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Fundamentals of POWER PLANT ENGINEERING

by

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Dedicated to my wife

Carolyn Perkins Remp

and to my son

George E. Remp, Jr.

PREFACE

This book is the outgrowth of the author's experience in operating power plants and in teaching power plant engineering to students in mechanical, electrical and chemical engineering. The principal portion of the material is confined to steam power plants and is presented in what the author has found to be a logical sequence, beginning with a study of load curves and power plant economics and progressing through vapor cycles and a detailed examination of the fundamental principles of the various plant components. Chapters are added, as a matter of interest, on the subjects of the economics of load division and Diesel-electric, hydro-electric and gas turbine power plants. No attempt is made to treat the subject of power plant wiring, as this subject properly belongs to the field of the electrical engineer.

The presentation of the material in this book is based on the assumption that it will be presented as a one-semester course, and that the student is familiar with the fundamentals of engineering thermodynamics. The author prefers the project method of presentation of problems to the student because he has found that the method has the advantage of making it possible to integrate the problems into a whole which has meaning to the student. Examples are given in the text in sufficient quantity and detail to guide the student in the execution of the projects. Only one series of projects is given in the text as an aid to the instructor in preparing additional projects from materials out of his own experience.

In order to hew to the line of fundamentals, it has been found necessary to say little about the minor details of design and operation, because these only serve to obscure the job at hand, which is to give a broad picture of power plant engineering in a limited time. It is expected that the instructor will make free use of visual aids, such as motion pictures and plant inspection trips, to supplement and clarify the presentation in the text. A bibliography of selected references is given at the end of each chapter for the benefit of those students who would delve more deeply into this extremely important and intensely interesting subject.

It is a pleasure for the author to acknowledge with thanks the encouragement and assistance of Professors Newton C. Ebaugh, John A. Dent and Paul C. Hoffman of the Mechanical Engineering Department of the College of Engineering of the University of Florida; Mr. Robert B. Cowan, Engineer-Manager of the Utilities Department of the City of Jacksonville, Florida; and Mr. J. H. White, Vice-President of the Florida Power and Light Company of Miami, Florida. Thanks are also due to Mr. L. N. Rowley, Executive Editor of *Power* for permission to use many of the illustrations which originally appeared in that excellent magazine, and to Mr. L. K. Gaventa for his capable aid in making the many drawings necessary in a work of this type.

The author wishes to thank the many manufacturers and engineers who have contributed illustrations and information. An effort has been made to see that proper credit lines are attached.

George E. Remp

Gainesville, Florida
July, 1949

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FUNDAMENTALS OF POWER PLANT ENGINEERING

CHAPTER I

INTRODUCTION

1. It is the function of the power plant engineer to specify the equipment for the production of power at the lowest possible cost per unit. This function requires the understanding of the fundamentals of power plant engineering from the standpoint of mechanical design as well as from the standpoint of economics. The word *specify* should be carefully noted. It is the function of the specialist in equipment design to supply machinery which will fit the specifications of the power plant engineer. Obviously, if the power plant engineer does not have a thorough knowledge of the possibilities and limitations of the machinery with which he is dealing, he cannot make workable recommendations.

2. **Growth of Power Generation in the United States**--Until Thomas A. Edison built the Pearl Street Station for the New York Edison Company in 1880, very little power was produced in the form of electricity. Most of the installed power machinery was in the form of steam engines of various specialized types in mills and mines. Some hydro power was utilized in mills located at the sites of the water wheels.

Before the turn of the century, the largest and most efficient steam power plants were found on ships. At about this time, however, the large central steam-electric station became a necessity and it was not long before these stations surpassed the marine power plant in both size and efficiency.

The growth of the power industry in the United States has been phenomenal. A study by the Twentieth Century Fund has shown conclusively that the rise in our standard of living has paralleled the rise in the utilization of power. Figures I-1 through I-3 show some important data on the growth of the power industry in the United States and the increase in our standard of living during the same period, with an extension of the electric production and installed capacity curves to 1960 to correspond with the Twentieth Century Fund's predictions.

3. **Improvement in Thermal Efficiency of Steam Power Plants**--Examination of the data on growth of the power industry is not sufficient to show the contributions of the engineer. The engineer's contribution has been the continual improvement in thermal efficiency of the power plant. Figure I-4 shows this improvement in terms of British thermal units

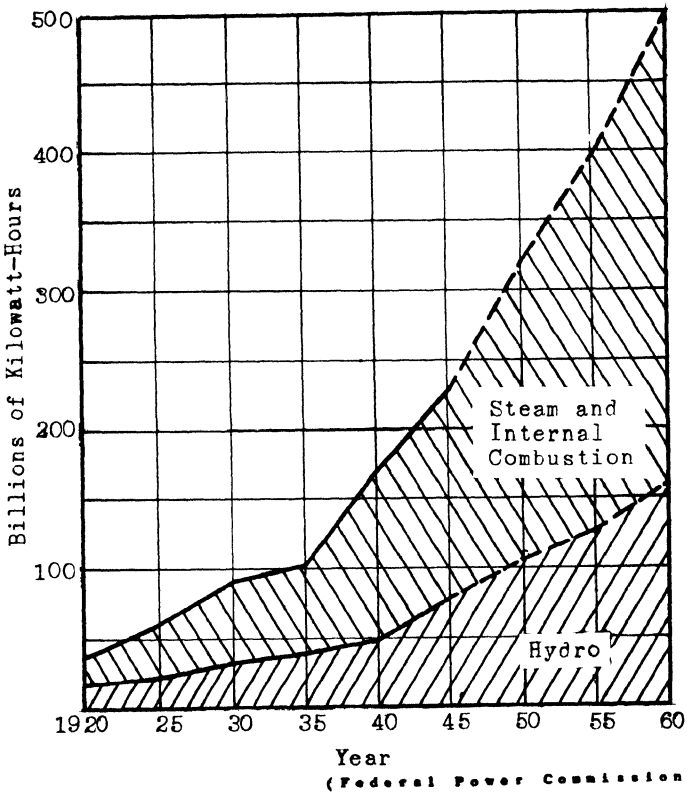


Fig. I-1. Production of electric energy by type of prime mover. 1920 - 1960.

per kilowatt-hour for plants in the United States. It will be seen that the rate of improvement has apparently reached a minimum, and truly it seems that it is impossible to further improve our steam power cycles. The end of the engineer's contribution is not yet in sight, however. Binary vapor cycles have been proven practicable and thermal efficiency improvements up to 50 per cent will be seen in the not-too-distant future. Power from nuclear fission may someday become economical when cheaper sources of energy become exhausted or so scarce as to be more valuable as raw materials for chemical syntheses.

4. Progress in Hydro and Internal Combustion Power--Fig-

ure I-1 showed that the larger part of the nation's power production has been obtained from steam power plants, and it is likely that such a relation will continue so long as fuels are easily obtainable. Hydro plants at present provide slightly more than half as much power as steam plants, and they are not likely to improve their relative position very much in the future due to the decreasing availability of suitable dam sites. A good example of maximum utilization of hydro power possibilities is to be seen in the installations of the Tennessee Valley Authority which has 26 dams in the more than 1000 miles of the Tennessee River and its tributaries. The TVA, as well as any other well designed hydro system, makes use of steam power plants as auxiliary power sources during the annual dry season.

In Figure I-1, internal combustion engine plants have been included with steam plants because the power produced by the internal combustion engine plants is somewhat less than one per cent of the total production. It must not be concluded, however, that the internal combustion engine plant

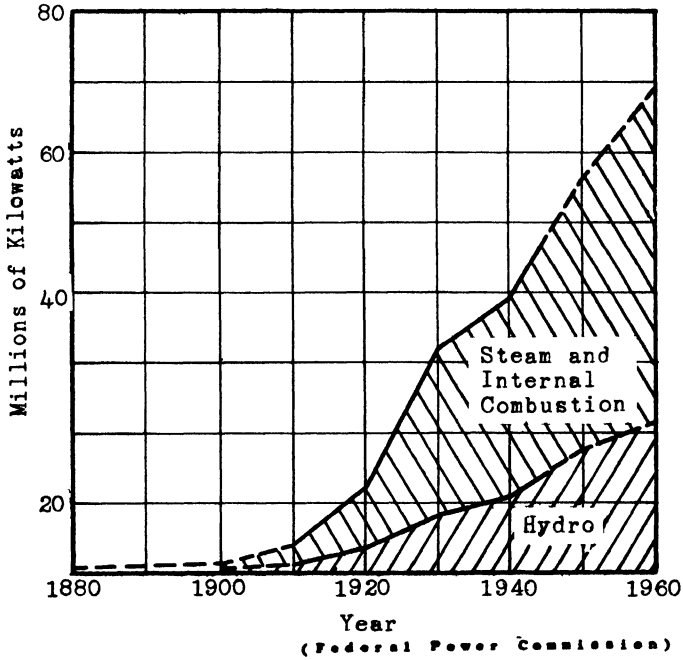


Fig. I-2. Installed capacity of generating plants. 1889 - 1960.

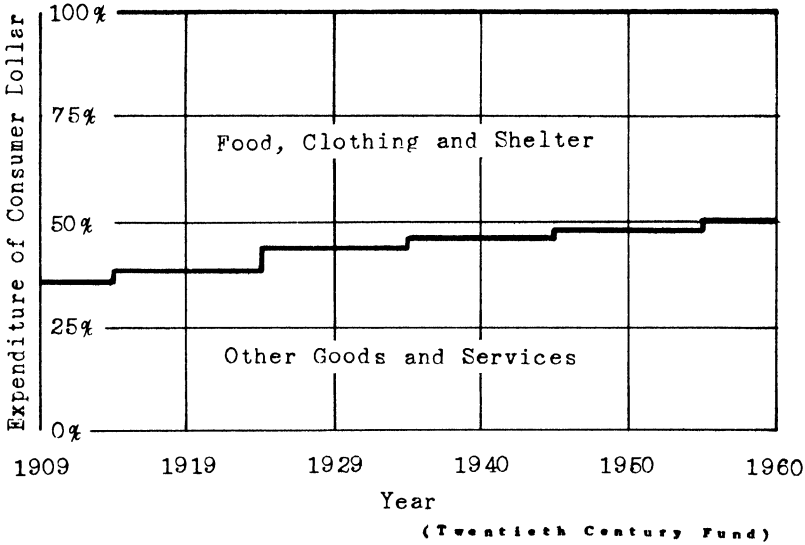


Fig. I-3. Standard of living in the United States. 1909 - 1960.

is insignificant, because there are locations where conditions are such that steam power plants would be impractical. As a general rule, where the total load is less than about 7,500 kilowatts the Diesel-generator plant will be found to be most economical.

5. Power Systems--Due to the fact that larger power plants can produce power more cheaply than small plants, we have the central station rather than individual power plants for each consumer. The problem of supplying power to the consumer from the central station gives rise to a rather complicated system of transmission and distribution lines. Figure I-5 shows the elements of a power system which includes a power plant and a primary and secondary distribution system. The secondary distribution system is always existent in any power system, but the primary distribution (sometimes called transmission) system may or may not be present depending upon the distance between the power plant and the area which it is to serve. The complexity of the secondary distribution system depends upon the types and sizes of the loads served. Figure I-6 shows a schematic wiring diagram for a typical power system with the various voltages used in present practice. The voltages selected for a particular system will depend largely on the distances

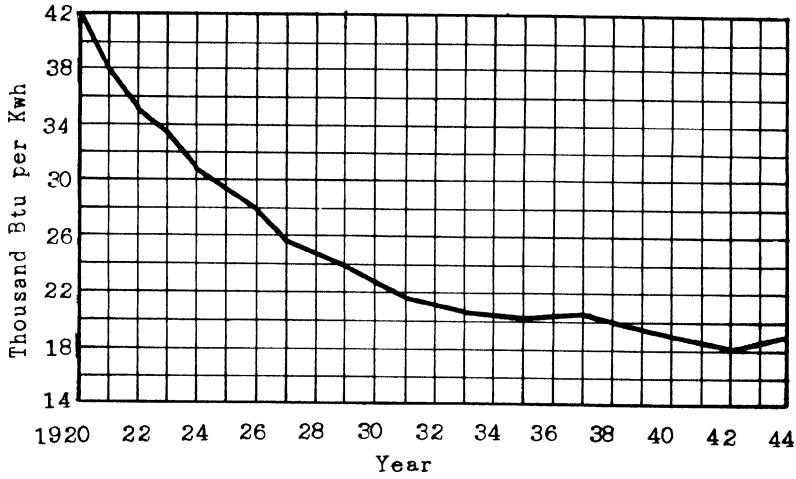


Fig. I-4. Plant heat rate, Btu per kwh, for plants in the United States, 1920 - 1944.

to be covered and the type of load to be supplied.

6. Public Utility Organization[1]--At the present time in the United States there are three classes of utility businesses:

1. Private utilities.
2. Municipal utilities.
3. Federal utilities.

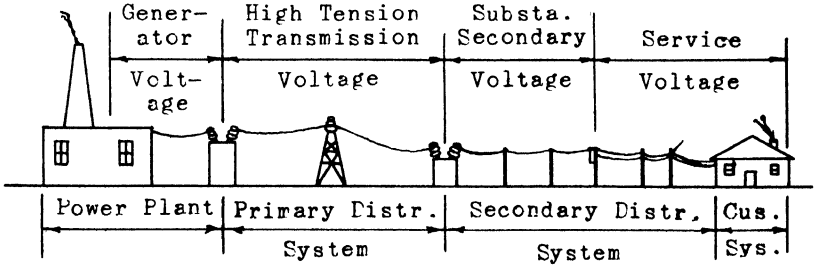


Fig. I-5. A typical power system.

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[1] "Public utility" is the generic term for utilities of all classes.

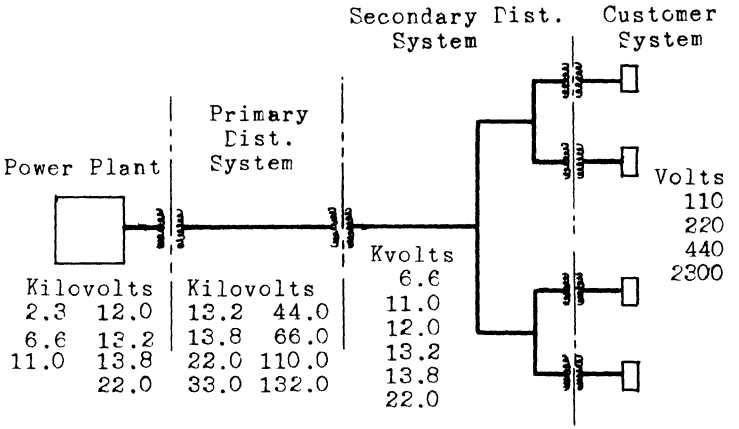


Fig. 1-6. Wiring diagram for a typical power system.

Private utilities are almost always incorporated and are usually a part of a very complex organization called a holding company. Briefly, the holding company owns all or a majority of the common stock of a number of subsidiary power companies, known as operating companies. The common stock of the holding company is usually held by the public, but a few individuals may hold sufficient of the common stock to exert effective control of the whole holding company system. Ordinarily the common stock in any corporation amounts to only 40 to 50 per cent of the capitalization, therefore it is possible by pyramiding through sub-holding companies for a few individuals to control huge enterprises. This is not to say that the holding company system is undesirable from the theoretical point of view, because it is possible to effect great economies in equipment purchasing and in the furnishing of engineering services with an organization of this type. The Public Utilities Holding Company Act of 1934 was intended to break up these large aggregations of power companies, and it has had some success to date with several which had been in particularly vulnerable positions due to mismanagement.

Municipal utilities are operated by municipal governing bodies for the benefit of the citizens of the municipality. Financing is obtained by the sale of either bonds or revenue certificates. Revenue certificates encumber only the future income of the system and usually do not require a property owners referendum for their authorization. Municipal utility financing lately has been largely accomplished with revenue certificates.

Federal utilities do not usually sell power directly to the consumers but wholesale it to municipalities, private utilities and rural electrification cooperatives. State governments are compensated for loss of tax revenues by payments in lieu of taxes which would have been collected from the former owners of lands which have been permanently flooded by storage reservoirs which are necessary for most hydroelectric plants. These payments are sometimes claimed to be inadequate by the States which receive them.

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CHAPTER II

LOAD CURVES

7. Before an attempt is made to design any type of power plant, whether a new installation (quite rare) or an extensio to existing facilities, it is necessary to make an exhaustive analysis of the load which the plant is to serve. This analysis must take into account the various types of loads, their probable maximum demands and their geographic location in relation to the plant. Other items for consideration would include a decision as to the relative priority for maintenance of service during an emergency and provision for future growth of load.

8. Demand and Diversity--Consideration of the problem of providing adequate plant capacity for a given situation will show that in very few cases will it be necessary to provide capacity to serve every electrical device in the system at the same time. Engineers have developed two statistical factors to deal with this fact: the demand factor and the diversity factor.

Demand factor expresses as a fraction the probability that any one customer will require full rated power for any particular class of service at any given moment, or during any given period of time. The periods of time are not standardized, but usually are taken as fifteen or thirty minutes. Expressed as an equation, the demand factor is the maximum load demand in kilowatts during a given period for a particular class of service divided by the total rated load in kilowatts for the same class of service, or

$$f_d = \frac{\text{actual maximum demand in kw}}{\text{total connected load in kw}}$$

Diversity factor expresses as a fraction the probability that any number of customers will require the maximum demand for a particular class of service at the same moment. Expressed as an equation, the diversity factor is the ratio of the maximum demand in kilowatts for a class of service, measured at the point of supply, to the sum of the individual customers' maximum demands in kilowatts for the same class of service, or

$$f'_d = \frac{\text{maximum demand in kw at point of supply}}{\Sigma \text{ individual maximum demands in kw}}$$

Table I gives the generally accepted demand and diversity factors for a number of classes of service.

TABLE I

DEMAND FACTORS

Residence Lighting	0.50
Commercial Lighting	
General commercial lighting	0.60
Restaurants, stores, offices	0.70
Theaters	0.60
Schools and churches	0.55
Hotels	0.50
Hospitals	0.45
Warehouses	0.40
General Power Service	
Less than 10 hp	0.75
10 to 20 hp	0.65
20 to 100 hp	0.55
Over 100 hp	0.50

DIVERSITY FACTORS

	Between Cust.	Between Trans.	Between Fdrs.	Between Substa.
Residence Lighting	0.30	0.75	0.85	0.90
Commercial Lighting	0.70	0.75	0.85	0.90
General Power	0.70	0.75	0.85	0.90

Example 1 shows the use of demand and diversity factors in the determination of the capacity of the various components of an elementary power system such as is shown in Figure II-1.

Example 1.

A power plant supplies energy to a town through a primary distribution system consisting of a transmission line and three substations. Substation A serves a residential district through two feeders and five transformers; Substation B serves a commercial district through two feeders and five transformers; and substation C serves an industrial district through three feeders and four transformers. In-

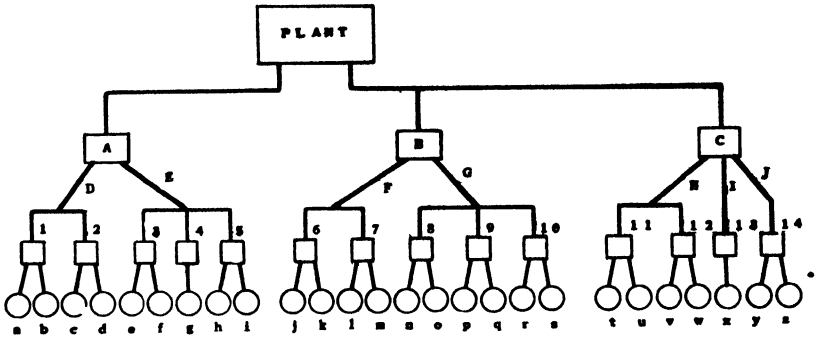


Fig. II-1. Elementary power system.

dividual customer connected loads are as follows (Refer to Figure II-1):

a. 3 kw
b. 2 kw
c. 5 kw
d. 4 kw
e. 6 kw
f. 7 kw
g. 5 kw
h. 10 kw
i. 8 kw

j. 15 kw (theater)
k. 20 kw (restaurant)
l. 17 kw (store)
m. 25 kw (warehouse)
n. 30 kw (school)
o. 26 kw (hospital)
p. 15 kw (office)
q. 18 kw (store)
r. 35 kw (store)
s. 40 kw (hotel)

t. 10 hp
u. 50 hp
v. 35 hp
w. 2 hp
x. 100 hp
y. 40 hp
z. 60 hp

Determine the rating of each transformer, feeder, substation, transmission line section; and the probable maximum demand on the power plant.

Solution:

1. Determine the probable maximum kilowatt demand for each customer by applying the demand factor appropriate for each case, as follows:

a. 3(0.5)=1.5 kw
b. 2(0.5)=1.0 kw
c. 5(0.5)=2.5 kw
d. 4(0.5)=2.0 kw
j. 15(0.60)= 9.0 kw
k. 20(0.70)=14.0 kw
l. 17(0.70)=11.9 kw
m. 25(0.40)=10.0 kw
t. 10(0.65)(0.746) ÷ 0.80 = 6.1 kw
u. 50(0.55)(0.746) ÷ 0.80 = 25.7 kw
v. 35(0.55)(0.746) ÷ 0.80 = 18.0 kw
w. 2(0.75)(0.746) ÷ 0.80 = 1.4 kw

e. 6(0.5)=3.0 kw
f. 7(0.5)=3.5 kw
g. 5(0.5)=2.5 kw
h. 10(0.5)=5.0 kw
i. 8(0.5)=4.0 kw
n. 30(0.55)=16.5 kw
o. 26(0.45)=11.7 kw
p. 15(0.70)=10.5 kw
q. 18(0.70)=12.6 kw
r. 35(0.70)=24.5 kw
s. 40(0.50)=20.0 kw
x. 100(0.55)(0.746) ÷ 0.80 = 51.3 kw
y. 40(0.55)(0.746) ÷ 0.80 = 20.5 kw
z. 60(0.55)(0.746) ÷ 0.80 = 30.8 kw

Note: Motor efficiency estimated at 80 per cent.

2. Determine the kilowatt rating of each transformer by applying the appropriate diversity factor for consumers, as follows:

1. (1.5 + 1.0)(0.30)=0.75 kw
2. (2.5 + 2.0)(0.30)=1.35 kw
3. (3.0 + 3.5)(0.30)=1.95 kw
4. (2.5)(no div.) =2.50 kw
5. (5.0 + 4.0)(0.30)=2.70 kw
6. (9.0 +14.0)(0.70)=16.1 kw
7. (11.9+10.0)(0.70)=15.3 kw
8. (16.5+11.7)(0.70)=19.8 kw
9. (10.5+12.6)(0.70)=16.2 kw
10. (24.5+20.0)(0.70)=31.2 kw
11. (6.1 +25.7)(0.70)=22.2 kw
12. (18.0+ 1.4)(0.70)=13.6 kw
13. (51.3)(no div.) =51.3 kw
14. (20.5+30.8)(0.70)=35.9 kw

3. Determine the kilowatt rating of each feeder by applying the diversity factor for transformers, as follows.

D. (0.75 + 1.35)(0.75) = 1.58 kw
E. (1.95 + 2.50 + 2.70)(0.75) = 5.36 kw
F. (16.1 + 15.3)(0.75) = 23.6 kw
G. (19.8 + 16.2 + 31.2)(0.75) = 50.4 kw
H. (22.2 + 13.6)(0.75) = 26.8 kw
I. (51.3)(no div.) = 51.3 kw
J. (35.9)(no div.) = 35.9 kw

4. Determine the kilowatt rating of each substation by applying the diversity factor for feeders, as follows:

A. (1.58 + 5.36)(0.85) = 5.9 kw
B. (23.6 + 50.4)(0.85) = 63 kw
C. (26.8 + 51.3 + 35.9)(0.85) = 97 kw

5. Determine the probable maximum demand on the power plant by applying the diversity factor for substations, as follows:

(5.9 + 63 + 97)(0.90) = 149 kw

It will be obvious from the preceeding analysis that the rating of any component of the system will never be less

than the probable maximum demand of the largest component served by it. For example, transformer 1 would of necessity have a rating of 1.5 kw in spite of the mathematics which indicates that the rating is 0.75 kw. However, as the size of the system increases, the behavior of the system approaches the statistical ideal and these irrationalities disappear.

9. Load Curves--The foregoing discussion of demand and diversity factors indicates that a constant load cannot be expected for any actual power plant. This indication is found to be true, and furthermore, it has also been found to be true that systems serving approximately the same classes of loads anywhere will have approximately the same type of load curves. For example, industrial plant load will show flat-topped curves with sharp drops at the time of shift changes and at meal times. Utility plant loads will show a minimum during the night; a minor and somewhat flat-topped peak during the morning; a sharp drop at noon; and a sharp peak in the early evening. These characteristics are shown

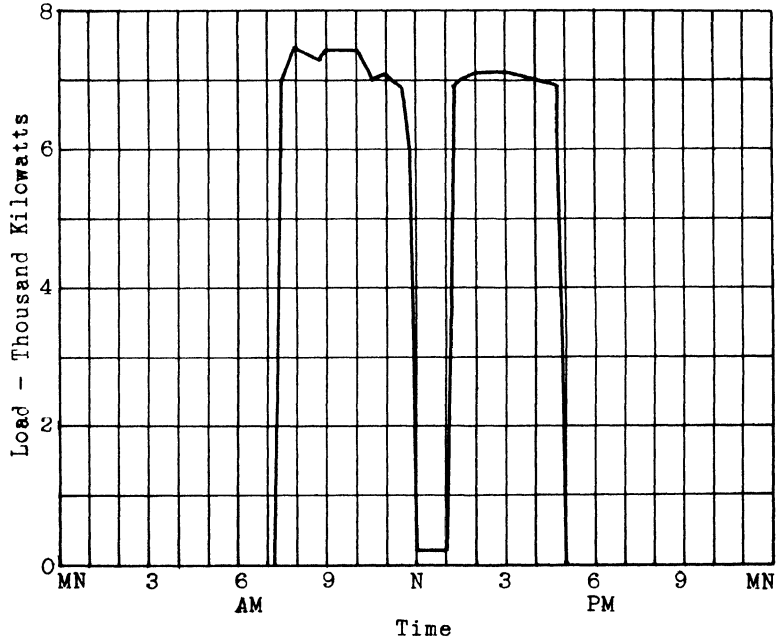


Fig. II-2. Typical daily load curve for industrial plant.

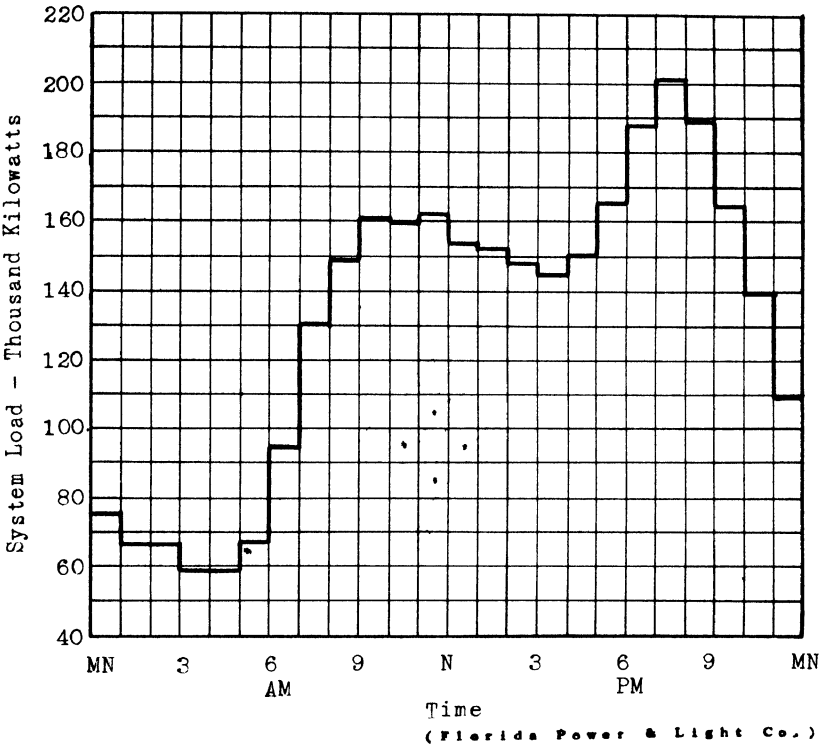


Fig. II-3. Typical daily load curve for public utility.

in Figures II-2 and II-3. Load curves of these types can easily be synthesized if the character and size of the loads of various classes along with the time of their demands are known.

Other types of load curves can be drawn in addition to the daily load curves. For example, the daily maximum loads may be plotted to give an annual peak load curve. This type of curve is useful in deciding upon the best time during the year for scheduling major plant maintenance operations. The yearly maximum loads may be plotted to give a load growth curve. This type of curve will give information as to when it will be necessary to increase plant capacity. These two types of curves are used most frequently with the public utility plant because electric power is the primary product. The industrial plant will make use of similar curves with units of production, such as tons of steel, for ordinates

rather than kilowatts of load. In the ordinary industrial plant power is not a salable commodity. There are cases, however, where industrial plants have arranged to sell power to public utilities, and vice versa, when the peaks in the two types of operations do not coincide. Figures II-4 and II-5 show typical annual peak and load growth curves for a public utility.

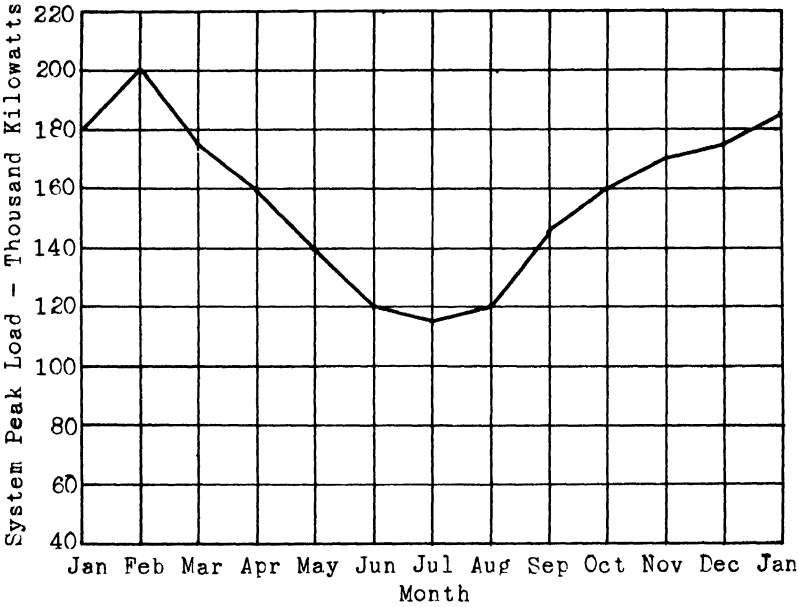


Fig. II-4. Annual peak load curve for public utility.

The daily load curve or the annual peak load curve may be plotted in a form known as the load duration curve. This curve is plotted with time units as abscissa and load as ordunate, such that any point on the curve gives the total time for which the particular load was in demand. Figure II-6 shows a typical daily load duration curve for a public utility. It will be noted that since power output is the product of load and time, the area under the load duration curve is the same as under the load curve.

Example 2 shows the method of synthesis of a daily load curve for the elementary power system of Example 1.

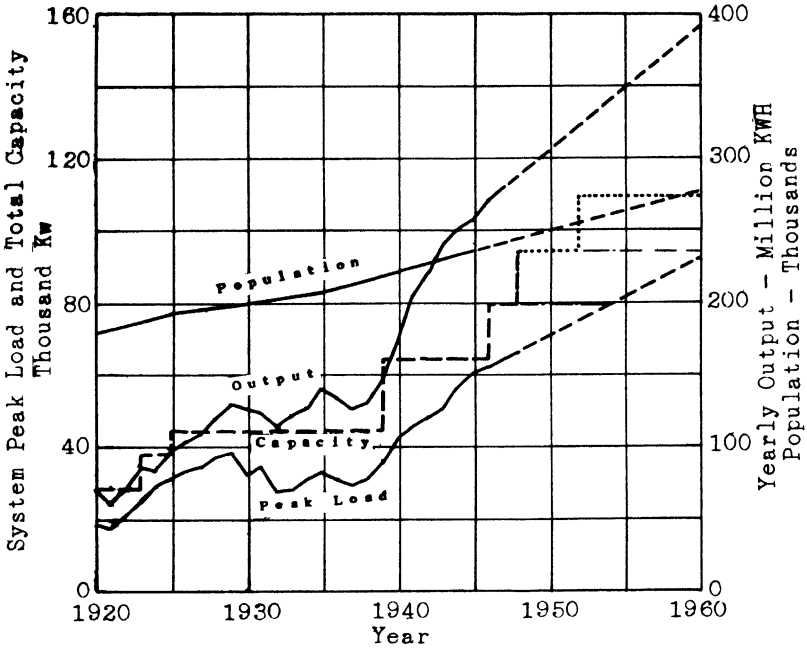


Fig. II-5. Load growth curve for public utility.

Example 2.

The various loads in the town of Example 1 are to be expected at the following times:

Residential load:	
10 o/o	all day
100 o/o	6 AM to 9 AM
	4 PM to 8 PM
Commercial load:	
Theater, j	11 AM to 11 PM
Restaurant, k	6 AM to 9 AM
	11 AM to 2 PM
	5 PM to 9 PM
Stores, l, q, r	9 AM to 6 PM
Offices, p	9 AM to 12 N
	1 PM to 5 PM
Schools, n	9 AM to 12 N
	1 PM to 4 PM

Hospitals, o	
10 o/o	all day
100 o/o	9 AM to 5 PM
Warehouses, m	6 AM to 6 PM
Hotels, s	
10 o/o	all day
100 o/o	7 AM to 10 PM
Industrial load:	
25 o/o	all day
100 o/o	8 AM to 12 N
	1 PM to 5 PM

Using the demand and diversity data from Example 1, set up a load table and plot an expected daily load curve.

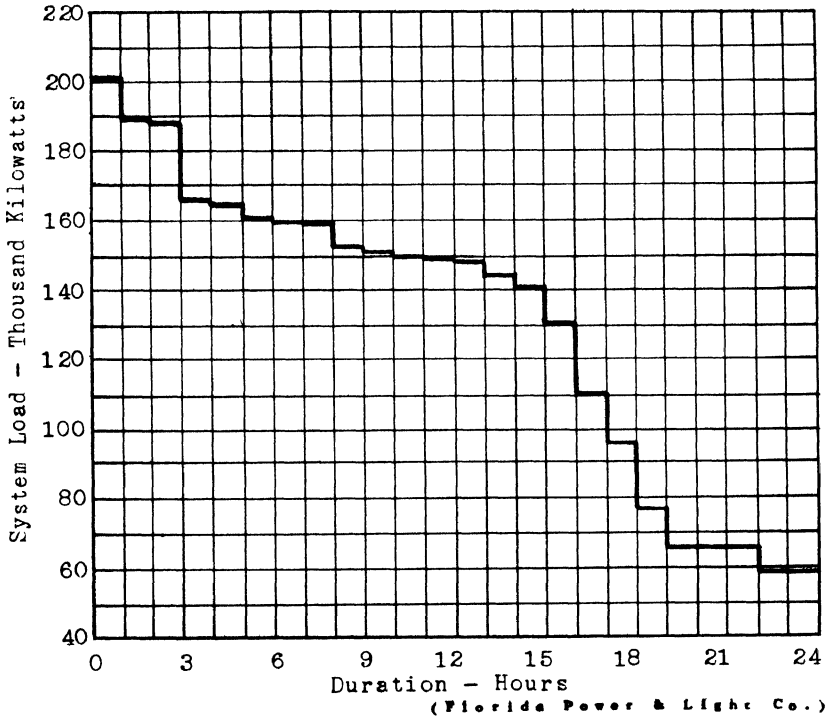


Fig. II-6. Daily load duration curve for public utility.

Solution:

LOAD TABLE

Service	Con. load	f_d	f'_d cons.	f'_d trans.	f'_d fdrs.	f'_d sub.	kw max. dem.
a	3 kw	0.50	0.30	0.75	0.85	0.90	0.26
b	2 kw	"	"	"	"	"	0.17
c	5 kw	"	"	"	"	"	0.43
d	4 kw	"	"	"	"	"	0.34
e	6 kw	"	"	"	"	"	0.52
f	7 kw	"	"	"	"	"	0.60
g	5 kw	"	1.00	"	"	"	1.44
h	10 kw	"	0.30	"	"	"	0.86
i	8 kw	"	"	"	"	"	0.69
j	15 kw	0.60	0.70	0.75	0.85	0.90	3.61
k	20 kw	0.70	"	"	"	"	5.62
l	17 kw	0.70	"	"	"	"	4.78
m	25 kw	0.40	"	"	"	"	4.01
n	30 kw	0.55	"	"	"	"	6.63
o	26 kw	0.45	"	"	"	"	4.70
p	15 kw	0.70	"	"	"	"	4.21
q	18 kw	0.70	"	"	"	"	5.06
r	35 kw	0.70	"	"	"	"	9.85
s	40 kw	0.50	"	"	"	"	8.04
t	10 hp	0.65	"	"	"	"	2.43
u	50 hp	0.55	"	"	"	"	10.28
v	35 hp	0.55	"	"	"	"	7.21
w	2 hp	0.75	"	"	"	"	0.56
x	100 hp	0.55	1.00	1.00	"	"	39.30
y	40 hp	0.55	0.70	"	"	"	11.00
z	60 hp	0.55	"	"	"	"	16.50

Serv.	MN-1AM	1-2AM	2-3AM	3-4AM	4-5AM	5-6AM
Res.	0.53	0.53	0.53	0.53	0.53	0.53
j k l,q,r m n o	0.47	0.47	0.47	0.47	0.47	0.47
p s	0.80	0.80	0.80	0.80	0.80	0.80
Ind.	21.70	21.70	21.70	21.70	21.70	21.70
Total	23.50	23.50	23.50	23.50	23.50	23.50

Serv.	6-7AM	7-8AM	8-9AM	9-10AM	10-11AM	11-12N
Res.	5.31	5.31	5.31	0.53	0.53	0.53
j						3.61
k	5.62	5.62	5.62			5.62
l,q,r				19.69	19.69	19.69
m				4.21	4.21	4.21
n				6.63	6.63	6.63
o	0.47	0.47	0.47	4.70	4.70	4.70
p	4.01	4.01	4.01	4.01	4.01	4.01
s	0.80	8.04	8.04	8.04	8.04	8.04
Ind.	21.70	21.70	86.78	86.78	86.78	86.78
Total	37.91	37.91	110.23	134.59	134.59	143.82

Serv.	12-1PM	1-2PM	2-3PM	3-4PM	4-5PM	5-6PM
Res.	0.53	0.53	0.53	0.53	5.31	5.31
j	3.61	3.61	3.61	3.61	3.61	3.61
k	5.62	5.62				5.62
l,q,r	19.69	19.69	19.69	19.69	19.69	19.69
m	4.21	4.21	4.21	4.21	4.21	4.21
n		6.63	6.63	6.63		
o	4.70	4.70	4.70	4.70	4.70	0.47
p		4.01	4.01	4.01	4.01	4.01
s	8.04	8.04	8.04	8.04	8.04	8.04
Ind.	21.70	86.78	86.78	86.78	86.78	21.70
Total	68.20	143.82	138.20	138.20	136.35	72.66

Serv.	6-7PM	7-8PM	8-9PM	9-10PM	10-11PM	11-MN
Res.	5.31	5.31	0.53	0.53	0.53	0.53
j	3.61	3.61	3.61	3.61	3.61	
k	5.62	5.62	5.62			
l,q,r						
m						
n						
o	0.47	0.47	0.47	0.47	0.47	0.47
p						
s	8.04	8.04	8.04	8.04	0.80	0.80
Ind.	21.70	21.70	21.70	21.70	21.70	21.70
Total	44.75	44.75	44.75	34.35	27.11	23.50

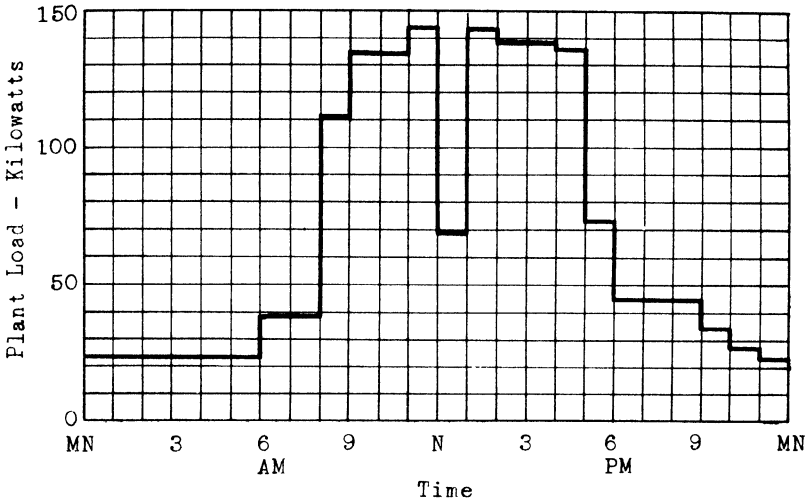


Fig. II-7. Load curve for elementary power system.

10. Factors Used in Operation Analysis--Due to the variability of the load on power systems, it is seldom that a plant operates at its ultimate capacity continuously. In order to express the power output of a plant in terms that are easily analyzed, several factors have come into use.

Load factor is the average load during any specified time divided by the peak load of any specified duration. The average load may be taken over a day, month or year, and the peak load duration may be taken as fifteen or thirty minutes or one hour. For the most common case of daily load factor:

$$f_l = \frac{\text{total generation for day in kwh}}{24[\text{maximum demand in kw sustained for one hour}]}$$

Capacity factor is the total power production for any specified time divided by the product of the installed capacity times the length of the specified period. For the most common case of daily capacity factor:

$$f_c = \frac{\text{total generation for day in kwh}}{24[\text{installed capacity in kw}]}$$

Use factor is the total power production for any given

time divided by the summation of the products of the hours operated times the installed capacity for each machine. For the most common case of daily use factor:

$$f_u = \frac{\text{total generation for day in kwh}}{\Sigma[(\text{hours operated})(\text{capacity of machine in kw})]}$$

II. Determination of Size of Equipment--The problem of variable load and the necessity for insuring continuity of service are the two factors which have the greatest influence in the selection of equipment for a power plant. It has been seen that the plant must have a capacity sufficient to carry the maximum demand, but it is almost never the case where only one generating unit is selected to meet this demand. It is much more usual to select two or more units for the installation. Examination of Figure II-8 will show why

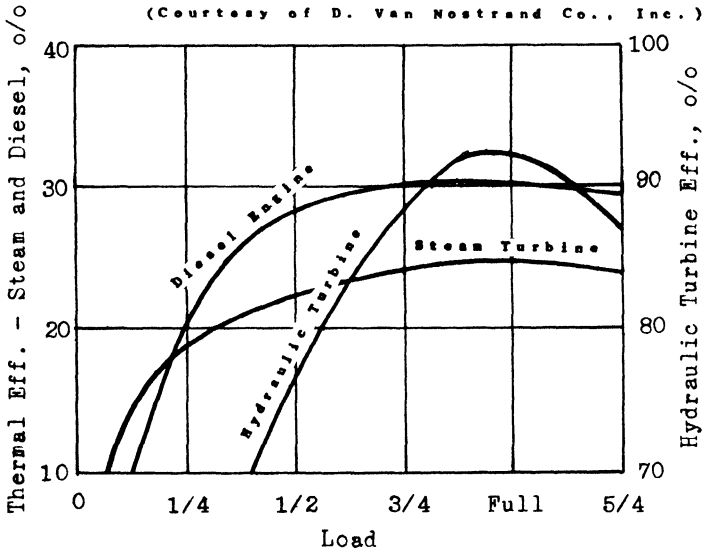


Fig. II-8. Efficiency vs load, engines and turbines.

this is the case. Power generating equipment design involves many compromises, especially when the equipment is expected to operate with variable load, and the usual result is that the thermal efficiency of the machine is at its maximum between three-fourths load and full load, with the efficiency falling as the load increases or decreases beyond this range

It can be seen, then, that for maximum operating efficiency the machine should operate at or near its rated load. This means that the usual plant will have more than one machine, and they may very well be of different sizes so that maximum efficiency could be approached at all loads. Such an ideal case is never the most economical, however, when the complete picture is considered. It is a fact that as the size of the machine increases the thermal efficiency at full load increases and the cost per kilowatt of installed capacity decreases. Economies in investment can also be made by installing duplicate machines wherever possible.

Continuity of service and ability to meet unusual conditions require that:

1. In order to insure against breakdown in equipment, reserve idle capacity must be provided equal to the capacity of the largest machine in the plant or system.

2. In order to insure against inability to meet sudden unusual demands, spinning or active reserve capacity must be provided, usually to the extent of about 25 per cent of the demand at any time.

The following criteria are useful in the examination of a proposed design, or will be of help in selecting equipment to fit a particular situation:

1. The total plant investment per kilowatt of capacity must be at the minumum, or it must be demonstrated that the sum of the operating costs and fixed charges are at the minimum.

2. Capacity and use factors for the plant must be at the maximum consistent with adequate idle and spinning reserves and with leeway for growth of load.

Similar considerations apply to the selection of boiler and other equipment in the plant. Each major item of equipment should be subjected to a critical analysis in order to determine the most economical combination.

Example 3-A shows the method of selection of machines for the installation considered in the elementary power system of Example 1 and Example 3-B shows the method of selection of machine sizes to fit an extension of a load growth curve.

Example 3-A.

The town of Examples 1 and 2 is to be served by a Diesel-electric plant. Available generator sizes are: 25 kw, 50 kw, 75 kw and 100 kw. Select a unit or units which will give the maximum use and capacity factors consistent with required reserves. Set up an operating schedule for the plant.

Solution:

Since the peak load is almost 150 kw, provision for adequate spinning reserve would dictate an assured plant capacity of at least 185 kw to care for present needs. This capacity would necessitate the use of at least two machines in addition to a spare machine for assuring plant capacity. Possible combinations are: (a) 3 - 100 kw (one spare); (b) 5 - 50 kw (one spare); (c) 1 - 25 kw, 1 - 50 kw and 2 - 100 kw (one spare); and (d) 2 - 50 kw and 2- 75 kw (one spare). Capacity factors for these combinations would be:

(a) $$f_c = \frac{1652.7}{24(300)} = 0.229$$

(b) and (d) $$f_c = \frac{1652.7}{24(250)} = 0.275$$

(c) $$f_c = \frac{1652.7}{24(275)} = 0.250$$

On the basis of capacity factors alone, (a) could be eliminated from further consideration, although some leeway would be provided for future growth of load. However, (b) offers the same leeway with a higher capacity factor, and (c) and (d) offer high capacity factors with no leeway for growth. From this analysis, then, (c) and (d) are eliminated and the next step is to investigate the use factors. Load factors are determined after setting up operating schedules as in Figure II-9. These schedules with use factors are:

(a) 1 - 100 kw on 24 hours
1 - 100 kw on 7:30 AM, off 6:30 PM, 11 hours

$$f_u = \frac{1652.7}{24(100) + 11(100)} = 0.472$$

(b) 1 - 50 kw on 24 hours
1 - 50 kw on 7:30 AM, off 6:30 PM, 11 hours
2 - 50 kw on 7:30 AM, off 5:30 PM, 20 hours

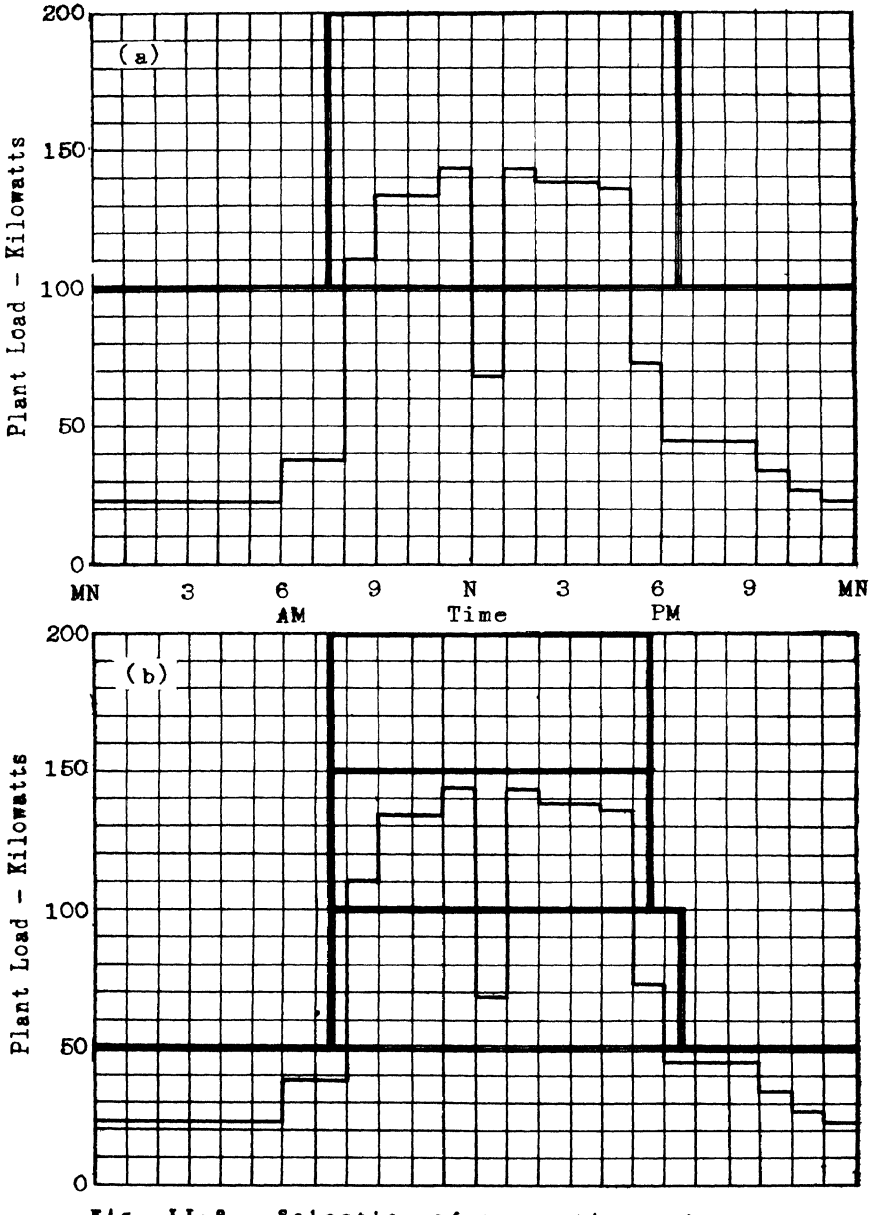


Fig. II-9. Selection of generating units.

$$f_u = \frac{1652.7}{24(50) + 11(50) + 20(50)} = 0.602$$

Then, from the standpoints of maximum use and capacity factors and leeway for growth, combination (b) consisting of 5 - 50 kw machines would be selected. Additional advantages would be realized in the purchase and maintenance of identical units.

Example 3-B.

The power plant whose load growth curve is shown in Figure II-5 had a net assured capacity (total plant capacity less the capacity of the largest machine in the plant) of 49,000 kw in 1945. At this time the peak load was 60,000 kw which necessitated operation with practically no reserve capacity. An order for a 15,000 kw machine had been placed in 1942, but, due to wartime conditions, the plant extention was not placed into operation until 1946. Another 15,000 kw machine was ordered in 1945 and was scheduled for operation before the 1948 peak load. In 1948 the net assured capacity of the plant was 79,000 kw and the peak load was 66,000 kw. At this time it was decided to plan for future load growth. The load growth curve was projected and it appeared that the peak load would equal the plant net assured capacity in 1954. It was decided to order another 15,000 kw unit to operate initially in 1952, and indications were that the plant net assured capacity would then be sufficient until about 1960. It was also decided that the situation would be resurveyed in 1955 with the view of retiring some of the older machines which had been operating since 1920.

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CHAPTER III

ECONOMICS OF POWER PRODUCTION

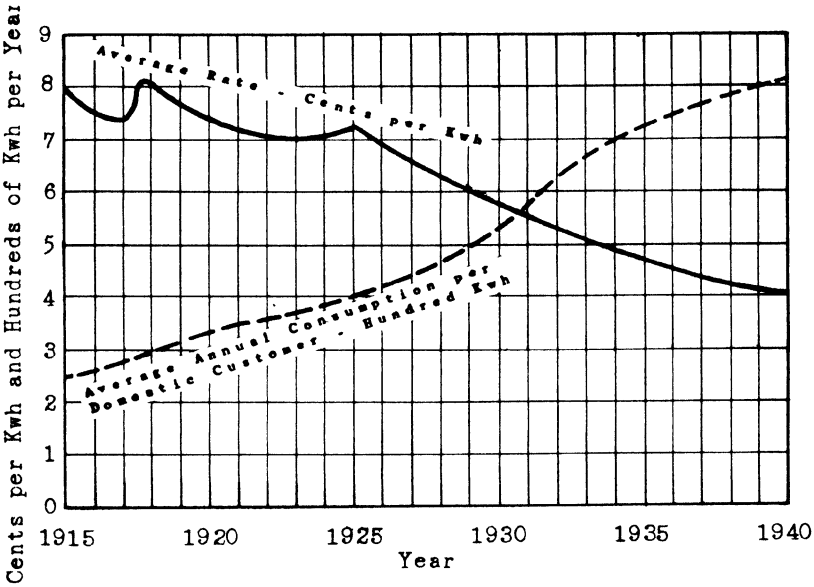
12. Power Plant Income--The public utility derives its income directly from the customers it serves, while the industrial power plant usually receives its operating funds from the revenues of the company of which it is a part.

It can be seen, after some thought, that the public utility company's charge, or rate, for electrical service to its customers must include an element to pay for the labor, materials and fuel, an element to pay for the cost of the necessary machinery, and an element which represents the investors' profit. Furthermore, since industrial customers usually supply a higher type of load than domestic customers, the industrial customers are usually accorded a more favorable rate than the domestic customers. These considerations, when coupled with the inevitability of daily and seasonal demand fluctuations, result in a somewhat complex rate structure for a public utility.

The industrial power plant is not usually faced with the problem of setting a rate for its power. The present method of cost accounting in industry takes only the average annual cost of power per unit of production for the determination of the power element in the cost of the manufactured product. This may not be a fair method of accounting if the industry suffers from seasonal peaks, but, on the other hand, it is only the net annual profit for the industry which is significant.

In spite of the tremendous growth of the manufacturing industries in this country, the domestic customer supplies the greater part of the public utilities' revenue. Figure III-1 shows the growth of load and decrease in cost per kilowatt-hour for domestic customers. The engineer's contribution can be seen clearly in these curves. Increasing efficiency, as seen in Figure I-4, has made lower rates possible, which in turn has made it possible for customers to increase their use of electricity. It should be noted that the trend of rates has been continually downward in spite of the fact of creeping inflation which has been reducing the real value of money.

13. Public Utilities as Monopolies--It does not take careful consideration to arrive at the conclusion that a service such as electric power can be supplied most economic-



(Courtesy of D. Van Nostrand Co., Inc.)

Fig. III-1. Cost and use of domestic electric service.

ally by only one company operating within a given area. Any other arrangement would be wasteful and even inconvenient. Consider, for example, the case of a large city which has two telephone companies competing in the same area. Obviously, the customer is being made to pay for two systems where one would be sufficient. The public utility, then, takes on the character of a monopoly, but abuses are prevented, in the case of private ownership, by the necessity of obtaining a renewal of its permit to do business (or *franchise*) at intervals of time. Franchise granting agencies always reserve the right to purchase the utility at the end of the franchise period, or to grant a new franchise. Further insurance against abuses is provided by regulation by various public utility commissions, local, State or Federal.

The municipal utility has no such restrictions upon it, and the rates charged may or may not include an element of profit. Most cities which own and operate their own power systems do include an element of profit which is intended to make it possible to charge lower ad valorem property taxes. This method of collecting taxes for municipal operating expenses is based on the theory that taxes will receive

the least opposition from the public when they are spread out in small payments attached to some widely used commodity.

14. Rates--Any rate for power should be examined with the following criteria in mind:

1. Fairness--Rates should distribute costs in accordance with the variability of the customer's demand.

2. Simplicity--Rates, especially domestic, should be as simple as possible in order to avoid antagonism from the public.

3. Cost--The outlay for metering equipment and accounting machinery should not be so great as to increase costs to a greater amount than can be paid for out of increased revenues from more complicated rate structures.

Every rate charged the consumer of electrical energy contains the following elements:

1. *Fixed element* is the element of cost which is present in the system operation whether or not energy is produced.

2. *Energy element* is the element of cost which is proportional to the amount of energy produced.

3. *Variable load element* is the element of cost which is due to the character of the load served.

4. *Customer element* is the element of cost which is proportional to the number of customers.

5. *Investors' profit* is the element of cost which goes to reimburse the investor for the use of his capital.

15. The Fixed Element--The fixed element of the cost of producing power is the sum of the following factors:

1. Capital cost of the power plant.
   a. Real estate.
   b. Building and machinery.
   c. Cost of construction.
   d. Engineering fees.

2. Capital cost of primary distribution or transmission system.

a. Cost of easements or right-of-way.
b. Cost of line and substation equipment.
c. Cost of construction.
d. Engineering fees.

3. Interest, taxes and insurance.

4. Depreciation of buildings and equipment.[1]

5. Sinking fund contributions for bond retirement.[1]

6. Cost of management.

7. Capitalized maintenance, or the cost of general maintenance required whether or not power is produced.

Estimating the capital cost of a power plant is a rather difficult problem due to variations in such factors as location, availability of labor and materials and size of plant Table II in connection with Figure III-2 may be useful in making a first approximation. The lower figures in Table II apply to larger plants.

In the final analysis, the only way to prepare an accurate cost estimate is from manufacturers' and contractors' bids after the general layout of the plant has been determined.

If the plant is not situated within very close proximity to the area which it is to serve, a primary distribution system will be necessary. This system should be laid out to carry the expected load of the plant, therefore its cost will be proportional to the capacity of the plant and to the distance over which the lines extend. It is almost impossible to give any figures as to cost per mile for transmission systems because of the many factors, such as type of terrain and size of conductors and carrying capacity, that enter into the cost. However, for purposes of estimating very

---

[1] Municipal utilities are required by State laws to include a sinking fund for bond retirement in the fixed element of the cost. Sometimes a depreciation reserve is also included to provide for replacement of equipment when it becomes obsolete, but more often a small reserve is maintained for minor replacements only, and when major improvements are required bonds or revenue certificates are sold.

The private utility always includes a depreciation reserve in the fixed element of the cost, but it is expected to provide a sinking fund for bond retirement out of the profit element. This is usually explained as "preventing the practice of making the customer pay for the capital required to provide him with service."

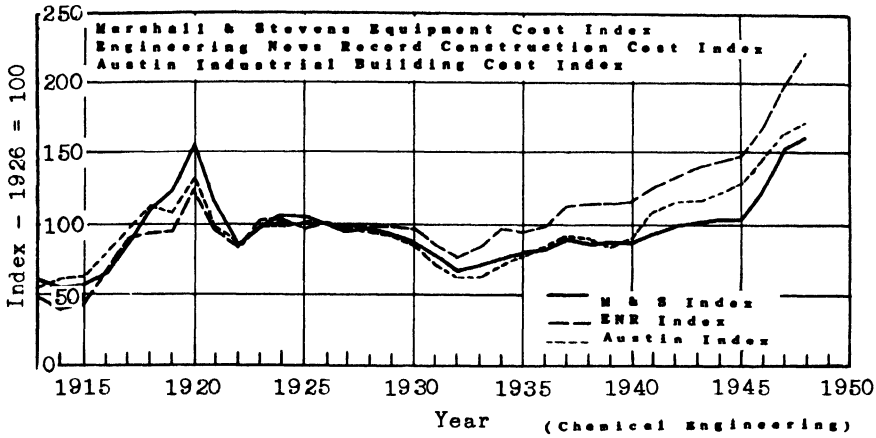


Fig. III-2. Building and equipment cost index.

TABLE II

APPROXIMATE POWER PLANT CAPITAL COSTS
dollars per kilowatt capacity
(base year 1932)

Turbo-generator plants	80 to 150
Engine-generator plants	70 to 150
Diesel-generator plants	130 to 250
Hydro-generator plants	100 to 300

roughly, the cost of the primary distribution system may be taken as ranging between $1500 and $5000 per mile (based on 1928), the lower figure applying to low voltages and light loads in relatively flat and open country.

Since it is usual to finance part or all of the cost of construction by the issuance of bonds or revenue certificates interest on these securities is part of the cost of operation Interest rates vary according to the money policies of the Federal Government. At the present time, interest rates are low, usually around three per cent, but in the past they have been as high as six per cent.

If the utility is privately owned, ad valorem property taxes and occupational licence fees must be paid. These

usually amount to from two to three per cent of the investment annually. In some States municipally owned utilities must pay the State occupational licence fee.

All utilities maintain insurance on their equipment and liability insurance for protection against claims for damages The cost of insurance amounts to from one to two per cent of the investment annually.

In order to provide a fund for eventual replacement of worn-out or obsolete equipment, a retirement reserve is accumulated over a period of years. The length of time for the accumulation of the reserve depends upon the estimated life of the equipment. Table III shows the legally approved retirement periods for various types of equipment. The reserve may be accumulated in two different ways: by the sinking fund method or by the straight line method, although the straight line method is most usual. In either case, the sum accumulated will be equal to the original cost of the equipment less a salvage value. For a number of years business organizations have been attempting to have income tax laws amended to allow retirement reserves to be accumulated on the basis of present replacement cost, but they have had no success up to the time of this writing. Inadequate retirement reserves have necessitated the sale of additional stocks and bonds to obtain capital for needed modernization.

The sinking fund for retirement of bonds or obsolete equipment is similar to an annuity, and, as a matter of fact, annuity tables can be used for computing the annual payment. The sinking fund is accumulated by making an annual payment to an account in a bank, which draws interest at the current rate, or by purchasing negotiable securities which draw interest. The total of the payments plus the interest earned over the retirement period will equal the total sinking fund reserve. The annual payment can be calculated from the following equation:

$$\text{annual payment} = \{P - S\}\{r \div [(1 + r)^n - 1]\}$$

where: P = original cost
S = salvage value
r = rate of interest earned (compounded annually)
n = number of years

Since the accumulation of the plant retirement reserve is not a very accurate process at best, it is more usual to use the straight line method of depreciation and to treat

TABLE III

PROBABLE LIFE OF POWER PLANT COMPONENTS

Component	Years
Boilers, fire-tube	10 to 15
Boilers, water-tube	20
Breechings and ducts	10 to 30
Buildings	20 to 30
Cables and feeders	15 to 25
Coal and ash machinery	10 to 20
Condensers	20
Cranes	30
Economizers and air heaters	15
Electric generators	20
Electric motors	20
Engines, steam	15 to 35
Engines, Diesel	15
Feed-water heaters	20
Fuel oil handling equipment	20
Pipe and pipe covering	15 to 25
Pumps	15 to 20
Stacks, brick or concrete	30
Stacks, steel	12 to 15
Stokers and other coal burning equipment	20
Superheaters	20
Switchboards and equipment	20
Transformers	15
Turbines, steam	15 to 20
Turbines, hydro	30

any interest earned as income. The annual payment can be calculated from the following equation, with symbols as above:

$$\text{annual payment} = \frac{(P - S)}{n}$$

Unlike the plant retirement reserve, the amount necessary for bond retirement is known exactly. For this reason, the sinking fund is universally used for bond retirement.

The annual payment can be calculated from the previous sinking fund equation (leavirg out the salvage item). It is necessary to recalculate the annual payment from time to time as interest rates change.

The cost of management is included in the fixed charges, and usually management is taken to include all administrative officers down to and including the plant superintendent.

Usually about ten per cent of the total maintenance for the system is included in the fixed charges. This so-called capitalized maintenance is assured to be the portion of the maintenance which is independent of the amount of power produced.

16. The Energy Element--The energy element of the cost of producing power is the sum of the following factors:

1. Cost of fuel.
2. Cost of labor.
3. Cost of water.
   a. Boiler feed makeup water.
   b. Condensing water.
   c. Service water.
4. Lubricating oil and operating supplies.
5. Maintenance.

The greatest portion of the energy element is due to the cost of fuel, and for this reason it will be found that highly skilled labor in the power plant will always operate the plant in such a way as to save more than enough fuel to pay the difference in salary over unskilled labor. Due to the fact that the labor force required is proportional to the capacity of the plant rather than to plant output, employment in the public utility business is very stable and attractive to those who would make a career in the business.

Since the steam power plant operates best with pure water, and natural waters are very seldom pure enough, the cost of preparation of the water for use as well as the cost of the water itself, in cases where it must be purchased or pumped, must be considered.

A not inconsiderable item in operating costs is that of supplies of various sorts. These would include forms and charts for record keeping, cleaning and wiping sundries, and

all other expendable items which might be needed. Lubricating oil is not a large item of expense in the well operated turbo-generator plant, since with proper care a lubricating oil charge will last almost indefinitely and requires only a small amount of makeup at infrequent intervals.

Maintenance costs include the cost of repair and of replacement of parts which wear out. Properly supervised plants have a schedule of continuous maintenance designed to keep the machinery in the best possible condition at all times. All but the smallest plants employ a maintenance force in addition to the plant operators. The cost of maintenance is usually estimated at about one per cent of the investment annually.

17. The Variable Load Element--This element of the cost of production of power is usually included with the energy element because of the difficulty in assessing its effect. Consideration would have to be made of the reserve capacity required and the status of the plants in the system with respect to the type of loading, that is, base load, standby or swinging.

18. The Customer Element--The customer element in the cost of producing power is the sum of the following factors:

1. Capital cost of the secondary distribution system.
   a. Cost of easements or right-of-way.
   b. Cost of line and substation equipment.
   c. Cost of construction.
   d. Engineering fees.
2. Interest, taxes and insurance.
3. Depreciation of equipment.
4. Sinking fund contributions for bond retirement.
5. Cost of franchise.
6. Publicity.
   a. Public relations.
   b. Advertising.
7. Cost of collecting revenue.
   a. Meter reading.
   b. Billing and collecting.
   c. Accounting.
8. Maintenance.

Most of the factors appearing in the customer element have been discussed under the fixed element. In the matter of depreciation and sinking fund, the remarks in the footnote on page 28 also apply.

Investment in the secondary distribution system is roughly proportional to the number of customers served, and for purposes of estimation may be taken as approximately $50 per customer (based on 1928).

The cost of publicity is usually lumped together with the cost of the franchise and may be taken as between one and two dollars per year per customer, depending upon the amount of advertising considered necessary. The cost of the franchise itself is usually nominal, and is usually considered to be in the nature of an occupational licence tax.

The cost of collecting revenue may vary between $1.50 and $3 per customer per year (based on 1932), the smaller figure applying to the larger systems.

19. Investors' Profit--The profit element in the cost of producing power may or may not be present, according to the type of utility operation. It is inherently present in the private utility system, and it may be present in the municipal utility operation, as previously pointed out, when it is desired to reduce property taxes. It is usually absent in the Federal utility system, and, as a matter of fact, the Federal utility may suffer a deficit without danger of bankrupcy.

The profit on electric utility operations is usually estimated at about ten per cent of the investment annually before income taxes and bond sinking fund deductions are made.

20. Types of Rates--There have been a great number of methods of calculating rates for electrical power used in the past, but of them only the following remain to any considerable extent:

Block Meter Rate—In this type of rate a certain specified price per unit is charged for all or part of a block of units, and reduced prices per unit are charge for succeeding blocks. Figure III-3 shows a rate schedule based on this system. The block meter rate has the advantage of encouraging the use of electricity, providing the initial blocks are not too large, and is almost universally used for residential service,

Rate Schedule RS-1

RESIDENTIAL SERVICE—ELECTRIC

APPLICATION:

For service for all domestic purposes in private residences and individually metered apartment units.

LIMITATION OF SERVICE:

All residential service required on the premises by Customer shall be supplied through one meter. Stand-by or resale service not permitted hereunder.

CHARACTER OF SERVICE:

Single phase, 115/230 volts, 3 wire or 115 volts, 2 wire depending upon Customer's requirements. Three phase, 230 volt service may be furnished but only under special arrangements.

MONTHLY RATE:

$1.00 which entitles Customer to use 14 kwh,
4.5¢ per kwh for the next 36 kwh,
2.5¢ per kwh for the next 130 kwh,
1.5¢ per kwh for all additional kwh.

Tax Adjustment,—Plus the applicable proportionate part of any taxes and assessments imposed by any governmental authority in excess of those in effect January 1, 1937, which are assessed on the basis of meters or customers or the price of or revenues from electric energy or service sold or the volume of energy generated or purchased for sale or sold

Inflation Adjustment,—In order to take care of extreme increases in costs in the event of inflation there shall be added to the above rate ½ of 1% for each 1% increase in cost of oil over $2.00 a barrel (or $2.00 per 6,300,000 Btu, if fuel used is other than oil) based on the average cost of fuel used in Company's plants during the next preceding month.

Excess Capacity Charge: For each kw of Demand in excess of 10, add $1.75 The kw of Demand is the average kw supplied during the 15-minute period of maximum use during the current month.

RULES AND REGULATIONS:

Service under this schedule is subject to orders of governmental bodies having jurisdiction and to the currently effective "General Rules and Regulations for Electric Service" on file in Company's office, which are hereby made a part hereof. A copy of the present effective "General Rules and Regulations for Electric Service" is attached hereto. In case of conflict between any provision of this schedule and said "General Rules and Regulations for Electric Service" the provision of this schedule shall apply.

FLORIDA POWER & LIGHT COMPANY Effective June 1, 1946

Fig. III-3. Residential rate schedule.

Block Hopkinson Demand Rate—In this type of rate a demand charge based on the maximum demand during any stated period is added to a block meter rate. Figure III-4 shows a rate schedule based on this system. It is named after Dr. John Hopkinson, an Englishman who did much to develop the theory of rate making. This rate has the advantage of encouraging commercial and industrial customers to develop a high load factor. It is almost never used for residential service because of the necessity for demand meters.

Room Rate--In this type of rate the block meter rate is modified to include the number of rooms in the residence. For example: 9¢ per kwh for the first three kwh per room; 6-1/2¢ per kwh for the next three kwh per room; and 3-1/2¢ per kwh for the excess over six kwh per room

Rate Schedule IR

INDUSTRIAL SERVICE—ELECTRIC

APPLICATION:

For power service for industrial, manufacturing or processing purposes. The use of energy for lighting purposes within and about the buildings, structures and premises housing or enclosing the power driven and operated machinery and equipment used in or in connection with such industrial, manufacturing or processing purposes and incidental to the use of power supplied hereunder for such purposes is permissible under this Schedule. For such lighting use, Customer will provide and maintain all transformers and auxiliary appurtenances

CHARACTER OF SERVICE:

Single or three phase, 60 cycles and at any available standard voltage.

LIMITATION OF SERVICE:

All service required on premises by Customer shall be furnished through one meter. Not applicable to service in stores, hotels, office buildings, theatres, apartment houses, restaurants, clubs, or in any other commercial establishments, nor to stand-by or resale service.

MONTHLY RATE:

$1.50 per kw for the first 400 kw of Demand,
$1.00 per kw for all additional kw of Demand.

2.6¢ per kwh for the first 1,700 kwh,
1.3¢ per kwh for the next 4,300 kwh,
1.0¢ per kwh for the next 34,000 kwh,
0.8¢ per kwh for the next 40,000 kwh,
0.6¢ per kwh for all additional kwh.

For each kw of the highest Excess On-Peak Demand established during the 12 months ending with the current month, add to the 2.6¢ block 100 kwh per kw for the first 50 kw, 80 kwh per kw for the next 100 kw, and 70 kwh per kw for all additional kw.

Adjustments:

First,—Minus or plus .0183¢ per kwh used for each 1¢ below 12¢ or above 18¢, respectively, in Company's cost per million British Thermal Units of fuel For this purpose there shall be employed the weighted average delivered cost (including freight, storage and handling costs) as shown by Company's books, of all fuel used during the next preceding month in the generating stations interconnected with Company's main transmission system

Second,—Plus the applicable proportionate part of any taxes and assessments imposed by any governmental authority in excess of those in effect January 1, 1937, which are assessed on the basis of meters or customers or the price of or revenues from electric energy or service sold or the volume of energy generated or purchased for sale or sold.

Minimum: $1.50 per kw of the highest Demand established during the 12 months ending with the current month, but not more than an amount sufficient to make the total charges for such 12 months equal to $20.00 per kw of such Demand, and not less than the charge for the currently effective Demand

The foregoing rate is net and not subject to any municipal, county or other discount.

