 0.035 per cent phosphorus in the pig iron.

Bicalcium Silicate.—One of the worst compounds to occur in a blast furnace slag is bicalcium silicate ($2CaO:SiO_2$) which expands on cooling and goes into an impalpable powder. It forms in slags where there is an excess of CaO after the formation of $CaO:SiO_2$ or of $2CaO:Al_2O_3:SiO_2$. Possibly blast furnacemen are not troubled with it any more, but it was a curse when using high-sulphur Cuban ores and oyster shells for flux; and it caused many "lime bums" in the nineties. Only once has it been known to be of use, and that was during the World War when it was desired to have a lime compound that would expand and go to an impalpable powder. When asked about such a slag that might be made by melting the proper rocks, Wilber Stout, assistant geologist of Ohio, gave the analysis, and said that "the slag contains a high percentage of the bicalcium silicate, $2CaO.SiO_2$. The slag as I recall it is approximately as follows: SiO_2, 29.50%; Al_2O_3, 13.50%; Fe_2O_3, 0.50%; CaO, 50.00%; MgO, 3.50%; S, 2.00%; MnO, 1.00%."

Calcium Sulphide.—As explained in the chapter on desulphurization, calcium sulphide is the very stable compound that carries off the sulphur from the iron. There must be sufficient volume of slag, hot enough and fluid enough, to form the magma for calcium sulphide. If the slag becomes excessively "limy" and there is not heat enough in the hearth to bring the temperature up to the point where the slag will be "free running," then the lime will not react to take the sulphur from the iron and "buckshot," a sluggish pasty mixture of iron shot and limy slag, will form and gradually stop up the iron notch and cinder notch unless the furnace hearth is brought up to the right temperature.

The highest sulphur and calcium sulphide content of which the author has record was 3.74 per cent sulphur (8.41 per cent

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[1] SWEETSER, R. H., "Barium Oxide in Blast Furnace Slag," *The Iron Age*, vol. 85, p. 259, 1910.

calcium sulphide) in a slag at a merchant furnace in Columbiana County, Ohio; the analysis of the slag was SiO_2, 28.20 per cent; Al_2O_3, 21.00 per cent; CaO, 43.71 per cent; MgO, 5.59 per cent; Fe, 0.20 per cent; Mn, 0.09 per cent.

Low Alumina.—A blast furnace burden that contains only small amounts of alumina in the gangue of the ore and in the coke ash is liable to cause difficulties in the composition of the slag. The danger line starts with slags containing less than 10 per cent alumina. Unless such a slag contains about 40 per cent silica, it will be very difficult to keep the hearth of the furnace hot enough to make the slag free running. A glance at the eutectic chart of blast furnace slags (Fig. 93) will explain this danger area.

High Magnesia.—In practice the author has never found that slags with high magnesia were desirable or profitable. In the Lehigh Valley where dolomite abounds, it was customary to use the magnesian limestone rather than pay a little more freight for the calcite from the Reading District. The slags would run from 17 to 23 per cent magnesia, and 26 to 28 per cent lime; the silica would be 30 to 34 per cent, and the alumina 13 to 11 per cent. Such a large amount of magnesia only added bulk to the slag volume, thus increasing the coke consumption; there was considerable iron oxide in the slag, and often much iron carried out mechanically by the slag. The calcium sulphide in this slag was about 4 to 5.75 per cent, there being considerable sulphur in the coke used.

CHEMICAL COMPOSITION OF WASTE GAS

The chemical composition of the waste gases passing out of the top of the blast furnace is one of the important indicators of the blast furnace operation and shows whether the reduction of the iron ore has been economically carried on. In previous sections it has been shown that the weight of the gases coming out of the furnace is greater by a half to three-quarters than the weight of all the solid materials going into the top of the furnace. The main constituent of the waste gas, as with the bosh gas and with the air blast, is nitrogen, that inert heatwaster of the blast furnace. For every ton of pig iron flowing through the iron notch, there will be 3 tons of nitrogen at top temperature carrying off more than half of the sensible heat that leaves at the top of the furnace.

The next constituent in point of weight is the oxygen which came into the furnace as a gas in the blast, as a solid in the oxygen of the ore and the carbonic acid of the limestone, and as a liquid in the moisture of the ore.

The third in weight is the carbon which came into the top of the furnace in solid form in the coke and the limestone; about 4 per cent of the carbon leaves the furnace in the liquid iron, and a very small part goes out as a solid in the flue dust; all the rest goes out as gas.

Water vapor accounts for about 10 per cent of the total weight of waste gases; water enters as moisture in the ore, coke, and limestone. The water vapor that enters in the blast is dissociated at the tuyeres; the hydrogen is a powerful reducing agent and in its reaction goes back to H_2O again. However, there is free hydrogen and some CH_4 in the waste gases off the top of the furnace.

The analysis of the waste gas varies for many different reasons as explained in other parts of this book, but in using the same materials and making the same kind of iron the analyses will be fairly uniform. The following analysis was of waste gas at an Ohio blast furnace making basic iron in the month of August:

CO_2, %	CO, %	H_2, %	CH_4	N_2, %	B.t.u.	CO/CO_2, %
13.2	25.8	2.1	.	57.9	89	1.95

The average outdoor temperature was 74°F.; the average moisture in the atmosphere was 4.80 grains per cu. ft.; the coke per ton of pig iron was 1,591 lb.; average silicon in pig was 1.27 per cent; average sulphur was 0.028 per cent. The coke had 92.7 per cent fixed carbon; 6.6 per cent ash; 0.70 per cent volatile; 3.79 per cent moisture; and 0.57 per cent sulphur. The superintendent of the furnace told the author that he always found more hydrogen in the gas than there was in the moisture of the air blast.

In this country, coke is the usual blast furnace fuel, but in Scotland there are some furnaces using bituminous coal as the only fuel. In such cases the waste gas is rich in the by-products of the low-temperature distillation of bituminous coal, and these by-products—tar, creosote, ammonia, and motor fuel—are recovered. When raw bituminous coal was used for blast furnace fuel in this country, there was no recovery of these by-products.

In Part V of this book are some analyses of waste gas showing two cases of fairly high carbon dioxide content. These gas samples were taken at one particular spot, and it is possible that the samples did not fairly represent all the gas moving out of the top of the furnace at that time. This difficulty of getting a representative sample is well shown in Fig. 84 (center figure), which gives the lines of equal carbon dioxide content.

PART IV

OPERATING THE BLAST FURNACE

In running an iron blast furnace the following fundamentals should be kept in mind:

1. The furnace makes iron only when the blast is on.
2. The blast furnace plant should be so constructed as to make it safe and easy for men to operate it in the right way.
3 There is a cumulative effect in a good thing; it is better to remove the cause of trouble than to continue to apply a remedy.
4. "If you want to make butter you must churn cream," Col. Nimson of North Carolina used to say in selecting materials for making low phos. pig iron.

LINING THE FURNACE

After the steel work of the blast furnace is completed the next step is to put in the blast furnace lining which must conform to the lines of the furnace. The dimensions of a blast furnace that denote the lines are the diameters of the hearth, of the bosh, and of the stock line; the height of the furnace inside, from the level of the iron notch up to the level of the top platform, which is usually the level of the top of the big hopper; the height of the bosh diameter above the center line of the tuyeres; the angle of the bosh; and if there is a straight part above the top of the bosh, the height of this cylindrical section is given.

When the lines have been decided and approved, then a brick count is made up which is a complete list of all the firebrick of each size and each shape that will be required to lay up the lining as designated by the cross section and elevation of the furnace lining. The different sections of the furnace require firebrick of different kinds of clays and of different characteristics and the brick are usually designated as "hearth and bosh," "inwall," and "top" brick as to composition and structure. In each of these classifications are all the sizes and shapes necessary to lay up the lining according to the design and dimensions.

Sizes of Bricks.—In this country most of the linings are made up of standard 9-in. and 13-in. brick as shown in Fig. 98, which shows a part of a brick count for a furnace built by Freyn Engineering Company. This furnace required a total of 450,937 gross 9-in. equivalent (442,380 net); and 177,000 lb. of ground fire clay. With these "straights" and "keys" any diameter of circle can be laid up. For the tuyere arches and cinder notch arch and arches for the bosh plates side arch and wedge are used (No. 1 arch and No. 1 wedge), as shown in Fig. 99. There was a time when shape brick were used, *i.e.*, large blocks of fire

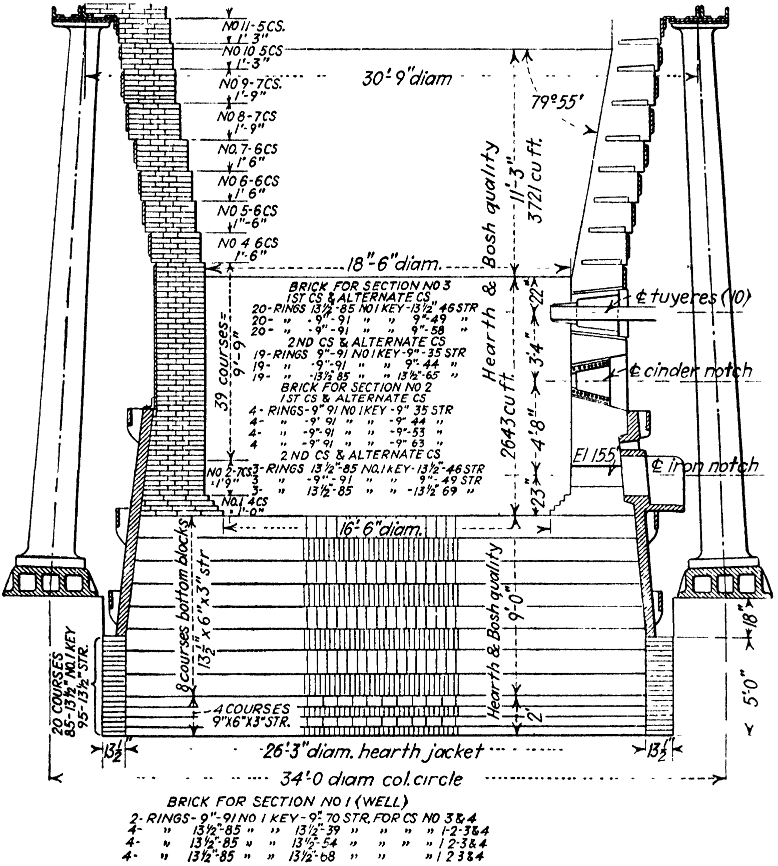


FIG. 98.—Part of brick count for a furnace. (*Courtesy of Freyn Engineering Company.*)

clay that were so shaped and of such size that only a few were needed to form the complete arch for a tuyere cooler. These big blocks were objectionable from every standpoint, and it is questionable if there was any saving in cost; it was difficult to get them properly burned all the way through.

Brick are sold on the basis of 9-in. equivalent (101.25 cu. in. but only 95 cu. in. is used for calculating the brick count); a 9-in. straight being, 9 in. × 4½ in. × 2½ in.

Requirements of the Brick.—The firebrick in the hearth of a blast furnace must withstand the very high temperatures of the combustion zones and of the molten slag and molten iron; they must also withstand the action of the various slags that are constantly changing in their composition in the region between the level of the tuyeres and the level of the cinder notch. Firebrick for this part of the furnace must not be susceptible to any further shrinkage.

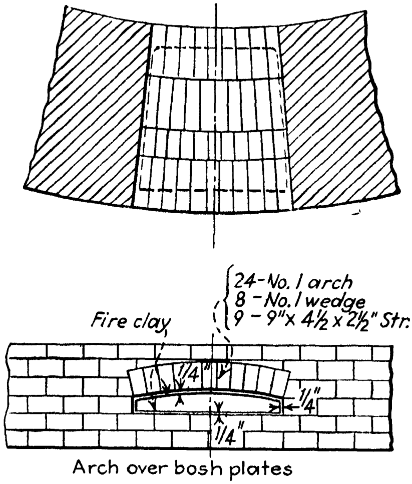


FIG. 99.—Arch over bosh plates. (*Courtesy of Freyn Engineering Company.*)

This secondary shrinkage of firebrick in the hearth bottom of furnaces has been the cause of many serious breakouts in the hearth. This sometimes has occurred within a few days after blowing in a new furnace or one that has been relined. There have been a few cases when the whole hearth bottom has floated, causing a newly blown in furnace to be blown out at once. It would appear that such a simple requirement would always be

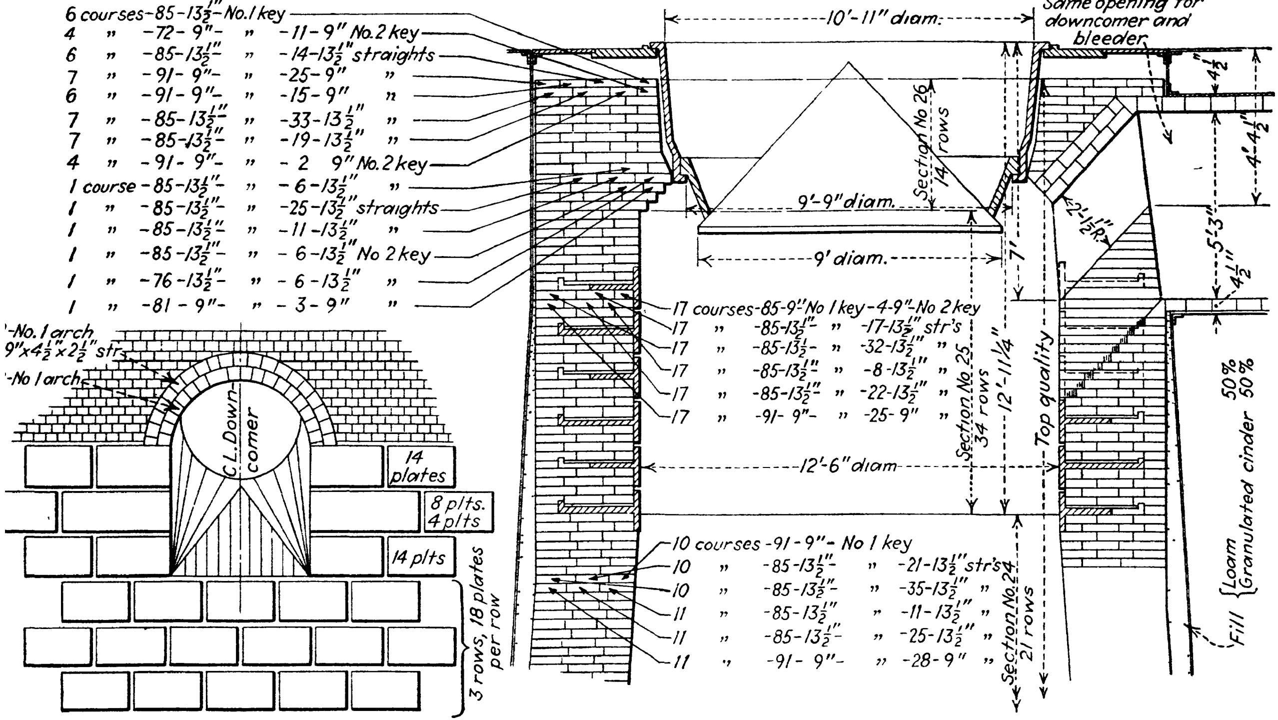


FIG. 100.—Brick count for top of small blast furnace (*Courtesy of The American Rolling Mill Company.*)

met and that it should not be mentioned in a book on modern blast furnace practice, but the author realizes that each generation of blast furnacemen must learn for itself and that no generation can bequeath experience to the following generation.

Each blast furnace superintendent should personally know that the firebrick going into the bottom lining of his blast furnace have been burned so hard that there will be no further shrinkage when the hot iron strikes them. A blast furnace superintendent should personally see the laying of the brick in a furnace lining to the extent of a personal inspection each day. The bricklayers may be very skillful and conscientious, but the superintendent is responsible for the lining as long as it lasts, and he should know how it was put in, what sort of joints were laid, and whether the packing between shell and brickwork was properly placed.

Blast furnace linings last so many years nowadays that it is possible that a furnaceman may seldom see a lining put in. Careful inspection may prevent a "hot spot" later on.

Top Brick.—The fire-clay mixture for top brick has the largest proportion of plastic clay, and is ground fine and hard burned. The top brick have to withstand abrasion and gas reactions; under certain conditions "carbon balls" will form and cause disintegration of the brick (see Fig. 100 for top-brick count).

Centering the Furnace.—One of the most important and most delicate details in putting in the lining of a new blast furnace is to set the center pole exactly in the center of the furnace from the hearth level to the top of the furnace. Many furnace linings have prematurely worn out in spots, or entirely, just because of failure to plumb the furnace and set the center pole exactly vertical. Sometimes, in order to speed up the lining of a furnace, brickwork has been started at the mantel and in the hearth bottom at the same time, using a different center pole for each section. In such cases the center pole should be reset from the bottom to top as soon as possible.

RELINING THE FURNACE

When the lining of a furnace is badly worn out in any part, or all parts, it must be blown out and relined. It is seldom that the whole lining, including the bottom brick, is renewed, but Fig. 101 shows such a case, where even the foundation was renewed. The shell and bustle pipe were shored up on timbers.

As soon as a furnace is blown out for relining, it is good practice immediately to get the lines of the worn-out lining by taking the measurements of the diameters every 4 or 5 ft. from top to bottom. A wire plumb bob is suspended from the top, centered at the center of the big hopper, and the measurements are taken

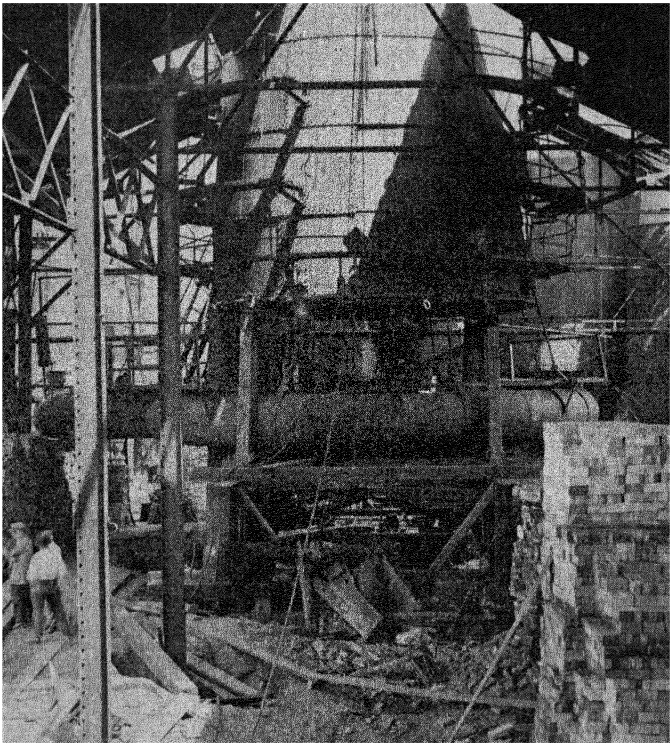
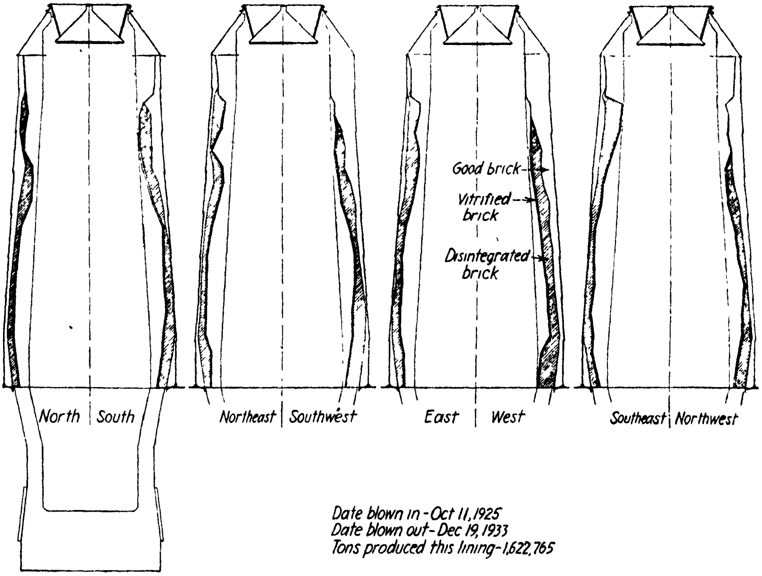


FIG. 101.—Relining a furnace and renewing foundation. (*Courtesy of The American Rolling Mill Company.*)

from a swinging scaffold let down through the furnace. These burned lines often give valuable information regarding the causes of failure of certain parts of the lining or of success of some new form of protection. In his paper[1] "Refractories for Iron Blast Furnaces," Roy A. Lindgren gave the burned lines of a furnace that had produced 1,622,765 tons of iron on the lining (see Fig. 102).

[1] *Trans. A.I.M.E.*, vol. 125, 1936.

Lindgren described the effects of the disintegration of firebrick by carbon deposition and gave results of tests made to find out why some firebrick will disintegrate in the furnace and others will not. They concluded that neither the percentage of total iron nor the percentage of iron oxide indicates whether or not a brick will disintegrate. He says, "The process of disintegration, we believe, begins with the blowing in of a furnace" and shows sections of the lining as measured after the first year and when blown out (see Fig. 103). This figure shows plainly the "skin" that forms on the face of the brickwork of a lining as a sort of glaze containing carbon and some alkalies fused with the original brick material.



Date blown in - Oct 11, 1925
Date blown out - Dec 19, 1933
Tons produced this lining - 1,622,765

FIG. 102. Burnt lines and sections through lining taken on four axes. (*Lindgren, Trans. A.I.M.E., vol.* 125.)

Although it is possible to reline the top part of a blast furnace without completely blowing out the furnace (but just letting the stock run down below the place to be repaired and then damping down), it is more satisfactory and safer to blow out completely and blow in again after the repairs.

Patching the Lining.—In the case of a blast furnace that is out of plumb, or was blown in without properly centering the bell (and there have been such cases), it is likely that the lining will wear out in some particular spot while the rest of the lining is in good condition. There are two ways of repairing the worn out part; first, by repairing from the outside without blowing out the furnace; second, by blowing out and putting in a patch of brickwork from the inside.

One very successful way of patching from the outside is to cut holes in the shell and insert the Dovel bronze, water-cooled plates, held in place by frames just like the bosh-plate frames described in a previous section. There have been cases where the life of a lining has been prolonged several years.

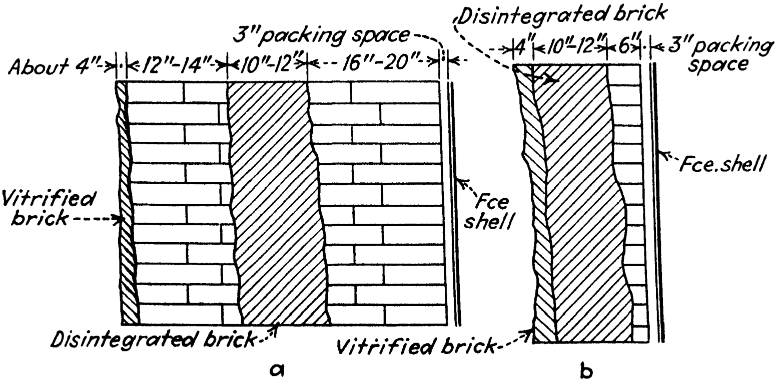


FIG. 103.—Progress of disintegration: (*a*) after first year, (*b*) when blown out. (*Lindgren, Trans. A.I.M.E*, *vol.* 125.)

Drying Out the Furnace.—In laying the brick in a blast furnace lining, the bond is a thin slurry of the best kind of ground fire clay of the same composition as the firebrick. This clay is made up into soup, or "slop" as the bricklayers call it, using wet steam to keep it warm and to get a good mix. This fire clay is spread over each course of brick with long-handled dippers so as to give as thin a joint as possible, and the brick are forced into place with wooden mallets. Literally, there will be tons of moisture in the brick lining of a blast furnace by the time the brick are laid.

In addition to all the moisture in the brickwork, there will be moisture in the packing put in between the shell and the brickwork, a space varying from an inch or two up to a foot. This packing is, preferably, screened, granulated, blast furnace slag, but loam can be used.

"As soon as a furnace-lining is completed it should be thoroughly dried out, whether it is to be blown-in soon or not; and the longer it is dried, the better for the furnace. At least two weeks is desirable; but good results can be had with 10 days of firing."[1] The above was written by the author in 1912, and it still holds good. Disastrous results will follow if a blast furnace is blown in with a green lining.

The fuel for drying out a blast furnace is natural gas, if available, or coke-oven gas, or clean blast furnace gas. In using gas of any kind the burner is near the top of the hearth brick on which a coke fire is kept continually burning so as to relight the gas in case of a temporary stoppage. The use of a wood, coal, or coke fire built directly on the hearth bottom and fed through a tuyere arch, is not good because of the accumulation of ashes which keep the bottom brick from being thoroughly heated and cause loss of time in cleaning out.

An effective and easily controlled method of drying out is to build a kind of Dutch oven outside the iron notch or outside a tuyere arch and use coke for fuel. A diagram of such a drying oven is shown in the article quoted on this page.

BLOWING IN THE FURNACE

There are probably as many variations of the method for blowing in blast furnaces as there are furnace superintendents. Some of these variations are poor practice and may result in troublesome and sometimes disastrous experiences; there are certain fundamentals that must be followed in order to insure a safe and successful blowing in, which is one of the greatest of metallurgical operations. On its degree of success depends much of the future life of the lining and the subsequent behavior of the furnace.

The objects to be obtained within a few hours after the lighting of the furnace are, first, the complete ignition of the bed of coke from the tuyeres down to the iron notch and heating to white heat the coke from the tuyeres upward in the bosh; second, the heating of the brick lining of the furnace up to the temperatures necessary in the different parts for the smelting of iron; third, the preheating of the materials in the shaft of the furnace and the

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[1] "Blowing-in a Blast-furnace," a paper presented at the Cleveland meeting of A I.M.E. in October, 1912; *Trans. A.I.M.E.*, vol. 54, 1913.

starting of the smelting process; fourth, the gradual movement of the stock in its downward course without the danger of having any of it stick to the upper walls and cause a heavy slip afterwards. Each and every detail of the preparation and of the actual blowing in is important and should be carefully checked by the superintendent, whether the furnace is a single furnace, a twin furnace, or one of a group of furnaces.

The most critical points are the simultaneous lighting at all the tuyeres, bringing down the gas, closing the iron notch, lighting the first gas at stoves and boilers, the first flush of cinder, and the first cast.