DEMAND:

The kw as determined from Company's demand meter for the 15-minute period of Customer's greatest use during the month, adjusted for power factor, but not less than 15 kw.

ON-PEAK DEMAND:

The kw as determined from Company's demand meter for the 15-minute period of Customer's greatest use during the On-Peak Hours of the current month, adjusted for power factor.

The On-Peak Hours shall be from 5 to 9 p.m. each day, excluding Sundays, Christmas and New Year's, from December 1 to March 31 inclusive Company reserves the right to change the monthly and hourly periods after giving 30 days' notice, but the On-Peak Hours of each day shall always be consecutive

EXCESS ON-PEAK DEMAND:

The number of kw by which the On-Peak Demand exceeds 20% of the average of the three highest Demands determined during the next preceding calendar months of April to November, inclusive

The Excess On-Peak Demand effective for each month of the first contract year will be mutually agreed upon by Company and Customer, and used until actual operating data are available.

POWER FACTOR:

If Customer's power factor shall average less than 85% lagging during any month, then Company may adjust the readings taken to determine the Demand by multiplying the kw obtained through such readings by 85 and by dividing the result by the average power factor actually established during the current month Such adjusted readings shall be used in determining the Demand.

TERM OF SERVICE:

Not less than one year. In the event this schedule is a part of an agreement for a term of less than 5 years, 5% shall be added to the amount computed under the above Monthly Rate, before Adjustments, and to the above Minimum.

RULES AND REGULATIONS:

Service under this schedule is subject to orders of governmental bodies having jurisdiction and to the currently effective "General Rules and Regulations for Electric Service" on file in Company's office, which are hereby made a part hereof. A copy of the present effective "General Rules and Regulations for Electric Service" is attached hereto. In case of conflict between any provision of this schedule and said "General Rules and Regulations for Electric Service" the provision of this schedule shall apply.

The computations invclved are somewhat cumbersome, but the rate is used to a great extent in large cities where the majority of the population lives in apartments.

Example 4 shows the method of computing rates for the elementary power system of Example 1, based on the assumption that the system is privately owned, and Example 5 shows the calculations for rate making for the same power system based on the assumption that the system is owned by a municipality.

Example 4.

The power plant of Examples 1, 2 and 3-A contains five 50 kw Diesel-generators which cost $250 per kw, installed, and have a salvage value of 10 o/o at the end of 15 years. The primary distribution system cost $20000 and has a salvage value of 20 o/o at the end of 12 years. Management cost is $6000 per year and taxes and insurance together are 7 o/o. Depreciation of the investment is on the straight line basis. Sixty per cent of the investment is raised by the sale of bonds which mature in 20 years and bear interest at 3.5 o/o. The bonds are to be retired out of profits and the remaining 40 o/o of the investment is raised by the sale of common stocks.

The engine heat rates (Btu/kwh net output) are: full load, 11800; 0.75 load, 12000; 0.5 load, 12900; 0.25 load, 14850. Fuel oil having 6,300,000 Btu/bbl and costing $3.00 per bbl is used; maintenance $600 per year; labor $800 per month; supplies $200 per year; and cost of water $100 per year.

The system has 1000 customers and the cost of collection is $3.00 per customer per year. The secondary distribution system cost $75000 and has a salvage value of 15 o/o at the end of 12 years; labor $1000 per month; maintenance $800 per year; and taxes and insurance together are 7 o/o. The depreciation and financing are managed in the same way as for the plant and primary distribution system.

The annual profit is expected to be 10 o/o of the total investment, before income taxes are deducted. The income tax rate is 30 o/o. Find the amount of money available for common stock dividends after setting up a sinking fund for bond retirement. The sinking fund earns interest at 2 o/o.

Make a block meter rate which will recover the fixed element in the first 8 kwh per customer per month; the customer element in the next 15 kwh per customer per month; and

the energy and profit elements from the excess over 30 kwh per customer per month.

Solution:

A. Fixed element:

Investment in plant = 250($250)	$ 62500
Investment in primary distribution system	20000
Annual depreciation of plant = $0.90 \frac{62500}{15}$	$ 3750
Ann. depr. of pri. dist. sys.= $0.80 \frac{20000}{12}$	1333
Taxes and insurance = 0.07(82500)	5775
Interest = 0.035(0.60)(82500)	1732
Capitalized maintenance = (0.10)(1400)	140
Management	6000
Total annual fixed element	$ 18730

B. Energy element:

In Figure III-5 a the engine heat rates are plotted vs kw output. Since all units are identical, the load will be divided equally among the units operating at any particular time. Figure III-5 b shows the plant heat rate vs plant load in kw. The following table can then be calculated:

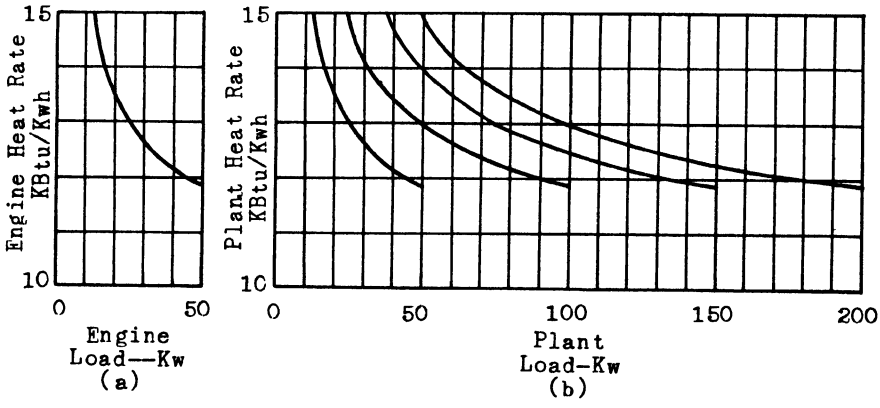


Fig. III-5. Engine heat rates for elementary power system.

Time AM	kwh	HR K	Heat KBtu	Time PM	kwh	HR K	Heat KBtu
MN- 1	23.5	13.1	308	N - 1	68.2	13.7	935
1 - 2	23.5	13.1	308	1 - 2	143.8	12.3	1770
2 - 3	23.5	13.1	308	2 - 3	138.2	12.4	1715
3 - 4	23.5	13.1	308	3 - 4	138.2	12.4	1715
4 - 5	23.5	13.1	308	4 - 5	136.4	12.4	1690
5 - 6	23.5	13.1	308	5 - 6	72.7	13.6 / 13.0	968
6 - 7	37.9	12.2	425	6 - 7	44.8	13.2 / 12.0	565
7 - 8	37.9	12.2 / 20.0	591	7 - 8	44.8	12.0	533
8 - 9	110.2	12.8	1410	8 - 9	44.8	12.0	533
9 -10	134.6	12.4	1670	9 -10	34.4	12.3	424
10-11	134.6	12.4	1670	10-11	27.1	12.8	347
11- N	143.8	12.3	1770	11-MN	23.5	13.1	308

Total Btu/day = 20,887,000

$$\text{Cost of fuel/day} = \frac{20,887,000}{6,300,000}(\$3.00) = \$9.95$$

Annual fuel cost = 365($9.95)	$3630
Labor = 12($800)	9600
Water	100
Supplies	200
Maintenance = 0.90($600)	540
Total annual energy element	$14070

C. Customer element:

Investment in sec. dist. sys. =	$75000
Depr. of sec. dist. sys. = $0.85\frac{75000}{12}$	$ 5310
Taxes and insurance = 0.07(75000)	5250
Interest = 0.035(0.60)(75000)	1575
Maintenance = 0.90(800)	720
Labor = 12(1000)	12000
Cost of collection = 1000($3.00)	3000
Total annual customer element	$27855

D. Profit element:

Total investment	$157500
Profit = 0.10(157500)	$15750
Less income tax = 0.30(15750)	4725
Profit after taxes	$11025
Less sinking fund cont.= $0.60(157500)\frac{0.02}{(1+0.02)^{20}-1}$	3880
Available for dividends	$ 7145
Dividend rate = $\frac{7145(100)}{0.40(157500)}$	11.3 o/o

E. Block meter rate:

First block:

$$\text{rate} = \frac{\$18730}{12(10000)} = \$0.156/\text{kwh for first 10 kwh}$$

Second block:

$$\text{rate} = \frac{\$27855}{12(20000)} = \$0.116/\text{kwh for next 20 kwh}$$

Third block:

$$\text{rate} = \frac{\$10803 + \$15750}{12[\frac{365(1653)}{12} - 30000]} = \$0.109/\text{kwh for excess over 30 kwh}$$

Example 5.

This example is the same as Example 4 except for the method of financing, which is typical of municipal practice. All of the capital is raised by the sale of revenue certificates which mature in 20 years and bear interest at 3.5 o/o and the sinking fund earns interest at 2 o/c. Profit of 10 o/o on the investment goes to defray town operating expenses. No taxes are paid, and insurance is 2 o/o.

Solution:

A. Fixed element:

Investment in plant = 250($250)	$ 62500
Investment in primary distribution system	20000
Annual depreciation of plant	$ 3750
Annual depr. of pri. dist. sys.	1333
Insurance = 0.02(82500)	1650
Interest = 0.035(82500)	2885
Capitalized maintenance	140
Management	6000
Sinking fund cont. = 0.0411(82500)	3390
Total annual fixed element	$19148

Energy element:

Total annual energy element	$10803

Customer element:

Investment in secondary distribution system	$75000
Depreciation of sec. dist. sys.	5310
Insurance = 0.02(75000)	1500
Interest = 0.035(75000)	2625
Maintenance	720
Labor	12000
Cost of collection	3000
Sinking fund cont. = 0.0411(75000)	3080
Total annualcustomer element	$28235

Profit element:

Profit = 0.10(157500)	$15750

Block meter rate:

First block:

$$\text{rate} = \frac{\$19148}{12(10000)} = \$0.159/\text{kwh for first 10 kwh}$$

Second Block:

$$\text{rate} = \frac{\$28235}{12(20000)} = \$0.118/\text{kwh for next 20 kwh}$$

Third block:

$$\text{rate} = \frac{\$10803 + \$15750}{12(20300)} = \$0.109/\text{kwh for excess over 30 kwh}$$

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PROJECT I

1. A certain town of 20,000 population is served by a private utility and has the equivalent of 6,000 customers, divided among three substations. Substation A serves a residential district; substation B serves a commercial district; and substation C serves an industrial district. Street lighting is supplied from substation D. The system (incomplete) is shown in Figure III-6. Connected loads and hours of use are as follows:

Class of Service	Connected Load kilowatts	Hours of Use
Substation A:		
Residences	7500	6 to 8 AM 5 to 11 PM
Apartments	2500	6 to 8 AM 5 to 11 PM
Substation B:		
Public buildings	250	9 AM to 5 PM
Churches	140	10 AM to 1 PM 6 to 9 PM
Hospitals	450	all day
Theaters	250	2 to 11 PM
Laundries	100	7 AM to 5 PM
Retail stores	450	9 AM to 6 PM
Offices	300	9 AM to 5 PM
Newspapers	150	9 AM to 8 PM
Substation C:		
Factories	3000	7 AM to 5 PM
Machine shops	500	8 AM to 5 PM
Substation D:		
Street lighting	500	6 PM to 6 AM

(a) Find the probable maximum demand for each class of service.

(b) Find the probable maximum demand on each substation.

(c) Find the probable maximum demand on the power plant and plot a typical daily load curve for the plant.

(d) Turbo-generator sizes available are: 500 kw, 750 kw, 1000 kw, 1500 kw, 2000 kw, 2500 kw and 3000 kw. Choose a unit or units which will give the maximum use and capacity factors

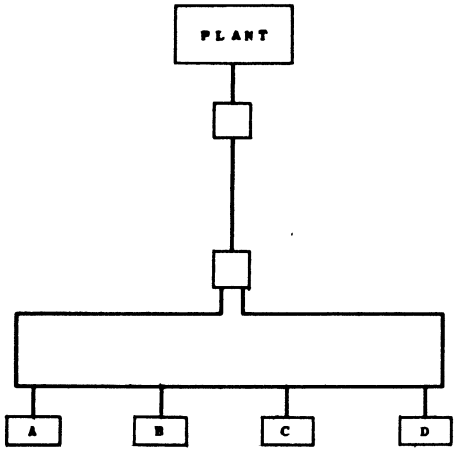


Fig. III-6. Elementary power system, Project I.

consistent with required reserves and leeway for growth, and set up an operating schedule for the plant.

2. (a) Estimate the cost of the plant and transmission system, assuming that the transmission system consists of approximately five miles of 13.2 kv line in flat country. Management cost is $10000 per year and taxes and insurance together are 7 o/o. Depreciation of the investment is on the straight line basis. Sixty per cent of the investment is financed by the sale of bonds which mature in twenty years and bear interest at 3 o/o. The remainder of the investment is financed by the sale of common stock. What is the annual fixed cost?

(b) If the turbo-generator heat rates (Btu per kwh net output) are estimated as: full load, 17500; 3/4 load, 17850; 1/2 load, 18650; and 1/4 load, 20500; fuel oil having 6,325,000 Btu per bbl, costing $1.50 per bbl is used; labor, $2,000 per month; supplies, $3,000 per year; and cost of water, $1,000 per year, what is the annual energy element? (Assume that the typical day in part one is the average day.)

(c) Estimate the cost of the secondary distribution system and the annual customer element if labor costs $5,000 per month and taxes and insurance together are 7 o/o. The depreciation and financing of the investment is in the same manner as with the plant and primary distribution system.

(d) If the annual gross profit is to be ten per cent of the investment, how much will be left for common stock dividends after setting up a sinking fund for bond retirement and paying income taxes? The sinking fund earns interest at two per cent and the income tax rate is 38 o/o.

(e) Set up a block meter rate which will recover the fixed element in the first ten, the customer element in the next 25 and the energy and profit elements in the excess over 35 kwh per customer per month.

CHAPTER IV

VAPOR POWER CYCLES

21. Carnot Cycle--A cycle composed of completely reversible processes was proposed by Sadi Carnot, a French engineer, in 1824. The Carnot cycle is accepted as being the most efficient between any two temperature limits. The efficiency of the Carnot cycle can only be approached, however, because all real processes are irreversible. Figure IV-1 shows the Carnot cycle on the T-S and H-S planes for saturated steam and for superheated steam, both produced from saturated water.[1]

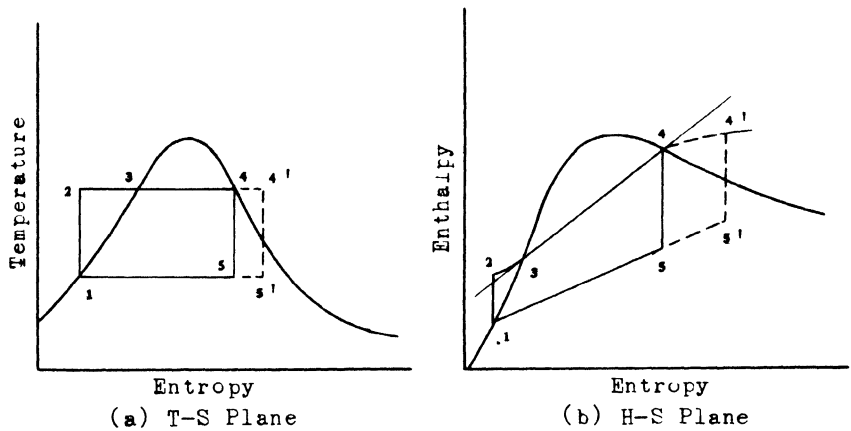


Fig. IV-1. Carnot cycle.

It will be noted that the Carnot cycle consists of two reversible isothermal and two reversible adiabatic processes. Examination of the cycle on the H-S plane will show that the characteristics of real vapors, such as steam, will not allow a practical realization of the Carnot cycle for the reason that the isothermal additions of heat from 2 to 3 and from 4 to 4' require that the pressure must decrease as the heat is being added.

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[1] Since these figures are not to scale, considerable distortion exists, especially in the liquid region.

22. Rankine Cycle--The simplest vapor power cycle which has been proposed was conceived by Prof. W. J. M. Rankine, of the University of Glasgow, in 1849. This cycle is shown on the T-S and H-S planes in Figure IV-2, and will be seen to be a modification of the Carnot cycle to meet the requirements of real vapors. The expansion and compression lines

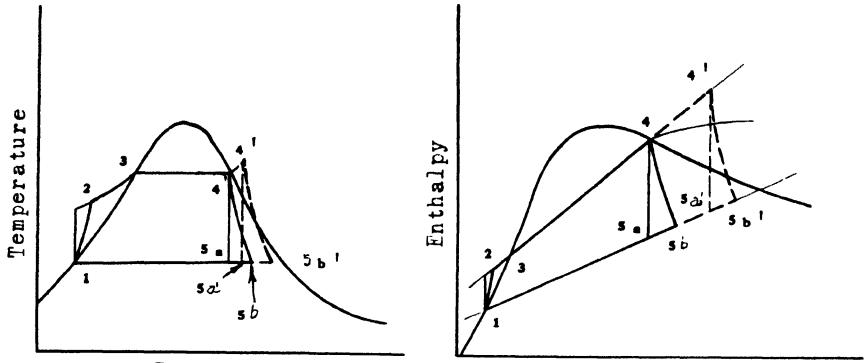


Fig. IV-2. Rankine cycle.

are shown to follow paths of increasing entropy because of the irreversibility of real processes. The ideal Rankine cycle would have these two processes follow paths of constant entropy.

A schematic diagram of the Rankine cycle is shown in Figure IV-3. The process 1-2 takes place in the pump and is one of subcooling in which the pressure is increased to that prevailing in the boiler. The process 2-3 takes place in the boiler and represents the constant pressure heating of water to the saturation temperature. The process 3-4 takes place in the boiler, also, and represents the production of steam from water at constant pressure. The steam at state 4 may be either wet or superheated. The process 4-5 represents the expansion in the engine, during which process work is done. The process 5-1 takes place in the condenser and is a constant pressure rejection of heat. It should be remembered that within the region of vapor mixtures (under the saturation line) a constant pressure process is identical with a constant temperature process.

The cycle represented in Figure IV-3 is closed, in that the same working fluid is used over and over. Often in

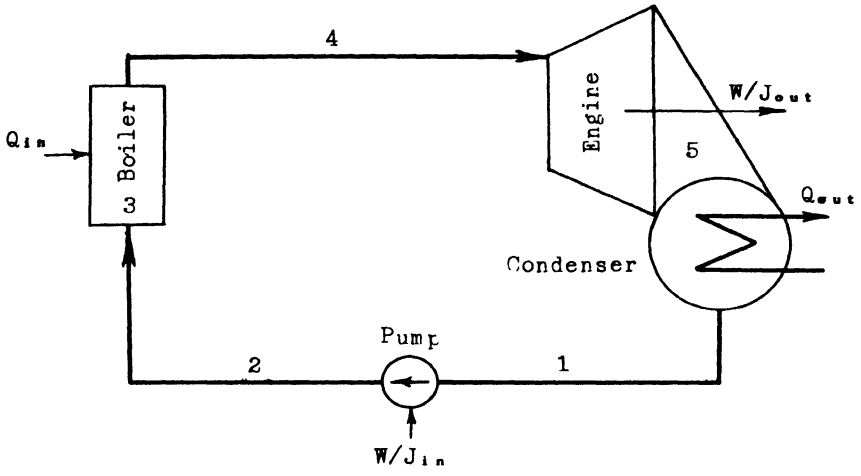


Fig. IV-3. Rankine cycle.

simple plants the cycle is open, that is, the condenser is absent and the steam is exhausted to the atmosphere at state 5. Sometimes part of the steam exhausted at state 5 in an open cycle is used to heat the feed-water going to the pump. This arrangement is shown in Figure IV-4.

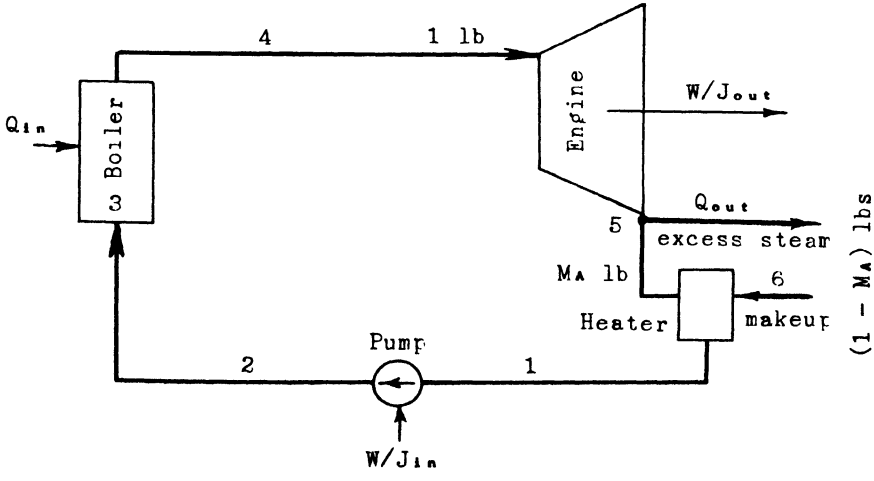


Fig. IV-4. Open Rankine cycle with feed-water heating.

The general energy equation of steady flow can be applied to each piece of equipment in the cycle and the various heat and work quantities determined, most conveniently on the basis of one pound of steam to the throttle of the engine.

For the closed Rankine cycle:

Pump:[1] $W/J_{in} = H_2 - H_1$

Boiler: $Q_{in} = H_4 - H_2 = H_4 - H_1 - (H_2 - H_1)$

Engine: $W/J_{out} = H_4 - H_{5_D}$

Condenser: $Q_{out} = H_{5_D} - H_1$

The efficiency of the cycle will be the net output divided by the input, or

$$e_{t_c} = \frac{H_4 - H_{5_D} - (H_2 - H_1)}{H_4 - H_1 - (H_2 - H_1)}$$

For the open Rankine cycle with feed-water heating:

Pump: $W/J_{in} = H_2 - H_1$

Boiler: $Q_{in} = H_4 - H_1 - (H_2 - H_1)$

Engine: $W/J_{out} = H_4 - H_{5_D}$

The preceeding relations are the same as for the closed Rankine cycle, but the fact that part of the exhaust steam is used for feed-water heating makes it necessary to introduce a weight term, M_A, to represent the amount of steam used for feed-water heating and to make an energy balance for the feed-water heater, as follows:

$$M_A (H_{5_D} - H_1) = (1 - M_A)(H_1 - H_6)$$

---

[1] For pressure rises in the pump of less than 300 lbs per sq in. the pump work terms may be neglected without appreciable error. For pressure rises greater than 300 lbs per sq in. the pump work can be determined from Table 4 of Thermodynamic Properties of Steam, by Keenan and Keyes.

$$M_{1A} = \frac{H_1 - H_6}{H_{5D} - H_6}$$

H_1 would ordinarily be unknown, but, from the conditions under which the cycle operates, it can be no greater than the enthalpy of saturated water at the exhaust pressure (atmospheric usually). Then as before,

$$e_{t_c} = \frac{H_4 - H_{5D} - (H_2 - H_1)}{H_4 - H_1 - (H_2 - H_1)}$$

This same sort of analysis could be applied to the open Rankine cycle without feed-water heating. The advantage of using part of the exhaust steam for feed-water heating can be seen if the expression for thermal efficiency is examined. With feed-water heating H_1 will be greater, thereby causing a decrease in the value of the denominator with a resulting increase in efficiency. In addition, less makeup water would be required.

23. Engine Efficiency--The ratio of the actual work energy removed from a pound of steam in the engine to the amount that could be removed in an adiabatic expansion is known by several names: *engine efficiency, Rankine cycle efficiency ratio,* and *Rankine cycle ratio*. The preferred name, however, is engine efficiency. The mathematical relation (referring to Figure IV-2) is:

$$e_e = \frac{H_4 - H_{5D}}{H_4 - H_{5a}}$$

The engine efficiency can be determined directly for steam engines because it is possible to follow the path of the steam expansion with an engine indicator and to determine the power delivered to the piston. In this case,

$$e_e = \frac{2545}{S_i(H_4 - H_{5a})}$$

where: S_i = steam rate, lbs/indicated hp-hr

In the case of the steam turbine, it is difficult to determine the engine efficiency because the path of the expansion cannot be followed completely and the mechanical efficiency cannot be determined easily. Therefore, the term

overall engine efficiency, which is the product of engine efficiency and mechanical efficiency (and generator efficiency, if electrical output is measured) is employed. In this case,

$$e_{e_o} = \frac{2545}{S_{,s}(H_4 - H_{5a})}$$

where: $S_{,s}$ = steam rate, lbs/shaft hp-hr

It should be pointed out here that the steam rate has significance in the above equations only for engines or turbines operating on the Rankine cycle where all of the steam passes completely through the engine or turbine. In other cases the steam rate is of value only in comparing similar cycles or for checking day to day performance of a particular machine.

24. Reheating Cycle--This cycle was proposed by Ferranti as a means of improving the efficiency of the Rankine cycle for real engines. It is a characteristic of real engines and turbines that the engine efficiency is greater in the region of superheat than in the region of mixtures. The ideal reheating cycle is intended to cause a greater portion of the expansion to take place in the region of superheat where the enthalpy drop between any two pressures is greater than the enthalpy drop in the region of mixtures between the same two pressures. This difference is slight, however, and results in very insignificant gains in thermal efficiency for the ideal cycle. The opposite is true for the real reheating cycle, and very significant gains are made as a result of the improved engine efficiency. Figure IV-5 shows the reheating cycle on the T-S and H-S planes, and Figure IV-6 shows a schematic diagram of the cycle.

The reheating of the steam may be done in one of three ways: (a) Using steam from the boiler in a heat exchanger; (b) using a separate reheating furnace; or (c) using a reheater built into the boiler gas passages. The reheating cycle utilizing the first method of reheating has very little advantage, if any, over the Rankine cycle due to thermal losses in the reheating system. The second method has thermodynamic advantages over the first method, but requires considerable additional investment in fuel burning equipment, etc. The third method has both thermodynamic and economic advantages over the first method.

The cycle can be analyzed as follows:

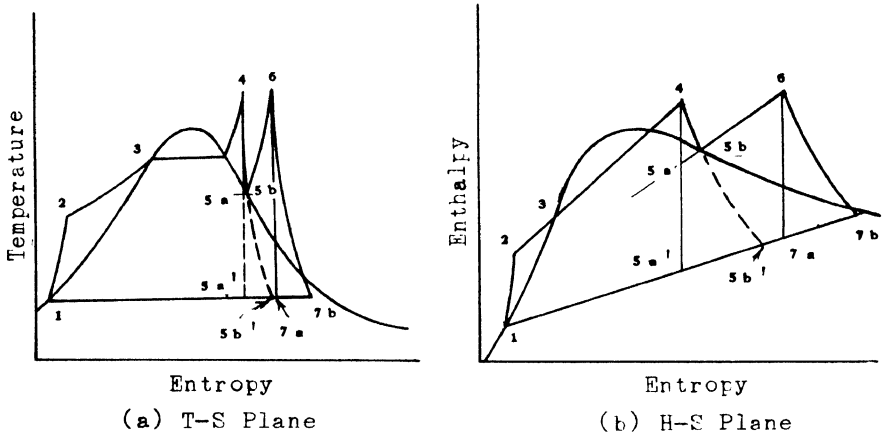


Fig. IV-5. Reheating cycle.

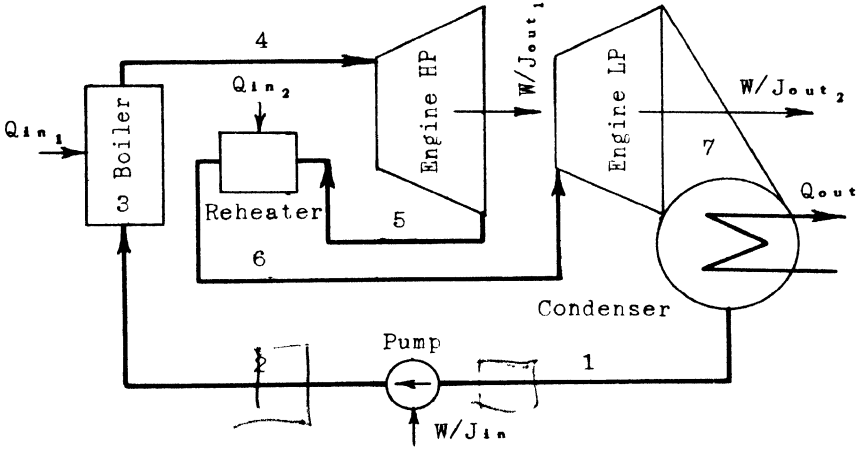


Fig. IV-6. Reheating cycle.

Pump: $W/J_{in} = P_2 - H_1$

Boiler: $Q_{in_1} = H_4 - H_1 - (H_2 - H_1)$

Engine H.P.: $W/J_{out_1} = H_4 - H_{5b}$

Reheater: $Q_{in_2} = H_6 - H_{5b}$

Engine L.P.: $W/J_{out_2} = H_6 - H_{7b}$

Condenser: $Q_{out} = H_{7b} - H_1$

$$e_{t_c} = \frac{H_4 - H_{5b} + H_6 - H_{7b} - (H_2 - H_1)}{H_4 - H_1 + H_6 - H_{5b} - (H_2 - H_1)}$$

25. Regenerative Cycle--This cycle was proposed by Prof. J. H. Cotterill in 1890, and depends for its improvement in thermal efficiency over the Rankine cycle upon the use of part of the steam from the engine, after it has done some work, to heat feed-water going to the boiler. The regenerative cycle is similar to the open Rankine cycle with feed-water heating except for the addition of the condenser to carry the expansion down to lower temperatures and to close the cycle. Figure IV-7 shows the regenerative cycle on the T-S and H-S planes, and Figure IV-8 (a) shows a schematic diagram of the cycle with two mixing (or open) heaters to correspond with Figure IV-7. Figure IV-8 (b) shows the modification of the schematic diagram and the lower part of the H-S plane that is necessary when the low pressure open heater is replaced by a closed (or surface) heater.

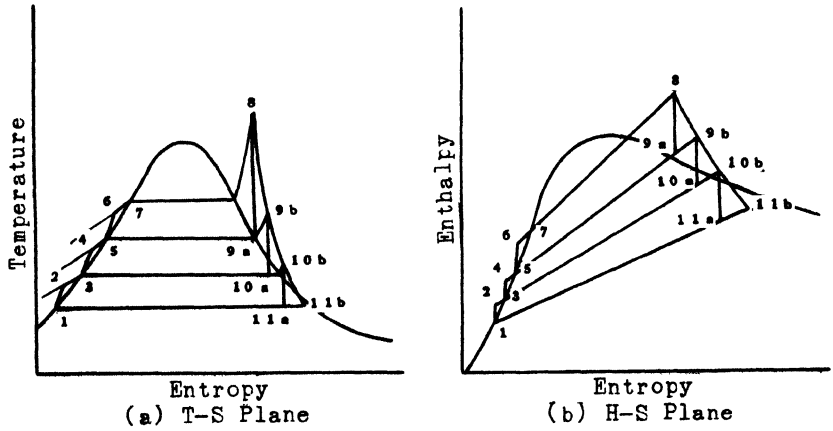


Fig. IV-7. Regenerative cycle.

R. L. Reynolds has given considerable data on the performance of regenerative cycles with various numbers of feed-water heaters, and Figure IV-9 shows some of his data which are used for the determination of the best final feed-water temperature. It will be noted that the curves in Figure IV-9 (a) are drawn for a standard throttle temperature of

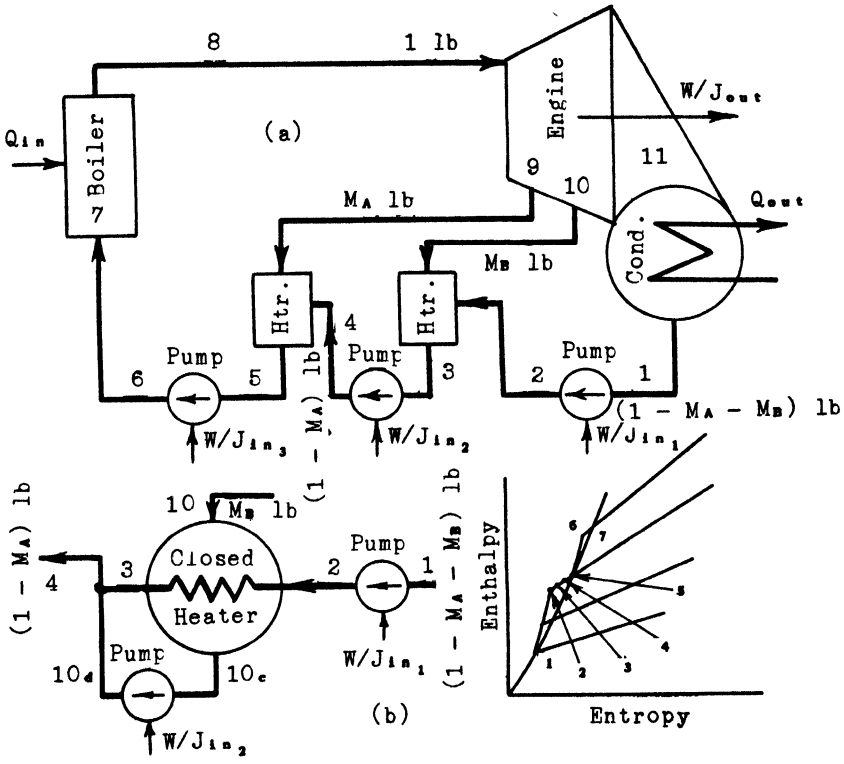


Fig. IV-8. Regenerative cycle.

750 F and a standard condenser vacuum of 29 inches of mercury. The effect of departure from these standards can be computed with the aid of the correction curves in Figures IV-9 (b) and IV-9 (c). It is customary to select the extraction pressures for feed-water heating so that the temperature rises in each heater are approximately equal. Ordinarily only one open heater is used in the modern regenerative cycle, so placed that the pressure in the heater is slightly above atmospheric at the minimum normal load.

The cycle can be analyzed as follows:

A. For two open heaters:

Pumps: $W/J_{in_1} = (H_2 - H_1)(1 - M_A - M_B)$

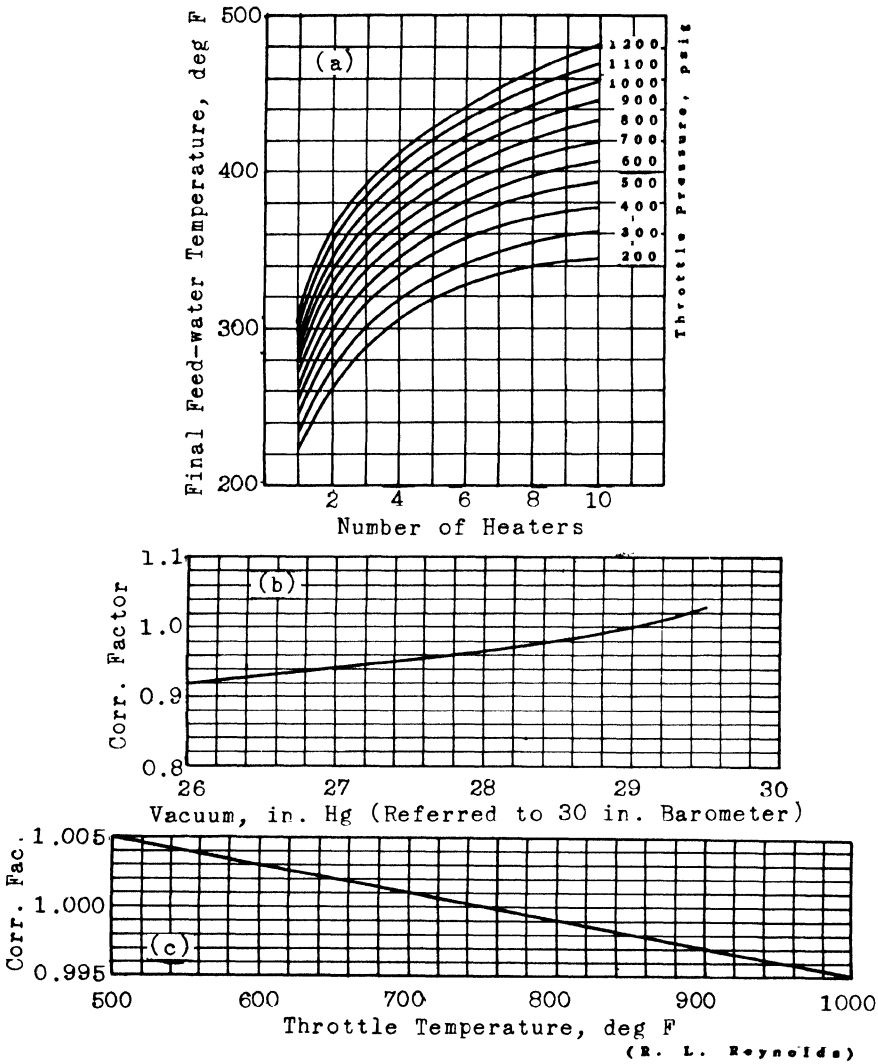


Fig. IV-9. Regenerative cycle feed-water temperatures.

$$W/J\,in_2 = (H_4 - H_3)(1 - M_A)$$

$$W/J\,in_3 = (H_6 - H_5)$$

Boiler: $Q_{in} = H_8 - H_5 - (H_6 - H_5)$

Engine: $W/J_{out} = H_8 - H_{9b} + (1 - M_A)(H_{9b} - H_{10b}) + (1 - M_A - M_B)(H_{10b} - H_{11b})$

Condenser: $Q_{out} = (1 - M_A - M_B)(H_{11b} - H_1)$

The extraction quantities can be determined by the use of energy balances for each feed-water heater, as follows:

$$M_A[H_{9b} - H_5] = [1 - M_A][H_5 - H_3 - (H_4 - H_3)]$$

$$M_B[H_{10b} - H_3] = [1 - M_A - M_B][H_3 - H_1 - (H_2 - H_1)]$$

The thermal efficiency is:

$$e_{t_c} = \frac{W/J_{out} - W/J_{in_1} - W/J_{in_2} - W/J_{in_3}}{Q_{in}}$$

B. For one high pressure open heater and one low pressure closed heater:

Pumps: $W/J_{in_1} = (H_2 - H_1)(1 - M_A - M_B)$

$W/J_{in_2} = (H_{10d} - H_{10c})(M_B)$

$W/J_{in_3} = (H_6 - H_5)$

Boiler: $Q_{in} = H_8 - H_5 - (H_6 - H_5)$

Engine: $W/J_{out} = H_8 - H_{9b} + (1 - M_A)(H_{9b} - H_{10b}) + (1 - M_A - M_B)(H_{10b} - H_{11b})$

Condenser: $Q_{out} = (1 - M_A - M_B)(H_{11b} - H_1)$

Extraction quantities:

$$M_A[H_{9b} - H_5] = [1 - M_A][H_5 - H_4]$$

$$H_4 = \frac{[1 - M_A - M_B][H_3] + [M_B][H_{10c} + (H_{10d} - H_{10c'})]}{[1 - M_A]}$$

$$M_B[H_{10b} - H_{10c}] = [1 - M_A - M_B][H_3 - H_1 - (H_2 - H_1)]$$

The addition of more stages of feed-water heating merely makes the mathematics more complicated. An energy balance for each feed-water heater and for each junction point where closed heater drip pumps discharge into the main condensate line will give sufficient equations to solve for all of the unknowns.

Modifications of the cycle are sometimes made in the minor details, such as disposal of the closed heater drips. Where closed heaters are placed in series, the drips may be cascaded counterflow to the condensate with a slight loss in thermodynamic efficiency, but with saving in installation and maintenance costs due to the elimiration of several pumps It is usual, however, to have at least one heater drip pump, located at the closed heater nearest to the condenser. Figure IV-10 shows the heat balance diagram for a modern high pressure regenerative cycle.

26. Reheating-Regenerative Cycle--The simple reheating cycle is no longer used in central station practice because greater efficiency gains can be realized by combining it with the regenerative cycle. In the last few years there have been several large stations built on this cycle using flue gas reheating. The reheating-regenerative cycle is generally considered to provide the ultimate improvement in efficiency over the Rankine cycle where only a single working fluid is concerned. The cycle analysis is made in the same manner as given for the two separate cycles. Figure IV-11 shows the heat balance diagram for a modern high pressure reheating-regenerative cycle.

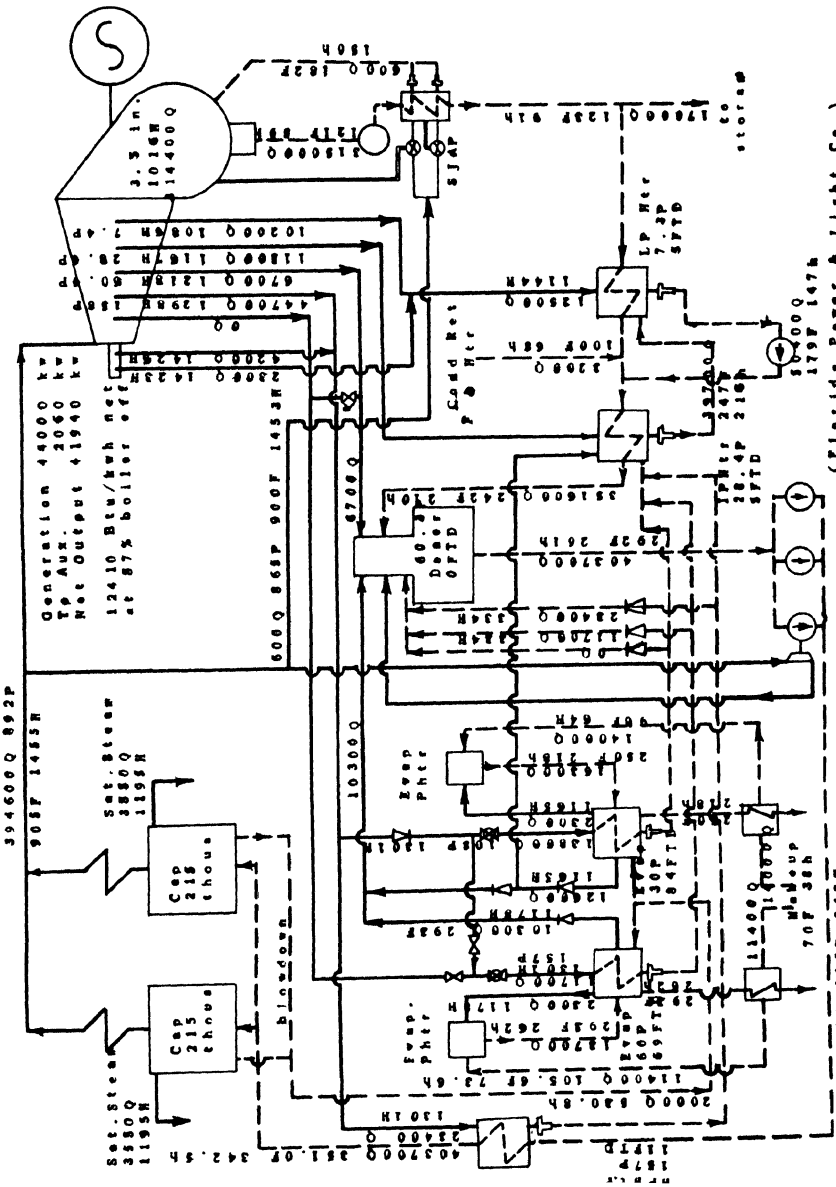
27. Field Cycle--This cycle was proposed by J. F. Field, of the British Electric Authority, in 1948. The cycle eliminates the boiler and depends upon vapor compression to bring the steam back to the saturation condition before superheating. The cycle is shown on the T-S and H-S planes in Figure IV-12, and a schematic diagram is shown in Figure IV-13. The unavailable energy is rejected in a small condenser called a "calorifier," and the condensate is returned to the system through a spray nozzle. Field has also shown modifications of the cycle which include reheating and regeneration.

The simple cycle can be analyzed as follows:

Pump: $W/J_{in_1} = .(M)(H_e - H_a)$

Compressor: $W/J_{in_2} = H_2 - H_{1_b}$

Superheater: $Q_{in} = H_3 - H_2$


Generation 44000 kw
Tp Aux. 2060 kw
Net Output 41940 kw
12410 Btu/kwh net
at 87% boiler eff
600Q 868P 900F 1453H
394600Q 892P
905F 1453H
Sat. Steam
385Q
1195H
Cap 215 thous
Cap 215 thous
Sat. Steam
385Q
1195H
blowdown
342.5h
Evap Phtr
Evap. Phtr
Load Ht Phtr
LP Htr
7.3p
97FD
TP Htr
28.4p
97FD
40.8p Deaer 0FFD
Make-up
70F 38h
(Florida Power & Light Co.)
Fig. IV-10. Heat balance diagram for Miami Steam Electric Station.

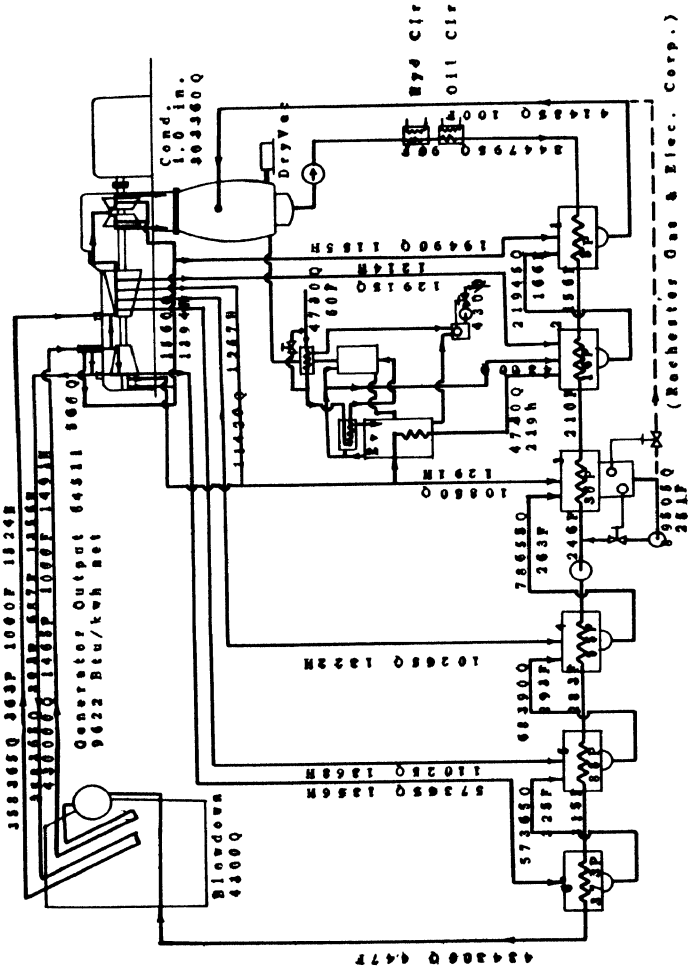


Fig. IV-11. Heat balance diagram for Russell Station.

Engine: $$W/J_{out} = H_3 - H_{4b}$$

Calorifier flow:

$$[1 - M][H_{4b} - H_{1b}] = M[H_{1b} - H_5 - (H_6 - H_5)]$$

$$e_{t_c} = \frac{H_3 - H_{4b} - H_2 - H_{1b} - M(H_6 - H_5)}{H_3 - H_2}$$

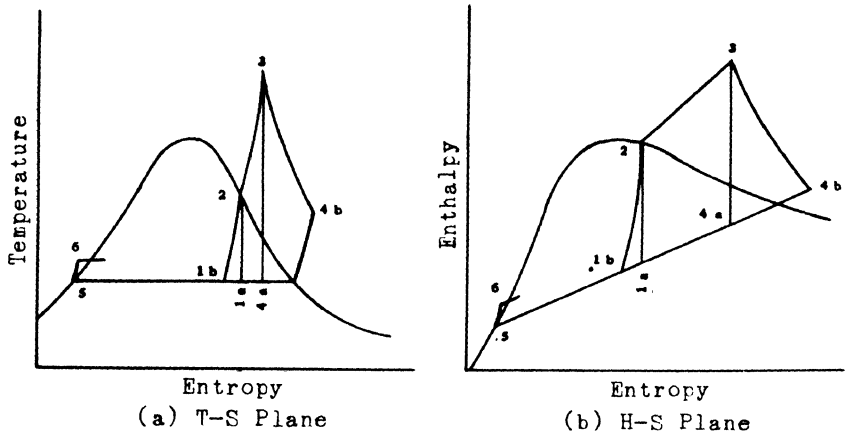


Fig. IV-12. Field cycle.

The theoretical advantages of this cycle are such as to make the efficiency much greater than that of the reheating-regenerative cycle because only a small portion of the steam flowing is condensed to water, The practical disadvantage, however, is the large amount of the output of the engine which is returned to the compressor. The cycle is similar to the gas turbine cycle in this respect (see Chapter XIX), and for all practical purposes is a closed gas turbine cycle using steam instead of air as the working fluid.

28. Superposed Cycle--The superposed (sometimes called "topping") cycle was developed during the depression of the 1930's to allow the addition of capacity without the necessity for building complete new plants. The cycle is a compound arrangement in which new high pressure boilers, replacing obsolete low pressure boilers, supply steam to a new high pressure turbo-generator which exhausts to the existing low pressure turbo-generators. The low pressure turbo-generators are rehabilitated to give additional useful life. This type of additional capacity can be installed for about one-half the cost of a complete new plant of the same capacity. The upper portion of the cycle is shown on the H-S plane in Figure IV-14, and a schematic diagram is shown in Figure IV-15. To date, superposition has been practiced only on regenerative cycles.

The cycle can be analyzed in the usual manner, remembering that the condition of the steam at state 10_b (the exhaust of the high pressure turbine) must be identical with

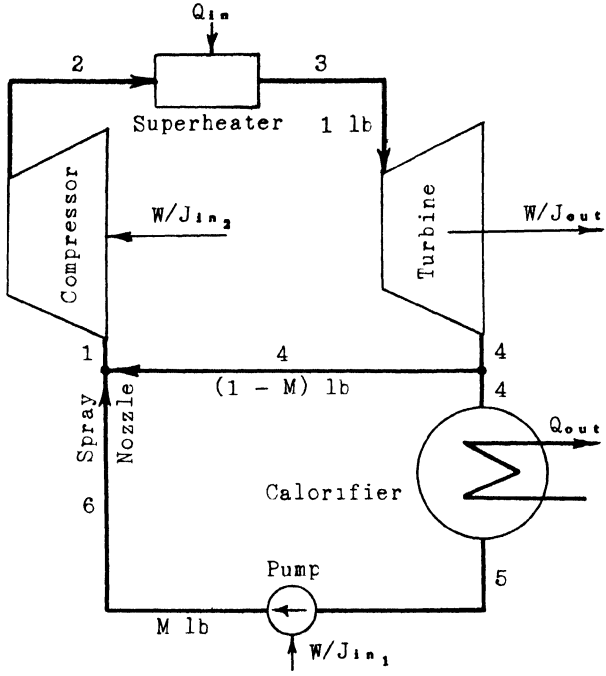


Fig. IV-13. Field cycle.

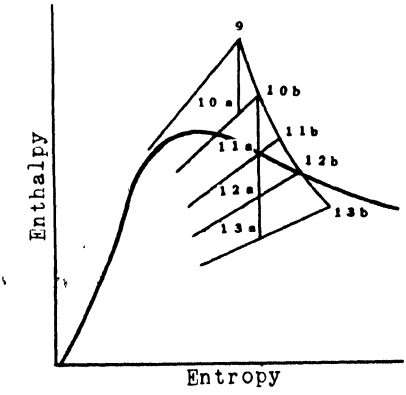


Fig. IV-14. Superposed cycle.

the specified conditions for the throttle of the old low pressure turbines. It will be seen that the high pressure turbine must pass large weights of steam, but the initial and final specific volumes are small enough to make the actual physical size of the high pressure turbine rather small in comparison with that of the low pressure turbines.

Perhaps the most important calculations in the superposed cycle have to do with the determination of the additional power produced by the

high pressure turbine. The heat balance of the regenerative cycle upon which the high pressure system is superimposed is already known, and it is only necessary to consider the effect of the superposition upon the complete system, as follows:

Additional pump work:

$$W/J_{in_{add}} = (H_6 - H_5)_{p_9} - (H_6 - H_5)_{p_{10}}$$

Additional engine work:

$$W/J_{out_1} = H_9 - H_{10_b}$$

State 10_b is known, but in order to determine state 9 the engine efficiency of the superposed turbine and the approximate amount of power required from it must be known. In general, a superposed turbine produces about one-third as much power as the low pressure turbines which it supplies with steam. Then, if M is the total steam flow in pounds per hour required for the low pressure turbines, and kw is the output of the low pressure turbines,

$$e_e = \frac{H_9 - H_{10_b}}{H_9 - H_{10_a}} = \frac{3413(kw)}{3M(H_9 - H_{10_a})}$$

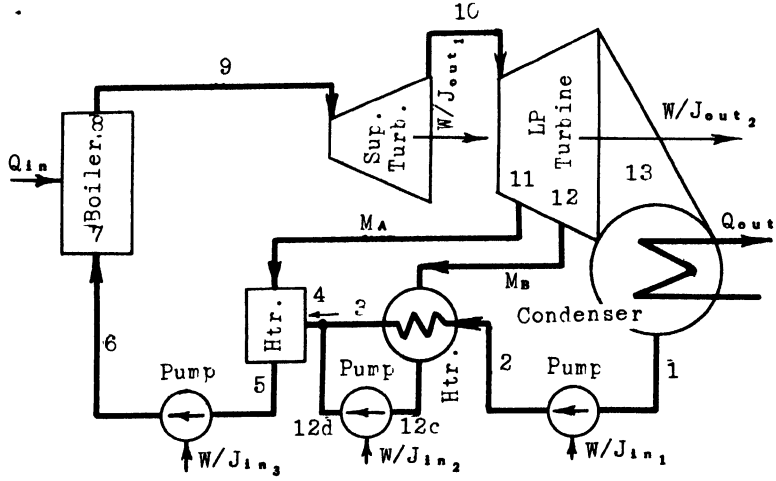


Fig. IV-15. Superposed cycle.

The two enthalpies, H_9 and H_{10a}, will serve to locate the pressure and temperature to the throttle of the superposed turbine, as a first approximation. A standard temperature and pressure nearest to the calculated requirement is selected and then the heat balance is adjusted accordingly. If steam is extracted from the superposed turbine for feed-water heating, the heat balance and throttle flow

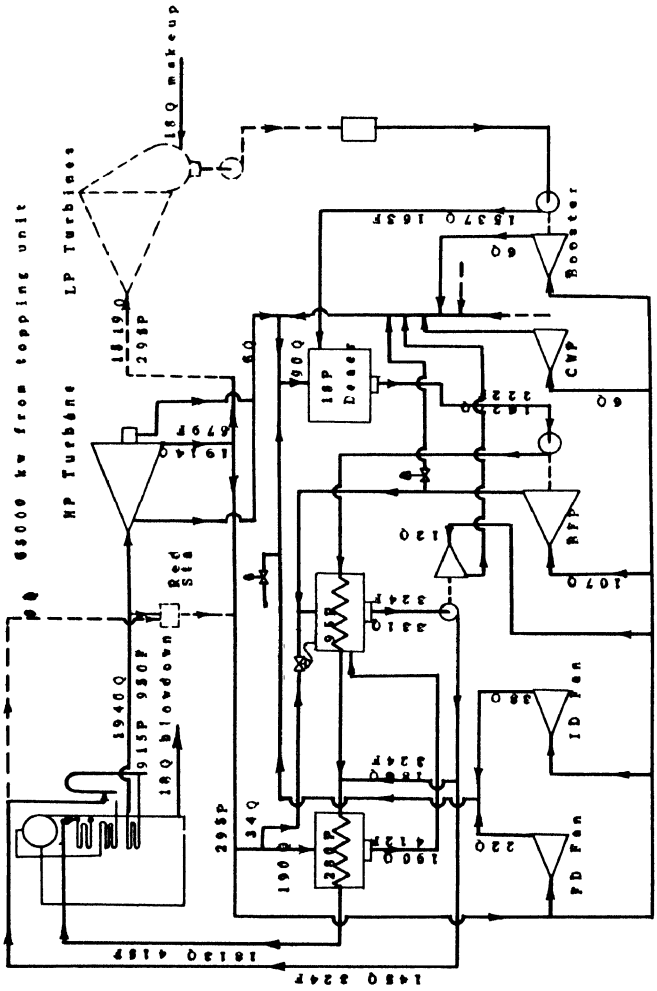


Fig. IV-16. Heat balance diagram for Hell Gate Station.

are further adjusted. Figure IV-16 shows the heat balance diagram for a modern superposed installation.

29. Binary Cycles--Some years ago it was realized that progress in increasing the efficiency of vapor power cycles was being retarded by the thermodynamic disadvantages of steam in the higher temperature ranges. That is, extremely high pressures are required for high initial temperatures so that the condition of the steam at the end of expansion in the engine will be within a range that can be economically handled. This limitation led to the development of the mercury-steam binary cycle. Mercury has the advantage of requiring much lower pressures for higher temperatures than does steam.

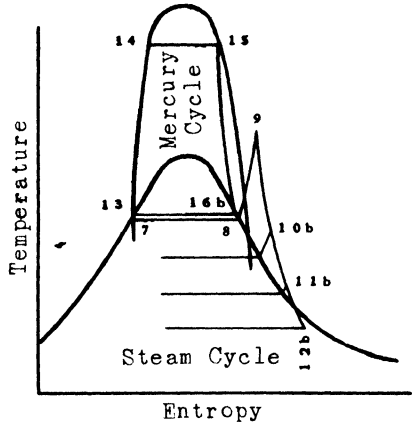


Fig. IV-17. Mercury-steam binary cycle.

The mercury-steam binary cycle utilizes the latent heat of condensation of the mercury to generate steam. Figure IV-17 shows the cycle on the T-S plane, and Figure IV-18 shows a schematic diagram of the cycle. Figure IV-19 is a Mollier diagram for mercury vapor.

The cycle can be analyzed in two parts on the basis of one pound of each fluid, and then combined into the binary cycle, as follows:

$$\frac{[\text{lbs Hg}]}{[\text{lbs } H_2O]} = \frac{H_8 - H_5 - (H_6 - H_5)}{H_{16b} - H_{13}}$$

$$W/J_{net_c} = W/J_{H_2O_{net}} + W/J_{Hg}\frac{[\text{lbs Hg}]}{[\text{lbs } H_2O]}$$

$$Q_{in_c} = Q_{in_1} + Q_{in_2}\frac{[\text{lbs Hg}]}{[\text{lbs } H_2O]}$$

$$e_{t_c} = \frac{W/J_{net_c}}{Q_{in_c}}$$

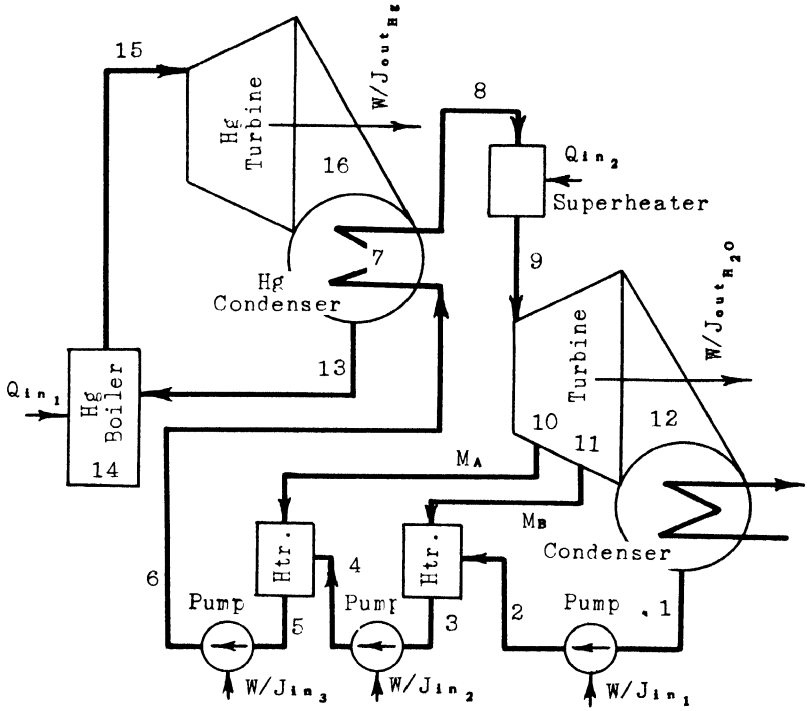


Fig. IV-18. Mercury-steam binary cycle.

An interesting feature of the mercury cycle is the absence of a mercury pump. The mercury turbire and condenser is placed on an elevation above the mercury boiler, and the difference in density between liquid and vapor is sufficient to feed the boiler. One problem that has slowed down the acceptance of the mercury-steam binary cycle is that of sealing in the highly toxic mercury vapors. However, this difficulty has been overcome satisfactorily and a complete plant is presently being built in New England.

Other binary cycles have been proposed which use steam as the upper fluid followed by sulphur dioxide, petroleum ether, butane or propane. The disadvantages of these cycles lie in the undesirable properties of steam at higher temperatures and in the toxicity and inflammability of some of the secondary fluids proposed. The advantage, however, is in the fact that both engines exhaust at pressures above atmospheric, thus elimirating the necessity for a vacuum pump

on the condenser. There is little, if any, gain in thermal efficiency over the straight steam cycle.

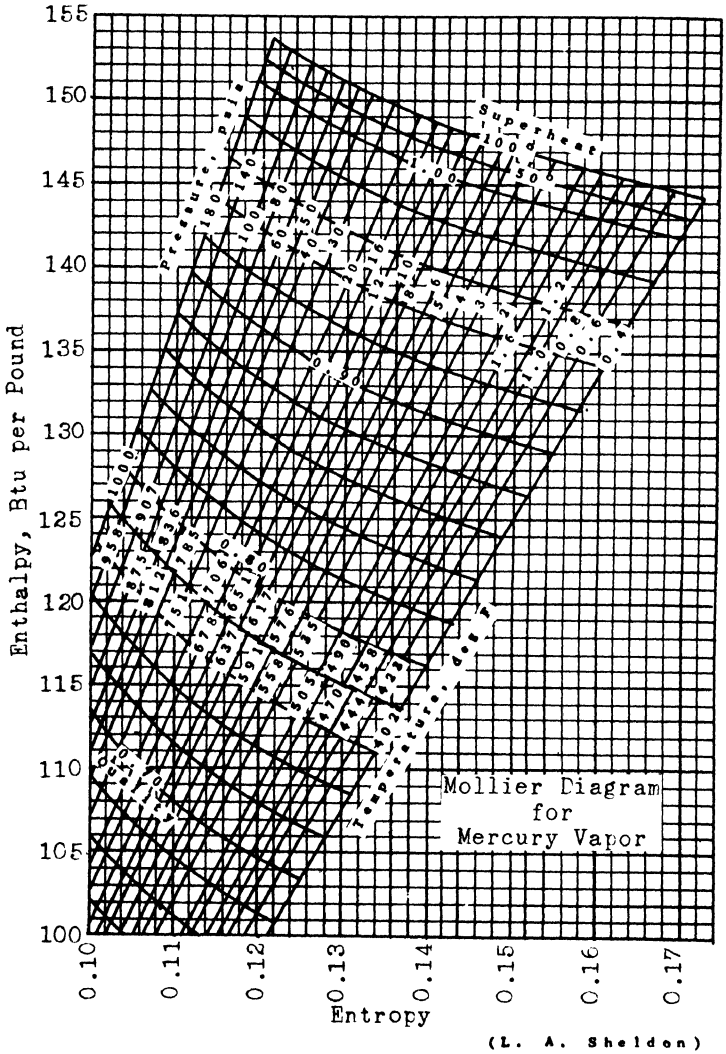


Fig. IV-19. Mollier diagram for mercury vapor.

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CHAPTER V

PRIME MOVERS

30. The only prime movers used in vapor power cycles are engines or turbines. The engine is a reciprocating device which utilizes both pressure and expansion energy of the steam, while the turbine is a rotating machine which utilizes only the expansion energy of the steam.

Steam engines in sizes below 500 hp are more efficient than steam turbines and find their greatest application where variable speed and exhaust steam for process use is required. Steam turbines have replaced steam engines in sizes over 500 hp, principally because of their compactness and higher efficiency.

31. Steam Engines--The steam engine became a practical reality in the 1600's, and after improvements by Newcomen and Watt, and many others, reached the peak of its growth and use in the early 1900's. Engine sizes reached 25,000 hp on a single shaft with four cylinder triple expansion machines for driving battleships. As previously mentioned, however, the steam engine is finding its field limited to small sizes. It appears that the steam engine on the railroads is also doomed to obsolescence. The American Locomotive Company, which built steam locomotives for 100 years, recently announced that its entire production in the future would be confined to Diesel-electric equipment.

The principal types of engine remaining in use today are divided into two general classifications, counterflow and uniflow, depending upon the location of the main exhaust ports with relation to the stroke of the piston. The classifications are further subdivided as to valve types, whether slide, rotary or poppet. It can be said, in general, that the uniflow engine is more efficient than the counterflow engine because of reduced thermal losses resulting from the avoidance of alternate heating and cooling of the cylinder. Rotary and poppet valve engines are more efficient than slide valve engines. The rotary and poppet valves reduce losses by avoiding the throttling of steam at the intake and exhaust. Figures V-1 and V-2 show two common types of steam engine.

The mechanical efficiency of a steam engine can be determined directly if the output horsepower (usually called brake horsepower because some form of brake or dynamometer is used for its measurement) and input horsepower (called indicated horsepower because an engine indicator is used

for its determination) are known. Figure V-3 shows one type of brake used to determine engine output, and Figure V-4 shows an engine indicator with a diagram (or card) drawn by it. If the constants of the brake, engine and indicator are known, the following equations will give the required information:

$$Bhp = \frac{2\pi FLN}{33000}$$

where: F = net force exerted by brake, lbs.
L = length of brake arm, ft.
N = speed of engine, rpm.

$$Ihp = \frac{P_{m_h} L A_h N}{33000} + \frac{P_{m_c} L A_c N}{33000}$$

where: P_{m_h} and P_{m_c} = mean effective pressures exerted on the head and crank ends of the piston, lbs /sq in.
L = length of piston stroke, ft.
A_h and A_c = effective piston area of head and crank ends, sq in.
N = speed of engine, rpm.

$$P_m = \frac{A_d S}{L_d}$$

where: A_d = area of indicator diagram, sq in.
L_d = length of indicator diagram, in.
S = scale of indicator spring, lbs/sq in./in.

$$e_m = \frac{Bhp}{Ihp}$$

The mechanical efficiency of steam engines is high, and the shape of the efficiency vs load curve depends primarily upon the valve type, as can be seen in Figure V-5. Engire efficiencies are moderately high and depend primarily upon the flow direction within the cylinder, as shown in Figure V-6.

32. Estimation of Steam Engine Dimensions-- In preliminary calculations for engine plants it is necessary to estimate the dimensions of the engine. This estimation is based on empirical data as to piston speeds and departure from the ideal expansion in the engine.

The approximate work obtained from the engine can be obtained from consideration of the ideal indicator diagram with the application of a diagram factor to allow for the effects of compression and the departure of the expansion from the adiabatic.[1] Figure V-7 shows the ideal indicator diagram with a realized diagram superimposed. From the ideal diagram:

Net area = net work

$$= P_1V_1 + P_1V_1 \log_e \frac{V_2}{V_1} - P_2V_2$$

V_2/V_1 is called the expansion ratio, R. It can be seen from the diagram that the larger the value of R, the larger the proportion of the total work done by the expansion of the steam. One method of governing the output of a steam engine is to vary the expansion ratio. For purposes of estimation for full load, R is usually taken as being between three and four. Making the substitution for R,

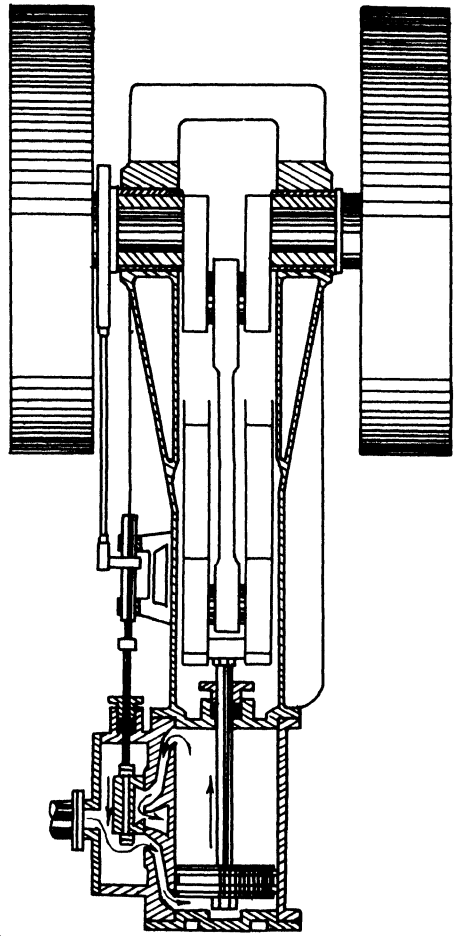


Fig. V-1. Counterflow steam engine with D slide valve.

---

[1] For simplicity, the derivation of the ideal diagram area assumes that the expansion is isothermal.

$$\frac{\text{Net work}}{V_s} = P_m = [(P_1/R)(1 + \log_e R) - P_2]F_d$$

where: P_m = mean effective pressure, lbs/sq in.
P_1 and P_2 = throttle and exhaust pressure, respectively, lbs/sq in abs.
R = expansion ratio
F_d = a diagram factor depending on the type of engine (Table IV)

The engine dimensions are affected by the rotational speed and the allowable piston speed, as shown in Table IV.

Example 6 shows the method of estimating steam engine dimensions by use of the preceeding information.

Example 6.

Determine the approximate dimensions of a single cylinder double-acting uniflow steam engine to develop 250 bhp at 200 rpm.

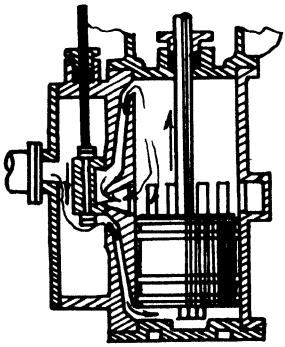


Fig. V-2. Uniflow steam engine cylinder with D slide valve.

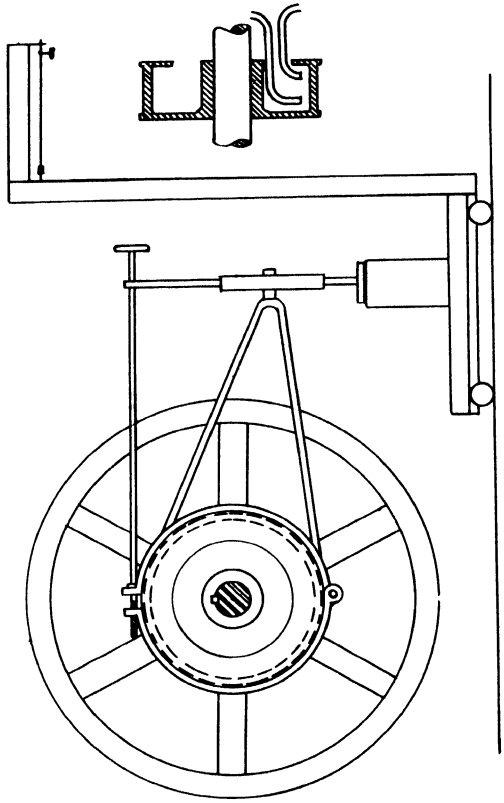


Fig. V-3. Prony brake.

Steam to the throttle is at 150 psig and saturated. Exhaust is at 3 in. Hg abs.

Solution:

From Figure V-5, the mechanical efficiency is found to be about 90 o/o, and from Table IV, the piston speed and diagram factor are estimated to be 750 fpm and 0.80 respectively. Taking the expansion ratio as 4,

$$P_m = [\frac{164.7}{4}(1 + \log_e 4) - 1.47][0.80] = 77.5 \text{ psi}$$

$$\text{Length of stroke} = \frac{750}{2(200)} = 1.875 \text{ ft} = 22.5 \text{ in.}$$

$$\text{Ihp} = \frac{250}{0.90} = 278 = \frac{77.5(1.875)(200)(2)A}{33000}$$

from which, A = 158 sq in. and d = 14.2 in.

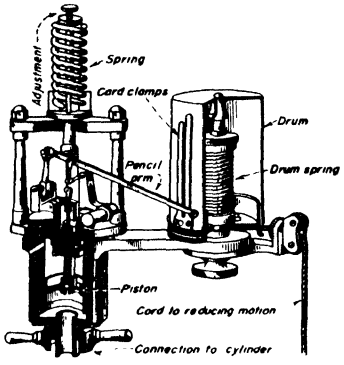
The required engine dimensions are 22½ in. X 14½ in. X 200 rpm.

TABLE IV

DESIGN DATA FOR STEAM ENGINES

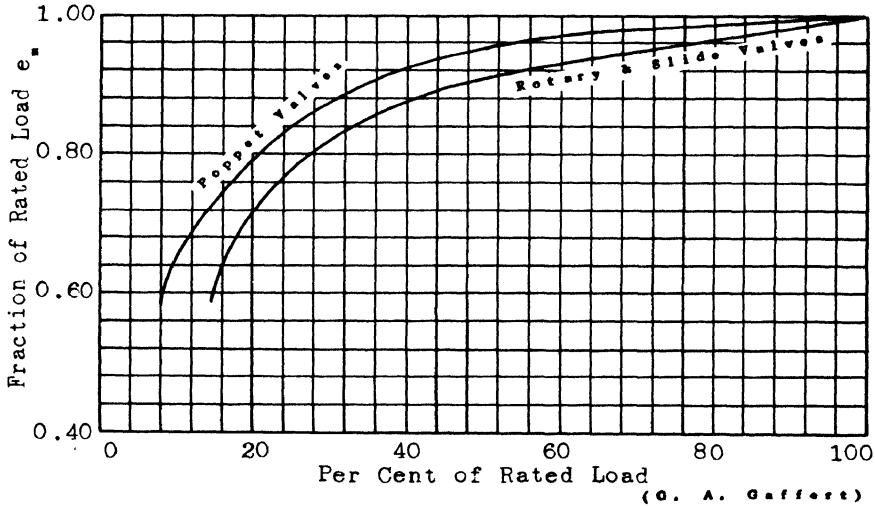
ROTATIONAL SPEEDS	
Counterflow engines	200 to 350 rpm
Uniflow engines	100 to 300 rpm
PISTON SPEEDS	
Counterflow engines	600 to 450 fpm
Uniflow engines	900 to 600 fpm
DIAGRAM FACTORS	
Counterflow engines	0.70 to 0.85
Uniflow engines	
Condensing	0.75 to 0.85
Non-condensing	0.70 to 0.80

Figure V-8 shows the approximate cost (based on 1936) of modern steam engine-generator sets.



(Power)

Fig. V-4. Engine indicator with diagram.



(C. A. Gaffert)

Type of engine	Full load e_m per cent
Four rotary valves	90 to 92
Uniflow	90 to 91
Slide valves (D or piston)	88 to 90

Fig. V-5. Mechanical efficiency of steam engines.

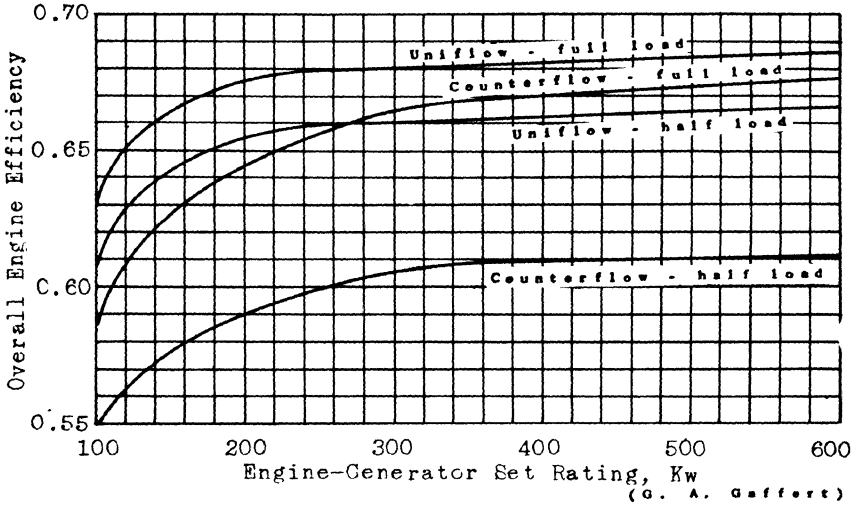


Fig. V-6. Engine efficiency of steam engines.

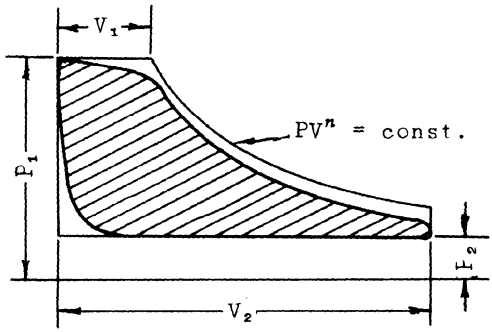


Fig. V-7. Ideal indicator diagram.

33. Steam Turbines--The steam turbine as we know it today has been developed from the machine invented by DeLaval in 1882 to run his cream separator. DeLaval's machine was of the single stage impulse type having an extremely high rotational speed. C. A. Parsons, an Englishman, invented the multistage reaction turbine; Rateau, a Frenchman, the pressure compounded impulse turbine; and C. G. Curtis, an American, the velocity compounded impulse turbine, all of which make it possible to reduce rotational speeds to reasonable levels.

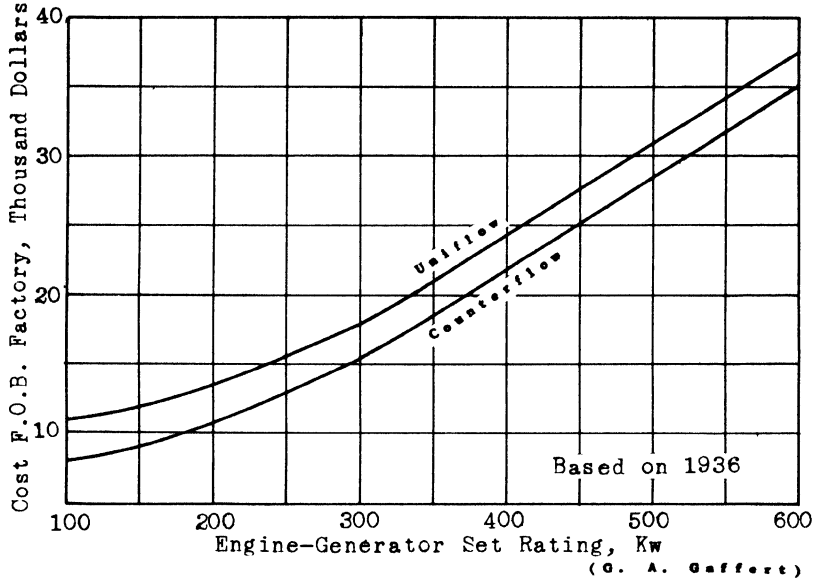


Fig. V-8. Cost of steam engine-generator sets.

The first commercial turbo-generator installations appeared around 1900, and were of the vertical type to conserve floor space. The largest vertical turbine, a 20,000 kw unit, was built in 1914, but shortly after its initial operation the horizontal turbine was introduced in order to eliminate troubles which had been experienced with thrust bearings in the vertical machines. By 1930 50,000 kw single cylinder machines had been built, but further increases in size required multi-cylinder cross or tandem compound arrangements. The largest cross compound unit in existence is a three cylinder 1800 rpm machine at State Line Station at Hammond, Indiana. This machine has a rated capacity of 208,000 kw, and consists of one high pressure and two low pressure cylinders with separate generators and steam reheating between high and low pressure cylinders. Manufacturers now are confining their production of compound machines to the tandem



Fig. V-9. DeLaval impulse stage.

type in capacities of from 40,000 to 100,000 kw and with speeds of 3600 rpm. The 3600 rpm machines are attractive because of their saving in space over the 1800 rpm machines.

All of the basic types of turbine are built in this country, and are more or less characteristic for the various manufacturers. Allis-Chalmers produces the Parsons reaction turbine; Westinghouse produces a combination machine, usually with one Curtis velocity compounded stage followed by Parsons stages; and General Electric makes what they call the Curtis turbine, but which at present is really a Rateau pressure compounded turbine, sometimes with an initial Curtis stage. DeLaval still builds the single impulse stage machine with reduction gearing. Figures V-9 through V-13 show the various types of staging, with pressure and velocity relations for the steam.

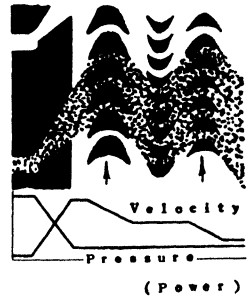


Fig. V-10. Curtis velocity compounded staging.

34. Engine Efficiencies and Willans' Line for Steam Turbines--Steam turbines for power plants are divided into two classifications: auxiliary or mechanical drive turbines, and turbines for generator drive.

Mechanical drive turbines are made in sizes from five to 2,000 hp and are used for driving fans, pumps, etc. They have from one to three velocity compounded stages and exhaust at a back pressure, ordinarily to the open heater in the feed-water system. They are not very efficient due to the small ratio of blade speed to jet velocity, but where process steam or steam for feed-water heating is required they can often be justified for continuous service. In other cases they are used for emergency service. Figure V-14 shows the variation in overall engine efficiency (including mechanical efficiency) for typical mechanical drive turbines.

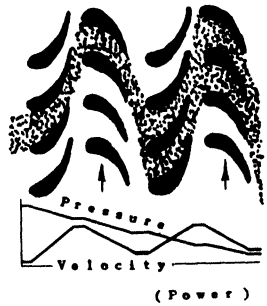


Fig. V-11. Parsons reaction staging.

Turbines for generator drive are made in sizes from 500 kw capacity upwards to a maximum of about 100,000 kw. All major manufacturers have adopted the A.S.M.E.-A.I.E.E. Standards for Turbo-Generators which are shown in Table V.

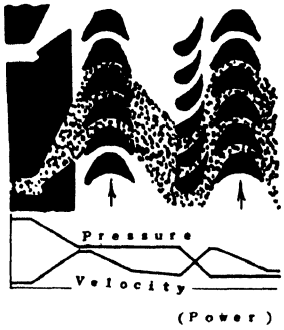


Fig. V-12. Rateau pressure compounded staging.

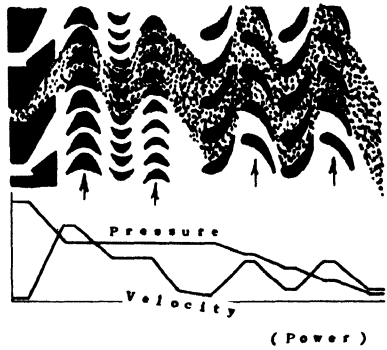


Fig. V-13. Curtis-Parsons staging.

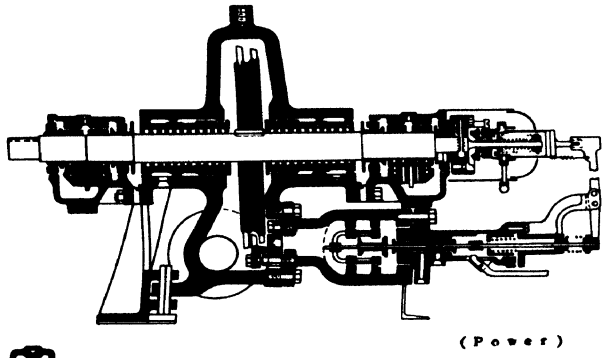
TABLE V

AIEE-ASME-STANDARDIZED TURBINE GENERATOR UNITS

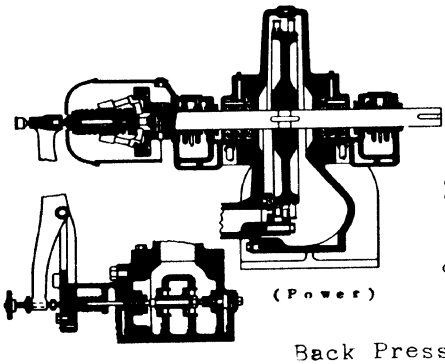
3600 rpm, 60 cycles, 3 phase

	Single-casing, Single-flow Turbine				Tandem-compound, Double-flow Turbine	
	Air-cooled Generator	Hydrogen-cooled Generator				
	11,500 Kw	15,000 Kw	20,000 Kw	30,000 Kw	40,000 Kw	60,000 Kw
Throttle pressure, lb gage	600	850	850	850	850 | 1250	850 | 1250
Throttle temperature, deg F	825	900	900	900	900 | 950	900 | 950
Exhaust pressure, in. Hg. abs.	1.5	1.5	1.5	1.5	1.5	1.5
Turbine capability, kw	12,650	16,500	22,000	33,000	44,000	66,000
Number of extraction openings	4	4	4	5	5	5
Saturation temperature at 1st	175	175	175	175	175	175
openings at turbine-gen- 2nd	235	235	235	235	235	235
erator ratings with all 3rd	285	285	285	285	285	285
extraction openings in 4th	350	350	350	350	350	350
service, deg F 5th	—	—	—	410	410	410
Generator kva						
Air-cooled generator	13,529	—	—	—	—	—
Hydrogen-cooled generator						
0.5 lb hydrogen pressure	—	17,647	23,529	35,294	47,058	70,588
15.0 lb hydrogen pressure	—	20,294	27,028	40,588	54,117	81,176
Power factor	0.85	0.85	0.85	0.85	0.85	0.85
Short-circuit ratio	0.8	0.8	0.8	0.8	0.8	0.8

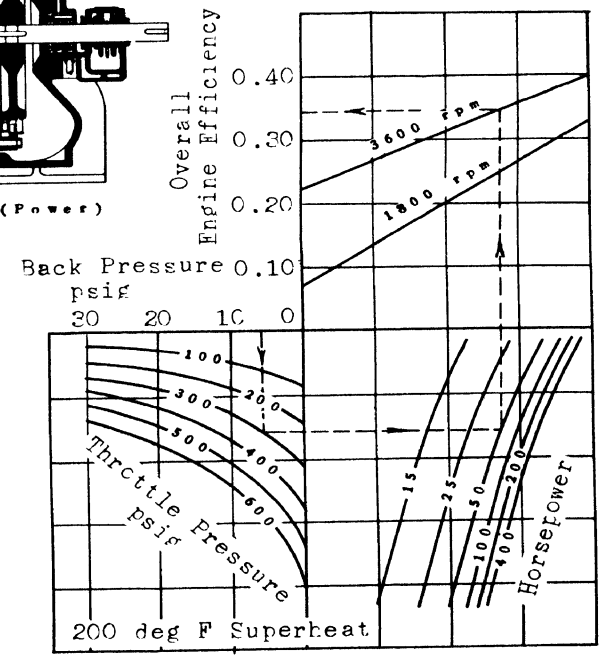
Figures V-15 and V-16 show the approximate overall engine efficiencies (including mechanical and generator efficiencies) to be expected from small turbo-generators, both condensing and non-condensing.



(Power)

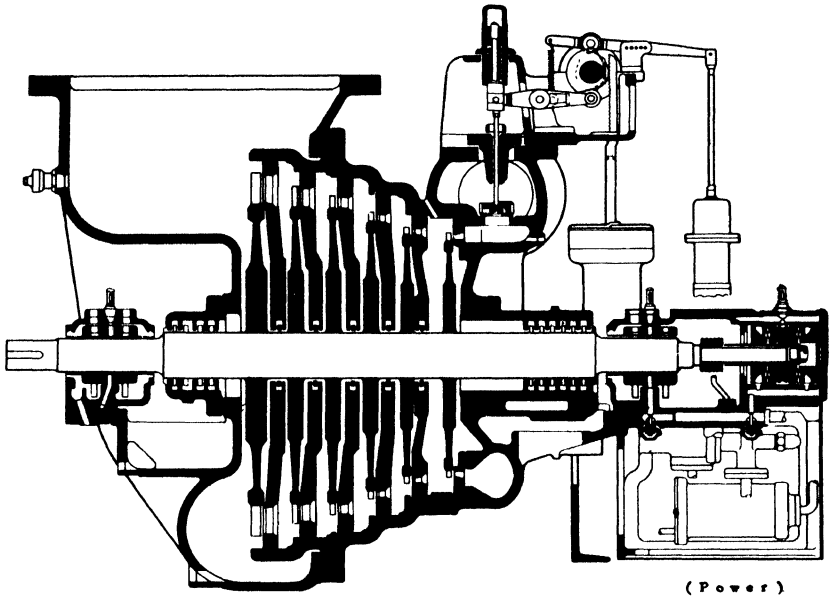


(Power)

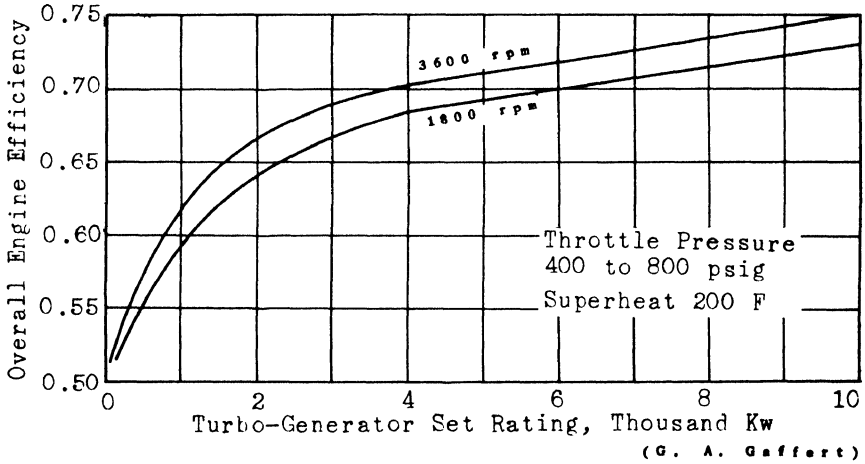


(G. A. Gaffert)

Fig. V-14. Mechanical drive turbines.



(Power)



(G. A. Gaffert)

Fig. V-15. Small condensing turbo-generators.

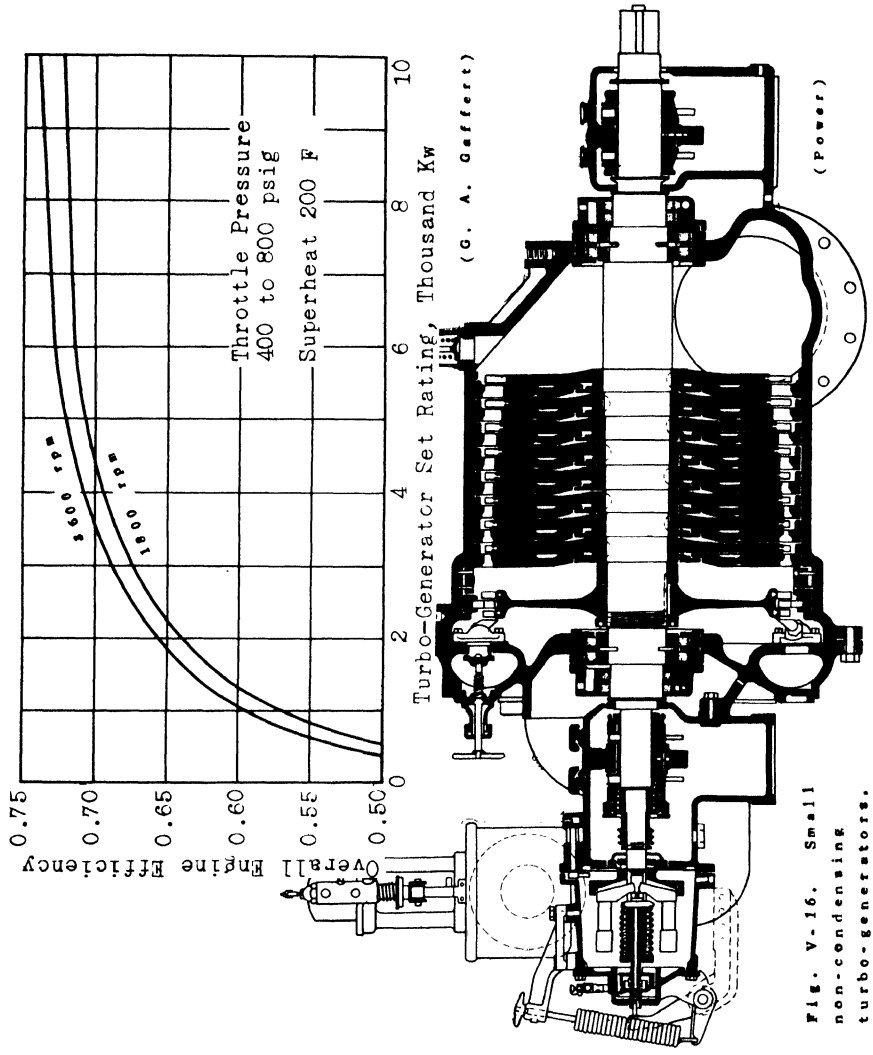
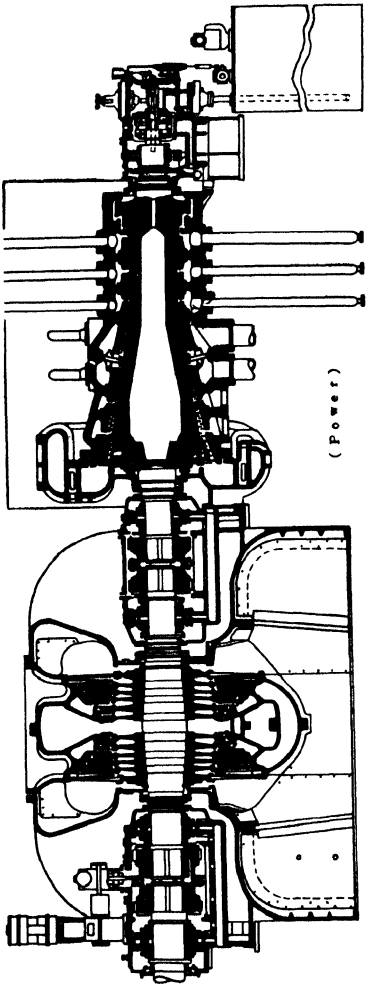


Fig. V-16. Small non-condensing turbo-generators.

Figure V-17 shows overall engine efficiency data for large condensing turbo-generators; Figure V-18 shows data for correcting engine efficiencies for part load operation; and Figure V-19 shows some turbo-generator cost data (based on 1945).



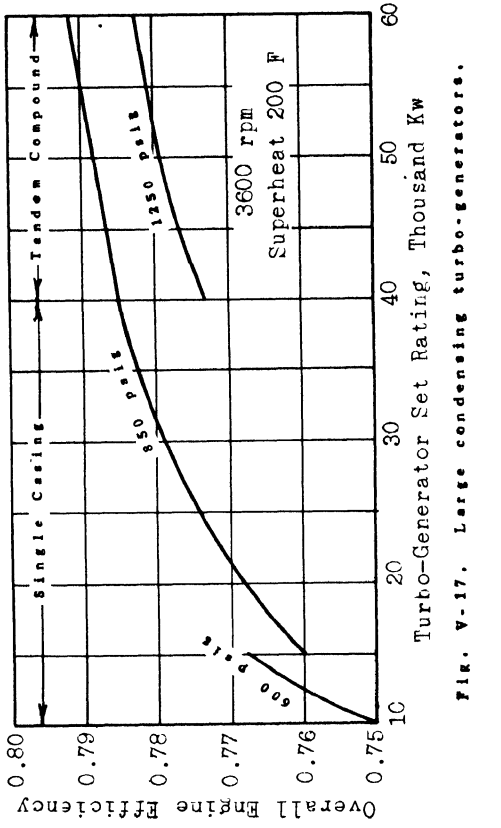


FIG. V-17. Large condensing turbo-generators.

Where it is necessary to estimate mechanical and generator efficiencies in order to predict the turbine expansion line, the following empirical formulae will be useful:

For 1800 rpm machines:

$$e_m = 1.00 - \frac{0.026(\text{Rating})}{\sqrt{\text{Rated kw}/1000}\ (\text{Load})}$$

$$e_g = 0.9885 - \frac{0.0685(\text{Rating})}{\sqrt[3]{\text{Rated kw}/1000}\ (\text{Load})}$$

For 3600 rpm machines: $e_m = 1.00 - \dfrac{0.04(\text{Rating})}{\sqrt{\text{Rated kw}/1000}\ (\text{Load})}$

$$e_g = 0.96 - \frac{0.019(\text{Rating})}{\sqrt[3]{\text{Rated kw}/1000}\ (\text{Load})}$$

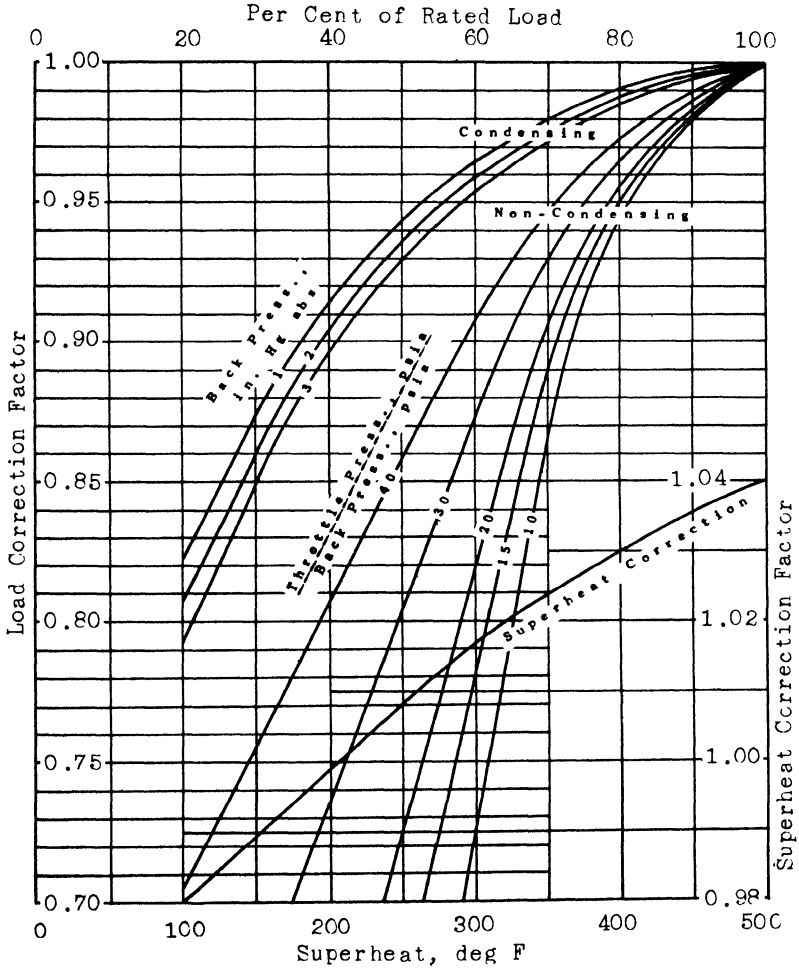


Fig. V-18. Engine efficiency correction factors for turbines.

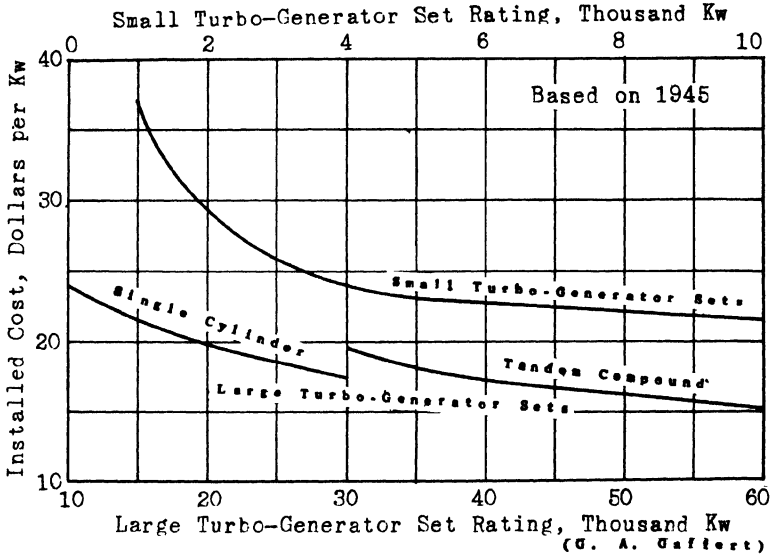


Fig. V-19. Turbo-generator cost data.

The likeness of a throttle-governed turbine to an orifice having the back pressure less than the critical makes it possible to predict extraction pressures at any partial load if they are known for any one load. It can be assumed, with very slight error, that the back pressure remains constant, and that the first stage and extraction absolute pressures will vary directly with load. With this relation it is possible to estimate part-load performance of a turbine, providing the expansion lines are known. The full load expansion line can be estimated quite closely, if the initial and final conditions are known, by referring to Figure V-20. Connect the initial and final steam conditions on the Mollier diagram by a straight line; move along the saturation line to point B which is 20 Btu per pound greater than point A, the intersection of the straight line with the saturation line. Connect the initial and final conditions with a smooth curve through point B so that the slope decreases gradually from the initial to the final conditions. The extraction conditions can then be located at the intersections of the pressure lines with the expansion lines. For part-load expansion lines, the curve will be of the same shape from the initial condition but with point X displaced to the right. A ship curve is excellent for drawing expansion lines.

The curve of
otal steam flow vs
itput for a turbine
s a straight line
alled *Willans'*
ine), and can be
stimated from engine,
echanical and gen-
ator efficiency
ata. The slope of
he line is constant
ily so long as a
ingle throttle valve
s employed. As add-
tional valves open
he slope becomes
teeper. Example 7
hows the method of
stimating Willans'
ine and the expan-
ion lines for a sin-
le valve turbine.

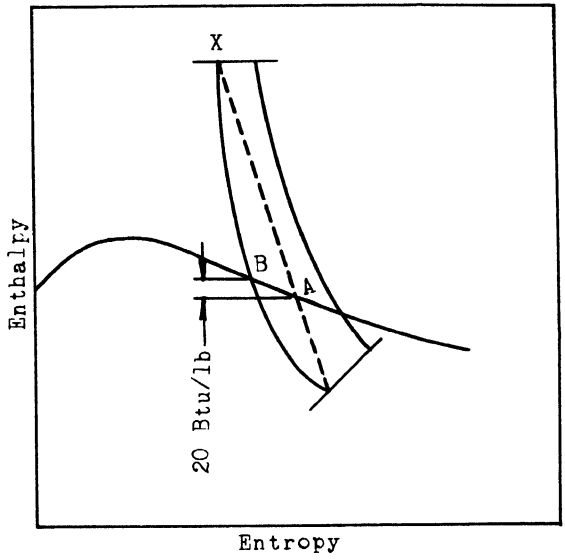


Fig. V-20. Estimating turbine expansion lines.

Example 7.

A 2500 kw turbo-generator operates at 3600 rpm with team to the throttle at 400 psig and 750 F and exhausts at in. Hg abs. Estimate the non-extraction Willans' line.

olution:

From Figure V-15, the full load overall engine effic-ency is estimated to be 0.68. From Figure V-18, the super-eat correction factor is found to be 1.017 (superheat 305F) nd the following table is made:

Load	Eng. eff. full load	supht. corr.	load corr.	corr. eng. eff.
Full	0.68	1.017	1.000	0.69
0.75	0.68	1.017	0.975	0.67
0.50	0.68	1.017	0.940	0.65
0.25	0.68	1.017	0.820	0.57

The expansion lines are drawn as in Figure V-21, and rom these lines the work output per pound of steam can be etermined as: full load, 320 Btu; 0.75 load, 298 Btu; 0.50 oad, 274 Btu; and 0.25 load, 216 Btu. From these work out-

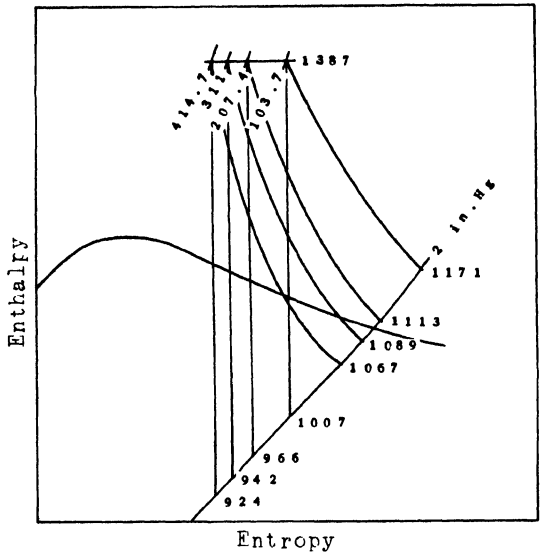


Fig. V-21. Turbine expansion lines for Example 7.

puts, the steam flows to the throttle at the various loads can be computed from the relation:

$$\text{Throttle flow, lbs/hr} = \frac{3413(2500)(\text{load frac.})}{\text{Work, Btu/lb}}$$

Flows from this relation are: Full load, 26700 lbs/hr; 0.75 load, 21450 lbs/hr; 0.50 load, 15600 lbs/hr; and 0.25 load, 9880 lbs/hr. Willans' line is plotted in Figure V-22.

Note: The expansion lines in Figure V-21 are "apparent" or based on the overall engine efficiencies. For the true expansion lines which give the actual enthalpies of the steam to the condenser, see Example 8.

Example 8 shows the method of calculating the approximate heat balance for a regenerative cycle using the steam turbine of Example 7.

Example 8.

The turbo-generator of Example 7 is placed in a regenerative cycle. One closed heater is used with the extraction point in the turbine located so that the extraction pressure

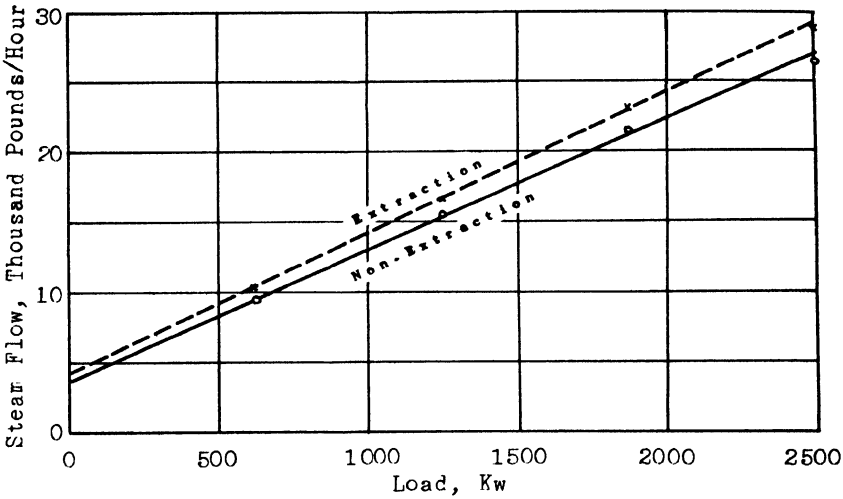


Fig. V-22. Willans' lines for Examples 7 and 8.

is 5 psia at 0.25 load. One open heater is placed in the cycle so that the extraction pressure is 16 psia at 0.25 load. The arrangement is similar to that in Figure IV-8(b). Neglect pump work. Make a heat balance and estimate the extraction Willans' line.

Solution:

The expansion lines and engine efficiencies of Example 7 were on the overall basis. In order to estimate the extraction performance it is necessary to estimate the mechanical and generator efficiencies and to replot the expansion lines.

$$e_m = 1.00 - \left[\frac{0.04(\text{rating})}{\sqrt{2500/1000}\ (\text{load})}\right]$$

$$e_g = 0.96 - \left[\frac{0.019(\text{rating})}{\sqrt{2500/1000}\ (\text{load})}\right]$$

Load	overall eng. eff.	mech. eff.	gen. eff.	internal eng. eff.
Full	0.69	0.975	0.946	0.749
0.75	0.67	0.966	0.941	0.737

Load	overall eng. eff.	mech. eff.	gen. eff.	internal eng. eff.
0.50	0.65	0.949	0.932	0.735
0.25	0.57	0.899	0.904	0.702

The expansion lines are plotted in Figure V-23 and the extraction enthalpies determined, remembering that the extraction pressures are directly proportional to load. The following table is set up to aid in the calculation of extraction quantities:

Load	H_1	H_{10_c}	H_3	H_5	H_8	H_{9_b}	H_{10_b}	H_{11_b}
Full	69.0	196.2	190.2	266.4	1387	1224	1150	1040
0.75	69.0	181.1	175.1	247.5	1387	1240	1169	1059
0.50	69.0	161.2	155.2	222.6	1387	1245	1175	1077
0.25	69.0	130.1	124.1	184.4	1387	1262	1195	1120

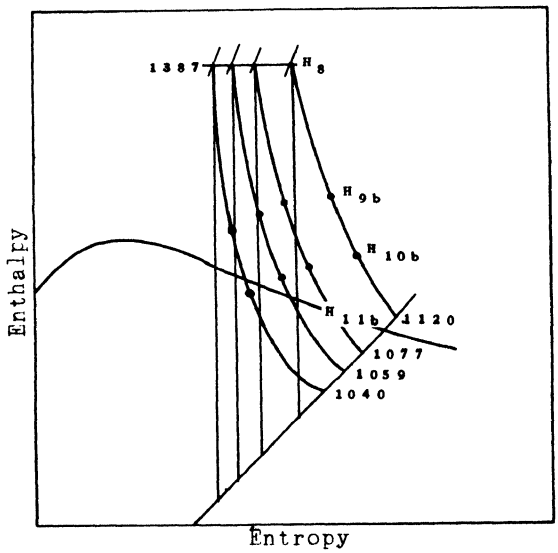


Fig. V-23. Turbine expansion lines for Example 8.

It should be noted that it was assumed in setting up the preceeding table that H_3 is 6 Btu/lb less than H_{10_c} due to the use of a closed feed-water heater. Also, in order to

avoid the necessity of solving for H_4, the drip from the closed heater is assumed to be pumped diredtly to the open heater.

The extraction quantities, M_A and M_B, can be found by use of the equations in Section 25, as follows:

Full load:

$$M_A(1224 - 266.4) = (1 - M_A - M_B)(266.4 - 190.2) + M_B(266.4 - 196.2)$$

$$M_B(1150 - 196.2) = (1 - M_A - M_B)(190.2 - 69.0)$$

	M_A =	M_B =
	0.073	0.104 lb/lb to throt.
0.75 load	0.068	0.099
0.50 load	0.062	0.074
0.25 load	0.053	0.047

Work output to the turbine shaft per pound of steam to the throttle is then calculated, as follows:

Full load:

$$W/J = (1387 - 1224) + 0.927(1224 - 1150) + 0.823(1150 - 1040)$$

	W/J =
	322.0 Btu/lb to throttle
0.75 load	304.8
0.50 load	292.3
0.25 load	256.0

Throttle flows are:

Full load: $\frac{3413(2500)}{322.0(0.975)(0.946)}$ =	28750 lbs/hr
0.75 load	23100
0.50 load	16500
0.25 load	10260

Extraction and condenser flows are:

Load	open htr. lbs/hr	closed htr. lbs/hr	conden-ser lbs/hr
Full	2100	3000	23700
0.75	1570	2290	19240

Load	open htr. lbs/hr	closed htr. lbs/hr	conden-ser lbs/hr
0.50	1027	1225	14298
0.25	545	481	9234

The Willans' line for extraction operation is plotted in Figure V-22.

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CHAPTER VI

CONDENSERS, FEED-WATER HEATERS AND EVAPORATORS

35. Condensers--The purpose of the condenser in a vapor cycle is primarily to lower the temperature of the prime mover exhaust so that the thermal efficiency of the cycle can be increased. Due to the nature of steam, operation of the condenser at a temperature less than 212 F requires that the pressure within the condenser be less than atmospheric. Operation of condensers at sub-atmospheric pressures requires the use of vacuum pumps to remove the air which unavoidably leaks into the condenser and which, if not removed, would make it impossible to maintain the low exhaust temperature.

Condensers may be divided into two general classes: mixing condensers and surface condensers. The most important type is the surface condenser which allows the reduction of exhaust temperature while at the same time allowing the recovery of the condensate. The mixing condenser is able only to lower the exhaust temperature without recovering the condensate.

36. Mixing Condensers--Mixing condensers may be either of the jet type or of the barometric type. The jet type depends upon the aspirating action of a jet of water to condense the steam and to remove the air from the condenser. A typical jet condenser is shown in Figure VI-1. The use of the jet for aspirating air requires more pump power for a given vacuum, but a separate vacuum pump is not required. The barometric condenser utilizes a leg of water to provide the seal for the condenser rather than power from a pump as in the jet condenser. The barometric condenser is always provided with a vacuum pump for air removal. A typical barometric condenser is shown in Figure VI-2. With 70 F cooling water, about the best vacuum which can be maintained with a mixing condenser is 28 inches of mercury. Due to the fact that the volume of the condenser is small in relation to the amount of steam and water handled, the mixing process does not reach equilibrium and the temperature of the mixture leaving the condenser will be about 5 F less than the saturation temperature corresponding to the pressure in the condenser. The following equations can be written for the mixing type condenser, considering it a steady flow device with no shaft work:

$$M_w(H_m - H_w) = M_v(H_v - H_m)$$

where: M_w = weight of condensing water, lbs/hr.
M_v = weight of steam, lbs/hr.
H_m = enthalpy of mixture leaving the condenser, Btu/lb.
H_v = enthalpy of steam entering the condenser, Btu/lb.
H_w = enthalpy of cooling water, Btu/lb.

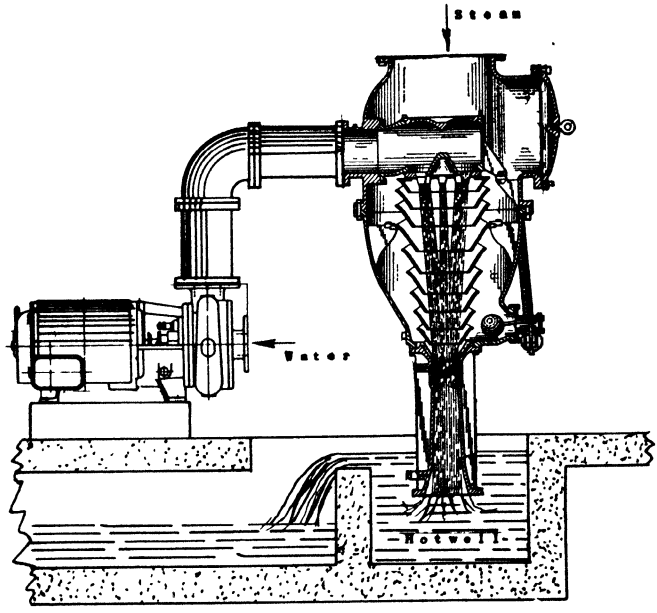


Fig. VI-1. Jet condenser.

37. Surface Condensers--The surface condenser has the advantage of making it possible to save the condensed steam for use as boiler feed, but keeping the condensing steam separate from the cooling water requires that the heat be transferred through a dividing wall. This necessity complicates the design of condensers by making it necessary to take into account the resistance of the dividing wall to heat flow. Two methods of calculating condenser size are available: calculating from the known and estimated resistances to heat flow

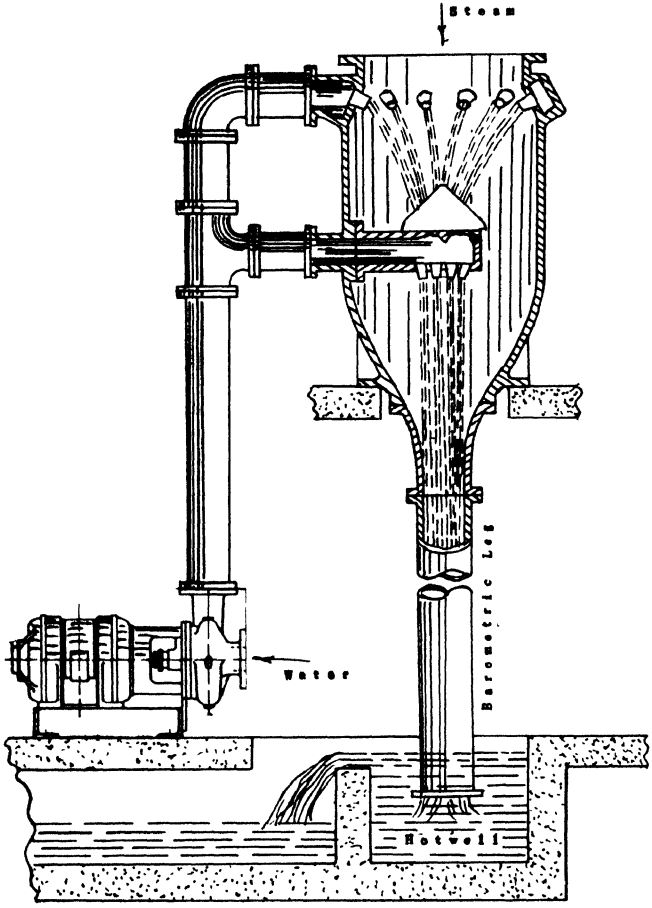


Fig. VI-2. Barometric condenser.

of the various elements in the heat flow path; and estimating from empirical data of the Heat Exchange Institute.

Surface condensers will be made in as many shapes and designs as there are manufacturers, the only similarity being in the existence of water boxes, tubes, a shell and a hotwell. Figure VI-3 shows a typical surface condenser with its various parts.

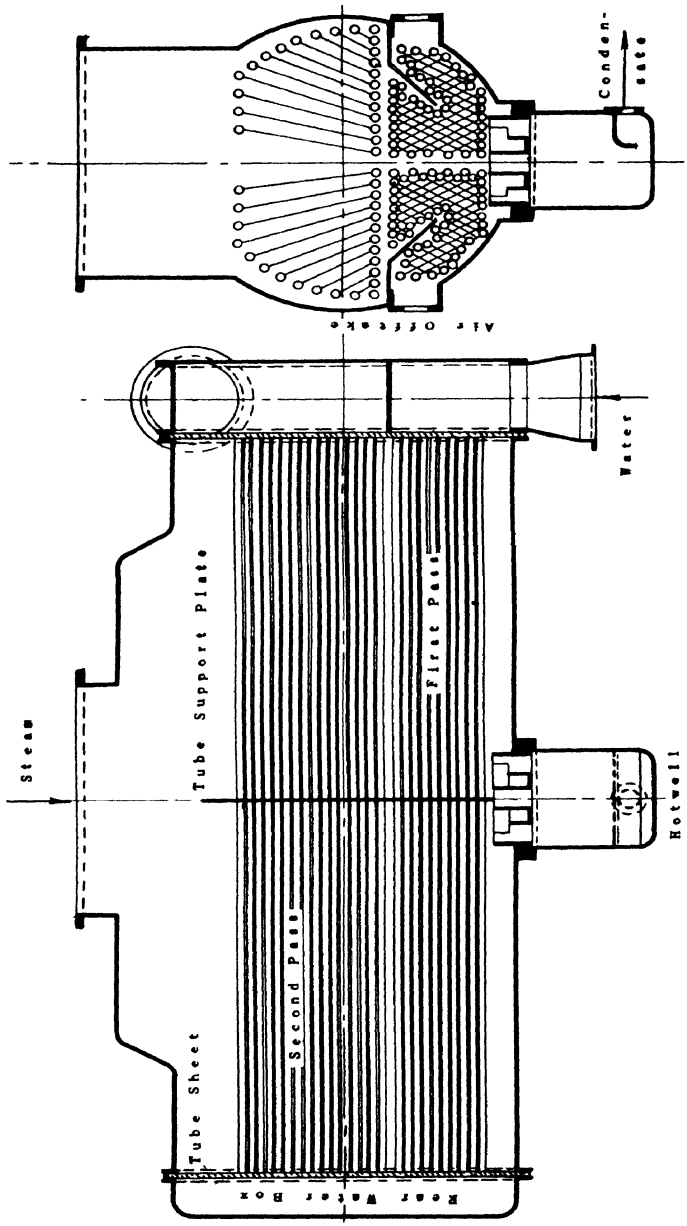
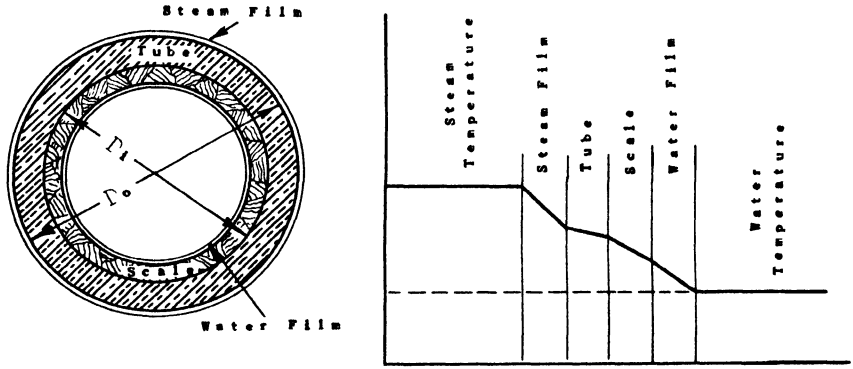


Fig. VI-3. Surface condenser.

38. Heat Transfer in Surface Condensers--Heat transfer in surface condensers is accomplished entirely by conduction, and consideration of the process will reveal that the heat must pass first through a film of water formed by the condensing steam, then in succession through the tube, scale from compounds and dirt deposited by the cooling water and finally through the boundary water film on the cooling water side of the tube. Figure VI-4 shows the heat paths in relation to a conventional condenser tube in which the tube conveys the cooling water and is surrounded by the steam.



(a) Tube (b) Temperature Drops

Fig. VI-4. Temperature relations in heat transfer through condenser tube.

The outside and inside diameters of the tube are the only definitely measureable distances in the heat path. It can be seen that the heat flow path is similar to series resistances in an electrical circuit, that is:

$$R = R_v + R_t + R_s + R_w$$

where: R = total resistance to heat flow
R_v = resistance of steam film
R_t = resistance of tube
R_w = resistance of water film
R_s = resistance of scale

If the individual resistances to heat flow are defined in terms of the thickness and area of each element,

$$R_t = \frac{1}{K_t S_t}, \text{ etc.}$$

where: R = resistance, (hr)(deg F)(sq ft)/Btu
l = thickness in feet
K = thermal conductivity, Btu/(hr)(sq ft)(deg F)(ft)
S = area, sq ft

and if 1/R is called the overall heat transfer coefficient U and S allowed to be one square foot,

$$U = \frac{1}{\frac{1}{K_v} + \frac{l_t}{K_t} + \frac{l_s}{K_s} + \frac{l_w}{K_w}}$$

As previously mentioned, the only readily determined dimensions are the inside and outside diameters of the tube. Furthermore, the area of condensing surface is always measured on the outside diameter of the tube. For these reasons all areas are corrected to the outside area of the tube, so that if all elements in the heat flow path except the tube are considered to have no thickness,

$$U = \frac{1}{\frac{1}{K_v} + \frac{(2D_o)}{D_o + D_i}\frac{(l_t)}{(K_t)} + \frac{D_o}{D_i}\frac{l_s}{K_s} + \frac{D_o}{D_i}\frac{l_w}{K_w}}$$

where: D_o and D_i are the outside and inside diameters of the tube

It is not possible to determine 1/K for any resistance except the tube wall, so empirical formulae based on rational concepts of heat flow are employed. Substitution of 1/h is made for the vapor film, scale and water film, so that,

$$U = \frac{1}{\frac{1}{h_v} + \frac{2D_o}{D_o + D_i}\frac{(l_t)}{(K_t)} + \frac{D_o}{D_i}\frac{1}{h_s} + \frac{D_o}{D_i}\frac{1}{h_w}}$$

The value of h for the vapor film is dependent principally on the amount of air dissolved in the film. Nusselt and others have found that this value varies between 1500 and 3000, and in the absence of better data a value of 2000

may be used.

Table VI shows approximate values of K for several materials which are commonly used for heat transfer surfaces.

TABLE VI

THERMAL CONDUCTIVITY OF METALS
Btu per hr(sq ft)(deg F)(ft)

Pure copper	220
Aluminum	118
Brasses (Admiralty, Muntz, etc.)	58
Steel	30

The amount of scale present in tubes is highly variable, depending upon the type of water and the season of the year, among other factors. For purposes of estimation, h for the scale may be taken as ranging between 4000 for favorable conditions and 2000 for unfavorable conditions, with an average of about 3000.

The value of h for the water film may be calculated from Nusselt's equation, with water velocity between 6 and 9 feet per second, as follows:

$$h_w = \frac{93.6(1 + 0.01\ t)V^{0.8}}{D_i^{0.2}}$$

where: t = arithmetic mean water temperature, deg F
V = water velocity, ft/sec
D_i = inside diameter of tube, ft

Table VII gives the most useful size constants for tubes of various thicknesses and diameters.

After having found the value of U for the condenser, the total surface required may be found from the relation,

$$A = \frac{Q}{Ut_m}$$

where: A = total area, sq ft
Q = heat transferred, Btu/hr

U = overall heat transfer coefficient

t_m = mean temperature difference between steam and water, deg F

TABLE VII

STANDARD CONDENSER TUBE DATA

OD in.	Thickness BWG	Thickness in.	ID in.	Outside surface sq ft/ft	Inside sectional area sq ft
5/8	16	0.065	0.495	0.1636	0.00134
	18	0.049	0.527	0.1636	0.00152
	20	0.035	0.555	0.1636	0.00168
3/4	14	0.083	0.584	0.1963	0.00186
	16	0.065	0.620	0.1963	0.00210
	18	0.049	0.652	0.1963	0.00232
7/8	14	0.083	0.709	0.2291	0.00274
	16	0.065	0.745	0.2291	0.00303
	18	0.049	0.777	0.2291	0.00329
1	14	0.083	0.834	0.2618	0.00379
	16	0.065	0.870	0.2618	0.00413
	18	0.049	0.902	0.2618	0.00444

The value of the mean temperature difference is somewhat different from the arithmetic mean temperature difference due to the fact that the temperature rise of the water is not a straight line function of the distance traversed by it. Figure VI-5 illustrates this point. It can be shown that

$$t_m = \frac{t_{w_o} - t_{w_i}}{\log_e \frac{t_v - t_{w_i}}{t_v - t_{w_o}}}$$

where: t_m = mean temperature difference between steam and water, deg F

t_v = temperature of steam, deg F

t_{w_i} and t_{w_o} = inlet and outlet cooling water temperatures, deg F

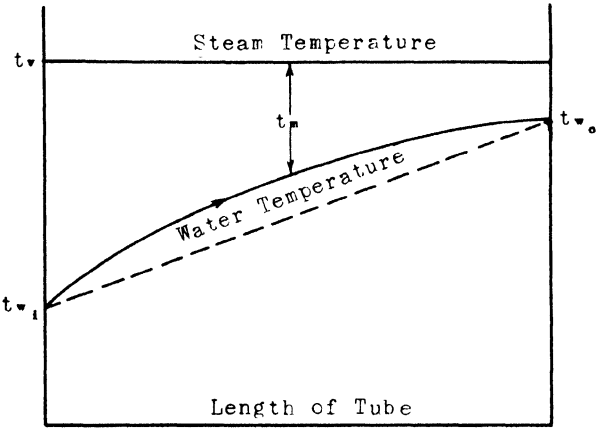


Fig. VI-5. Temperature relations in heat transfer through condenser tube.

It is necessary to have a temperature difference between the steam and the outlet cooling water in order to maintain heat flow. This difference in temperature is called the terminal difference, and is usually from 5 to 10 F for surface condensers, the smaller applying to two pass and the larger to single pass designs. Refrigeration or reheating (according to the design of the condenser) is encountered with the water leaving the hotwell. This action will have to be taken into account in the computation of the heat transferred, but it must be ignored in the computation of the mean temperature difference because of the smallness of the effect of removal of sensible heat in the condenser. In well designed condensers refrigeration will not exceed 5 F, and some designs will actually reheat as much as 2 F.

Example 9 shows the method of calculating the principal dimensions of a surface condenser for the regenerative cycle of Example 8.

Example 9.

Estimate the principal dimensions of a surface condenser to serve the turbine of Example 8. Inlet cooling water temperature 72 F, terminal difference 8 F. Use 3/4" X 18 BWG aluminum brass tubes with a water velocity of 8 fps. Assume $h_s = 3000$.

Solution:

From Example 8, the condenser flow at full load is 23700 lbs per hour, and the heat removed in the condenser is (1040 - 69) = 971 Btu/lb. The temperature of the steam in the condenser is 101 F.

$$Q = 23700(971) = 23{,}000{,}000 \text{ Btu/hr}$$

$$t_m = \frac{(101 - 8) - 72}{\log_e \frac{101 - 72}{101 - (101 - 8)}} = \frac{21}{\log_e \frac{29}{8}} = 16.3 \text{ F}$$

$$h_w = \frac{93.6[1 + 0.01(82.5)][8]^{0.8}}{[0.652/12]^{0.2}} = 1615$$

$$U = \frac{1}{\frac{1}{2000} + [\frac{1.5}{0.75+0.652}][\frac{0.049}{12(58)}] + \frac{0.75}{0.652}[\frac{1}{3000}] + \frac{0.75}{0.652}[\frac{1}{1615}]}$$

$$U = \frac{1}{0.00167} = 599$$

$$A = \frac{23{,}000{,}000}{599(16.3)} = 2360 \text{ sq ft}$$

$$\text{Water required} = \frac{23{,}000{,}000}{21(60)(8.33)} = 2190 \text{ gal/min} = 4.88 \text{ cu ft/sec}$$

$$\text{Flow area} = \frac{4.88}{8} = 0.61 \text{ sq ft}$$

$$\text{Number of tubes} = \frac{0.61}{0.00232} = 264$$

$$\text{Length of tubes} = \frac{2360}{264(0.1963)} = 45.5 \text{ ft}$$

The condenser would be too long for a single pass, so two passes, each 22'-9" long, are specified.

The principal dimensions of the condenser are:

Area	2360 sq ft
Tube material	3/4" X 18 BWG Alum. brass
Number of passes	2
Active tube length	22'-9"
Heat duty	23 million Btu/hr

39. Commercial Heat Transfer Standards for Surface Condensers--Several of the large manufacturers of heat transfer equipment have cooperated in setting up the Heat Exchange Institute with the purpose of standardizing design data for this type of equipment. Figure VI-6 shows the curves in use for surface condensers. These curves are drawn for tubes

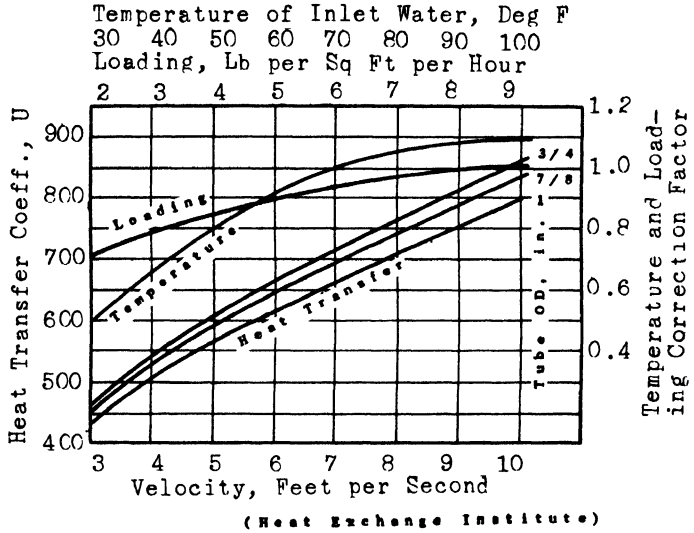


Fig. VI-6. Heat Exchange Institute design data for surface condensers.

with no scale on the water side. In use, the overall heat transfer coefficient from the curves is reduced by a so-called "cleanliness factor," which is usually taken as about 0.80. Two other correction factors, for loading and inlet water temperature, are used in addition to the cleanliness factor. In commercial practice loading ranges from 7 to 10 pounds of steam per square foot per hour. Example 10 shows the method of application of the Heat Exchange Institute data to the determination of the dimensions of a surface condenser for the same duty as in Example 9.

Example 10.

Estimate the principal dimensions of the condenser of Example 9 by means of the Heat Exchange Institute data. Take the cleanliness factor as 0.85.

Solution:

From Figure VI-6, U = 765, temperature corr. = 1.01, loading corr. = 1.0.

Corrected U = 765(1.01)(1.0)(0.85) = 657

$$A = \frac{23{,}000{,}000}{657(16.3)} = 2150 \text{ sq ft}$$

Cooling water flow and number of tubes would be the same as in Example 9.

$$\text{Length of tubes} = \frac{2150}{264(0.1963)(2)} = 20.7 \text{ ft}$$

The principal dimensions of the condenser are:

Area	2150 sq ft
Tube material	3/4" X 18 BWG Alum. brass
Number of passes	2
Active tube length	20'-9"
Heat duty	23 million Btu/hr

These calculations show that the method of Example 9 is more conservative than the method of the Heat Exchange Institute.

40. Feed-Water Heaters--The primary function of feed-water heaters is to utilize extracted or exhaust steam from prime movers to increase the temperature of water before feeding it to boilers. Feed-water heaters may be divided into two general classes: open (or mixing) and closed (or surface) heaters. Feed-water heaters are counterparts of condensers, the difference being in their smaller size and higher operating temperature.

41. Open Heaters--The name "open heater" often leads to a misconception of the operation of this type of heater. Actually, an open heater can operate at any pressure, not necessarily atmospheric. All modern regenerative cycles include one open heater in the feed-water circuit, so designed as to act as a scrubber for deaerating the feed-water before it enters the boiler. Deaeration is necessary to remove oxygen and other gases which are harmful to boilers and piping, and which have entered the system by leaking into the condenser. There are a number of types of deaerating open heaters in use, but the most common is the tray type shown in Figure VI-7. It is quite common to provide integral or connected

storage for deaerated feed-water, as shown in Figure VI-8. This storage is usually about a two or three minute supply at full load. Often additional surge tanks are connected through overflows and surge pumps with the water storage section of the deaerating heater to provide additional emergency storage for unusual conditions.

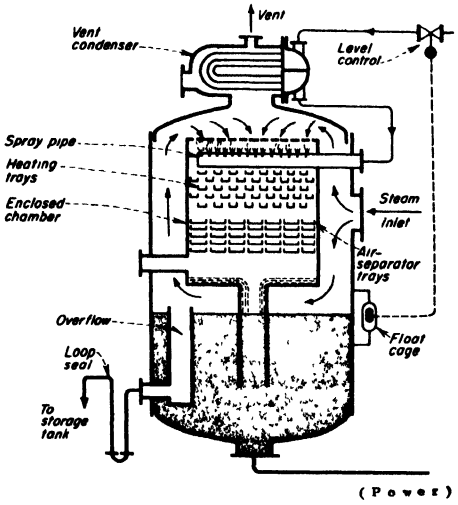


Fig. VI-7. Tray type deaerating feed-water heater.

The same considerations of heat balance apply to open heaters as to mixing condensers. Well proportioned deaerating heaters will produce water with almost immeasureable quantities of dissolved gases and with practically zero terminal difference.

42. Closed Heaters--Due to the fact that the water is separated from the steam in a closed heater, it is possible to operate them at high water pressures in relation to the steam pressure. Figure VI-9 shows a section of a typical closed feed-water heater.

The same considerations of heat transfer apply to closed feed-water heaters as to surface condensers. Because feed-water heaters operate with relatively clean tubes, the value of h for scale can be taken to be about 6000. Following are the terminal differences to be expected in good heater designs:

Temperature of exit feed-water deg F	Terminal difference deg F
86 - 230	5
230 - 300	10
300 - 400	15
400 - 525	20

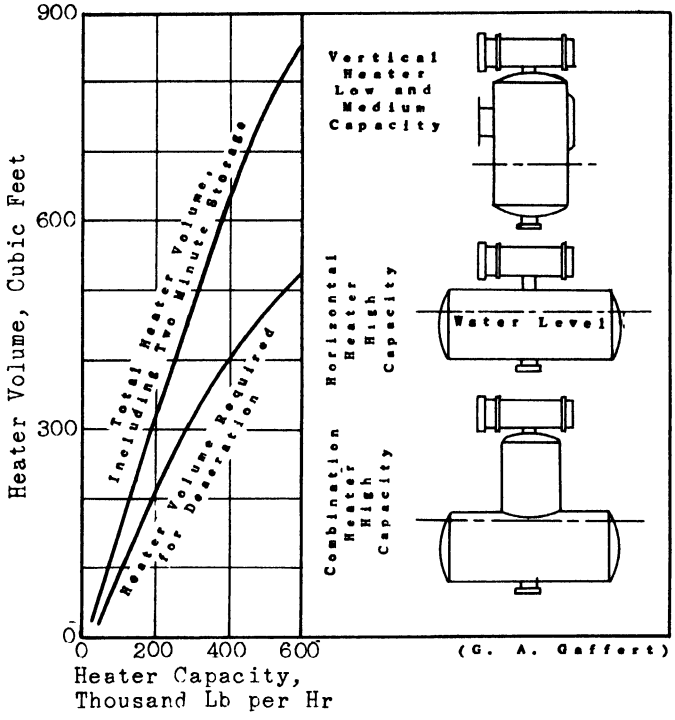


Fig. VI-8. Design data for deaerating feed-water heaters.

Refrigeration in the hotwell of horizontal heaters will be of about the same magnitude as for surface condensers, but will be from 10 to 15 F for vertical heaters. Water velocities are somewhat smaller than for surface condensers, ranging from 3 to 8 feet per second. The drainage from closed heaters is usually flashed to the next lower heater in the circuit, while the drainage from the first closed heater may be either pumped to the condensate line before the

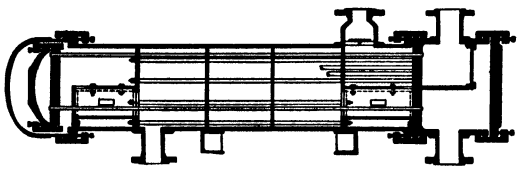


Fig. VI-9. Closed feed-water heater.

deaerating heater or flashed to the hotwell of the condenser. The heater air offtakes are connected to the condenser through flow limiting orifices.

Commercial closed heaters are designed using Kittredge's data from Figure VI-10.

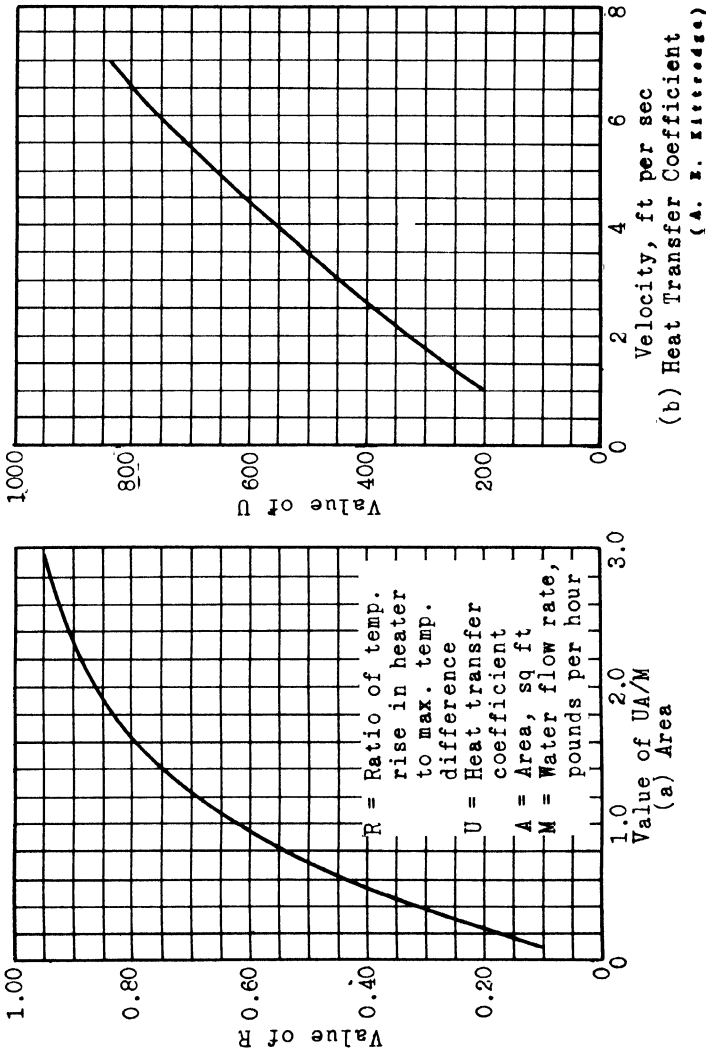


Fig. VI-10. Commercial design data for closed feed-water heaters.

Examples 11 and 12 show the method of computing the principal dimensions of a closed feed-water for the regenerative cycle of Example 8.

Example 11.

Specify the principal dimensions of a six-pass closed feed-water heater to serve the regenerative cycle of Example 8. Terminal difference 6 F. Use 5/8" X 16 BWG Admiralty brass tubes. Water velocity 6 ft/sec and $h_s = 6000$.

Solution:

From Example 8, the extracted steam to the closed heater at full load is 3000 lbs/hr and the heat given up by the steam is (1150 - 196.2) = 953.8 Btu/lb. The temperature of the steam in the heater is 228 F; water temperature to the heater 101 F and from the heater 222 F.

$$Q = 3000(953.8) = 2,860,000 \text{ Btu/hr}$$

$$t_m = \frac{222 - 101}{\log_e \frac{228 - 101}{228 - 222}} = \frac{121}{\log_e \frac{127}{6}} = 39.7 \text{ F}$$

$$h_w = \frac{93.6[1 + 0.01(161.5)][6]^{0.8}}{[0.495/12]^{0.2}} = 1945$$

$$U = \frac{1}{\frac{1}{2000} + [\frac{1.25}{0.625+0.495}][\frac{0.065}{12(58)}] + \frac{0.625}{0.495}[\frac{1}{6000}] + \frac{0.625}{0.495}[\frac{1}{1945}]}$$

$$U = 684$$

$$A = \frac{2,860,000}{684(39.7)} = 105.5 \text{ sq ft}$$

Water flow = condenser flow = 23700 lbs/hr

$$= \frac{23700}{3600}(0.0164) = 0.108 \text{ cu ft/sec}$$

$$\text{Flow area} = \frac{0.108}{6} = 0.018 \text{ sq ft}$$

$$\text{Number of tubes} = \frac{0.018}{0.00134} = 14 \text{ per pass}$$

$$\text{Length of tubes} = \frac{105.5}{14(0.1636)(6)} = 7.68 \text{ ft}$$

The principal dimensions of the feed-water heater are:

Area	105.5 sq ft
Tube material	5/8" X 16 BWG Adm. brass
Number of passes	6
Active tube length	7'-8"
Heat duty	2.86 million Btu/hr

Example 12.

Estimate the area required for the closed feed-water heater of Example 11 by means of the Kittredge data.

Solution:

Using Figure VI-10, $R = \frac{222 - 101}{228 - 101} = 0.953$, $\frac{UA}{M} = 3.0$ and U = 760. From Example 10, M = 23700 lbs/hr, then,

$$A = \frac{23700(3.0)}{760} = 107 \text{ sq ft.}$$

This area is quite close to the area determined by the method of Example 11.

43. Vacuum Pumps--As previously mentioned, a condenser must be supplied with some sort of air removal apparatus. The usual equipment consists of steam ejectors with suitable coolers, although some plants make use of mechanical air pumps.

Figures VI-11 and VI-12 show some details of the steam ejector type of vacuum pump, and Figure VI-13 shows some operating characteristics. The size of the vacuum equipment will depend upon the air leakage to be expected,

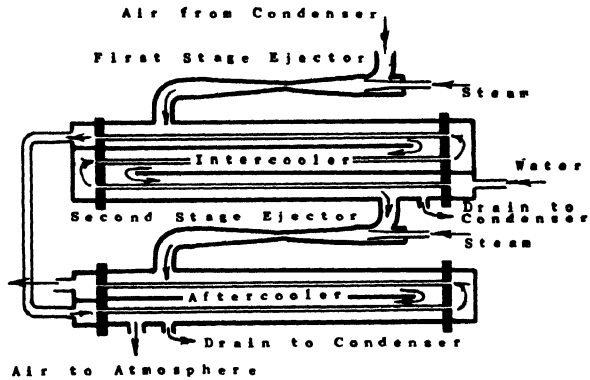
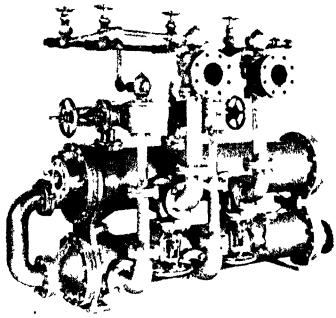


Fig. VI-11. Steam jet vacuum pump.