The furnace is lighted at all the tuyeres at the same time, with hot iron rods if the furnace is a single stack; with the hot blast from the stoves, if gas from another furnace has been available. Kindling wood and oily waste have been placed in front of each tuyere and a layer of dry cordwood has been placed all across the hearth on top of the coke that fills the hearth up to a few feet below the center line of the tuyeres. The former practice of filling the hearth and bosh with cordwood made too much "blow-in" gas that was sickening and even dangerous to the men.

In order to ignite the coke that fills the hearth and to heat up the hearth bottom before the molten slag and iron come down, a 4-in. iron pipe is placed horizontally at the center of the iron notch and allowed to extend about 2 ft. inside the hearth wall and to extend outside about halfway down the iron trough. The inside end is left open but the pipe is protected with stiff mud. Near the outside end of the pipe are four holes 90 deg. apart in which hooks can be inserted for pulling out the pipe when the time comes to shut the iron notch. The rich gas roaring out through this pipe is kept lighted by a wood fire in the trough (which also is heated up to receive the first cast). When the first signs of slag appear at the end of the pipe, the pipe is pulled out and the iron notch closed with the clay gun.

On top of the coke blank above the tuyeres are filled charges of coke and easily melted slag, such as cupola slag or Bessemer slag, with enough limestone to flux. Then follow charges with gradually increasing weights of ore and decreasing amounts of slag. When the stock fills the furnace up to about 30 ft. below the bell, it is good practice to examine the top of the stock and take measurements as explained by Francis Crockard[1] and shown in his diagram (Fig. 104). Measurements are taken after each charge, and adjustments made in the gage rods and, if found necessary, in the balancing and centering of the big bell.

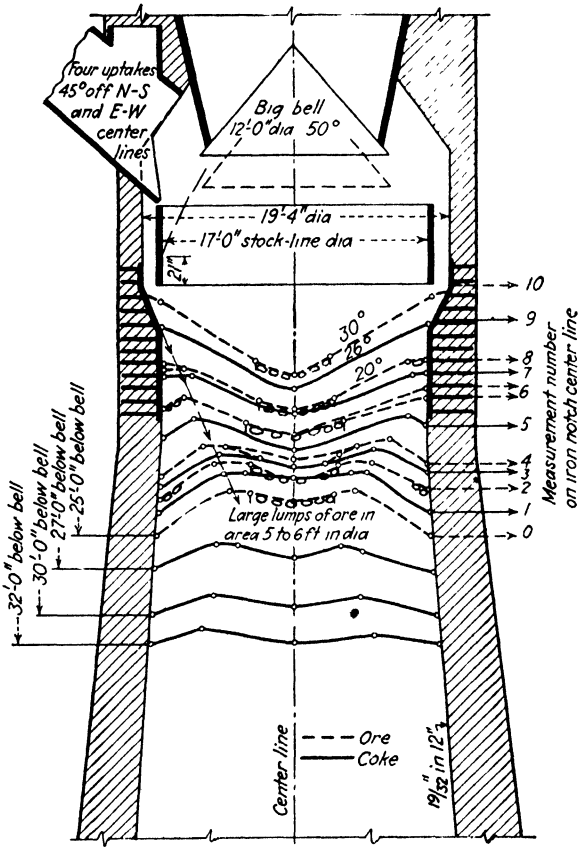

FIG. 104.—Cross section of filling a furnace. (*Crockard, Trans. A.I.M.E., vol.* 120.)

The amount of wind to be blown must be carefully watched and gradually increased in order to prevent any hesitation in the downward movement of the stock or any abrupt increase in the blast pressure.

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[1] "Progress in Southern Blast-furnace Practice," *Trans. A.I.M.E.*, vol. 120, 1936.

If the furnace is a single furnace, there should be extra precautions taken in closing the bells and bringing down the gas and lighting under boilers and stoves, which will not be necessary where the furnace is one of a group of furnaces already in blast. A precaution against gas explosions is to use the steam jet in the downcomer and dust catcher to drive out all the air before the rich blow-in gas enters the gas mains.

BLOWING OUT THE FURNACE

A blast furnace is blown out by not putting in any more stock, tapping out all the molten iron and slag and taking off the blast. It is not all so simple as that because there are many precautions to be taken, depending largely on the reason for blowing out. If the furnace is in good condition and is being blown out because there is no demand for the pig iron, care should be taken to protect the lining from all damage including too rapid cooling down. If the lining in the upper part of the furnace is in such bad condition that the shell is exposed to the heat and flames, then precautions will have to be taken to prevent the buckling of the bare sheets of the shell.

Whatever the reasons for blowing out, it is essential that the last ton of molten iron should be run out of the furnace at the last cast, and that the bell and hopper should be protected from getting red hot and warped. Usually by the time a blast furnace is blown out, the bottom of the hearth is burned out several feet below the level of the iron notch and the last of the iron must be forced out by the blast so as to prevent the solidifying of a lot of iron in the salamander; therefore there must be sufficient stock above the tuyeres to give plenty of pressure at the last cast. This is usually done by dumping a lot of wet fine iron ore or fine pyrites cinder on top of the last regular charge put in the furnace.

There is no need to blow a furnace out "all the way down to the tuyeres"; most of the iron ore has been smelted long before that and it is better to wet down the coke and rabble it out of the furnace than to burn it all up. Sometimes a lot of limestone is filled into the furnace after the last regular charge so as to have a lot of nonexplosive gas in the upper part of the furnace when the stock gets low. There is a much better way than that, *viz.*, to start streams of water down the two or more try holes just as soon as the last charge has been dumped and the big bell locked shut and sealed. All this water will go to steam, thus preventing the top temperature from getting dangerously hot. Excess gas and steam can be released through the bleeders.

The volume of blast is gradually decreased; the blowing engines must be kept turning until the last blow pipe is taken down.

In order to keep the big bell cool it is sealed all around at the lip ring with wet ore, and a spray of water is kept on it. But water must not be allowed to collect in the hopper. It hardly seems necessary to give such a warning nowadays, but after knowing of two horrible accidents of the same nature about a generation apart, and realizing that a new crop of blast furnacemen comes along each generation, the author *cautions that the big bell and hopper should not be kept cool by sealing the lip ring with clay and filling the hopper with water.* If, after the blast is taken off the furnace, the bell should be lowered and the large quantity of water dumped down into the furnace with its red hot walls and incandescent coke, there would be a water-gas explosion that would rip the furnace to pieces and kill or maim all the men anywhere near the furnace.

Banking the Furnace.—It is surprising how long a blast furnace can be kept "banked" and then started up again with comparatively little trouble. "To bank or to blow out," is a topic much discussed by blast furnacemen, and the answer depends much on the local conditions and also on the physical condition of the blast furnace, especially of its bronzes.

The essentials in banking a furnace are, first, to get the furnace as dry as possible of all slag and iron, and, second, to keep any air from entering the furnace thus preventing the combustion of the coke. A "blank" of coke, with enough limestone to flux for a lean slag, followed by lighter burden than normal, is charged into the furnace so as to reach the tuyeres after the last cast. The size of this blank depends upon the probable length of time that the furnace will be shut down.

BURDENING THE FURNACE

The burdening of the blast furnace is the art of calculating the right weights of coke, iron ores, and iron-bearing by-products and flux, so that the mixture, when smelted in the blast furnace, will produce pig iron and slag of the desired analysis and tonnage and in the most economical manner. The size of the coke unit, *i.e.*, the weight of coke per charge, depends upon the size of the furnace and somewhat upon the kind of coke, especially its weight per cubic foot.

The character of the ore burden varies greatly in different parts of the country and depends much on whether the furnace is making hot metal for a steel plant or merchant pig iron for the open market. At some integrated steel plant blast furnaces, the ore burden will contain less than two-thirds iron ores, the rest being iron-bearing by-products such as described in Part II. Since there is such an increase in the use of sintered iron ores, it may be better to classify sintered iron ores as *beneficiated iron ores* rather than as "secondary iron-bearing materials" which was proper when sinter was first used.

In making certain kinds of merchant pig iron, such as low-phosphorus and malleable, the ore burden is usually made up of virgin iron ores, and care must be taken in getting the right analysis for coke and flux also.

In a subsequent section, Slag Control, the volume and variations in analysis of blast furnace slags will be discussed, but here only the need for a *complete* analysis of all the raw materials making up the furnace burden will be mentioned; this is necessary in order to know how properly to flux the furnace and to prevent injurious elements getting into the mixture. In many cases, dolomite is used for the flux stone instead of calcite with a little magnesia mixed with it. In burdening the furnace, the magnesia is often ignored, and only the calcium oxide is used in the calculation.

It is good practice to estimate that it takes 98 units of iron to make 100 units of pig iron, in spite of the fact that there are only about 94 units of iron in the pig iron; the other four units being added to take care of the loss in flue dust, in slag, and in the unrecoverable loss in manufacture. The richness of an iron ore has several direct influences upon the operation and results of the furnace; first, a low-grade iron ore is usually high in slag-forming ingredients, and it requires much limestone to flux it if it should be a Lake Superior ore. The increase in the silica content in lake ores is a matter of much concern. In looking over notes of twenty five years ago, the author found a card of "limestone factors" (the percentages of limestone needed to flux the silica and alumina) for the ores used at a merchant-furnace plant. It began with Beaver at 7.2 per cent of flux and ended with Richmond at 80.2 per cent; both these ores are still being shipped, but with less iron and more silica. There were many ores between these two extremes, mostly from mines now exhausted. A glance at Fig. 48 will show how the silica has increased and the iron decreased in lake ores since 1902. A word of caution is necessary at this point, and that is that anyone making comparisons of analyses of lake ores should be careful to differentiate between the reported analysis of silica in the dry state (at 212°F.) and in the natural state (as received, with moisture included).

CLEANING THE FURNACE

From various causes and at various times, the walls of the furnace "get dirty" and scabs and scaffolds begin to form. These accretions on the inwall are sometimes high up, not far below the stock line, sometimes near the bosh line; and, less frequently, the bosh builds up or the hearth gets dirty. All such dirt troubles slow down the movement of stock and effect the quality of the iron, even to the extent of making bad iron for the steel plant, or off iron for the market.

In the case of scabs high up, it may be possible to examine them by "blowing down" below them, *i.e.*, by not filling the furnace for a while. When the extent of the scab or scaffold is known, the remedy can be decided and tried. Whatever remedy is used, it is certain that extra coke must be in the furnace to take care of the accumulation of dirt and cold stock when it is dislodged. Possibly heavy scrap can be filled in such a way as to strike the scab.

The cause of the dirt trouble should be determined and removed as soon as possible. Coke breeze, "black ends" (coal not well coked) and spongy coke are sure causes of a dirty furnace; a big bell not properly centered or a revolving top that has stopped revolving will cause cutting out on one side and building up on the other. During periods of "slack-wind blowing," as described by Francis Rich,[1] the lining is apt to build up;

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[1] "Slack-wind Blast Furnace Operation," *Trans. A.I.M.E.*, vol. 116, 1935.

he says, "the usual remedy is to upset the filling in an attempt to clean off the scabs."

In the same paper Mr. Rich says, "The use of cleaners is a subject on which many furnacemen disagree. Some prefer to 'slug' the furnace with charges of siliceous material, such as mill cinder, brick bats, bessemer slag or high-silica ore." He tells of one experience that was so successful that when the wind is brought down to about 30,000 cu. ft. per minute, they prefer to "slug" the furnace at regular intervals.

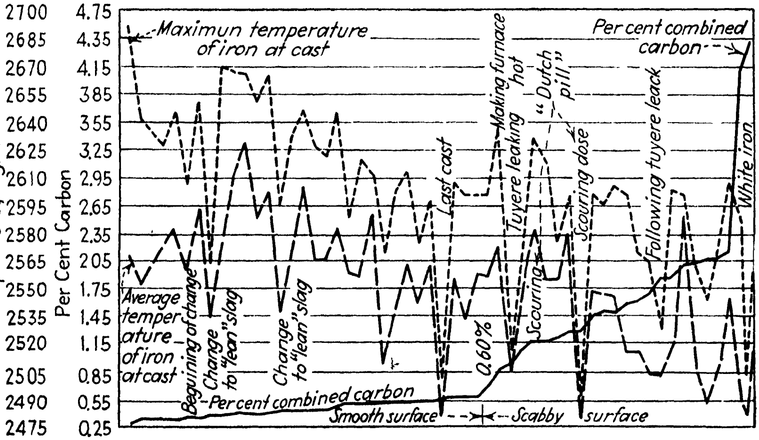

FIG. 105.—Chilling effects of "Dutch pill." (*Sweetser, Trans. A.I.M.E., vol.* 131, 1938.)

Dutch Pill.—In the author's own experience he used a "Dutch pill" to clean out a furnace when it got built up on the walls. The remedy was named after a Pennsylvania Dutchman, an excellent general foreman, who first taught the author how to use it. First, the hearth was made hot with some extra coke and a lighter burden; then a large slag volume with "spittings" from the Bessemer department was obtained. The Dutch pill consisted of charges of coke, scrap, lean slag, and siliceous ores with only enough limestone to make a very lean slag, charged into the furnace at intervals of about 12 hr. Care was taken to keep the furnace hot throughout the cleaning.

Although the Dutch pill, or scouring dose, will not necessarily make off iron as far as silicon and sulphur are concerned, the author believes it will make "bad" iron for the steel plant unless special precautions are taken. The chart[1] in Fig. 105 shows the effects of a scouring dose on the temperature of the iron and especially on the percentage of combined carbon which was high enough to result in "scabby sheets" when these casts went through the open-hearth furnaces and the sheet mill. In Fig. 85 the analysis and temperatures of the two casts affected by the Dutch pill can be seen at the extreme left of the chart; the pill in these two figures is called "scouring dose."

HOT-BLAST CONTROL

The temperature of the hot blast used in this country and abroad has been steadily increasing ever since the days of the iron-pipe stoves with their maximum temperature of about 900°F.; there was, however, a dropping back in temperature during the time of learning to use 100 per cent Mesaba ores, when "the furnace would not take the heat." Nowadays, blast temperatures of 1600°F. are not uncommon, and even 1800°F. has been used. Such high temperatures are only possible with very clean gas, pressure burners, special checker brick and high capacity of the hot-blast stoves.

Heat carried into the furnace by the hot blast is instantly delivered at the point where it can do the most good. Usually about one-sixth of the total heat requirements of the furnace reactions is brought in by the heat in the hot blast. The maximum economical hot-blast temperature has not yet been determined, but if the open-hearth men should find that higher temperatures of hot metal are desirable, it is likely that the blast furnacemen will use higher hot-blast temperatures and, in turn, will demand higher temperature refractories from the brick manufacturers.

If too much heat is brought into the hearth by the blast, *i.e.*, too much excess above the requirements for the kind of slag and the kind of iron desired—the "critical temperature" of J. E. Johnson, Jr.—then there will be too much heat in the zone above the bosh, and the furnace "will not take the heat," but will stick and go on high pressure until the condition is relieved by cold wind or slacking the blast. The furnace must be properly burdened for high heats.

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[1] SWEETSER, R. H.: "Combined Carbon: A Controlling Factor in the Quality of Basic Pig Iron," *Trans. A.I.M.E.*, vol. 131, 1938.

SLAG CONTROL

To control the slag in an iron blast furnace is to control the quality of the iron produced (and, to a certain extent, the tonnage) and to control the whole operation of the furnace itself, including a large part of the cost of production. The character of the slag is the determining factor in the character of the pig iron as to the controllable limits of sulphur, silicon, and, to a certain extent, the manganese; it has an influence on the proportions of combined and graphitic carbons.

The slag character depends on the kind of fuel used, as well as on the analysis of the ore burden and of the flux itself. When blast furnaces used only charcoal for fuel, there was not much difficulty in slag control, because there was no trouble in making low-sulphur pig iron. But when mineral fuels, anthracite and block coal, were introduced, now nearly 100 years ago, there was plenty of trouble on account of proper slag control; they introduced the problems of sulphur elimination, hearth temperature, and slag volume.

Blast Furnace Fuels in Relation to the Slag.—The five principal blast furnace fuels used in this country during about three centuries of iron smelting—charcoal, anthracite, raw coal (bituminous), beehive coke, and by-product coke—have imparted certain characteristics to the slags produced as well as to the pig iron.

The early anthracite blast furnaces were handicapped by tremendous slag volumes—the exact opposite of the charcoal furnaces—and this helped to keep down the tonnage of pig iron made; 2 tons of anthracite, 2 tons of iron ore and 1½ tons of limestone (all gross tons) was not conducive to high tonnage and low costs. In those days when there were no chemists at the blast furnaces, much low-grade limestone was used as well as low-grade ore. The general practice of using dolomite for flux caused an excess slag volume, excess fuel consumption, and decreased output without any advantage in removing sulphur.

Beehive coke had a hard time getting started as a blast furnace fuel, but when the right kind of coal was used the progress was rapid; then when coking coals with high ash and high sulphur were used for beehive coke, a new set of slag troubles worried the blast furnacemen at the same time they were learning to use Mesaba ores.

Research work in blast furnace slags was so meager before the World War that when the Bureau of Mines sent Alexander Feild to the Columbus blast furnaces early in 1917 it was necessary to revise the whole technique of taking samples of slag and of making the daily analyses. Since the war there has been much progress in the study of blast furnace slags; we have passed from beehive coke to by-product coke as the predominating blast furnace fuel; consequently there is a change in the character of the furnace slags, especially in respect to decreased basicity and volume.

Volume of the Blast Furnace Slag.—The campaign for clean coal for blast furnace coke that was waged several years ago resulted in a considerable reduction of the weight of slag per ton of pig iron. Now we are working to decrease the amount of waste materials shipped in Lake Superior iron ores and to increase the iron contents. All this is in the interest of low-cost iron and steel, but it reacts to reduce the amounts of materials put into the blast furnace, and to reduce the slag volume.

It is metallurgically sound to have the slag volume in the blast furnace as low as possible for the elimination of impurities of the fuel and ore burden. It is not advisable to run a furnace *too* close to the minimum volume of slag requisite to remove the sulphur and other impurities; this is all the more true when the volume is small because a slight variation in analysis might make a great difference in the free-running temperature of the slag. When we consider a blast furnace slag as a magma in which the various minerals and metalloids are in solution as separate compounds, we can readily see that when we have enough of the solvent there is no need in having too much; the right quantity in each case can be established by actual practice.

The compound that carries the sulphur is calcium sulphide (CaS), and the amount that can be dissolved by the magma depends upon its chemical and physical make-up.

Variations in Slag Analysis inside the Furnace.—The variations in slag analysis from one side of the furnace to the other are sometimes so great that it is a wonder that it is possible to keep the furnace on such regular iron as we do. A cold steel rod pushed into the furnace through the peephole at any tuyere, and removed quickly, would have slag of different analysis for each depth of penetration into the hearth. Often there are different kinds of slag at the different tuyeres. The author has removed slag from inside the hearth through the tuyeres with a water-cooled sampling pipe with cups every 12 in. and has seen the variations in slag composition.

This variation shows up at the flushes and at casting time, not only in appearance and analysis, but also in temperature.[1] This variation is also shown in taking samples of slag at the cinder notch, iron notch, and tuyeres.

Just above the tuyere level there must be enough excess lime in the slag to take care of the residue of ash left in the coke at the time of its complete combustion at the tuyeres. With very high-ash coke this condition is objectionable and often causes serious trouble, especially when the coke is in large pieces of irregular sizes.

A sample of slag taken from inside a blast furnace at the tuyere level (furnace making basic iron) analyzed 31.60 per cent SiO_2; 16.71 per cent Al_2O_3; 36.25 per cent CaO; 3.41 per cent MgO; 0.25 per cent S; 0.70 per cent Mn; 13.29 per cent Fe_2O_3. The flush that came out at the cinder notch 30 min. later was clean and had a temperature of 2668 to 2729°F. The iron that came 90 min. later had 0.94 per cent Si and 0.030 per cent S. The unreduced iron oxide in the slag shows that there is much chemical action and reaction in that part of the blast furnace hearth extending from the tuyere level to the level of the cinder notch 2½ to 3½ ft. below, and further reaction in the molten iron between the cinder notch level and the bottom of the hearth at the iron notch.

Although lime (CaO) and silica (SiO_2) are the principal constituents, except in the case of high-alumina slags, there are two other elements that must be carefully considered in getting a slag that will function smoothly and economically. When the total alumina in the furnace burden is so low that the slag contains less than 6 per cent, there is apt to be trouble because a comparatively slight drop in the percentage of alumina greatly increases the free-running temperature of the slag, and the

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[1] *Trans. A.I.M.E. Tech. Paper* 11, 1927.

furnace goes "off" onto bad iron. The author once had the following experience with the same silica but decreased alumina:

Slag					Pig Iron		
Blast, °F.	SiO_2, %	Al_2O_3, %	S, %	P, %	Si, %	S, %	P, %
1025	37.30	4.90	0.393	0.0144	0.05	0.214	0.010
1000	37.24	6.51	0.671	0.0028	2.08	0.022	0.028

Evidently the hearth was so cold that much of the phosphorus went into the slag instead of into the pig iron.

SLACK-WIND BLOWING

By the end of the year 1931, there had been forced into blast furnace operations of this country a new kind of practice, so contrary to all the previous blast furnace practice and traditions that when the author had proposed it, less than two years before, the executives said that it was impracticable, uneconomical, and —it just could not be done anyway. But when steel plant and blast furnace operations were cut down to about 10 per cent of capacity and there were surpluses of hot metal, of iron in pigs, and of blast furnaces, but still an intermittent demand for hot metal for perhaps one or two open-hearth furnaces, the executives put the problem up to the blast furnacemen, and they solved it by various phases of slack-wind blowing.

In cases where the steel plant would take all the hot metal from one or more blast furnaces for only four or five days out of a week, the blast furnace would be banked until there was a demand for hot metal again; this prevented the piling up of cold iron in pigs, and it was found that no harm was done to the furnace. In one case the only furnace in blast was blown for five hours out of each eight-hour shift so as to make just enough hot metal for the open-hearth furnaces.

The best description of this unique slow driving of blast furnaces was presented by Francis M. Rich, superintendent of blast furnaces, Republic Steel Corporation, Youngstown, Ohio, at the annual meeting of A.I.M.E., February, 1935, for which Mr. Rich received the J. E. Johnson, Jr., Award that year. His paper was entitled, Some Observations and Theory on Slack-wind Blast-furnace Operation.[1] and the following extracts are given verbatim:

> Before the world-wide depression, the primary purpose of most blast furnace operators was to produce a maximum tonnage of pig iron per day for each furnace in blast; . . . the idea was well established that low-cost pig iron was attainable only when each furnace was producing a high tonnage. After the depression had set in, the picture changed considerably. Each blast furnace operator was forced to run his plant in a manner that best fitted the economical set-up of his company. . . . Because of this abnormal condition, the blast furnace man was compelled to indulge in various practices of which many had been believed to be next to impossible up to that time. The ultimate purpose of these innovations was either one or a combination of the following:
>
> 1. To produce only enough pig iron for immediate consumption at a minimum cost.
> 2. To produce gas for boiler or mill use to supplant some higher priced fuel.
> 3. To consume the coke produced at the coke plant, which was often viewed as a byproduct.
> 4. To protect the cash position of the company.
>
> These conditions were met by diverse methods, some of which were:
>
> 1. Slow or decreased wind. In some instances the blast blown was held as low as 25 per cent of the normal volume.
> 2. Intermittent operation, in which the furnaces were shut down or "fanned" at frequent intervals.
> 3. Slow wind for a week or so, then normal wind for a short period. Each substantial change of wind was often accompanied by a change of burden, to produce a different grade of iron.
>
> It is needless to say that in spite of these methods the operators were required, more than ever before, to produce iron of excellent quality to meet the keen competition of other companies and the rigid specifications of customers. That the blast-furnace man has fulfilled these obligations is a tribute to his ingenuity, courage and skill.

FUNDAMENTAL REQUIREMENTS OF SUCCESSFUL SLOW-WIND OPERATION

Many volumes could be written on the experiences of the blast-furnace operators during the depression, but in our opinion the slow-wind operation has done more towards perfecting blast-furnace technique than any other development. Most furnacemen have found that lowering the wind on the furnaces meant a decrease in fuel consumption and

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[1] *Trans. A.I.M.E.*, vol. 116.

flue-dust losses, in spite of the fact that there were many "sick" furnaces before the fundamentals of success for slow blowing were appreciated. An inspection of these fundamentals reveals nothing new to the blast-furnace man, but we are convinced that an infraction of these rules is accompanied by far more serious results on slow wind than on normal wind. These principles have been proved many times in practice and are tabulated below:

1. The furnace lining must be in fairly good shape. The brickwork should not be cut out or built up excessively and the walls of the furnace must be kept clean at all times. The lining should be plumb, the ideal condition being that the traces of all horizontal planes with the inwall shall be perfect circles, the loci of whose centers shall form a straight vertical line, which is the true center line of the furnace.
2. The top-charging mechanism must be correctly designed, located and operated. The vertical center lines of both bells and their respective hoppers should be co-linear with the true center line of the furnace in all positions. Both bells and their hoppers must be kept clean at all times. The distributor must be working correctly, and the entire charging equipment operating so that equal portions of each raw material are deposited in all sectors of the same size in the furnace.
3. The correct filling must be used. By this is meant that there are always a few methods of filling, with regard to the sequence and quantity of each raw material charged, that give the best results on the furnace under the operating conditions at the time.
4. Each raw material should be as nearly uniform in chemical analysis and physical properties as possible; also, each material should be weighed and measured correctly at all times according to the schedule determined by the operators.
5. Enough slag volume should be carried to run the furnace on a lean or glassy slag, if the raw materials and the sulfur-content limits of the product will permit. Some plants are limited in this matter because the slag is used for commercial purposes and must meet the tests of the customers successfully. It is the general opinion that more slag volume is required as the wind is decreased.
6. The blast distribution must be uniform in temperature and quantity at each tuyere, or at least at each pair of adjacent tuyeres.
7. The correct size of tuyeres must be used to meet the operating conditions.

THEORY AND PRACTICE ON SLOW-WIND OPERATION

If the above-mentioned fundamentals are complied with, the furnace should show a substantial decrease in fuel consumption and flue-dust losses, in spite of the fact that the radiation loss is a constant value per unit of time, and hence the percentage increases directly with the decrease in daily production.

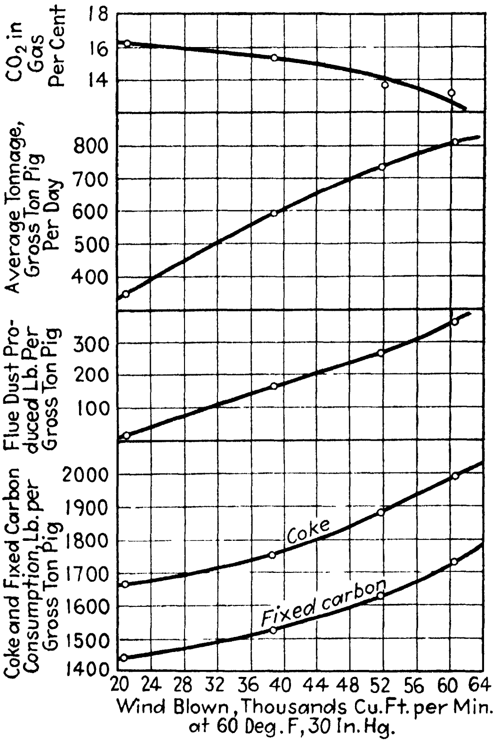

Fig. 106.—Practice on blast furnace B. (*Rich, Trans. A.I.M.E., vol.* 116.)

We are fortunate in having the actual practice of two furnaces, B and C, the lines of which are given below. The practice on B is charted on Fig. 8 [Fig. 106], and for convenience is tabulated in Table XVIII.

Measurement	Furnace B	Furnace C
Height	93 ft 11 in.	88 ft.
Hearth diameter	27 ft	21 ft.
Bosh diameter	28 ft. 6 in.	24 ft.
Stockline diameter	19 ft	17 ft.
Big Bell diameter	13 ft.	13 ft.
Height of bosh .	12 ft. 7½ in.	8 ft.
Height of straight part .	4 ft. 4 in.	7 ft
Angle of bosh. . . .	86 deg. 36 min.	79 deg. 59 min. 30 sec
Batter of inwall.	1$\frac{3}{16}$ to 12 in.	0 914 to 12 in.

TABLE XVIII.—PRACTICE ON TWO FURNACES

<table>
<tr><th rowspan="2">Number of months</th><th rowspan="2">Average wind, M. cu. ft. per min. at 60°F., 30-in. Hg</th><th rowspan="2">Average tonnage, G.T. pig per day</th><th colspan="2">Fuel consumption, lb. per G.T. pig</th><th colspan="2">Flue dust, lb. per G T pig</th><th rowspan="2">Purch. scrap charged lb per G.T. pig</th><th rowspan="2">Top gas, average CO_2, per cent</th></tr>
<tr><th>Coke</th><th>Fixed carbon</th><th>Produced</th><th>Charged</th></tr>
<tr><td colspan="9">FURNACE B</td></tr>
<tr><td>4</td><td>20.87</td><td>347</td><td>1661</td><td>1439</td><td>20</td><td>20</td><td>24</td><td>16.1</td></tr>
<tr><td>4</td><td>38.87</td><td>592</td><td>1751</td><td>1523</td><td>165</td><td>183</td><td>39</td><td>15.3</td></tr>
<tr><td>4</td><td>51.82</td><td>734</td><td>1880</td><td>1627</td><td>271</td><td>245</td><td>19</td><td>13.8</td></tr>
<tr><td>1</td><td>60.50</td><td>811</td><td>1994</td><td>1727</td><td>361</td><td>361</td><td>7</td><td>13.6</td></tr>
<tr><td colspan="9">Average ash in coke, 10.72 per cent; average sulphur in coke, 0.96 per cent; number gas samples taken, 58 (4-hr. samples).</td></tr>
<tr><td colspan="9">FURNACE C</td></tr>
<tr><td>5</td><td>26.60</td><td>396</td><td>1818</td><td>1583</td><td>122</td><td>0</td><td>0</td><td>15.1</td></tr>
<tr><td>5</td><td>39.90</td><td>618</td><td>1869</td><td>1620</td><td>147</td><td>0</td><td>0</td><td>15.0</td></tr>
<tr><td>8</td><td>50.00</td><td>757</td><td>1899</td><td>1652</td><td>154</td><td>0</td><td>0</td><td>14.3</td></tr>
<tr><td>7</td><td>56.60</td><td>833</td><td>1949</td><td>1687</td><td>233</td><td>0</td><td>0</td><td>13.0</td></tr>
<tr><td colspan="9">Average ash in coke, 9.83 per cent; average sulphur in coke, 0.91 per cent; number gas samples taken, 2082 (mostly snap samples).</td></tr>
</table>

The following gas samples (1017 in number) were taken at 9 in. from the inwall over a 12-month period:

Wind, Cu Ft. per Min.	CO_2, Per Cent
50.0	9.2
37.0	13.6
25.5	14.5

The practice for each of these furnaces was selected from normal months during which no banking or blowing in was done, so as not to distort the results. The monthly practice data were averaged for months in which the average wind was approximately the same. A total of 13 months practice was used for furnace B and 25 months for furnace C. Little or no purchased scrap was used on either furnace during these months, the maximum amount for any one month being 46 lb. per G.T. pig for furnace B.

The curves are almost identical in shape, although furnace B had the better practice on low wind. This may be because furnace B had the larger stack, which would increase the time of gas-solid contact. Furnace C had the lower flue-dust losses on blast volumes averaging over 36,000 cu. ft. per min., though the fact that all the flue dust produced by furnace B was charged back "raw" greatly aggravated this condition. We also believe that the large inwall batter of furnace B (1.187 in. per foot) was partly responsible for the relatively large increase in flue-dust production with great blast volumes. The tonnage and top-gas CO_2 curves are practically identical. [The author's own view on this point is that the stock-line diameter of 19 ft. in furnace B is entirely out of line with a hearth diameter of 27 ft. and a blast volume of 60,500 cu. ft. per minute, which gives too great a gas velocity at the stock line.]

Our reasons for the decrease in fuel consumption are twofold. First, the gas distribution through the stock is more uniform and free from channeling particularly up the walls. . . . The other reason advanced for the lowering of the coke rate is that each particle of ore is subjected to the action of the reducing gases for a longer interval of time as the wind is lowered. The same holds true for each unit volume of CO gas in contact with the ore. . . .

The question may arise as to how fast the wind can be increased or decreased on a furnace without seriously affecting the operation of the furnace and the quality of the product. Our experience is that the wind can be increased at the rate of 2000 to 2500 cu. ft. per min. per 24 hr. and decreased at twice this rate, provided the walls are fairly clean and that the correct tuyere size is used at all times. Where the wind was increased substantially, the practice for the first month of operation on the higher blast volume has been unsatisfactory. At the end of this first month the furnace was generally operating normally.

The question of just how low it is possible to go with the wind on a given furnace is often asked. It is our opinion that the minimum size of tuyeres would be the limiting factor. It would be possible to operate on 2-in. tuyeres, but we feel that with a smaller size great difficulty would be experienced. . . . [Mr. Rich gives calculations in his paper on the relations of blast volume to tuyere area, which are omitted here for lack of space.] Another consideration is that the bottom and walls of the hearth tend to build up on low wind. It is altogether possible that the bottom might build up to the point where the product could not be extracted from the tapping hole. The fuel-consumption curves of Fig. 106 show that the rate of decrease of coke consumption is lower with each corresponding decrease of wind. This implies that the coke rate will reach a minimum at some low volume and then increase as the wind volume is lowered still more. This point is where the fuel economies affected by the low wind and resulting efficient gas-solid contact exactly balance the ever-increasing radiation and cooling-water loss.

Conclusions and Recommendations

We are convinced that practically all blast-furnace operators in this country were overblowing their furnaces prior to the depression by reason of the data set forth. There is one particular volume of blast for each furnace that will produce a certain tonnage of iron at a cost lower than the cost will be at any other blast volume, with the same raw materials, prices, labor costs and equipment. It is the duty of each operator to determine this point on each furnace under his supervision, and thus arrive at the most economical rating for each size of furnace operating under the given set of conditions. Thus when a furnace is to be relined or rebuilt the operator will know the size furnace to build in order to produce the tonnage required, in the same manner that an electrical engineer determines the size of motor to be installed when he is acquainted with the average, minimum and maximum load and speed requirements.

From the above it is evident that the large-hearth, high furnace with the wide top is the best for Lake ore practice. This large furnace is very flexible as far as tonnage is concerned, and is more economical to operate when the conservation of raw materials is considered. Furnace B, for instance, with a 27-ft. hearth produced a minimum of 347 gross tons of pig per day over a four-month period, and made as high as 811 gross tons pig per day. It is believed by the operators of this furnace that it is possible to produce 1200 gross tons of pig per day. This is a production regulation of $\frac{100(1200 - 347)}{1200}$, or 71.2 per cent.

The decreased coke rates and flue-dust productions on slow wind are due partly to the decreased volume of blast and partly to the slowing up of the descent of the column of stock. It is impossible to determine, at the present time, the relative effect each of these conditions has on the increased economical working of the furnace, but it is our opinion that the lower blast volume has the greater effect. This would mean that the much talked of practice of increasing the oxygen content of the blast might be developed, in order to produce the required tonnage of iron and still keep the total volume of blast down low.

STOCKING AND CHARGING

Distribution of the Charge.—The problem of the proper distribution of each charge of stock as it is filled into the top of the furnace is of the greatest importance, because so much of the success of the entire operation of the blast furnace depends upon the right solution. It is essential that the ore, coke, and limestone are evenly deposited upon the big bell; this is a matter of mechanical design and was discussed in previous sections, Construction of the Top, the McKee Revolving Top, and Bells and Hoppers.

Unless the bell is evenly balanced and drops away from the lip ring all around the circle at the same instant, there is the danger of irregular distribution of the stock around the periphery at the stock line. If the bell and lip ring are not properly centered too much ore and not enough coke will be filled on one side of the furnace resulting in irregularities in the working and the product of the furnace.

The aim in the placing of the layers of ore, coke, and limestone inside the furnace at the stock line is to get the best possible contact between each particle of iron ore, coke, and limestone and the ascending hot gases so that the solids will be preheated evenly across the whole plane of the furnace before they move down into the next plane below and so that the hot gases will give up most of their sensible heat before passing out of the top of the furnace.

Furthermore the stock should be so evenly distributed that when each charge is lowered into the furnace it will have the same depth all around the circle of the stock line (see Depth of Charge Layer under Movement of Stock Column, Part III).

The methods used for stocking and charging the raw materials —ore, coke, and limestone—into a blast furnace vary in different parts of the country, chiefly as to whether the furnace depends on Lake Superior iron ores delivered during only about seven months of the season of navigation on the Great Lakes, or upon a supply that is delivered by rail all the year round, as in the South, Utah, or the Adirondack region. In either case there must be a bin system from which the different ores, scrap (if used), and flux may be accurately weighed into the scale car which delivers the charge to the ore buckets or skip cars which carry the ore burden and coke to the top of the furnace and drop them into the receiving hopper of the bell and hopper mechanism.

With but few exceptions in this country, the old-fashioned vertical hoist and buggy system with hand filling and single bell, has become obsolete.

It is the usual practice to have a big coke bin directly in line with the skip hoist so that the coke may be filled directly into the skip cars by volume, and not by weight on a scale car as in the case of ore and limestone. At some furnaces, where the Neeland charging bucket is used, the coke is first drawn from coke bins into the buckets on a car, but not necessarily weighed. In most cases, even when the coke has been thoroughly screened at the coke ovens, there are screens in the bottom or in the chutes of the coke bin so as to take out the coke breeze before filling into the furnace. Figure 107 shows the standard arrangement recommended for the 1,000-ton blast furnace (new Inland furnace).

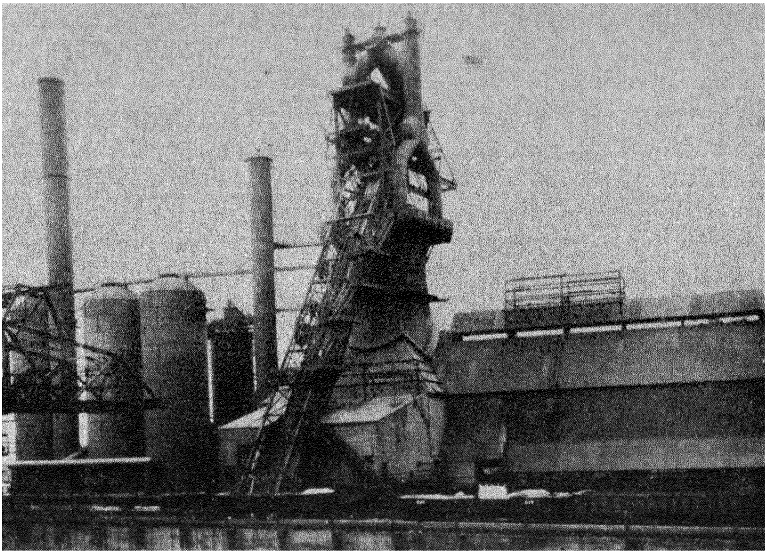

FIG. 107.—Skip hoist and stock house for 1,000-ton furnace. The new Inland furnace as seen from ore yard. (*Courtesy of Arthur G. McKee & Co*)

In lake-ore practice the cargoes of iron ore are so scheduled throughout the season of navigation (usually from the middle of April to Nov. 10) that a little over half of each cargo, or part of a cargo, will be unloaded from the railroad cars into the ore bins and charged into the furnace at once, and the balance is stocked in the ore piles, usually under an ore bridge. This applies to inland furnaces; in the case of lake-front furnaces, the ore is taken directly out of the ore boats with the ore bridges and put into the ore bins as needed and the balance dropped onto the ore piles to be recovered during the winter and spring months.

At furnaces using iron ores other than Lake Superior ores, it is not necessary to have an ore bridge, but it is necessary to have piles of ore reserves in case there is any interruption of railroad service, or, as in the case of brown-ore mining in the South, there is a prolonged spell of bad weather. When needed, the ore is reloaded into railroad cars by a locomotive crane or steam shovel.

Coke Bin.—Usually the coke bin at a blast furnace is kept reasonably full, and coke is unloaded from the railroad cars regularly as they are shipped from the coke ovens. The practice of dumping coke directly from the quenching cars into the furnace coke bin is completely done away with for several practical and financial reasons. Coke is generally charged into the furnace by volume instead of weighing each skip load of coke before it is hoisted to the top of the furnace. It is necessary to have a regular check on the weights charged against the furnace by comparing with the railroad weights of the coke unloaded into the coke bin.

Size of Coke Charge.—The coke charge, *i.e.*, the weight of coke that is filled into the furnace for each charge, varies according to the size of the furnace, the character of the coke, and the experience of the furnace operator; it runs from 5,400 up to 10,000 lb. or more. The weight of the coke charge governs the weight of the ore and limestone in each charge.

TAPPING THE FURNACE

The length of time between casts varies from 4 to 6 hr. according to the size of the furnace and the requirements for the hot metal; this makes six casts to four casts every 24 hr. The amount of molten iron flowing through the iron notch at a single cast may vary from 100 up to 250 tons, or even as high as 300 tons. The length of time required for this much iron to run out of the furnace will vary with the size of the drill used to open the iron notch, with the fluidity of the iron, and with the condition of the iron notch. When high-silicon low-sulphur iron is being made the iron is apt to be "mushy" and thick running and require a larger drill than a 3-in. bit to open the iron notch.

The angle of the drill for opening the hole should be the same as the angle of the iron-notch gun for closing it.

Care of the Iron Notch.—It is essential that the iron notch stay shut until casting time; with the modern iron-notch gun and the proper kind of clay, it is seldom that an iron notch breaks out before the keeper is ready to cast. There is no danger of a breakout if the keeper "keeps the hole well back." W. E. Brewster, when he was superintendent of blast furnaces of Wisconsin Steel Works, told the author that he wanted 60 in. depth of iron notch and felt that anything less than 48 in. was dangerous. To Mr. Brewster the author is indebted for the following analysis of a very satisfactory stopping clay from Ottawa, Ill., for the iron-notch gun:

Contents	Percentage
Iron	1.51
Silica	66 06
Alumina	21 18
Lime	0.40
Magnesia	0 65
Loss on ignition	8 13

A stopping clay from southern Ohio that proved very satisfactory had 2.88 per cent Fe, 61.12 per cent SiO_2, 25.40 per cent Al_2O_3, and 8.81 per cent volatile matter. The author's records show that it was shipped by Lafe Howdyshell of Gore, Ohio.

Care of Hot-metal Ladles.—The hot-metal ladles which receive the molten iron at temperatures between 2500 and 2700°F. must be kept clean and safe in order to prevent any leakage of iron through the lining (see Figs. 28 and 29) and shell. The accumulation of kish in the big ladles is cleaned out once every 24 hr., and the linings are examined every time the ladle is poured. Good ladle practice prevents the ladles from skulling up; every joint in the brick lining should be visible in ladles of the open-top type.

The kind of firebrick that make the best ladle linings are different from the more refractory brick of the blast furnace linings, have a large percentage of plastic clay, and are machine pressed. At some plants a lining of 2½-in. bevel brick is laid against the steel shell and then another course of 2½-in. brick of No. 1 quality put in; this is for lining a ladle like that in Fig. 26.

The linings for the Pugh-type mixer ladles carrying 125 to 150 tons of hot metal are 8 to 15 in. as shown in Figs. 27

and 28. One masonry superintendent wrote that for ladles like that shown in Fig. 26, for transferring hot metal to the open-hearth furnace, he used a 4½-in. lining of No. 1 clay brick and then 2 in. of Gunite, one part loam and one part ground firebrick.

DISPOSAL OF THE PIG IRON

Most of the pig iron made in this country is never made into pigs at all but goes direct to the open-hearth furnaces, the Bessemer converters, and the big foundries of the integrated steel plants. The U. S. Tariff Commission has ruled (February, 1927) that "molten pig iron is not an article of commerce since it can not be transported outside of the plant where made." (The very next year after this statement was made, molten pig iron, produced at the furnace of the Hamilton Coke & Iron Company, Hamilton, Ohio, was hauled 11 miles over the tracks of the Baltimore & Ohio Railroad to the steel plant of The American Rolling Mill Company, Middletown, Ohio, and poured into transfer ladles at the open-hearth department as shown in Fig. 108.)

At some steel plants the hot metal is poured from the blast furnace ladles into big mixers holding from 500 to 1,300 tons of hot metal, from which the iron is taken in transfer ladles to the open-hearth furnaces or to the Bessemer converters. Usually there are gas burners in these mixers for keeping the metal hot.

Merchant pig iron is all poured into pigs at a pig-casting machine and then is shipped direct to the customer, or else is stocked in the iron yard for future shipments. The iron from the furnace may vary in silicon and sulphur contents from one end of the cast to the other but when poured into the ladle it is thoroughly mixed so that the iron in each ladle is homogeneous when cast into pigs at the pig machine. For foundry and malleable iron each cast is piled by itself, but where basic or Bessemer iron is made by a merchant furnace, several casts of like analysis may be piled together in the iron yard.

At a few large gray-iron foundries, especially where ingot molds are made, direct metal from the blast furnace is mixed with molten iron from a cupola and poured into large castings, or poured direct without mixing with cupola iron.

Merchant pig iron, "iron in pigs" (see Fig. 1), is shipped to the consumers in railroad cars (by vessel or barge if the furnace is on navigable water).

Carloads of pig iron are carefully inspected as to loading in the car and as to appearance and freedom from dirt of any kind. Although there has been a great decrease in the number of merchant furnaces in this country since the World War, there is still a demand for quality pig iron for gray-iron and malleable castings and for steel-making irons.

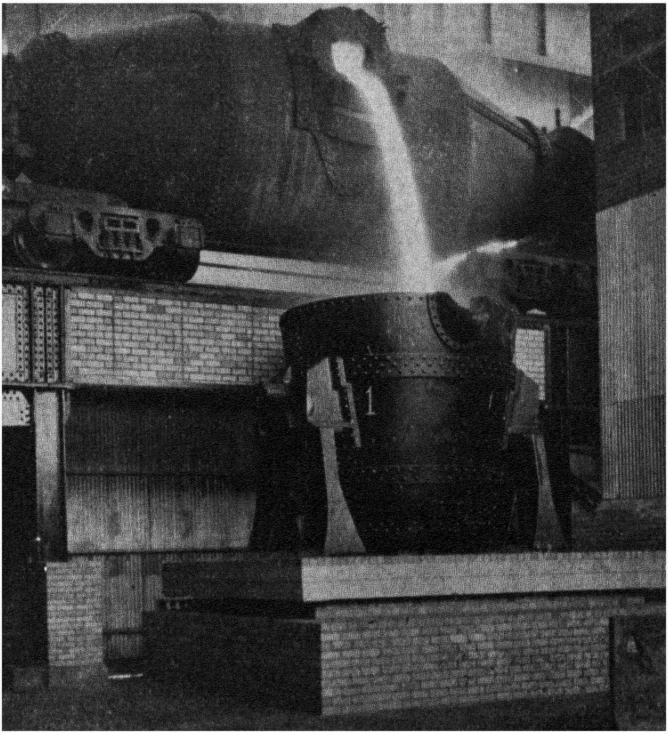

FIG. 108—Pouring hot metal into open-hearth transfer ladle. (*Courtesy of The American Rolling Mill Company*)

The most comprehensive survey of the manufacture and consumption of merchant pig iron ever made was by the staff of *The Iron Age* in cooperation with a pig-iron sales agency and published in the issue of June 16, 1927. Inasmuch as the year

1926 has been often used as a base, or normal year, the two charts of that survey are herewith reproduced; Fig. 109 shows the

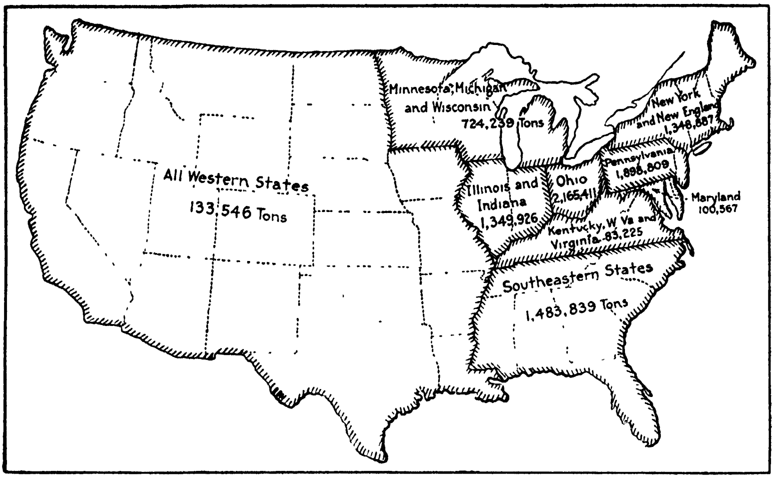

FIG. 109.—Distribution by districts of merchant pig iron produced in 1926. (*From The Iron Age, June* 16, 1927.)

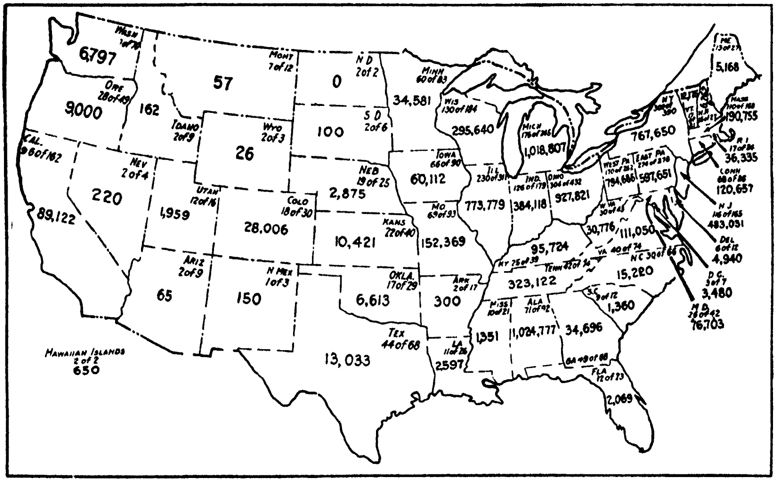

FIG. 110.—Consumption of merchant pig iron in 1926 by states. (*From The Iron Age, June* 16, 1927.)

districts where merchant pig iron was produced in 1926, and Fig. 110 shows where it was consumed.

Disposal of the Slag.—In Part I, the several methods of handling the slag were described and illustrations of slag pits and slag pots were given (Figs. 24 and 25); in later chapters the various uses of blast furnace slag will be discussed.

There are still some vacant lowlands or river banks near blast furnace plants where the slag is more valuable for filling-in purposes than for any other use. Usually the slag has some other commercial value. In recent years, the railroads have been glad to get whole trainloads of heavy blast furnace slag to protect their roadbeds in times of heavy floods.

BLAST FURNACEMEN. THE FORCE

The superintendent of a blast furnace plant and his force of furnacemen have much the same relationship as the captain of a ship and his crew at sea; success and safety in both cases depend upon the skillful leadership of the commander and the loyalty and training of the crew. A furnace in blast and a ship at sea must have the continuous care of the man in charge—in person and through his foremen or mates. There is a comradeship among the men running a blast furnace that grows stronger with the close association together in getting good results in the face of difficulties and dangers. The sight of a new broom on top of a blast furnace whenever a new tonnage record is made is a pleasure and an incentive to the whole furnace force, as well as to those in "the front office."

A blast furnace superintendent should take care that his foremen and furnacemen know as much as possible about the operations of the furnaces, the daily tonnages and coke consumption, and the details of practice. At one blast furnace plant where the author became the thirteenth blast furnace superintendent within 8 years, the management and the men were surprised when the night foreman was allowed to "carry the keys to the scales" and the foremen were shown how to change the burden and the weights on the scale beams. This saved many night-trips to the furnace, and it was easy to break all previous tonnage records.

What H. A. Brassert said about the human element in his able paper[1] "Modern American Blast Furnace Practice" was so true then and is so true now that it is quoted here, in part, as follows:

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[1] At the May meeting of the American Iron and Steel Institute in 1914.

> To achieve uniformly good practice nothing is more essential than the building up of an intelligent, watchful and active furnace organization. . . . Being continually in close contact with the furnace, they must be relied upon to watch the many little, yet important details of operation. The furnace manager who fails to devote as much of his thought and energy to studying and improving his organization as he gives to correcting the design of his plant, misses one of his best opportunities. Any effort on his part to instill into his men a keener interest in the efficiency of the plant will make his task the easier. . . . In no branch of industry is the exchange of experience more helpful and necessary to progress than in blast furnace work.