(Allis-Chalmers Co.)

Fig. VI-12. Steam jet vacuum pump.

which in turn depends upon the size and type of condenser. Figure VI-14 shows the approximate maximum air leakage to be expected.

44. Water Cooling Equipment --Plants must often be located where an abundant source of condenser cooling water is not available. In these cases it is necessary to provide a spray pond or cooling tower and to use a closed circuit for the cooling water. Both spray ponds and cooling towers depend upon the evaporation into the air of a part of the water to be cooled.

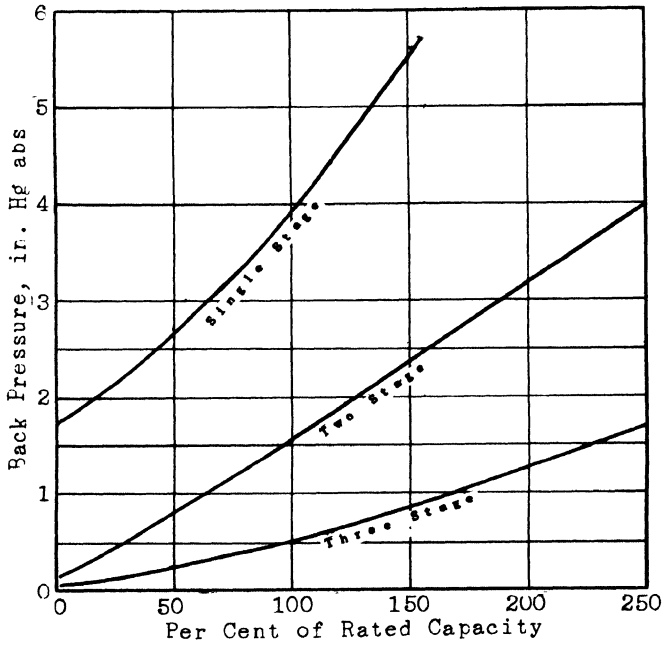


Fig. VI-13. Ejector operating characteristics.

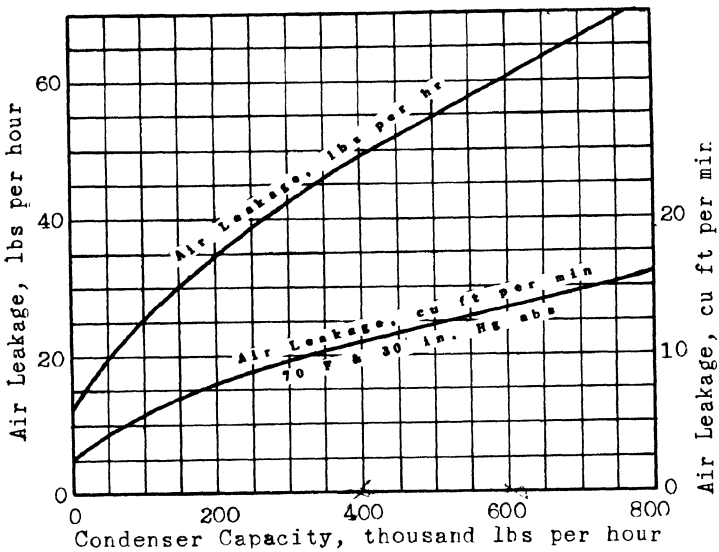
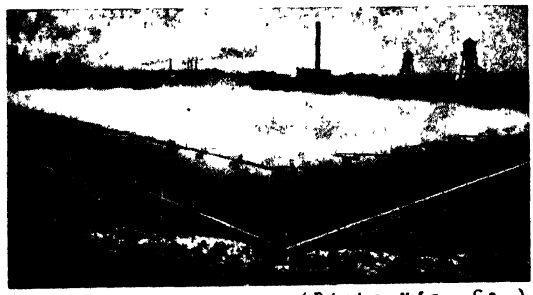


Fig. VI-14. Maximum expected condenser air leakage.

Spray ponds are wasteful of ground space because they depend upon natural air motion for their effective operation. On the other hand, they are relatively inexpensive to operate because they only require enough power to produce a pressure of about 10 pounds per square inch at the spray nozzles. Figure VI-15 shows a spray pond with the nozzles arranged in clusters, each cluster having a capacity of about 200 gallons per minute. It can be estimated that a spray pond will require about one square foot of ground area for each 250 pounds per hour of water to be cooled. The depth of the pond need not be greater than three feet. Figure VI-16 shows some typical spray pond performance data.



(Binks Mfg. Co.)

Fig. VI-15. Spray pond.

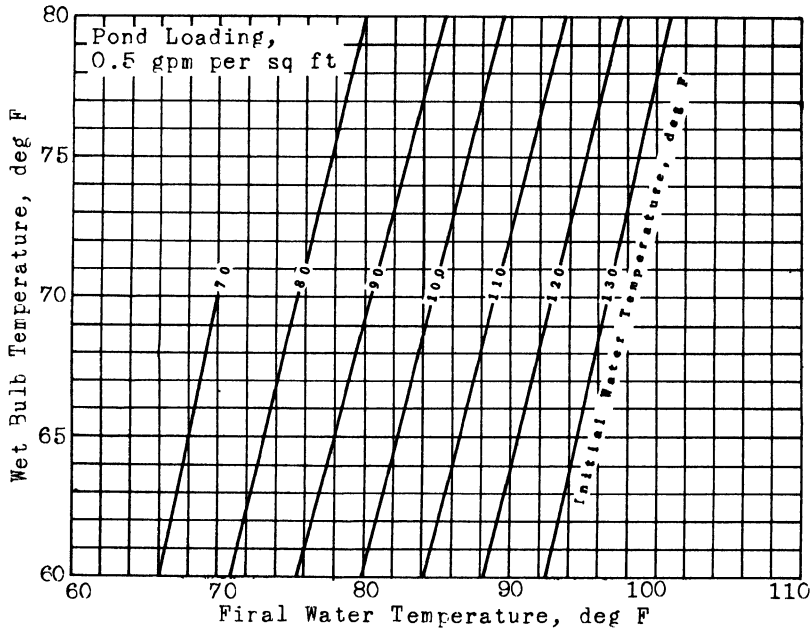
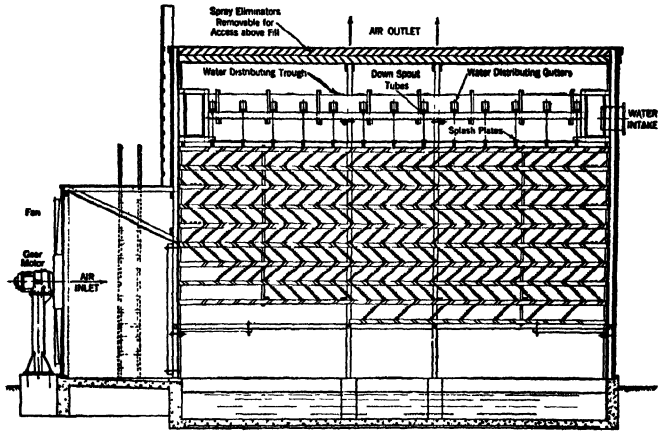


Fig. VI-16. Spray pond performance.

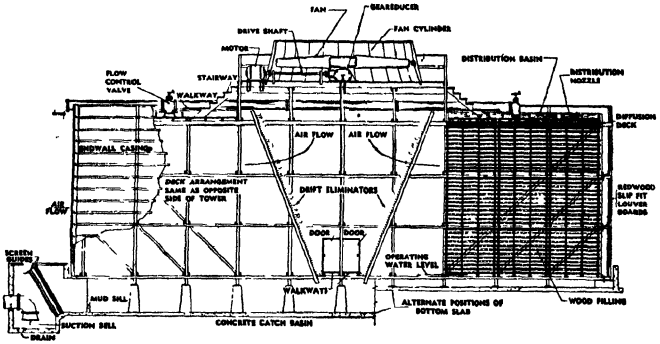
Cooling towers of the forced or induced draft types are much more economical of ground space than the spray pond because they do not depend upon natural air motion for their cooling effectiveness. In either type the water is broken into drops by being allowed to impinge upon wooden packing in the tower. The air flows through the falling water drops. The tower requires sufficient pump power to raise the water to the distributing troughs at the top, and sufficient fan power to move the required amount of air. Figures VI-17 and VI-18 show forced and induced draft towers, and Figure VI-19 shows some typical performance data.

45. Evaporators--Since regenerative cycles operate with the same water continuously and leakage is slight, it has been found advantageous to use evaporators to produce distilled water for the small amount of makeup required. Makeup requirements vary from about two to five per cent, depending upon a number of factors such as the amount of boiler blowdown and auxiliary steam unrecovered. The makeup water might be introduced directly to the boiler as raw or treated



(Foster-Wheeler Corp.)

Fig. VI-17. Forced draft cooling tower.



(The Marley Co.)

Fig. VI-18. Induced draft cooling tower.

water, but it has been found to be much easier to clean a small evaporator than to clean a large boiler.

Evaporators are most often fitted into the feed-water and steam cycle so that they use steam from one of the high pressure extraction nozzles in the turbine and use condensate to condense the vapor produced. Figure VI-20 shows one of the methods of arrangement of an evaporator set in a regen-

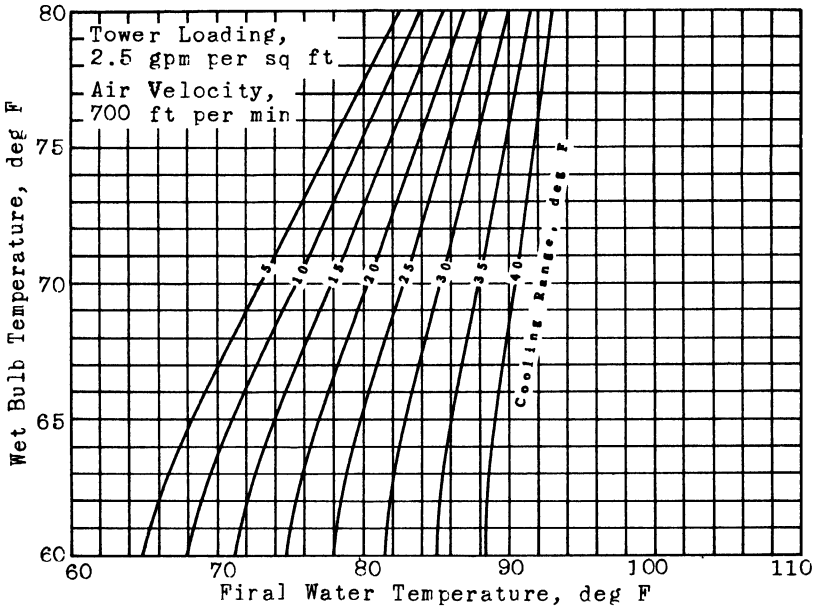


Fig. VI-19. Forced and induced draft tower performance.

erative cycle. It will be noted that the only heat loss from the system is due to the necessary blowdown from the evaporator shell. Figure VI-21 shows one of the usual types of evaporator.

In process industries which perform evaporation on a product, multiple effect evaporator systems are used because of their economy of operation. Figure VI-22 shows a typical quadruple effect system with a finishing pan for the production of citrus molasses. It will be noted that the vapor from a preceeding effect is used as a source of heat for successive evaporations. The evaporators are of the long tube type with vapor separating heads. In this type of evaporator the liquid flows inside the tubes. In the first four effects the circulation is natural, and in the finishing pan a pump forces circulation. Figure VI-23 shows long tube types of evaporator.

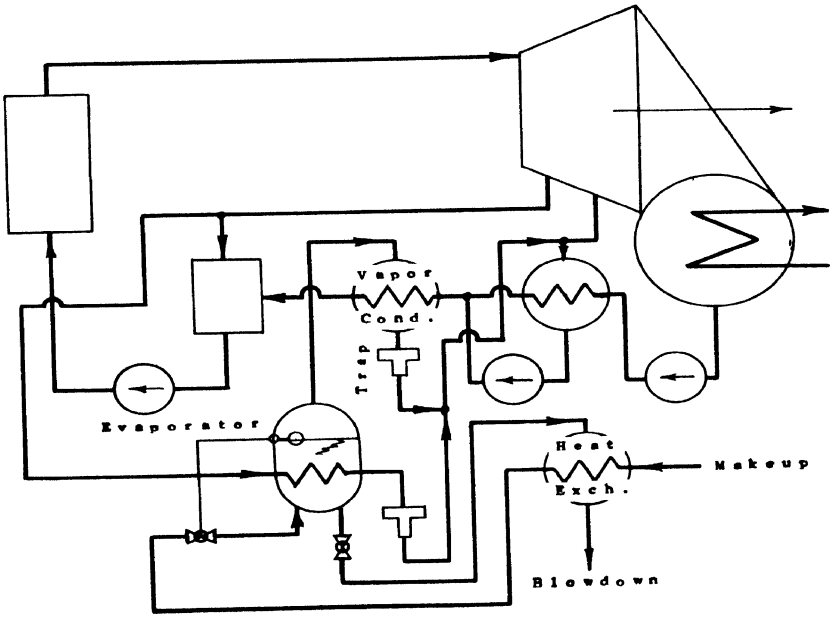
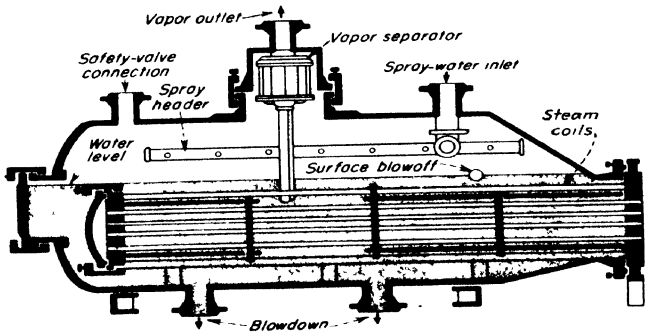
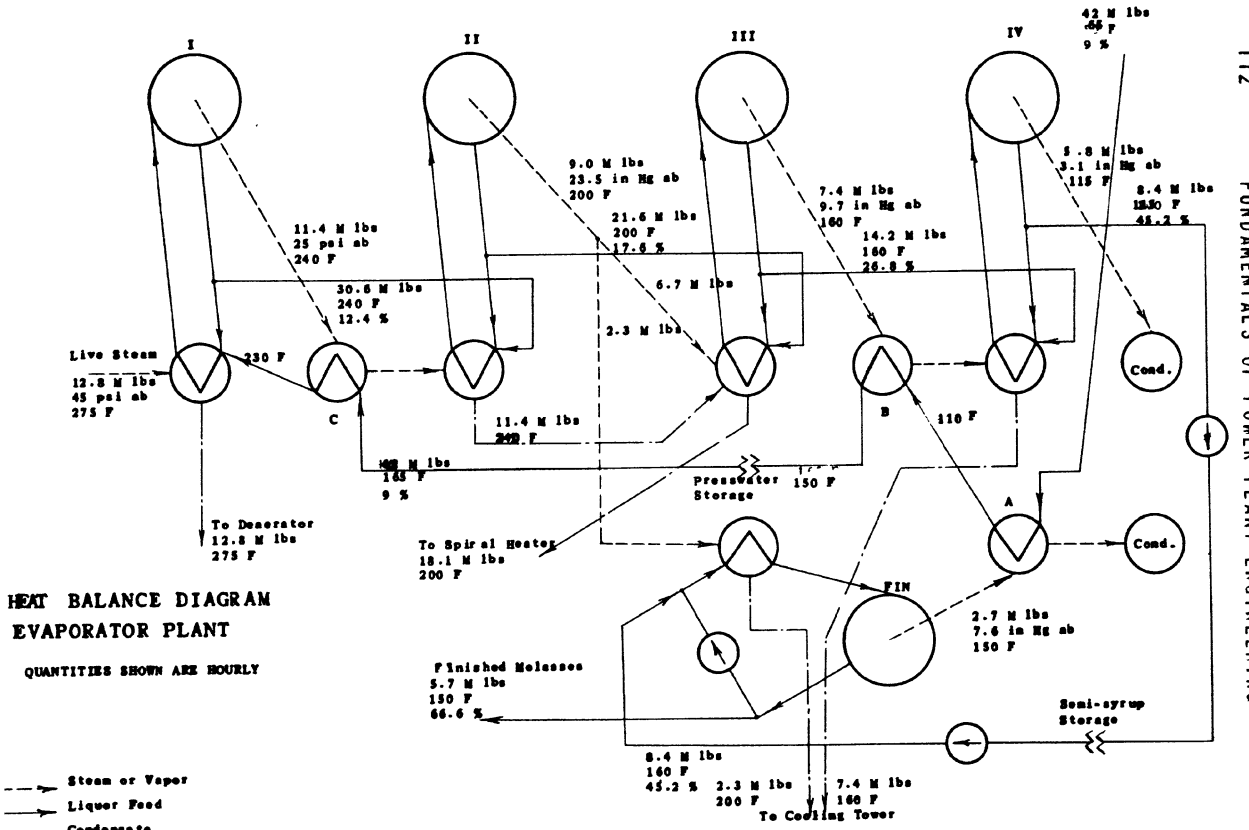


Fig. VI-20. Evaporator in regenerative cycle.



(Power)

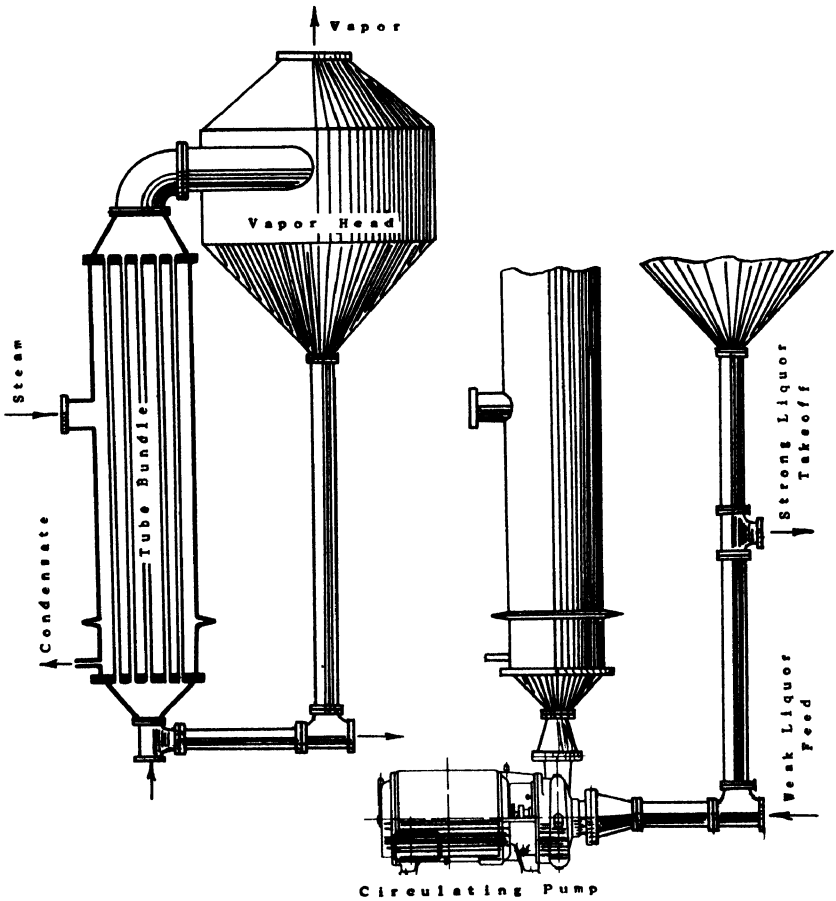
Fig. VI-21. Shell and tube evaporator.



HEAT BALANCE DIAGRAM
EVAPORATOR PLANT

QUANTITIES SHOWN ARE HOURLY

Fig. VI-22. Quadruple effect evaporator system with finishing pan for production of citrus molasses.



(a) Natural Circulation (b) Forced Circulation

Fig. VI-23. Long tube evaporators.

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PROJECT 11

1. The power plant of Project I is to be designed around three turbo-generator units. One of the units will operate continuously, one unit will be operated to handle peak loads and the remaining unit will be a spare. The plant will operate on the regenerative cycle with one closed feed-water heater and one evaporator vapor condenser per machine. There will be one evaporator and one deaerating feed-water heater common to all machines. Boiler blowdown is fed to the evaporator shell. The flow diagram is shown in Figure VI-24.

It is expected that boiler and evaporator blowdown will each be five per cent and makeup will be two per cent. The open heater and evaporator will be supplied with steam from extraction points in the turbines so located that at full load the water temperature leaving the open heater will be at the most economical value. The closed heaters will be supplied with steam from extraction points in the turbines so located that at full load half of the feed-water temperature rise will be supplied by the open heater. Throttle conditions are: 350 psig, 725 F. Back pressure is 2.5 in. Hg abs. Refrigeration in the condenser hotwell is 2 F and terminal difference in the open heater is zero. Make heat balances for the plant at full and half load (two machines operating).

2. Specify the principal dimensions for a surface condenser to serve one of the turbines of part one. The average temperature of the inlet cooling water is 85 F. Use 3/4" OD X 18 BWG Admiralty metal tubes with a water velocity of 7 ft per sec.

3. Specify the area of an induced draft cooling tower to serve the condenser of part two. Design wet bulb temperature is 78 F.

4. Specify the principal dimensions of a closed feed-water heater to serve one of the turbines of part one. Use 5/8" OD X 16 BWG Admiralty metal tubes with a water velocity of 5 ft per sec. Maximum tube length is six feet.

5. Specify the principal dimensions of the deaerating feed-water heater for the regenerative cycle of part one.

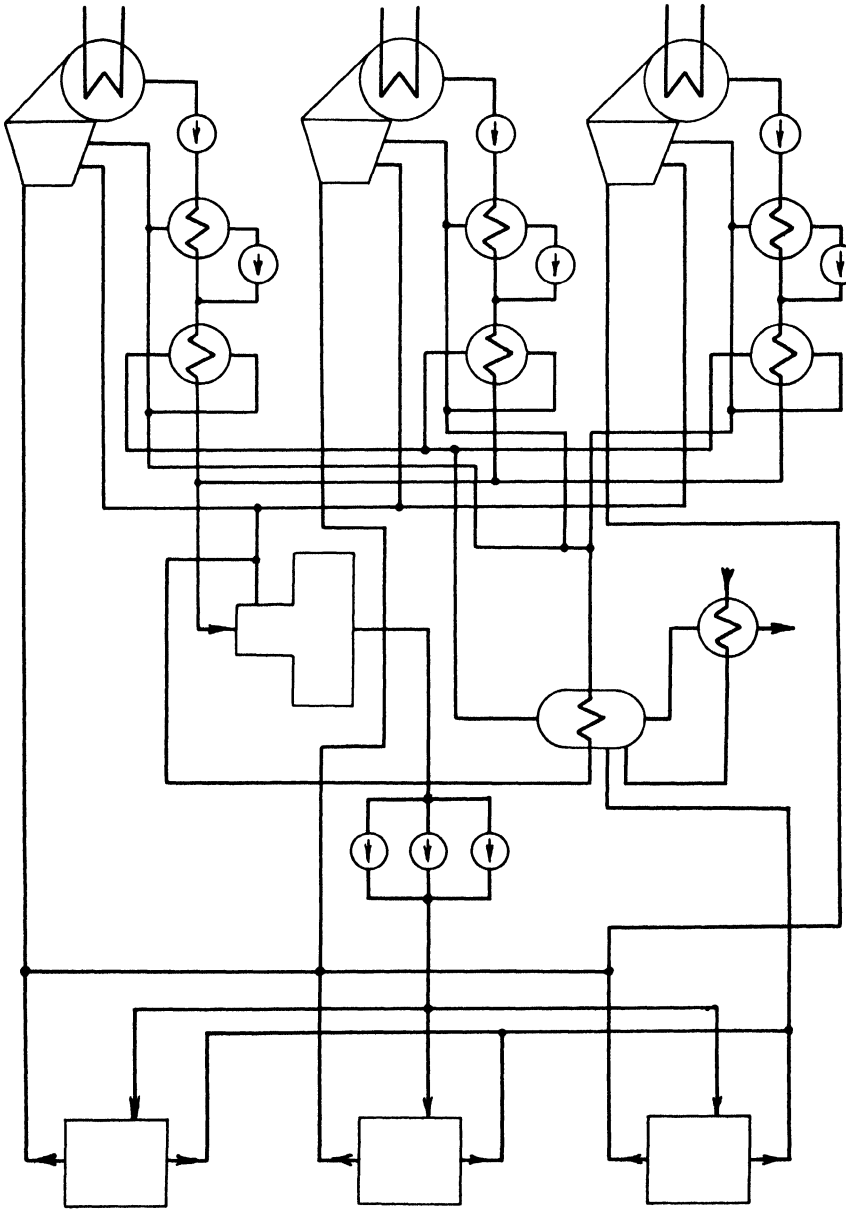


Fig. VI-24. Flow diagram for power plant of elementary power system, Project II.

CHAPTER VII

FUELS AND COMBUSTION

46. The variety of fuels used for the production of power is large, and the type used in any particular locality is always dependent upon economic factors. The most important fuels for commercial power production, in order of importance, are: coal, natural gas and fuel oil. Process industries often make use of cellulosic wastes as fuel.

47. Coal--Coal is a product of fermentation of vegetable matter laid down in prehistoric times. In this country, coal is found in almost every State in various phases of the evolutionary process. The most important coals for power production are the bituminous and semi-bituminous types, but some use is made of lignite and anthracite which are respectively younger and older than bituminous coal.

Coal is made up of moisture, volatile matter, fixed carbon and ash. The proportions of moisture and volatile matter decrease as the age of the coal deposit increases. Volatile matter consists of hydrocarbons which have a greater heating value than carbon on a weight basis, but which are more difficult to burn in small furnace volumes. Table VIII shows the analysis of some of the more important coals, both in the proximate form (fixed carbon, volatile, ash and moisture) and in the ultimate form.

48. Fuel Oil--The fuel oil ordinarily used in the production of electrical power is residuum from petroleum refining operations. Petroleum is found in large areas throughthe United States and South America, and is also a product of the fermentation of vegetable matter laid down in past ages. Its principal difference from coal is the almost complete absence of fixed carbon and ash. Table IX shows some analyses of typical fuel oils. The most important sources of fuel oil for the United States are the Pacific and Gulf coasts and Venezuela.

49. Natural Gas--Natural gas is principally a by-product from petroleum wells, although much gas is removed from the earth's crust through wells which are not connected with petroleum operations. Natural gas is a product of the fermentation of vegetable matter to produce coal and petroleum. Table X shows some analyses for natural gas.

TABLE VIII

ANALYSES OF TYPICAL AMERICAN COALS

	Proximate				Ultimate – mois. incl.					
	H_2O	Vol.	FC	Ash	S	H	C	N	O	HHV
Ark. Semi-anth.	1.28	12.84	73.69	12.21	2.01	3.74	77.29	1.39	3.36	13406
Penna. Anth.	2.19	5.67	86.24	5.90	0.57	2.70	86.37	0.91	3.55	13828
Penna. Semi-bit.	2.95	21.29	66.92	8.84	1.35	4.74	78.51	1.19	5.37	13901
W. Va. Semi-bit.	3.10	17.91	75.26	3.73	0.55	4.50	84.02	1.17	6.03	14724
Penna. Bit.	2.44	28.44	60.68	8.44	1.32	5.07	76.91	1.31	6.95	13732
Ala. Bit.	2.53	26.94	59.48	11.05	0.79	4.80	74.44	1.59	7.33	13286
Ill. Bit.	13.31	33.62	41.34	11.73	3.75	5.19	59.07	0.95	19.31	10548
Ind. Bit.	9.69	38.59	41.04	10.68	4.79	5.39	62.36	1.28	15.50	11412
N. Dak. Lig.	36.18	29.77	25.35	8.70	0.68	6.76	39.45	0.59	43.82	6700
Texas Br. Lig.	13.04	42.75	29.00	14.85	1.04	5.51	52.06	0.95	25.33	9358

(U. S. Bureau of Mines)

TABLE IX

ANALYSES OF TYPICAL FUEL OILS

	Ultimate – mois. incl.					API°	
	C	H	S	N	O	60 F	HHV
Mexican	84.02	10.06	4.93	0.09	0.00	11.9	18510
Mid-cont.	85.62	11.98	0.35	0.50	0.60	27.1	19376
Calif.	84.67	12.36	1.16	0.90	0.91	16.7	18835
Texas	83.26	12.41	1.80	1.50	1.03	21.2	19654

TABLE X

ANALYSES OF TYPICAL NATURAL GASES

	Volumetric – std. cond. 60 F, 30 in. Hg								
	CH_4	C_2H_4	C_2H_6	CO	H_2	O_2	N_2	CO_2	HHV
Marion, Ind.	93.56	0.16	0.00	0.60	1.20	0.55	3.42	0.30	1000
Pittsburgh, Pa.	72.18	3.00	0.00	1.00	20.00	0.80	0.00	0.80	920
Findlay, O.	93.35	0.35	0.00	0.41	1.64	0.39	3.41	0.25	1010
Monroe, La.	78.80	0.00	9.50	0.00	0.00	0.34	11.30	0.06	960

(Various sources)

50. Combustion--The process of combustion of fuels is one of rapid oxidation of the carbon, hydrogen and sulphur which it contains. In order to calculate the amount of air, which is the source of oxygen, for combustion, it is necessary to know the ultimate analysis of the fuel. Since the combustion process takes place too rapidly to reach equilibrium, it is always necessary to supply more than the theoretical amount of air. The air supplied in relation to the theoretical air is known as the total air, while that supplied above the theoretical air is called the excess air. Both total air and excess air are expressed as percentages by weight of the theoretical air. Examples 13 and 14 show the method of making combustion calculations for each of the principal types of fuels.

Example 13.

Determine the weight of air required for theoretically perfect combustion and the flue gas analysis for a fuel with the following analysis by weight: C = 0.8339; H = 0.0428; O = 0.0283; N = 0.0103;, S = 0.0064; moisture = 0.025; and ash = 0.0533. Also, determine the weight of air required and the flue gas analysis for combustion with 30 o/o excess air.

Solution:

The combustion reactions are:

$C + O_2 \longrightarrow CO_2$, $O_2 = 2.67\ C$, $CO_2 = 3.67\ C$

$H_2 + \frac{1}{2}\ O_2 \longrightarrow H_2O$, $O_2 = 8\ H$, $H_2O = 9\ H$

$S + O_2 \longrightarrow SO_2$, $O_2 = S$, $SO_2 = 2\ S$

N_2 from air = 3.31 O_2 from air

Theoretically perfect combustion: Basis, one lb fuel.

Const.	weight	O_2 req.	prod.	wght. prod.	mol. wt.	mols.	anal. by vol. wet o/o	anal. by vol. dry o/o
C	0.8339	2.230	CO_2	3.060	44	0.0696	17.70	18.78
H	0.0428	0.342	H_2O	0.385	18	0.0214	5.80	
O	0.0283	-0.028						
N	0.0103		N_2	0.010	28	0.0004	76.50	81.22
S	0.0064	0.006	SO_2	0.012	64	0.0002		
moist.	0.0250		H_2O	0.025	18	0.0014		
ash	0.0533							

	weight	O_2 req.	wght. prod.	mols,
	1.0000	2.550	3.492	0.0930
N_2 air		8.440	8.440	0.3010
Totals/lb		10.990 air	11.932 gas	

For theoretically perfect combustion, 10.99 lbs of air are required and 11.932 lbs of gas are produced per lb of fuel burned. The dry (Orsat) analysis of the flue gas would be: CO_2 = 18.78 o/o and N_2 = 81.22 o/o.

Combustion with 30 o/o excess air: Basis, one lb fuel.

O_2 req.	2.550	Gas prod., theo.	11.932
O_2 suppl.	3.320	Excess O_2	0.770
N_2 air	11.000	N_2 with exc. O_2	2.560
Air suppl.	14.320	Gas produced	15.262

Prod.	wght. prod.	mol. wt.	mols.	anal. by vol. wet o/o	anal. by vol. dry o/o
CO_2	3.060	44	0.0696	13.70	14.30
H_2O	0.410	18	0.0228	4.48	
O_2	0.770	32	0.0240	4.71	4.93
N_2	11.010	28	0.3930	77.21	80.72
SO_2	0.012	64	0.0002		
	15.262 gas		0.5096		

For combustion with 30 o/o excess air, 14.32 lbs of air are required and 15.262 lbs of gas are produced per lb of fuel burned. The dry (Orsat) analysis of the flue gas would be: CO_2 = 14.30 o/o, O_2 = 4.93 o/o and N_2 = 80.72 o/o.

Example 14.

Determine the weight of air required for theoretically perfect combustion and the flue gas analysis for a gaseous fuel with the following analysis by volume: CO_2 = 0.004; CH_4 = 0.921; C_2H_6 = 0.041; and N_2 = 0.034. Also, determine the amount of air required and the flue gas analysis for

combustion with 20 o/o excess air.

Solution:

Combustion reactions are:

$CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$, $O_2 = 4\ CH_4$, $CO_2 = 2.75\ CH_4$, $H_2O = 2.25\ CH_4$

$C_2H_6 + 3\frac{1}{2}\ O_2 \longrightarrow 2\ CO_2 + 3\ H_2O$, $O_2 = 3.73\ C_2H_6$, $CO_2 = 2.94\ C_2H_6$, $H_2O = 1.79\ C_2H_6$

N_2 from air = 3.31 O_2 from air

Theoretically perfect combustion: Basis, one lb fuel.

Const.	anal. by vol.	mol. wt.	lbs.	anal. by wt.	O_2 req.	Products CO_2	H_2O	N_2
CO_2	0.004	44	0.176	0.0103		0.01		
CH_4	0.921	16	14.750	0.8630	3.45	2.37	1.94	
C_2H_6	0.041	30	1.230	0.0720	0.27	0.21	0.13	
N_2	0.034	28	0.953	0.0557				0.06
	1.000		17.109	1.0010	3.72	2.59	2.07	0.06
N_2 from air					12.30			12.30
Total					air 16.02	2.59	2.07	12.36	17.02
				Mol. wt.		44	18	28	gas
				mols.		0.06	0.12	0.44	0.62
				Anal. by. vol. wet.o/o		9.60	18.7	71.70	
				Anal. by vol. dry o/o		11.80		88.20	

From the preceeding analysis it is seen that one pound of this particular fuel gas requires 16.02 lbs of air for theoretically perfect combustion and produces 17.02 lbs of wet flue gas. The dry (Orsat) analysis of the flue gas would be: CO_2 = 11.80 o/o and N_2 = 88.20 o/o.

Combustion with 20 o/o excess air: Basis, one lb fuel.

O_2 req.	3.72	Gas prod., theo.	17.02
O_2 suppl.	4.46	Excess O_2	0.74
N_2 from air	14.76	N_2 with exc. O_2	2.46
Air supplied	19.22	Gas produced	20.22

Prod.	wght. prod.	mol. wt.	mols	anal. by vol. wet o/o	anal. by vol. dry o/o
CO_2	2.59	44	0.0589	8.10	9.63
H_2O	2.07	18	0.1150	15.82	
O_2	0.74	32	0.0231	3.08	3.78
N_2	14.82	28	0.5300	73.00	86.59
	20.22 gas		0.7270		

For combustion with 20 o/o excess air, 19.22 lbs of air are required and 20.22 lbs of flue gas are produced per lb of fuel. The dry (Orsat) analysis of the flue gas would be: CO_2 = 9.63 o/o, O_2 = 3.78 o/o and N_2 = 86.59 o/o.

Often it is necessary to determine combustion conditions from a fuel analysis and an analysis of the flue gas. Examples 15 and 16 show the method followed for each of the types of fuels.

Example 15.

Fuel with an ultimate analysis of: C = 0.83; H = 0.127; O = 0.012; N = 0.016; S = 0.004; moisture = 0.01; and ash = 0.001 is burned in a boiler furnace. The flue gas has the following volumetric analysis on the dry basis: CO_2 = 13.7 o/o; O_2 = 2.6 o/o; CO = 0.4 o/o; and N_2 = 83.3 o/o. Find the theoretical air, actual air and flue gas produced in lbs per lb of fuel fired.

Solution:

1. The theoretical air can be found from the formula:

$$M_{at} = 11.53\ C_{burned} + 34.36[H - \frac{O}{8}] + 4.32\ S \text{ lbs/lb fuel}$$

$$M_{at} = 11.53(0.83) + 34.36[0.127 - \frac{0.012}{8}] + 4.32(0.004)$$

$$M_{at} = 13.91 \text{ lbs/lb fuel}$$

2. The dry flue gas produced can be determined with the aid of a carbon balance, as follows:

$$M_{gd} = \frac{44\ CO_2 + 32\ O_2 + 28(N_2 + CO)}{12(CO_2 + CO)}[C_{burned} + \tfrac{3}{8}S] + \tfrac{8}{8}S \text{ lbs/lb}$$

$$M_{gd} = \frac{44(13.7)+32(2.6)+28(83.3+0.4)}{12(13.7+C.4)}[0.83+(0.375)0.004]+ \\ +0.625(0.004)$$

M_{gd} = 19.93 lbs/lb fuel

Note: Sulphur dioxide in the flue gas is analyzed as carbon dioxide by the Orsat apparatus. If all of carbon in the fuel is not burned a correction is made (see Example 17).

3. The wet flue gas produced can be found from a weight balance, as follows:

$M_{gw} = M_{gd} + 9\ H$ + moisture lbs/lb fuel

$M_{gw} = 19.93 + 9(0.127) + 0.01 = 21.08$ lbs/lb fuel

4. The actual air supplied can be found from a weight balance, as follows:

$$M_{aa} = M_{gd} + 8[H - \frac{O}{8}] - C_{burned} - S - N \text{ lbs/lb fuel}$$

$$M_{aa} = 19.93 + 8[C.127 - \frac{0.012}{8}] - 0.83 - 0.004 - 0.016$$

M_{aa} = 20.08 lbs/lb fuel

5. Excess air can be found from the relation:

$$\text{Excess air o/o} = \frac{M_{aa} - M_{at}}{M_{at}}(100)$$

$$\text{Excess air o/o} = \frac{20.08 - 13.91}{13.91}(100) = 44.3 \text{ o/o}$$

Example 16.

A fuel gas having an analysis of CH_4 = 77.5 o/o, C_2H_6 = 16.0 o/o, CO_2 = 6.3 o/o, N_2 = 0.2 o/o is burned in a boiler furnace. The flue gas has the following analysis on the dry basis: CO_2 = 9.0 o/o, O_2 = 3.0 o/o, CO = 0.2 o/o, N_2 = 87.8 o/o. Find the theoretical air, actual air and flue gas in lbs per lb of fuel fired and the percentage of excess air supplied.

Solution:

The first step in the solution is the conversion of the volumetric analysis to a gravimetric analysis.

Const.	anal. by vol.	mol. wt.	lbs.	anal. by wt.
CH_4	0.775	16	12.40	0.619
C_2H_6	0.160	30	4.80	0.239
CO_2	0.063	44	2.77	0.138
N_2	0.002	28	0.06	0.004
	1.000		20.03	1.000

1. Theoretical air:

$$M_{at} = 17.25\ CH_4 + 16.10\ C_2H_6 + 14.8\ C_2H_4 + 34.5\ H_2 \text{ lbs/lb}$$

$$M_{at} = 17.25(0.619) + 16.10(0.239) = 14.53 \text{ lbs/lb fuel}$$

2. Dry flue gas:

$$M_{gd} = \frac{44\ CO_2 + 32\ O_2 + 28(N_2 + CO)}{12(CO_2 + CO)}[0.75\ CH_4 + 0.8\ C_2H_6 + 0.857\ C_2H_4] + CO_{2f} + N_{2f}$$

$$M_{gd} = \frac{44(9.0)+32(3.0)+28(87.8+0.2)}{12(9.0+0.2)}[0.75(0.619)+0.8(0.239)] + 0.138 + 0.004$$

$$M_{gd} = 17.64 \text{ lbs/lb fuel}$$

3. Wet flue gas:

$$M_{gw} = M_{gd} + 2.25\ CH_4 + 1.8\ C_2H_6 + 1.29\ C_2H_4 + 9\ H_2$$

$$M_{gw} = 17.64 + 2.25(0.619) + 1.8(0.239) = 19.46 \text{ lbs/lb fuel}$$

4. Actual air supplied:

$$M_{aa} = M_{gd} + 1.25\ CH_4 + 0.80\ C_2H_6 + 0.29\ C_2H_4 + 8\ H_2 - N_2 - CO_2$$

$$M_{aa} = 17.64 + 1.25(0.619) + 0.80(0.239) - 0.002 - 0.138$$

$$M_{aa} = 18.47 \text{ lbs/lb fuel}$$

5. Excess air:

$$\text{Excess air} = \frac{18.47 - 14.53}{14.53}(100) = 27.1 \text{ o/o}$$

51. Heating Value of Fuels--One of the most important properties of any fuel is its heating value per unit of weight or volume. The higher heating value (HHV) is the value which would be obtained if the products of combustion were cooled to the temperature of the original fuel and air. The lower heating value (LHV) is the higher heating value less the latent heat of vaporization of the moisture formed in the combustion process and present in the fuel originally. It is customary to base efficiencies on the higher heating values, although efficiencies would appear to be higher if they were based on the lower heating value.

The heating values of fuels can be determined approximately by calculation if the ultimate analysis, proximate analysis (for coal) or specific gravity (for fuel oil) is known.

For solid or liquid fuels with the ultimate analysis known:

$$HHV = 14600\ C + 62000\left(H - \frac{O}{8}\right) + 4050\ S$$

where: HHV = higher heating value, Btu/lb
C, H, O and S = carbon, hydrogen, oxygen and sulphur, lbs/lb fuel

For coals with the proximate analysis known, the heating value can be determined from Table XI. It will be noted that the proximate analysis must be converted to the combustible basis before the table is used, and the result converted to the as fired basis. These conversions may be made as follows:

Converting proximate analysis as fired to combustible basis, lbs/lb fuel:

$$\text{Volatile matter} = \frac{\text{Volatile matter as fired}}{1 - \text{moisture as fired} - \text{ash as fired}}$$

$$\text{Fixed carbon} = \frac{\text{Fixed carbon as fired}}{1 - \text{moisture as fired} - \text{ash as fired}}$$

Converting heating value on combustible basis to as fired basis, Btu/lb:

$$HHV = (\text{HV on comb. basis})(1 - \text{mois. as fired} - \text{ash as fired})$$

TABLE XI

HEATING VALUE OF COAL BASED ON PROXIMATE ANALYSIS

States	Per cent Volatile on Combustible Basis	Btu/lb on Combustible Basis
Pa., Ohio, W.Va., Md., Va., Ky., Ga., Tenn.,	0 – 16	HHV = 14550 + 7810 V
Ala., Ind., Iowa, Neb., Kan., Mo., Okla.,	16 – 36	HHV = 16160 – 2250 V
Ark., and Texas	36 – up	HHV = 18750 – 9440 V
Ill. and Mich.	all	HHV = 16062 – 3830 V

where: HHV = higher heating value
V = decimal fraction volatile on combustible basis

(F. C. Evans)

For heavy fuel oils with the specific gravity known:

$$HHV = 18650 + 40(A.P.I.^{\circ} - 10)$$

where: A.P.I.° = specific gravity on the American Petroleum Institute scale, or

$$A.P.I.^{\circ} = 141.5 - (131.5/sp.gr.^{\frac{60}{60}})$$

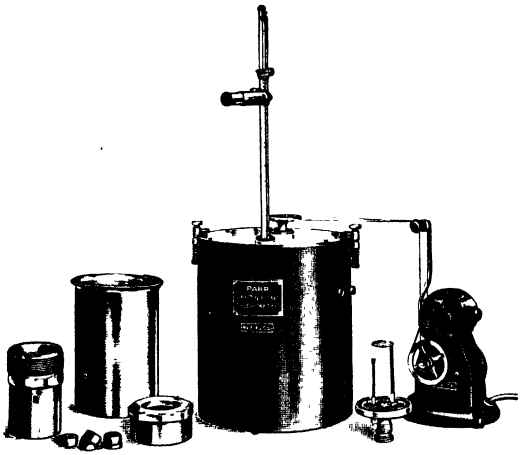
For gaseous fuels with the volumetric analysis known:

$$HHV = 323\ CO + 328\ H_2 + 1012\ CH_4 + 1762\ C_2H_6 + 1641\ C_2H_4$$

where: HHV = higher heating value, Btu/cu ft at 60 F and 30 in. Hg

CO, H_2, CH_4, C_2H_6 and C_2H_4 = carbon monoxide, hydrogen, methane, ethane and ethylene, volume fractions as fired.

The preceeding equations are only approximate, and for the most precise determination of heating value it will be necessary to employ a calorimeter of a suitable type.

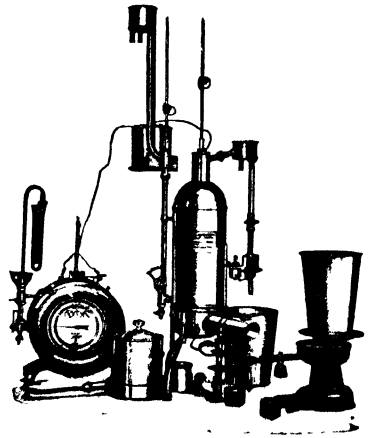


(Parr Instrument Co.)

Fig. VII-1. Parr bomb calorimeter.

For heating value determinations on solid or heavy liquid fuels, it is customary to employ one of the constant volume "bomb" types of calorimeter. The Parr bomb calorimeter is shown in Figure VII-1, and consists of a heavy steel container into which the fuel sample is placed with sufficient pure oxygen to insure complete combustion. The bomb is immersed in a known weight of water whose temperature rise is determined after igniting the fuel sample with an electric resistance wire.

For heating value determinations on gaseous or light liquid fuels, the steady flow calorimeter is used. The Sargent calorimeter shown in Figure VII-2 is of this type and consists of a water jacket with flues for absorbing heat from the products of combustion of the fuel. If the products of combustion leave the calorimeter at the same temperature as the incoming fuel and air, the higher heating value will be determined. The heating value is calculated from the known weight of water heated through a known temperature rise by a known volume or weight of fuel.

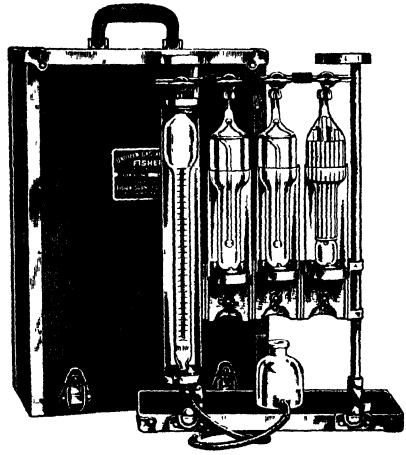


(Precision Scientific Co.)

Fig. VII-2. Sargent calorimeter.

52. Flue Gas Analysis-- Analysis of the products of combustion is most conveniently made with an Orsat type

of apparatus which absorbs the various flue gas constituents, one at a time, by means of chemical solutions. Figure VII-3 shows a common portable form of the apparatus.



(Fisher Scientific Co.)

Fig. VII-3. Orsat gas analysis apparatus.

The Orsat analysis is given on the dry basis because the sample remains saturated with moisture throughout the test procedure. The ordinary form of the apparatus measures volumetric or mol fractions of carbon dioxide, oxygen and carbon monoxide. It is assumed that the remaining gas is nitrogen. Due to the fact that the reagent for carbon dioxide will absorb all acid gases, the sulphurous gases in the products of combustion will be analyzed as carbon dioxide, but the error is slight for ordinary fuels.

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CHAPTER VIII
STEAM GENERATORS

53. *Steam generator* is the preferred name for equipment which produces steam from water by means of fuel. Steam generators are divided into two general classifications: fire-tube and water-tube, depending upon whether the water surrounds the tubes or is contained within the tubes. It might be said here that the term *boiler* is used somewhat flexibly, but strictly speaking should only be applied to the convection steam generating surface in a steam generator, while the term *steam generator* includes the boiler and all auxiliary heat recovery apparatus.

Steam generators in small sizes are rated in terms of boiler horsepower, which amounts to a heat absorption of 33,480 Btu per hour per boiler horsepower, or 34.5 pounds of steam per hour per boiler horsepower from and at 212 F. One boiler horsepower is also approximately equal to ten square feet of convection heating surface. Large steam generators are rated in terms of the actual weight of steam produced per hour at definite outlet conditions with feed-water at a definite temperature.

54. Steam Generator Efficiency--Steam generator efficiency is the quotient of the heat output of the steam generator divided by the heat input from the fuel. That is:

$$e_{sg} = \frac{M_v(H_v - h_{f_1}) + M_b(h_{f_2} - h_{f_1})}{M_f(HHV)}$$

where: M_v = steam flow, lbs/hr
M_b = blowdown rate, lbs/hr
M_f = fuel feed rate, lbs/hr or cu ft/hr
H_v = enthalpy of steam at boiler outlet, Btu/lb
h_{f_1} = enthalpy of boiler feed, Btu/lb
h_{f_2} = enthalpy of saturated water at boiler pressure, Btu/lb
HHV = higher heating value of fuel, Btu/lb or Btu/cu ft

Quite often it is impossible to measure accurately the quantities of fuel, steam and blowdown, making it necessary

to determine the steam generator efficiency by the method of losses. This method requires that the flue gas analysis and ultimate analysis of the fuel, as well as combustion air temperature, fuel temperature and flue gas temperature be known. The various losses per pound of fuel can then be calculated and the difference between the heating value of the fuel and the losses considered as the heat absorbed by the steam generator. The losses are:

(a) Due to sensible heat in the dry flue gases.

(b) Due to sensible and latent heat in the vapor formed from the moisture in the fuel.

(c) Due to sensible and latent heat in the vapor formed from the combustion of hydrogen in the fuel.

(d) Due to carbon monoxide resulting from the incomplete combustion of carbon.

(e) Due to unburned carbon in the ash pit refuse and in fly ash.

(f) Due to radiation from the boiler setting.

(g) Due to unaccounted for losses, such as sensible hea in the ash pit refuse, unburned hydrocarbons, and moisture in the air used for combustion. (This item can be estimated at from 0.1 to 0.2 per cent.)

The above losses might be regrouped into two general classifications, as follows:

A. Combustion losses due to failure to develop the full heating value of the fuel. These items would include items (d) and (e) and part of (g).

B. Conversion losses due to failure to transmit all of the heat developed to the steam. These losses would include items (a), (b), (c) and (f) and part of (g).

Example 17 shows the method of determination of steam generator efficiency by the direct method and by the method of losses for solid or liquid fuels, and Example 18 shows the same procedure for gaseous fuels.

Example 17.

The following data were recorded for a test on a boiler

rated at 200,000 lbs per hour and equipped with a completely water-cooled furnace:

Average steam temperature	900 F
Average steam pressure	910 psig
Steam generated in 8 hours	1,600,000 lbs
Average feed-water temperature	300 F
Heating value of coal as fired	14,400 Btu/lb
Fuel fired in 8 hours	74 tons
Heating value of refuse	5,100 Btu/lb
Refuse collected in 8 hours	5.9 tons
Average flue gas temperature	250 F
Average combustion air temperature	110 F
Average fuel temperature	70 F

Flue gas analysis by volume

CO_2 = 12.8 o/o
O_2 = 6.4 o/o
CO = 0.2 o/o
N_2 = 80.6 o/o

Fuel analysis lb/lb as fired

C = 0.8152
H = 0.0447
O = 0.0495
N = 0.0100
S = 0.0063
ash = 0.0521
mois. = 0.0222

Make a heat balance for the boiler:

Solution:

A. Carbon burned:

$$C_{burned} = C - \left[\frac{\text{wt. of refuse(heating value of refuse)}}{14600(\text{wt. of fuel})}\right]$$

$$C_{burned} = 0.8152 - \left[\frac{5.9(5100)}{14600(74)}\right] = 0.7873 \text{ lb/lb fuel}$$

B. Dry gas: (See Example 15)

$$M_{gd} = \frac{44(12.8)+32(0.4)+28(80.6+0.2)}{12(12.8+0.2)}[0.7873+0.375(0.0063)] + 0.625(0.0063)$$

$$= 15.30 \text{ lbs/lb fuel}$$

C. Heat absorbed by boiler:

$$Q_1 = \frac{\text{Wt. of water evaporated(heat added to water)}}{\text{Wt. of fuel fired}} \text{ Btu/lb}$$

$$Q_1 = \frac{1{,}600{,}000(1450.9 - 269.6)}{74(2000)} = 12{,}780 \text{ Btu/lb fuel}$$

D. Heat loss due to dry flue gas:

Q_2 = 0.24(M_{gd})(temp. of flue gas − temp. of comb. air)

Q_2 = 0.24(15.30)(250 − 110) = 515 Btu/lb fuel

E. Heat loss due to moisture in fuel:

When temperature of flue gas < 575 F:

Q_3 = [mois. in fuel][1089 − temp. of fuel + 0.46(temp. of flue gas)]

When temperature of flue gas > 575 F:

Q_3 = [mois. in fuel][1066 − temp. of fuel + 0.50(temp. of flue gas)]

Q_3 = 0.0222[1089 − 70 + 0.46(250)] = 25 Btu/lb fuel

F. Heat loss due to moisture from combustion of H:

When temperature of flue gas < 575 F:

Q_4 = [9 H][1089 − temp. of fuel + 0.46(temp. of flue gas)]

When temperature of flue gas > 575 F:

Q_4 = [9 H][1066 − temp of fuel + 0.50(temp. of flue gas)]

Q_4 = 9[0.0447][1089 − 70 + 0.46(250)] = 456 Btu/lb fuel

G. Heat loss due to carbon monoxide in flue gas:

$$Q_5 = \frac{CO}{CO_2 + CO}(10160)(C_{burned})$$

$$Q_5 = \frac{0.2}{12.8 + 0.2}(10160)(0.7873) = 123 \text{ Btu/lb fuel}$$

H. Heat loss due to combustible in refuse:

$$Q_6 = \frac{\text{Wt. of refuse}}{\text{Wt. of fuel}}(\text{heating value of refuse})$$

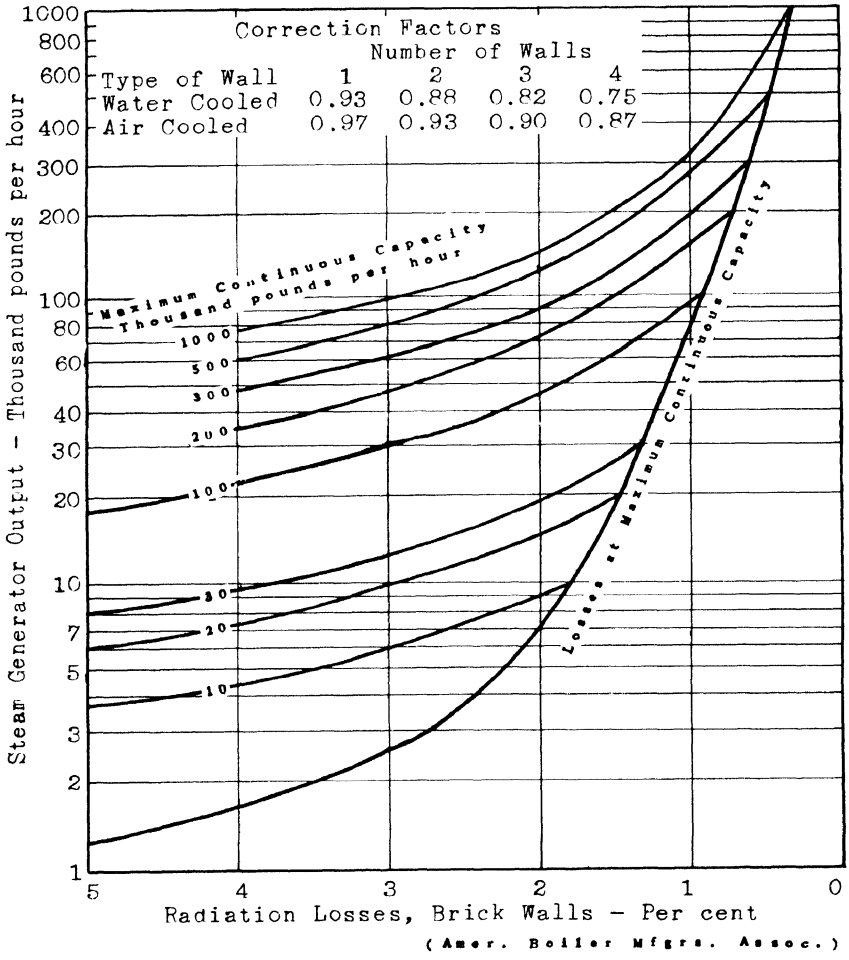


Fig. VIII-1. A.B.M.A. boiler radiation loss chart.

$$Q_e = \frac{5.9}{74}(5100) = 407 \text{ Btu/lb fuel}$$

I. Radiation losses from boiler setting:

From Figure VIII-1, radiation losses for a 200,000 lb/hr boiler at full load are 0.75 o/o for brick walls, with a

correction factor of 0.75 for four water-cooled walls.

$Q_7 = 0.0075(0.75)(14400) = 81$ Btu/lb fuel

J. Unaccounted for losses:

Q_8 = Heating value of fuel − $[Q_1 + Q_2 + Q_3 + Q_4' + Q_5 + Q_6 + Q_7]$

$Q_8 = 14400 - [12780+515+25+456+123+407+81] = 13$ Btu/lb fuel

Recapitulation: Basis, one lb fuel as fired.

Heat absorbed by boiler	12780	Btu/lb	88.7 o/o
Heat loss due to dry flue gas	515		3.6
Heat loss due to moisture in fuel	25		0.2
Heat loss due to mois. from comb. of H	456		3.2
Heat loss due to carbon monoxide	123		0.8
Heat loss due to comb. in refuse	407		2.8
Heat loss due to radiation	81		0.6
Unaccounted for losses	13		0.1
Heating value of fuel	14400	Btu/lb	100.0 o/o

Example 18.

The following data were recorded for a test on a boiler rated at 25,000 lbs per hour and equipped with plain brick furnace walls:

Average steam pressure	215 psig
Average steam temperature	540 F
Steam generated in 4 hours	86,000 lbs
Average feed-water temperature	260 F
Heating value of gas (std.cond.)	1,060 Btu/cu ft
Fuel fired in 4 hours, at 70 F and 3 psig	89,400 cu ft
Average flue gas temperature	350 F
Average combustion air temp.	100 F

Flue gas analysis by volume

$CO_2' = 9.3$ o/o
$O_2' = 2.5$ o/o
$CO = 0.3$ o/o
$N_2 = 87.9$ o/o

Fuel analysis by volume

$CH_4 = 0.840$
$C_2H_6 = 0.120$
$N_2 = 0.025$

Make a heat balance for the boiler.

Solution:

The volumetric fuel analysis is first changed to a gravimetric analysis:

Const.	anal. by vol.	mol. wt.	lbs.	anal. by wt.
CH_4	0.840	16	13.45	0.759
C_2H_6	0.120	30	3.60	0.203
N_2	0.025	28	0.70	0.038
	1.000		17.75	1.000

A. Dry gas: (See Example 16)

$$M_{gd} = \frac{44(9.3)+32(2.5)+28(87.9+0.3)}{12(9.3+0.3)}[0.75(0.759)+0.8(0.203)] + 0.038$$

M_{gd} = 18.82 lbs/lb fuel

B. Heat absorbed by boiler: (See Example 17)

From the calculations converting the fuel analysis to the gravimetric basis, the apparent molecular weight is 17.75, from which R = 1544/17.75 = 87.0. The weight of fuel fired is:

$$M_f = \frac{(3+14.7)(144)(89400)}{87(530)} = 4950 \text{ lbs}$$

The weight of one cubic foot of fuel at standard conditions is:

$$\rho = \frac{30(0.491)(144)}{87(520)} = 0.0469 \text{ lb/cu ft}$$

from which the heating value of the fuel is:

$$HHV = \frac{1060}{0.0469} = 22600 \text{ Btu/lb}$$

$$Q_1 = \frac{86{,}000(1287.8 - 228.6)}{4950} = 18400 \text{ Btu/lb fuel}$$

C. Heat loss due to dry flue gas: (See Example 17)

$Q_2 = 0.24(18.82)(350 - 100) = 1130$ Btu/lb fuel

D. Heat loss due to moisture from combustion of H:

When temperature of flue gas < 575 F:

$Q_4 = [2.25\ CH_4 + 1.8\ C_2H_6 + 1.29\ C_2H_4 + 9\ H_2][1089 - \text{temp. of fuel} + 0.46(\text{temp. of flue gas})]$

When temperature of flue gas > 575 F:

$Q_4 = [2.25\ CH_4 + 1.8\ C_2H_6 + 1.29\ C_2H_4 + 9\ H_2][1066 - \text{temp. of fuel} + 0.50(\text{temp. of flue gas})]$

$Q_4 = [2.25(0.759) + 1.8(0.203)][1089 - 70 + 0.46(350)]$

$Q_4 = 2440$ Btu/lb fuel

E. Heat loss due to carbon monoxide in flue gas:

$$Q_5 = \frac{CO}{CO_2 + CO}(10160)(0.75\ CH_4 + 0.8\ C_2H_6 + 0.857\ C_2H_4)$$

$$Q_5 = \frac{0.3}{9.3 + 0.3}(10160)(0.75[0.759] + 0.8[0.203]) = 232 \text{ Btu/lb}$$

F. Radiation losses from boiler setting:

From Figure VIII-1, radiation losses for a 25,000 lb/hr boiler operating at 21,500 lbs/hr are 1.5 o/o.

$Q_7 = 0.015(22600) = 339$ Btu/lb fuel

G. Unaccounted for losses:

$Q_8 = 22600 - [18400+1130+2440+232+339] = 59$ Btu/lb fuel

Recapitulation: Basis, one lb fuel as fired.

Heat absorbed by boiler	18400 Btu/lb	81.5 o/o
Heat loss due to dry flue gas	1130	5.0
Heat loss due to mois. from comb. of H	2440	10.8
Heat loss due to carbon monoxide	232	1.0
Heat loss due to radiation	339	1.5

Unaccounted for losses	59	0.2
Heating value of fuel	22600 Btu/lb	100.0 o/o

55. Fire-Tube Boilers--Fire-tube boilers (or steam generators) are built in sizes up to about 500 horsepower and for pressures up to about 200 psig. The principal types are: horizontal return tubular; Scotch marine; vertical tubular; and firebox tubular.

Horizontal return tubular boilers consist of a drum with longitudinal flues set over a brick firebox, as shown in Figure VIII-2. They are moderately efficient and are suitable for use with any kind of fuel.

Scotch marine boilers are so named because they were first used in steam powered ships built in Scotland. They have been adapted to stationary power plants and are most popular for packaged units because the furnace is internal to the boiler. Figure VIII-3 shows a modern Scotch marine package unit.

Vertical tubular boilers are built in small sizes up to about 50 boiler horsepower and are popular for laundries and small food processing plants because of the small floor space requirement. Due to the fact that part of the flues are above the water line, the steam is delivered with a small amount of superheat. Figure VIII-4 shows a boiler of this type.

Firebox tubular boilers are made in a number of different designs, one of which is shown in Figure VIII-5. Their advantage is the ability to put more heating surface in a given total boiler volume than the other fire-tube types.

Fire-tube boilers are not made for high pressures because of the difficulty of staying the flat tube sheets against bulging, and because tubes are relatively less resistant to collapse from external pressure than they are to rupture from internal pressure.

56. Water-Tube Boilers--Water-tube boilers are built in capacities from about 100 boiler horsepower to more than one million pounds of steam per hour, with pressures ranging from 15 to 3500 psig. The variety of water-tube boilers is very large, but the general types are: straight tube and bent tube.

Straight tube boilers require the use of headers for the tube ends. The main disadvantage is that the many hand-

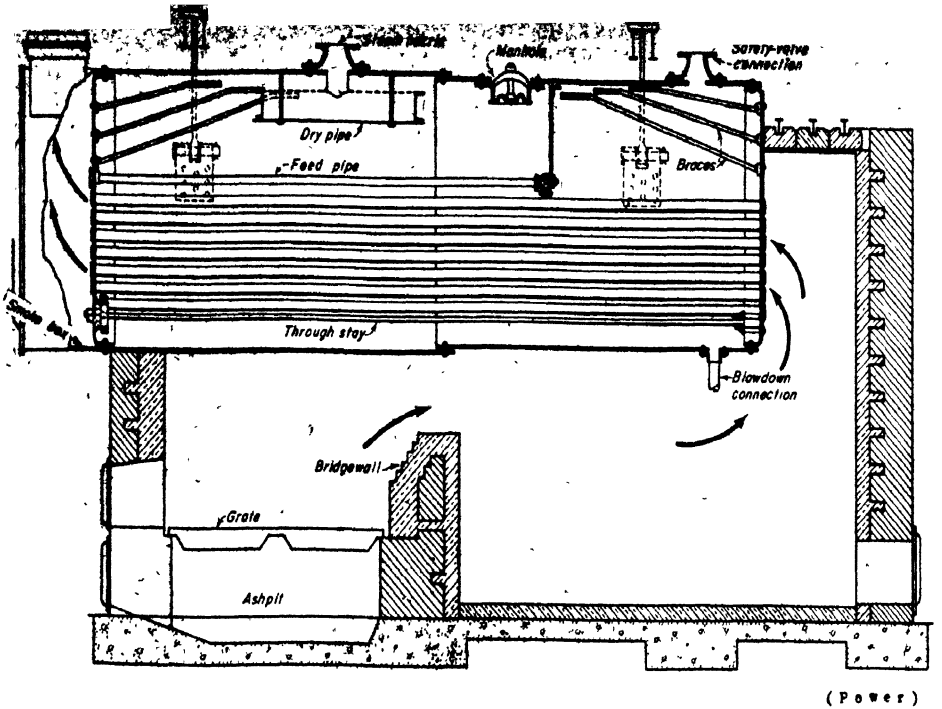


Fig. VIII-2. Horizontal return tubular boiler.

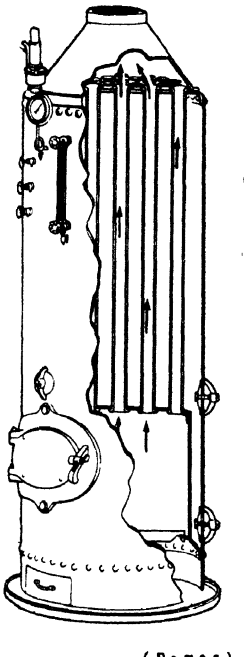


Fig. VIII-4. Vertical tubular boiler.

(Cleaver-Brooks Co.)

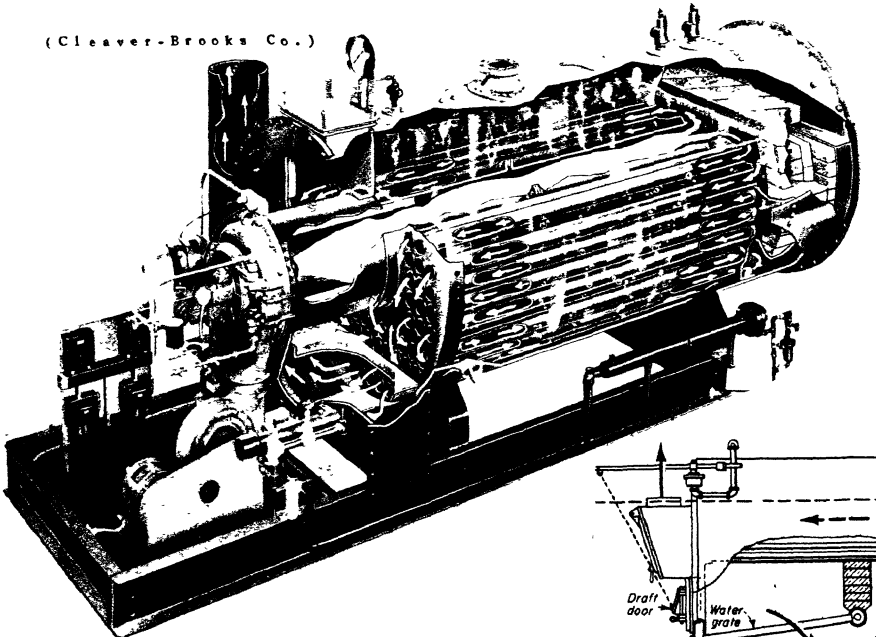


Fig. VIII-3. Package Scotch marine type boiler.

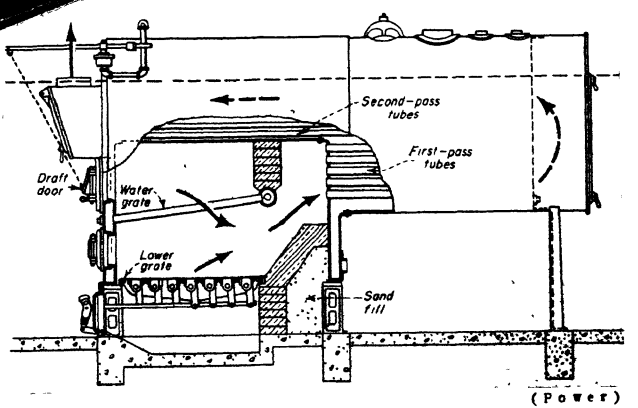


Fig. VIII-5. Firebox tubular boiler.

hole covers which are necessary have a tendency to leak. The main advantages are that all of the steam generating tubes are alike and they are easy to clean, when necessary. Figures VIII-6 and VIII-7 show two types of straight tube boilers.

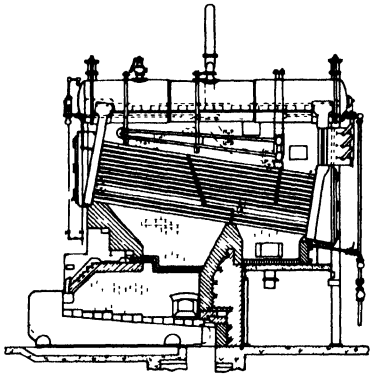


Fig. VIII-6. Longitudinal drum straight tube boiler.

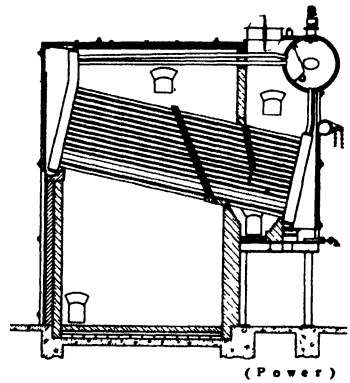
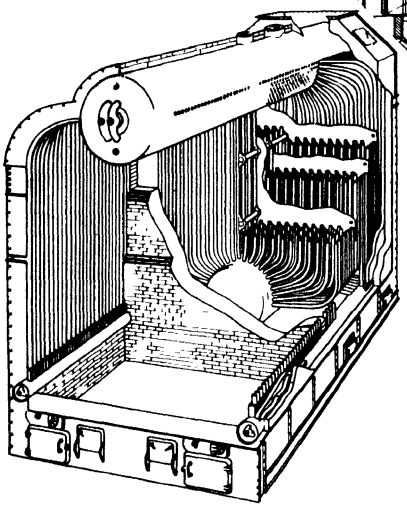


Fig. VIII-7. Cross drum straight tube boiler.

Bent tube boilers were designed to eliminate the tube headers and handhole covers which gave trouble in the straight tube boilers in the higher pressure ranges. Figures VIII-8 through VIII-11 show some modern bent tube boilers of various sizes and arrangements and Figure VIII-12 shows boiler cost data (based on 1946).