Just after the World War, Dwight T. Farnum, at a big refractories plant in St. Louis, gave the author a signed description of his idea of "The 100% Efficient Plant Superintendent," and one item on organizing ability, along the lines of Brassert's remarks given above, is as follows:

> Organizing ability—that quality sometimes described as "team-sense" which enables a man to recognize and develop the cooperative team-sense in others in such a way that each fits into an executive organization—so that it operates as a welded unit, securing results without friction. The ability to delegate authority and to develop initiative in others is absolutely necessary if the executive is to secure the most effective results from his assistants.

The blast furnace plant is an excellent training ground for future executives in the steel industry.

The number of men required to operate a blast furnace today is very much less than before the World War, in spite of the universal adoption of the three 8-hr. shifts in place of the day and night shifts of 12 hr. each. The heavy, hot drudgery work has happily been eliminated and the blast furnace has become almost completely mechanized. A keeper and a cinderman (sometimes a keeper's helper) can handle all the work of the cast house on each shift, "in front of the furnace" this is called; and a skip man and one scale-car man can fill the furnace on each shift; a stove tender and a blower look after the hot blast and the working of the furnace. Sometimes there is a general foreman whose regular shift is always on day-turn; at a single-furnace or a two-furnace plant he usually has no other blower on his shift.

In the engine room there will be a blowing engineer and one or two oilers or helpers according to the number of blowing engines and other machines to look after. Three men at the pig machine can handle the iron from one or two furnaces.

The boilers require two or more men according to the size and equipment of the plant. A millwright and an electrician are needed for each shift, and a blacksmith and helper on the day-turn. The number of locomotive crews depends on the methods used for handling the iron and the slag.

KEEPING THE FURNACE RECORDS

Ever since the author first worked around blast furnaces, the following item from the *Journal of the Franklin Institute*, 1876 (page 6), has been in the front of his little card file, and it is herewith recommended to all who read this book:

> *Keeping Records.*—As surely as development and growth are processes of improvement and accretion, so surely does the progress of engineering in all its branches have its basis upon the preservation of present attainments by *record,* and making them available for future use.

Blast furnace records have been kept in much detail for many years; weights, volumes, and analyses of raw materials and of products have been carefully recorded; the temperatures of atmosphere, hot blast, top gas, stack gas, feed water, slag, hot metal, inwall lining, and, sometimes, the interior of the furnace are observed and recorded, many of them on self-recording instruments; the pressures of cold blast, hot blast, steam, supply water, feed water, cooling water, top gas, and gas washers are recorded on 24-hr. charts; the number of blowing engine revolutions, skip-hoist trips, revolving-top revolutions, ladles of iron, charges, and the times the big bell is lowered—all are recorded somewhere. Figure 111 shows a stock-line recorder.

The character of the coke is closely watched and the analysis, porosity, shatter test, moisture, and general appearance are recorded. A change in coke-oven practice is very soon reflected in the operation of the furnace and at many integrated plants the coke-oven records are sent to the blast furnace superintendent.

The Ore Analyses.—The iron ores are sampled daily and analyzed for moisture, and a cumulative sample is run for the usual elements. When a regular mixture is kept on the furnace, the ore sampling need not be so frequent; but, in the case of special steel-making irons and merchant pig irons, the ores have to be checked closely. All these iron-ore analyses enter into the records of theoretical yield, actual yield and loss, or gain, in yield on the daily furnace report and in the cost sheet at the end of the month. The weights of each ore in the furnace burden and the number of charges put into the furnace on each shift are recorded. In good practice, a balance sheet of each iron ore is kept, and a "Consumption, Production, and Loss" statement is made up at the end of each month to show how many ton-units of iron (Fe) were charged into the furnace, and how many ton-units of iron were accounted for in the pig iron (at 94 per cent Fe), in the slag, and in the flue dust; the difference between the ton-units charged into the furnace and the ton-units recovered is the loss, or gain, in yield for the month "unaccounted-for."

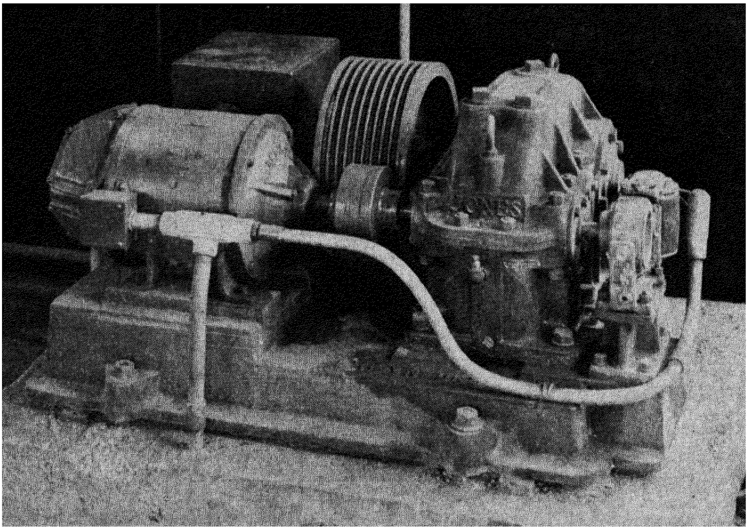

FIG. 111.—Stock-line recorder. (*Courtesy of Freyn Engineering Company.*)

Flux Analyses.—The limestone used for flux at a blast furnace, whether calcite or dolomite, is generally of quite regular analysis, but it is safer to have frequent sampling and analysis, especially for silica and alumina.

Cast Analyses.—Every cast of pig iron is sampled, top, bottom, and middle, and the samples examined for fracture and estimated for silicon and sulphur. Each ladle of iron is sampled and analyzed for silicon, sulphur, phosphorus, and manganese. Occasionally a cast is analyzed for total carbon, graphite, and combined carbon. The total carbon in pig iron at the same furnace and making the same kind of pig iron does not vary much, but the combined carbon varies with the operation of the furnace, and the author has found that the percentage of combined carbon is a good indicator of the quality of pig iron.[1]

Flush Samples.—Every flush of slag is sampled and put in "the box" for examination over several shifts. A daily (or oftener) cumulative sample is analyzed for silica, alumina, sulphur, iron, lime, and magnesia.

Other Records.—Where a water-softening plant is part of the blast furnace plant, there are several continuous records of temperature and analysis besides quantities. The power plant (steam and electric) and the sinter plant usually come under the supervision of the blast furnace superintendent, and they furnish daily sets of records. At a blast furnace plant using Lake Superior iron ores, there are the records of ore vessels all during the season of navigation. Usually the cargoes are sampled and analyzed when unloaded at the Lake-front docks as well as when received in railroad cars at inland furnaces.

It is probable that there are other records kept for the guidance of the operating force and the management of blast furnaces, especially where some new device or method is being tried out. There are certain ratios of analysis that act as guides to operators. and are recorded daily, such as the ratio of calcium oxide to silica in the slag, and the ratio of carbon monoxide to carbon dioxide in the blast furnace gas. Since the blast furnace is more susceptible to changes in the weather than the most delicate watch, it is necessary to keep regular weather bureau records of the weather at the furnace and to receive the daily weather maps. When the author first went to Columbus, Ohio, to run two blast furnaces (now dismantled), he explained to the head of the local weather bureau the importance of the outdoor temperature and humidity. The head of the bureau was so interested that when a

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[1] See SWEETSER, R. H., "Combined Carbon: A Controlling Factor in Quality of Basic Pig Iron," *Trans. A.I.M.E.*, vol. 131, 1938.

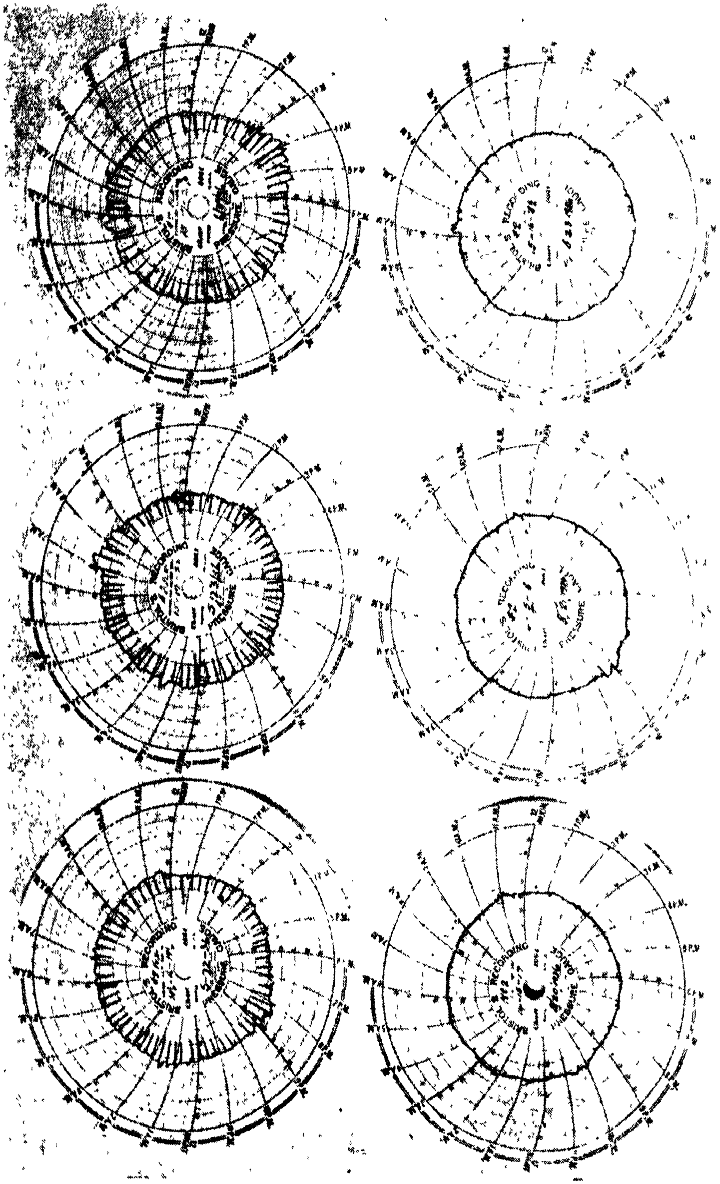

FIG. 112.—Blast pressure before (left) and after (right) using sinter, sized ore and electric clay gun. (*Hassler, Trans. A.I.M.E., vol.* 125.)

cold wave was approaching, before all the ore cargoes were delivered, he would telephone a warning so that the company would not get caught with a lot of frozen cars of ore. Incidentally, the ore burden would be increased in order to have it meet the heavier and drier air at the tuyeres.

A case of using records and charts to indicate the results of new methods and devices, was cited[1] by J. M. Hassler to show the improvements in practice brought about by the installation of an electric automatic clay gun and the use of sinter and sized ore. His illustration is herewith shown in Fig. 112.

By keeping such records, and making use of them, the art of making pig iron in the iron blast furnace has been advanced until the blast furnace process is one of the most efficient of all metallurgical processes.

COKE PER TON OF PIG IRON

The number of pounds of coke per ton of pig iron is usually the criterion, among blast furnacemen, of the kind of work that a blast furnace is doing, *i.e.*, whether it is good, bad, or just average. There is probably no yardstick of accomplishment that is so elastic as "coke per ton of pig iron," but when properly qualified it gives a very clear idea of the efficiency of the operation of the blast furnace in question.

Properly stated, the "coke per ton of pig iron" should be the number of pounds of coke actually charged into the blast furnace per ton (2,240 lb.) of pig iron produced, railroad weights to govern. If coke breeze is screened out at the stockhouse coke bin, it should be weighed and credited to the coke bin and charged to whatever use it may be put.

The number of pounds of coke per ton of pig has been gradually decreasing with each improvement in the preparation of the raw materials; with each improvement in regularity of operation, such as the automatic iron-notch gun; with each improvement in furnace design; and with each increase in blast temperature. Not very long ago the average practice was one pound of coke for each pound of pig iron. Recently there have been many

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[1] "Offsetting Increased Labor Costs in Blast-furnace Operation," *Trans. A.I.M.E.*, vol. 125, 1937.

cases of less than 1,600 lb. of coke per ton of pig. At the February, 1938, meeting of A.I.M.E., C. E. Agnew reported:[1]

> One furnace, newly lined, has produced basic for the past year on an average of 1479 lb. of coke per ton of iron, with a best month of 1379 lb. per ton of iron. This includes the blow-in month. For the year, an average of 93 lb. of flue dust per ton of iron has been produced, with a best month of 40 lb. . . . The furnace burden is normally 80 to 85 per cent sinter, the balance being miscellaneous materials such as roll scale, heating cinder, open-hearth slag, etc. At one period 95 per cent of sinter was used.

He reported that "furnace pressures are normal; top heat 350 to 400 deg. No water used on the stock. The CO/CO_2 ratio runs 2:1 to 2.1:1."

SAFETY WORK AND ACCIDENT PREVENTION

A blast furnaceman is less likely to be hurt at his blast furnace plant than at his home, or at his sports, or on the streets and highways. This was not true, however, until many men were killed or maimed by blast furnace accidents, accidents that were terrific and horrible. The mechanical advancement in equipment and size of blast furnaces in the last decade of the nineteenth century was greater than the metallurgical progress in blast furnace practice. Fast driving, high blast pressures, larger quantities of molten iron in the hearth, underground gas flues, low-grade refractories, almost entire absence of safety guards, no safety walks or ladders, introduction of fine Mesabi ores, and a general recklessness in the face of danger made life around the blast furnace hard and dangerous. Every man assumed the risk of his occupation.

The author's first year at a blast furnace plant of four furnaces was so filled with narrow escapes from instant death by explosions, breakouts, gas and falling objects that he made up his mind to do all he could to make blast furnacing safe. Many a blast furnace nowadays has gone a year or more without a lost-time accident to any one.

A successful accident-prevention campaign usually starts with the man at the top of the management, and it needs the full and willing cooperation of every man and woman along the line.

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[1] "Benefits from the Use of High-iron Concentrates in a Blast Furnace," *Trans. A.I.M.E.*, vol. 131, 1938.

There are not many women connected in any way with the operation of a blast furnace, but tribute should be paid to one who was the registered nurse at the first aid hospital of a blast furnace plant that operated a whole year without a lost-time accident; she instilled in the men the danger of neglecting even a slight scratch or burn, and thus reduced the lost time on account of infection to zero.

After the terrible record of the "Making of Steel and the Killing of Men" during the first decade of this century, there was a definite and concerted action among the iron and steel men to make the plants safe and to prevent accidents. The author's first experience was in seeing the safety devices put on the blast furnaces of the United States Steel Corporation; such devices as railing, foot guards, gates, and danger signs—simple details that are now so commonplace as to be accepted as a matter of course and demanded by law; but at first they were sometimes ridiculed.

Soon came the Workmen's Compensation Law in Ohio, which was one of the best laws ever enacted; then men and management fully cooperated to prevent accidents at blast furnaces and other industrial plants. The legislators ignorantly exempted all farmers from the provisions of this law and the factory inspection laws, with the result that a farmer operates his farm machinery without restrictions and lawful safety devices and thus farming is a more dangerous occupation than blast furnacing or coal mining.

The next big step in accident prevention was the first aid instruction given by the U. S. Bureau of Mines; practically all blast furnacemen have received this instruction, and each plant has its safety committee made up entirely of employees who suggest and recommend safety rules before they are put into effect by the management. The safety committees at the different plants unite in local safety councils which have been established in many industrial sections all over the country. These local councils send delegates to the National Safety Council, which is the clearing house for methods and devices for the advancement of safety in industry, in the home, and on the highways. If the same spirit of cooperation and education that was put into the safety campaign for blast furnacemen could be put into a safety campaign for motorists there would soon be as much safety on the highways as there is at blast furnace plants.

The hazards at a blast furnace are those that naturally result from the continuous production of large quantities of molten iron, molten slag, and enormous volumes of an explosive gas. In addition to the task of confining these molten and gaseous streams within their proper channels, there is the work of handling thousands of tons of raw materials, and the work of producing the power and providing the water for the operation of the whole plant. Air and gas, flames and steam, flowing water and molten slag, refractories and molten iron must all be kept side by side and in their proper places. Serious troubles are apt to result if they are prematurely mixed.

The accidents peculiar to blast furnaces are the gas explosions, breakouts, and slips. Fortunately, owing to the improvements in construction and practice in blast furnaces, such accidents are becoming very infrequent, but the dangers of neglect of right construction and of safe operation should not be overlooked. Besides the explosion danger of blast furnace gas, there is the sickening, and even fatal, effect of breathing air mixed with the gas. An experienced furnaceman will detect the presence quickly and will get to fresh air if possible. Gas masks and respirators are provided at the first aid stations. Carelessness and ignorance in blast furnace operations still bring disastrous results.

PART V

BY-PRODUCTS OF THE BLAST FURNACE

WASTE GAS

Although the prime product of the iron blast furnace is pig iron, one of the chief by-products, the waste gas or the blast furnace gas, outweighs the tonnage of iron in the ratio of about 5.7:1. In the case of a 1,000-ton furnace, there would be about 5,700 tons of blast furnace gas going out of the top of the furnace.

One of the greatest advances in blast furnace practice in recent years has been brought about by the cooperation of the combustion engineers, the blast furnace engineers, the manufacturers of refractories, and the steam engineers whereby the requirements for heating the blast and raising steam have been greatly reduced thus releasing great volumes of gas so thoroughly cleaned that it can be used to great advantage at the steel plant and coke-oven plant.

At the temperature of the top gas, 250 to 450°F. under normal conditions, there is, of course, much sensible heat carried out of the top of the furnace, and all the water that went into the furnace with the raw materials and as water vapor in the air blast comes out as steam. In Fig. 74 the weights of these different gases per 2,240 lb. of pig iron are given, with a total volume of 150,000 cu. ft. of gas weighing 12,721 lb. per ton of pig iron produced (a ratio of 5.68:1). In Fig. 73 these weights and volumes are expressed in a different way starting with 100 lbs. of an actual iron ore (Hanna ore, producing 53.35 lb. of pig iron); the gases weigh 261.56 lb., a ratio of 4.90:1. In the first case, the coke per ton of pig iron was 2,162 lb., and in the second case, 1,754 lb. per ton. The weights and volumes will vary with each different furnace burden.

The calorific value of the blast furnace gas varies from about 90 up to about 105 B.t.u.; this amounts to about 12,000,000 B.t.u. per ton of pig iron produced. The values recorded in private reports and in published articles vary in the total available

B.t.u. in the waste gas; and, no wonder, because it is possible for the composition of the gas to change in the few minutes required to take the sample. The author has seen such changes, especially when the furnace was slipping a little on top. In making any extended study of the values and volumes of blast furnace gas, it is essential that all the conditions be observed and recorded. Below are some gas analyses from the author's own experience. And he herewith confesses that he did not record enough of the facts. As a rule, however, a high CO/CO_2 ratio indicates faulty practice somewhere, probably a high solution loss of coke.

Analyses of Blast Furnace Gas

CO_2, %	CO, %	O_2, %	H, %	CH_4, %	Nitrogen and others, %	$CO:CO_2$	Remarks
12.4	25.8	0.0	2 3	1 0	58 5	2 08	Furnace settled one-half charge
11 0	28.0	0.1	0 6	2 4	57.9	2 55	Oyster shells for flux
13 8	23 8	0 0	1 2	1 8	59 4	1 72	Top temp. 680 to 715°F.
2 95	28 42	3 15	0 8	2 1	62 54	21 90	Furnace being banked
7 9	31.4	0 0	2 9	0 4	57 4	3 97	B.t.u. = 115

It has been noticed that the waste gas with the red ores of Alabama is similar to the gas from furnaces in the Lehigh Valley using a high percentage of magnetite ores.

Wet Washing.—It is now well recognized that it is necessary to cool the waste gas in order to clean it sufficiently low enough in grains of dust per cubic foot to allow its use in underfiring of coke ovens and in heating the small checkers of the modern hot-blast stove. Not only does wet washing remove most of the dust, but it also removes most of the moisture which is so abundant in the waste gases of furnaces smelting lake ores which is due to the moisture in the ores and also to the water sprays on the stock to keep the dust down.

A. J. Boynton said,[1] in part:

> Final cleaning of gas by wet methods in any of the three types of apparatus just specified is best effected after a preliminary cooling of

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[1] In his report "Gas Cleaning and Stove Equipment" in connection with the 1,000-ton blast furnace.

the gas in a tower scrubber. For the sake both of cooling and preliminary cleaning, the distribution of water within the primary washing tower should be as complete and perfect as is possible. It is practically certain that the final cleanness of the gas is affected in some degree by the efficiency of the primary cleaning. With average top temperatures the consumption of water will run from 19 to 24 gallons per 1000 cu. ft. of gas.

One of the difficulties in wet washing is the extremely fine particles of iron-ore dust which pass through the water towers without being wet. The Theisen disintegrator is used to complete this wetting; it uses 2¾ gal. of water and ⅕ kw.-hr. of power per 1,000 cu. ft. of gas. This cleans the gas to minus 0.01 grain dust per cubic foot of gas.

T. B. Counselman said:[1]

> The raw gas coming out of the furnace carries about 10 grains of flue dust per cubic foot of gas, under best operating conditions. With the furnace "rolling" or slipping, this quantity may temporarily be greatly increased. This dust would, of course, deposit on the checkers of the stoves, or plug the burners under the boilers; therefore the gas must be cleaned. The first step . . . is dry dust catchers which reduce the dust content from 10 grains to between 4 and 6 grains per cubic foot, and recover roughly half the total flue dust in the gas. The wet washers recover most of the remaining dust, reducing the dust content to about ¼ grain per cubic foot. Electrical precipitators, if used, further reduce the dust content to about 0.01 grain per cubic foot of gas.

Counselman's flow sheet is herewith reproduced in Fig. 113. The wash water from the scrubbers contains too much valuable fine dust to throw away, and, furthermore, it would pollute the streams or lakes if not removed by thickeners and filters.[2]

Dry Separators.—The dry cleaning of gas is only a part-way process; it takes out the coarse particles of dust, but it is impossible to effect the cleaning necessary for the more valuable uses of blast furnace gas. The primary dust catchers and centrifugal dry cleaners were described in Part I; they are now almost universally followed by some sort of wet cleaning. For a long time the *hot dry* method was thought to be superior to the *cold wet* method because of the sensible heat in the top gas, but the

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[1] In his paper "Recovery of Blast-furnace Flue Dust from Scrubber Water," *Trans. A.I.M.E.*, vol. 125, 1936.

[2] See *ibid.*

chilling effect of the water vapor when the gas was burned was overlooked.

At some European blast furnace plants the dust is removed by filtration through a series of cloth bags, which makes the gas clean enough for use in gas engines.

Electric Separators.—The cleaning of blast furnace gas by the Cottrell electric precipitator was unsatisfactory at first because the hot, dry gas was sent directly to the tubes of the precipitator. In Fig. 34 is shown the modified electric precipitator in which the gas, cooled and previously wetted, is cleaned to the desired degree. This removes not only the remnants of dust but takes out the water vapor in a process similar to the removal of the last traces of tar in the electric cleaning of coke-oven gas.

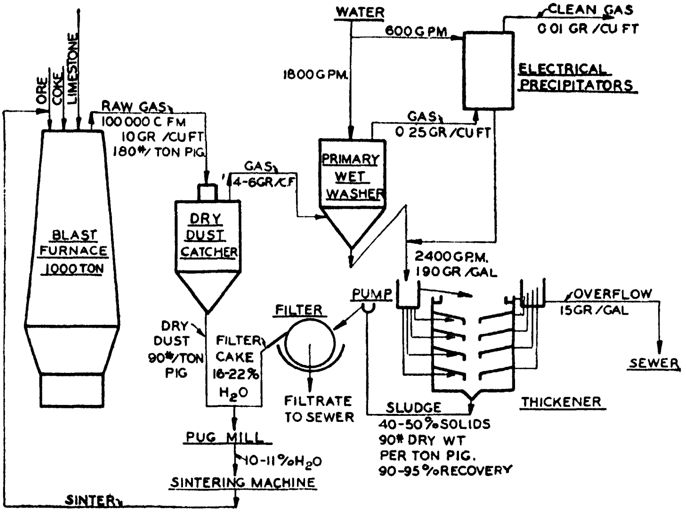

FIG. 113.—Flow sheet of cleaning blast furnace gas and recovering flue dust. (*Counselman, Trans A.I.M.E , vol* 125.)

USES OF BLAST FURNACE GAS

Under Boilers.—Blast furnace gas has been the logical fuel for the boilers of a blast furnace plant ever since the days when the boilers were built on top of the furnaces instead of on the ground, but the recent developments in cleaning and combustion have shown that it can be profitably replaced by certain grades of bituminous coal. Most of the existing blast furnaces are equipped for using blast furnace gas under the boilers, and, even where most of the surplus gas goes to other parts of the integrated plant, there will still be arrangements for using a part of the furnace gas for raising steam.

It is possible to use hot dry gas under the boilers; however, the flue dust not only reduces the available heat from the combustion of the gas, but it is heated to a pasty slagging condition that adheres to the boiler tubes and slags the brickwork of the boilers. Tube cleaners of various kinds have been used to remove the flue dust and clinker from the boiler tubes, but new installations will use the clean gas.

In the Stoves.—The percentage of the total volume of blast furnace gas required for heating the blast is generally estimated to be between 20 and 25 per cent; the better the cleaning of the gas, the lower the requirements. The total thermal value of the top gas is variously reported to be between 12,000,000 and 12,925,000 B.t.u.; this latter figure was calculated[1] by Theodore Nagel from the data shown in Fig. 74. At an average requirement of 22.5 per cent of the gas for the stoves, it would take a total of 2,908,125 B.t.u. for the stoves, of which, according to the same author, 2,650,000 B.t.u. would be returned to the furnace in the hot blast.

Underfiring Coke Ovens.—The use of thoroughly cleaned blast furnace gas for the underfiring of by-product coke ovens was first introduced on a large scale in this country at a plant having a contract for large volumes of city gas; since then the use of blast furnace gas has extended to many operations in the integrated steel plant.

At the Federal Plant of the Interlake Iron Corporation in Chicago, the blast furnace gas, cleaned to less than 0.01 grain of dust per cubic foot is sent under the river in a 60-in. gas main and used for underfiring the coke ovens that furnish gas for the city.

At one plant in the Ohio Valley the coke ovens are arranged to use either straight blast furnace gas or a mixture of furnace gas and coke-oven gas. The gas from the blast furnaces is cleaned in a Brassert dry whirler, a tower washer, and a disintegrator; thence it goes to a million cubic feet gas holder.