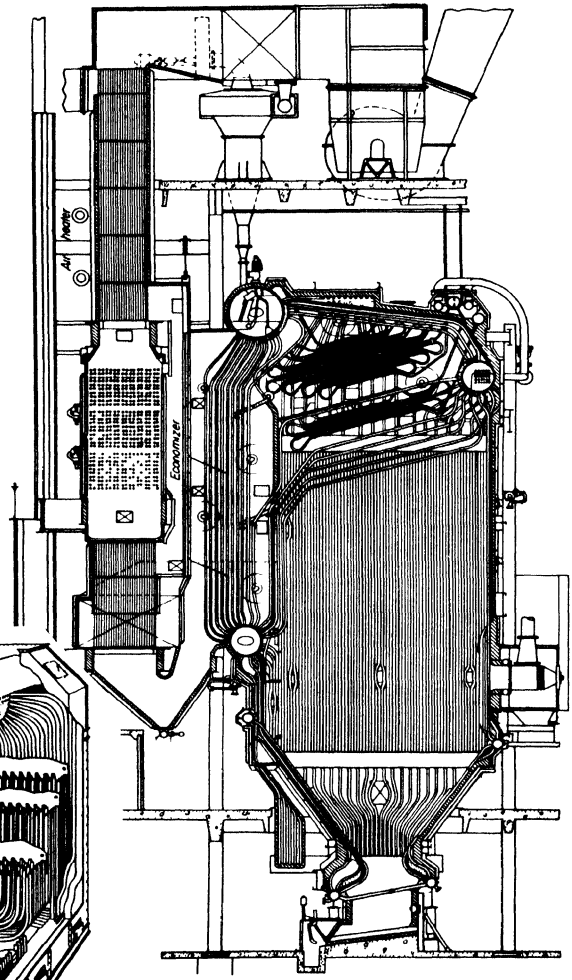
57. Heat Transfer in Boilers--The major portion of the heat transfer in boilers takes place by convection from the flue gases and by conduction through the tubes. Consideration of the mechanisms of heat transfer in boilers will show that, while they are similar to those in surface condensers, some of the factors are not easily determined. For instance, in most boilers the circulation of water is by natural forces set up by the difference in density between steam and water, and as a consequence it is not easy to determine the velocity of the water passing over the boiler surface. In a similar manner to the effect of velocity on water film coefficients, the velocity of the flue gas over the surface of the tubes affects the gas film coefficient. For these reasons, manufacturers of boilers employ empirical formulae to a great extent in calculating the heating surface required.

One of the best known empirical formulae for estimation



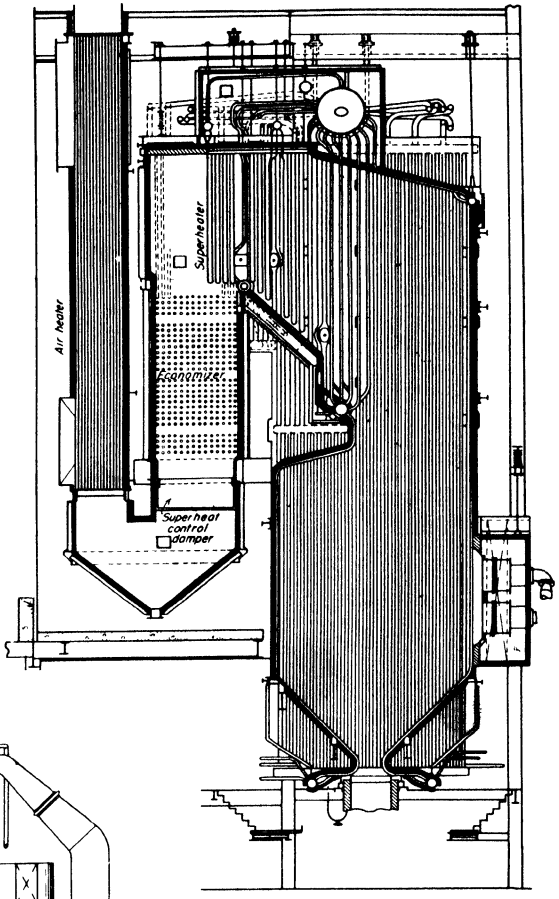
(Power)

Fig. VIII-8. Longitudinal drum bent tube boiler.



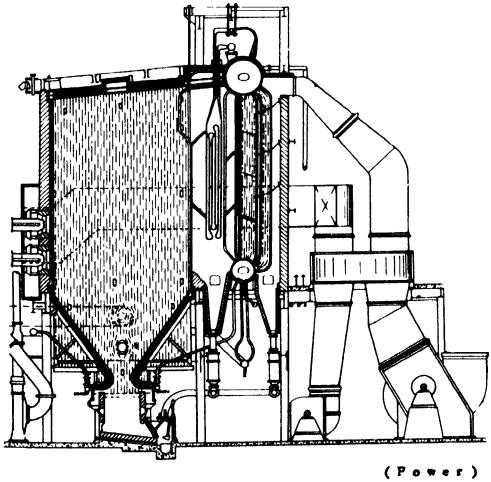
(Power)

Fig. VIII-9. Three drum bent tube boiler.



(Power)

Fig. VIII-10. Radiant boiler.



(Power)

Fig. VIII-11. Two drum bent drum boiler.

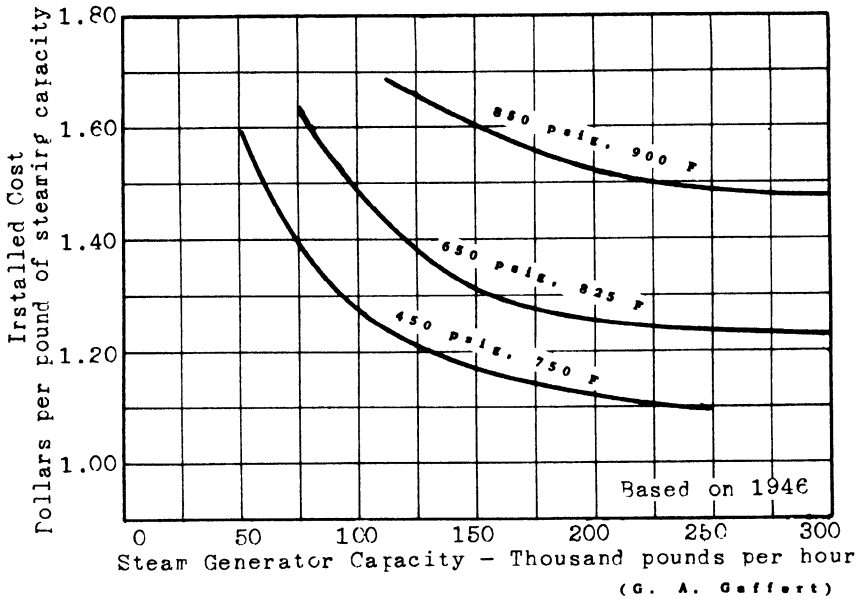


Fig. VIII-12. Boiler cost data.

of overall heat transfer coefficients in water-tube boilers is the Babcock and Wilcox equation:

$$U = 2.00 + 0.0014\ G$$

where: G = mass flow of gas, lbs/hr per sq ft of projected flow area transverse to the tubes.

Example 19 shows the method of estimating the surface required for a water-tube boiler.

Example 19.

A boiler using fuel oil of the analysis of Example 15 with a heating value of 18500 Btu/lb and with the same flue gas analysis is to produce 20,000 pounds of steam per hour at 150 psig and saturated from feed-water at 212 F. Temperature of flue gas 500 F, temperature of combustion air 80 F, temperature of combustion 2500 F, and temperature of fuel 180 F. The boiler is to be of the three-pass straight

tube sectional header type with 3 in. OD tubes spaced 5 in. on centers. There will be 24 tubes per bank, and the tubes will be 12 ft long. Determine the number of banks required, neglecting the area of the sectional headers and the boiler drum. The furnace has plain brick walls. Assume that no refuse is formed.

Solution:

The heat absorbed by the boiler per pound of fuel fired can be determined by the method of losses, allowing about 1 o/o for unaccounted for.

$Q_2 = 0.24(19.93)(500 - 80) =$ 2010 Btu/lb

$Q_3 = 0.01(1089 - 180 + 0.46[500]) =$ 11

$Q_4 = 9(0.1270)(1089 - 180 + 0.46[500]) =$ 1300

$Q_5 = \frac{0.4}{13.7 + 0.4}(10160)(0.83) =$ 239

$Q_7 = 0.015(18500) =$ 278

$Q_8 = 0.01(18500) =$ 185

Total losses 4023

$Q_1 = 18500 - 4023 =$ 14477 Btu/lb

The weight of fuel fired per hour is:

$$M_f = \frac{20{,}000(1195.6 - 180.1)}{14477} = 1405 \text{ lbs/hr}$$

The heat transferred is:

$$Q = 20{,}000(1195.6 - 180.1) = 20{,}300{,}000 \text{ Btu/hr}$$

The gas flow is:

$$M_{gw} = 21.08(1405) = 29600 \text{ lbs/hr}$$

The transverse gas flow area between tubes is:

$$A_f = \frac{(24 - 1)(5 - 3)12}{3(12)} = 15.35 \text{ sq ft}$$

from which, $G = \frac{29600}{15.35} = 1930$ lbs/hr/sq ft

and from the Babcock and Wilcox equation,

$$U = 2.00 + 0.0014(1930) = 4.70$$

The mean temperature difference is:

$$t_m = \frac{2500 - 500}{\log_e \frac{366 - 2500}{366 - 500}} = 724 \text{ F}$$

and the boiler area required is:

$$A = \frac{20,300,000}{4.70(724)} = 5970 \text{ sq ft}$$

Each bank of tubes contains $12(\frac{3\pi}{12})(24) = 226$ sq ft

therefore, the number of banks of tubes required is:

$$\frac{5970}{226} = 26 \text{ banks of tubes.}$$

58. **Water-Cooled Furnaces**--The water-cooled furnace was introduced as a means of reducing maintenance on furnace refractories. Acceptance was slow because of difficulties with water circulation, but a modern steam generator is almost all water-cooled furnace with only enough boiler surface to reduce the gas temperature to an economical point for use in economizers or air heaters. Reference to the illustrations of water-tube boilers will show the application of furnace cooling.

Heat transfer to furnace cooling surface is almost entirely by radiation and the heat transfer coefficients are extremely high. The amount of radiant heating surface required in a furnace is a function of several variables, such as the volume of the furnace, the temperature of the flue gas leaving the furnace, the sensible heat in the flue gas and the arrangement of the cooling surface.

Table XII gives some generally accepted data on values of heat release per unit of furnace volume.

The temperature of the flue gas leaving the furnace should always be at least 200 F and preferably 250 F less tha the ash fusion temperature of the fuel used in order to avoid tightly adhering deposits in the convection sections of the steam generator. The result is that with fuels with very low

ash fusion temperatures (fuel oil has an ash fusion temperature of about 1600 F) the steam generator would necessarily be mostly furnace.

The sensible heat in the flue gas can be calculated from the following relation:

$$\text{Sensible heat/lb fuel} = LHV - h' - h'' + h'''$$

where: LHV = lower heating value of fuel
h' = heat lost by radiation and convection from the boiler setting
h'' = heat lost due to incomplete combustion and due to combustible in refuse
h''' = heat gained by use of preheated air

TABLE XII

FURNACE HEAT RELEASE

KBtu per cubic foot per hour

Fuel	All refractory	Air cooled	Water cooled
Coal			
Pulverized	12 - 18	15 - 20	18 - 25
Stokers	15 - 25	25 - 40	30 - 45
Grates	25 - 40	35 - 45	40 - 50
Gas and Oil	20 - 35	25 - 40	30 - 50

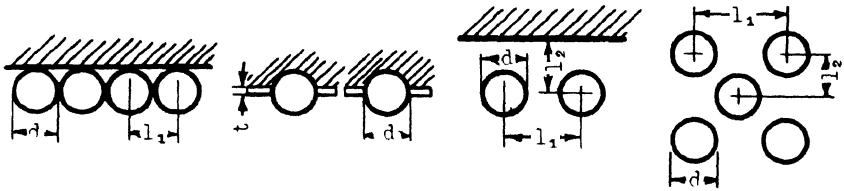
Lower values in a range are for smaller boilers.

The arrangement of the cooling surface affects the effective area as shown in Figure VIII-13. The effective area is related to the projected area on the furnace envelope by the equation:

$$S_r = s\delta S_p$$

where: S_r = effective radiant cooling surface, sq ft

s = a slagging factor (0.90 to 0.95)
S_p = projected tube area, sq ft
δ = an arrangement factor



$\delta = [\pi/2][l_1/d]$ up to $l_1/d = 1.5$ $\quad \delta = \pi/2 + 6t$ $\quad \delta = [\pi/2][l_1/d]$ up to $l_1/d = 1.5$ $\quad \delta = 2$

(Courtesy of D. Van Nostrand Co., Inc.)

Fig. VIII-13. Arrangement of radiant heat transfer surface.

Figure VIII-14 shows some empirical data which ties together the preceeding factors in the estimation of furnace cooling area and Example 20 shows the method of estimation of the pricipal dimensions of a water-cooled furnace.

Example 20.

Determine for the boiler of Example 17:

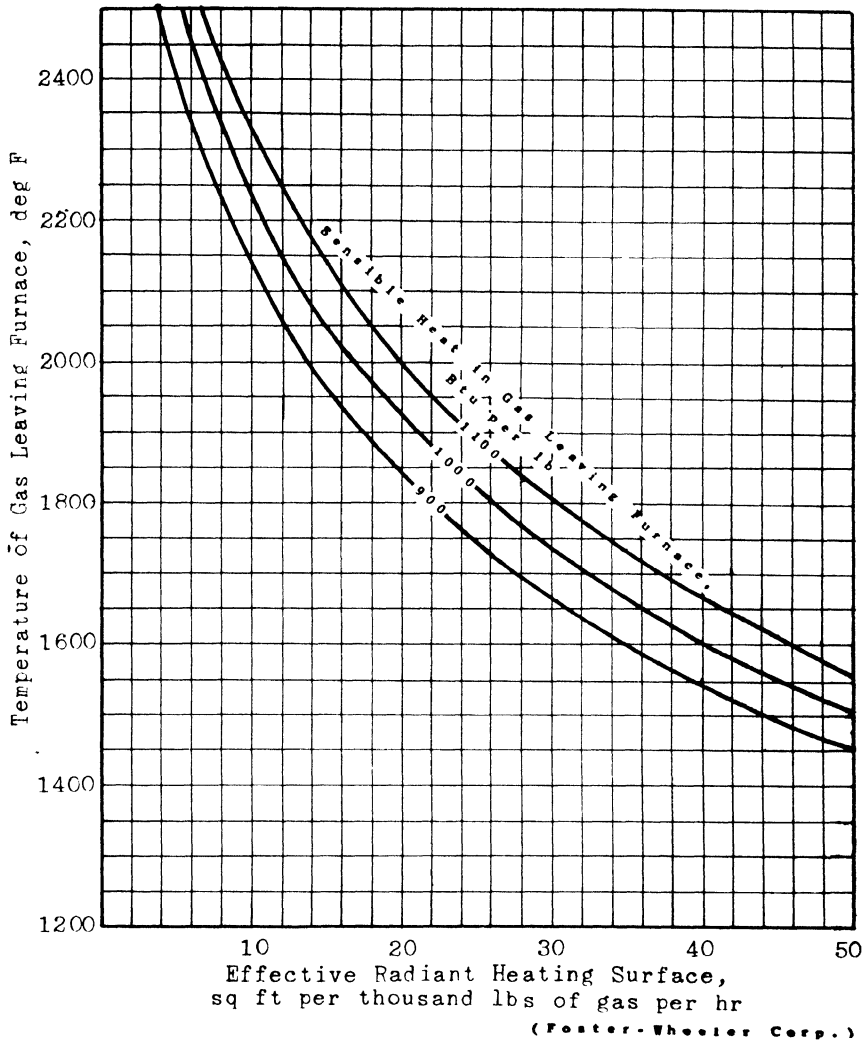
1. The furnace volume required for full load operation using pulverized coal.

2. The amount of effective radiant furnace cooling surface required for a gas temperature of 1950 F entering the superheater (250 F less than the ash fusion temperature). Assume that the preheated air temperature is 535 F.

3. The number and length of 2½ in. OD furnace tubes, spaced on three inch centers. The boiler screen consists of three banks of 2½ in. OD tubes spaced on nine inch centers. The plan dimensions of the furnace are 20 ft X 20 ft.

Solution:

1. From Table XII, a heat release value of 22,000 Btu per cubic foot per hour is selected. The total heat re-



(Foster-Wheeler Corp.)

Fig. VIII-14. Furnace cooling surface design curves.

leased in the furnace is:

$$Q = \frac{74}{8}(2000)(14400) = 266{,}000{,}000 \text{ Btu/hr}$$

from which the furnace volume is:

$$V_f = \frac{266{,}000{,}000}{22000} = 12100 \text{ cu ft}$$

2. The sensible heat per pound of flue gas is:

$$SH = \frac{LHV - h' - h'' + h'''}{M_{gx}}$$

$$+ 0.24[535 - 70]$$

$$SH = \frac{14400 - [9(0.0447) + 0.0222][1066] - 81 - [123 + 497]}{15.30 + 9(0.0447) + 0.0222}$$

SH = 856 Btu/lb flue gas

Then, from Figure VIII-14, the area of effective radiant surface per thousand pounds of gas per hour is 14 sq ft. The total area is:

$$S_r = \frac{14(15.72)(2000)(74/8)}{1000} = 4070 \text{ sq ft}$$

3. The boiler screen will have 20 ft tubes, and there will be 20(12)/9 = 26 tubes per bank. Assuming a slagging factor of 0.90 and δ = 2, the effective radiant area of the boiler screen will be:

$$S_r = 0.90(2)(2.25/12)(20)(26)(3) = 525 \text{ sq ft}$$

The furnace walls will have an effective radiant surface of 4070 - 525 = 3545 sq ft. The length of the furnace wall tubes will be approximately the same as the height of the furnace, or 30.2 ft. Assuming a slagging factor of 0.90 and $\delta = (\pi/2)(3/2.25) = 2.09$, the projected area of the furnace wall tubes will be:

$$S_p = \frac{3545}{0.90(2.09)} = 1885 \text{ sq ft}$$

The furnace walls can each have 20(12)/3 = 80 tubes, each 30.2 ft long, for a total of:

$$S_{p_{walls}} = 4(80)(30.2)(2.25/12) = 1810 \text{ sq ft}$$

This leaves 75 sq ft of projected area for the furnace floor, and since each floor tube would have a projected area of 20(2.25)/12 = 3.75 sq ft, there would be 75/3.75 = 20 floor tubes.

59. Furnace Refractories and Insulation--In order to minimize heat losses from furnaces, it is necessary to supply some sort of insulating material, and in order to prevent fire damage to insulation it is necessary to supply refractory.

Refractories are made from materials which have good resistance to damage from direct flame impingement. They are usually supplied in brick form, although plastic refractories are available. The standard refractory brick is $2\frac{1}{2}$" X $4\frac{1}{2}$" X 9", and other sizes are available in multiples and submultiples of these dimensions as well as in special shapes. Figure VIII-15 shows some heat conductivity data for various refractory materials.

Insulation is made of material which has good resistance to heat flow but which is not necessarily resistant to direct flame impingement. Several companies make insulating refractories which are very useful. Figure VIII-16 shows some heat conductivity data for various insulating materials.

Heat flows through the furnace wall by conduction and leaves the outer wall by radiation and convection. It is usually assumed that the heat lost by convection is about 50 per cent of that lost by radiation, so that

$$Q = 1.5\ CA(T_1^4 - T_2^4)$$

where: Q = heat loss, Btu/hr
C = a radiation coefficient
A = area of radiating surface, sq ft
T_1 = temperature of radiating surface, deg R
T_2 = ambient temperature, deg R

The preceeding expression will be recognized as a modification of the Stefan-Boltzman relation, and values of the radiation coefficient can be found from Table XIII.

It is obvious that the heat lost from the wall surface must be equal to the heat flowing through the wall, so that the determination of the thickness of insulation required resolves itself into a trial and error process. Ordinarily it will be known how much structural brick is necessary on the outside of the furnace wall and how much refractory is used inside the furnace (from $2\frac{1}{2}$" to $4\frac{1}{2}$" for backing water walls and from 9" to $13\frac{1}{2}$" for plain walls). Example 21

shows the method of procedure.

TABLE XIII

RADIATION COEFFICIENTS

Bare brick work	16.3×10^{-10}
Unpainted steel	16.3×10^{-10}
Asbestos cloth	16.0×10^{-10}
Aluminum paint	11.0×10^{-10}
Flat black paint	16.4×10^{-10}
Glossy black paint	14.0×10^{-10}

Example 21.

Determine the thickness of insulation required for a furnace wall which consists of Armstrong insulation sandwiched between eight inches of hard burned red brick and nine inches of kaolin refractory brick. The furnace temperature is 2300 F and ambient temperature is 95 F. Desirable outside wall temperature is 175 F.

Solution:

The heat transferred through the wall is:

$$Q = 1.5[16.3 \times 10^{-10}][(635)^4 - (555)^4]$$

$$Q = 164 \text{ Btu/hr/sq ft}$$

Temperature drop through the wall is 2300 - 175 = 2125F. Temperature drops through the individual sections of the wall will be determined by trial.

Assume mean temperature of red brick = 300 F and mean temperature of kaolin brick = 2150 F. From Figure VIII-15, the values of k at these temperatures will be 6.5 for red brick and 15.0 for kaolin brick.

Then, for red brick, $\Delta t = Qd/k = 164(8)/6.5 = 202$ F, and for kaolin brick, $\Delta t = 164(9)/15.0 = 98.5$ F.

Recalculation of mean temperatures gives for red brick, $0.5[175 + (175 + 202)] = 276$ F, and for kaolin brick, $0.5[2300 + (2300 - 98.5)] = 2251$ F. At these mean temperatures, k for red brick is 6.4 and for kaolin brick is 15.5.

Then, for red brick, $\Delta t = 164(8)/6.4 = 205$ F, and for kaolin brick, $\Delta t = 164(9)/15.5 = 95.3$ F.

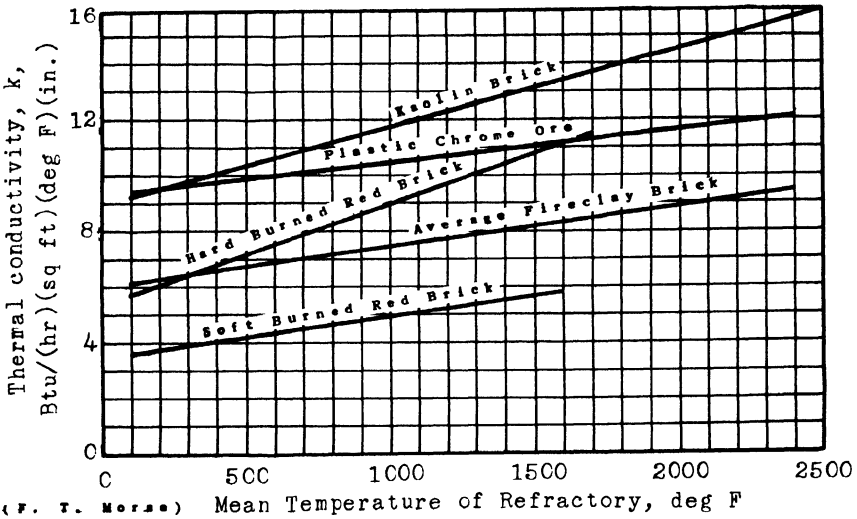


Fig. VIII-15. Thermal conductivity of refractory materials.

Recalculation of mean temperatures gives for red brick, $0.5[175 + (175 + 205)] = 278$ F, and for kaolin brick, $0.5[2300 + (2300 - 95.3)] = 2257$ F. These mean temperatures are reasonably close to the previous calculations so that further trials are not considered necessary.

The temperature drop for the insulation will be $\Delta t = (2300 - 95.3) - (175 + 205) = 1825$ F, and the mean temperature is $0.5(2205 + 380) = 1292$ F. At this mean temperature, k for the insulation is 1.7, and the insulation thickness is $d = k\Delta t/Q = 1.7(1825)/164 = 18.9$ inches.

Example 21 shows clearly why insulated refractory and brick furnaces are seldom used in modern boiler installations. Better arrangements are water-cooled or air-cooled walls.

In the water-cooled wall the inside wall temperature is reduced almost to the saturation temperature of the steam in the boiler, thus necessitating less refractory and insulation. As previously mentioned, water walls are backed with up to $4\frac{1}{2}$" of refractory, and ir addition a layer of Superex block and 3" of rockwool (conductivities of these materials can be found from Figure X-13) with an outside casing of sheet metal are usually used to complete the wall. The effect of the metal casing can be ignored with respect to the

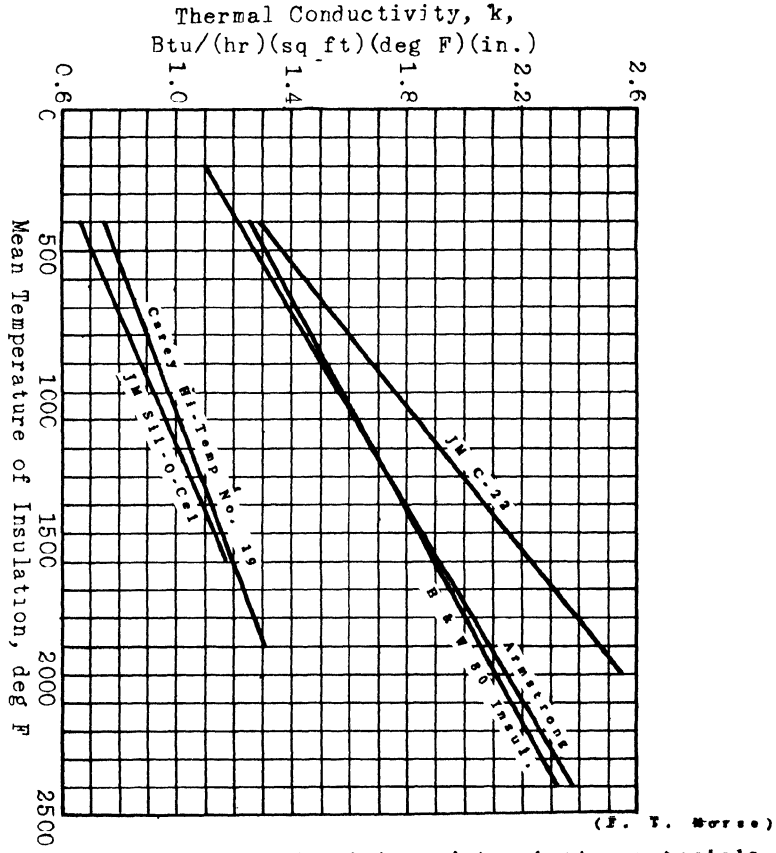


Fig. VIII-16. Thermal conductivity of insulating materials.

amount of insulation required, but the exterior finish (color of paint) must be considered in determination of the heat loss from the surface.

In the air-cooled wall the refractory and structural brick are separated by an air space which serves as a conduit for combustion air. Thus, most of the heat passing through the refractory is salvaged and returned to the furnace.

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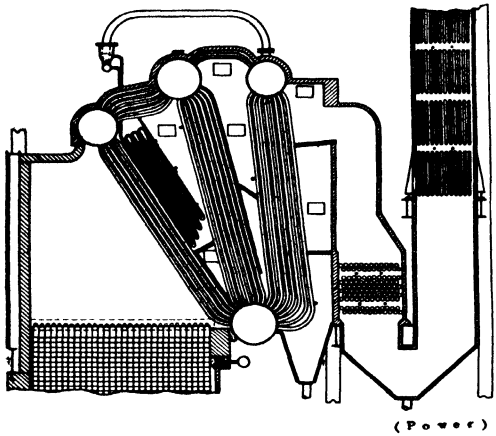
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CHAPTER IX

SUPERHEATERS, REHEATERS, ECONOMIZERS AND AIR HEATERS

60. Superheaters--The economies to be realized with superheated steam in a vapor power cycle have been set forth previously under the discussion of the various cycles. Superheaters are always made up of tubular elements and they are classified as to their arrangement in the boiler, that is, pendant or drainable, convection or radiant.

Pendant superheaters are hung from headers which are located at the top of the boiler. This is the simplest arrangement, but they are difficult to clean. Figure IX-1 shows a pendant superheater in a bent tube boiler.



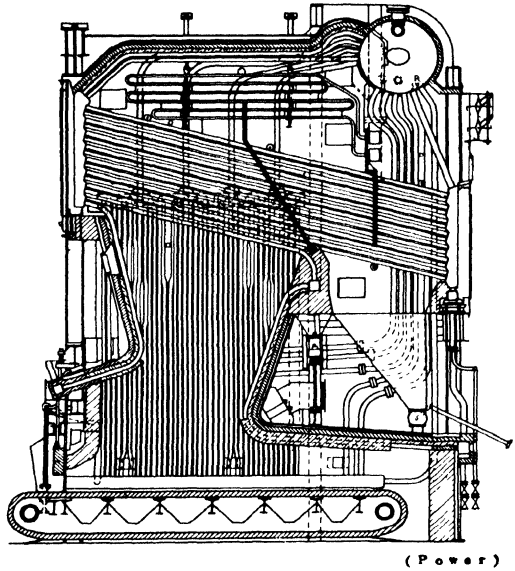
(Power)

Fig. IX-1. Pendant superheater in bent tube boiler.

Drainable superheaters are mounted in such a way that condensation in the elements can drain back to the headers. This type of superheater is more difficult to place in the boiler because it requires that all of the element slope toward the headers, but they are easy to clean. Figure IX-2 shows a drainable superheater in a straight tube boiler.

Convection superheaters are so named because they receive all or a major portion of their heat by convection from the flue gas. They have a rising temperature characteristic because of increase in heat transfer coefficients with increasing gas velocities. For this reason, modern boilers which contain convection superheaters alone have some means of bypassing part of the flue gas around part of the superheater to effect temperature control in the steam from the superheater. The temperature control damper can be seen in Figure VIII-10.

Radiant superheaters receive all or most of their heat through radiation because they are mounted where they can "see" the fire in the furnace. They have a drooping temperature characteristic because the temperature of the fire in the furnace remains essentially constant throughout the load range. Radiant superheaters are often placed in series with convection superheaters, and proper proportioning of the areas in each will result in a nearly constant steam temperature characteristic over the normal boiler operating range. Figure IX-3 shows a radiant superheater mounted in series with a convection superheater, and Figure IX-4 shows the temperature characteristics.



(Power)

Fig. IX-2. Drainable superheater in straight tube boiler.

61. Heat Transfer in Superheaters.--Heat transfer in a convection superheater involves a decreasing flue gas temperature and an increasing steam temperature. Wherever possible the surfaces are arranged so that the gases enter the superheater at the same end at which the steam leaves. This counterflow principle results in more uniform temperature differences and higher steam outlet temperatures in comparison with parallel flow arrangements. Figure IX-5 shows a comparison of the temperatures existing in the two arrangements.

The logarithmic mean temperature difference for the counterflow case can be found from the relation:

$$t_m = \frac{(t_{g_i} - t_{v_o}) - (t_{g_o} - t_{v_i})}{\log_e \frac{t_{g_i} - t_{v_o}}{t_{g_o} - t_{v_i}}}$$

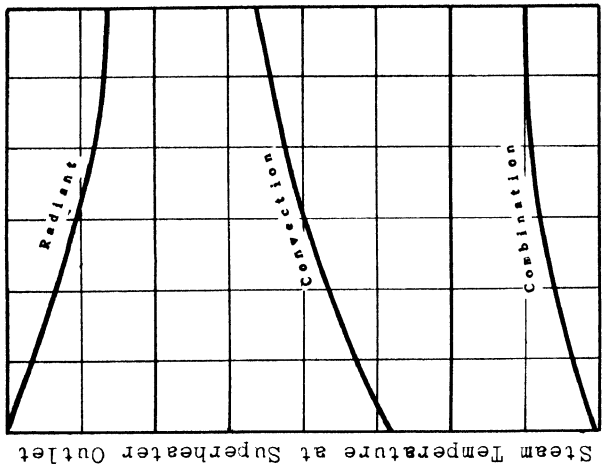


Fig. IX-4. Superheater characteristics.

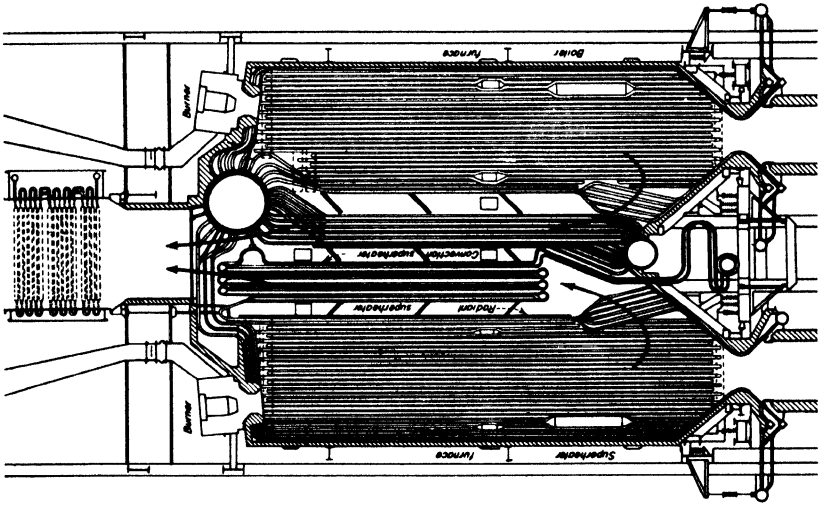
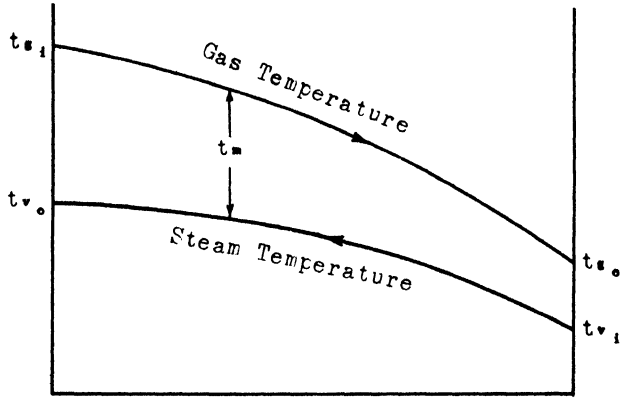


Fig. IX-3. Radiant superheater.

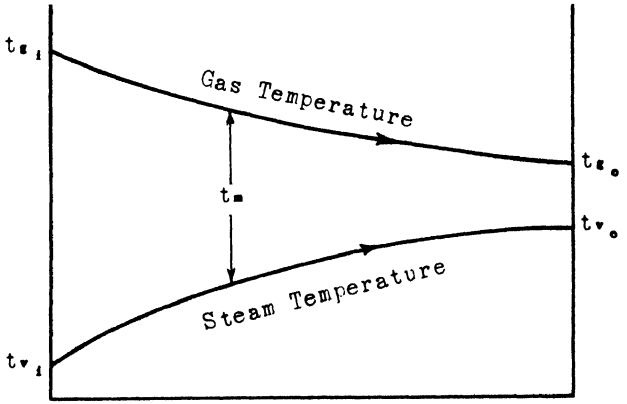
where: t_m = log mean temperature difference, deg F

t_{g_i} and t_{g_o} = inlet and outlet flue gas temperatures, deg F

t_{v_i} and t_{v_o} = inlet and outlet steam temperatures, deg F



(a) Counterflow



(b) Parallel flow

Fig. IX-5. Temperature relations in heat transfer.

and for the parallel flow case from the relation:

$$t_m = \frac{(t_{g_i} - t_{v_i}) - (t_{g_o} - t_{v_o})}{\log_e \frac{t_{g_i} - t_{v_i}}{t_{g_o} - t_{v_o}}}$$

The overall heat transfer coefficient for a convection superheater is calculated in a manner similar to that for other heat transfer apparatus. There is no reliable empirical equation for the overall heat transfer coefficient as there is for boilers, so that is is necessary to estimate film coefficients and combine them according to the usual manner with the addition of a slagging factor, as follows:

$$U = s \frac{1}{\frac{1}{h_g} + \frac{2D_o}{D_o + D_i} \frac{1}{K_t} + \frac{D_o}{D_i} \frac{1}{h_v}}$$

The gas film coefficient can be estimated from the equation:

$$h_g = \frac{0.41\ v_g^{0.585}\ T^{0.315}}{D_o^{0.415}}$$

where: v_g = mass flow of gas, lbs/sec per sq ft of gas flow area

T = arithmetic mean gas temperature, deg R

D_o = outside diameter of tube, ft

The steam film coefficient can be approximated from the following equation:

$$h_v = 8.0\ v_v^{0.8}$$

where: v_v = mass flow of steam, lbs/sec per sq ft of steam flow area

The Nusselt equation for radiant superheaters is used for the determination of the overall heat transfer coefficient, as follows:

$$U = \frac{0.0333\ k^{0.214}\ (G\ c_p)^{0.786}}{D_t^{0.214}}$$

where: k = steam conductivity,
$= 0.0121 + 0.000029\ t$
t = arithmetic mean steam temperature, deg F
G = mass flow of steam, lbs/hr per sq ft of steam flow area
c_p = arithmetic mean specific heat of steam
D_i = inside diameter of tube, ft

Example 22-A shows the method of calculating the dimensions of a convection superheater and Example 22-B shows the procedure for a radiant superheater.

Example 22-A.

Determine the number and length of tubes required for a convection superheater for the boiler of Examples 17 and 20. The tubes are 2 in. OD X 8 BWG and are spaced on 4½ in. centers. Assume counterflow and a slagging factor of 0.90. Dispose of the superheater in two of the three boiler passes.

Solution:

$$M_{gas} = (74/8)(2000)(15.72) = 291{,}000 \text{ lbs/hr}$$

$$Q = 200{,}000(1450.9 - 1197.8) = 50{,}600{,}000 \text{ Btu/hr}$$

$$\Delta t_{flue\ gas} = \frac{50{,}600{,}000}{291000(0.24)} = 725 \text{ F}$$

Temperature of gas at superheater inlet	1950 F
Temperature of gas at superheater outlet	1225 F
Temperature of steam at superheater inlet	535 F
Temperature of steam at superheater outlet	900 F

$$t_m = \frac{(1950 - 900) - (1225 - 535)}{\log_e \frac{1950 - 900}{1225 - 535}} = 860 \text{ F}$$

Since the boiler is 20 ft wide, there will be 20(12)/4.5 = 53 tubes in the superheater. Each tube has a flow area of $[\pi/4][2.0 - 2(0.165)]^2/144 = 0.0152$ sq ft, and the total steam flow area is 53(0.0152) = 0.806 sq ft.

The mass flow of steam through the tubes will be:

$$v_v = \frac{200000}{3600(0.806)} = 69.0 \text{ lbs/sec/sq ft}$$

and, $h_v = 8.0(69.0)^{0.8} = 236$

If the superheater is disposed in two of three boiler passes, each pass will be 20 ft wide by 6.67 ft deep. Then the area for gas flow between the superheater tubes will be $(53 - 1)(4.5 - 2)(6.67)/12 = 23$ sq ft.

The mass flow of gas between the tubes will be:

$$v_g = \frac{291000}{3600(23)} = 3.52 \text{ lbs/sec/sq ft}$$

and, $$h_g' = \frac{0.41(3.52)^{0.585}(2048)^{0.315}}{(2.0/12)^{0.415}} = 19.8$$

Then the overall heat transfer coefficient is:

$$U = (0.90)\frac{1}{\frac{1}{19.8} + \frac{4.0}{2.0 + 1.67}\left[\frac{0.165}{12(30)}\right] + \frac{2.0}{1.67}\left[\frac{1}{236}\right]} = 16.1$$

Superheater area is:

$$A = \frac{50,600,000}{16.1(860)} = 3666 \text{ sq ft}$$

Each foot of superheater tube has an area of $2\pi/12 = 0.523$ sq ft. There will be $3666/0.523 = 7000$ linear feet of tube, and the length of each element will be $7000/53 = 132$ feet.

Example 22-B.

The boiler of Examples 17 and 20 is to be fitted with a combination convection-radiant superheater. Half of the temperature rise in the superheated steam is to be supplied by the radiant section which is in series with and follows the convection section. The radiant superheater is to replace part of the rear furnace wall cooling surface. The tubes will be 2½ in. OD X 8 BWG spaced on 3 in. centers with a length of 5 feet. Find the number of tubes in the radiant superheater.

Solution:

Steam temperature at rad. suphtr. inlet	718 F
Steam temperature at rad. suphtr. outlet	900 F
Temperature in furnace	1950 F

$$t_m = \frac{900 - 718}{\log_e \frac{1950 - 718}{1950 - 900}} = 1134 \text{ F}$$

The heat transferred in the radiant superheater is:

$$Q = 200{,}000(1450.9 - 1342.1) = 21{,}800{,}000 \text{ Btu/hr}$$

Assume, as a first approximation, that U = 400 based on effective radiant surface. Then the effective radiant surface required would be 21800000/[(400)(1134)] = 48 sq ft. One linear foot of 2.25 in. OD tube, in this particular wall arrangement, has an effective radiant surface of $0.90(\pi/2)(3.0/2.25)(2.25/12) = 0.354$ sq ft. Then the linear length of tube required would be 48/0.354 = 136 ft. If each tube is 5 ft long, there would be 136/5 = 27 tubes in the radiant superheater.

It is necessary to check the assumed value of U by use of the Nusselt equation, as follows:

The steam flow area per tube is $[\pi/4][2.25-2(0.165)]^2/144$ = 0.02 sq ft, and the total steam flow area is 27(0.02) = 0.54 sq ft. The mass flow of steam is G = 200000/0.54 = 370000 lbs/hr/sq ft. The conductivity of the steam is k = 0.0131 + 0.000029(809) = 0.0365 and the mean specific heat is 0.62, then the overall heat transfer coefficient is:

$$U = 0.0332\left[\frac{0.0365}{1.92/12}\right]^{0.214} [370000(0.62)]^{0.786} = 404$$

This value of U checks very closely with the assumed value.

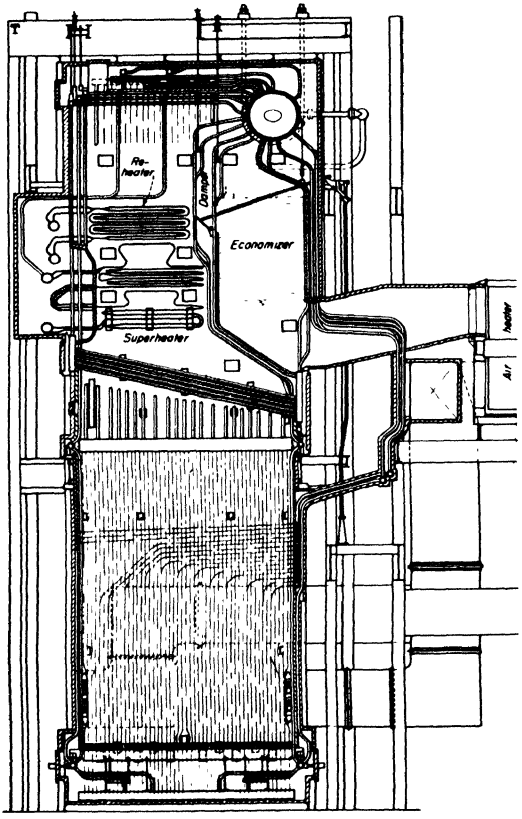
62. Reheaters--All reheaters which are presently being built use flue gas as the heat source. For this reason, the reheater may be considered to be the same as a superheater. Figure IX-6 shows a modern reheating steam generator.

63. Economizers--An economizer is essentially a feedwater heater employing flue gas as the heat source. Its primary purpose is to lower the temperature of the flue gas leaving the steam generator in order to increase the efficiency. Economizers are made in several styles, some of

which are shown in Figure IX-7.

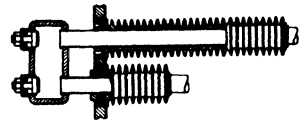
64. Heat Transfer in Economizers--Heat transfer in an economizer is from flue gas at decreasing temperature to water at increasing temperature. The overall heat transfer coefficient may be approximated from the same Babcock and Wilcox equation used for boilers.

Example 23 shows the method of estimating economizer surface.

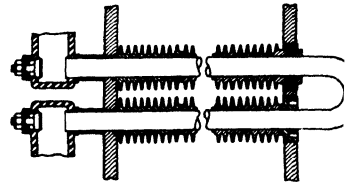


(Power)

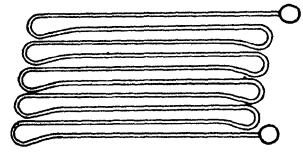
Fig. IX-6. Reheating steam generator.



A straight-tube economizer of extended-surface type. Each pair of tubes makes up in a header that acts as a manifold to connect successive passes together. Tubes, being straight, are readily replaced



U-bend or return-bend economizer contains a forged-steel header into which tubes are rolled and handhole plugs installed for tube maintenance



As its name implies, continuous-tube economizer is constructed of a looped tube between two connections

(Power)

Fig. IX-7. Economizer

Example 23.

Determine the number and length of tubes required for an economizer for the boiler of Examples 17 and 20. The tubes are 2 in. OD X 8 BWG and are spaced on 3 in. centers. Tubes run lengthwise in the economizer casing whose plan dimensions are 12 ft X 18 ft. The water flows counterflow to the gas. Gas inlet temperature is 1225 F, water inlet temperature is 300 F and water outlet temperature 485 F.

Solution:

The heat transferred in the economizer is:

$$Q = 200000(470.2 - 269.6) = 40,100,000 \text{ Btu/hr}$$

The weight of wet flue gas is 291000 lbs/hr, so that the flue gas temperature drop is 40100000/[291000(0.24)] = 575 F. Then the flue gas temperature leaving the economizer is 1225 − 575 = 650 F.

$$t_m = \frac{(1225 - 485) - (650 - 300)}{\log_e \frac{1225 - 485}{650 - 300}} = 520 \text{ F}$$

Since the economizer casing is 12 ft wide, there will be 12(12)/3 = 48 tubes giving a gas flow area of (48 − 1)(3 − 2)(18)/12 = 70.5 sq ft and a gas mass flow G = 291000/70.5 = 4130 lbs/hr/sq ft.

Then, the overall heat transfer coefficient is:

$$U = 2.0 + 0.0014(4130) = 7.78$$

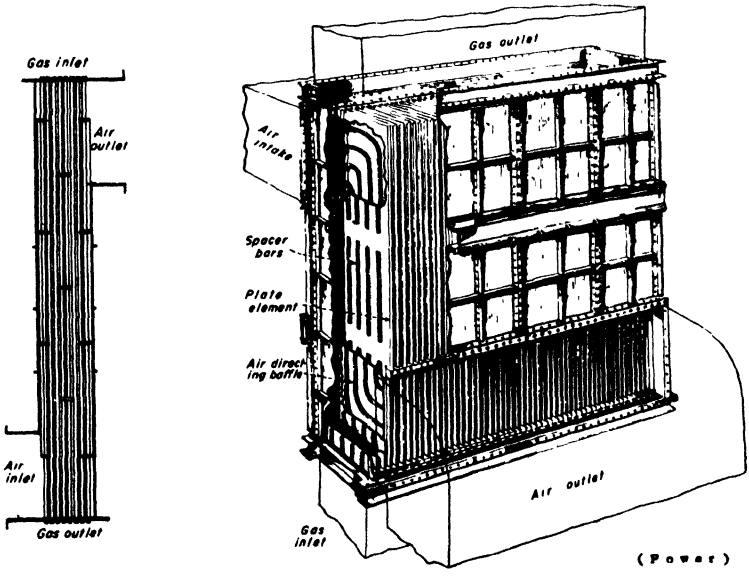
and,
$$A = \frac{40,100,000}{7.78(520)} = 9900 \text{ sq ft}$$

Each linear foot of economizer tube has a surface area of 0.523 sq ft, so that there will be 9900/0.523 = 18950 linear feet of tube. Then, the length of each tube will be 18950/48 = 395 feet.

65. Air Heaters--Air heaters are also devices for salvaging heat from the flue gas in order to improve overall steam generator efficiency. They are of two general types: recuperative, either tubular or plate; and regenerative.

Recuperative air heaters depend upon the flow of heat from the flue gas through a dividing wall to the air. Ord-

narily, in the tubular type the air flows around the outside f the tubes and the flue gas passes through the tubes. In he plate type the gas and air flow through alternate passges. Figure IX-8 shows the tubular and plate types of air eater.

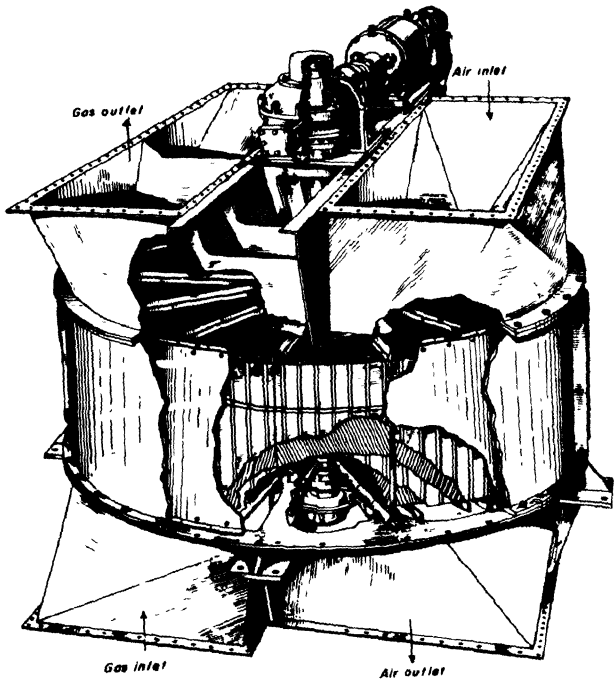


(a) Tubular Type (b) Plate Type

Fig. IX-8. Recuperative air heaters.

Regenerative air heaters depend upon the transfer of heat from gas to air by the alternate heating and cooling of a mass of metal or other heat storing material. Figure IX-9 shows the principal type of regenerative air heater in use at the present time. This type uses corrugated steel sheets for the heat storage material.

66. Heat Transfer in Air Heaters--Heat transfer in air heaters is a similar mechanism to those previously discussed. For tubular air heaters where the gas flows through the tubes and the air flows across the tubes, the overall heat transfer coefficient can be estimated from the equation:



(Power)

Fig. IX-9. Regenerative air heater.

$$U = 0.45 + 0.00045\ G$$

where: G = arithmetic mean mass flow of air and gas, lbs/hr/sq ft

For plate type air heaters the overall coefficient of heat transfer can be approximated from the following equation:

$$U = 0.28\ V^{0.75}$$

where: V = arithmetic mean velocity of gas and air, ft/sec

Regenerative air heaters do not depend upon the transfer of heat through a dividing wall for their action. The temperature relations are somewhat complicated, but, for purposes of estimation, it can be assumed that (with the rotor turning at the usual speed of three revolutions per minute) the weight of metal in the rotor will be:

$$W_m = \frac{M_g}{93.8}$$

where: W_m = weight of metal, lbs
M_g = gas flow, lbs/hr

and, if 20 USG steel sheets are used, the area would be (one side of the sheet):

$$A = \frac{M_g}{140.7}$$

where: A = area (one side) of 20 U.S. gage steel sheets, square feet

Example 24 shows the method of estimation of the dimensions of a tubular air heater.

Example 24.

Determine the number and length of tubes and number of passes on the air side required for a tubular air heater for the boiler of Examples 17 and 20. The tubes are 1½ in. OD X 14 BWG and are spaced on 2½ in. centers. The gas flows through the tubes in a single pass and the air flows across the tubes. Plan dimensions of the air heater casing are 12 ft X 18 ft and the tubes run vertically. The air inlet is 6 ft X 12 ft and placed so that counterflow is obtained.

Solution:

From previous examples:

Air temperature entering air heater	110 F
Gas temperature entering air heater	650 F
Gas temperature leaving air heater	250 F

Heat transferred in the air heater:

$$Q = 291{,}000(0.24)(650 - 250) = 28{,}000{,}000 \text{ Btu/hr}$$

Weight of air heated:

$$M_{aa} = [74/8][2000][15.30+8(0.0447-\frac{0.0495}{8})-0.7873-0.0063 \\ -0.01]$$

M_{aa} = 274,000 lbs/hr

Temperature rise in the air is 28000000/[274000(0.24)] = 425 F and the temperature of the air leaving the air heater is 110 + 425 = 535 F.

$$t_m = \frac{(650 - 425) - (250 - 110)}{\log_e \frac{650 - 425}{250 - 110}} = 179 \text{ F}$$

Since the air heater tube sheet is 12 ft X 18 ft, there will be [12(12)/2.5][18(12)/2.5] = 5000 tubes in the air heater. The gas flow area is 5000[π/4][1.5 - 2(0.083)]²/144 = 48.5 sq ft, and the mass flow of gas is G_g = 291000/48.5 = 6000 lbs/hr/sq ft.

Since the air enters the short side of the air heater, the air passes between 58 tubes in the first row. The air flow area per pass is (58 - 1)(2.5 - 1.5)(6)/12 = 28.5 sq ft and the mass flow of air is G_a = 274000/28.5 = 9600 lbs/hr per sq ft.

The overall coefficient of heat transfer is:

$$U = 0.45 + 0.00045(\frac{9600 + 6000}{2}) = 3.96$$

and,
$$A = \frac{28,000,000}{3.96(179)} = 39,500 \text{ sq ft.}$$

Each 1½ in. OD tube has an area of 1.5π/12 = 0.393 sq per linear foot, so the total length of tube required would be 39500/0.393 = 100,500 ft, and since there are 5000 tubes the tubes would be 100500/5000 = 20.1 feet long. Each air pass is 6 feet high, so there would be 3 passes on the air side.

67. Apportionment of Heating Surface--The relative amount of heating surface provided in a complete steam generator installation is a compromise between the economic factors and the practical necessities. For example, air heater surface is the cheapest, but combustion considerations limit gas temperatures to about 600 F for pulverized coal, oil or gas and to about 350 F for stokers. In order to avoid corrosi

difficulties, the minimum gas outlet temperature for air heaters should be about 250 F. It is usual to limit the water temperature leaving the economizer to about 50 F less than the saturation temperature in the boiler in order to avoid steaming in the economizer.

Equations can be set up to give the most economical temperatures at the various locations after the superheater in the steam generator. The temperature of the gas leaving the furnace is fixed by the characteristics of the fuel; the temperature of the water entering the economizer is fixed by the most efficient operation of the regenerative cycle; the temperatures of the gas and air leaving the air heater are fixed as previously mentioned; and the temperature of the air entering the air heater is fixed by ambient conditions. The boiler screen is ordinarily two or three rows deep and receives the major portion of its heat by radiation, so that it may be included as part of the furnace cooling surface. Then, the temperature of the gas entering the superheater will be fixed as the temperature of the gas leaving the furnace. The temperature of the gas leaving the superheater will be determined by the necessities of heat transfer in the superheater. The boiler, economizer and air heater are then subject to economic analysis as follows (according to Helander):

Let: C = annual charges per square foot of additional surface, dollars

U = heat transfer coefficient for surface

C_f = annual saving per Btu of heat recovered per hour, dollars

= value of Btu X hours service per year ÷ overall steam generator efficiency

M_a, M_g and M_w = air, gas and water flows, lbs/hr

t_g = gas temperatures, deg F

t_a = air temperatures, deg F

t_w = water temperatures, deg F

t_v = saturation temperature in boiler, deg F

a, b, e, i and o are subscripts referring to air heater, boiler, economizer, in and out

To determine the most economical temperature of the outlet gas from an economizer when the inlet gas and inlet water temperatures are fixed:

$$\frac{C_e}{U_e C_f} = \frac{(t_{goe} - t_{uie})(t_{gie} - t_{uoe})}{(t_{gie} - t_{uie})}$$

$$\frac{0.24\ M_g}{c_{pu}\ M_u} = \frac{(t_{uoe} - t_{uie})}{(t_{gie} - t_{goe})} = e$$

To determine the most economical temperature of the outlet gas from an air heater when the inlet gas and inlet air temperatures are fixed:

$$\frac{C_a}{U_a C_f} = \frac{(t_{goa} - t_{aia})(t_{gia} - t_{aoa})}{(t_{gia} - t_{aia})}$$

$$\frac{M_g}{M_a} = \frac{(t_{aoa} - t_{aia})}{(t_{gia} - t_{goa})} = a$$

To determine the most economical boiler outlet gas temperature and water temperature leaving the economizer in the case of a boiler-economizer combiration when the economizer gas outlet temperature and inlet water temperature are fixed:

$$\frac{C_e U_b}{U_e C_b} = \frac{(t_{gie} - t_{uoe})}{(t_{gie} - t_v)}$$

To determine the most economical boiler outlet gas temperature and air temperature leaving the air heater in the case of a boiler-air heater combination when the air heater gas outlet temperature and entering air temperature are fixed:

$$\frac{C_a U_b}{U_a C_b} = \frac{(t_{gia} - t_{aoa})}{(t_{gia} - t_v)}$$

To determine the most economical boiler and economizer outlet gas temperatures, water temperature leaving the economizer and air temperature leaving the air heater in the case of a boiler-economizer-air heater combination when the air heater gas outlet temperature, entering air temperature and water inlet temperature are fixed:

$$\frac{C_b U_e}{C_e U_b} = \frac{(t_{gie} - t_v)}{(t_{gie} - t_{uoe})}$$

$$\frac{U_e C_a}{C_e U_a} = \frac{(t_{gie} - t_{uie})(t_{gia} - t_{aoa})}{(t_{gie} - t_{uoe})(t_{gia} - t_{uie})}$$

The following notes will be helpful in coming to a decision as to the proper combination of boiler and heat recovery apparatus:

1. If the water outlet temperature in a boiler-economizer combination is not at least 50 F less than the saturation temperature in the boiler, try adding an air heater to the combination.

2. If the air outlet temperature from the air heater in a boiler-air heater combination is greater than 600 F for pulverized coal, oil or gas, or 350 F for stokers, try adding an economizer to the combination.

Table XIV gives some mass flows and heat transfer coefficients to be expected in commercial practice. After making an estimate from the table, the final values of economical temperatures can be arrived at by successive approximations.

TABLE XIV

GAS MASS FLOWS AND COEFFICIENTS OF HEAT TRANSFER FOR STEAM GENERATOR COMPONENTS

	G Lbs/hr/sq ft	U Btu/hr/sq ft/deg
Boiler	1000 to 5000	3 to 8
Superheater	2000 to 9000	10 to 25
Economizer	2000 to 9000	6.5 to 9
Air Heater	2000 to 9000	2.5 to 4

Example 25 shows the method of application of the preceeding equations to the determination of the most economical division of heat transfer surface.

Example 25.

Determine the most economical temperatures for the boil-

er of Examples 17 and 20, given the following additional data:

Annual fixed charges	15 o/o
Cost of additional boiler surface	$10.00 /sq ft
Cost of additional econ. surface	$ 4.00 / sq ft
Cost of additional air htr. surface	$ 1.00 /sq ft
Boiler heat transfer coefficient	4.7
Econ. heat transfer coefficient	7.8
Air htr. heat transfer coefficient	4.0
Cost of fuel	$ 8.00 /ton
Hours operated per year	8000

Solution:

$$C_f = \frac{\$8.00(8000)}{2000(14400)(0.887)} = 0.00251$$

$$C_b = 10(0.15) = 1.50$$

$$C_e = 4(0.15) = 0.60$$

$$C_a = 1(0.15) = 0.15$$

1. Assuming a boiler-economizer combination:

The temperature of the water entering the economizer is greater than the temperature specified for the flue gas outlet temperature, therefore this combination would be impossible.

2. Assuming a boiler-air heater combination:

$$t_{goa} = 250 \text{ F} \qquad t_{aia} = 110 \text{ F} \qquad t_v = 535 \text{ F}$$

$$\frac{0.15(4.7)}{4.0(1.50)} = 0.1175 = \frac{(t_{gia} - t_{aoa})}{(t_{gia} - 535)}$$

$$a = \frac{291000}{274000} = 1.06 = \frac{(t_{aoa} - 110)}{(t_{gia} - 250)}$$

from which, $t_{gia} = 1230$ F and $t_{aoa} = 1145$ F.

These temperatures indicate that no boiler surface could be justified, but the temperature of the air leaving the air heater is too high for satisfactory operation.

3. Assuming an economizer-air heater combination:

$$\frac{7.8(0.15)}{0.60(4.0)} = 0.488 = \frac{(1225 - 300)(t_{gia} - t_{aoa})}{(1225 - t_{uoe})(t_{gia} - 300)} \qquad [A]$$

$$\frac{t_{uoe} - 300}{1225 - t_{gia}} = 0.322 \qquad \frac{t_{aoa} - 110}{t_{gia} - 250} = 1.06$$

Assume for a first approximation that $t_{uoe} = 485$ F, then, $t_{gia} = 650$ F and $t_{aoa} = 535$ F. Substitution of these temperatures in equation [A] gives a ratio of 0.414 instead of the required value of 0.488.

Assume for a second approximation that $t_{uoe} = 500$ F, then, $t_{gia} = 602$ F and $t_{aoa} = 483$ F. Substitution of these temperatures in equation [A] gives a ratio of 0.503.

Interpolation gives $t_{uoe} = 498$ F, however, this temperature is too close to the saturation temperature in the boiler so the first approximation will be taken as most satisfactory.

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CHAPTER X

PIPING AND DUCT-WORK

68. Power plants require conduit for the transportation of fuel, air, gas, water and steam. Conduit for air and gas are called ducts, and for other materials are called pipe. The variety of conduit is large, but the laws of fluid flow apply to all.

69. Piping--Calculations for piping involve the determination of pipe size, pressure class and pressure drop.

Pipe size is determined from the fluid velocity which will produce a pressure drop which is not excessive. Table XV gives practical velocities for various fluids and vapors.

TABLE XV

PIPE LINE VELOCITIES

	ft per sec
Low press. sat. steam	65 - 100
High press. sat. steam	100 - 170
High press. suphtd. steam	170 - 250
Atmos. exhaust steam	130 - 200
Low press. exhaust steam	330 - 400
Boiler feed-water	8 - 12
Pump suction, water	4 - 7
General service water	5 - 10
Fuel oil	1 - 4

Application of the continuity equation will give the solution for pipe size, as follows:

$$A = \frac{Mv}{3600\ V} \qquad d_i = 0.4\sqrt{Mv/\pi V}$$

where: M = flow, lbs/hr
v = specific volume, cu ft/lb
V = velocity, ft/sec
d_i = inside diameter of pipe, in.
A = flow area, sq ft

Pressure class (or schedule number) is determined from the relation:

$$SN = \frac{1000\ P}{s}$$

where: SN = pipe schedule number
P = working pressure in pipe, lbs/sq in. gage

TABLE XVI

(Crane Co.)

Dimensions of Welded and Seamless Steel Pipe

Nominal Pipe Size	Outside Diam.	Nominal Wall Thicknesses for Schedule Numbers											
		Schedule 10	Schedule 20	Schedule 30	Schedule 40	Schedule 60	Schedule 80	Schedule 100	Schedule 120	Schedule 140	Schedule 160		
⅛	405				068		095						
¼	540				088		119						
⅜	675				091		126						
½	840				109		147						187
¾	1 050				113		154						218
1	1 315				133		179						250
1¼	1 660				140		191						250
1½	1 900				145		200						281
2	2 375				154		218						343
2½	2 875				203		276						375
3	3 500				216		300						437
3½	4 00				226		318						
4	4 500				237		337		437				531
5	5 563				258		375		500				625
6	6 625				280		432		562				718
8	8 625		250	277	312	406	500	593	718	812			906
10	10 75		250	307	365	500	593	718	843	1 000		1 125	
12	12 75		250	330	406	562	687	843	1 000	1 125		1 312	
14 OD	14 00	250	312	375	437	593	750	937	1 062	1 250		1 406	
16 OD	16 00	250	312	375	500	656	843	1 031	1 218	1 437		1 562	
18 OD	18 00	250	312	437	562	718	937	1 156	1 343	1 562		1 750	
20 OD	20 00	250	375	500	593	812	1 031	1 250	1 500	1 750			
24 OD	24 00	250	375	562	687	937	1 218	1 500	1 750				

Dimensions of Welded Wrought-Iron Pipe

Nominal Pipe Size	Outside Diameter	Nominal Wall Thicknesses for Schedule Numbers					
		Schedule 10	Schedule 20	Schedule 30	Schedule 40	Schedule 60	Schedule 80
⅛	405				070		098
¼	540				090		122
⅜	675				093		129
½	840				111		151
¾	1 050				115		157
1	1 315				136		183
1¼	1 660				143		195
1½	1 900				148		204

s = allowable working stress,
lbs/sq in. (10 to 15 per cent
of ultimate tensile strength)

Table XVI gives pertinent data for the various pipe schedules made at the present time, along with minimum tensile strengths for the various grades of steel and wrought iron piping materials.

TABLE XVI
continued

2	2 375					158			223	
2½	2 875					208			282	
3	3 500					221			306	
3½	4 000					231			325	
4	4 500					242			344	
5	5 563					263			383	
6	6 625					286			441	
8	8 625				283	329			510	
10	10 75				313	372	510			
12	12 75				336					

Note: Bold face numbers in Schedules 40 and 80 correspond to standard and extra strong weights respectively.

A.P.I. and A.S.T.M. Specifications for Pipe, With Tensile Strengths Called for and the Corresponding Uses for Which Each Material Is Intended

Title	Tensile Strength Lbs per Sq In.	Scope
Line Pipe Specifications (A P I 5-L)	Furnace welded Bessemer, 50,000 min Open-hearth, Class I, 45,000 min Open-hearth, Class II, 48 000 min Wrought iron, 42,000 min Seamless or electric welded Open-hearth, Grade A, 48,000 min Open-hearth, Grade B, 60,000 min Open-hearth, Grade C, 75,000 min Seamless or furnace welded Open-hearth iron, 42 000 min	Pipe for line pipe purposes, to convey gas, water, or oil Sizes covered, ⅛ inch nominal size to 24-inch outside diameter Couplings for threaded line pipe are of special design Threads on pipe and in couplings are subject to official gage limits
Seamless Carbon-Molybdenum Alloy-Steel Pipe for Service at Temperatures from 750 to 1000 F (A S T M A200)	55,000 min	Seamless carbon—½ per cent molybdenum alloy steel pipe intended for service at metal temperatures from 750 to 1000 F Suitable for bending, flanging, and similar forming operations, and for fusion welding
Seamless Alloy-Steel Pipe for Service at Temperatures From 750 to 1100 F (A S T M A158	Ferritic, 60,000 min Austenitic 75,000 min	Seamless alloy-steel pipe intended for service at metal temperatures from 750 to 1100 F Several classes of materials that have been rather extensively used are included Choice from the respective steels should be made on the basis of requirements of design, service conditions and the physical properties

Pressure drop is determined by the application of the pipe friction formula, as follows:

$$\Delta P = 0.00518 \frac{f\ L\ V^2}{v\ d_i} \qquad \Delta h = 0.745 \frac{f\ L\ V^2}{d_i}$$

where: ΔP = pressure drop, lbs/sq in.
Δh = pressure drop, ft of fluid
f = a friction factor
L = equivalent length of pipe, ft
V = average fluid velocity, ft/sec
v = specific volume of fluid, cu ft/lb
d_i = inside diameter of pipe, in.

The equivalent length of pipe is equal to the sum of the length of straight pipe plus an allowance for valves and fittings. Figure X-1 gives the equivalent pipe length allowances.

The friction factor is a function of Reynolds' number, which is in turn a function of the size of the pipe, and the velocity, density and viscosity of the fluid. That is,

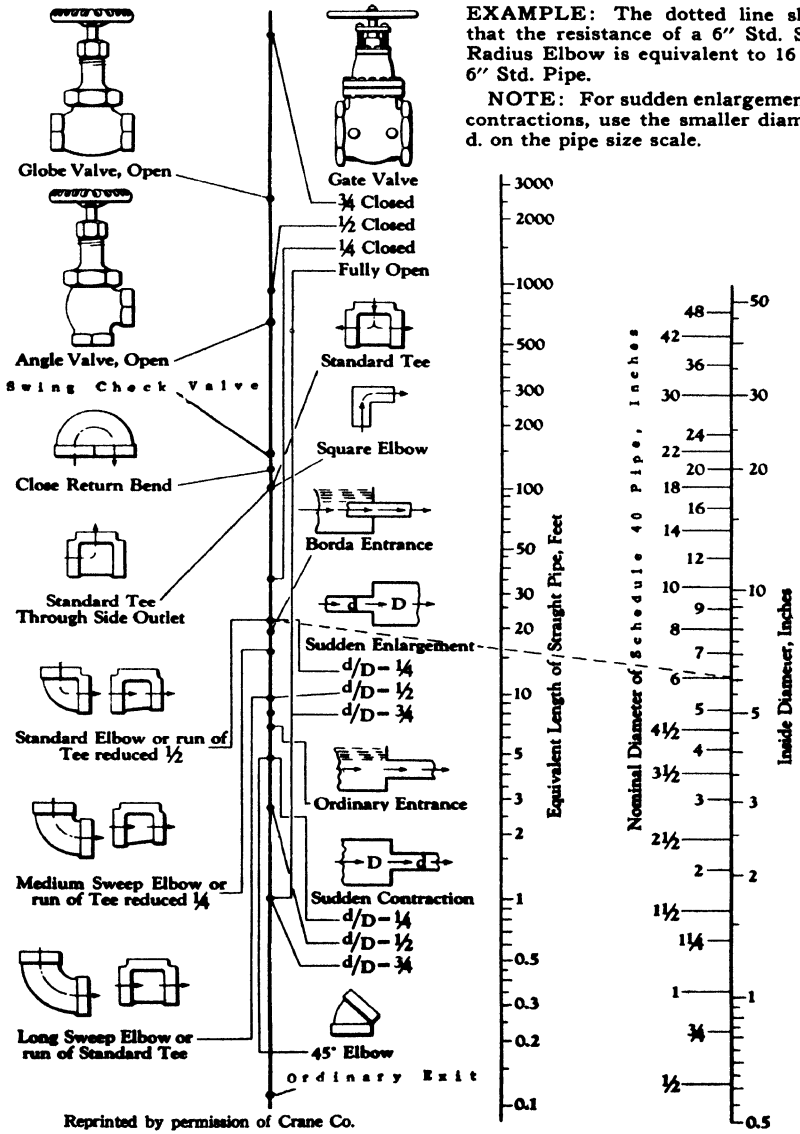
$$r = 122.5 \frac{d_i\ V}{z\ v}$$

where: r = Reynolds' number
z = viscosity of fluid, centipoises

Figures X-2 and X-3 show curves of viscosity for water, steam and oils, and specific gravity for oils. Figure X-4 shows the relation of friction factor to Reynolds' number.

Pipe fittings are specified by pressure class and material. Figures X-5 and X-6 and Table XVII show some piping details and standard types of fittings. Figure X-7 shows some of the various types of valves used in power plants.

Examples 26-A and 26-B show the method of calculation of pipe data based on the preceeding information.

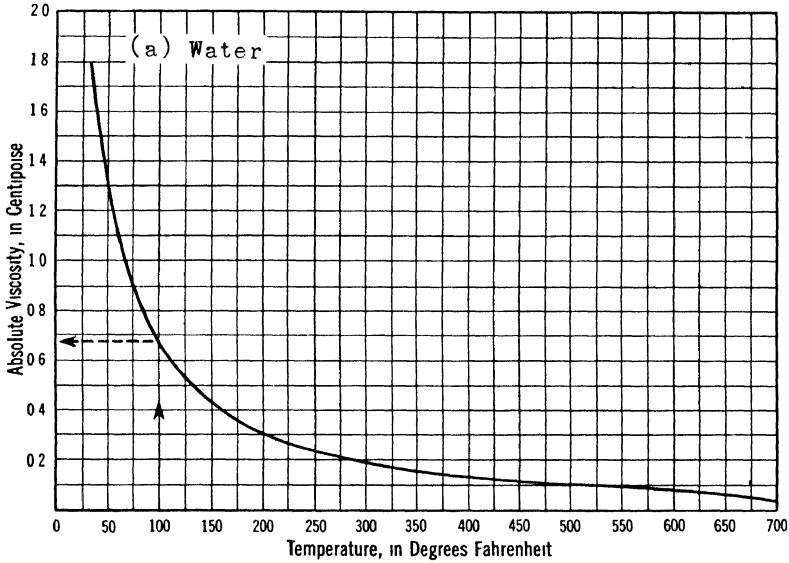


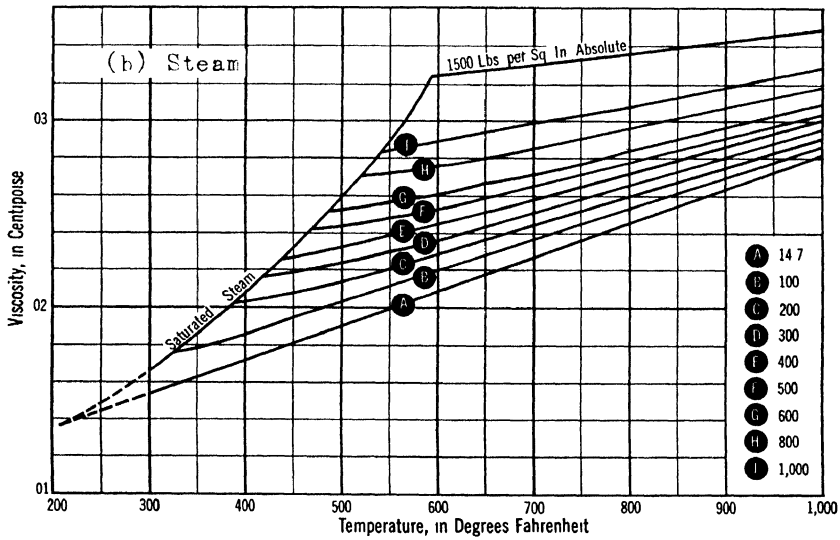
EXAMPLE: The dotted line shows that the resistance of a 6″ Std. Short Radius Elbow is equivalent to 16 ft of 6″ Std. Pipe.

NOTE: For sudden enlargements or contractions, use the smaller diameter, d. on the pipe size scale.

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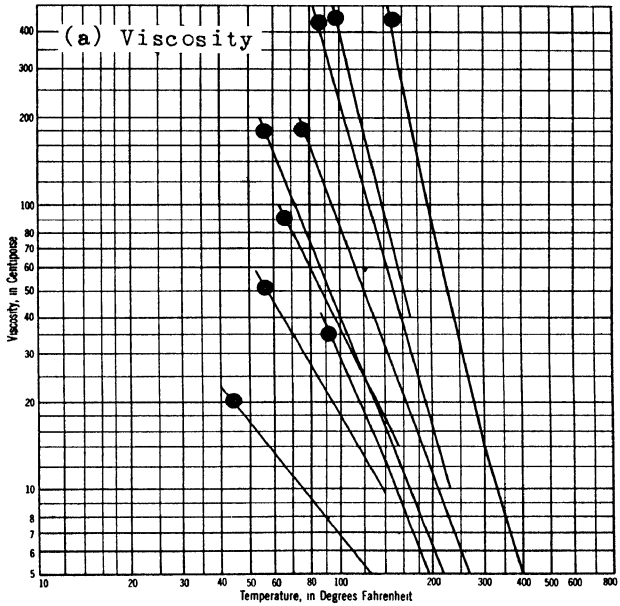
Fig. X-1. Equivalent straight pipe length for valves and pipe fittings.



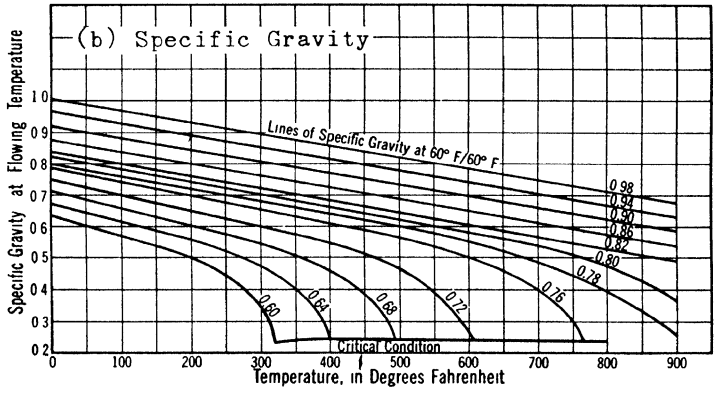


(Crane Co.)

Fig. X-2. Viscosity of water and steam.

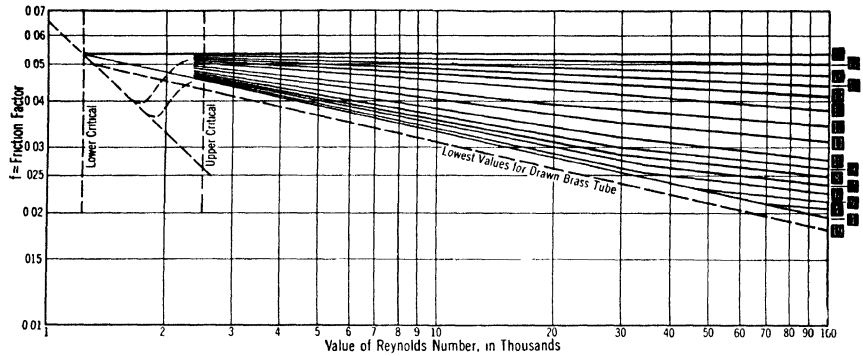


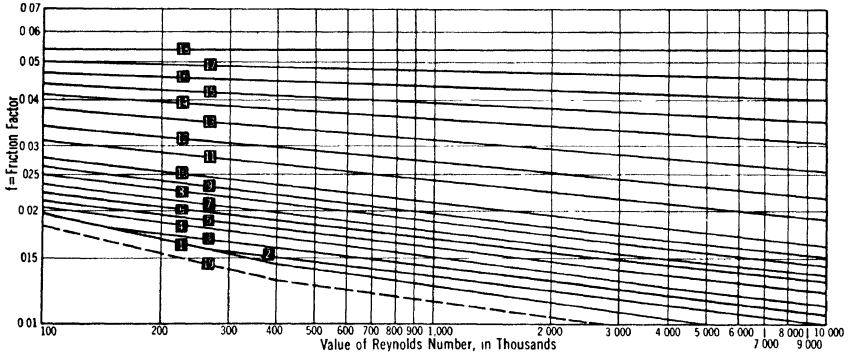
1) Midcontinent residuum, S=0.97; (2) California heavy crude, S=0.976; (3) Residuum, S=0.94; (4) Eastern light lubricating oil, SAE 30; (5) Midcontinent light lubricating oil, S=0.90; (6) Olive oil; (7) Eastern light lubricating oil, SAE 10; (8) California light crude, S=0.91; (9) Midcontinent crude, S=0.85.



(Crane Co.)

Fig. X-3. Characteristics of petroleum oils.





Curve No.	Roughness %	Diameter of Pipe, in Inches					
		Type A	Type B	Type C	Type D	Type E	Type F
1	0 2	0 35 up	72				
2	0 45		48 to 66				
3	0.81		14 to 42	30	48 to 96	96	220
4	1.35		6 to 12	10 to 24	20 to 48	42 to 96	84 to 204
5	2 1		4 to 5	6 to 8	12 to 16	24 to 36	48 to 72
6	3 0		2 to 3	3 to 5	5 to 10	10 to 20	20 to 42
7	3 8		1½	2½	3 to 4	6 to 8	16 to 18
8	4.8		1 to 1¼	1½ to 2	2 to 2½	4 to 5	10 to 14
9	6 0		¾	1¼	1½	3	8
10	7 2		½	1	1¼		5
11	10.5		⅜	¾	1		4
12	14.5		¼	½			3
13	19 0		⅛				
14	24 0	0.125		⅜			
15	28 0						
16	31 5			¼			
17	34.0						
18	37.5	0 0625		⅛			

Type A: Drawn tubing, and brass tin, lead, and glass pipe

Type B: Clean steel and wrought iron pipe

Type C: Clean galvanized pipe.

In drawn tubing, the actual inside diameter is given

Type D: Best cast iron pipe, cement, and light riveted sheet ducts

Type E: Average cast iron pipe and rough formed concrete ducts

Type F: First class brick, heavy riveted, and spiral riveted ducts

In pipe, the nominal size of standard weight is given

(Crane Co.)

Fig. X-4. Friction factor with relation to Reynolds' number.

Fig. X-5. Pipe fitting types. (Crane Co.)

TABLE XVII

(Crane Co.)

Standard Malleable Iron Fittings

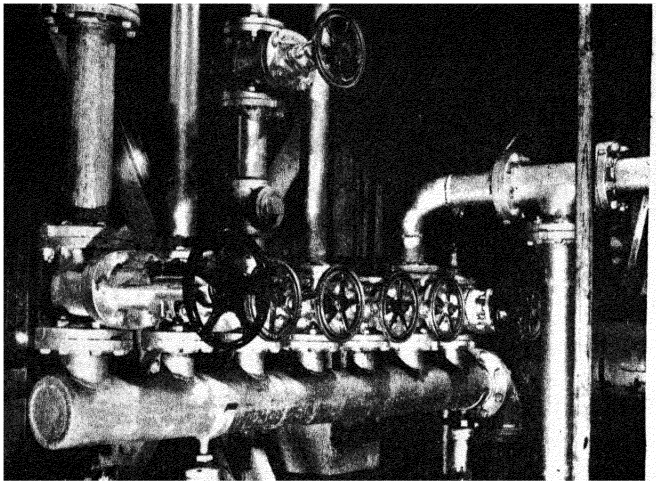
WORKING PRESSURES, BANDED FITTINGS
150 pounds steam
300 pounds cold water, oil, or gas, non-shock

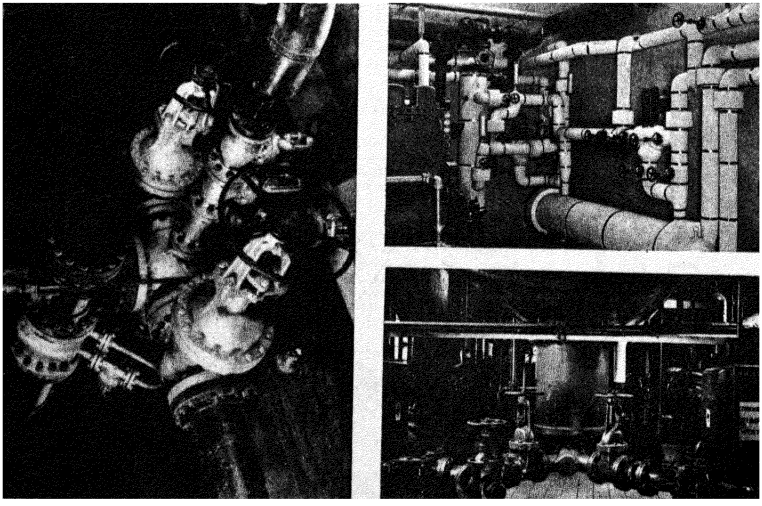
Dimensions, in Inches

Size	A	B	C	D	E	F	G	H	J	K	Z
⅛	1 1/16	½	1	1 1/16	1 3/16			9/16	15/16		¼
¼	1 3/16	¾	1 3/16	5/8	1 5/16			5/8	1 1/16	1	3/8
⅜	1 5/16	1 3/16	1 7/16	1 1/16	1 1/16	2 1/8	1 7/16	3/4	1 3/16	1 1/8	3/8
½	1 1/8	⅞	1 5/8	1 3/16	1 3/16	2 7/16	1 11/16	⅞	1 5/16	1 1/4	½
¾	1 5/16	1	1 7/8	1 5/16	1 5/16	2 13/16	2 1/16	1 1/16	1 1/2	1 7/16	9/16
1	1 1/2	1 1/8	2 1/8	1 1/16	1 1/2	3 3/8	2 7/16	1 13/16	1 11/16	1 11/16	11/16
1 1/4	1 3/4	1 5/16	2 7/16	1 1/4	1 11/16	4 1/16	2 15/16	1 1/4	1 15/16	2 1/16	11/16
1 1/2	1 15/16	1 7/16	2 11/16	1 3/8	1 7/8	4 1/2	3 5/16	1 5/8	2 1/8	2 5/16	11/16
2	2 1/4	1 11/16	3 1/4	1 11/16	2 1/4	5 7/16	4	1 7/16	2 1/2	2 13/16	¾
2 1/2	2 11/16	1 15/16	3 13/16	1 15/16	2 5/8	6 1/4	4 11/16	1 11/16	2 7/8	3 1/4	15/16
3	3 1/8	2 3/16	4 1/2	2 1/16	3 1/4	7 1/4	5 9/16	1 13/16	3 3/16	3 11/16	1
3 1/2	3 7/16	2 7/16	5 1/8	2 3/16	3 3/4			1 15/16		4	1 1/16
4	3 3/4	2 5/8	5 11/16	2 3/8	4 1/4	8 1/8	6 15/16	2 1/16	3 11/16	4 3/8	1 1/8
5	4 1/2	3 1/16	6 7/16	2 3/4	5 1/8			2 5/16	4 1/16	5 1/8	1 1/4
6	5 1/8	3 7/16	7	3 1/16	5 3/4			2 9/16	4 5/8	6	1 5/16

Size	M	N
Close Pattern Return Bends		
½	1	1 3/4
¾	1 1/4	2 3/16
1	1 1/2	2 1/2
1 1/4	1 3/4	2 13/16
1 1/2	2 3/16	3 3/16
2	2 5/8	3 5/8
Medium Pattern Return Bends		
½	1 1/4	1 5/8
¾	1 1/2	1 15/16
1	1 7/8	2 1/4
1 1/4	2 1/4	2 13/16
1 1/2	2 3/4	3 3/16
2	3 3/8	4
2 1/2	4 1/8	4 15/16
3	5	5 9/16
4	6	6 11/16
Open Pattern Return Bends		
½	1 1/2	1 7/8
¾	2	2 1/4
1	2 1/2	2 5/8
1 1/4	3	3 3/16
1 1/2	3 1/2	3 5/8
2	4	4 3/8
2 1/2	4 1/2	4 15/16
3	5	5 9/16
4	6	6 11/16

TABLE XVII continued in APPENDIX





(Crane Co.)

Fig. X-6. Piping details.

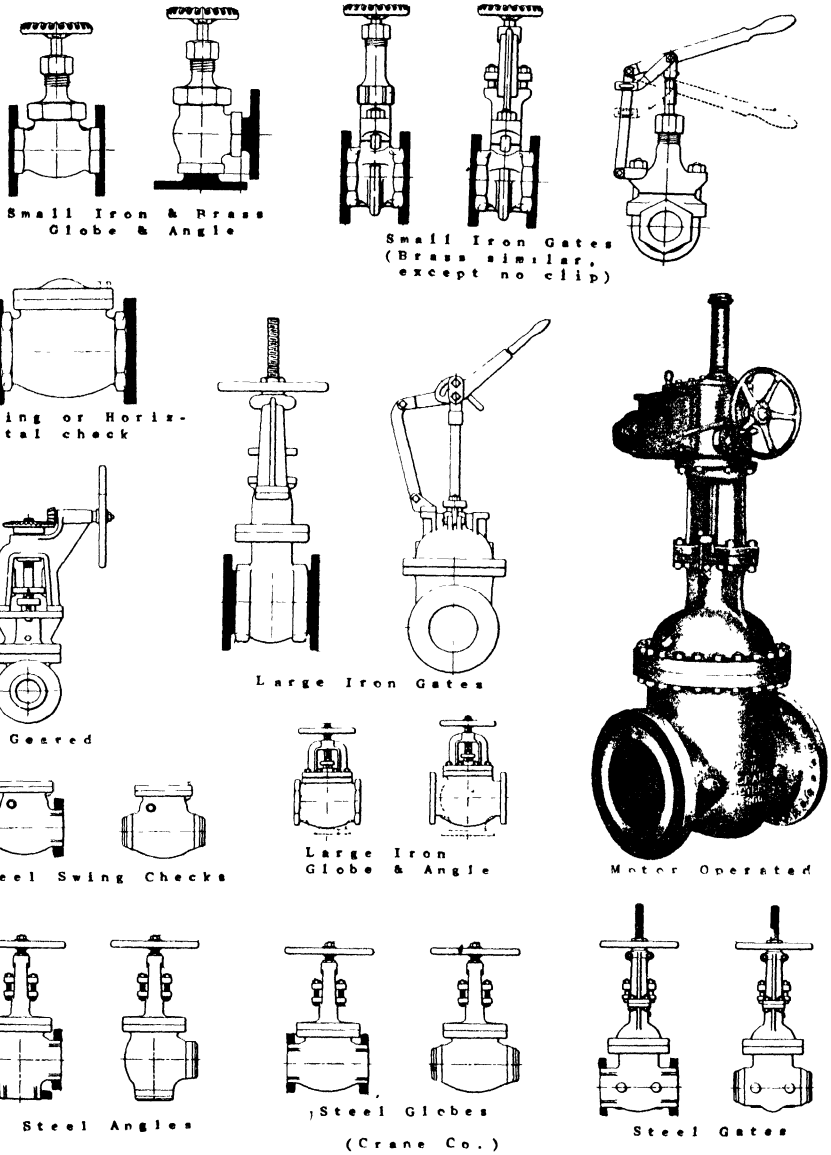


Fig. X-7 Power plant valve types.

Example 26-A.

Determine the nearest standard pipe size and pressure drop for a steam line (seamless Grade A steel pipe) carrying 30,000 lbs/hr at 215 psig and 560 F. The line contains 100 ft of straight pipe, 2 gate valves, 1 globe valve, 1 swing check valve and 3-90° elbows.

Solution:

The steam is at a moderately high pressure and is superheated, so a velocity of 180 ft/sec is selected. The required inside diameter is:

$$d_i = 0.4\left[\frac{30000(2.531)}{180\ \pi}\right]^{0.5} = 4.65 \text{ in.}$$

The pipe schedule number (allowing a factor of safety of about 10) is:

$$SN = \frac{1000(215)}{4800} = 45$$

Schedule 40 pipe would be safe enough. The inside diameter of 5 in. Schedule 40 pipe is 5.05 in. which is close enough to the required 4.65 in. The true velocity of the steam is:

$$V = \frac{0.16(30000)(2.531)}{\pi(5.05)^2} = 152 \text{ ft/sec}$$

In order to determine the friction factor, Reynolds' number is calculated (finding the viscosity, z, from Figure X-2) as follows:

$$r = \frac{122.5(5.05)(152)}{0.025(2.531)} = 1{,}485{,}000$$

From Figure X-4, the friction factor is 0.016.

The total equivalent length of pipe is found with the aid of Figure X-1, as follows:

Straight pipe	100 ft
2 Gate valves 2(2.8) =	5.6 ft
1 Globe valve	140 ft
1 Swing check valve	31 ft
3 90° Elbows 3(14)	42 ft
Total equivalent length	318.6 ft

The pressure drop is:

$$\Delta P = 0.0051 f \frac{(0.016)(318.6)(152)^2}{2.521(5.05)} = 47.7 \text{ psi}$$

Example 26-6.

Determine the nearest standard pipe size and pressure drop for a seamless Grade A steel pipe carrying 40,000 lbs/hr of residual fuel oil at a pressure of 200 psig and a temperature of 200 F. The specific gravity of the oil at 60°/60° is 0.94. The pipe line contains 500 ft of straight pipe, 6-90° elbows, 2 gate valves, 1 swing check valve, and 1 globe valve.

Solution:

From Figure X-2 b, the specific gravity of the oil at 200°/60° is 0.89, from which the specific volume v is 1/[62.4(0.89)] = 0.018 cu ft/lb, and taking V = 2 ft/sec,

$$d_i = 0.4\left[\frac{40000(0.018)}{2\pi}\right]^{0.5} = 3.5 \text{ in.}$$

3½ in. Schedule 40 pipe has an inside diameter of 3.548 in. The actual velocity would be:

$$V = \frac{0.16(40000)(0.018)}{\pi(3.548)^2} = 2.91 \text{ ft/sec}$$

Reynolds' number is calculated using the viscosity, z, from Figure X-3 a, as follows:

$$r = \frac{122.5(3.548)(2.91)}{17(0.018)} = 4130$$

From Figure X-4, the friction factor is 0.041.

The total equivalent length of pipe is:

Straight pipe	500	ft
6 90° Elbows 6(9.5)	57	
2 Gate valves 2(2.0)	4	
1 Swing check valve	21	
1 Globe valve	100	
Total equivalent length	682	ft

The pressure drop is:

$$\Delta h = 0.745 \frac{(0.041)(682)(2.91)^2}{3.548} = 49.5 \text{ ft of oil}$$

70. Friction in Condensers and Feed-Water Heaters.--Friction losses in condensers and feed-water heaters may be calculated from the pipe friction formula, but it is more usual to use the curves shown in Figure X-8 for the losses in the tubes and Figure X-9 for the losses in the water boxes.

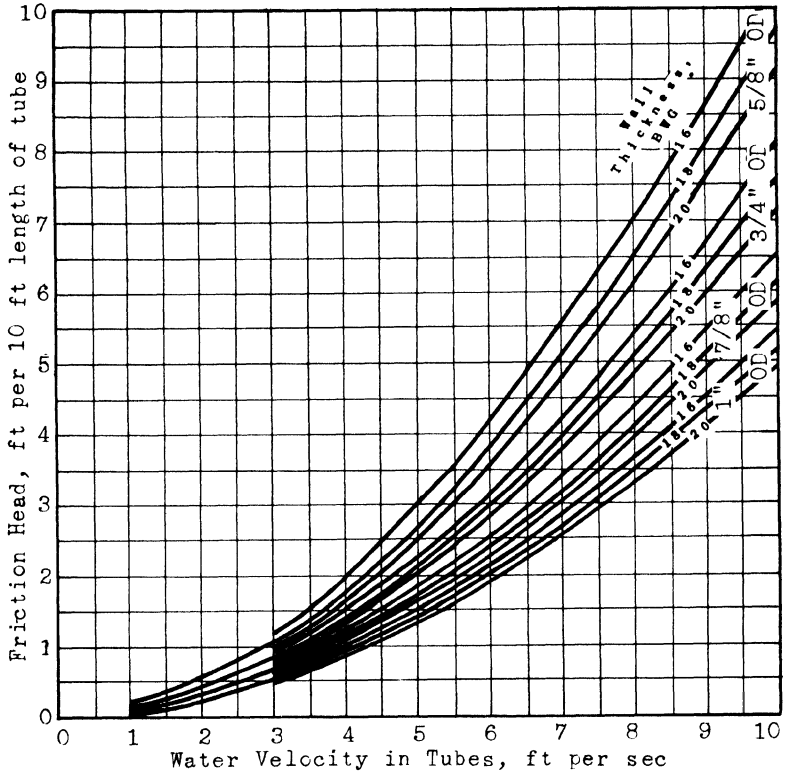


Fig. X-8. Head loss in condenser and feed-water heater tubes.

Examples 27-A and 27-B show the method of calculation of head losses in the condenser and feed-water heater of Examples 9 and 11.

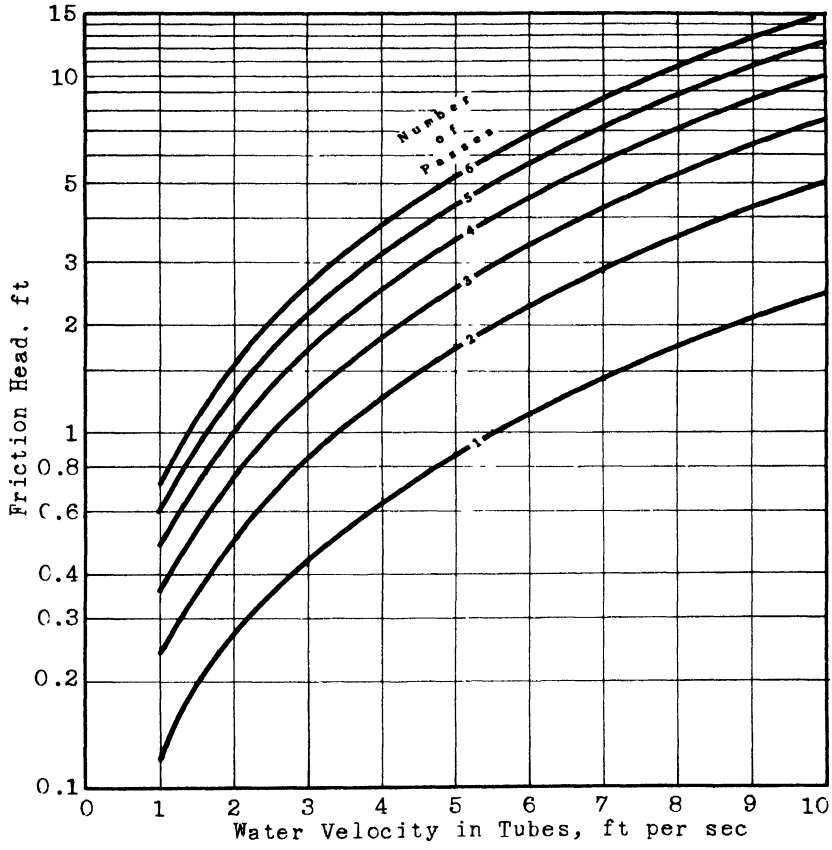


Fig. X-9. Head loss in condenser and feed-water heater water boxes.

Example 27-A.

Determine the head loss in the tubes and water boxes of the condenser of Example 9.

Solution:

From Figure X-8, the head loss in 3/4 in. X 18 BWG tubes at a velocity of 8 ft/sec is 5.1 ft per 10 ft length of tube. The water box head loss for a two-pass condenser at a velocity of 8 ft/sec, from Figure X-9, is 3.6 ft. Then the total head loss is:

Tubes	5.1(45.5/10)	23.3 ft
Water boxes		3.6
Total head loss		26.9 ft

Example 27-B.

Determine the head loss in the tubes and water boxes of the feed-water heater of Example 11.

Solution:

From Figure X-8, the head loss in 5/8 in. X 16 BWG tubes at a velocity of 6 ft/sec is 4.2 ft per 10 ft length of tube. The water box head loss for a six-pass heater at a velocity of 6 ft/sec, from Figure X-9, is 6.9 ft. Then the total head loss is:

Tubes	4.2[7.68(6)/10]	19.4 ft
Water boxes		6.9
Total head loss		26.3 ft

71. Duct-Work--The method of calculating the dimensions of ducts for gas or air are very similar to those employed for piping. Ducts usually operate at maximum pressures of the order of several inches of water, so that ordinarily if the duct is strong enough to support itself without buckling, it will be strong enough to withstand the pressure.

Duct size is determined by substituting the allowable velocity in the continuity equation, as for piping. Ducts, however, are usually rectangular in cross section rather than round. Table XVIII gives reasonable velocities in ducts. The higher velocities apply to higher static pressures.

TABLE XVIII

DUCT VELOCITIES

	ft per sec
Air ducts	30 - 50
Gas ducts	20 - 40
Stacks	20 - 40

Pressure drop (or draft loss) is usually measured in inches of water, and is given by the equation:

$$\Delta p = 0.00298 \frac{\rho f L V^2}{R}$$

where: Δp = draft loss, in. water
ρ = density of gas, lbs/cu ft
R = hydraulic radius of duct, ft
= area/perimeter

Reynolds' number is as for piping, except that the smallest dimension of the duct (if rectangular) is substituted for the inside diameter of the pipe. Viscosity in centipoises for various gases can be found from the following equations:

Flue gas: $z = 0.0153 + 2.5 \times 10^{-5} t$

Air: $z = 0.0165 + 2.5 \times 10^{-5} t$

where: t = temperature, deg F

Figure X-10 shows densities for air and flue gas.

Length allowances for bends may be found from Table XIX after converting rectangular duct sizes to equivalent round duct diameter by the equation:

$$d_e = 1.35 \frac{(a\ b)^{0.627}}{(a + b)^{0.255}}$$

where: d_e = equivalent round duct diameter, in.
a and b = rectangular duct dimensions, in.

Figure X-11 shows some typical ducts, and Example 28 shows some sample duct calculations.

Example 28.

Determire the draft loss in the flue gas duct between the economizer and air heater for the boiler of Example 17. The duct has a straight length of 20 ft and has 2-90° bends with a radius of 8 ft. The maximum width of duct is 12 ft and the maximum gas velocity is 20 ft/sec.

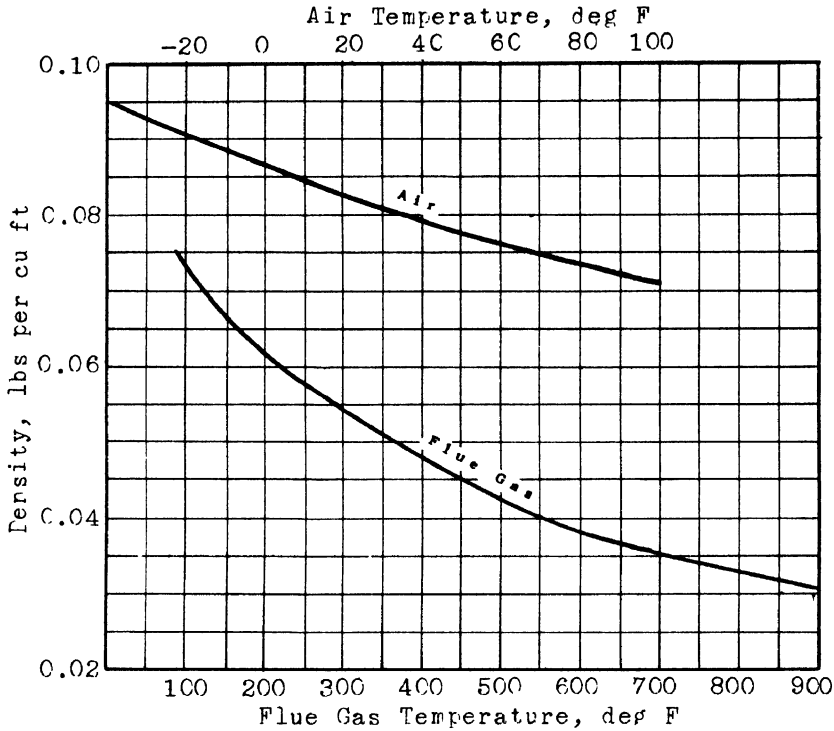


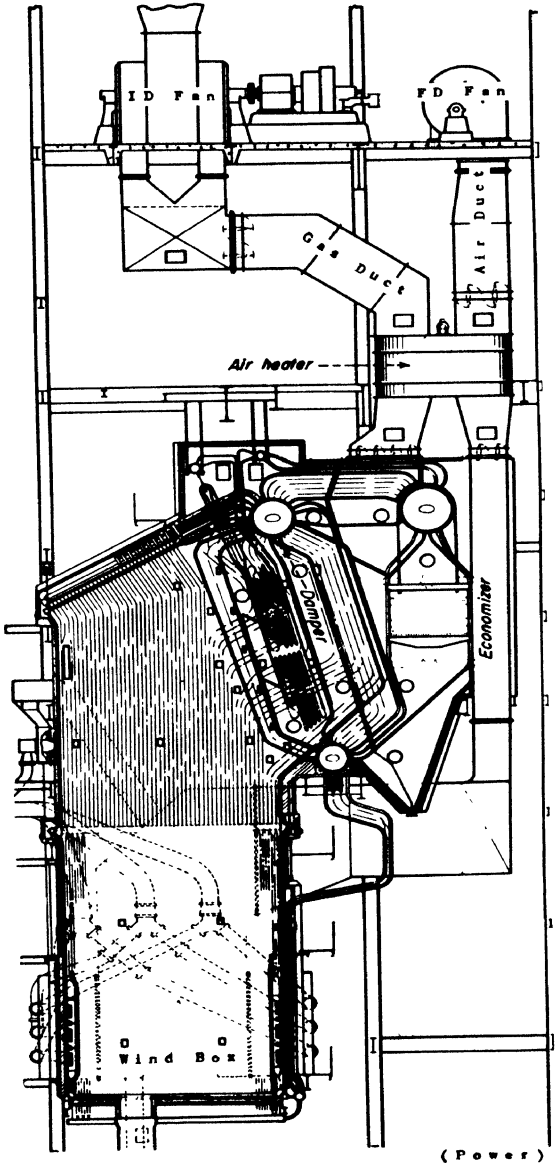
Fig. X-10. Densities of air and flue gas.

TABLE XIX

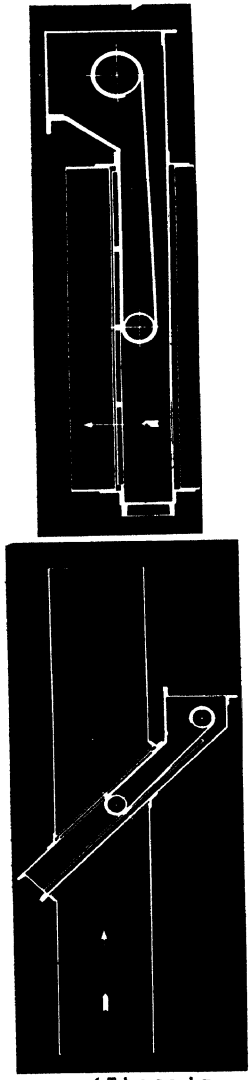
EQUIVALENT LENGTHS OF DUCT BENDS

Diameters of Straight Duct

Right angle bends	
Center line radius 2 to 8 dia.	10
Center line radius 1 dia.	20
Mitred right angle elbow	50



(Power)



(Thermix Engrg. Co.)

Curtain Dampers

Fig. X-11. Duct-work.

Solution:

From Example 22, the gas temperature is 650 F, and from Figure X-10, the density of the gas is 0.0375 lbs/cu ft, which is equivalent to a specific volume of 26.7 cu ft/lb. The required area of duct is:

$$A = \frac{291000(26.7)}{3600(20)} = 108 \text{ sq ft}$$

The duct dimensions are then 9 ft X 12 ft.

The viscosity of the gas is $z = 0.0153 + 2.5 \times 10^{-5}(650) = 0.03155$ centipoises. Reynolds' number is:

$$r = \frac{122.5(9)(12)(20)}{0.03155(26.7)} = 314{,}000$$

and the friction factor is found to be 0.0152 (Curve 1, Figure X-4).

The equivalent duct diameter is:

$$d_e = 1.35[\{(108)(144)\}^{0.627}/\{108 + 144\}^{0.255}] = 83 \text{ in.}$$

and the radius of the bends is 8(12)/83 = 1.15 dia., for which the allowance is 20 diameters of duct each. The total equivalent duct length is:

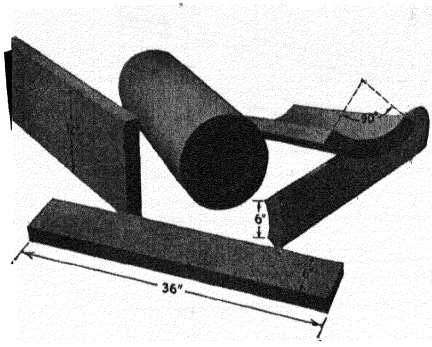
Straight duct	20 ft
2-90° bends $\frac{2(20)(83)}{12}$	277
Total equiv. length	297 ft

The draft loss in the duct is:

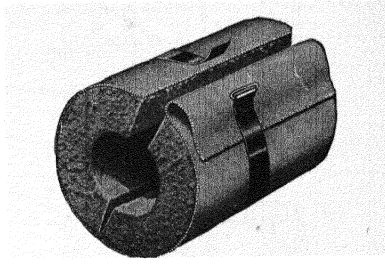
$$\Delta p = 0.00298\frac{(0.0375)(0.0152)(297)(20)^2}{108/[2(12) + 2(9)]} = 0.078 \text{ in. water}$$

72. Pipe and Duct Insulation--Most pipes and ducts which carry liquids or gases whose temperature is very much different from the ambient temperature require insulation of some kind to prevent heat transfer to or from the surroundings. The most common insulation materials for pipe and ducts are asbestos, magnesia, mineral wool and diatomite. These materials are made in the form of blocks, moulded circular sections, blankets or plastic for application with a

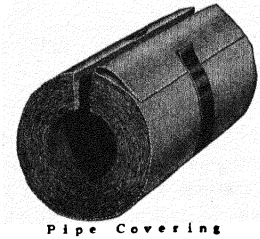
rowel. Figure X-12 shows some of the various forms of insulation and Figure X-13 gives thermal conductivities for a ariety of materials with the approximate temperature ranges or best utilization.



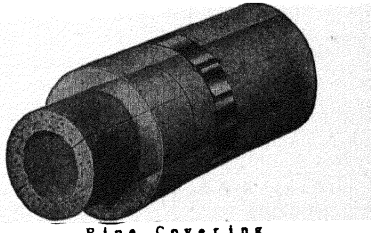
Standard Moulded Shapes
Magnesia or Diatomite



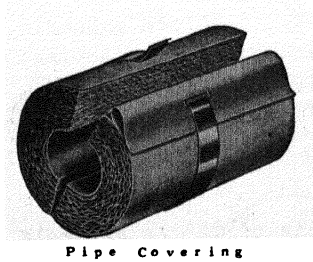
Pipe Covering
Magnesia or Diatomite



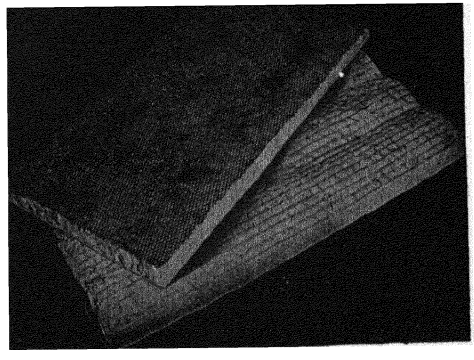
Pipe Covering
Asbestos Paper



Pipe Covering
Diatomite Inner Layer
Magnesia Outer Layer



Pipe Covering
Corrugated
Asbestos Paper



Mineral Wool Blankets
Wire Reinforced
(Philip Carey Co.)

Fig. X-12. Insulating materials.

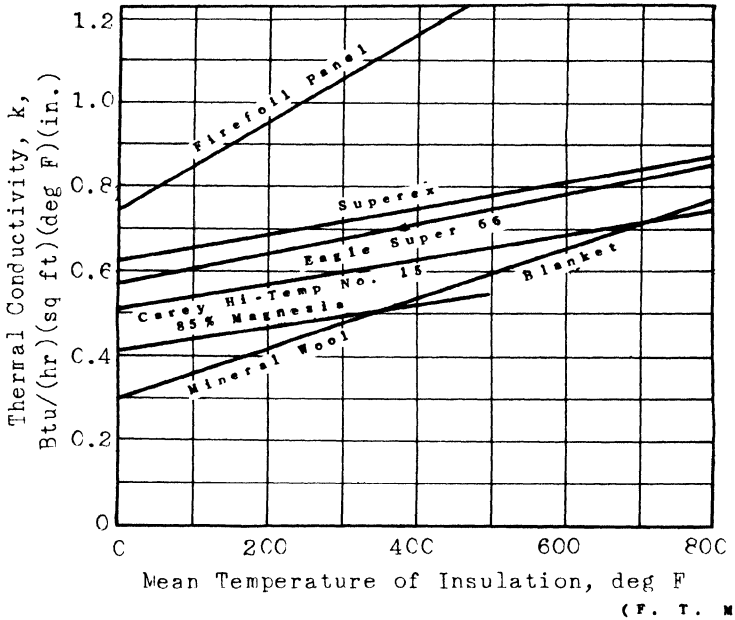


Fig. X-13. Thermal conductivities of insulating materials.

Heat transfer through insulation follows the same laws as previously discussed. It is not usual, however, to make an exhaustive analysis of the economic factors involved, but to use an economic selection chart such as is shown ir Figure X-14. Example 29 shows the use of the chart.

Example 29.

Find the most economical thickness of 85 o/o magnesia pipe covering for the steam line of Example 26-A. Ambient temperature is 90 F; cost of insulation 24 cents/bd ft; fixed charges 20 o/o; used 8000 hrs/yr; fuel costs $2.00 per bbl of 6,300,000 Btu.

Solution:

From Figure X-13, the conductivity of 85 o/o magnesia at a mean temperature of 325 F is 0.53. The value of the heat ir the fuel is $0.318 per million Btu. Entering Figur X-14 at 8000 hours and following the dotted lines, the most economical thickness of 85 o/o magnesia insulation for a 5 in. pipe is determined as 2 in.

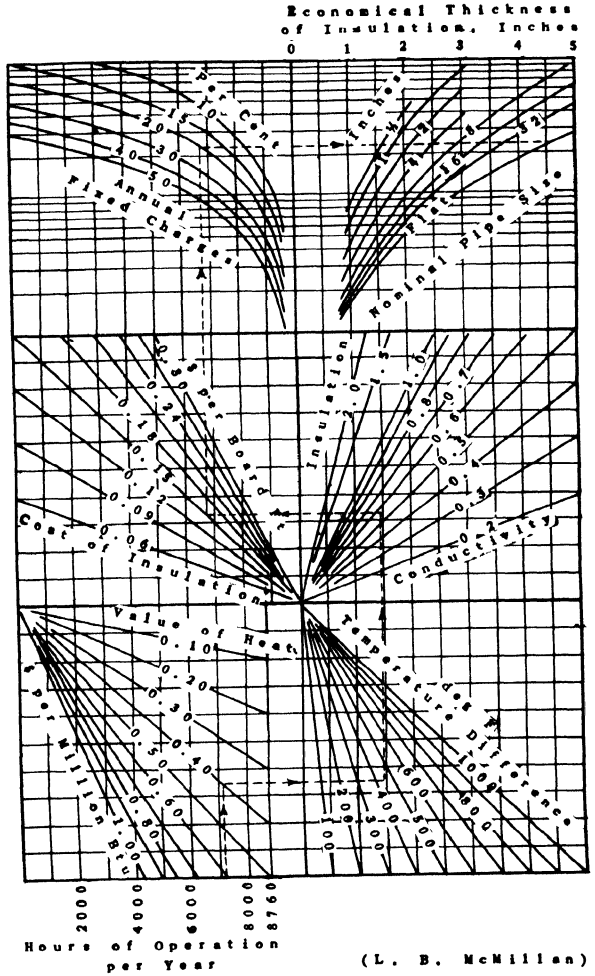


Fig. X-14. Selection chart for insulation thickness.

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Walker, J. H., and Crocker, S., *Piping Handbook*, McGraw-Hill, New York, 1939.

PROJECT III

1. The power plant of Projects I and II is to contain three steam generators. One will be operated continuously, one will be operated to handle peak loads and one will be a spare. Each steam generator will have a capacity sufficient to handle one turbo-generator at full load. The fuel oil has a higher heating value of 18,500 Btu per lb as fired and the analysis is as follows: Carbon = 0.851, hydrogen = 0.11, oxygen = 0.022, nitrogen = 0.002, sulphur = 0.013, and moisture = 0.002. The expected flue gas analysis is: Carbon dioxide = 14.0 o/o, carbon monoxide = 0 o/o, and oxygen = 3.0 o/o. Expected steam generator efficiency is 86.5 o/o. Temperatures expected are: Combustion air, 100 F; flue gas to stack, 300 F; fuel oil at burners, 175 F; and gas entering superheater, 1500 F.

(a) Make a heat balance for the steam generator and calculate the weight of fuel fired per hour.

(b) Estimate the furnace volume required and specify the furnace dimensions.

(c) Estimate the effective radiant surface in the furnace and the number of linear feet of $2\frac{1}{4}$" OD tubes spaced on four inch centers in the furnace walls and boiler screen (assume that the boiler screen consists of three staggered rows).

(d) Estimate the superheater surface required and calculate the number and length of 2" OD X 12 BWG tubes required (assume that the superheater is placed in one boiler pass).

(e) Estimate the most economical temperatures for the remainder of the steam generator. Assume that boiler surface costs $8.00, economizer surface $3.50 and air heater surface $0.90 per incremental square foot with annual fixed charges of 12 o/o.

(f) If boiler surface is justified, estimate the amount necessary and the number of rows and banks of $2\frac{1}{4}$" OD X 12 BWG tubes required.

(g) If economizer surface is justified, estimate the amount necessary and the number and length of $1\frac{1}{8}$" X 12 BWG tubes required.

(h) If air heater surface is justified, estimate the amount necessary and the number and length of $1\frac{1}{2}$" OD X 16 BWG tubes required for one of the recuperative type with the gas

through the tubes. Calculate the number of gas passes necessary if the maximum tube length is 20 ft.

2. Specify the pipe sizes and calculate the pressure drops for the following lines in the power plant of Projects I and II:

(a) Circulating water: Suction line, 50 ft with three 90° elbows. Pump to condenser, 6 ft with one 90° elbow and one gate valve. Condenser discharge, 100 ft with four 90° elbows.

(b) Condensate: Suction line, 10 ft with two 90° elbows and one gate valve. Discharge line, 50 ft with eight 90° elbows, six gate valves and one swing check valve. Assume vapor condenser tube velocity is 5 ft per sec through two 6 ft passes.

(c) Boiler feed: Suction line, 40 ft with three 90° elbows and one gate valve. Discharge line, 75 ft with eight 90° elbows, two gate valves, two swing check valves and one globe valve.

(d) Main turbine lead (manifold to throttle): Length, 50 ft with the equivalent of 3-90° elbows and one gate valve.

(e) Extraction to closed heater: Length, 15 ft with two 90° elbows, one gate valve and one swing check valve.

3. Specify the size and estimate the draft loss for the following ducts for one of the steam generators of part one:

(a) Air heater to windbox (if necessary): Length, 50 ft with two 90° bends.

(b) Economizer to air heater (if necessary): Length, 20 ft with two 90° bends.

(c) Air heater, economizer or boiler to induced draft fan: Two ducts in parallel, each with length of 20 ft with one 90° bend and one 45° bend.

4. Specify the insulation thickness to be used in the following locations in the power plant of Projects I and II (fixed charges 15 o/o and ambient temperature 90 F):

(a) Main turbine lead: 85 o/o magnesia at $C.21 per bd ft.

(b) Preheated air duct: Mineral wool at $C.05 per bd ft.

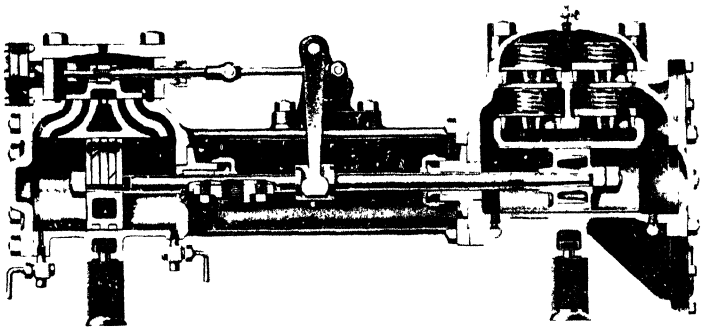
CHAPTER XI

WATER HANDLING EQUIPMENT

73. Water handling equipment consists of pumps and water softeners. Pumps may be either reciprocating or rotating; and water softeners may be either precipitating or base exchanging.

74. Types of Pumps--Pumps are used to move liquids, usually through pipe lines, and at the same time to increase the pressure (head) of the liquid.

Reciprocating pumps may be simplex or multiplex; steam driven or motor driven; or of the plunger or piston type. Figures X-1 and X-2 show two of the various types of reciprocating pumps. Reciprocating pumps have the advantage of being able to operate at extremely high discharge heads or extremely low suction (inlet) heads; and to operate at variable delivery with good efficiency.



(Warren Steam Pump Co.)

Fig. XI-1. Duplex steam driven pump.

Rotating pumps may be centrifugal, turbine, screw or gear; steam driven or motor driven; single stage or multistage. Figures XI-3 through XI-7 show a number of rotating pumps of various types. Rotating pumps have the advantage of simplicity and being adapted to direct drive by high speed turbines or motors. They have the disadvantage of being unable to start pumping at negative suction pressures without being primed. This disadvantage is not serious, however, because it is always possible to find a type of pump which can be installed with a flooded suction.

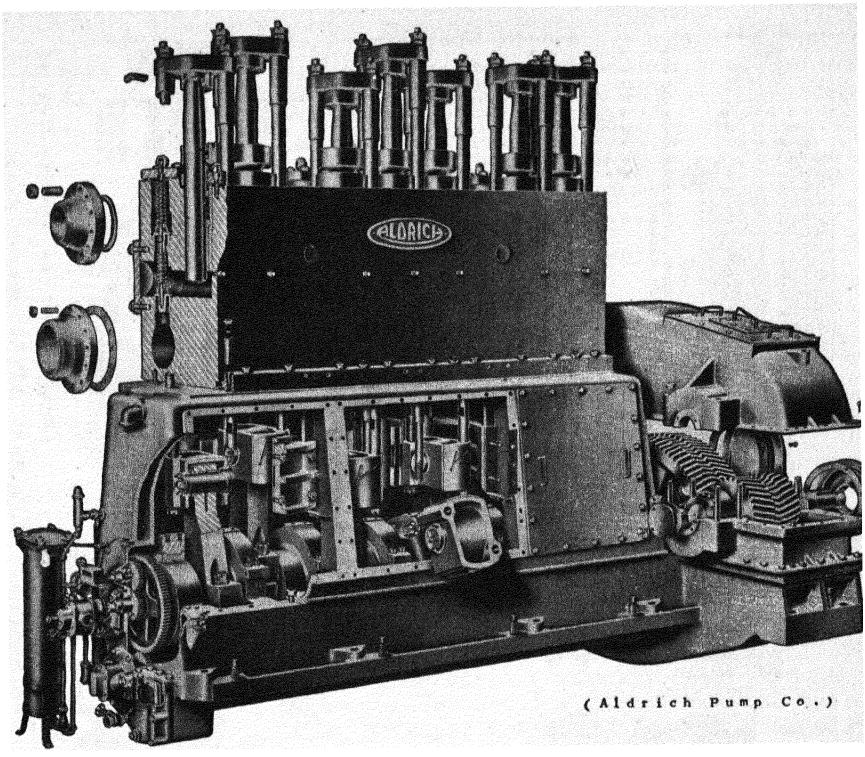
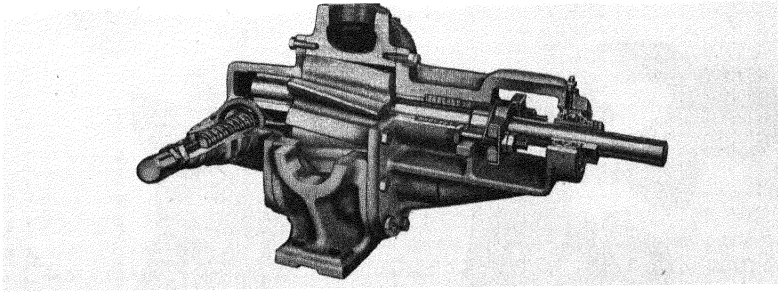
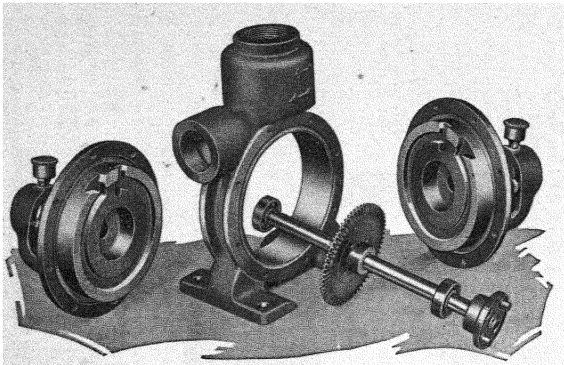


Fig. XI-2. Multiplex motor driven plunger pump.



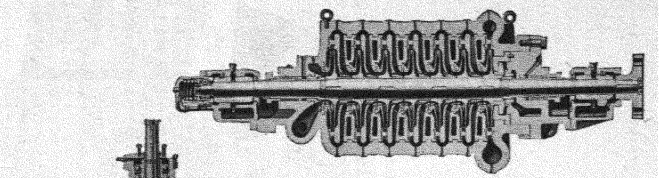
(Geo. D. Roper Corp.)

Fig. XI-3. Gear pump.



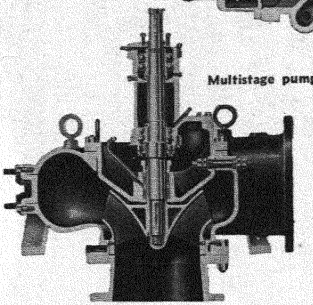
(Aurora Pump Co.)

Fig. XI-4. Turbine pump.



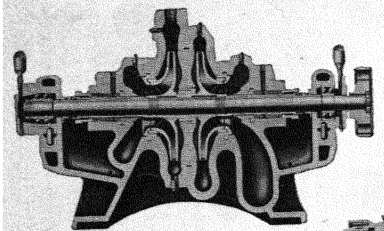
Multistage pump with hydraulic self-balancing device for very high pressures.

(DeLaval)

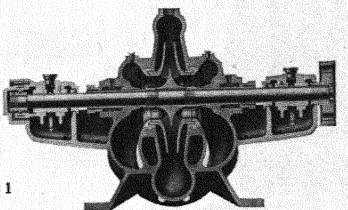


Mixed flow pump for large capacity against low heads at high speed.

Fig. XI-5. Centrifugal pumps.



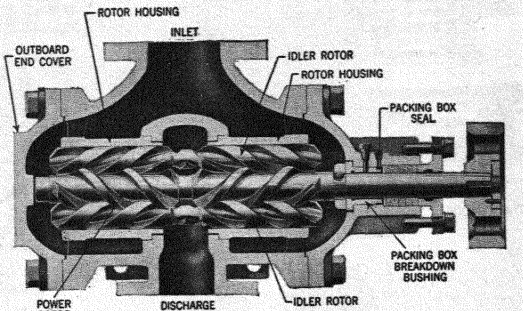
Opposed impeller series pump.



Single-stage, double-suction pump. (Sleeve or Ball Bearing)

(DeLaval)

Fig. XI-6. Centrifugal pumps.



(DeLaval Steam Turbine Co.)

Fig. XI-7. Screw pump.

75. Head and Work Relations in Pumps--Consideration of a pump as a work transferring device will show that the work input to the pump is equal to the work output plus the losses, or:

$$whp = e_p(shp)$$

where: whp and shp = water horsepower and shaft horsepower

e_p = pump efficiency

Water horsepower is the power required to move the water, or:

$$whp = \frac{M_u H_t}{60 \times 33000}$$

where: M_u = water flow, lbs/hr

H_t = total head on pump, ft of fluid

The total head on the pump is the sum of the friction losses in the pipe, the increase in velocity head through the pump, the entry losses and leaving losses for the system, the difference in pressure between inlet and discharge and the difference in static heads, or:

$$H_t = H_f + \frac{V_d^2 - V_i^2}{2g} + H_{s_d} - H_{s_i} + H_{p_d} - H_{p_i} + H_{e_d} + H_{e_i}$$

where: H_f = friction in piping, ft

V = velocity, ft/sec

H_s = static head, ft

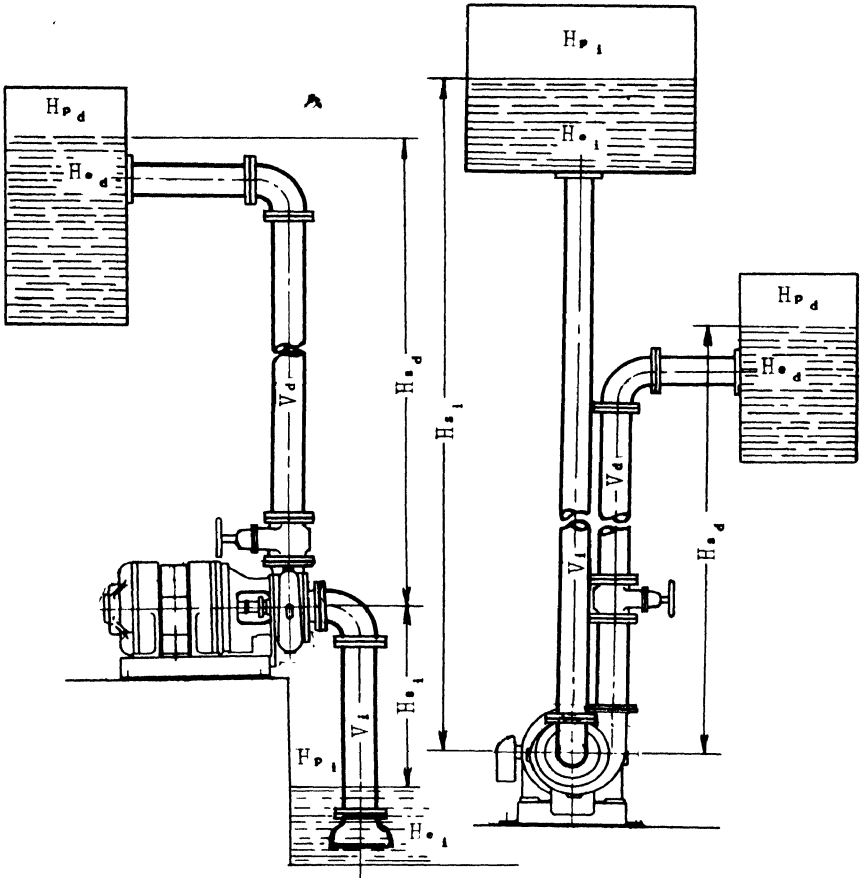
H_p = pressure head, ft

H_e = entry and exit losses, ft

Figure XI-8 shows pump and pipe systems with the various heads in relation to the above equation. It should be noted that the static head on the inlet side of hot water pumps should always be great enough to prevent boiling in the eye of the pump impeller due to pressure reduction below the saturation pressure corresponding to the temperature of the water. An empirical equation which gives the static head at the pump suction is as follows:

$$h = 0.32 \times 10^{-7}\ t^{3.6}$$

where: h = static head on pump suction, ft.
t = water temperature, deg F.



(a) Negative suction head (b) Positive suction head

Fig. XI-8. Head relations in pump systems.

76. Pump Efficiencies--In general, large slow speed pumps have higher efficiencies than small high speed pumps. Table XX shows the ranges of speed and efficiency to be

expected for various types of pumps for power plant service.

TABLE XX

CENTRIFUGAL PUMP DATA

	Cap., gpm	Head, ft	Speed, rpm	Eff., o/o
Boiler feed	10 to 400	200 to 6000	1200 to 3600	70
Condensate	10 to 400	50 to 300	1200 to 3600	70
Condenser	200 to 50000	10 to 50	120 to 450	80
General	5 to 100	10 to 300	1200 to 3600	75

77. Laws of Similarity for Centrifugal Pumps.--The performance of centrifugal pumps follows certain definite patterns and laws. Figure XI-9 shows typical performance curves for two types of centrifugal pump. It will be noted that the head capacity curve has a falling characteristic and the horsepower curve reaches a maximum and then falls. The "self-limiting" power characteristic is of value in preventing the overloading of the driver in case the pump should operate against zero head.

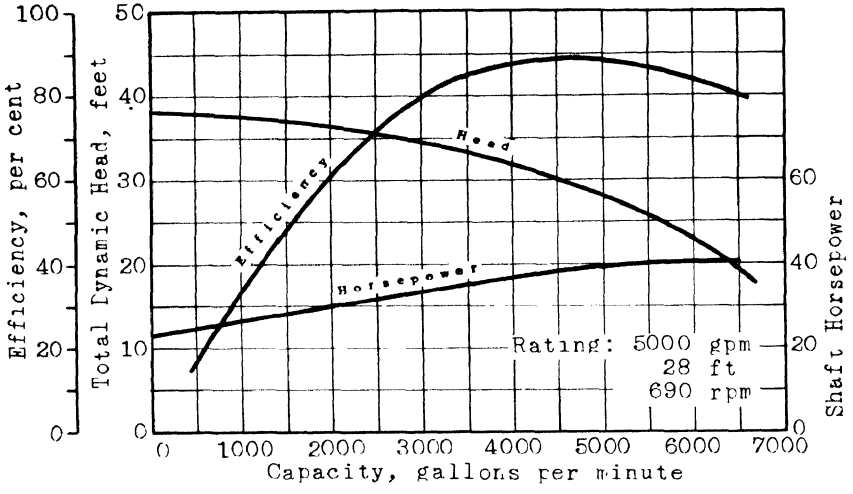
The following equation expresses the laws of similarity for centrifugal pumps.

$$\frac{A_1}{A_2} = \frac{[B_1]^X}{[B_2]^X} \frac{[\rho_1]^Y}{[\rho_2]^Y}$$

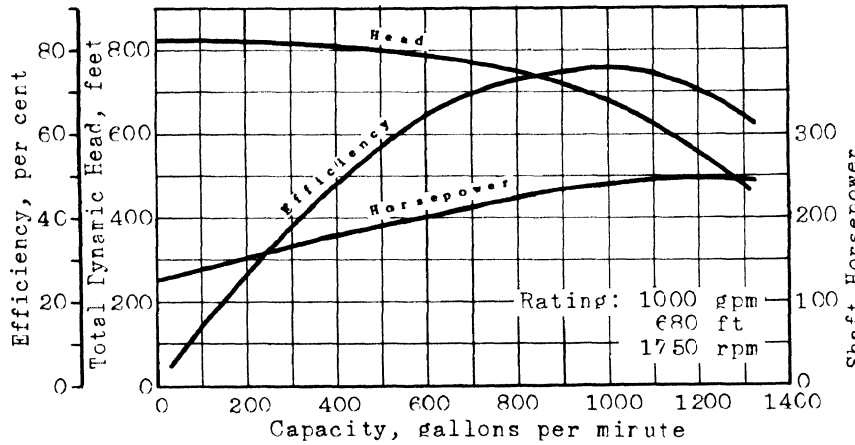
	X				Y				
A =	Q	M	P	H	Q	M	P	H	= A
B = N	1	1	3	2	0	1	1	1	D const
B = D	2	2	5	2	0	1	1	1	N const

where: Q = capacity, volume N = speed P = power
M = capacity, weight ρ = density H = head
D = diameter

It will be seen that, for any given pump, the quantity of water delivered varies directly with the speed, the head with the square of the speed and the power with the cube of the speed. The equation will be valuable in predicting the effect of changes of speed or impeller diameter for a particular pump.



(a) Slow speed, low head



(b) High speed, high head

Fig. XI-9. Centrifugal pump performance curves.

Example 30 shows the method of computing the specifications for a centrifugal pump, and Example 31 shows the method of estimating the effect of changes in pump speed or impeller diameter.

Example 30.

Specify the capacity in gallons per minute and total dynamic head in feet for a centrifugal boiler feed pump to operate under the following conditions: Flow 28800 lbs/hr at 297 F; static lift 20 ft; friction losses 2 ft in suction line and 20 ft in discharge line; inlet velocity 5 ft/sec and outlet velocity 10 ft/sec; entrance and exit losses one-half of the velocity head; pressure in boiler 400 psia and in open heater 64 psia.

Solution:

The capacity of the pump is:

$$\text{Cap.} = 28800(0.01742)(7.48)/60 = 62.5 \text{ gpm}$$

The total dynamic head is:

Static lift	20 ft
Friction losses	22
Velocity head $[10^2-5^2]/2g$	1.2
Entrance and exit losses	0.6
Press. head $(400-64)(144)(0.01742)$	= 843 ft
Total dynamic head	886.8 ft

Example 31-A.

A centrifugal pump with an impeller diameter of 12 in. operates at 3600 rpm and delivers 100 gpm at 300 ft head. What would be the capacity and head if (a) the impeller diameter were reduced to 10 inches, or (b) the speed were reduced to 1800 rpm?

Solution:

(a) At constant speed, the capacity and head are proportional to the square of the diameter.

$$\frac{100}{Q_2} = \frac{(12)^2}{(10)^2} \qquad \frac{300}{H_2} = \frac{(12)^2}{(10)^2}$$

$$Q_2 = 69.5 \text{ gpm} \qquad H_2 = 208 \text{ ft}$$

(b) At constant diameter, the capacity is proportional to the speed and the head is proportional to the square of the speed.

$$\frac{100}{Q_2} = \frac{3600}{1800} \qquad \frac{300}{H_2} = \frac{(3600)^2}{(1800)^2}$$

$$Q_2 = 50 \text{ gpm} \qquad H_2 = 75 \text{ ft}$$

Example 31-B.

A three stage boiler feed pump with 17 inch diameter impellers is rated at 1000 gpm at 675 ft TDH with a motor speed of 1750 rpm. The characteristic curves are shown as solid lines in Figure XI-10. It was found when the pump was placed into operation that the boiler feed system head loss had been overestimated, and instead of being 675 ft at 1000 gpm was actually 600 ft. It was proposed to correct the pump characteristics by turning down the outside diameter of the impeller. Calculate the required impeller diameter and plot the new characteristic curves for the pump.

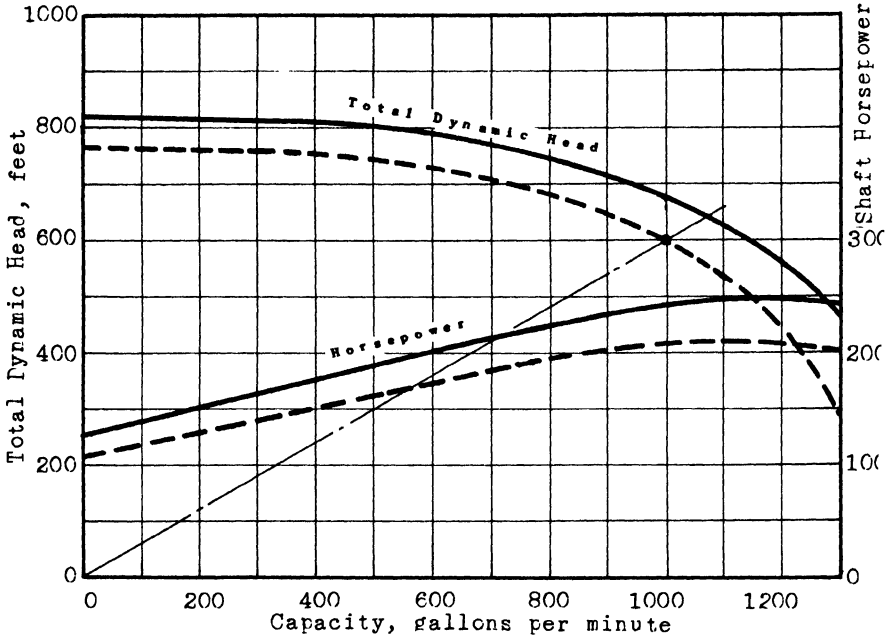


Fig. XI-10. Effect of reduced impeller diameter on centrifugal pump characteristics.

Solution:

An empirical method for determination of the new impeller diameter is as follows:

1. Draw a line from the origin through the new specification point to intersect the original head–capacity curve.

2. Read the head and capacity at the point of intersection and solve for the impeller diameter from both head and capacity relations in the pump equation.

3. Obtain the root mean square of the two solutions for impeller diameter.

This method can be illustrated, as follows:

1. The line from the origin through the new specification point intersects the original head-capacity curve at 640 ft and 1070 gpm.

2. Solving for impeller diameter,

$$\frac{1070}{1000} = \frac{(17)^2}{(D_2)^2} \qquad \frac{640}{600} = \frac{(17)^2}{(D_2)^2}$$

$$D_2 = 16.40 \text{ in.} \qquad D_2 = 16.45 \text{ in.}$$

3. The root mean square of these two solutions is:

$$D_2 = \sqrt{\left[\frac{(16.40)^2 + (16.45)^2}{2}\right]} = 16.425 \text{ in.}$$

The new head curve can be plotted by applying the pump equation at several points on the original curve, as follows:

$$\frac{1200}{Q_2} = \frac{555}{H_2} = \frac{(17.000)^2}{(16.425)^2} = 1.07 \qquad \begin{aligned} Q_2 &= 1120 \text{ gpm} \\ H_2 &= 519 \text{ ft} \end{aligned}$$

$$\frac{800}{Q_2} = \frac{745}{H_2} = 1.07 \qquad \begin{aligned} Q_2 &= 748 \text{ gpm} \\ H_2 &= 696 \text{ ft} \end{aligned}$$

etc.

The new power curve can be plotted in a similar manner, as follows:

$Q_1 = 1200$ gpm $\quad \frac{248}{P_2} = \frac{(17.000)^5}{(16.425)^5} = 1.182 \quad P_2 = 210$ hp

$Q_2 = 1120$ gpm

$Q_1 = 800$ gpm $\quad \frac{224}{P_2} = 1.182 \quad P_2 = 190$ hp

$Q_2 = 748$ gpm

etc.

The new characteristic curves are shown as dotted lines on Figure XI-10.

78. Water Treatment--All natural waters contain quantities of dissolved salts which make the water undesirable for use in steam generators. Calcium and magnesium salts precipitate in the boiler to form scales or sludges which adversely affect the heat transfer coefficients. Sodium salts are soluble at all temperatures, but excessive concentrations of dissolved sodium salts lead to foaming which has the bad effect of causing deposits in superheaters and turbines. It is the purpose of water treatment to either remove the undesirable salts before they reach the boiler or to produce conditions within the boiler which are such as to cause precipitation of the undesirable salts in forms which will not produce scale and which can be easily removed from the boiler by blowdown.

Calcium and magnesium bicarbonates are soluble at ordinary temperatures, but when water containing them is boiled the bicarbonates decompose to carbonates and precipitate. The fact that bicarbonates can be removed by boiling gives them the name *temporary hardness* (hardness is a measure of the soap destroying power of water). Non-carbonate salts of calcium and magnesium produce what is termed *permanent hardness*, that is, boiling has no effect as with temporary hardness.

Hardness can be removed from water in two general ways (in addition to boiling to remove temporary hardness, which has no extensive commercial application): by precipitation or by base exchange.

79. Precipitation Softening--Precipitation softeners may operate either by the cold process or by the hot process. Due to the fact that most of the slightly soluble calcium and magnesium salts exhibit a decreasing solubility with increasing temperature, the hot process of softening is more efficient than the cold process. There are cases, however, where the cold process must be used (such as softening of municipal water supplies). Following are detailed explan-

ations of the various processes.

The cold lime and alum process uses either quicklime or hydrated lime for the precipitation of temporary hardness and filter alum for the production of a floc which aids in the coagulation of the precipitate and in the removal of bacteria and dirt. Figure XI-11 shows a typical softener operating with this process. The reactions are:

$$Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2CaCO_3\downarrow + 2H_2O$$
$$Mg(HCO_3)_2 + 2Ca(OH)_2 \longrightarrow Mg(OH)_2\downarrow + 2CaCO_3\downarrow + 2H_2O$$
$$CO_2 + Ca(OH)_2 \longrightarrow CaCO_3\downarrow + H_2O$$
$$Al_2(SO_4)_3 + 3Ca(OH)_2 \longrightarrow 2Al(OH)_3\downarrow + 3CaSO_4\downarrow$$

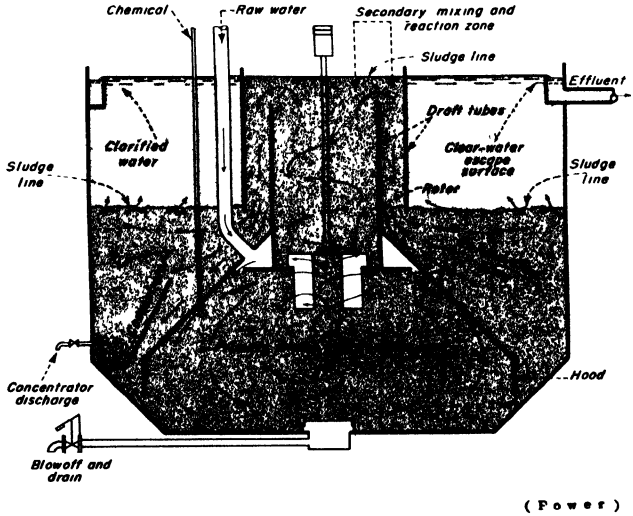


Fig. XI-11. Cold process softener.

The lowest hardness which can be produced by this process is about 70 parts per million, which is the solubility of calcium carbonate at ordinary temperatures.

The cold lime-soda and alum process uses lime and alum, as in the previous process, plus soda ash to precipitate non-carbonate hardness. The apparatus employed is identical with that used for the lime and alum process. The additional reactions are:

$$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3\downarrow + Na_2SO_4$$
$$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3\downarrow + 2NaCl$$
$$MgSO_4 + Ca(OH)_2 + Na_2CO_3 \rightarrow Mg(OH)_2\downarrow + CaCO_3\downarrow + Na_2SO_4$$
$$MgCl_2 + Ca(OH)_2 + Na_2CO_3 \rightarrow Mg(OH)_2\downarrow + CaCO_3\downarrow + 2NaCl$$

In this process it is customary to use excess soda ash in order to depress the solubility of calcium carbonate by common ion effect. Figure XI-12 shows the hardness attainable by the use of excess soda ash.

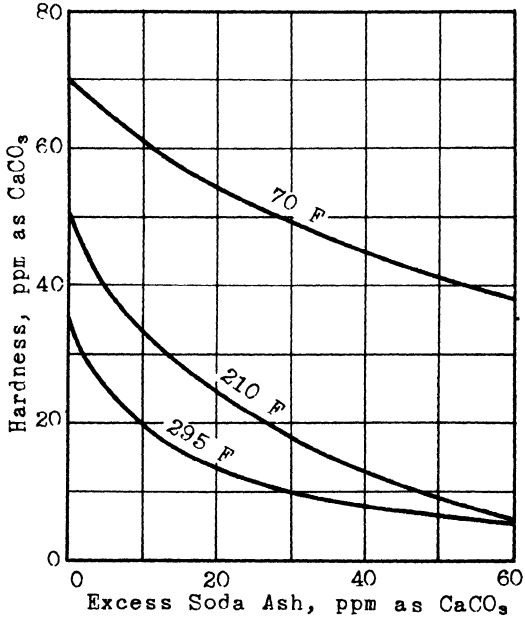


Fig. XI-12. Residual hardness resulting from use of excess soda ash.

The hot lime-soda process is similar to the cold lime-soda and alum process, except that the alum is not used because at elevated temperatures magnesium hydroxide forms a floc. The reactions are the same as previously given, and the residual hardness can be estimated from Figure XI-12. Figure XI-13 shows a typical hot process softener with its auxiliaries.