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[1] Presented in his paper "Blast-Furnace Air-Blast Beneficiation," *A.I.M.E.* (manuscript mimeographed), 1935.

The air and furnace gas are put through the regenerators in 20-min. reversals. The coke gas is mixed with the furnace gas right at the burners.

Blast furnace gas has been successfully used in place of the coke-oven gas, thus releasing the equivalent of the higher value gas for the market or for plant use. It was a rather startling innovation at first, but it was sound in principle and has proved profitable in practice.

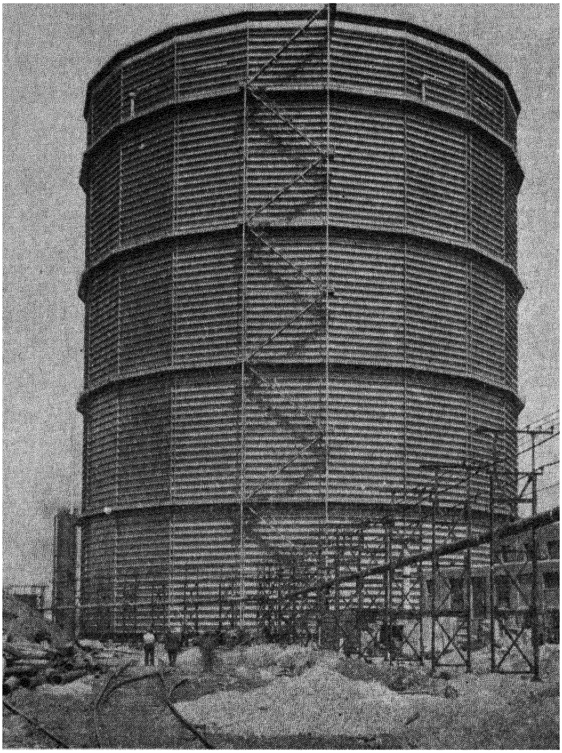

FIG. 114.—Gas holder—new type. (*Courtesy of The American Rolling Mill Company.*)

In the Steel Plant.—Blast furnace gas, in spite of its low B.t.u. value, has gradually taken the place of producer gas in different furnaces, such as the soaking pits, reheating furnaces, and, mixed with coke-oven gas, open-hearth furnaces, at the integrated steel plants. At the integrated steel plant of the Great Lakes Steel Corp., on the Detroit River just below Detroit, Mich., the coke ovens are fired with blast furnace gas from their blast furnaces on Zug Island. *The Iron Age*, July 22, 1937, says:

> The 130 coke ovens under construction will have a capacity of 2550 tons of total coke every 24 hr. . . . The gas plant installation includes a holder which will be 170 ft. high and 118 ft. in diameter and a 42-in. main almost three miles long. The coke ovens will be fired with gas from the blast furnaces. Excess blast furnace gas and the coke oven gas will be delivered through the mains to be used throughout the Great Lakes operations including slab and billet reheating, and open-hearth, box annealing, and normalizing furnace heating. The gas production will be approximately 83,000,000 cu. ft. per day.

The gas holder of The Hamilton Coke & Iron Company for coke-oven gas is 210 ft. high and 194 ft. in diameter, and holds 5,000,000 cu. ft. of gas. Instead of being round, it has many sides as shown in Fig. 114; instead of an inverted dome in a water seal, this holder has an immense piston to fit snugly inside the holder, rising and falling with the volume of gas and keeping a constant pressure of gas regardless of volume.

BLAST FURNACE SLAG

Dry Solid Slag.—Blast furnace slags, containing the non-metallic minerals of the furnace burden in the form of silicates of lime, magnesia, and alumina, will solidify in the air very soon after flowing in the molten state from the blast furnace. The density of the air-cooled slag depends upon its composition; the specific gravity varies from about 1.83 up to 2.82; and the weight per cubic feet varies from 114 up to 176 lb. A test made at Columbus showed a weight of 121¾ lb. per cubic foot for a slag from a furnace making basic iron.

The methods for pouring the molten slag on the slag dump or into special slag pits have various effects upon the slag when crushed and screened. If the stream of slag is thin and quickly cooled, it will be more friable than if cooled slowly and in thicker layers. For road material (called "road metal"), the crushed slag should be strong and tough, qualities obtained by slow cooling in rather thick layers. This method is used by the

Tennessee Coal, Iron & Railroad Company at their Ensley Works, the slag is hauled in big cinder pots and dumped into

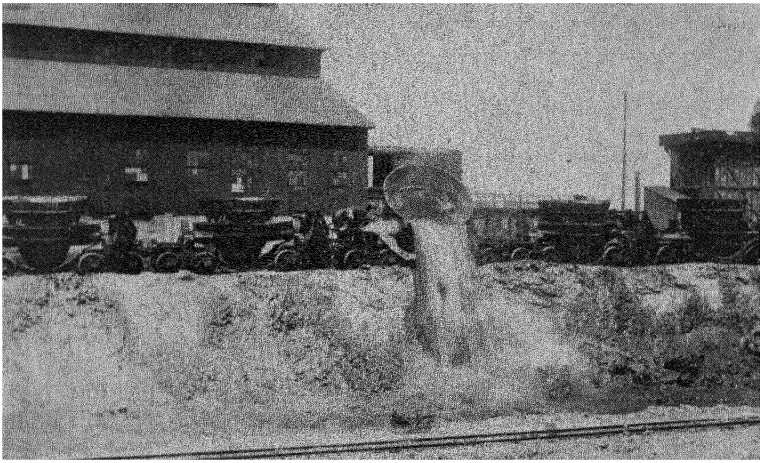

FIG. 115.—Molten slag poured into cinder pits. (*Courtesy of Birmingham Slag Company.*)

FIG. 116.—Loading slag from modified slag pits into hopper cars. (*Courtesy of Birmingham Slag Company.*)

long dry pits about 15 ft. deep (as shown in Fig. 115) and is dug out with electric shovels and taken to the slag-crushing plant of the Birmingham Slag Company and prepared for the market

This electrically operated crushing, screening, and washing plant has a capacity of 4,000 tons per day This same company has a similar plant near the Fairfield blast furnaces and another at Alabama City taking slag from the Gadsden furnace

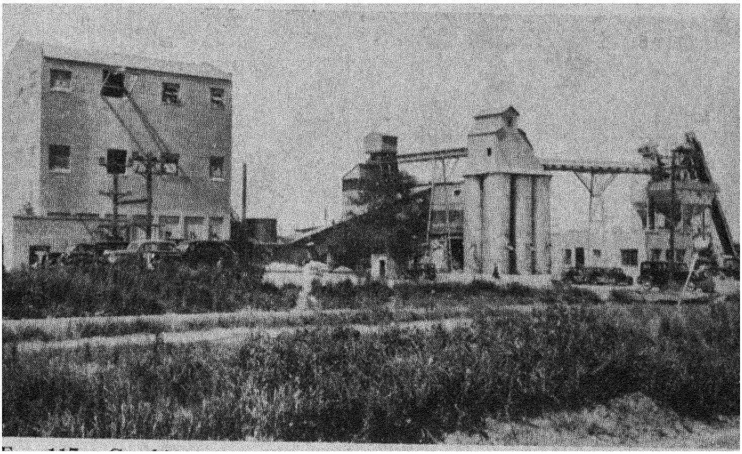

FIG 117.—Crushing and screening plant Left to right asphalt plant, slag **washing** plant; slag storage, ready-mix concrete (*Courtesy of Birmingham Slag Company.*)

The standard sizes for this company are as follows:

Number	Use	Sizes
1	For roads	4 to 2½ in.
12	For roads	4 to 1½ in.
2	For roads	2½ to 1½ in.
23	For concrete	2½ to ¾ in.
3	For concrete	1½ to ¾ in.
34	For concrete	1½ to ¼ in.
4	For concrete	¾ to ¼ in.
46	For roads	¾ in. to 10 mesh
6	For roads	⅝ in. to 10 mesh
6-A	Washed roofing	⅝ to ¼ in.
7	For roads	¼ in. to dust

Probably the first practical use for dry solid slag was for making roads and for railroad ballast, no special preparation was required or given for many years, but nowadays, with competition from sized limestone and other rock products, there are strict requirements for sizing, cleanliness, porosity, and strength. For certain uses there are limits on analysis of magnesia and sulphur.

Wet Granulated Slag.—For convenience and for low operating cost in restricted space, the wet granulation of blast furnace slag has been carried on at some plants by running the molten slag direct from the furnace into pits partly filled with water. Under the nose of the cinder spout would be a water-spray nozzle that would granulate most of the slag before it struck the body of water.

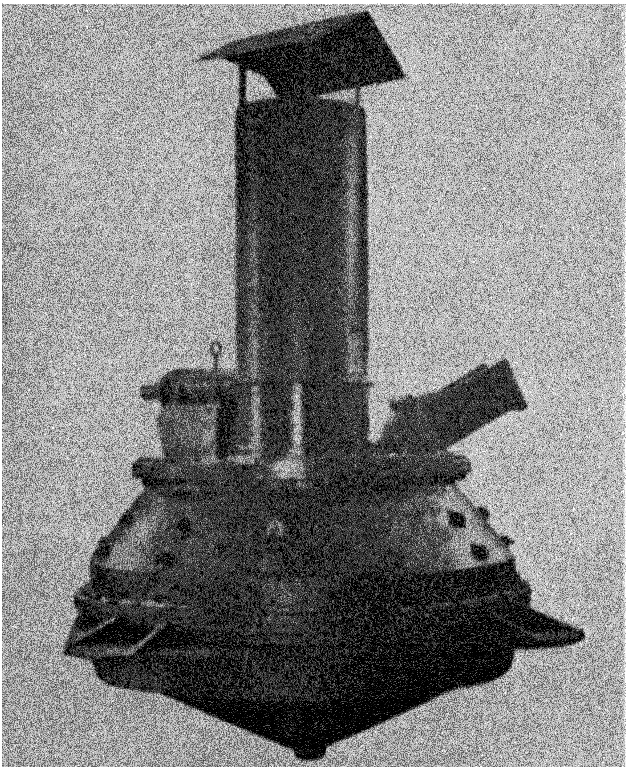

Fig. 118.—Dry slag granulating mill. (*Courtesy of Edgar E. Brosius, Inc.*)

At plants where the wet granulated slag is to be used for making cement, the molten slag flows down the "cinder fall" and into a long sloping ditch or sluice, passing over a granulating spout which has a high pressure jet of water on the underside. The slag is granulated into a sort of fine sand and is carried by the stream of water to a loading station and drained before loading onto cars for shipment to the cement plant.

Granulated slag has been used for many miles of railroad fill and even for roadbed. It has slow-setting cement qualities and is very easy to handle, and sometimes is flushed into place with hydraulic jets. For lightweight filling on bridges and structures, for fireproof filling, for runways on flying fields, for flooring in large warehouses, wet granulated slag has found extensive use.

FIG. 119.—Coarse Superock, actual size. (*Hassler, Trans. A.I.M.E. vol.* 125.)

Dry Granulated Slag.—Another form of granulated slag has been introduced into this country, a sort of "dry" granulated slag, made by pouring the molten slag from the slag pots into a patented rotating machine containing paddles. J. M. Hassler describes[1] the Superock (the name given to this granulated slag) plant at Thomas Works of the Republic Steel Corp. in Birmingham, Ala., and Fig. 119 is taken from that article. Hassler explains the making of Superock as follows:

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[1] In his article "Offsetting Increased Labor Cost in Blast-furnace Operation," *Trans. A.I.M.E.*, vol. 125, 1937.

It is made by pouring molten blast-furnace slag into a rotating machine, which whips and cools it and breaks up the lumps. A small amount of water is used at the entrance spout, which literally explodes the hot slag. The concussion, the rotary paddle force of the machine, and the expansion of gases released from the slag while in the machine, blows up the cooling, or hardening slag, while still plastic, into a mass of tiny cells. Each cell is separated from the others and surrounded by a thin wall of very hard and dense material. The cells have no passageways joining them nor do they connect. Under the microscope Superock is found to be a mass of these tiny air cells of varying size that cannot be seen with the eye.

While the shell of the aggregate is very hard and dense, so little of the total volume is occupied by the shell, or cell wall, that the weight is light and the large pieces are readily crushed, or broken, and screened into sizes desired. Superock thus has tensile and compressive strength approaching dump slag, yet weighs from 32 to 46 lb. per cubic foot. depending on the size, which is less than half of ordinary silicious sand aggregates. Superock mixed with Portland cement and rodded dry averages 46 lb. per cubic foot.

Crushing and Screening.—The crushing and screening of dry solid slag are like the preparation of rock products especially of limestone, except that it is necessary at all slag plants to run the slag over a magnetic pulley in order to remove the scrap iron that runs out with the slag as shot iron in the flushes and in larger pieces at casting time.

The crushing and screening of slag, some of it still quite warm, is a very dusty job and some recent plants have put in dust collectors. For certain fine sizes, the crushed slag is washed.

Concrete Aggregate.—The use of sized slag for concrete was indicated in the table of standard sizes given above. Its superiority as an aggregate in fireproof construction has been well demonstrated; in some cities the building codes specify slag aggregate for buildings above a certain low height. The finer sizes of slag are used for aggregate in hollow tile and solid building blocks, which are fire resisting and have good insulating properties.

James R. Cudworth and Joseph C. Mead describe[1] the use of crushed slag for ready-mixed concrete (in some years more

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[1] In a paper "Utilization of Slag in the Birmingham District, Alabama," *Trans. A.I.M.E.*, vol. 125, 1937.

money was made on slag than on pig iron where this method was used):

READY-MIX CONCRETE PLANTS

Several companies in the Birmingham district operate ready-mix concrete plants. In fact, the Sloss-Sheffield Steel and Iron Co. pioneered this branch with a plant built in 1924. The plant has been enlarged and modernized until now it has a capacity for mixing 1500 cu. yd. per day.

This ready-mix plant, which is representative of the practice in the district, utilizes the air-cooled slag from the company's blast furnaces. The slag is crushed and screened in the slag plant and then conveyed from the storage bins. Sand mixtures are also stocked in storage bins and conveyed to the ready-mix plant. Extensive experimentation has determined the proper mixtures of sand and aggregates to prevent segregation during the period of delivery. The sand and slag are stored at the ready-mix plant in three bins for three proportions of aggregates and in three bins for sand mixtures. The use of cement in large quantities requires special cement-handling equipment consisting of a power shovel, vibrating screen, cement pump and four storage tanks. Each tank has a capacity of 500 bbl. Both Portland cement and slag cement are used and mixtures of the two are frequently specified. The materials are conveyed to weighing hoppers and pass from them into the three mixers. From the mixers, which are of the tilting type, the product is delivered in open-body trucks.[1] Recently revolving mixers of 3-cu. yd. capacity mounted on truck chassis have been added to the equipment.

Roofing Material.—The use of fine crushed slag for "tar roofs" has long been known as a fire-resisting material. The size known as "washed roofing" is through ⅝-in. screen and on ¼ in. The finer sizes are used in the rolled roofing. Slags of certain analysis and structure are used for making special coverings and shingles, such as Flintkote.

Slag for Road Building.—Crushed and sized blast furnace slag is successfully used in building roads, not only in aggregate for concrete and in waterbound macadam, but the finer sizes have been used with asphalt and tars for surfacing, and for making bituminous paving mixtures which can be laid and rolled cold. It is natural and economical for a region to use its local resources for paving its highways and streets—clay paving brick for Ohio, concrete for Pennsylvania and Tennessee, granite paving blocks for Boston and New York, and crushed blast

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[1] M. F. BEISLER, *Pit & Quarry*, vol. 22, no. 5, p. 49.

The chief value of flue dust, of course, is in its iron content which varies almost directly with the percentage of iron in the ore burden. The second valuable ingredient is the fine coke breeze which varies greatly according to the period it was produced, the place in the gas-cleaning system it was deposited, and the smoothness of the blast furnace practice.

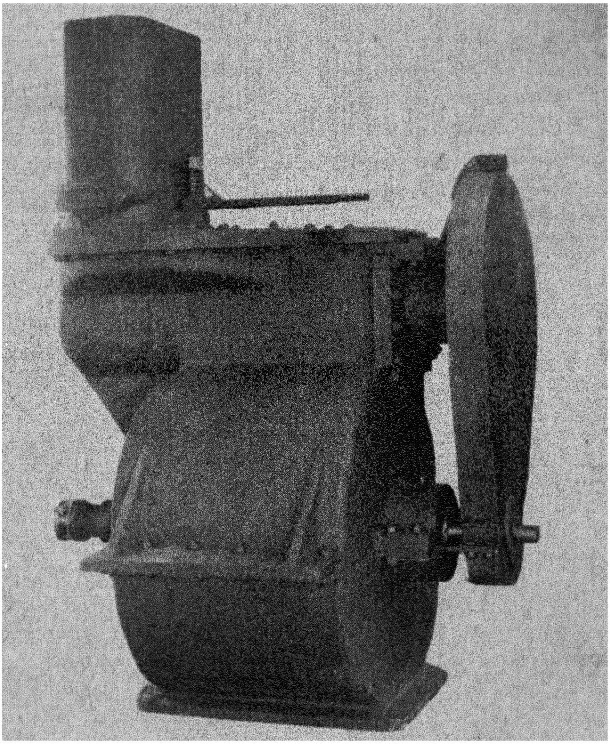

Fig. 120.—Flue-dust conditioner to remove and to moisten dust from the dry dust catcher (*Courtesy of Edgar E. Brosius, Inc.*)

There are still some large stockpiles of flue dust at furnace plants in this country awaiting the right time to be sintered. With the advancement of the art of sintering iron ores, the carbon content of these old flue-dust piles becomes more and more valuable because the finely divided carbon contained in the coke breeze scattered through the flue dust is an ideal fuel for sintering fine iron ores. Stock flue dust has been known to contain as much as 33 per cent carbon. Recently the author saw old dust that contained 25 per cent carbon, compared with about 15 per cent carbon in the flue dust being produced at the same furnaces.

The better screening of the coke that is charged into the furnace and the smoother the movement of the furnace, the less will be the carbon in the flue dust. The fixed carbon at an Ohio furnace was as low as 7.11 per cent with iron up to 55.20 per cent in the flue dust.

The flue dust that is carried off from wet washers in the scrubber water is so fine that over 80 per cent will pass through 200 mesh. Counselman in his paper (see Wet Washing, page 283) describes the recovery of 92.5 per cent of this very fine dust by thickeners and filters, and says that "the usual method of agglomeration is sintering."

PART VI

THE COMMERCIAL SIDE OF BLAST FURNACE PRACTICE

The author had been furnacing for a dozen years before anyone taught him the intricacies of steel plant cost sheets and showed him the intimate and vital connections between costs of pig iron and blast furnace practice. Men approach the position of blast furnace superintendent through different channels—sometimes the laboratory, often the "monkey wrench gang," but seldom the cost department—and the more channels he works in the broader his experience and the more chances for success.

This part of the book will deal with some of the commercial questions relating to the making of pig, especially the details of pig-iron costs.

PIG-IRON COST SHEETS

A pig-iron cost sheet should show all the details of quantities, analysis, and prices of raw materials, total tons, and total costs, and the total cost per ton of pig iron produced; the details of labor costs, and total cost per ton; the details of labor cost and materials for repairs, maintenance, and service; details of miscellaneous operating expenses, and the total costs per ton above the cost of materials. These costs vary greatly in different parts of the country largely on account of the differences in the assembling costs as seen in Table XXI in the section on that subject.

For obvious reasons the name of the companies and the prices and costs in the two examples of cost sheets (pages 298–301) are omitted, but the items are shown in detail; the first is for a lake-front furnace and the second is for an inland furnace.

THE COMPARATIVE COST SYSTEM FOR PIG IRON

A dependable cost system is necessary for the profitable manufacture of any product, and such a cost system must be based on reliable data, collected and assembled so as to

_____ COMPANY

Cost Sheet for Blast Furnace Department, *A* Furnace
Month of March 193__

Items	Material per ton, lb	% metallic contents	Gross tons	Price	Amount	Cost per ton	Average to date
Ore		35 58	546				
Ore		50 49	7,832				
Ore		51 04	7,545				
Ore		50 20	2,040				
Ore		47 05	1,115				
Ore		52 08	2,481				
Ore							
Ore							
Ore							
Total ore	3,376	50 28	21,559				
Scrap	512	85 00	3,269				
Sinter	127	48 00	809				
Mill scale	53	65 00	336				
Total other iron-bearing material	692	76 70	4,414				
Total metallic mixture	4,068	54 77	25,973				
Coke	1,579		11,297				
Limestone	806		5,767				
Total raw materials	6,453		43,037				
Raw materials stocking			Labor	Other	Total		
Unloading to stockpile							
Loading transfer car							
Dock storage charges							
Total							
Total materials charged							
Superintendents, foremen, blowers, etc							
Stocking bins and charging—labor							
Blast and stoves—labor							
Cast house—labor							
Disposal of slag—labor							
Pig casting—labor							
Pig-iron stocking and handling—labor							
Other furnace labor							
Labor in furnace repairs and maintenance							
Total furnace labor							
Material in furnace repairs and maintenance							
Lubricants, waste, and packing							
Pig casting—supplies and other							
Pig-iron stocking and handling—supplies							
Tools and miscellaneous—supplies							
Tuyeres, blocks, and cooling plates							
Refractories							
Demurrage							
Personal injury							

______ COMPANY.—(*Continued*)

Items	Gross tons	Price	Amount	Cost per ton	Average to date
Steam (410.3975 tons coal @ $3.65)					
Water					
Electric power and light					
Yard switching (175 tons coal @ $3.65)					
Laboratory					
Stable and Garage					
Shop expense					
Store expense					
General works expense					
General administration					
Relining stacks and stoves and painting					
Miscellaneous credits					
Cost above materials charged					
Less credits: Slag					
Net cost above materials charged					
Net total works cost					

Product				
Foundry		Number of days in operation	31	Total materials charged
Malleable	14,303	Average product per 24 hr	461	Total labor
Basic				Total other
Total	14,303	Tons made since Jan 1	40,838	Total cost
Average silicon in iron	1.83	Cubic feet air per minute	33,660	Average to date
% Hi Sul Iron—Mo	Nil			Total materials charged
% Hi Sul Iron—To date	Nil	Cubic air per pound coke	65	Total labor
		Lb. coke per ton iron to date	1,611	Total other
		Lb. stone per ton iron to date	779	Total cost
		Actual yield metal	55.07	
		Theoretical yield	58.63	
		Furnace loss	3.56	
Coal for miscellaneous purposes, 200 tons @ $3.65				
Tons made on lining	127,113	Furnace blown in ______		Furnace blown out ______

accurately reflect all the varying conditions that have a bearing on the actual cost of that particular product. Many executives are misled in making decisions as to the prices of their commodities because their cost sheets do not tell all the truth; and many operating men are wrongfully blamed sometimes when the cost sheets show higher costs than for the preceding months.

______ COMPANY

Cost Sheet ______ Division Works

Blast Furnace ______ Production Unit, Gross Ton Date ______ 19__

Item	% of mix	% iron content	Lb. per gross ton		Quantity		Price	Actual cost		
			This month	Last month	Total	Unit		Amount	Production unit cost	
									This month	Last month
Ore	32 06	54 66	1.282	1,208		Gross ton				
Ore	24 91	50 35	996	1,047		Gross ton				
Ore	15 24	53 04	610	604		Gross ton				
Ore	17	35 85	6	10		Gross ton				
Ore	3 05	45 00	122	121		Gross ton				
Sinter	2 35	52 68	94	88		Gross ton				
Open-hearth slag	7 18	25 80	287	352		Gross ton				
Scale	3 80	65 78	152	131		Gross ton				
Scrap	7 26	92 00	290	306		Gross ton				
Skimmings	87	27 50	35			Gross ton				
Pit cinder	2 53	65 78	101	58		Gross ton				
Shot scrap.	58	92 00	23			Gross ton				
Total metallic	100 00	54 29	3,998	3,925		Gross ton				
Coke	89 51 carbon	N.t.	1,655	1,656		Net ton				
Limestone	49 22 CaO	N.t	605	604		Net ton				
Total material charged			6,258	6,185						
Fuel for miscellaneous purposes:										
Coal for boilers										
Smithing coal										
Total miscellaneous fuel										
Producing labor:										
Stocking and charging						Hr.				
Blowing						Hr.				
Casting						Hr.				
Casting machine						Hr.				
Other producing labor						Hr.				
Total producing labor						Hr.				
Labor in repairs:										
Boilers						Hr.				
Blowing engines						Hr.				
Water works						Hr.				
Casting machine						Hr.				
Bonus paid to mechanical crew										
General						Hr				
Total labor in repairs						Hr.				
Total labor in maintenance						Hr				
Total labor						Hr.				
Material in repairs:										
Boilers										
Blowing engines.										
Water works										

______ COMPANY —(*Continued*)

Item	Lb per gross ton		Quantity		Price	Actual cost		
	This month	Last month	Total	Unit		Amount	Production unit cost	
							This month	Last month
Casting machine								
General								
Total material in repairs								
Total material in maintenance								
Shops overhead								
Boilers								
Blowing engines								
Casting machine								
General								
Maintenance								
Total shops overhead								
Miscellaneous material:								
Lubricants								
Tools and miscellaneous supplies								
Tuyeres and cooling plates								
Stopping clay								
Brick and clay for lining ladles								
Other refractories								
Boiler compound								
Total miscellaneous material								
Service accounts								
Yard switching								
Locomotive cranes								
Electric light and power			103 700	Kw -hr				
Total service accounts								
General operating expenses.								
Supt , foremen and clerks			1,334	Hr				
Works office			291	Hr.				
Laboratory			520	Hr				
Trucks								
Reserve for depreciation								
Reserve for relining and renewal								
Total general operating expenses.								
Total cost over material charged								
Total material charged								
M.O.E. at $.012 of $1.00 of cost								
Total cost of production								
Brought forward								
Less credits								
Scrap sales								
Steam sales								
Water sales								
Slag sales								
Switching and handling								
Coke breeze								
Other sales								
Total credits								
Net cost of production								

In the steel industry there has been much progress in cost accounting since the World War, but there are still so many varying opinions as to the proper handling of certain items of cost that we cannot yet say that the industry has attained a stable cost accounting system for its multifarious products. These divergent opinions are very evident in comparing the costs of one integrated steel company with those of some other integrated steel company; and even in the same company controlling several different plants making the same product there is great difficulty in having all the items of the cost sheets completely comparable in all the different plants. An analysis of the reason for these differences shows us that there are slight differences in raw materials, equipment, quality of product, or personnel that affect the costs and prevent a truly accurate comparison of costs.