Example 32 shows the method of calculation of quantities of chemicals required for softening by the various

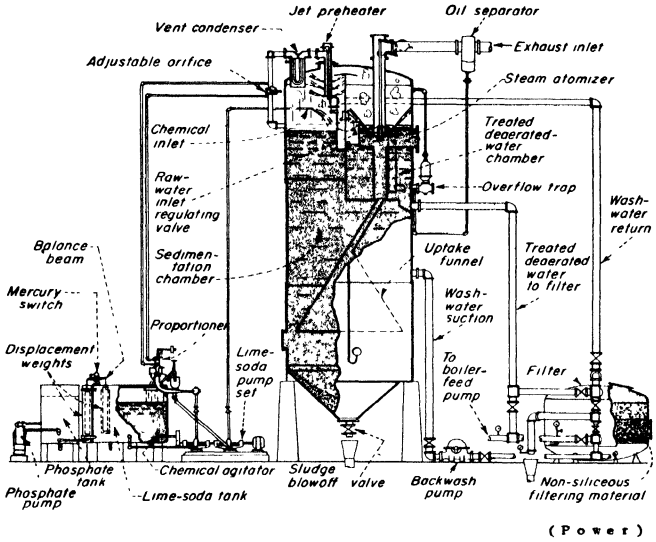


Fig. XI-13. Hot process softener.

precipitation methods. Useful chemical tables will be found in the Appendix.

Example 32-A.

A water of the following analysis is to be softened with lime and coagulated with 10 ppm of aluminum sulphate (filter alum): Ca = 62 ppm; Mg = 31 ppm; Na = 38 ppm; HCO_3 = 250 ppm; SO_4 = 139 ppm; Cl = 11 ppm; CO_2 = 16 ppm. Determine the weight of 90 o/o hydrated lime and 95 o/o crystalline filter alum required per thousand gallons of water.

Solution:

The first step in the solution is the conversion of the ionic analysis to the hypothetically combined form, as follows:

Ions	ppm	+epm	-epm	Combinations	epm	ppm
Ca	62	3.10		$Ca(HCO_3)_2$	3.10	251.5
Mg	31	2.55		$Mg(HCO_3)_2$	1.00	73.2
Na	38	1.65		$MgSO_4$	1.55	93.5

Ions	ppm	+epm	-epm	Combinations	epm	ppm
HCO_3	250		4.10	Na_2SO_4	1.34	95.1
SO_4	139		2.89	NaCl	0.31	18.2
Cl	11		0.31			
Sub.tot	531	7.30	7.30		7.30	531.5
CO_2	16					16
Total	547					547.5

It will be noted that the hypothetical combinations are made in a definite order, as follows:

Positive ions	Negative ions
Ca	HCO_3
Mg	SO_4
Na	Cl

Next, the reactions are written with molecular weights and parts per million, as follows:

$$\underset{251.5}{Ca(HCO_3)_2} + \underset{x_1 = 115 \text{ ppm}}{Ca(OH)_2} \longrightarrow 2\,CaCO_3\downarrow + H_2O$$

$$\underset{73.2}{Mg(HCO_3)_2} + 2\,\underset{x_2 = 74.1 \text{ ppm}}{Ca(OH)_2} \longrightarrow Mg(OH)_2\downarrow + 2\,CaCO_3\downarrow + 2\,H_2O$$

$$\underset{93.5}{MgSO_4} + \underset{x_3 = 57.5 \text{ ppm}}{Ca(OH)_2} \longrightarrow Mg(OH)_2\downarrow + CaSO_4\downarrow$$

$$\underset{16.0}{CO_2} + \underset{x_4 = 27.0 \text{ ppm}}{Ca(OH)_2} \longrightarrow CaCO_3\downarrow + H_2O$$

$$\underset{10(0.95)}{Al_2(SO_4)_3\,18H_2O} + 3\,\underset{x_5 = 3.2 \text{ ppm}}{Ca(OH)_2} \longrightarrow 2\,Al(OH)_3\downarrow + 3\,CaSO_4\downarrow + 18\,H_2$$

Total 90 o/o hydrated lime required = 276.8/0.90 = 308 ppm
Total 95 o/o filter alum required 10 ppm

The final water analysis would be: NaCl = 18 ppm; Na_2SO_4 = 95 ppm; hardness about 70 ppm as $CaCO_3$.

One thousand gallons of water = 8.33×10^{-3} million lb Therefore, the lime required is 2.56 lbs per thousand gallo and the alum required is 0.083 lbs per thousand gallons.

Example 32-B.

The water of Example 32-A is to be softened by the lime soda and alum process. In order to depress the solubility of calcium carbonate, 25 ppm of excess soda ash is added. Determine the weight of 95 o/o soda ash required in addition to the lime and alum.

Solution:

The reactions with molecular weights and parts per million are:

$$\underset{\substack{120.4\\ 99.5}}{MgSO_4} + Ca(OH)_2 + \underset{\substack{106.0\\ y_1 = 82.3 \text{ ppm}}}{Na_2CO_3} \longrightarrow Mg(OH)_2\downarrow + CaCO_3\downarrow + \underset{\substack{142.0\\ z_1 = 110.0 \text{ ppm}}}{Na_2SO_4}$$

$$\underset{\substack{666.4\\ 9.5}}{Al_2(SO_4)_3 \cdot 18H_2O} + 3\,Ca(OH)_2 + \underset{\substack{318.0\\ y_2 = 4.5 \text{ ppm}}}{3\,Na_2CO_3} \longrightarrow 2\,Al(OH)_3\downarrow + 3\,CaCO_3\downarrow + \underset{\substack{426.0\\ z_2 = 6.1 \text{ ppm}}}{3\,Na_2SO_4}$$

The total 95 o/o soda ash required (including excess) is 111.8/0.95 = 118 ppm.

The final water analysis would be: NaCl = 18 ppm; Na_2SO_4 = 211 ppm; Na_2CO_3 = 25 ppm; hardness about 50 ppm as $CaCO_3$.

The soda ash required would be 0.98 lbs per thousand gallons.

If this water were to be softened by the hot lime soda process (atmospheric pressure), the alum would be omitted and the final water analysis would be: NaCl = 18 ppm; Na_2SO_4 = 205 ppm; Na_2CO_3 = 25 ppm; hardness about 22 ppm as $CaCO_3$. Slightly less lime would be used because of the omission of the alum.

80. Base Exchange Softening--Several natural minerals called *zeolites* (complex sodium aluminum silicates) have the property of base exchange, that is, they will exchange their sodium for calcium or magnesium, or vice versa, depending upon which is present in the greatest concentration in the solution passing over them. Synthetic zeolites of various types have been made which have greater exchange capacity

than the natural materials as well as the ability to operate with acids or bases.

The sodium cycle exchanges sodium for calcium or magnesium in the softening run, and vice versa in the regenerating run. Regeneration is accomplished with strong brine (ordinary salt) solution. Some of the reactions are:

Softening:

$$Na_2Z + Ca(HCO_3)_2 \longrightarrow 2NaHCO_3 + CaZ$$
$$Na_2Z + Mg(HCO_3)_2 \longrightarrow 2NaHCO_3 + MgZ$$
$$Na_2Z + MgCl_2 \longrightarrow 2NaCl + MgZ$$

Regeneration:

$$CaZ + 2NaCl \longrightarrow Na_2Z + CaCl_2$$
$$MgZ + 2NaCl \longrightarrow Na_2Z + MgCl_2$$

Both magnesium and calcium chlorides are extremely soluble and are washed out, with the excess brine, with raw water. When the wash water becomes soft the washing is stopped and the zeolite is ready for another softening run. Figure XI-14 shows a typical zeolite softener which operates on the sodium cycle.

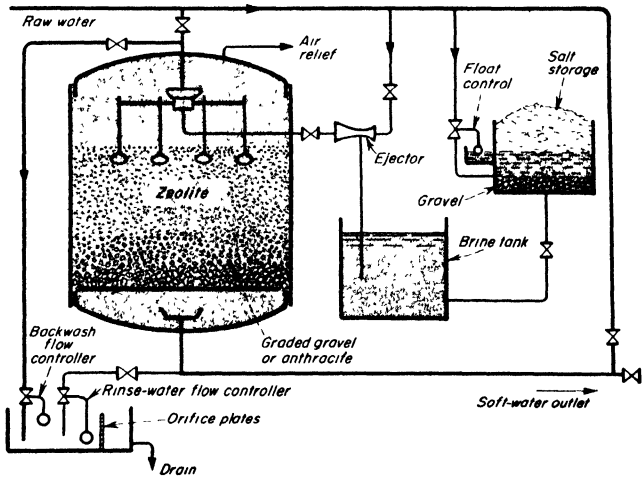


Fig. XI-14. Zeolite softener, sodium cycle.

The hydrogen cycle exchanges hydrogen for all metals, and the regeneration is accomplished with acid. Some of the reactions are:

Softening:

$$H_2Z + Ca(HCO_3)_2 \longrightarrow 2H_2CO_3 + CaZ$$

$$H_2Z + CaCl_2 \longrightarrow 2HCl + CaZ$$

Regeneration:

$$CaZ + H_2SO_4 \longrightarrow H_2Z + CaSO_4$$

The carbonic acid can be removed from the water by aeration. The other acids produced in this cycle are extremely corrosive, so the water is blended with effluent from a sodium cycle softener before aeration to produce essentially neutral water by the reaction of sodium bicarbonate with the acids. Figure XI-15 shows a typical zeolite softener which operates on the dual cycle.

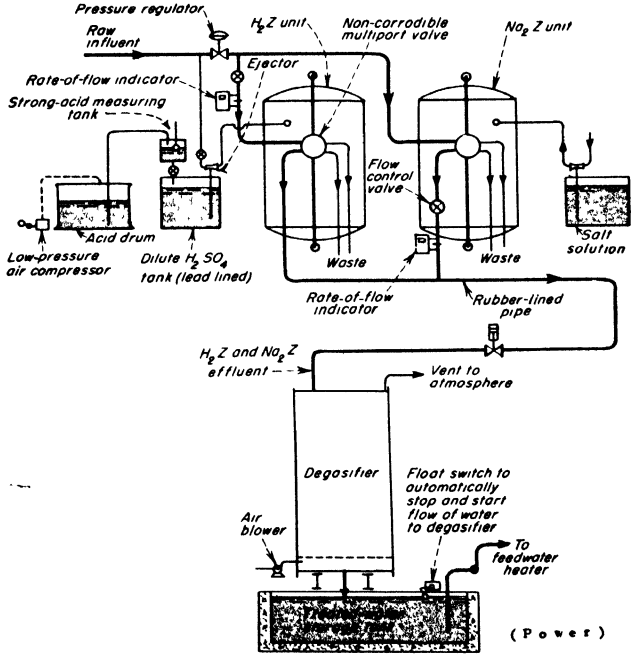


Fig. XI-15. Zeolite softener, dual cycle.

The acid adsorbing cycle employs a synthetic resin which has the property of being able to adsorb acids from solution and of being regenerated by alkali, as follows:

Adsorption:

$$R + HCl \longrightarrow R \cdot HCl$$

Regeneration:

$$R \cdot HCl + NaOH \longrightarrow R + NaCl + H_2O$$

When the acid adsorbing cycle follows a hydrogen zeolite cycle and a deaerator water of almost as good quality as commercially distilled water is produced. The process is quite economical and requires much less investment than a distillation plant where pure water is required for industrial use. It does not appear, however, that the process has any advantages over the evaporator in a regenerative power cycle.

81. **Boiler Water Treatment**--Even in cycles which use evaporators for makeup water it is necessary to use some form of boiler water treatment because contamination of the boiler water results from even a small amount of condenser leakage or carryover from evaporators. It is even more necessary to treat boiler water in cycles where makeup is raw or softened water. Boiler water treatment has four objectives:

1. To prevent corrosion of the boiler or power piping.
2. To prevent embrittlement of boiler metal.
3. To prevent formation of scale in the boiler.
4. To prevent the formation of deposits in superheaters or turbires.

The methods of accomplishing these objectives are as follows:

Corrosion is prevented by maintaining the boiler water within a narrow alkaline range as indicated by the pH (which should be between 10 and 11) and by removing as much as possible of the dissolved gases in the condensate or boiler feed before it reaches the boiler.

The alkalinity is maintained by the use of caustic soda, soda ash or one or more of the polybasic phosphates. The phosphates have the advantage of helping to prevent scale; caustic soda has the disadvantage of inconvenience ir hand-

ling as well as the ability to cause boiler embrittlement when not closely controlled; and soda ash has the disadvantage of decomposing to caustic soda and releasing carbon dioxide which, when in solution, is corrosive to piping.

The removal of dissolved gases was discussed under feed-water heaters. The best deaerating feed-water heaters will not remove all of the dissolved oxygen from the boiler feed, so it is customary to maintain a residual of about 10 ppm of sodium sulphite in the boiler water to act as an oxygen scavenger, according to the reaction:

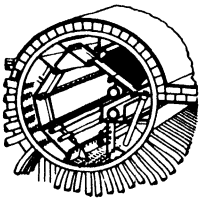
$$2Na_2SO_3 + O_2 \longrightarrow 2Na_2SO_4$$

The sodium sulphate produced has the advantage of helping to inhibit boiler embrittlement.

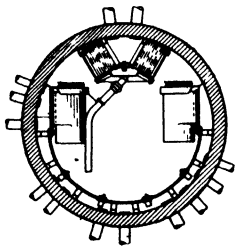
Boiler embrittlement, which is caused by caustic attack on intergranular cementite, is prevented primarily by avoiding riveted boiler drums, and inhibited in all cases by maintaining concentrations of certain materials in the boiler water. The best known inhibitor is sodium sulphate which is maintained at a ratio of about three to one with relation to the concentration of sodium carbonate in the boiler water. Trisodium phosphate has an embrittlement inhibiting property, and will replace an equal weight of sodium sulphate for this purpose. Organic inhibitors, such as sodium lignin sulphonate (from sulphite paper mill wastes) and quebracho extract (a tannin) are also used to some extent.

Scale formation is usually prevented or minimized by maintaining a residual of phosphate ion (about 50 ppm) in the boiler water. Calcium phosphate is less soluble than calcium carbonate or calcium sulphate, which are the principal constituents of boiler scale, but it precipitates as a sludge which is much less adherent than the other calcium precipitates. Sludge conditioners, such as sodium alginate (from certain seaweeds) and starches, are sometimes used to improve the fluidity of the sludge, thus making it easier to remove by boiler blowdown.

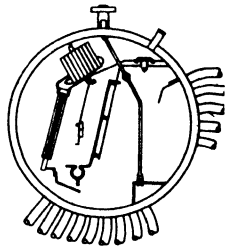
Deposits in superheaters and turbines are the result of carryover of solids from the boiler with the steam. These deposits can be prevented or minimized by careful attention to the maintenance of a practical minimum of dissolved solids in the boiler water by proper blowdown, and by the installation of efficient steam purifiers inside the boiler. Figure XI-16 shows several types of steam purifiers which are used in modern steam generators.



Internal drum construction to improve separation of steam from water and to clean steam involves baffles to change direction and "washing" of steam by feedwater



Steam leaves baffle to enter centrifugal separator in exit zone



Steam enters above water lev el, flows to baffles, scrubbers, driers

(Power)

Fig. XI-16. Steam purifiers.

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CHAPTER XII

FUEL HANDLING EQUIPMENT

82. The simplest fuel handling equipment will be found in the plant which burns gas. The complexity of the system increases when fuel oil is used, and becomes a large part of the plant investment when coal is burned.

83. Gas Burning Equipment--The fuel handling equipment for a gas burning plant would consist of a pipe line bringing the gas to the plant, a gas holder (when the supply is subject to fluctuation), gas meters, control valves and burners. Figure XII-1 shows the elements of a gas fuel system and figure XII-2 shows a typical gas burner.

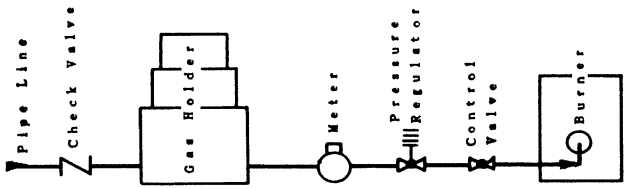
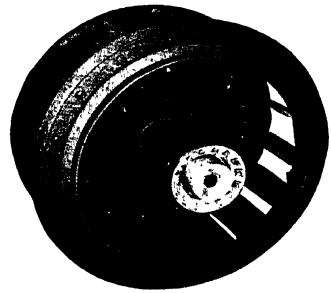


Fig. XII-1. Gas fuel system.

84. Fuel Oil Burning Equipment--The fuel handling equipment for a fuel oil burning plant would consist of unloading facilities (docks or railroad sidings), tanks (for about a 30 day supply), pumps, strainers, heaters, control valves and burners. Figure XII-3 shows the elements of a fuel oil burning system and Figure XII-4 shows a typical oil burner with mechanical atomizing and steam atomizing burner tip details. Figure XII-5 shows a so-called rotary cup oil burner which embodies a forced draft primary air fan, fuel oil pump and controls. This type of burner is well adapted to small



(Forney Engineering Co.)

Fig. XII-2. Gas burner.

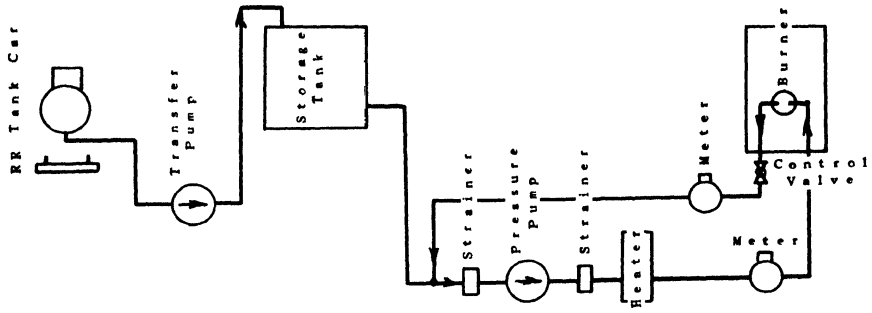
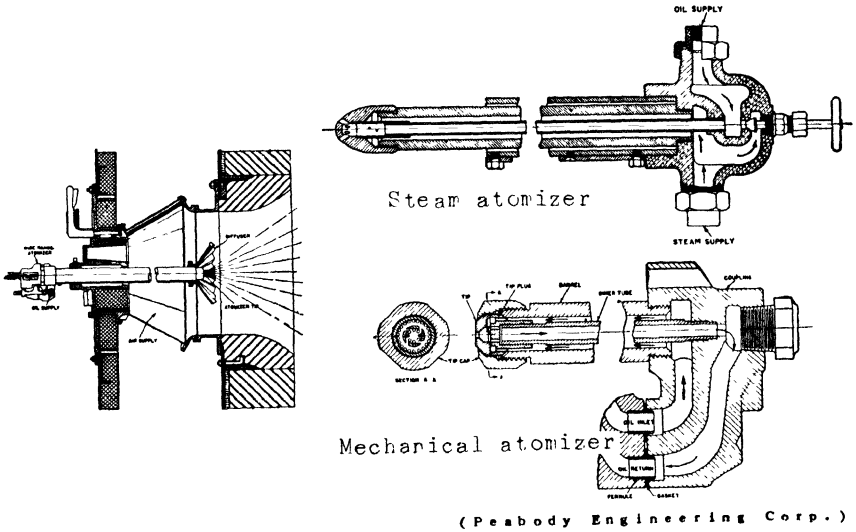


Fig. XII-3. Fuel oil system.

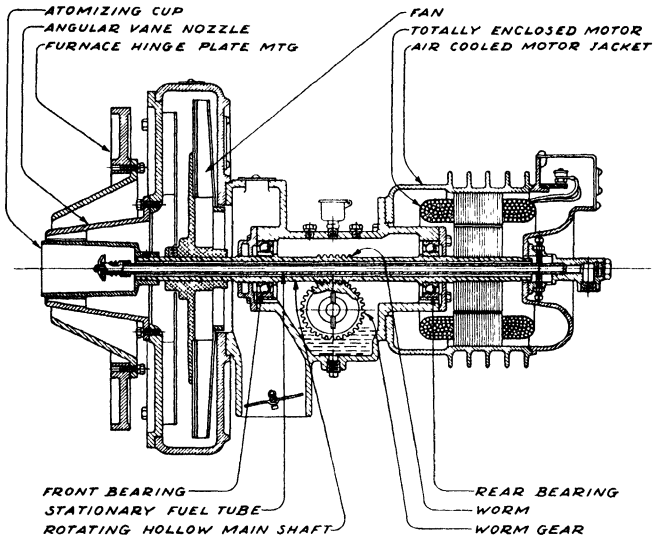


(Peabody Engineering Corp.)

Fig. XII-4. Oil burner.

boilers, since burners of this type are available ir sizes to handle up to about 200 boiler horsepower.

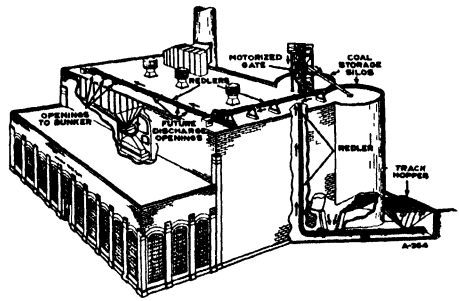
85. Coal Burning Equipment.--The variety of fuel handling equipment for a coal burning plant is quite large. Whether the plant burns lump coal or pulverized coal, a storage yard of sufficient size for about a 30 day supply of



(Ray Oil Burner Co.)

Fig. XII-5. Rotary cup oil burner.

coal is necessary; as well as conveying equipment for storing and reclaiming the coal, bringing the coal to sizing crushers and then to the plant bunkers. If the plant operates with lump coal it will be fed from the bunkers to the stokers through weighing devices. Then, after the fuel is burned, the ash must be disposed of in some way (some companies sell it for road surfacing or for concrete block aggregate). Figure XII-6 shows a typical lump coal (stoker) burning system, and Figure XII-7 shows a pulverized coal system of the direct firing type.



(Stephens-Adamson Mfg. Co.)

Fig. XII-6. Coal stoker system.

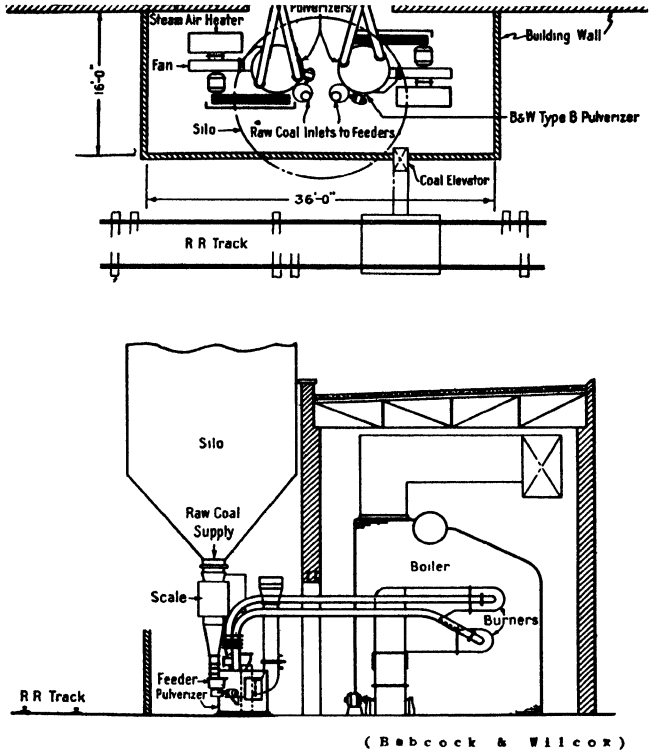


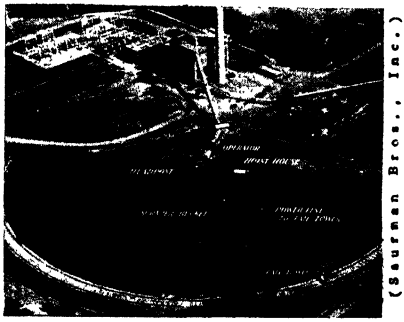
Fig. XII-7. Coal pulverizer system, direct firing.

Sometimes the pulverizers are operated to store pulverized coal in bunkers from which it is fed to the burners. The storage system requires smaller pulverizers than the direct firing system, but the storage of pulverized coal is hazardous and more plant space is taken up by the extra set of bunkers. Figure XII-8 shows a coal storage yard with the coal handling machinery.

86. Stokers--The equipment used for burning lump coal in a boiler furrace is known as a stoker, and it may be either underfeed or overfeed, depending upon whether the coal comes in under or over the air supply.

Overfeed stokers may be of the travelling grate type

(suitable for free burning coals), the chain grate type (suitable for caking coals), or the spreader type with dumping or travelling grates (suitable for a wide variety of coals). Figure XII-9 shows some of the various overfeed stokers in use at the present time.



(Saurman Bros., Inc.)

Underfeed stokers are of the retort type and are suitable for high volatile coals. There may be one or more retorts, depending upon the amount of fuel to be burned. Figure XII-10 shows typical single and multiple retort stokers presently in use.

(Link Belt Co.)

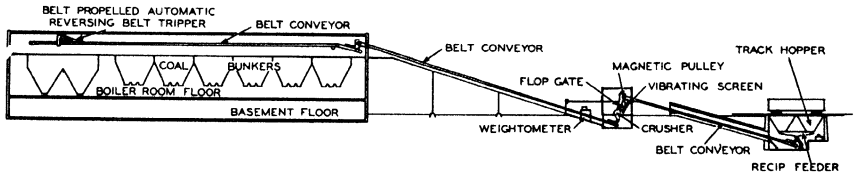


Fig. XII-8. Coal storage system.

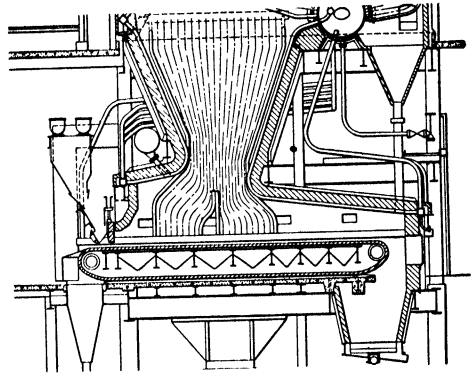
Table XXI shows some approximate data for fuel burning rates per square foot of area for the various types of stokers.

TABLE XXI

FUEL BURNING RATES FOR STOKERS

Pounds per hour per square foot

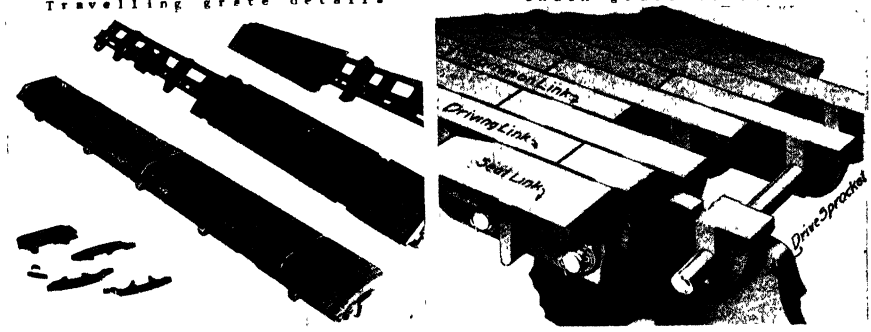
Overfeed	
Spreader	35 - 40
Travelling and chain grates	
Anthracite	25
Bituminous	60
Underfeed	
Single retort	40
Multiple retort	50 - 60



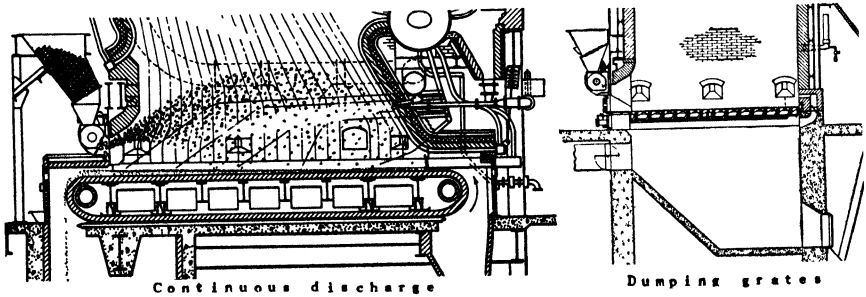
General arrangement

Traveling grate details

Chain grate details



(a) Traveling grate or chain grate



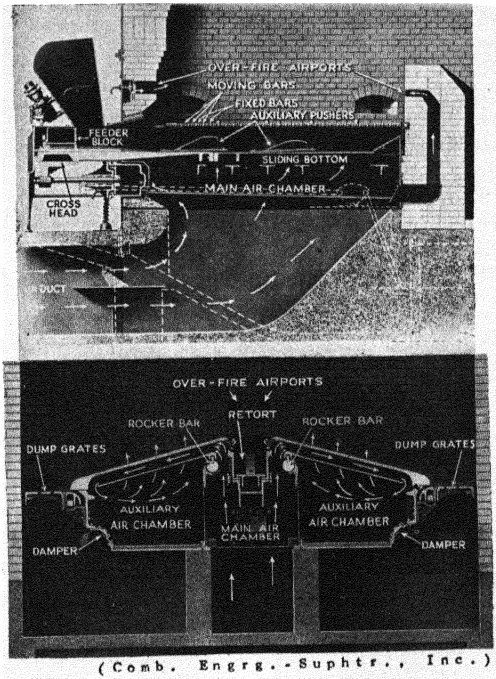
Continuous discharge

Dumping grates

(b) Spreader

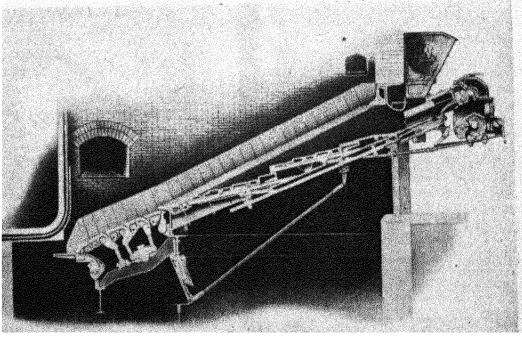
(Comb. Engrg.-Suphtr., Inc.)

Fig. XII-9. Overfeed stokers.



(Comb. Engrg.-Suphtr., Inc.)

(a) Single retort

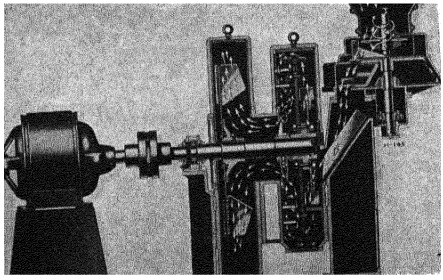


(Westinghouse Elec. Corp.)

(b) Multiple retort

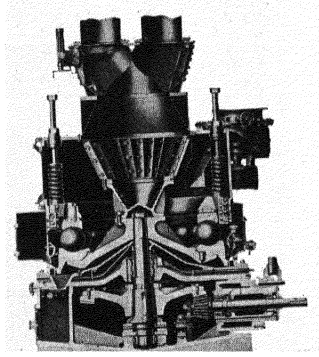
Fig. XII-10. Underfeed stokers.

87. Pulverizers--The function of a pulverizer is to grind previously crushed coal to a fine powder (about 90 per cent through a 200 mesh screen) so that it will burn in a manner similar to gas or oil. The pulverizer may be of the types shown in Figure XII-11. Mill exhauster fans may be built into the pulverizer, as with the attrition mill, or they may be separate. Mill feeders may also be built in or separate. About twenty per cent of the total combustion air is used as primary air (always preheated) for conveying the coal from the pulverizers to the burners. Pulverizers require powerful motors, and Table XXII shows approximate power requirements for the various types of mill.



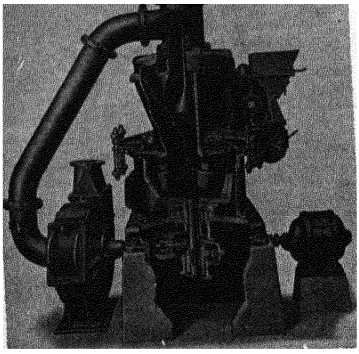
(Riley Stoker Corp.)

(a) Attrition mill



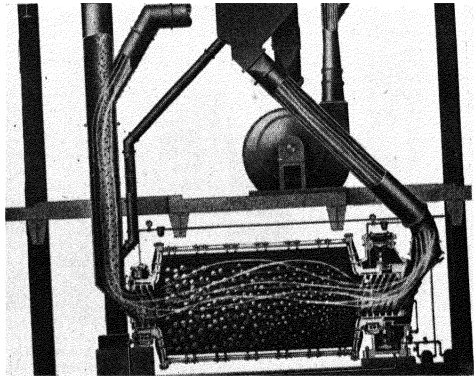
(Babcock & Wilcox)

(b) Ball mill



(Comb. Engrg.--Suphtr., Inc.)

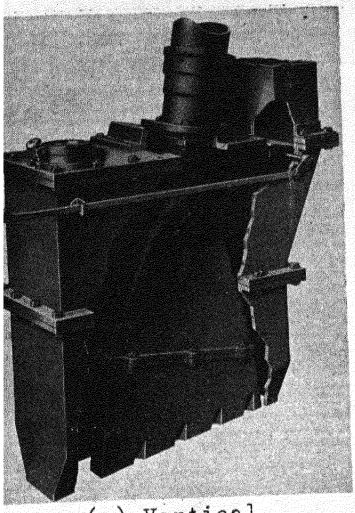
(c) Bowl mill



(Kennedy-Van Saun Mfg. Corp.)

(d) Tube mill

Fig. XII-11. Pulverizers.



(a) Vertical

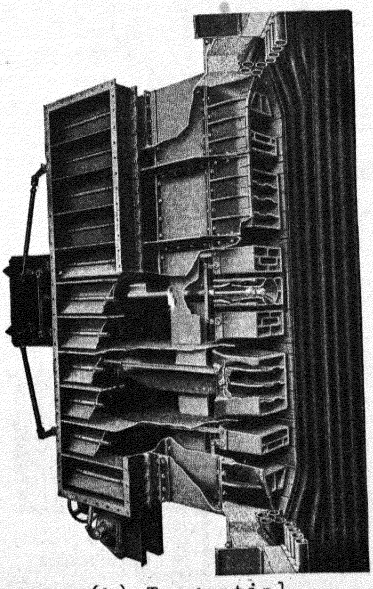
TABLE XXII

PULVERIZER POWER REQUIREMENTS

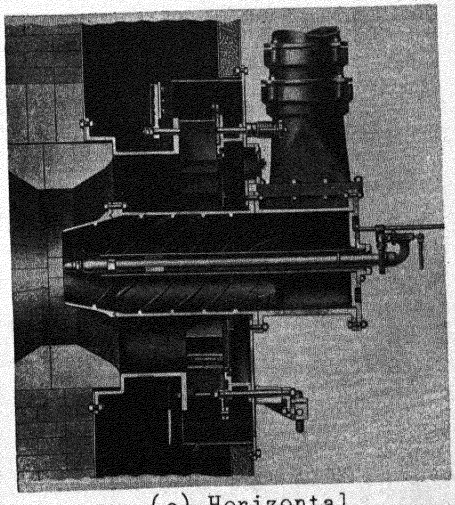
	KWH per ton
Ball and race mill	8 - 12
Bowl mill	11 - 16
Tube mill	11 - 17
Attrition mill	11 - 17

88. Pulverized Coal Burners--A pulverized coal burner is designed to mix the coal and primary air with secondary air as it is blown into the furnace. A few of the many types of pulverized coal burners are shown in Figure XII-12.

89. Horizontal Cyclone Burner--A recent development



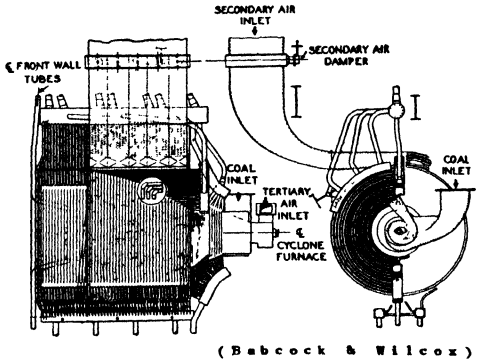
(b) Tangential



(c) Horizontal

(Comb. Engrg.-Suphtr., Inc.)

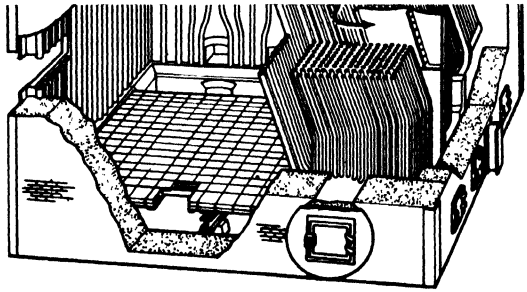
Fig. XII-12. Pulverized coal burners.



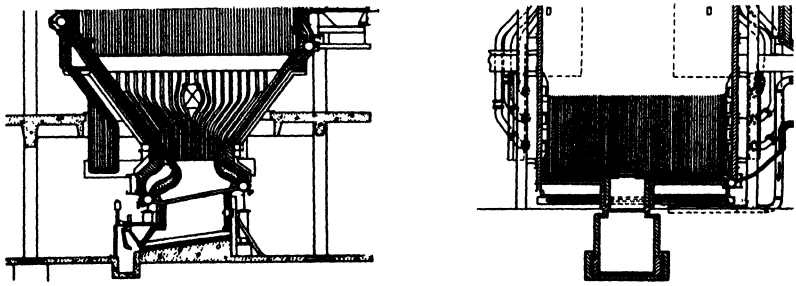
(Babcock & Wilcox)

Fig. XII-13. Horizontal cyclone burner.

in coal burning equipment is the horizontal cyclone burner which is designed to burn low grades of coal at high rates without the necessity for pulverizing it. Figure XII-13 shows the burner which would be attached to the side of a furnace and connected into the waterwall circulation. The furnace is smaller than is usual with other



(a) Oil or gas



Dry bottom Wet bottom

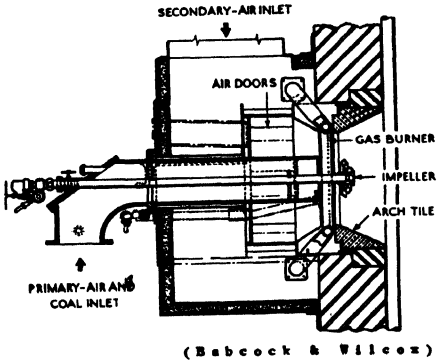
(b) Pulverized coal

(Power)

Fig. XII-14. Furnace bottoms.

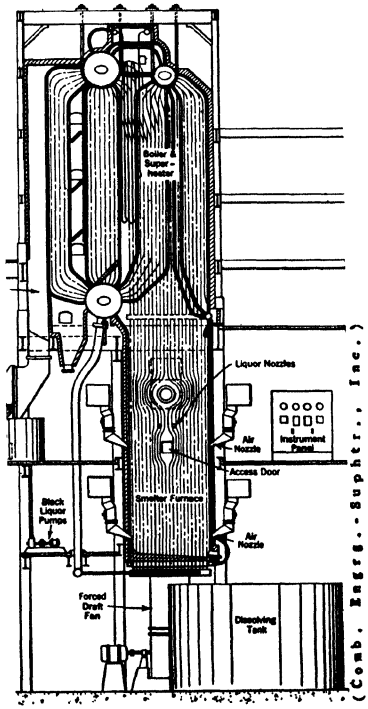
types of fuel burning equipment because most of the combustion takes place in the cyclone. Coal, crushed to about four mesh size, is fed with primary air at high velocity into the rear end of the burner where it is met by a high velocity tangential stream of secondary air. The coal sticks into a layer of molten slag and burns as the air blows across it.. The slag is continuously moving toward a drain hole at the bottom of the burner front from which it drips into the main furnace.

90. Furnace Bottoms--Furnace bottoms vary in design depending upon the type of fuel to be burned. Some of the various types of furnace bottoms are shown in Figure XII-14. Furnaces for gas or oil usually have sloping flat water cooled bottoms. Furnaces for stokers, naturally, have the bottom made up of grates or retorts. Furnaces for pulverized coal may be of the wet or dry bottom types. The wet bottom type has little or no cooling surface on the furnace bottom, so that the ash which falls on it remains in the molten condition in a pool, from which it is tapped, either continuously or intermittently. The dry bottom furnace has a completely cooled hopper bottom, so that the ash which falls to the bottom is cooled sufficiently to be removed in granular form.



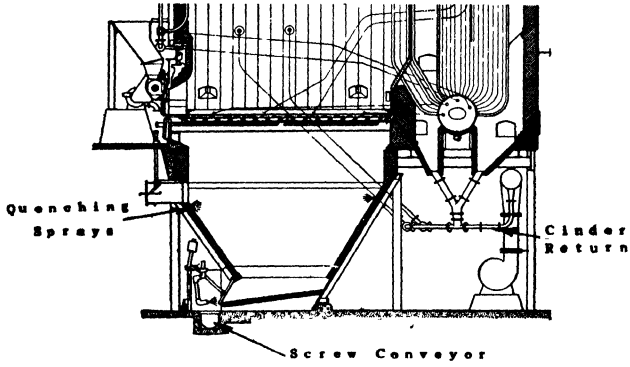
(Babcock & Wilcox)

Fig. XII-15. Three-fuel burner.



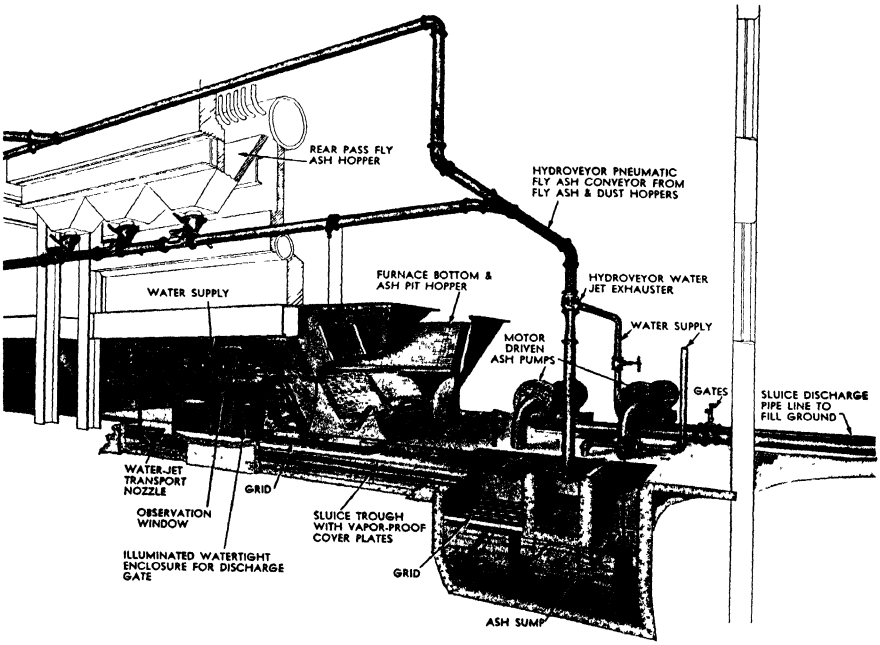
(Comb. Engrg.-Suphtr., Inc.)

Fig. XII-16. Sulphate paper mill chemical recovery boiler.



(Comb. Eng.-Suphtr., Inc.)

Fig. XII-17. Stoker ash disposal system.



(United Conveyor Corp.)

Fig. XII-18. Pulverized coal ash disposal system.

91. Multiple Fuel Burning Installations--In some localities more than one fuel may be available, and plants have been designed to burn two or three fuels separately or in combination. Figure XII-15 shows a three-fuel burner for pulverized coal, oil or gas. Other plants have been designed to burn industrial wastes in combination with some other fuel. Figure XII-16 shows a sulphate paper mill chemical recovery boiler which burns black liquor (containing lignin) in combination with fuel oil.

92. Ash Removal Systems--Coal burning plants must have some means of ash removal. Stoker firing produces a large cinder which can be dropped into a hopper car in an air lock under the boiler, or removed by a screw conveyor, as shown in Figure XII-17. Pulverized coal ash can be tapped from wet bottom furnaces into quench pits from which it can be transferred to any desired location by sludge pumps. Dry bottom furnaces may discharge into a conveyor or a quench pit as with the wet bottom furnace. One of these systems is shown in Figure XII-18.

93. Dust Collectors--Coal burning plants which are located close to population centers must be furnished with some sort of apparatus to remove dust and cinders from the flue gas in order to avoid the creation of a nuisance. Pulverized coal plants produce an extremely fine ash (called flyash), and at least half of the ash in the fuel goes along with the flue gas. Stoker fired plants do not produce significant amounts of flyash but some small cinders do travel through the steam generator. It is often thought that fuel oil produces no flyash, but some Florida cities have ordinances requiring dust collectors on fuel oil burning power plants within their municipal limits.

Cirder catchers operate on the principle of changing the direction of gas flow so that heavy particles will drop out of the gas stream. Figure XII-19 shows a cirder trap of this type.

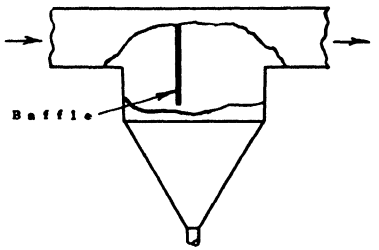
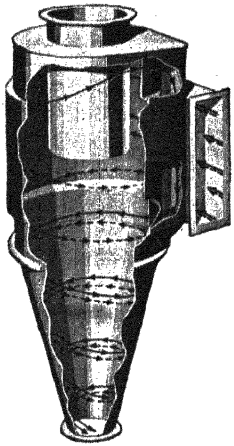
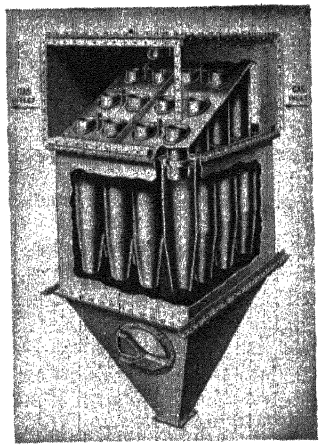


Fig. XII-19. Cinder trap.

Dust collectors may be of the centrifugal type, which operate in a manner somewhat similar to the cinder trap except that the gas velocity is higher; the electrostatic type which uses a high direct current potential to charge the



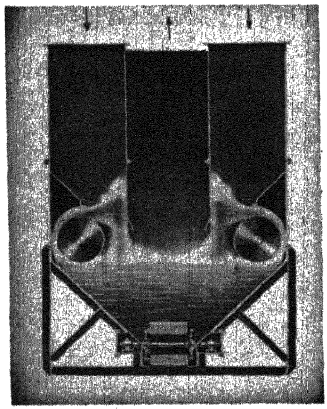
(Buell Engrg. Co.)
(a) Single



(Western Precip. Co.)
(b) Multiple

Fig. XII-20. Cyclone dust collectors.

the dust particles so that they may be collected on electrodes; the bag type which employs fabric bags to filter the gas; and the wet scrubber which uses water for washing the gas. Figures XII-2C through XII-23 show these various types of dust collector.



(Schmieg Industries)

Fig. XII-21. Flue gas scrubber.

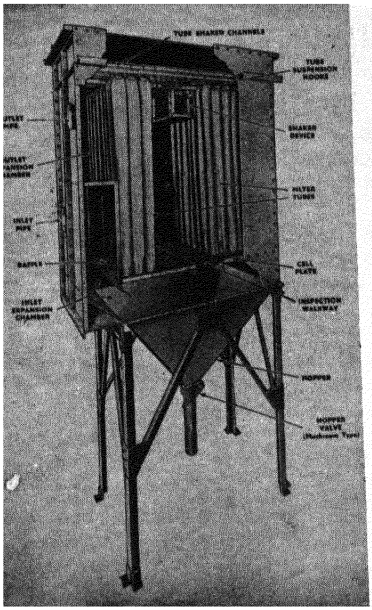
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Heinrich, K., "Dust Collector Comparison," *Combustion*, February, 1937.

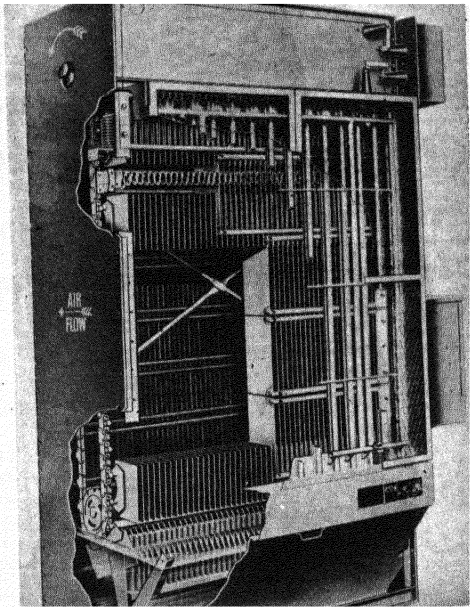
Kreisinger, H., "Combustion of Pulverized Coal," *Transactions A.S.M.E.*, May, 1938.

Worker, J. G., and Bennett, J. S., "Development and Recent Design of Stoker-fired Equipment for Steam Generation," *Transactions A.S.M.E.*, Volume 50, 1927-28.



(Amer. Foundry Equip. Co.)

Fig. XII-22. Bag type dust collector.



(American Air Filter Co.)

Fig. XII-23. Electrostatic dust collector.

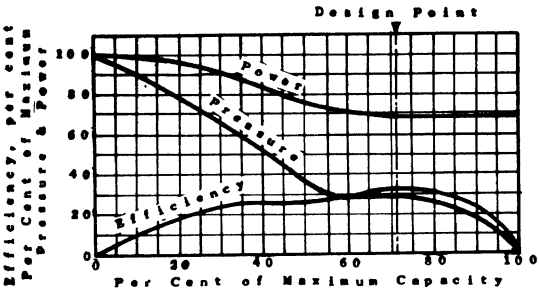
CHAPTER XIII

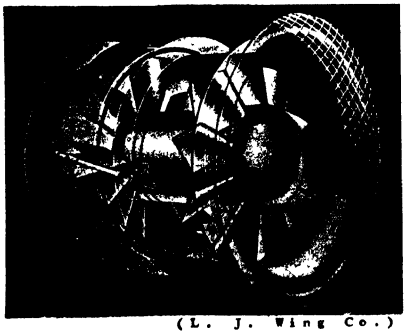
DRAFT EQUIPMENT

94. Draft equipment consists of fans and stacks (or chimneys) whose purpose is to supply air for the combustion of fuel and to remove the products of combustion from the steam generator for disposal to the surrounding air.

95. **Fans**--Fans in use for the production of draft are almost always of the centrifugal type, although some small installations use axial flow fans and the new horizontal burners use axial flow blowers.

Axial flow fans follow the same laws of similarity as centrifugal pumps, but the shapes of the characteristic curves are considerably different. It will be noted from Figure XIII-1 that the pressure curve has an unstable region which makes it impossible to parallel two axial flow fans within the region of best operating efficiency.

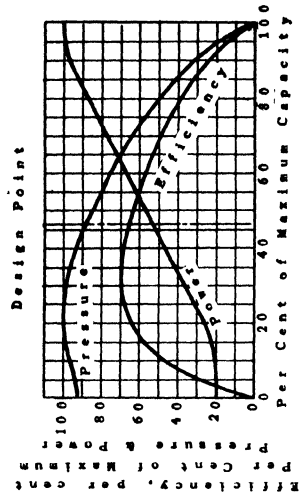




(L. J. Wing Co.)

Fig. XIII-1. Axial flow fan characteristics.

Centrifugal fans follow the same laws of similarity as centrifugal pumps, but their characteristic curves will have somewhat different shapes due to the use of several different types of blade arrangement. Blade arrangements, as shown in Figures XIII-2 through XIII-5, may be either forward curved, backward curved, radial or combination.



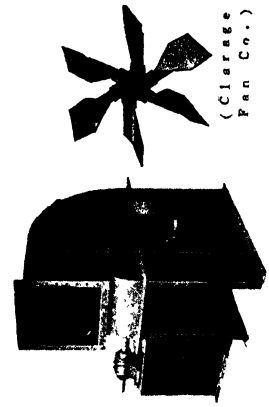
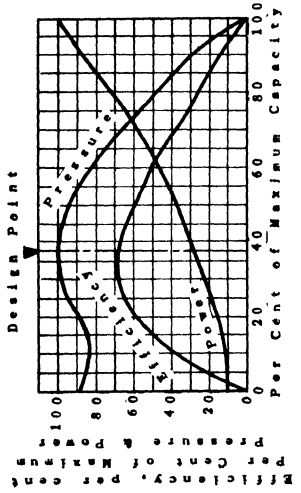


Fig. XIII-3. Radial blade fan characteristics.



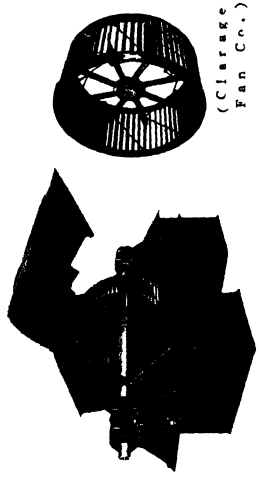
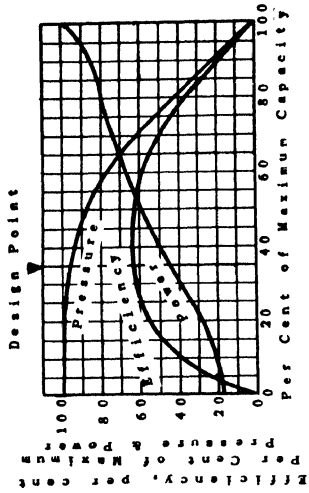


Fig. XIII-2. Forward curved blade fan characteristics.

The forward curved blade fan has a limited application in power plants because it is possible to overload the motor at zero head. In addition, it is impossible to operate these fans in parallel because of the existence of more than one point on the head–capacity curve which has the same ordinate. Such a characteristic leads to hunting (instability) in the system.



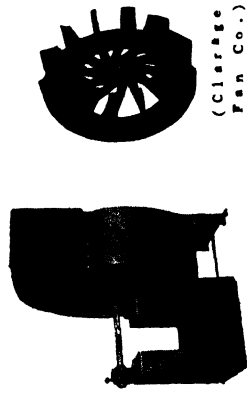
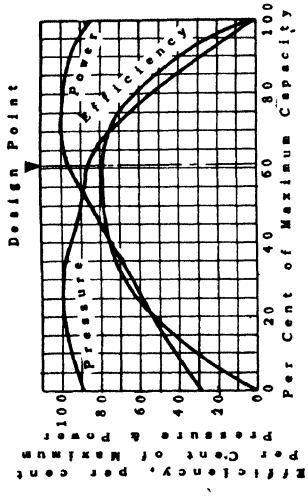


Fig. XIII-5. Combination blade fan characteristics.



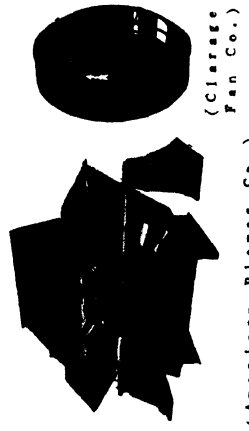


Fig. XIII-4. Backward curved blade fan characteristics.

The radial blade fan is extensively used in pulverizer exhausters because it is difficult for the blades to become fouled. Otherwise, the power characteristic is unfavorable as with the forward curved blade fan.

The backward curved blade fan is the most popular type in use in power plants because, like the centrifugal pump,

it has a self-limiting power characteristic, and, due to the continually falling head-capacity characteristic, two or more fans can be operated in parallel without hunting.

The combination blade fan has characteristics intermediate between those of the radial and backward curved blade fans.

96. Head and Work Relations in Fans--As previously mentioned, centrifugal fans are similar to centrifugal pumps, the only difference being in the fluid pumped and the magnitude of the pressure rise. It can be seen that:

$$ahp = e_f(shp)$$

where: ahp and shp = air horsepower and shaft horsepower
e_f = fan efficiency

Air horsepower is the power required to move the air, or

$$ahp = \frac{M_a H_t}{60 \times 33000}$$

where: M_a = flow, lbs/hr
H_t = total head on fan ft of fluid

Since pressures in the steam generator combustion air and flue gas circuits are stated in terms of inches of water and fan capacities are stated in cubic feet per minute, air horsepower is also

$$ahp = \frac{62.4\ Q\ h_t}{12 \times 33000}$$

where: Q = fan capacity, cu ft/min
h_t = total pressure rise through fan, in. water

The total pressure rise through the fan is the sum of the friction losses in the ducts and apparatus; the increase in velocity head through the fan; the losses at the entrance and exit of the system; the difference in pressure between the inlet and discharge; and the static head (or chimney effect), or

$$h_t = h_f + \frac{V_d^2 - V_i^2}{2g} + h_{s_d} - h_{s_i} + h_{p_d} - h_{p_i} + h_{e_d} + h_{e_i}$$

Figure XIII-6 shows a steam generator with its fan and duct system and the location of the various positive and negative pressures.

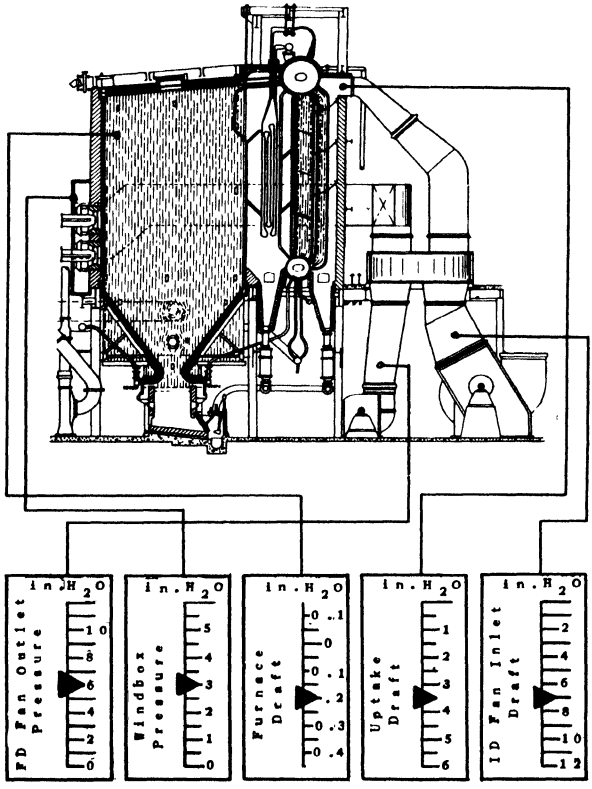


Fig. XIII-6. Steam generator fan and duct system.

97. Fan Speeds--The maximum efficiency of fans is approximately the same regardless of type or size. Larger fans will operate at slower speeds than smaller ones for the same head. Table XXIII shows the ranges of speeds and sizes to be expected for fans in use in power plants.

TABLE XXIII

ABBREVIATED PERFORMANCE—IMPROVED EXHAUSTERS—RIM OR L.S. WHEEL

Fan Size No.		11	13	15	17	19	21	23	25	29	33	37	41
Wheel Diam.		16″	20″	23″	26″	30″	33″	36″	40″	46″	53″	60″	66″
2″ S P.	CFM	1172	1886	2170	2794	3526	4312	5176	6120	8248	10640	13396	16464
2000 O.V.	RPM	1305	1040	905	800	694	631	579	520	452	393	346	315
	BHP	66	.90	1 23	1 58	2 00	2 43	2 92	3 46	4 58	6 01	7 56	9 30
3″ S P.	CFM	1465	1982	2712	3492	4407	5390	6470	7650	10310	13300	16745	20580
2500 O.V.	RPM	1600	1285	1110	984	850	776	710	640	555	483	426	388
	BHP	1.25	1 69	2 31	2 97	3 75	4 58	5 50	6 50	8 78	11 30	14 20	17 50
4″ S P.	CFM	1758	2379	3255	4191	5289	6468	7764	9180	12372	15960	20094	24696
3000 O.V.	RPM	1865	1490	1295	1140	990	905	830	745	647	562	495	450
	BHP	2 02	2 73	3 74	4 80	6 06	7 40	8 90	10 50	14 20	18 30	23 00	28 40
5″ S P.	CFM	1904	2577	3526	4540	5730	7007	8411	9945	13403	17290	21768	26754
3250 O.V.	RPM	2065	1650	1430	1268	1100	1000	918	825	715	623	550	500
	BHP	2 70	3 66	5 00	6 45	8 14	9 91	11 90	14 10	19 00	24 50	30 90	38 00
6″ S P.	CFM	2051	2775	3797	4889	6170	7546	9058	10710	14434	18620	23443	28812
3500 O.V.	RPM	2260	1805	1570	1390	1205	1095	1005	900	784	683	600	546
	BHP	3 48	4.72	6 45	8 30	10 50	12 80	15 40	18 20	24 55	31 70	39 80	49 00
7″ S P.	CFM	2197	2974	4068	5239	6610	8085	9705	11475	15465	19950	25117	30870
3750 O.V.	RPM	2440	1950	1695	1495	1300	1180	1080	978	845	736	650	590
	BHP	4 34	5.86	8 05	10 35	13 05	15 95	19 15	22 60	30 50	39 40	49 50	61 00
8″ S P.	CFM	2344	3172	4340	5588	7052	8624	10352	12240	16496	21280	26792	32928
4000 O.V.	RPM	2605	2090	1805	1600	1385	1265	1155	1040	903	782	692	630
	BHP	5 30	7 16	9 80	12 60	15 95	19 45	23 35	27 60	37 20	48 00	60.50	74.40
10″ S P.	CFM	2637	3568	4882	6286	7933	9702	11646	13770	18558	23940	30141	37044
4500 O.V.	RPM	2920	2330	2025	1790	1550	1415	1295	1165	1010	880	776	705
	BHP	7 50	10 15	13 90	17 85	22 60	27 60	33 20	39 10	52 90	68 20	85 90	105 50
12″ S P.	CFM	2930	3965	5425	6985	8815	10780	12940	15300	20620	26600	33490	41160
5000 O.V.	RPM	3215	2860	2225	1970	1710	1555	1425	1285	1110	968	858	776
	BHP	10 00	13 50	18 50	23 80	30 10	36 70	44 10	52 20	70 30	90 75	114 00	140 50

ABBREVIATED PERFORMANCE—TYPE HV FANS, SINGLE WIDTH, SINGLE INLET

Fan Size No.		1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	4	4½	5
Wheel Dia.		13″	16¼″	19½″	22¾″	26″	29¼″	32½″	35¾″	39″	42½″	45½″	52″	58½″	65″
¼″ S P.	CFM	1035	1613	2322	3156	4128	5220	6444	7782	9288	10890	12660	16524	20880	25800
1200 O V.	RPM	509	407	327	281	245	217	197	178	164	146	136	120	106	96
.090 V.P.	HP	.12	18	.22	29	.38	.48	.59	75	85	1 04	1 22	1 59	2 00	2 47
½″ S P.	CFM	1122	1748	2516	3419	4472	5655	6981	8430	10062	11798	13715	17910	22620	27950
1300 O V.	RPM	637	510	412	353	308	273	247	224	206	188	174	152	135	122
.106 V.P.	HP	.19	.29	.36	.49	.64	81	1 00	1 20	1 44	1 64	1 90	2 48	3 13	3 87
¾″ S P.	CFM	1208	1882	2709	3682	4816	6090	7518	9078	10836	12705	14770	19278	24360	30100
1400 O V.	RPM	748	598	490	420	367	325	294	264	245	222	206	180	160	144
.123 V.P.	HP	.28	.44	.54	73	.95	1 20	1 48	1 76	2 13	2 45	2 85	3 72	4 70	5 80
1″ S.P.	CFM	1294	2016	2903	3945	5160	6525	8055	9727	11610	13613	15825	20655	26100	32250
1500 O.V.	RPM	851	680	557	478	417	369	335	302	279	252	233	204	181	163
.140 V.P.	HP	.39	.61	.72	.98	1 28	1 61	1 99	2 38	2 87	3 28	3 80	4 97	6 26	7 75
1¼″ S.P.	CFM	1380	2150	3096	4208	5504	6960	8592	10375	12384	14520	16880	22032	27840	34400
1600 O.V.	RPM	944	754	618	530	463	410	371	336	309	280	261	228	203	182
.160 V.P.	HP	52	.80	.93	1.26	1 66	2 09	2 58	3 13	3 72	4 33	5 02	6 55	8 27	10 2
1½″ S.P.	CFM	1552	2420	3482	4734	6192	7830	9666	11672	13932	16335	18990	24786	31320	38700
1800 O.V.	RPM	1039	830	683	585	512	453	410	369	341	308	286	250	222	200
.202 V.P.	HP	.70	1 09	1 30	1.77	2 31	2 92	3 61	4 25	5 20	5 82	6 77	8 82	11 1	13.8

NOTE. For performance of double width, double inlet HV Fans (available in sizes No 1½ and larger) multiply CFM x 2, RPM x 1 015, BHP x 2 1 and OV x 1 11

ABBREVIATED PERFORMANCE—TYPE W FANS, SINGLE WIDTH, SINGLE INLET

Fan Size No.		1¼	1⅝	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3⅞	4¼	4¾
Wheel Dia.		16¼″	17⅞″	19½″	22¾″	26″	29¼″	32½″	35¾″	39″	42¼″	45½″	80⅜″	55¼″	61¾″
¼″ S.P.	CFM	1344	1627	1935	2630	3440	4350	5370	6485	7740	9075	10550	12900	15519	19390
1000 O.V.	RPM	809	735	620	532	464	412	372	338	310	286	266	240	218	196
.062 V.P.	HP	.11	.13	.14	.19	.25	.32	39	48	57	.66	77	94	1 13	1 41
½″ S P.	CFM	1613	1952	2322	3156	4128	5220	6444	7782	9288	10890	12660	15480	18623	23268
1200 O.V.	RPM	1035	940	792	680	594	528	476	432	396	366	340	308	280	250
.090 V.P.	HP	.24	.29	.29	.40	.52	.66	.81	98	1 17	1 37	1 59	1 94	2 34	2 92
¾″ S.P.	CFM	1747	2115	2516	3419	4472	5655	6981	8430	10062	11798	13715	16770	20175	25207
1300 O.V.	RPM	1188	1079	908	778	680	604	544	494	454	418	389	351	320	286
.106 V.P.	HP	.37	.45	.43	.59	.77	.98	1 20	1 46	1 73	2 04	2 36	2 89	3 48	4 35
1″ S.P.	CFM	1882	2278	2709	3682	4816	6090	7518	9079	10836	12705	14770	18060	21727	27146
1400 O V.	RPM	1325	1203	1012	868	760	676	608	552	506	468	434	392	358	320
.123 V.P.	HP	.51	.62	.60	.83	1.08	1 36	1 68	2 04	2 41	2 84	3 30	4 02	4 85	6 05
1¼″ S.P.	CFM	2016	2441	2903	3945	5160	6525	8055	9727	11610	13613	15825	19350	23279	29085
1600 O.V.	RPM	1449	1317	1108	948	830	736	664	604	554	511	474	428	390	349
.140 V.P.	HP	68	.82	.80	1.09	1.42	1 79	2 21	2 68	3 19	3 75	4 35	5 32	6 40	8 00
1½″ S.P.	CFM	2150	2603	3096	4208	5504	6960	8592	10376	12384	14520	16880	20640	24830	31024
1600 O.V.	RPM	1567	1423	1204	1032	902	800	722	656	602	555	516	465	424	380
.160 V.P.	HP	.86	1 04	1 01	1 37	1 80	2 25	2 81	3 41	4 03	4 76	5 48	6 75	8 13	10 15

NOTE. For performance of double width, double inlet type W Fans (available in sizes No 1⅞ and larger) multiply CFM x 2, RPM x 1 02, BHP x 2 08 and OV x 1 11.

(Clarage Fan Co.)

98. Draft Losses--Since a steam generator installation may include both forced and induced draft fans, the draft losses may be divided into two classifications, as follows:

1. Forced draft(pressure) losses (air system).
   a. Loss in duct between fan and air heater.
   b. Loss in air heater.
   c. Loss in duct between air heater and windbox.
   d. Loss through fuel bed or burner.

2. Induced draft losses (flue gas system).
   a. Loss between furnace and boiler outlet.
   b. Loss in duct between boiler and economizer.
   c. Loss in economizer.
   d. Loss in duct between economizer and air heater.
   e. Loss in air heater.
   f. Loss in duct between air heater and fan.
   g. Loss in duct between fan and stack.

All of the draft losses, except those for the ducts, are usually taken from data supplied by the manufacturers, but the methods of estimating the losses are of interest.

Duct draft losses have been discussed in Chapter X.

Air heater draft losses vary according to the arrangement of the surfaces. The draft loss on the gas side of tubular air heaters can be estimated by treating the air heater tubes as round ducts in parallel and using the average gas velocity; considering the inlet and outlet boxes as part of the main ducts; and adding 0.05 inches of water draft loss for each right angle turn. The draft loss on the air side of tubular air heaters may be estimated by using the empirical formula (adding 0.05 in. H_2O for each right angle turn):

$$\Delta p = 0.0002307 \frac{f\ N\ (G/1000)^2}{\rho}$$

where: Δp = draft loss, in. water
f = a friction factor
= 0.06 for in-line tubes
= 0.09 for staggered tubes
N = number of restrictions
ρ = arithmetic mean gas density, lbs/cu ft
G = mass flow of gas, lbs/hr per sq ft of flow area

Fuel bed or burner draft losses can be estimated from Figures XIII-7 and XIII-8.

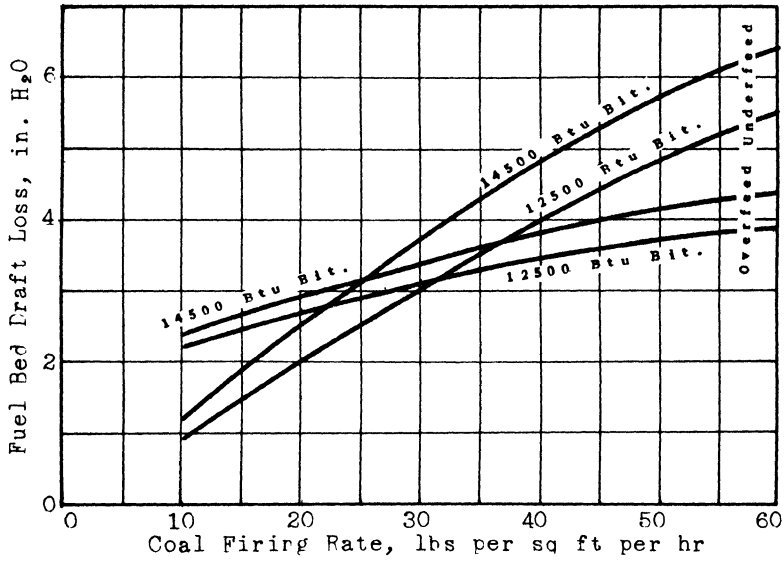


Fig. XIII-7. Fuel bed draft losses.

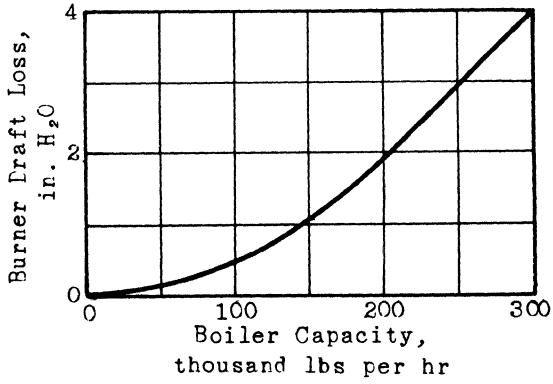


Fig. XIII-8. Burner draft losses.

Boiler, superheater and economizer draft losses depend upon the arrangement of the surfaces and the mass flow of the gas. Draft losses for fire-tube boilers can be estimated in the same manner as for the gas side of tubular air heaters. Draft losses for water-tube boilers, superheaters and economizers can be estimated in the same way as for the air side of tubular air heaters.

Due to the fact that ducts and boiler settings are never gas tight, an allowance of ten per cent on the gas volume and air volume should be made when specifying fan sizes. The normal practice is to control the furnace draft at between 0.1 and 0.2 inches of water to allow the opening of inspection doors without danger to the operators. Some modern steam generators, however, especially marine types and those utilizing the horizontal cyclone burner, dispense with the induced draft fan and operate entirely with forced draft. Figure XIII-9 shows some draft loss curves for a typical steam generator. It will be seen that, as in all devices involving fluid flow, the draft loss is proportional to the square of the quantity flowing.