Pig-iron Costs.—Pig iron is usually an intermediate product in a modern steel plant, in spite of the fact that it is the origin of practically all the steel now being made, and once was the origin in cases when steel is made from scrap. The true cost of pig iron is seldom shown by the cost sheets of steel companies because the manufacturing cost of the pig iron does not reflect its proportion of the fixed charges on the facilities that provide the raw materials for the blast furnace, and usually the fixed charges on the blast furnace itself are included only in the balance sheet of the final accounting of the corporation. When in vertical operations the cost sheet for pig iron does not reflect the cost of depletion and depreciation on iron ore, coal, coke, and other raw materials but these items are included in the lump sum for these accounts after all manufacturing costs, then the true cost of the pig iron is not available to the executive who decides what the price of his pig iron shall be to other departments of his steel plant, or in the open market. In those rare cases where the true cost of pig iron is expressed by the pig-iron cost sheet there seems to be a wide difference between that cost and the pig-iron cost in integrated steel plants that do not find their cost of pig iron in the same way. This is especially true in the case of steel plants located on the shores of the Great Lakes, and owning iron-ore mines, coal mines, and quarries. Oftentimes the price of raw materials to the blast furnace will not include any charges for ore docks and handling machinery other than the direct operating costs. Under such circumstances pig iron can be put below the true cost with the executive kept in ignorance of the fact that he is losing money.

Comparing Costs.—In comparing the costs of pig iron at the different plants of the same company, or in comparing the costs of different companies, there are always differences of conditions and accounting that make true comparisons impossible. But, even if all the rightful charges are included in the pig-iron cost sheets, there is one other question that must be answered before the executive has the necessary information for making his final decision as to the right cost and the right price for his pig iron. That question is: How near does the actual cost of the pig iron, as shown on the cost sheets, come to the ideal cost under the conditions of prices and analyses of raw materials, of labor rates, of plant capacity, and kind of product prevailing during the period covered by the cost sheet?

When the answer to this question is known, then comparisons of pig-iron costs at different plants can safely be considered. Furthermore, if such comparisons show up unfavorable costs, it will be possible to find the reason and to plan for the remedy.

Ideal Cost.—The ideal cost of pig iron at any blast furnace for any cost period is that cost per ton of pig iron which would be obtained if the furnace produced 100 per cent of capacity, recovered 100 per cent of the available iron units in the ore mixture, and operated at the agreed number of hours of labor at the standard rates, and with the standard daily cost for supplies and service, for overhead and relining, and for depreciation. The ideal cost for any cost period involves the actual prices and analyses of the raw materials used during that period and includes salaries, relining charges, and depreciation at the predetermined rates. The "ideal cost" as adopted includes only seven items, as follows:

Ore
Coke
Flux
Labor
Supplies and service
Overhead
Relining and depreciation

If desired, the seventh item (relining and depreciation) can be omitted, because it is usually a fixed charge per ton and does not vary with the tonnage. However, it is better to include it and to show each part separately, as in Tables XIX and XX.

The Columbus Comparative Cost System (First Evolved at Columbus, Ohio).[1]—The Columbus comparative cost system for pig iron compares the actual cost per ton of pig iron each month (or for each cost period) with the ideal cost for that month or that particular cost period and shows exactly where there has been an excess cost or loss in yield and generally points to the reasons. It is based on the metallurgical values of the ore mixture, coke, and limestone used in the blast furnace for making pig iron and combines costs and analyses in such a way that the management can evaluate the varying qualities of these raw materials. It places directly upon the management the responsibility for quality and prices and relieves the operating superintendent of blame for not getting high-grade production and costs with low-grade and high-cost materials.

The Columbus comparative cost system for pig iron is a guide for operations and the purchase of materials, as well as being a check on waste of materials, supplies and labor. It in no way changes or interferes with the cost accounting system in use, but it sometimes detects errors that may have crept into the cost sheets. It requires certain facts and figures already included somewhere in the cost-keeping and time-keeping records.

The fairness, brevity, and clearness of this system of comparing costs make it dependable and helpful to both the executive and the operator and provides a measuring stick for performance that is almost uncanny in detecting leaks of time, materials, and money. The comparison between the actual cost and the ideal cost can be so condensed that it literally can all be "put on a postal card." Generally, all the figures are accompanied by a brief explanation of why the actual cost of each of the six items is above or below the ideal cost of that item.

The system is based on the metallurgical laws of making pig iron, the capacity of the blast furnace, the equipment of the plant, and the kind of pig iron produced.

Basis for Ideal Cost.—In order to set up a Comparative Cost System for a blast furnace (a separate cost sheet for each blast

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[1] Initiated by the late J. H. Frantz, vice chairman of The American Rolling Mill Company.

furnace in a plant is essential for good management) it is necessary to recognize certain base lines from which to start, and from which we can make the many adjustments made necessary by the ever varying conditions of price, analysis, and operation. These base lines are as follows:

1. The rated daily capacity of the blast furnace
2. An ore mixture containing 51.50 per cent Fe (natural)
3. Coke containing 90 per cent fixed carbon
4. Flux stone containing 49 per cent CaO
5. The standard force sheet for that furnace
6. Agreement on the daily cost for supplies and service
7. Agreement on the daily cost for overhead expense
8. Agreement as to the per-ton charge for relining and depreciation

Blast Furnace Capacity.—The capacity of a blast furnace expressed in tons (2,240 lb. to the ton, gross ton) of pig iron per 24 hr., is essential to the comparative cost system in spite of the fact that the generally accepted rule established by the Southern Ohio Pig Iron and Coke Association in 1920, expresses blast furnace capacity in pounds of coke burned in 24 hr.

This rule is that a blast furnace of modern construction should burn 60 lb. of coke per cubic foot of working volume in 24 hr.

The base coke in this system contains 90 per cent carbon (at 212°F.) and 3 per cent moisture as received. The "working volume" of a blast furnace is the cubical contents from the level of the center line of the tuyeres to the level of 2 ft. below the big bell when closed.

A big-hearth furnace will make more pig iron than a furnace with less diameter in the hearth to the extent of the increase in the working volume, and no more; and even not then, unless the other dimensions of the furnace are properly proportioned. There is something wrong somewhere when a blast furnace does not burn about 60 lb. of coke per cubic foot of working volume in 24 hr.; the trouble is either in the coke or in the furnace; if it is in the furnace, it may be in construction, in equipment, or in the handling of the furnace.

This rule holds good regardless of the kind of iron that is being made because the tonnage of coke consumed is the governing factor. Some kinds of iron require more coke per ton and, therefore, the tons of pig iron produced on the total coke consumed in 24 hr. will be less.

Base Ore Mixture.—The ore-mixture basis of this system is half Old Range ores and half Mesaba ores, containing 51.50 per cent iron (Fe) in the natural state. The theoretical yield of pig iron from such a mixture is 54.78 per cent pig iron containing 94 per cent Fe. The percentage of silica in this base ore mixture is assumed to be 8.00 per cent. The quantity of ore mixture required per ton (2,240 lb.) of pig iron is 1.825 tons, 4,088 lb., containing a total of 210,532 units of iron (Fe), assuming that there is 100 per cent recovery, which is practically impossible, but often is so recorded in the cost sheets.

A balance sheet of all units of iron bought and delivered into the furnace is carefully kept, so as to guide the management in the accounting and in the inventory. It is not unusual for this balance sheet, Cost Data Sheet No. 4 (called the consumption, production, and loss statement) to show a greater recovery of pig iron than is theoretically possible. When this persists month after month, it is certain that there are errors in the furnace records somewhere: weight of material or of product may be wrong; samples taken for analysis may not be truly representative. Each month all of the units of iron contained in the ore mixture charged into the furnace are debited and all the units of iron in the pig iron, in the flue dust, and in the slag are credited, and the difference is the unaccounted-for loss or gain for that month.

This consumption, production, and loss statement is a wonderful metallurgical and inventory check on blast furnace operations and a guide for the supervision of sampling, analyzing, weighing, and accounting. This record begins with the filling of ore into the furnace for blowing in and continues throughout the blast. If the records are accurately kept, there will be a certain unaccounted-for loss which will represent that loss of iron in manufacture that was not recovered as pig iron, castings, or scrap, or else was not accounted for in flue dust or slag.

Adjustments for variations of the percentage of iron in the ore mixture will be explained later under the subject of adjustments.

Base Coke.—Although the base coke approved by the Southern Ohio Pig Iron and Coke Association in August, 1920, was a coke containing 89 per cent fixed carbon, the base coke adopted for the Columbus comparative cost system contains 90 per cent fixed carbon (at 212°F.) and 3 per cent moisture as received, railroad weights govern. The coke should be tough, but not dense or fragile, and free from breeze. This is called "commercial coke" (to differentiate it from "dry coke").

It is assumed that it requires 1,800 lb. of "commercial coke" as described above, to make 1 ton of pig iron from an ore mixture containing 51.50 per cent iron (Fe), natural, and with blast temperature at 1200°F. The base coke contains 1 to 2 per cent volatile matter and less than 1.00 per cent sulphur; obviously, the ash in the base coke will not be over 9.00 per cent. Adjustments for variations in the analysis of the coke used will be explained later on.

Sometimes the character of the coke is such that it is impossible for the furnace to consume 60 lb. of coke per cubic foot of working volume in 24 hr., even when all conditions of furnace construction and accessories are satisfactory. Usually in such a case, the ash in the coke is excessive and the coke is blocky and dense, causing high blast pressure and sticking and slipping of the furnace. The obvious remedy is the immediate reduction of the ash in the coking coals and such adjustments in the coking time and heat of ovens as will reduce the density of the coke.

Base Limestone.—The base limestone is calcite with 49 per cent calcium oxide. Magnesia is not considered at all, and only the calcium oxide enters into the calculations for values, although in some cases it will be necessary to have not less than about 7.00 per cent magnesia in the blast furnace slag. A calcite limestone without any magnesia is a very unsatisfactory flux in the blast furnace, and often it is necessary to use some dolomite mixed with the calcite.

The method for making the necessary adjustments on account of variations in percentage of calcium oxide and the use of open-hearth slag in the ore mixture will be explained later.

Labor.—Just as it is necessary to know how much pig iron a blast furnace will produce in a day, just so is it necessary to know how much work a man should do for a day's work at a blast furnace; a man-day at a blast furnace is one man working 8 hr.

The ideal amount of labor per ton of pig iron, expressed in hours and in money, is found by dividing the ideal daily tonnage of the blast furnace into the total hours of labor and the total cost of labor per day as shown on the standard force sheet approved by the management and in use throughout the cost period. The ideal labor cost includes all the items of labor included in the regular cost sheets used for pig iron. All salaries charged against pig iron are included in the cost for overhead.

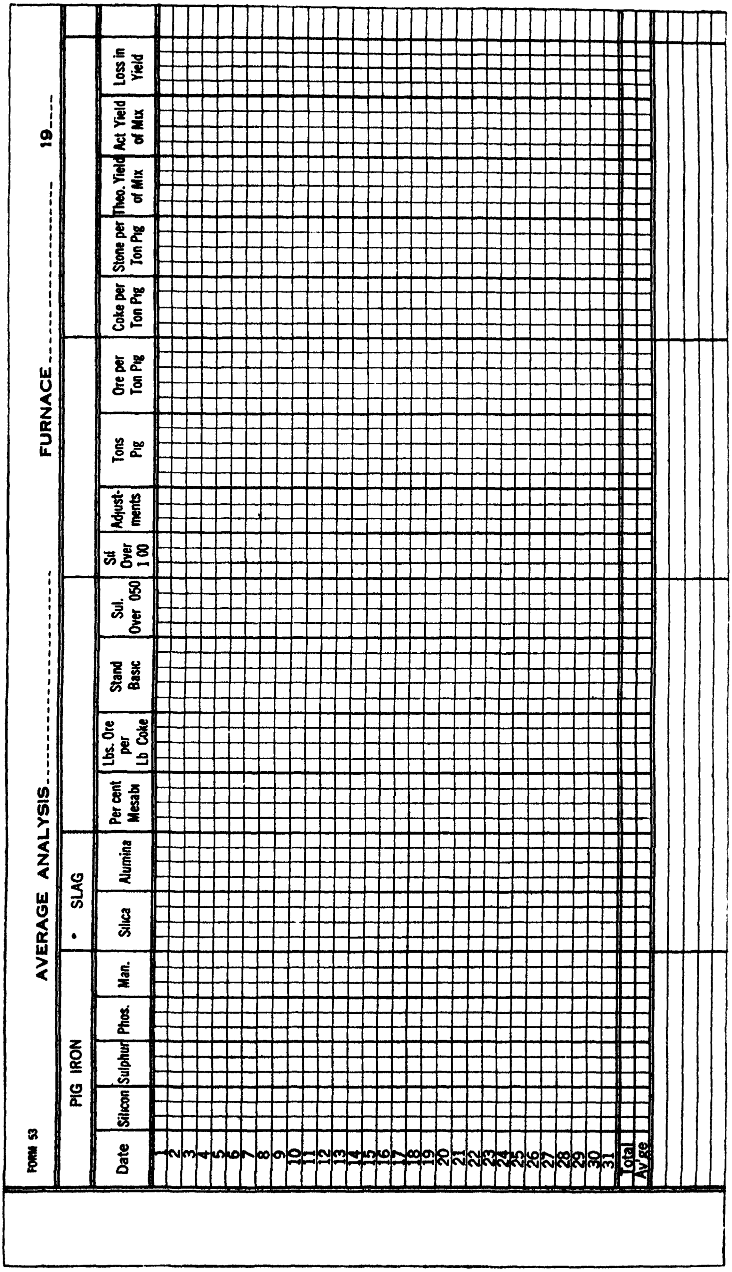
The standard force sheet shows the total number of employees on the hourly payroll and shows the total number of hours worked by all the wage earners in a 24-hr. period and the total wages earned. From these figures are derived the hours of labor per ton of pig iron and the average rate of wages per hour. The ideal labor cost for the ideal tonnage can then be shown. Adjustments for variations in rates and tonnages will be explained later.

Supplies and Service.—The cost of supplies and the cost of service are combined into one item in the Columbus comparative cost system under the heading of "Supplies and Service." The total cost of this item for a 24-hr. period is ascertained by adding the average daily quantities and costs of coal, sand, refractories, bronzes, tools, chemicals for water treatment, all materials in repairs and maintenance, lubricants, yard switching, locomotive crane service, electric light and power, steam, and any other supplies and services that are included in the regular cost sheets.

The ideal cost for supplies and service is expressed in total cost per 24 hr. and then in cost per ton for the ideal daily tonnage. This item does not have to be adjusted each month except that the per-ton cost will vary directly with the average daily production of pig iron. However, there are so many small items included under this heading that it is advisable to review the whole list of supplies and service occasionally so as to make the necessary revisions. Changes in practice, equipment, or accounting methods should be watched closely and the daily total ideal cost for supplies and service changed accordingly.

This item per ton is directly reduced by increased daily pig-iron production.

Overhead.—The cost of overhead includes all those items usually carried under general operating expense and miscellaneous operating expense in the regular pig-iron cost sheet, excepting the charges for relining and for depreciation. It includes salaries, taxes (whenever taxes are shown in the regular cost sheet, and notation should be made when not so included), insurance,



FORM 53

AVERAGE ANALYSIS.................... FURNACE.................... 19....

Date	PIG IRON				SLAG		Per cent Mesabi	Lbs. Ore per Lb Coke	Stand Basic	Sul. Over 050	Sil Over 1 00	Adjustments	Tons Pig	Ore per Ton Pig	Coke per Ton Pig	Stone per Ton Pig	Theo. Yield of Mix	Act Yield of Mix	Loss in Yield	
	Silicon	Sulphur	Phos.	Man.	Silica	Alumina														
1																				
2																				
3																				
4																				
5																				
6																				
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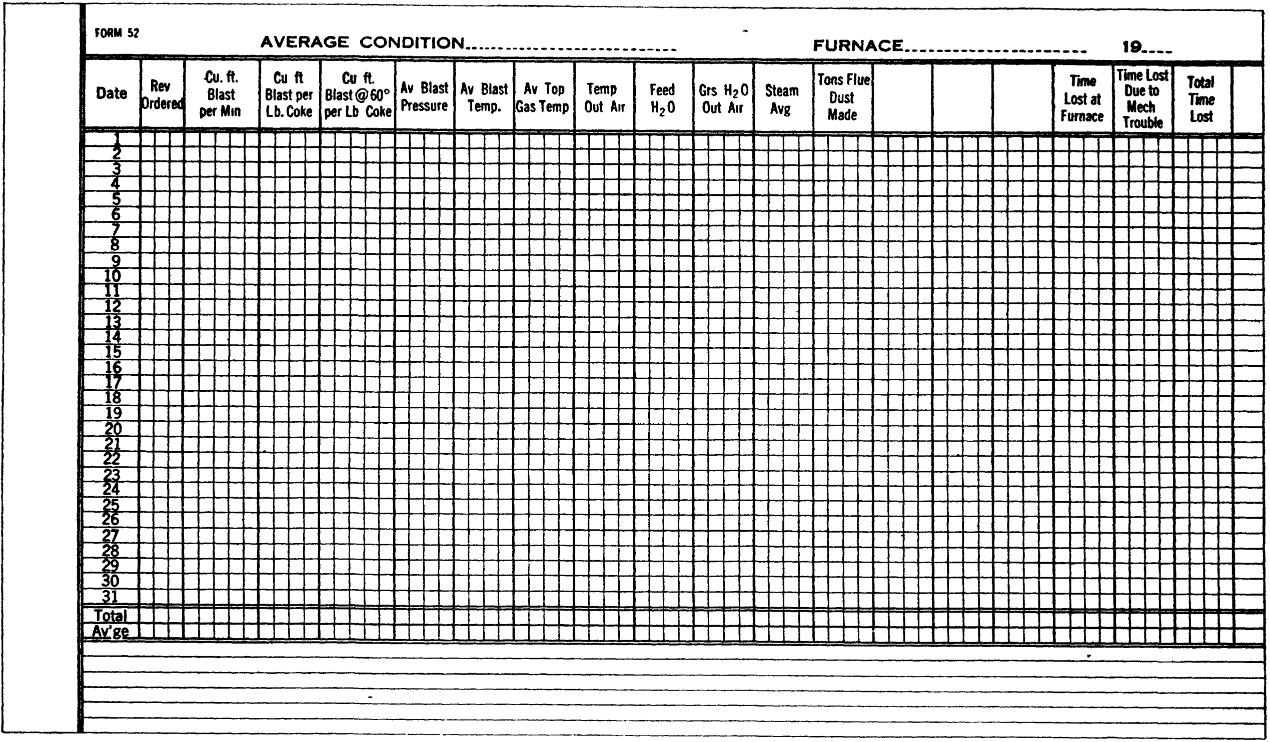
28																				
29																				
30																				
31																				
Total																				
Av'ge																				

FIG. 121.—Form for average analysis.



FORM 52

AVERAGE CONDITION.............................. FURNACE........................ 19....

Date	Rev Ordered	Cu. ft. Blast per Min	Cu ft Blast per Lb. Coke	Cu ft. Blast @ 60° per Lb Coke	Av Blast Pressure	Av Blast Temp.	Av Top Gas Temp	Temp Out Air	Feed H_2O	Grs H_2O Out Air	Steam Avg	Tons Flue Dust Made				Time Lost at Furnace	Time Lost Due to Mech Trouble	Total Time Lost	
1																			
2																			
3																			
4																			
5																			
6																			
7																			
8																			
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29																			
30																			
31																			
Total																			
Av'ge																			

FIG. 122.—Form for average conditions.

fees, office expense, hospital and first aid, laboratory, demurrage, telephone and telegraph, watchmen and police, automobiles and teams.

Relining and Depreciation.—The relining charges are fixed at so much per ton and should be shown separately from depreciation charges, which may be either so much per ton regardless of tonnage, or so much per month and varying directly with the tonnage. Even if depreciation charges are not usually included

PIG IRON

COST DATA SHEET NO. 1
The ______ Company
______ Division
Data for the month of ______ 193_

	No. 1 furnace	No. 2 furnace	By
Total tons pig iron made			
Number of days in operation			
Average production per 24 hr			
Total tonnage made on lining			
Date furnace blown in			
Cubic feet air blown per minute			
Theoretical yield (at 94 per cent Fe)			
Cubic feet of air at 60°F per pound coke			
Actual yield			
Average percentage Fe in mixture			
Loss in yield			
Average silica in mixture			
Average fixed carbon in coke			
Average sulphur in coke			
Average moisture in coke			
Average CaO in limestone			
Flue dust recovered (tons)			
Flue dust recovered (pounds)			
Flue dust sintered (tons)			
Pounds flue dust per ton pig iron			
Total man-days worked			
Total hours worked at ______ hr per man-day			
Total hours worked by sinter plant			
Total hours worked by salaried employees			
Total hours worked on construction			
Total hours worked unloading to stockpile			
Net hours labor entering the labor cost			
Hours of labor per ton of pig iron			

PIG IRON

COST DATA SHEET NO. 2

The ______ Company
______ Division
Data for month of ______ 193__

______ Furnace

Charge	Lb per ton pig	Tons per ton pig	Total tons used	Price per ton	Total cost	Cost per ton pig
Ore and metals (2,240 lb. ton)						
Coke (2,000 lb. ton)						
Limestone (2,000 lb ton)						
Labor ..... Total hours	at			per hour		
Supplies and service	Per day for			tons		
Overhead	Per day for			tons		
Depreciation ______ ; Relining and renewals				per ton		
Total						

Production ______ tons
Ideal production for this month ______ tons

______ Furnace

Charge	Lb per ton pig	Tons per ton pig	Total tons used	Price per ton	Total cost	Cost per ton pig
Ore and metals (2,240 lb. ton)						
Coke (2,000 lb ton).						
Limestone (2,000 lb. ton)						
Labor. .. Total hours	at			per hour		
Supplies and service	Per day for			tons		
Overhead	Per day for			tons		
Depreciation ______ ; Relining and renewals				per ton		
Total						

Production ______ tons.
Ideal production for this month ______ tons

Totals for both furnaces

	Tons pig	Total cost	Cost per ton
______ furnace			
______ furnace			
Both furnaces			

Date ______ 19__

Data furnished by ______

PIG IRON

COST DATA SHEET NO. 3

The ______ Company

List of records to be kept and instructions as to source and by whom recorded

Data	Origin	Recorded on data sheet	Recorded by
Total tons pig iron made	Daily furnace report	No 1	Furnace clerk
Number of days in operation	Daily furnace report	No 1	Furnace clerk
Average production per 24 hr	Daily furnace report	No 1	Furnace clerk
Total tonnage made on lining	Daily furnace report	No 1	Furnace clerk
Date furnace blown in . . .	Daily furnace report	No 1	Furnace clerk
Cubic feet air at 60°F per pound coke	Daily furnace report	No 1	Furnace clerk
Theoretical yield (at 94 per cent Fe)	Daily furnace report	No 1	Furnace clerk
Actual yield	Daily furnace report	No 1	Furnace clerk
Average per cent Fe in mixture	Daily furnace report	No 1	Furnace clerk
Loss in yield	Daily furnace report	No 1	Furnace clerk
Average silica in mixture	Laboratory reports	No 1	Chemist
Average fixed carbon in coke	Laboratory reports	No 1	Chemist
Average sulphur in coke	Laboratory reports	No 1	Chemist
Average moisture in coke	Laboratory reports	No. 1	Chemist
Average CaO in limestone	Laboratory reports	No. 1	Chemist
Flue dust recovered (tons) .	Yardmaster reports	No 1	Yardmaster
Flue dust recovered (pounds)	Yardmaster reports	No. 1	Yardmaster
Flue dust sintered	Yardmaster reports	No 1	Yardmaster
Pounds flue dust per ton pig iron .	Calculated	No. 1	Cost clerk
Total man-days worked	Daily labor report	No 1	Time office
Total man-days at ______ hr , per man-day	Daily labor report	No 1	Time office
Total hours worked by sinter plant	Daily labor report	No. 1	Time office
Total hours worked by salaried employees	Daily labor report	No 1	Time office
Total hours worked on construction .	Daily labor report	No. 1	Time office

COST DATA SHEET NO. 3.—(*Continued*)

Data	Origin	Recorded on data sheet	Recorded by
Total hours worked unloading to the stockpile	Daily labor report	No 1	Time office
Net hours labor entering the labor cost . . .	Daily labor report	No 1	Time office
Hours of labor per ton of pig iron	Calculated	No 1	Cost department
Materials per ton pig iron	Monthly cost sheet	No. 2	Cost department
Prices per ton of materials	Monthly cost sheet	No 2	Cost department
Total cost of labor	Monthly cost sheet	No. 2	Cost department
Total cost of supplies and service	Monthly cost sheet	No. 2	Cost department
Total cost of overhead	Monthly cost sheet	No 2	Cost department
Total cost of relining and depreciation	Monthly cost sheet	No 2	Cost department
Total cost of pig iron	Monthly cost sheet	No 2	Cost department
Ideal production—tons pig iron	Calculated	No. 2	Cost department
Actual costs of the 7 items	Cost data sheet No 2	No 5	Cost department
Ideal costs of the 7 items	Calculated	No 5	Cost department
Excess costs of the 7 items	Calculated	No. 5	Cost department
Analyses, yields, and other data	Cost data sheet No 1	No. 5	Cost department
Excess cost due to management ...	Calculated	No 5	Cost department
Causes for excess cost .	Study of all records	No 5	Asst to executive

in the regular cost sheet, it is almost necessary to include them in comparing the pig-iron costs at different plants.

Collecting the Data.—In order to facilitate the work of comparing the actual cost of pig iron with the ideal cost according to the methods of the Columbus comparative cost system, use is made of Cost Data Sheet No. 1 and Cost Data Sheet No. 2, forms of which are herewith shown. On Cost Data Sheet No. 3 is shown the source of each item and where recorded. From all these data, the final comparative cost sheet is made up (Cost Data Sheet No. 5). To facilitate the work of getting monthly averages of analyses and conditions, forms, such as are ordinarily used for keeping furnace data, are made a part of the comparative cost system for pig iron (see Figs. 121 and 122).

PIG IRON
COST DATA SHEET NO. 4
The ______ Company
Consumption, Production, and Loss
______ Furnace Month of ______ 193__

Ore mixture	Tons used	Per cent Fe (nat.)	Total ton-units of Fe
______ Ore			
______ Ore			
______ Ore			
______ Ore			
______ Ore			
______ Ore			
Sinter			
Roll scale			
Open-hearth slag			
Scrap			
______			
______			
Coke			

Total ton-units ______
Total pig at 94 per cent Fe ______
Actual tons pig made ______
Difference in tons to be accounted for ______
Otherwise accounted for:
Tons % Fe nat
Flue dust ______ ______ ______
Slag ______ ______ ______
Total Fe otherwise accounted for ______
Equivalent in pig iron at 94 per cent ______
Gross tons pig iron in furnace (proportion of next cast) ______ ______
Total tons otherwise accounted ______ ______
Unaccounted-for {Gain ______
Unaccounted-for {Loss ______

An example of actual pig-iron costs showing that in one case where pig iron was costing $20.82 per ton (in May, 1922) there

PIG IRON

COST DATA SHEET NO. 5
The ______ Company
Comparison of Ideal and Actual Costs of Pig Iron
______ Furnace Month of ______ 193__
______ Furnace in blast

Basis for ideal cost							Excess due to management		
	Tons	Lb.	Units	Furnaces in blast		Ideal amounts per ton for this month	Tons	Lb	Amount
				One	Two				
Ore	1 825	4088	210,532 Fe.	Same					
Coke	0 900	1800	157,140 C.	Same					
Stone	0 425	850	49,000 CaO	Same					
Labor—Number hr per ton pig									
Supplies and service per day per furnace									
Overhead, per day per furnace									
Relining, Depreciation						Total			

Ideal cost at this month's prices and analysis		Actual cost this month	
Ore		Ore	
Coke		Coke	
Stone		Stone	
Labor		Labor	
Supplies		Supplies	
Overhead		Overhead	
Relining and depreciation		Relining and depreciation	
Total		Total	
Due to management		Cost of materials	
		Cost above materials	

Excess cost

Items	Tons	Per ton	Per cent	Causes
Ore				
Coke				
Stone				
Labor				
Supplies				
Overhead				
Total				

Tonnage	Monthly	Daily	Yield	Analyses	Labor
Ideal			Theor.______	Fix. carb. in coke______	Hr. labor per ton pig______
Actual			Actual______	CaO in limestone______	
Diff			Loss______	SiO_2 in ores______ S in coke______	Tons pig per man-day______

Date ______ Data furnished by ______

was better work done than in the case at another furnace, Table XX, where the cost was $15.57 per ton (in July, 1928).

TABLE XIX

ACTUAL COST THIS MONTH

May, 1922

Ore —4168 lb.—1.860 tons at $5.286	= $ 9.836
Coke —1975 lb.—0.988 ton at 7.683	= 7.588
Stone—1051 lb.—0.525 ton at 1.117	= 0.587
Labor—2.366 hr. at 34 cents per hour	= 0.805
Supplies and service	= 0.378
Overhead	= 0.478
Relining—25 cents—Depreciation—90 cents	= 1.150
Total	= $20.822
Materials	= 18.011
Cost above materials	= $ 2.811

IDEAL AT THIS MONTH'S PRICES

Ore —1.863 tons at $5.286	= $ 9.848
Coke —0.923 ton at 7.683	= 7.095
Stone—0.581 ton at 1.117	= 0.649
Labor—2.62 hr. at 33.6 cents per hour	= 0.880
Supplies and service—$270 per 24 hr.	= 0.786
Overhead —$240 per 24 hr.	= 0.698
Relining—25 cents—Depreciation—90 cents	= 1.150
Total	= $21.106
Materials	= 17.592
Cost above materials	= $ 3.514

EXCESS COST

	Tons	Per Ton Pig	Causes
Ore	—*0.003**	*$0.012*	Practically ideal
Coke	—0.0645	$0.493	Excess coke—increased iron tonnage
Stone	—*0.0555*	*$0.062*	Partly due to low S in coke
Labor	—*0.254* hr.	*$0.075*	Economical supervision. Record tonnage
Supplies		*$0.408*	Great economy—record tonnage
Overhead		*$0.220*	Great economy—record tonnage
Total		*$0.284*	3d consecutive month lower than ideal

* Figures in italics are red; and this is once when "red figures" are desirable.

Adjustments.—After determining the working volume of a blast furnace by calculation and after agreement on the operating organization and their wages and salaries, on the daily budget for supplies and service and overhead, and on the per-ton charge for relining and depreciation, then there must be made each

TABLE XX

ACTUAL COST THIS MONTH—PER TON

July 1928

Ore —4196 lb.—1.873 tons at $5 077	= $ 9.509
Coke —1735 lb.—0.868 ton at $2.945	= 2.555
Stone— 734 lb.—0.367 ton at $1 490	= 0.547
Labor—1.658 hr. at 50 cents	= 0.829
Supplies—$694 for 566 tons	= 1 225
Overhead—$371 for 566 tons	= 0.656
Relining—25 cents (no depreciation)	= 0.250
Total	= $15 571
Materials	= 12.611
Cost above materials	= $ 2.960

IDEAL AT THIS MONTH'S PRICE

Ore —1 853 tons at $5.077	= $ 9.408
Coke —0 889 ton at 2 945	= 2 618
Stone—0.342 ton at 1 490	= 0 510
Labor—1 16 hr. at 47 1 cents per hour	= 0 546
Supplies—$336 for 579 tons	= 0 580
Overhead—$286 for 579 tons	= 0 495
Relining—25 cents	= 0 250
Total	= $14 407
Materials	= 12 536
Cost above materials	= $ 1.871

EXCESS COST

	Tons	Per Ton Pig	Causes
Ore	—0.020	$0 101	Loss in yield of 0.58%
Coke	*—0 021**	*0 063*	Beat the ideal by 43 lb.
Stone	—0.025	0 037	Rather basic slag
Labor	—0 498 hr.	0 283	Too many men—lack of tonnage
Supplies	—	0 645	Heavy repairs—excessive service
Overhead	—	0 161	Too much main office expense
		$1.164	Excessive cost above materials

NOTE: The excessive switching charges included in the "excessive service" were eventually greatly reduced.

* Figures in italics are red; and this is once when "red figures" are desirable

month certain adjustments, in order to conform to the metallurgical variations in the raw materials.

The working volume of the blast furnace is mathematically fixed by the lines of the furnace when blown in, and there are no changes until these dimensions are altered.

The daily sums of money budgeted for labor, salaries, supplies, service, and overhead are fixed by conference and agreement, and are not changed except on authority of the executive in charge of operations. The charges per ton of pig iron for relining and depreciation are also fixed by agreement and are not changed except on the same authority.

Management Responsibility.—The responsibility for the capacity of the blast furnace and its equipment rests with the management; the superintendent is responsible for the maintenance and repairs. The responsibility for the quality and the price of ore, coke, and limestone rests directly upon the management; the responsibility of the superintendent is limited by these prices and by the analyses of the raw materials.

The function of the Columbus comparative cost system for pig iron is twofold: it guides the management in obtaining the most economical combinations of ore, coke, and limestone, and it guides the superintendent in producing the greatest possible tonnage of pig iron with the least possible cost from the raw materials furnished by the management. The fairness of this comparative system commends itself to both the management and the operating superintendent.

The comparison of pig-iron costs is not made with the costs of some other blast furnace plant, nor with previous costs at the same furnace under different prices and analyses. But the actual cost each month is compared with the ideal (100 per cent) perfect cost for that particular month and under the conditions of prices and analyses of raw materials that prevailed during that month. Such a comparison is a measuring stick for the ability of the management and the skill of the superintendent.

Coke Adjustment.—Pig iron is produced in an iron blast furnace only when fuel is burned, and the rate of production depends upon the rate of combustion of the fuel. In blast furnaces using coke as fuel, the ideal rate of combustion is 60 lb. of coke per 24 hr. for each cubic foot of working volume. As previously explained the "base" coke for the comparative cost system contains 90 per cent fixed carbon (dried at 212°F.) and 3 per cent moisture (commercial, railroad weights governing). It is acknowledged that 1,800 lb. of such coke will be used in making a ton of pig iron (2,240 lb.) from 1.825 tons of an ore mixture containing 51.50 per cent iron (natural), using 850 lb. of limestone flux containing 49 per cent calcium oxide; this means 157,140 units of fixed carbon (3 per cent moisture in 1,800 lb. "commercial" coke = 54 lb. and 1,800 − 54 = 1,746; 1,746 × 90 = 157,140).

If the percentage of fixed carbon in the coke used in any month is less than 90 per cent, then this lower percentage is subtracted from 90 per cent and the difference is doubled, and this amount is subtracted from 90 per cent to find the available carbon. It is assumed that each increase in ash requires an equal amount of carbon to take care of this ash and the limestone needed to flux it. The percentage of available carbon divided into 157,140 units will give the "comparative value" of that particular coke expressed in pounds of coke required for making 1 ton of basic iron under the conditions given above for the analysis of ore mixture (51.50 per cent iron natural).

If it should happen (and it occasionally does happen, where clean coal is coked) that the coke contains more than 90 per cent fixed carbon, then the difference is doubled and *added* to 90 per cent to find the available carbon.

The actual coke charged into a furnace during any one month is the total of the railroad weights of coke after allowance has been made so that by-product coke should contain not more than 3 per cent of moisture. There is no such adjustment for beehive coke, but the actual railroad weights shall be used.

The ideal total coke consumed in 24 hr. is found by multiplying the cubic feet of working volume by 60. This total coke per 24 hr. divided by the "comparative value" of the coke for the month, as determined above, will give the ideal tons of pig iron per day, using the coke provided for that month but with an ore mixture containing 51.50 per cent iron. Adjustments for variations in the percentage of iron in the ore mixture will be explained later on.

The total amount of coke burned in a given furnace in 24 hr. is a fixed quantity. The tonnage of pig iron produced in that furnace in the same time is a variable quantity, depending on the character and available carbon of the coke and on the richness of the ore mixture.

Therefore, there is another adjustment to be made for the ideal coke per ton of pig iron as follows: After the ideal daily tonnage of pig iron has been determined according to the quality of the coke and the richness of the ore mixture, then the ideal total weight of coke burned in 24 hr. is to be divided by that month's ideal tonnage of pig iron for 24 hr. This will give the ideal coke per ton of pig iron for that particular month, using coke of that particular analysis and smelting an ore mixture of that particular iron content.

Ore Adjustment.—The ideal number tons of ore mixture required per ton of pig iron for any particular month is found by dividing 1.00 by the per cent theoretical yield of the ore mixture for that month, carrying the decimal to four places (the per cent of theoretical yield is taken from Cost Data Sheet No. 1). To check this result, the total tons of ore mixture (including all iron-bearing materials) should be divided by the ideal total tons of pig iron for that particular month.

The ideal price of the ore mixture for any month is the actual average price of all the ore- and iron-bearing materials charged into the furnace (or melted in the casting ladle) during that month. This price is to be obtained from cost data sheet No. 2, which is filled out each month by the accounting department.

There is an item in the consumption, production, and loss statement (Cost Data Sheet No. 4) that does not enter into the price of the ore mixture but does enter into the tonnage, *viz.*, the small percentage of iron contained in the coke. Although this is usually 1.00 per cent or less, the sum total in all the coke consumed will more than offset the small percentage of iron chemically combined in the blast furnace slag and which is accounted for in the same Cost Data Sheet—No. 4.

Ore Allowances.—In some companies it is the rule to add a certain small percentage to all recorded weights of ore and iron-bearing materials charged into the blast furnace, so as to take care of any shrinkages in handling the raw materials. This adjustment may be 0.5 or 1 per cent of the stockhouse weights as shown on the daily filling reports.

Whenever this rule prevails, the actual tonnages and the adjusted tonnages should be shown on Cost Data Sheet No. 4.

Limestone Adjustment.—The actual tons (2,000 lb.) of limestone required per ton of pig iron for any particular month is found by dividing 49 by the actual average percentage of calcium oxide found in the limestone used, whether this limestone be calcite or dolomite (this percentage is taken from Cost Data Sheet No. 1), and multiplying the result by 0.425 ton (850 lb., limestone being the basis). This gives the correction for the quality of the limestone.

The adjustment in weight of flux on account of the variation in ash in the coke is found by multiplying the weight of limestone adjusted for quality of the limestone by the ideal pounds of coke per ton of pig iron and dividing by 1,800.

Whenever open-hearth slag is used in the metallic mixture (ore mixture), adjustments must be made for the amount of available calcium oxide in the open-hearth slag, and this is subtracted from the amount determined as above.

We do not yet know enough about the behavior of sulphur in blast furnace slags to make adjustments in the limestone required per ton of pig iron, but we do know that, when the ore mixture is low, the actual limestone per ton of pig iron is lower than the "ideal" amount as calculated by the above rules.

Labor Adjustment.—The basis for the ideal comparative cost for labor per ton of pig iron is the total number of hours shown on the standard force sheet for the blast furnace for a 24-hr. period and at the hourly rate found by dividing the total man-hours for a 24-hr. period into the total wages paid for that period as shown on the standard force sheet.

The total daily hours and the total daily amount of wages divided by the ideal daily tons of pig iron will give the ideal number of hours per ton pig and the ideal cost of labor per ton of pig respectively.

The actual average hourly rate of wages for any one month is found by dividing the total amount of money paid for wages that month (as shown on Cost Data Sheet No. 2) by the total "Net hours of labor entering the labor cost," as shown on Cost Data Sheet No. 1. The actual number of hours of labor per ton of pig iron for any one month is found by making the several deductions as shown on Cost Data Sheet No. 1.

In order to get a correct comparison of labor costs between two different blast furnaces or between different monthly costs of the same furnace, much care must be taken to include all the hours of labor and all the hourly wages paid, whether this labor is direct operating labor, or labor that is included in service or in overhead. Although the regular cost sheet may include such indirect labor under other headings, yet it is the intention of the comparative cost system to put all labor hours and costs under the heading of "Labor." Only by such methods can a true comparison be made.

Therefore, from the total hours worked there should be deducted the following hours:

1. Hours worked by salaried employees
2. Hours worked on construction
3. Total hours worked unloading to stockpiles, including crane and ore bridge labor, in cases where unloading charges follow the ore
4. Hours worked at sinter plant
5. Hours worked by porter

Hours of labor charged to locomotives, cranes, power plant, pumping, or any other service account must be segregated so as to include time and money under the single item of "Labor."

Each standard daily labor report, or "force sheet" must show the date it becomes effective and must be approved in writing before being used in the comparative cost system.

Ideal Production of Pig Iron for Any Month.—The ideal pig-iron production of a blast furnace for any particular month is controlled by two variable factors, *viz.*, the ideal pounds of coke required per ton of pig iron for that month, and the corrected theoretical yield (corrected as to allowances for shrinkage, if any) of the ore mixture for that month. The control of these two varying factors is largely in the hands of the management. There are times, such as in the depression of 1930–1932, when the selection of a low-grade ore mixture is advantageous, especially where the volume of blast furnace gas is a desirable factor in the operation, and where there is already a surplus of pig iron.

The ideal total amount of coke consumed in 24 hr. is a fixed amount of "commercial" coke (coke as received, adjusted to not over 3 per cent moisture in the case of by-product coke), found by multiplying the cubic feet of working volume of the furnace by 60. This figure divided by the ideal number of pounds of coke per ton of pig iron (as found according to the directions given under coke adjustment, page 320) will give the ideal amount of pig iron to be produced per day with the quality of coke actually used that particular month. This daily tonnage multiplied by the number of days in the month will give the ideal tonnage of pig iron for the month to be shown on Cost Data Sheets Nos. 2 and 5.

This calculation can be reduced to a single factor that is used to multiply the corrected theoretical yield each month. This factor is obtained as follows:

$$\text{Factor} = \frac{\text{corrected theoretical yield}}{54.78} \times \text{rated capacity}$$

The rated capacity is the tons of pig iron the furnace will make using coke with 90 per cent fixed carbon and ore containing 51 50 per cent iron natural.

Excess Due to Management.—If the management provides raw materials better than the ore, coke, and limestone used as the basis of the comparative cost system as previously described, then the management is entitled to the credits that arise from the use of better materials. On the other hand, if the management provides lower grade materials than described, then there are debits against the management.

If the furnace plant is not running full because of lack of orders, there will be certain increased costs which are debited against the management. The credits and debits are balanced, and the net result is added to or subtracted from the ideal cost for the month to show how much gain or loss was due to the management.

The superintendent is responsible for what he actually receives in the way of materials.

Presentation to the Executive.—The final analysis of the pig-iron costs each month is made by the assistant to the executive in charge of operations and is condensed on Cost Data Sheet No. 5. This single page contains a concise statement of the actual pig-iron costs compared with the ideal cost for that month and shows the reasons for excess costs or for costs less than the ideal.

This Cost Data Sheet No. 5 is submitted to the executive in charge of operations accompanied by a one-page letter commenting briefly on each of the six items of cost controlled by the superintendent. (Relining and depreciation costs are fixed by the management.) A copy of this letter and copies of Cost Data Sheets Nos. 1, 2, 4, and 5, are sent to all the superintendents and other persons entitled to receive the original pig-iron cost sheets. Where there are several blast furnace plants in the same company, these comparative cost reports can be exchanged.

It is expedient that someone outside the operating or accounting departments should make the final analysis of the costs and give the reasons for any excess. Obviously, such a man must be familiar with blast furnace operations and know considerable about pig-iron cost accounting. Such a man must be able to point out the causes of excellence and of waste in the blast furnace practice and be able to point out where further economies can be made by changes in materials or in practice.

In making such a searching analysis, it is possible to detect errors in accounting that creep in occasionally even in the best accounting departments. For instance, an excess cost for supplies at a blast furnace was found to be in error because a storekeeper and a clerk got mixed up and charged "five barrels of grease" to the blast furnace instead of charging "five barrels of black paint" to one of the coal mines of the same company. Departmental overcharges can often be detected by the superintendent on studying the cost data sheets.

The mere setting up of the basis for ideal costs calls immediate attention to any defects in construction, practice, or accounting. The continued use of the comparative cost system for pig iron improves the blast furnace practice and reduces the costs.

ASSEMBLING COSTS OF PIG IRON

The reader of the preceding sections has seen how variable are the quantities of materials required to produce a ton of pig iron in different parts of the country and how they vary chiefly according to the variations in the quality of the materials used. Low cost per ton of materials delivered to the blast furnace does not always mean low cost per ton of pig iron. Low-grade iron ores, even though cheap in price, require not only 2½ to 3 or more tons of ore per ton of pig iron (instead of about one and a half tons of a rich ore), but they require large increases in flux and a pyramiding increase in fuel, all resulting in higher costs per ton of pig iron.

The cost of transporting the raw materials and supplies for the making of a ton of pig iron is called the "assembling cost." There are no consistent per-ton-mile freight rates on the raw materials for pig iron; freight rate structures are more complicated than the carbon reactions in the top of the furnace, but in each case one thing is certain—what finally comes off the top of the furnace is the answer there; and what you have to pay is the freight rate.

Very few places in all the world are as fortunately located for low assembling costs for pig iron as is the Birmingham District of Alabama. Coking coals, iron ores, and fluxes (and in some cases they do not need any flux) are all within short switching distances of the furnaces. But even in Birmingham, it costs more and more to move materials from where they are to where they are to be used; and the freight on pig iron to a large part of the market is higher than in most other places.

In the making of pig iron, as a rule, the iron ores move toward the fuels; that is why Pittsburgh and Ohio, without any present minable iron ores, have maintained their prestige as iron and steel centers. The foundation of Pittsburgh's steel industry is the Pittsburgh seam of coking coal; Ohio is the meeting place of the coals from Kentucky, West Virginia, and Pittsburgh and the iron ores from the Lake Superior region.

It is apparent also, that the frequent changes in freight rates which are due to increasing labor costs and other causes, may affect the various iron-making sections differently. Water transportation is on the increase in the iron and steel industry. Recently the railroads have been granted another increase in freight rates. Under such conditions, a thorough study and comparison of assembling costs at some certain period can be used to show the freight advantages and disadvantages of different sections of the country, as in the following:

Freight Charges and Delivered Costs[1]

Freight costs involved in assembling raw materials and in transporting the product together constitute the largest single element in the total cost of iron in pigs delivered to the consumer. Such freight factor amounts to about 50 per cent of the price of domestic iron in pigs at New York and other Atlantic ports, and about 25 per cent of the price of imported iron in pigs delivered at the same markets. Freight is the controlling factor in the location of blast furnace plants, the appraisal of competitive power in different markets, and even in the location of some iron-consuming industries.

Freight costs are treated herein under two categories: (1) Cost of assembling raw materials at the blast furnace plants, and (2) Cost of shipping iron in pigs to the consumer.

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[1] "Iron in Pigs," *Report of U. S. Tariff Commission*, 1927, pp. 20–21.

Table XXI shows, for certain domestic and foreign-producing localities, estimated average freight costs of assembling raw materials and shipping iron in pigs to New York during the period 1924–1926. Data respecting European and Indian freight rates are too fragmentary to permit of more than an approximation within a range wide enough to allow for variations in exchange and in freight rates.

TABLE XXI.*—PIG IRON—ESTIMATED FREIGHT COST OF ASSEMBLING RAW MATERIALS AND DELIVERING DOMESTIC AND FOREIGN IRON IN PIGS TO NEW YORK, PER LONG TON 1924–1926

Point of manufacture	Freight charges					
	Ore	Fuel	Flux	Total raw materials	Iron in pigs	Total to New York
Domestic Plants						
Western district: Mahoning and Shenango Valleys	$5.00	$2.50	$0.55	$8.05	$6.03	$14.08
Eastern district: Eastern Pennsylvania	5.70	4.10	.55	10.35	2.61	12.96
Buffalo district	3.40	2.80	.25	6.45	4.91	11.36
Virginia district: Roanoke, Va., and vicinity	5.00	2.50	.15	7.65	5.54	13.19
Alabama district	1.25	1.10	.30	2.65	9.24	11.89
Foreign Plants						
British India				3.75	6.65	10.40
Middlesborough, England:						
Using British ore				2.50	3.50	6.00
Using imported ore				4.00	3.50	7.50
Ruhr, Germany				2.50–3.50	3.75	6.75
Longwy, France				2.00–3.00	3.75	6.25
Luxemburg				2.50–3.50	3.75	6.75
Liège, Belgium				2.50–3.50	3.75	6.75

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* This is Table 19 in the report.

Raw Material Assembling Cost.—About 80 per cent of the consumption of domestic ore is mined in Minnesota and Michigan and is shipped 500 miles or more to blast furnaces, most of which are in the Western and Buffalo districts. Most of the remaining 20 per cent of the domestic ore is consumed by plants located near the mines, as in Alabama where 25 miles is considered a long haul for ore.

The total cost of assembling raw materials is probably as low in Alabama as in any producing district, domestic or foreign.

Plants in the Eastern and Virginia districts use a portion of local ore, the remainder being transported from Michigan or Minnesota, or from Sweden, Spain, Chile, Cuba, or other foreign countries. Some plants use imported ore exclusively while others depend principally upon domestic ores.

The average costs of assembling are uniformly lower for fuel than for ore, since the consumption of fuel per ton of pig iron produced is less and the plants tend, for other reasons than cost of assembling, to locate in the vicinity of the coal fields rather than at the ore mines.

Suitable fluxing material (limestone or dolomite) is usually obtainable in the vicinity of the blast furnace plants and may be transported to the furnace at a relatively low cost per ton of pig iron.

Foreign producers have short hauls by rail or canal or the advantage of low ocean freights on both raw materials and iron in pigs.

Delivered Costs.—As the cost of transportation constitutes a large proportion of the total laid-down cost of iron in pigs, domestic iron is marketed within relatively short distances of the points of production. On the Atlantic seaboard the imported iron competes with the iron produced in the Eastern, Buffalo, and Virginia districts. The furnaces of this region, principally the merchant furnaces, which manufacture for the open market, therefore bear the brunt of competition from abroad. The Alabama furnaces formerly sold appreciable quantities along the Atlantic seaboard, but high transportation costs even by the all-water route, have resulted in the loss of a large part of this trade. Virginia and Tennessee are also handicapped in reaching important consuming markets by reason of the longer haul. The local markets being insufficient to absorb their full production, most of the furnaces of this region have been idle since 1923.

By 1937 every iron blast furnace in the state of Virginia had been dismantled and scrapped; the only furnace left in operation was the ferromanganese furnace at Reusens, Virginia.

Freight Rates on Lake Superior Iron Ores.—Because of the method used for the evaluation and pricing of Lake Superior iron ores, *i.e.*, using a base price for ore containing 51.50 per cent Fe f.o.b. Lake Erie ports, much of the assembling cost for such ores is not apparent without further analysis. The freight, for instance, on Lake ores delivered to blast furnaces in the Ohio Valley is divided as shown in the table at the top of page 329.

These rates include dumping charge at upper lake docks; all rates are on gross ton of ore (2,240 lb.). These rates became effective Mar. 28, 1938, but there were three periods of "emergency charges" (1932–1933; 1935–1936; and 1936) when a flat

UPPER RAIL FREIGHT ON IRON ORE[1]

Source	Destination	Cost
Mines in eastern Marquette Range	Shipping port Marquette	$0 71
Mines in western Marquette Range	Shipping port Marquette	0 77
Mines in Menominee and Marquette Ranges	Shipping port Escanaba	0 89
Mines in Gogebic Range	Shipping port Ashland	0 89
Mines in Mesaba Range	Shipping port Duluth-Superior	0 92
Mines in Mesaba and Vermilion Ranges	Shipping port Two Harbors	0 92
Mines in Cuyuna Range	Shipping port Superior	0 92

[1] Data from the 1938 ore book of The M A Hanna Company, Agent, Cleveland, Ohio

charge of 6.72 to 11.2 cents per gross ton was added to the then existing, rates which were effective from 1924 to 1937.

Iron ore loaded at the head of the lakes as above, is carried in the lake ore boats (10,000- to 14,000-ton cargoes) at the following rates:

CONTRACT LAKE IRON ORE RATES, YEAR 1938[1]

Escanaba to Chicago	Escanaba to Lake Erie	Marquette	Head of Lake Superior	Unloading charge included in vessel freight
$0 61	$0.73	$0.85	$0 93	$0 13

[1] Data from the 1938 ore book of The M A Hanna Company, Agent, Cleveland, Ohio

This water-transportation freight rate carries the ore to "the rail of vessel." From the rail of vessel to railroad cars, or to dock stockpile, the rail freight rates have been effective in the past fifteen years, as shown on page 330 except for some minor changes in rates and effective dates to destinations taking small tonnages.

In the case of a ton of Mesaba iron ore to the Pittsburgh district there would be the following charges;

	Rate
Upper rail—Mesaba to Duluth	$0 92
Lake haul, Duluth to Lake Erie ports	0 93
Handling charge—Lake Erie ports	0 09
Line haul to Pittsburgh District	1 21
Spotting charge at destination	0 03
Total freight charges	$3 18

RAIL FREIGHT RATES ON IRON ORE[1]

	1937	1938
Direct Ore—Rail of vessel to car, handling charge	$0.08	$0.09[h]
(Add to above) Line haul		
To Mahoning and Shenango Valleys	0.82	0.88[g]
To New Castle	0.88	0.94[g]
To Midland, Steubenville, Weirton and Neville Island	0.99	1.05[g]
To Pittsburgh and Wheeling Districts	1.15	1.21[g]
To Monessen	1.22	1.28[g]
To Johnstown District	1.30	1.36[g]
To Jackson and Hamilton Districts (Toledo)	0.90	0.96[g]
To Jackson District (Cleveland)	1.12	1.18[g]
To Ironton (Cleveland and Toledo) and Hamilton Districts (Cleveland)	1.25	1.31[g]
To Virginia District	2.07	2.13[g]
To Lehigh and Schuylkill Valleys, Riddlesburg, (Buffalo and Erie)	1.94	2.00[g]
To Riddlesburg (Ashtabula Harbor, Conneaut and Erie)*	1.73*	1.79[g]
To Sparrows Point (Buffalo and Erie)	1.94	2.00[g]
To Troy (Buffalo)	1.31	1.37[g]
To Granite City (Chicago)	1.20	1.26[g]
Dock Ore—In addition to line haul—Rail of vessel to dock stockpile	0.20	0.22[h]
Dock stockpile to car	0.13	0.14[h]
Storage charge per ton per month	0.01	0.01

In addition to the above rates there is a service charge at destination for spotting cars In some cases 3 cents per ton

g = effective Nov. 15, 1937

h = effective Mar 28, 1938

* Effective June 21, 1929 (from Ashtabula Harbor and Erie to Riddlesburg)

[1] Data adapted from the 1938 ore book of The M A. Hanna Company, Agent, Cleveland, Ohio.

The average iron contents of all the Mesaba iron ores shipped in 1937 was 51.53 per cent, so that the total freight rate on such ore, $3.18 per ton, was equivalent to 6.17 cents per unit of iron ($3.18/51.53 = 6.17 cents). It would take 1.824 tons of such an ore to make a ton of pig iron. Therefore, the freight on ore per ton of pig iron would be $5.80.

Freight on Fuel and Flux.—The freight on blast furnace fuel is practically the total freight on the coking coal necessary to make a ton of blast furnace coke. Roughly, it takes 1.45 tons of coal to make a ton of blast furnace coke. Many coke-oven plants are located so as to receive coking coal in river barges, thus reducing the assembling cost for fuel. Limestone also is often shipped by water, as in the case of the big limestone quarries of Michigan and northern Ohio.

EFFECTS OF IMPORTED PIG IRON

Obviously, the only pig iron that can practically be imported into this country is "iron in pigs," which limits foreign pig iron almost exclusively to foundry iron with possibly some special cases of steel-making irons. It would be *possible*, however, for the Algoma Steel Corporation at Sault Ste. Marie, Ontario, to ship hot metal across the International Bridge at the Falls of the Saint Mary River into Michigan if there were a steel plant there, but it is a most improbable occurrence; therefore, this study of the effects of imported pig iron will be confined to "iron in pigs."

The manufacture of pig iron in the United States began along the Atlantic coast. The influences of blast furnace fuels (which for 200 years was exclusively charcoal), and the location of adequate supplies of iron ore, gradually forced the blast furnaces westward and away from the seacoast. For half a century a flourishing iron industry was built up in the valleys contiguous to the anthracite coal fields of Pennsylvania, but only in a few cases was the momentum great enough for such iron and steel centers to survive the cost-reducing competition of the Lake Superior iron ores and of low-cost coke.

Many of the large foundries built along the Atlantic seaboard were once able to receive their pig iron from furnaces that could ship by canalboat. These same foundries can now receive iron from abroad by vessel, and do often take advantage of lower costs of foreign pig iron.

One of the effects of imported pig iron was the hastening of the scrapping of small single blast furnaces and, in some cases, groups of several merchant blast furnaces in the states bordering on the Atlantic coast, especially in Pennsylvania and New Jersey. There were other causes, such as obsolescence and high assembling costs, but in several specific cases the importation of foreign pig iron was the final burden that put merchant blast furnaces out of business.

In a previous section it was shown that the freight costs of assembling raw materials and of delivering pig iron to New York

City and other Atlantic ports amounts to about 50 per cent of the total cost of iron in pigs delivered to the consumer, whereas the total freight on foreign pig iron delivered to the same ports amounts to only about 25 per cent of the total cost. This fact is one reason why foreign pig iron does not, up to the present time, go very far beyond the immediate vicinity of the Atlantic seaports. On the other hand, however, there is an indirect effect of imported pig iron on the inland merchant blast furnaces, especially those in the Ohio Valley, and that is that the Buffalo blast furnaces have lost some of their New England and Atlantic seaboard trade to foreign pig iron and are forced to compete for the foundry business of the Middle West.

Nearly all imports are consumed within 200 miles of the port of importation. The districts chiefly affected are the Eastern, Buffalo and Virginia districts. During the period 1920–1925 the proportion of total imports to total production in these districts has probably been about 5 per cent. If, however, we compare imports through the North Atlantic coast ports with the production of iron in pigs made for sale in the districts affected (assumed to be 26 per cent of total production) the proportion of such imports is about 15 per cent.[1]

TABLE XXII.*—IRON IN PIGS—UNITED STATES IMPORTS IN LONG TONS—1922 TO 1926

Year	Quantity	Value	Value per ton
1922[1]	383,445	$8,670,860	$22 61
1923[2]	367,820	9,005,844	24 48
1924[2]	209,092	3,740,994	17 89
1925[2]	441,425	7,951,283	18 01
1926[3]	413,430	7,203,148	17 42

* Table 6 in report

[1] General imports

[2] Imports for consumption.

[3] Imports for consumption, 10 months, January to October.

It may seem strange to inject these data of ten to fifteen years ago, but the predictions made at the many tariff hearings in Washington have been fulfilled. Although the importation of foreign pig iron was not the controlling factor in the demise of many merchant blast furnaces it might be that "The last straw breaks the camel's back."

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[1] "Iron in Pigs," *Report of the U. S. Tariff Commission*, 1927, pp. 7–8.

TABLE XXIII.*—IRON IN PIGS—UNITED STATES IMPORTS BY COUNTRIES IN LONG TONS, 1922 TO 1926

Country	1922[1]			1923[2]			1924[2]		
	Quantity	Per cent of total	Value	Quantity	Per cent of total	Value	Quantity	Per cent of total	Value
Belgium	64,449	16 8	$1,252,180	14,980	4 1	$332,345	3,019	1 4	$62,972
France	41,704	10 9	851,377	57,722	15 7	1,233,672	22,195	10 6	396,270
Germany	4,085	1 1	85,597	20,740	5 6	473,899	11,228	5 4	213,129
Netherlands	2,537	7	46,099		.		23,857	11 4	459,528
Great Britain	251,783	65 6	5,951,538	198,138	53 9	5,146,890	57,189	27 4	1,249,328
British India				17,988	4 9	374,336	71,370	34 1	924,231
All other	18,887	4 9	484,069	58,252	15 8	1,444,702	20,234	9 7	435,536
Total	383,445	100 0	8,670,860	367,820	100 0	9,005,844	209,092	100 0	3,740,994

Country	1925[2]			1926[2, 3]		
	Quantity	Per cent of total	Value	Quantity	Per cent of total	Value
Belgium	11,068	2 5	$198,237	6,138	1 5	$100,233
France	9,814	2 2	181,451	27,333	6 6	434,926
Germany	75,052	17 0	1,362,682	137,475	33 3	2,276,845
Netherlands	54,904	12 4	1,033,686	62,100	15 0	1,106,320
Great Britain	96,869	21 9	1,926,275	92,039	22 3	1,684,906
British India	184,325	41 8	3,020,816	81,229	19 6	1,428,584
All other	9,393	2 2	228,136	7,116	1 7	171,334
Total	441,425	100 0	7,951,283	413,430	100 0	7,203,148

* Table 7 in report

[1] General imports

[2] Imports for consumption

[3] Ten months, January to October.

The following quotation from the *Report* is of further interest:

Grades of Imported Iron.—Imports consist largely of the various grades of foundry and malleable iron. Great Britain produces foundry irons of a wide variety of chemical analyses and nearly all the imported high-grade steel-making iron. Much of the latter is low-phosphorus iron, which commands a relatively high price, as is shown by the high invoice value of British imports ($21.90 in 1924 compared with $20.80 for Belgium, the next highest, and $13 for British India, the lowest). Imports from British India are principally foundry iron containing a high percentage of manganese. Imported iron in pigs made from Lorraine ores often contains a high percentage of phosphorus, and is often lower priced than other iron.

Principal Competing Countries.—The percentage of the total imports of iron in pigs into the United States which was supplied by the principal competing countries is shown in Table XXIV:

TABLE XXIV.*—IRON IN PIGS—PERCENTAGE OF TOTAL UNITED STATES IMPORTS SUPPLIED BY PRINCIPAL COMPETING COUNTRIES, 1922 TO 1926

Country	Per cent of total				
	1922	1923	1924	1925	1926[1]
British India	...	4.9	34.1	42.7	19.6
Great Britain	65.6	53.9	27.4	22.0	22.3
Germany	1.1	5.6	5.4	17.0	33.3
All others	33.3	35.6	33.1	18.3	24.8
Total	100.0	100.0	100.0	100.0	100.0

* Table 8 in report.

[1] Ten months, January to October.

Foreign producers have, with respect to transportation costs, an even greater advantage along the Pacific and Gulf coasts than along the Atlantic seaboard. Iron in pigs is desirable as ballasting cargo, and water rates on foreign iron are so low as to make possible economical transportation to the United States from many foreign countries. The rail rates for iron from the inland furnaces of the United States to domestic consumers often considerably exceed the ocean freight rates from foreign countries to our Atlantic seaboard. Iron in pigs can be shipped for about $3 per ton from Europe to the Atlantic seaboard and for about $4 per ton to the Pacific coast. The ocean rates from Calcutta, the principal port from which British Indian iron is shipped, is about $5 per ton to Atlantic ports. The domestic coastwise rate from Atlantic to Pacific ports is $6.72 per ton. The combination overland rate is $14 to $23 per ton, which prevents economical overland shipments. The facts presented in preceding sections of this report show that imported iron in pigs is competitive with iron in pigs manufactured in the United States and that it is comparable in quality.

The amounts by which domestic costs exceed foreign delivered costs, as shown by the several computations, are, respectively, $7.77, $7.07 and $7.16.[1]

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[1] *Ibid.*, pp. 21–22.

These are for prices delivered in New York City as shown in the following table.[1]

TABLE XXV.*—IRON IN PIGS—COMPARISON OF COSTS OF PRODUCTION OF FOUNDRY AND MALLEABLE IRON IN THE UNITED STATES AND IN BRITISH INDIA PLUS COSTS OF MOVING THE SAME TO NEW YORK, PER LONG TON, 1924

Item	Domestic iron in pigs			Foreign iron in pigs
	Eastern district	Buffalo district	Average	British India
1. Domestic cost and foreign costs, f.o.b. plant	$25 17	$22 17	[1]$23 41	$13 36
2. Transportation and other charges[2] to New York . . .	[3]2 61	4 91	[4]3 76	6 65
3 Total costs delivered to New York	27 78	27 08	27 17	20 01
4 Amount by which domestic delivered cost exceeds foreign delivered cost.	7 77	7 07	7 16	. .

* Table 21 in report

[1] Weighted on the basis of the approximate tonnage produced in the respective districts

[2] Transportation includes all freight from point of manufacture to New York Other charges include consular fee, brokerage fee, transshipment, and insurance

[3] Average of rates from Swedeland, Robesonia, and Reading

[4] Not weighted.

In January, 1929, there was another hearing before the U. S. Tariff Commission in Washington, and the representatives of 73 different companies, owning 119 merchant blast furnaces with an annual capacity of 11,311,800 tons of iron in pigs, asked for a tariff of $3 per ton on pig iron. By the middle of 1937 there were only 46 of these blast furnaces left standing and three of these had become steel-plant furnaces; the other 73 had been completely dismantled and scrapped. The number of operating companies had dropped from 73 to 43, with a total annual capacity of about 6,500,000 tons of iron in pigs.

CHANGING DEMANDS FOR STEEL MAKING PIG IRONS

Most of the pig iron made in this country goes directly to the steel plants, consequently the kind of iron made must meet the demands of the steel makers. The steel makers, in turn, make

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[1] *Ibid.*, p. 27

their demands to suit the kind of pig iron that can be made from the iron ores available. Bessemer pig iron, with one notable exception in the Birmingham district, must be made from Bessemer iron ores; in this country, with the acid Bessemer process, the pig iron must not contain more than 0.10 per cent phosphorus; in Europe with the basic Bessemer process the pig iron must be high in phosphorus.

In Alabama, the iron ores are high in phosphorus and the steel makers can make excellent steel with the high phosphorus pig iron. With great quantities of lake ores to work with, the steel makers in the Northern states can make Bessemer steel or basic steel from pig iron with moderate amounts of phosphorus; they would like to have the phosphorus as near to "off Bessemer" grade as possible and not exceeding 0.200 per cent. To be sure they could make good steel with higher phosphorus pig iron if they had to.

When it was found that manganese was a great help in the basic open-hearth process, there was a demand for basic pig iron with more manganese. Some open-hearth men would like to have the manganese between 1.50 and 2.00 per cent and phosphorus not over 0.200 per cent.

The question of the amount of sulphur permissible in steel-making pig irons is not yet finally answered; sometimes sulphur is desirable for certain steels, but open-hearth men now are asking for sulphur not over 0.025 per cent, and in one conference of open-hearth men and blast furnacemen it was said that, if the open-hearth men could get iron with only 0.020 per cent sulphur they felt that the savings at the steel plant would more than offset the extra cost at the blast furnace. This is another unanswered question of the iron and steel industry.

ACTUAL COSTS OF PRODUCING PIG IRON

To compare costs of pig iron at different plants is difficult, as has been explained in a previous section. The costs at different periods for the same furnace will vary; the year of 1926, however, has been taken as a "normal year" for many comparisons of costs and prices. Table XXVI shows the actual operating costs for making pig iron in the year of 1926 at a merchant plant in the North using lake ores and at one in Alabama using red ores and brown ores.

TABLE XXVI.—ACTUAL COSTS OF MAKING PIG IRON IN 1926

Items	North	South
Total tons pig iron made	132,637	79,441
Pounds of ore mixture per ton of pig	4,061	5,855
Tons of ore mixture per ton of pig	1 813	2.613
Price per ton of ore mixture	$ 5.651	$ 2 518
Cost per ton of pig iron for ore mixture	$10 244	$ 6.580
Pounds of coke per ton of pig iron	1682	3184
Price per ton of coke (2,000 lb.)	$ 5 396	$2 768
Cost per ton of pig iron for coke	$ 4 538	$ 4.407
Pounds of limestone per ton pig	618	485 (dolomite)
Price per ton of limestone	$ 1 796	$ 0 772
Cost per ton of pig for limestone	$ 0 555	$ 0 167
Cost of labor per ton of pig	$ 1 420	$ 1 416
Cost of supplies and service	$ 0 406	$ 0 794
Cost of overhead per ton pig	$ 0 448	$ 0 322
Depreciation	$ 0 350	$ 0 280
Relining and renewals	$ 0 250	$ 0 500
Total cost per ton of pig iron	$18.211	$14.464
Cost of materials per ton of pig iron	$15.337	$11 154
Cost above cost of materials	$ 2 874	$ 3 310

DISMANTLING OF BLAST FURNACE PLANTS

The dismantling of blast furnaces was so extensive throughout the recent depression that some alarm was felt as to the drastic reduction in the number of plants and the possibility that pig-iron capacity was being cut too much. It is appropriate to quote here the following material which the author originally wrote for *Mining and Metallurgy:*[1]

Roy P. Hudson's apprehensive letter calls attention to the apparent alarming rate of dismantling of blast furnaces in this country, especially of merchant furnaces. The actual decrease in the number of individual blast-furnace stacks has been not only "approaching serious proportions," as Mr. Hudson says, but has really passed that point, as is shown by the shrinkage in this twentieth century alone from the peak number (for this century) of 474 active furnaces in 1910 down to 279 furnaces on Jan. 1, 1933. That looks on the face of the figures of individual furnaces like a serious decline in potential pig-iron production, but it is not, as the statistics will show.

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[1] *Mining and Metallurgy,* June, 1934. In reply to a letter by Roy P Hudson, member A.I.M.E.

This continual dismantling of blast furnaces, merchant stacks, and steel-plant stacks alike, has been going on in this country for nearly 300 years. An interesting account of the early start of this wiping out of iron works is found in the Tenth Census Reports of 1880. . . . According to the late James M. Swank, Secretary of the American Iron & Steel Association and Special Agent for the Tenth Census, the first successful iron works established in the Colonies was on the Saugus River near Lynn, Mass., soon after its settlement in 1629. It was owned by "The Company of Undertakers for the Iron Works." Whether that funereal name of the corporation was significant or not, the records show that they "finally ceased operations about 1681."

Since that time the whole charcoal iron and anthracite iron industry of New England has been wiped out; for the first 100 years Massachusetts Colony was the biggest producer of pig iron in the New World and every colony made charcoal pig iron and had its iron works. The 168 charcoal blast furnaces and the 200 anthracite blast furnaces on the active list in 1887 are entirely dismantled; the raw coal furnaces of the Hocking Valley and other sections of the country are gone. Only one charcoal blast furnace in Tennessee and four in Michigan remain on the active list. Even they are no longer recognized as full-fledged members of the steel industry but have been turned over to the mercies of the Hardwood Distillation Industry, Approved Code No. 110.

In the Annual Statistical Reports of the American Iron & Steel Institute are the figures of capacities and productions of the blast furnaces of this country. The wide difference between the theoretical capacity of the 459 blast furnaces in 1918 (49,269,565 tons) and the actual production of 39,054,644 tons, which was not enough as Mr. Hudson truly says, was due to two factors which have since been corrected. In the first place there was no adequate rule for rating the capacities of blast furnaces previous to the rule announced by the Southern Ohio Pig Iron & Coke Association in 1920. The capacity of some of the merchant furnaces in those days was based on statements that sounded pretty well, but would be contrary to the Securities Act of 1933. There were 371 blast furnaces in operation in 1920 and their rated capacity was 42,000,000 tons.

The chief cause of failure, however, was the poor quality of coal that went into the coke ovens. This failure was the reason for the hearing before the Director of Steel at Washington in September, 1918, when the "wastefulness of high ash" in coking coals was so clearly demonstrated (see "Clean Coal," chapter II, Penton Publishing Co., 1927). Coke with 17 per cent ash, and sulfur up to 1.60 to 1.90 per cent, was the reason for the decrease of 27 per cent in production in one case reported at that meeting. This failure to produce enough pig iron in

1918 was not due to lack of enough blast-furnace stacks—it was because we did not use clean coal for our coke.

In the Annual Statistical Report of The Iron & Steel Institute for 1926 is shown the "The Practical Pig-Iron Capacity of Completed Blast Furnaces, December 31, 1925–1926," as shown in the accompanying table.

Blast-furnace Capacity

Date	Total furnaces	Annual capacity, tons	Practical capacity, tons	Actual product, tons
Dec. 31, 1925	395	50,424,190	45,000,000	36,700,566
Dec. 31, 1926	379	51,681,000	45,500,000	39,372,729

The dismantling of about 100 stacks (or the removal from the active list) has not greatly reduced the "practical capacity" since 1926.

The peak production of pig iron in this country was reached in 1929, when 42,613,918 tons was made, but only about 80 per cent of capacity (pig iron and ferro-alloys) was utilized. Since then constant improvement has taken place in the quality of blast-furnace coke and in the enrichment of ore-burdens, which increases potential capacity without physical enlargement.

In spite of a total of 582 completed stacks in 1887, the rated annual capacity was only 10,990,993 tons of pig iron. At the end of 1932 the number of active stacks had been reduced to 279 (including nineteen blast furnaces making ferro-alloys) but the rated capacity (not counting eighteen coke furnaces that had been a long time idle) was 50,455,975 tons. It is evident therefore, that sufficient blast-furnace capacity exists in the country to take care of even extraordinary demands for pig iron. Today there is an idle merchant iron capacity of 750,000 tons in only six blast furnaces in the eastern territory, not counting the idle steel-plant merchant-iron furnaces, nor some other stacks that have been a long time idle.

It would be hard to predict the future demand for merchant pig iron. Metallurgically speaking, there is a tendency toward iron of better quality, and the research work of the gray-iron foundrymen is now showing what remarkable results can be obtained with the right kind of pig iron mixed with alloys and properly handled in the cupola. Humanly speaking, the "social trend" may possibly put the iron business back again into the hands of the ironmasters themselves. Prophetically speaking, some of my friends have said that the iron-blast-furnace process is doomed, like the copper blast furnace, and that new processes will furnish us iron more directly, as has been heard ever since Dr. Heroult came to the Canadian Soo about thirty years ago and set up his electric furnace for making pig iron.

Progress and her twin sister, Obsolescence, have brought about many changes in the manufacture of iron and steel. Plants and processes *must* change, and sometimes be completely abandoned; deposits of iron ore and coal cannot change their location, but their values may be greatly changed by time and by the means of transportation. An editorial on the "Time Value of Minerals" in the October, 1931, *Mining and Metallurgy* brings out this fact very clearly. As recently as 1890 the maximum tonnage of charcoal pig iron was reached in the United States; that was also the year of maximum production of anthracite pig iron. It is possible that changes in the time value and changes in the political economy of our national life may again make it profitable to use these two fuels in blast furnaces; metallurgically, they both make better pig iron than does coke. Reforestation and increased forest reserves for flood protection may help to revive the charcoal iron industry in sections where such forest reserves are near suitable iron-ore deposits.

Charcoal, anthracite, and lignite have virtues as blast-furnace fuels not possessed by coke. Electricity, if cheap enough, may yet play an important part in making pig iron. Any extended use of these fuels might call for a different type of iron furnace. Meanwhile it is evident that we have sufficient blast-furnace capacity to take care of all the demands for merchant pig iron and steel-making iron that may develop in the United States in the near future.

The total number of blast furnaces built in the United States in the past three centuries up to the end of 1937 is as follows:[1]

	Charcoal	Anthracite	Raw coal	Coke	Total
Total furnace built. .	993	275	70	531	1,869
Total furnace dismantled	988	275	70	294	1,627
Active furnaces Dec. 31, 1937	5	0	0	237	242

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[1] In the author's article, "Blast Furnace Fuels: Their Regional Influences," published in *The Iron Age*, Nov. 29, 1934, are charts showing the number of blast furnaces erected each year, according to the fuel used, in this country. Since that article was published, the author has learned from his friend Charles Rufus Harte that a total of 28 charcoal blast furnaces had been built in Connecticut instead of the 17 the author originally reported; my error has been corrected in the table above, with thanks to Mr. Harte, who, with Herbert C. Keith, presented a paper on "The Early Iron Industry of Connecticut," before The Connecticut Society of Civil Engineers, Feb. 20, 1935, which gives much data on the charcoal and anthracite furnaces of western Connecticut and southwestern Massachusetts.

Pig-iron and blast furnace statistics were not so accurately kept during the seventeenth and eighteenth centuries as they were in the last half of the nineteenth century and in the twentieth century. It took men like John Peter Lesley, Secretary of the American Iron Association, James M. Swank, who succeeded him and was Secretary of the American Iron and Steel Association (the forerunner of the present American Iron and Steel Institute) —it took men like these to gather and prepare the data. The student of history, and especially of the history of the iron and steel industry, will find the reports of these two devoted and able men of great interest and help.

The present capacity of the blast furnaces of the United States is as follows:

Type	Tons per Year
Coke blast furnaces	48,587,937
Coke ferroalloy furnaces	924,800
Charcoal blast furnaces	92,000
Total	49,604,737

OBSOLESCENCE AND DEPRECIATION

Obsolescence of iron blast furnace plants has been due to the obsolescence of blast furnace fuels and methods and of the modes of transporting the raw materials and the product, rather than to any obsolescence of the process itself, as was the case of the copper blast furnaces. The principles and chemistry of the blast furnace process—the combustion of fuel in the hearth to furnish heat for melting and preheating the raw materials, and to produce the carbon monoxide gas for reduction of the iron ores in the shaft of the furnace—are just the same in the modern 1,200-ton coke blast furnace as they were in the 1-ton charcoal furnace of colonial days.

The blast furnace fuels, kinds of stacks, and modes of transportation have been successively as follows:

Fuel	Kind of stack	Transportation
Charcoal	Small stone stacks	Pack horse; rafts; or cart
Anthracite	Larger stone stacks	Canalboat, railroad
Raw coal	Sheet-iron stacks	Canalboat, railroad
Beehive coke	Sheet-iron and steel	Railroad, ore boat
By-product coke	Steel stacks	Railroad; oreboat; motor truck

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Not only do the blast furnace plants themselves become obsolete and dismantled because of the obsolescence of fuels, methods, and transportation, but whole towns and areas become affected when pig-iron production ceases from any of the above causes. There are now 17 states that used to produce pig iron in a total of 307 blast furnaces, which now do not have a single blast furnace standing; New Jersey, Virginia, and Wisconsin are notable examples of former pig-iron producers. There are now no blast furnaces in the states on the Pacific Coast.

In the case of consolidation of several iron and steel companies, the main object of the merger is often the purpose of dismantling the obsolete and high cost plants, even if these plants should be included in the capital structure of the new corporation at high valuations. Such was the case with the United States Steel Corporation, which was formed by the consolidation of eleven steel companies in 1900, with an aggregate capitalization of $1,053,500,000; by the end of 1934 there had been charged off to depreciation a total of $1,750,000,000, besides $2,200,000,000 to maintenance and repairs. "The Corporation set aside $508,000,000 to amortize cost to U. S. Steel Corporation of stocks of subsidiary companies in excess of their investment in tangible property, and used $116,000,000 of subsidiary surplus in 1902 for additional writedown of plant."[1]

Recent Federal taxation laws will undoubtedly bring about changes in the cost accounting in the manufacture of pig iron, so as to take care of this great item of obsolescence.

In spite of occasional predictions to the contrary, the iron blast furnace process itself is not likely to become obsolete as the most economical process for the mass reduction of iron from its ores.

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[1] *Fortune*, March, 1936.

INDEX