Example 33 shows the method of making fan specifications

Example 33.

Determine the fan specifications for an oil fired boiler producing 300,000 lbs per hour of steam at 925 psia and 900 F from feed-water at 300 F. The fuel is that of Example 15 with a heating value of 18500 Btu/lb, and it is burned with 15 o/o excess air to produce a boiler efficiency of 89 o/o. Air temperature is 100 F and flue gas temperature is 300 F. The boiler draft losses are shown in Figure XIII-9.

Solution:

Heat added to steam = (1450.9 − 269.6)	= 1180.3	Btu/lb
Oil fired = $\frac{300000(1180.3)}{0.89(18500)}$ =	21500	lbs/hr
Theoretical air	13.9	lbs/lb
Actual air = 13.9(1.15)	16.0	lbs/lb
Weight of air per hr.(incl. 10 o/o leakage)	378000	lbs/hr
Density of air at 100 F	0.07	lbs/ft³
Volume of air at 100 F	88800	cfm

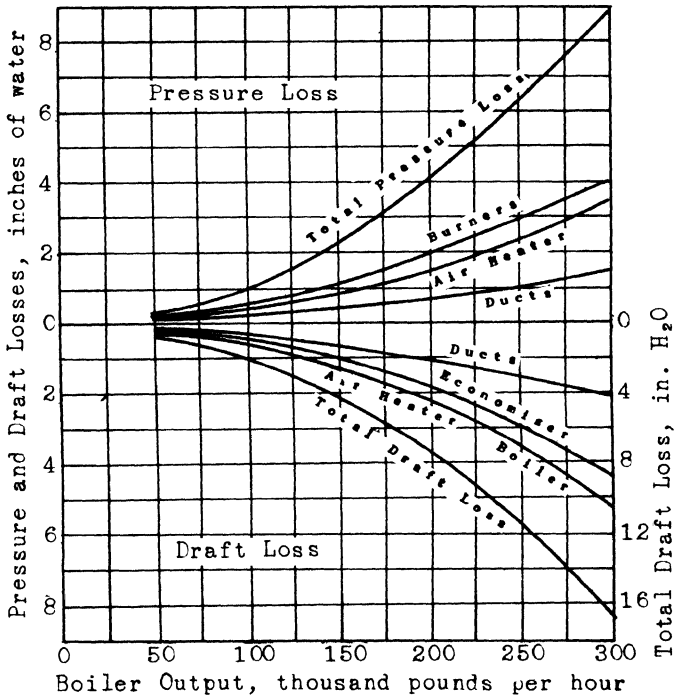


Fig. XIII-9. Steam generator draft losses.

Wet gas produced	17.0	lbs/lb
Weight of gas per hr. (incl. 10 o/o leakage)	402000	lbs/hr
Density of gas at 300 F	0.055	lbs/ft
Volume of gas at 300 F	122000	cfm

From Figure XIII-9, the forced draft loss is 8.8 in. of water, and the induced draft loss is 16.7 in. of water at a steam flow of 300,000 lbs/hr.

The fan specifications would be:

Forced draft fan: 89,000 cfm air at 100 F, 9 in. water

Induced draft fan: 122,000 cfm gas at 300 F, 17 in. water.

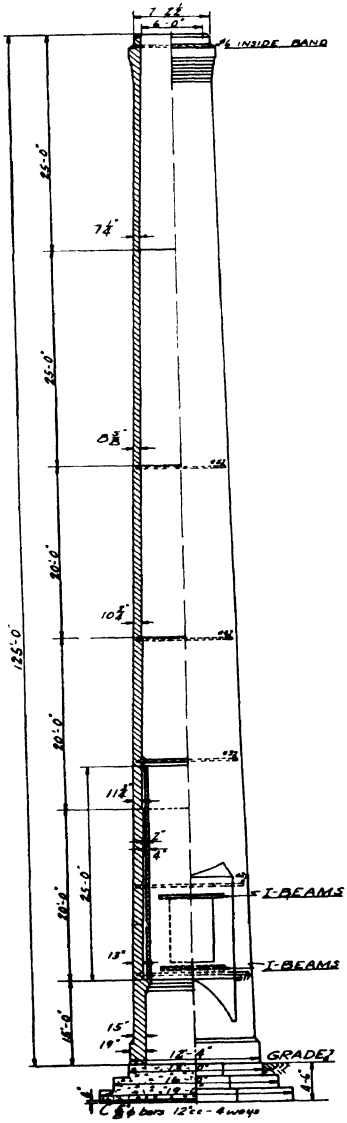
99. Stacks--Small boilers may depend entirely upon stacks for the production of the necessary draft for operation, while large steam generators use stacks mainly for flue gas disposal, with draft production for emergency operation without the fans a secondary consideration. As a matter of fact, most large steam generators are completely incapable of being operated without the induced draft fan.

A stack produces draft because the hot gas inside is less dense than the air outside. The draft produced by a stack is proportional to the height of the stack and to the difference in density between the outside air and the flue gas, or (allowing for friction in the stack)

$$h = 0.254\ B\ H\ \left(\frac{1}{T_a} - \frac{1}{T_g}\right) - 0.77\ \frac{\rho\ f\ H^2}{D_i}\left(\frac{T_g}{T_a} - 1\right)$$

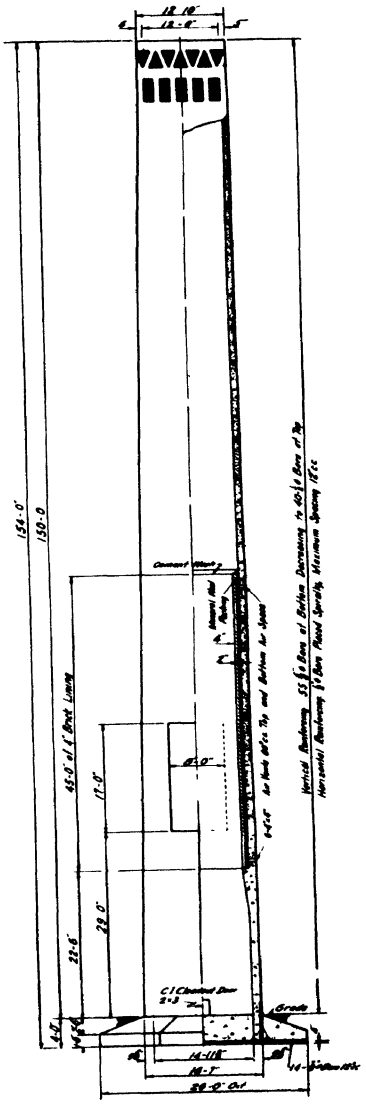
where: h = draft produced by stack, in. water
B = barometric pressure, in. Hg
H = height of stack above duct inlet, ft
T_a = outside air temp, deg R
T_g = arithmetic mean gas temperature, deg R
ρ = density of gas, lbs/cu ft
D_i = inside diameter of stack, ft
f = a friction factor
= 0.0013 for steel stacks
= 0.0018 for brick-lined stacks

It will be seen that, if given a certain draft to be produced, both stack height and diameter will be unknown, but if the first term on the right hand side of the equation is solved the minimum stack height will be obtained. Then the dimensions can be determined by trial with due consideration to stability of self-supporting stacks and to economy of construction. As a general rule, a guyed stack can be designed for maximum economy, a condition that is obtained when the product of the height and diameter is at the minimum. Self-supporting stacks must be designed to give maximum economy within the range of stability, a condition which will be met when the ratio of diameter to height is between 0.03 and 0.08 and the product of diameter and height is nearest to that for maximum economy. Figures XIII-10 and XIII-11 show two common types of power plant stacks, and Example 34 shows the method of calculating stack dimensions.



(Consolidated Chimney Co.)

Fig. XIII-10. Radial brick stack.



(Consolidated Chimney Co.)

Fig. XIII-11. Reinforced concrete stack.

Example 34.

Determine the most economical dimensions for a brick stack to produce a draft of 0.6 inches of water for the boiler of Example 33. Barometric pressure is 30 inches of mercury and ambient temperature is 90 F.

Solution:

For a first approximation of the height,

$$0.6 = 0.254(30)\ H\ \left(\frac{1}{550} - \frac{1}{760}\right)$$

$$H_{min} = 156 \text{ ft}$$

Then, by trial in the equation for stacks:

$$0.6 = 0.00384\ H - 0.0000226\ \frac{H^2}{D_i}$$

H	160	170	180	190	200
D_i	38.6	12.3	8.0	6.3	5.4
HD_i	6180	2090	1448	1192	1070
D_i/H	0.241	0.072	0.045	0.033	0.027

It is apparent that the product HD_i is still decreasing at a stack height of 200 ft. From the standpoints of economy and stability, the best choice would be the 6.3 ft diameter by 190 ft tall stack.

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CHAPTER XIV

SUPERVISORY AND CONTROL EQUIPMENT

100. Every power plant contains a great variety of instruments and equipment for indicating, recording and controlling the performance of the plant in many details. The various instruments and controls may be divided into classifications as to the variable, such as temperature, pressure, speed, fluid level, combustion conditions, chemical characteristics and fluid flow.

101. Temperature--Temperature may be indicated by mercury thermometers, bourdon tube thermometers, thermocouples or electric resistance thermometers. In addition, all of these devices, except the mercury thermometer, may be made to control temperature by means of secondary devices such as valves or switches and may be made to record the temperature with relation to time. Figures XIV-1 through XIV-5 show some of the many temperature devices which are used in power plants.

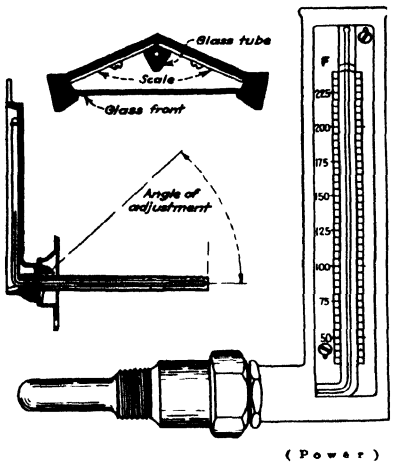


Fig. XIV-1. Industrial mercury thermometer.

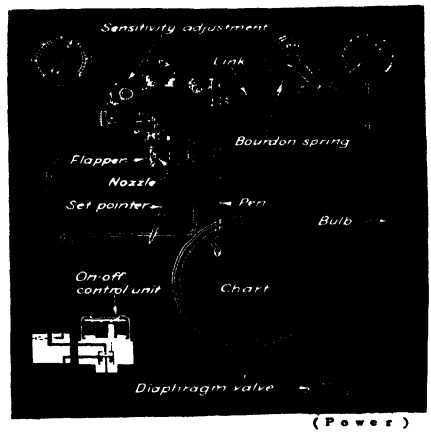


Fig. XIV-2. Air operated temperature controller.

102. Pressure--Pressures may be indicated by manometers using various fluids, bourdon gages or diaphragm gages, depending upon the pressure range to be covered. The ranges

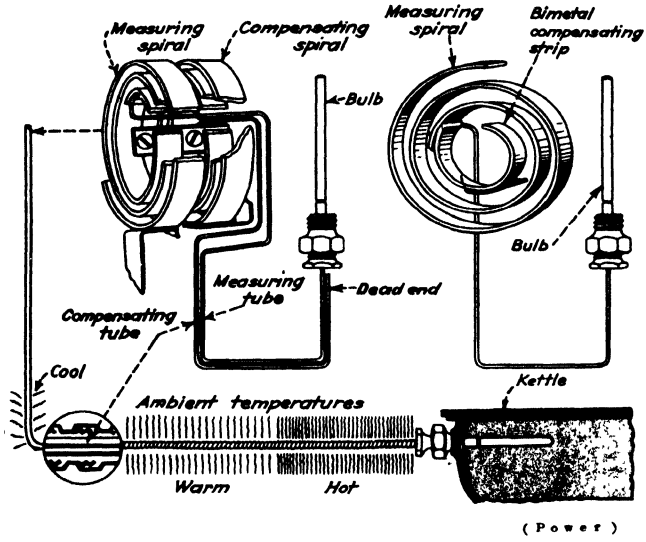


Fig. XIV-3. Bourdon tube thermometers.

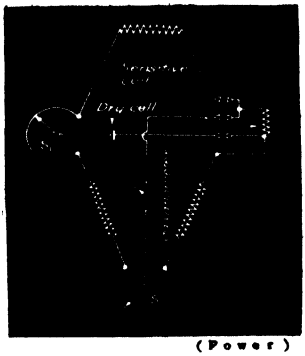


Fig. XIV-4. Electrical resistance temperature bridge.

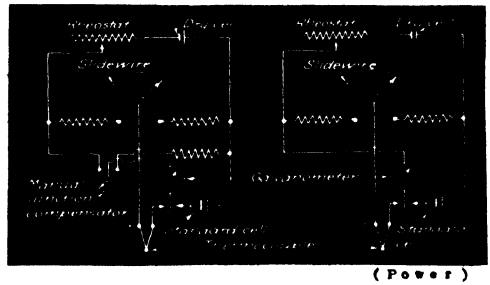


Fig. XIV-5. Thermocouple temperature potentiometers.

of usefulness of these various types overlap somewhat, but in general, manometers are used for indicating pressures in the range from 0.001 inch of water to 100 inches of mercury; diaphragm gages for indicating, recording or controlling pressures in the range from 0.01 inch of water to 10 pounds per square inch; and bourdon gages for indicating, recording or controlling pressures in the range from one pound per

square inch to the maximum obtainable. Figures XIV-6 through XIV-10 show some of the instruments of this class.

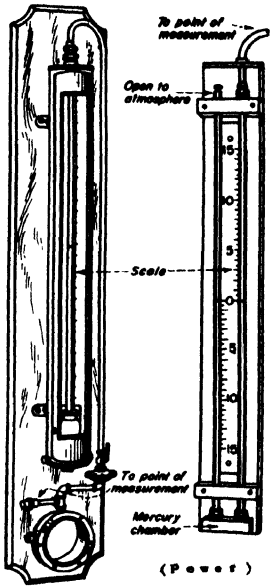


Fig. XIV-6. Mercury manometers.

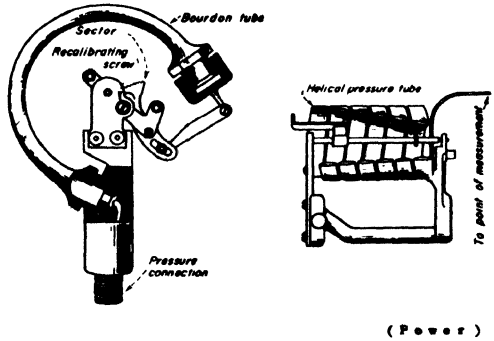


Fig. XIV-7. Bourdon tube pressure gages.

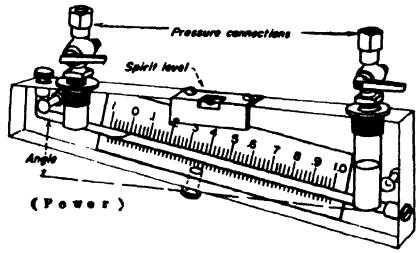


Fig. XIV-9. Inclined draft gage.

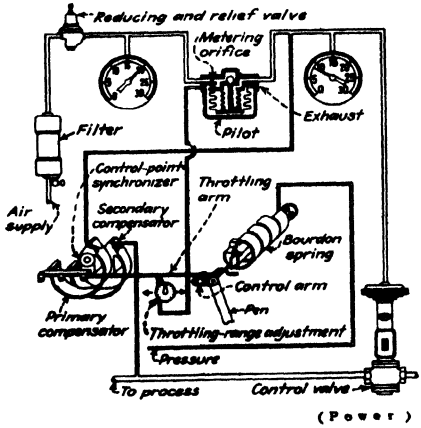


Fig. XIV-8. Air operated pressure controller.

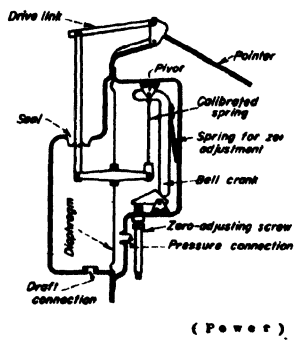
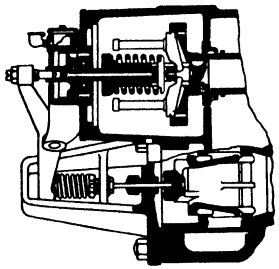


Fig. XIV-10. Diaphragm draft gage.

103. Speed--The most common speed controlling device is the centrifugal flyball resisted by a spring, as shown in Figure XIV-11. The radial motion of the flyballs may be transferred to a throttle valve for controlling the speed of a turbine or engine within predetermined limits. A change in speed is always necessary to actuate the controlling device, therefore flyball governors have regulation characteristics as shown in Figure XIV-12. Since turbo-generators or engine-generators are constant speed apparatus, it is necessary to provide a device for readjusting the flyballs to a new load position. This device is arranged to adjust the governor spring tension or the throttle valve position, either locally or remotely by manual or automatic means.



(Power)

Fig. XIV-11. Flyball governor, direct acting.

The hydraulic governor is found on certain makes of steam turbines and consists essentially of an oil pump on the turbine shaft which produces a pressure which is proportional to speed in the same relation as with a flyball device. The pressure produced by the pump is resisted by a spring which has a load adjustment as in the flyball type of governor. A governor of this type is shown in Figure XIV-13.

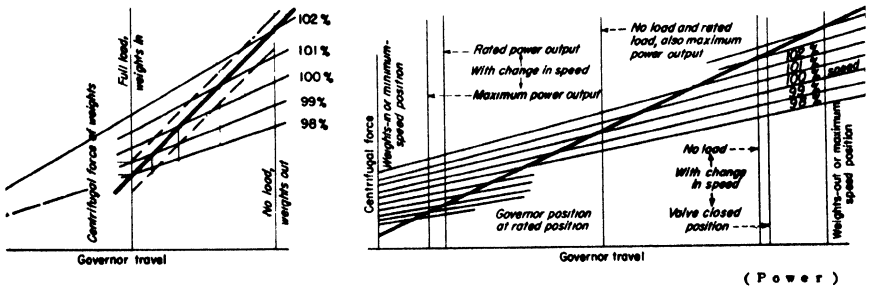


Fig. XIV-12. Governor characteristics.

The direct acting flyball or hydraulic governors are satisfactory for small turbines or engines of not more than a few hundred kilowatts capacity, but in larger sizes the governing forces are not sufficient to operate the heavy valve gear. To overcome this difficulty, hydraulic relays of various kinds are used to amplify the governor forces. Figures XIV-14 and XIV-15 show two of these relay systems.

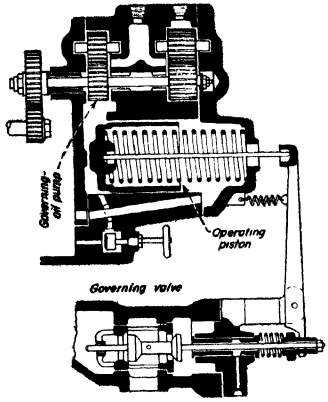


Fig. XIV-13. Hydraulic governor, direct acting.

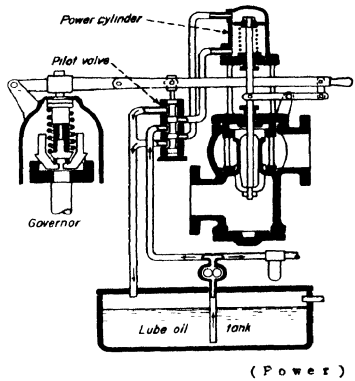


Fig. XIV-14. Flyball governor, relayed.

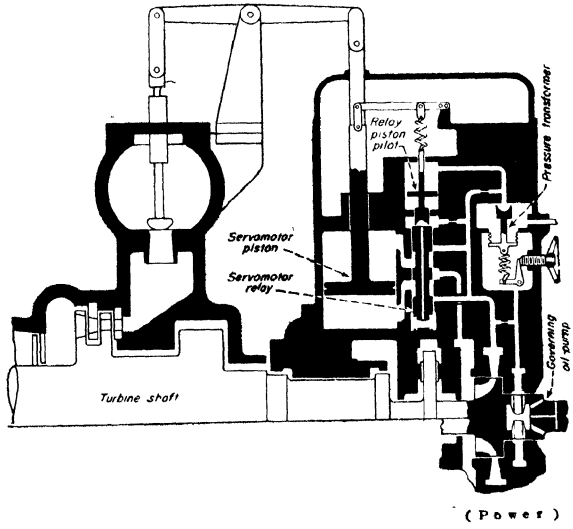
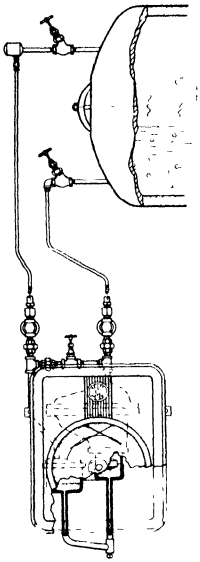


Fig. XIV-15. Hydraulic governor, relayed.

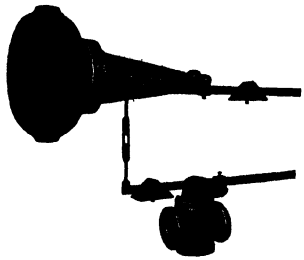
104. Fluid Level--Fluid level instrumerts very frequently contain floats whose motion is transmitted to irdicating, recording or controlling devices. The float type of instru-

ment is applicable to any pressure or level range for which a suitable float system can be devised. Figures XIV-16 through XIV-20 show several of the float type of fluid level instruments.



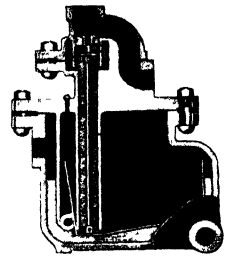
(Bailey Meter Co.)

Fig. XIV-16. Boiler water level recorder.



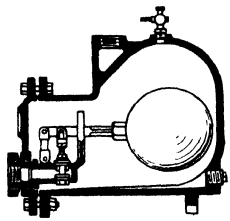
(Mason-Nielan Reg. Co.)

Fig. XIV-17. Float controlled feeder.



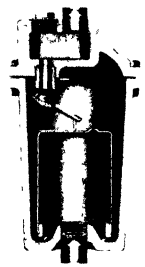
(Strong, Carlisle & Hammond Co.)

Fig. XIV-19. Open bucket trap.



(Power)

Fig. XIV-18. Float controlled drainer.

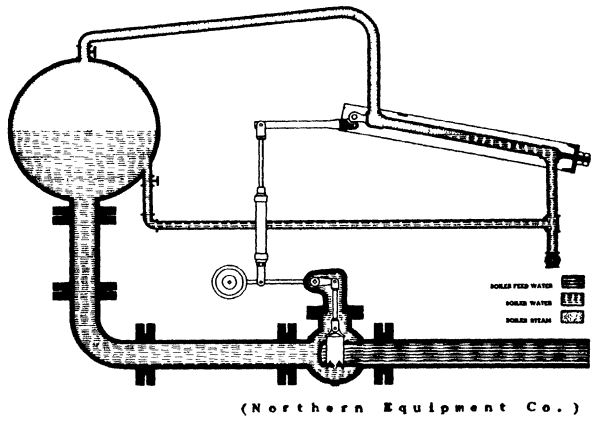


(Armstrong Machine Works)

Fig. XIV-20. Inverted bucket trap.

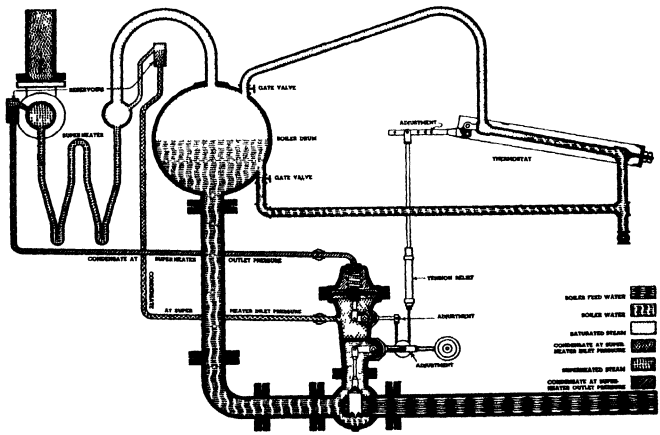
Fluid level in boilers may be controlled by float types of instruments, but it is much more usual to employ a thermostatic device or a thermohydraulic regulator. The first, shown in Figure XIV-21, utilizes a long inclined polished metal tube connected at the bottom end to the water space and at the top end to the steam space of the boiler. The tube is arranged with a bell crank and lever so that any change in length of the tube will be reflected as a change in water control valve position. As the water level in the boiler falls the tube lengthens, because the steam in the upper part of the tube has a higher temperature than the water in the lower part of the tube. This lengthening of the tube is employed to open the water control valve. A rise in water

level causes a reverse action. These regulators have a falling water level characteristic with relation to boiler load, and the operating limits may be too wide for modern steam generators which are extremely sensitive to water level variations (with respect to steam quality). In these cases a second element which contains a spring loaded diaphragm is connected to the regulator in such a way that the pressure drop across the superheater is used to modify the thermostatic tube characteristics to maintain the water level withir closer limits over the load range. This modification is shown in Figure XIV-22, and a hydraulic or air relay may be used to operate large valves.



(Northern Equipment Co.)

Fig. XIV-21. Thermostatic feed-water regulator.



(Northern Equipment Co.)

Fig. XIV-22. Two-element thermostatic feed-water regulator.

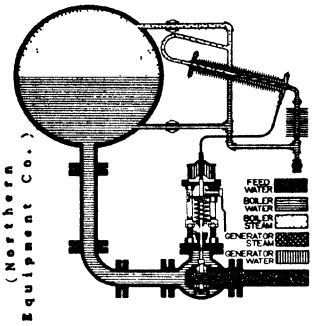
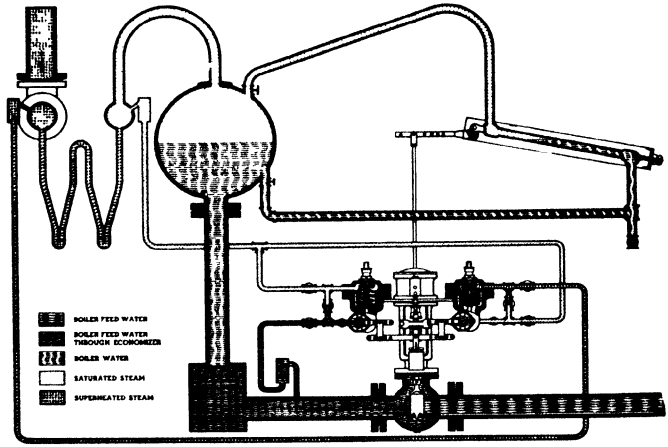


Fig. XIV-23. Thermo-hydraulic feed-water regulator.

The thermohydraulic boiler water level control employs an inclined tube similar to the thermostatic regulator except that it is surrounded by a jacket with heat radiating fins. The jacket is connected by tubirg to a diaphragm type water control valve. The generator jacket, connecting tubirg and diaphragm chamber are completely filled with water so that any decrease in water level in the boiler will result in an increase in pressure in the generator jacket and an opening action in the water control valve. This type of regulator is shown in Figure XIV-23. Its characteristics are similar to those of the thermostatic type.

A third element, sensitive to water flow, may be added to the two-element regulator to coordinate water flow with steam flow and water level for smoother operation on rapid load changes, as shown in Figure XIV-24.



(Northern Equipment Co.)

Fig. XIV-24. Three-element thermostatic feed-water regulator.

105. Combustion--Some of the most valuable instruments in modern power plants are automatic combustion controls

which relieve the fireman from the necessity of manually controlling fuel and air flow, and which, incidentally, do a much better job than any human fireman could possibly do. Combustion controls are available for the smallest boiler as well as for the largest steam generator, and they will pay for themselves from fuel savings in a relatively short time.

All combustion controls for boilers or steam generators operate to maintain a constant pressure at the turbine throttle by varying the fuel and air supplied to the furnace. In addition, some controls have an element which maintains a constant draft in the furnace. Figures XIV-25 through XIV-27 show simple modulating or positioning electric controls for application to various fuels in small boilers. Large steam generators employ elaborate controls which meter fuel and air flows in exact relation to each other and to load. Some

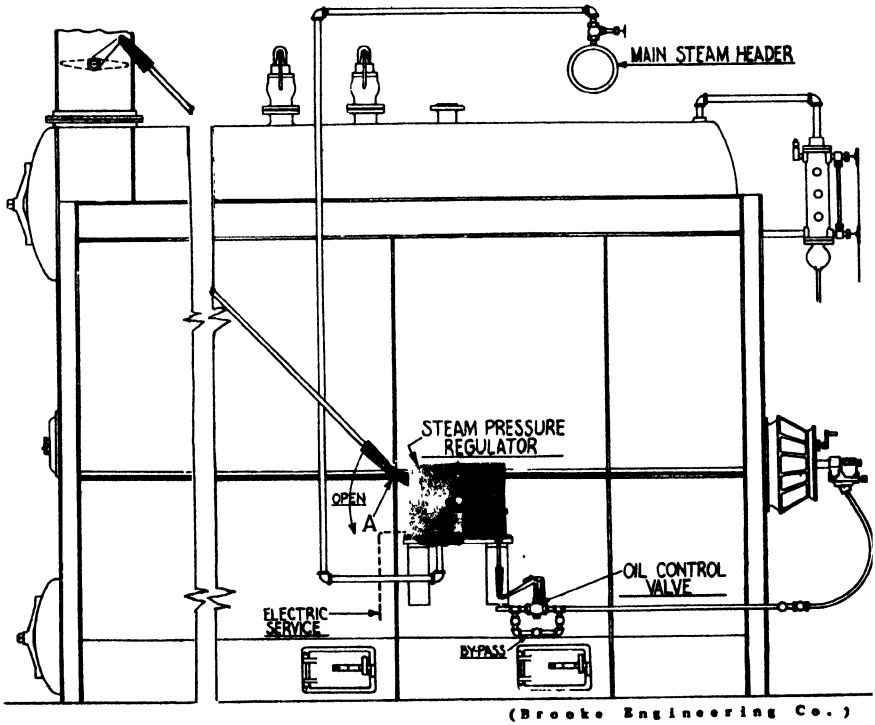
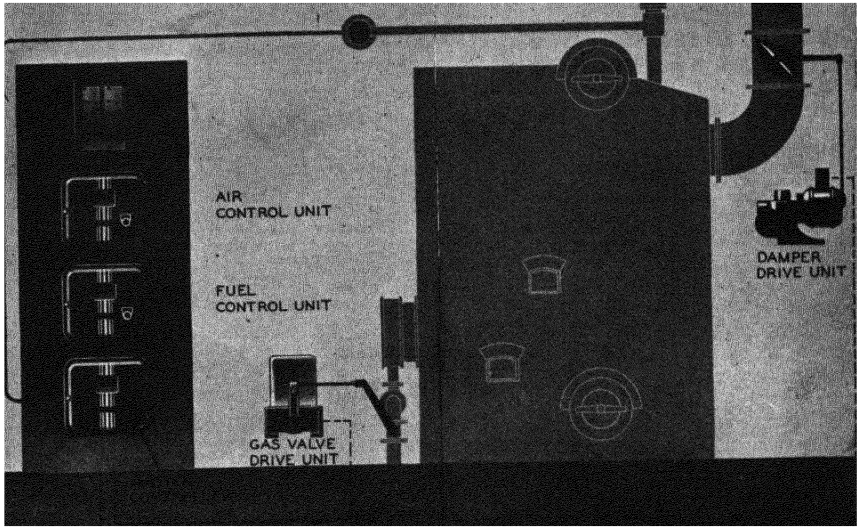


Fig. XIV-25. Modulating oil burner control.

of these control systems are shown in Figures XIV-28 through XIV-31.

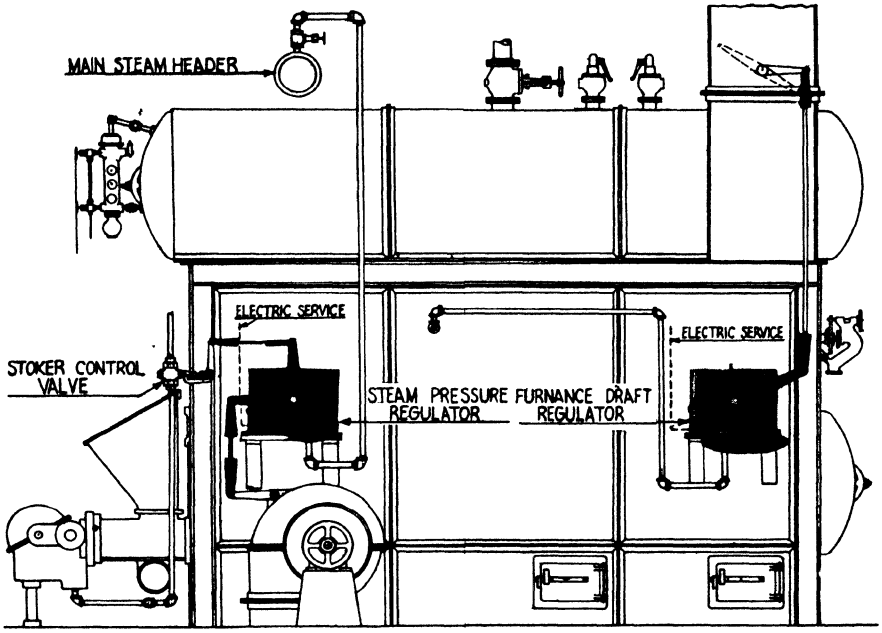


(Leeds & Northrup)

Fig. XIV-26. Modulating gas burner control.

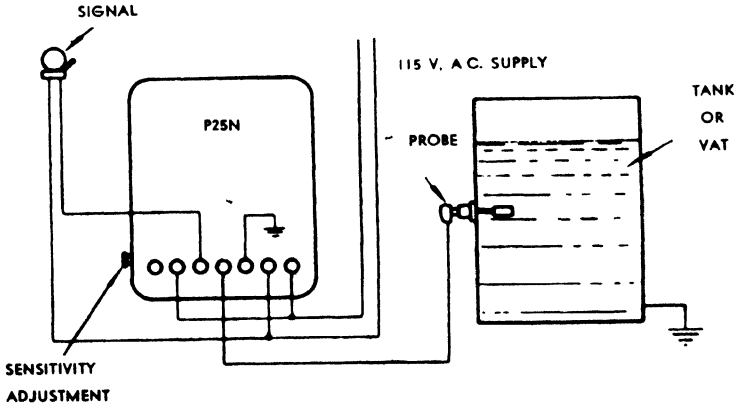
106. Chemical Characteristics--Chemical characteristics of water in power plants are often controlled or supervised by electrical instruments. The chemical characteristics which are useful as control variables are pH and electrolytic conductivity. pH can be controlled in precipitation water softening because the pH of the water is affected by the softening chemicals. Electrolytic conductivity is most often used as a variable for operating alarm devices for signalling contamination of condensate by condenser leakage or faulty evaporator operation. Figures XIV-32 through XIV-34 show some of the instruments used for these purposes.

107. Fluid Flow--The most common fluid flow measuring devices utilized in power plants are nozzles and orifices with various types of secondary elements for measuring and recording the pressure differential produced by the primary element in terms of flow units. Figures XIV-35 through XIV-39 show some of the more common primary and secondary head type flow measuring devices.



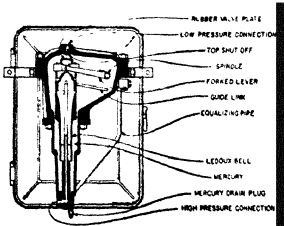
(Brooke Engineering Co.)

Fig. XIV-27. Modulating stoker control.



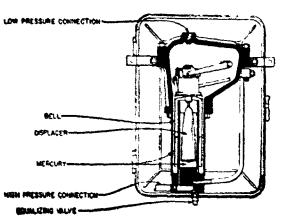
(Photoswitch, Inc.)

Fig. XIV-34. Conductivity alarm.



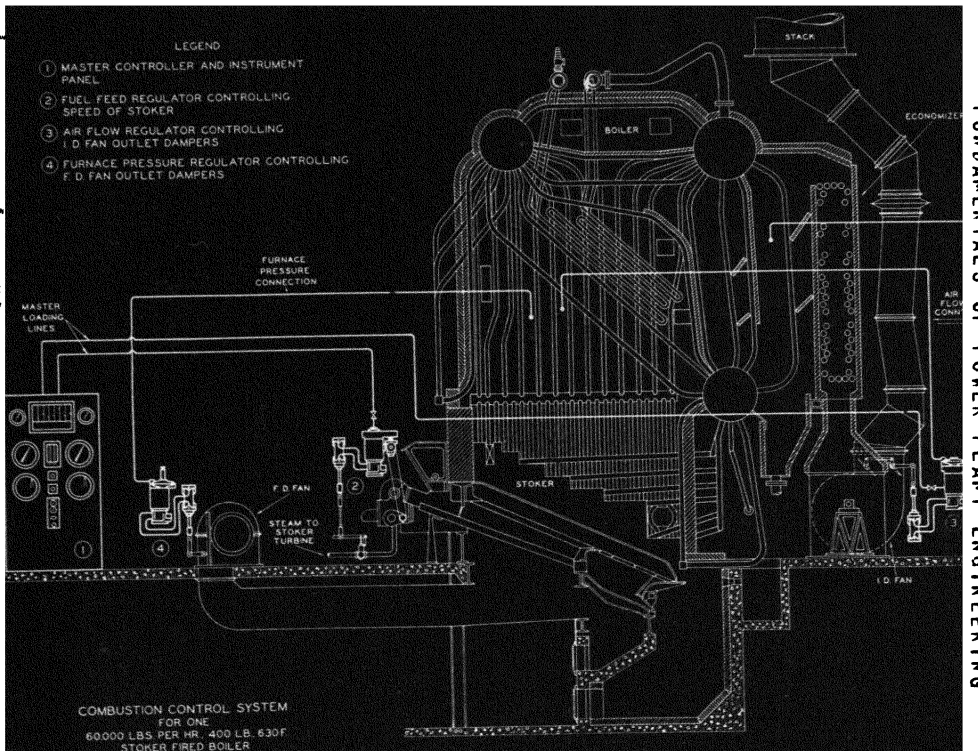
(Bailey Meter Co.)

Fig. XIV-35. Ledoux bell secondary flow measuring device.



(Bailey Meter Co.)

Fig. XIV-36. Shaped displacer secondary flow measuring device.



(Republic Flow Meters Co.)

Fig. XIV-28. Air-hydraulic combustion control for stokers, metering.

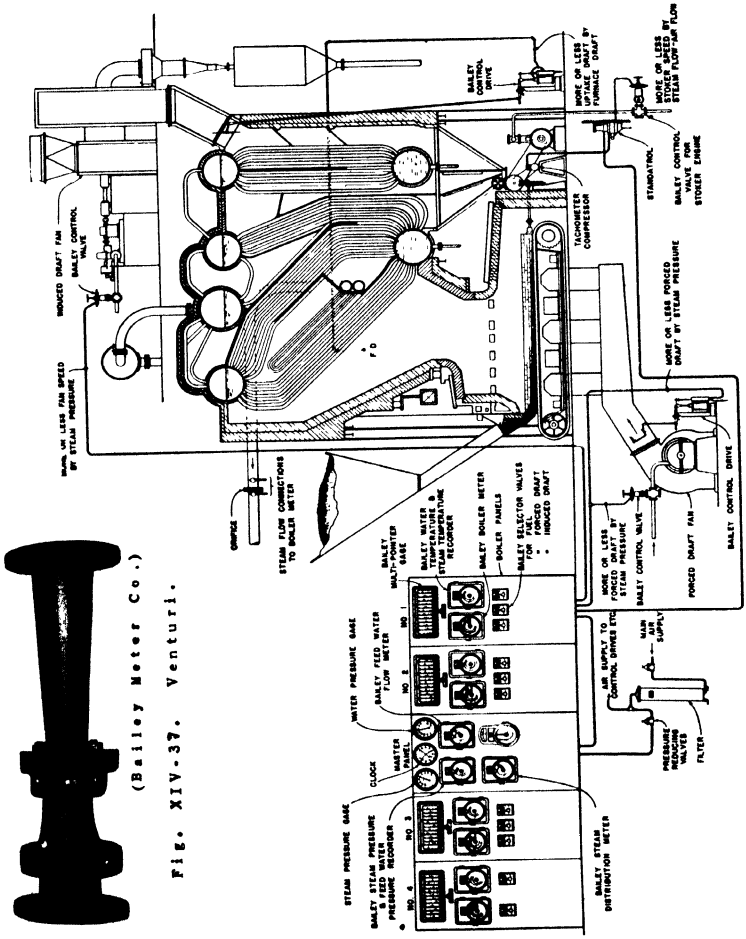
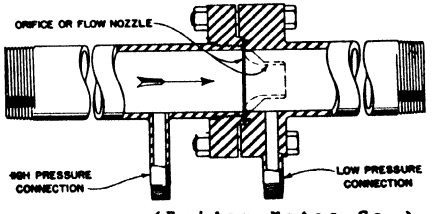


Fig. XIV-29. Air combustion control for stokers, metering.

(Bailey Meter Co.)

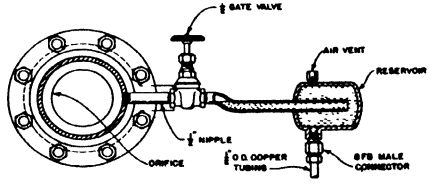
(Bailey Meter Co.)

Fig. XIV-37. Venturi.



(Bailey Meter Co.)

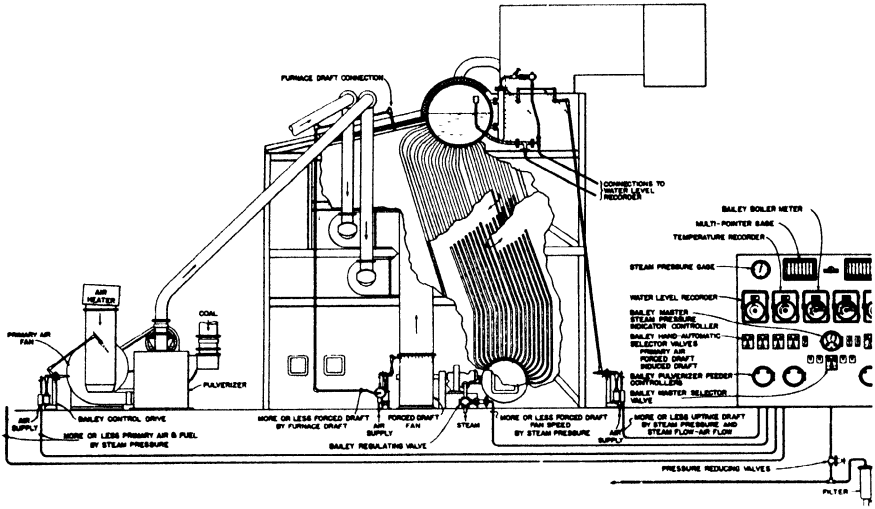
Fig. XIV-38.



(Bailey Meter Co.)

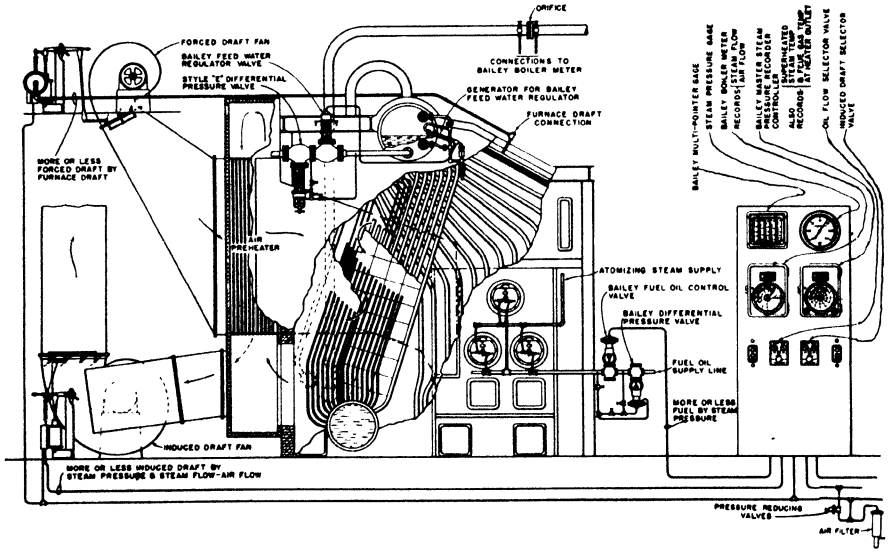
Fig. XIV-39.

...ressure device in steam line.



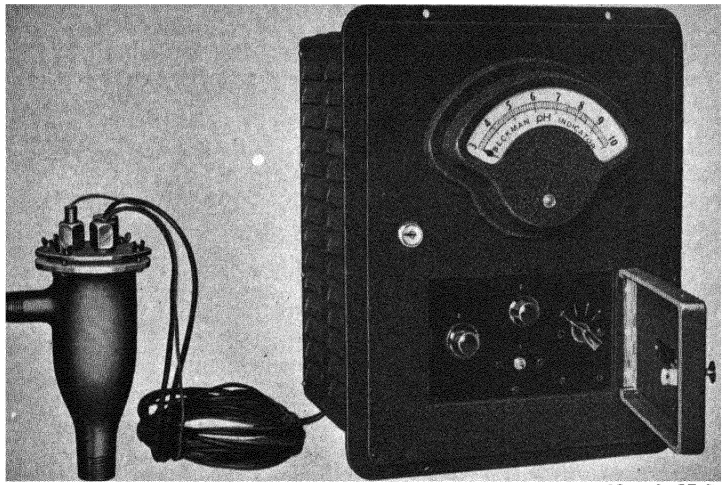
(Bailey Meter Co.)

Fig. XIV-30. Air combustion control for pulverizers, metering.



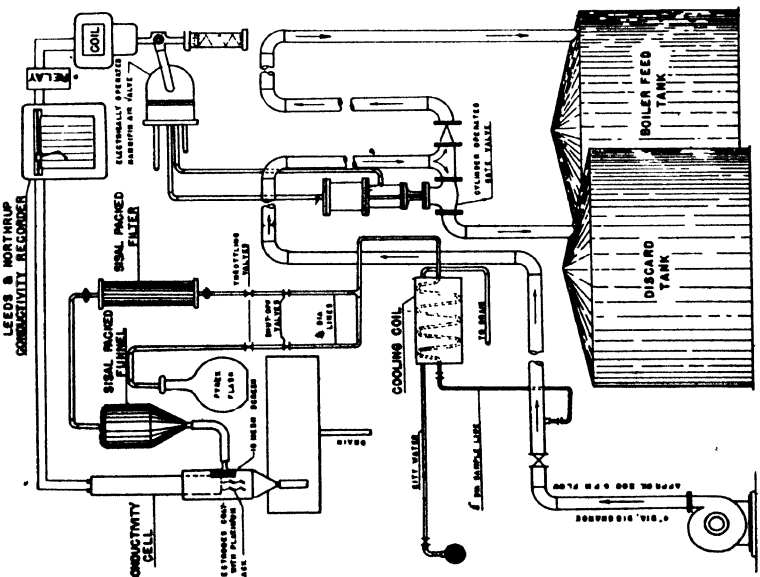
(Bailey Meter Co.)

Fig. XIV-31. Air combustion control for fuel oil, metering.



(National Technical Laboratories)

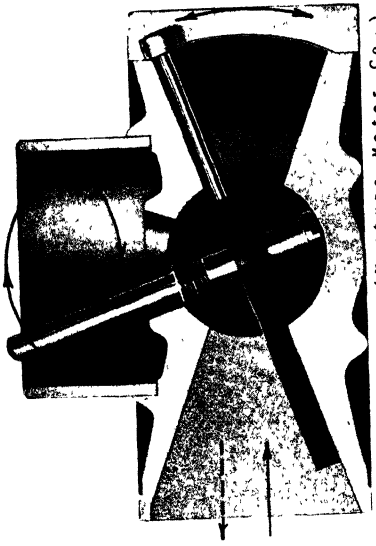
Fig. XIV-32. pH indicator and controller.



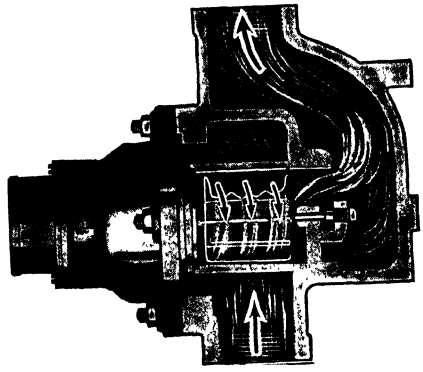
(Southern Power & Industry)

Fig. XIV-33. Conductivity recorder and alarm.

Some special flow measuring applications make use of fluid meters of the disc or vortex types, as shown in Figures XIV–40 and XIV–41. Rotameters, one of which is shown in Figure XIV–42, have a float which rises inside a tapered tube in proportion to the flow.



(Neptune Meter Co.)

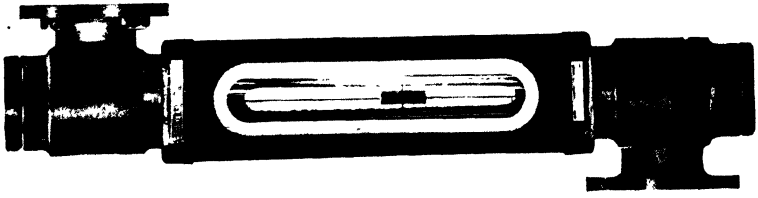


(Hennsey Co.)

Fig. XIV-40. (above) Disc fluid meter.

Fig. XIV-41. (right) Vortex fluid meter.

Fig. XIV-42. (left) Rotameter.



(Fischer & Porter Co.)

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Moyer, J. A., *Power Plant Testing*, McGraw-Hill, New York, 1934.

CHAPTER XV

THE COMPLETE POWER PLANT

108. The design of a power plant, it has been seen, involves the integration of many pieces of equipment into a whole system which must meet exacting economic requirements as well as requirements for reliability and ease of operation. The steps in the design of a power plant are essentially as follows:

1. A study of present and future load requirements.

2. A study to determine the best possible location for a new plant or for an extension to an existing plant in a system.

3. A study of cycle types and arrangements to reveal the most economical solution for the operating conditions.

4. Selection of the major equipment to fit the cycle decided upon.

5. Making a preliminary layout of the plant and analyzing it from the standpoint of ease of operation and economy of floor space and building volume.

6. Making a final layout of the plant and writing specifications for the minor equipment.

Some of these steps may be transposed, or several may be carried on simultaneously. It is always true that subsequent discoveries may invalidate some of the conclusions drawn in earlier steps, thus requiring modifications. The final design should be the result of exhaustive analysis and detailed study from all standpoints.

After the consulting engineers have completed the design of the plant their function is limited to aiding in the analysis of bids for equipment and supervising the construction and initial operation of the plant. In some cases, especially with municipal projects, they will aid in securing the financing of the project.

109. Details of Design--The actual details of the design of a power plant are so voluminous that it is impossible to deal with even a small part of them in a text on fundamentals. Probably the best way for a student to gain some

insight into the process of power plant design is to examine very carefully the design of actual plants, both in the field and from drawings, trying to determine the reason for each detail in the light of his knowledge of the fundamentals.

In order to show some of the multitude of design details, a portion of a set of power plant drawings is given in Figures XV-1 through XV-6.

It will be seen, from an examination of the complete power plant, that the mechanical equipment falls into several major groups, corresponding somewhat to the chapter headings in this book, as follows:

1. Prime movers.
2. Condensers, feed-water heaters and evaporators.
3. Steam generators and auxiliaries.
4. Piping and duct-work.
5. Water handling equipment.
6. Fuel handling equipment.
7. Draft equipment.
8. Supervisory and control equipment.

Another method of grouping the equipment would be as follows:

1. Prime movers.
   a. Lubricating oil system.
   b. Generator cooling system.
   c. Shaft gland sealing system.
2. Condensers.
   a. Condensate pumps.
   b. Circulating water pumps.
   c. Vacuum pumps.
3. Feed-water heaters and evaporators.
   a. Drip pumps.
   b. Evaporator feed pumps.
4. Boiler feed system.
   a. Boiler feed pumps.

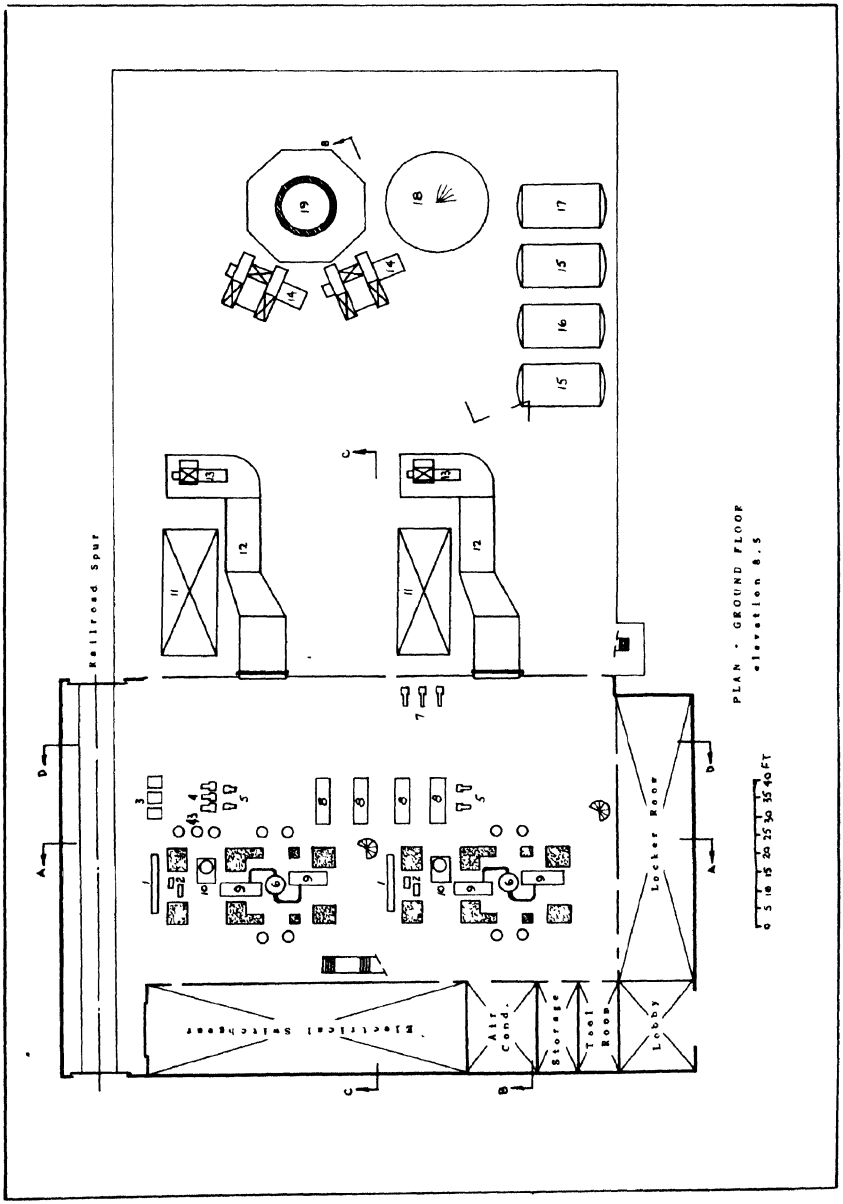


Fig. XV-1. City of Jacksonville, Florida, Power Plant No. 2.

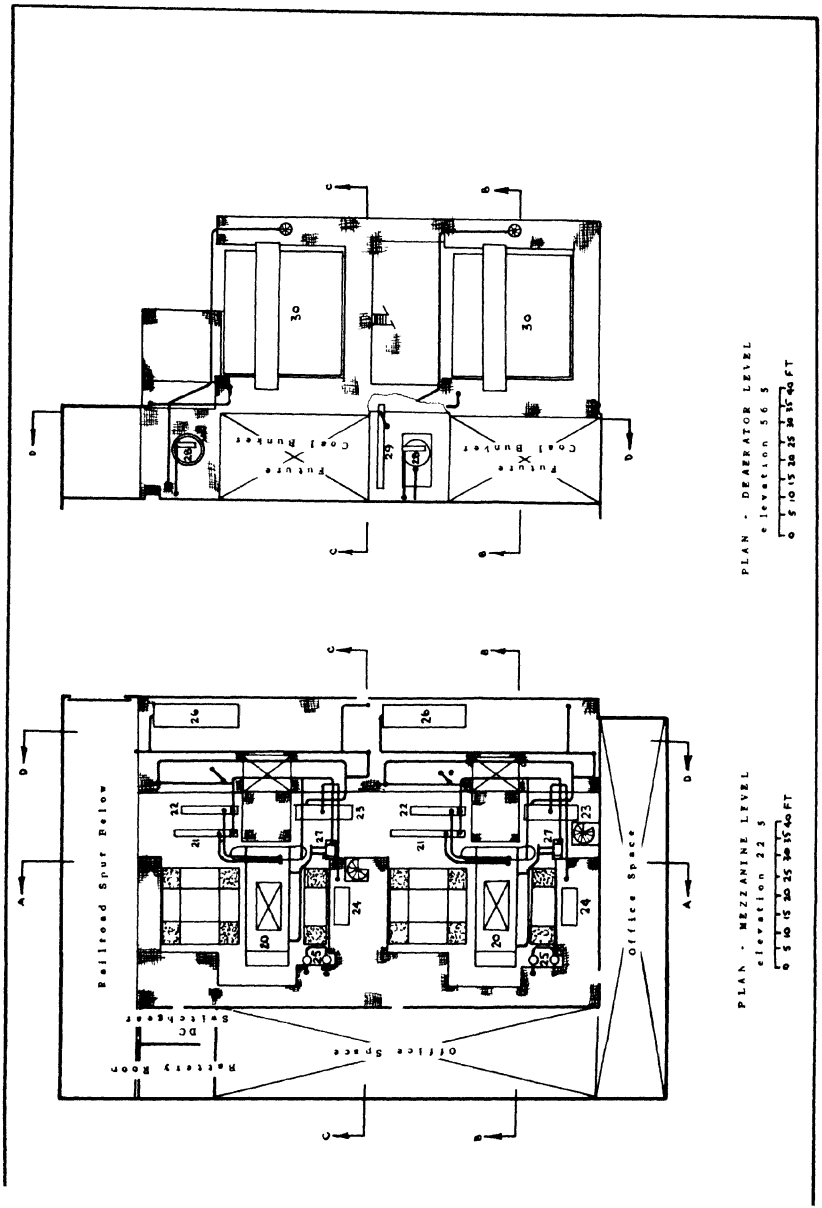
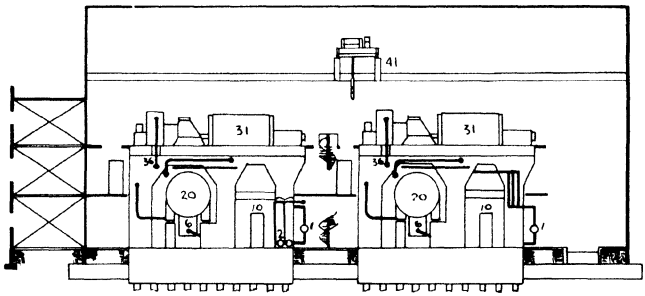


Fig. XV-2. City of Jacksonville, Florida, Power Plant No. 2.

Fig. VV-3 Plan of Tarkannville, Florida, Power Plant No. 2.



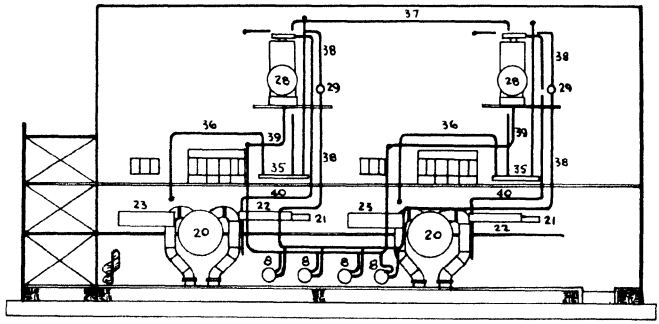


Fig. XV-4. City of Jacksonville, Florida, Power Plant No. 2.

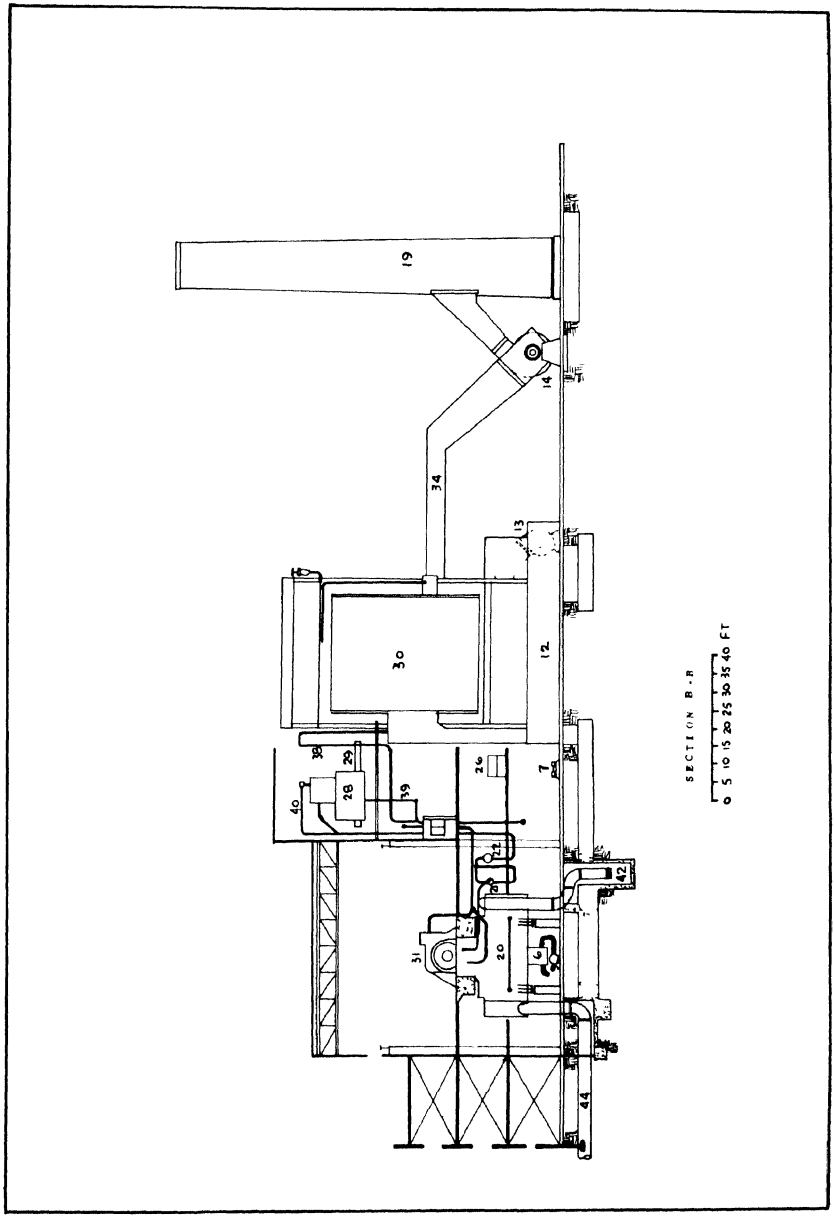
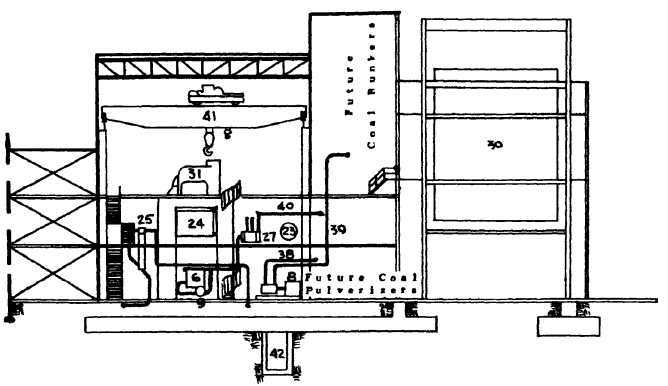


Fig. XV-5. City of Jacksonville, Florida, Power Plant No. 2.



SECTION C-C

0 5 10 15 20 25 30 35 40 FT

KEY

1. Exciter air cooler heat exchanger.
2. Exciter air cooler water circulating pumps.
3. Boiler water treatment chemical feed pumps.
4. Raw water service pumps.
5. Heater drip pumps
6. Hotwell.
7. Fuel oil pumps
8. Boiler feed pumps.
9. Condensate pumps.
10. Hydrogen seal oil treating units.
11. Air heaters
12. Ventilating ducts.
13. Forced draft fans.
14. Induced draft fans
15. Surge tanks.
16. Condensate storage tank
17. Boiler water storage tank
18. Raw water storage tank
19. Stack.
20. Condensers
21. 23rd Stage heaters
22. 26th Stage heaters
23. Evaporators
24. Oil reservoirs.
25. Oil coolers
26. Fuel oil heaters.
27. Air ejectors
28. Deaerators.
29. 15th Stage heaters
30. Boilers
31. Turbo-generators.
32. Turbine gage boards
33. Boiler gage boards.
34. Induced draft fan inlet ducts.
35. Main steam headers
36. Turbine leads
37. Main steam crossover
38. Boiler feed line
39. Boiler feed pump suction lines
40. Condensate lines
41. Travelling crane
42. Circulating water discharge tunnel
43. Water softeners.
44. Circulating water inlet from screen house

Fig. XV-6. City of Jacksonville, Florida, Power Plant No. 2.

b. Surge tanks and pumps.
c. Feed-water regulators.

5. Steam generator.
   a. Boiler and furnace.
   b. Superheater.
   c. Economizer.
   d. Air heater.
   e. Fans and stack.

6. Fuel system.
   a. Fuel oil pumps or coal conveyors.
   b. Fuel oil heaters or coal pulverizers.
   c. Burners.
   d. Ash disposal.

7. Piping and duct-work.
   a. Circulating water system.
   b. Condensate system.
   c. Boiler feed system.
   d. Steam system.
   e. Service and fire protection water system.
   f. Lubricating oil system.
   g. Fuel oil, fuel gas or coal system.
   h. Air ducts.
   i. Gas ducts.
   j. Compressed air system.

8. Water supply.
   a. Condenser cooling system.
   b. Boiler feed makeup.
   c. Service and fire protection water.

9. Fuel supply.
   a. Unloading facilities.
   b. Storage facilities.

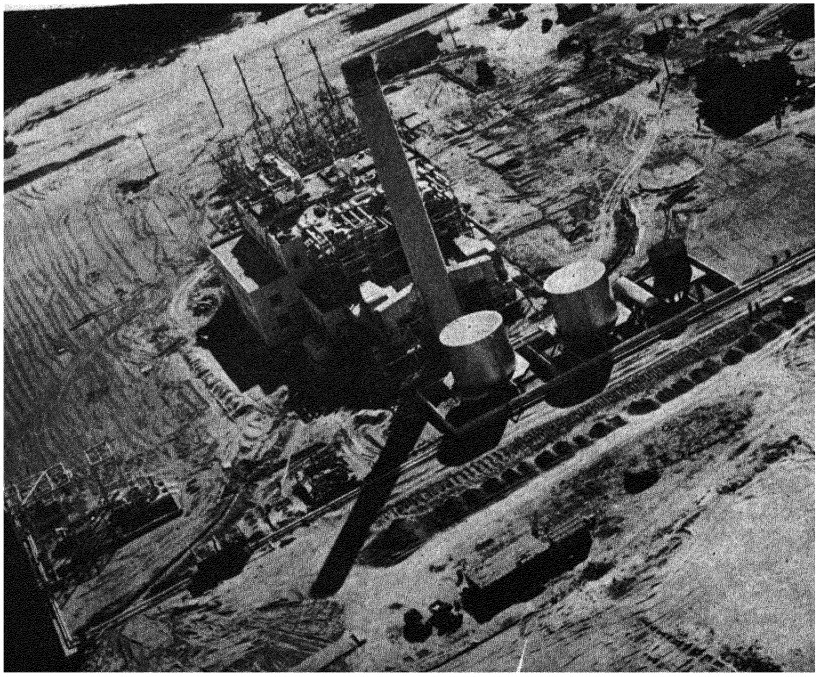
110. Power Plant Buildings--In past years the aim of power plant architecture was to give the impression of power and stability. This aim resulted in buildings that were much too expensive for their primary purpose of sheltering the power generating equipment. The last ten years has proven the ascendency of functional power plant architecture in the acceptance of the semi-outdoor and outdoor plant.

In the semi-outdoor plant more or less of the steam generating equipment is left exposed to the weather (with weatherproof casings) and the turbine equipment and boiler operating stations are completely sheltered. The outdoor power plant is just what the name implies, except that a

shelter is provided for the boiler and turbine operating stations.

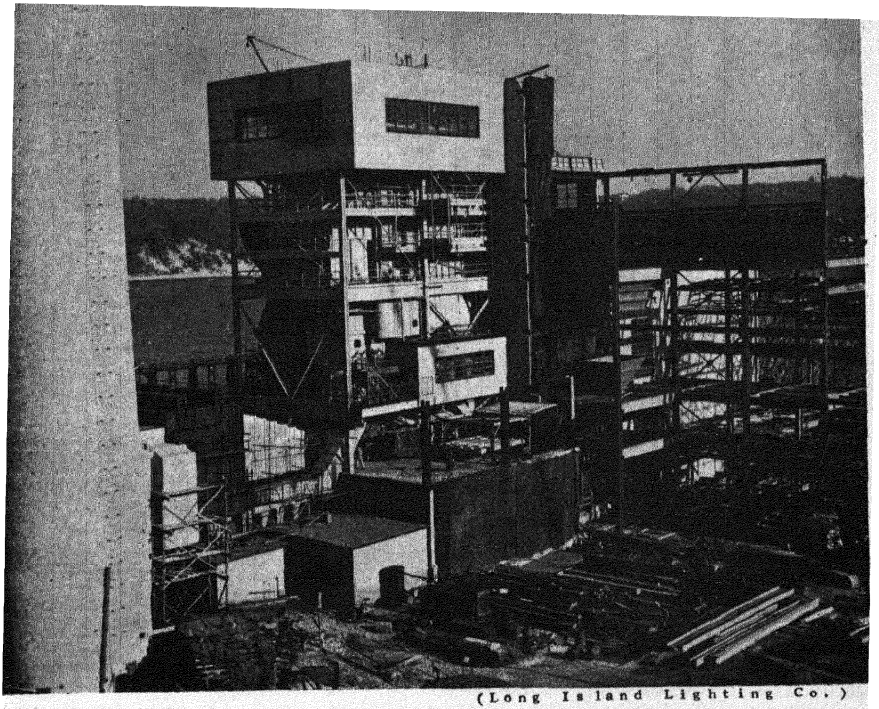
At present, with few exceptions, in plants which are designed for complete shelter, as well as for semi-outdoor installations, the buildings are made as inexpensively as possible in order to reduce the capital outlay to the minimum. Probably the cheapest type of power plant building construction (but not unattractive with proper treatment) makes use of corrugated asbestos-cement sheeting fastened to a structural steel frame. This construction is fire resistant and weatherproof, and has the additional advantage of being easily modified for expansion in any direction.

Figures XV-7 through XV-15 show some views of power plants of the various types of construction.



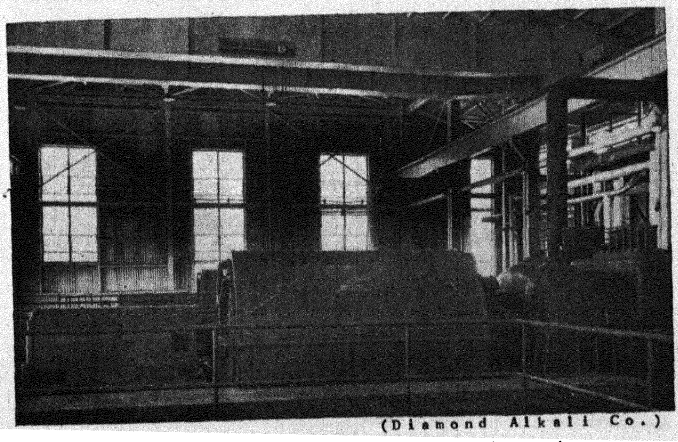
(Florida Power & Light Co.)

Fig. XV-7. Semi-outdoor plant, exterior.



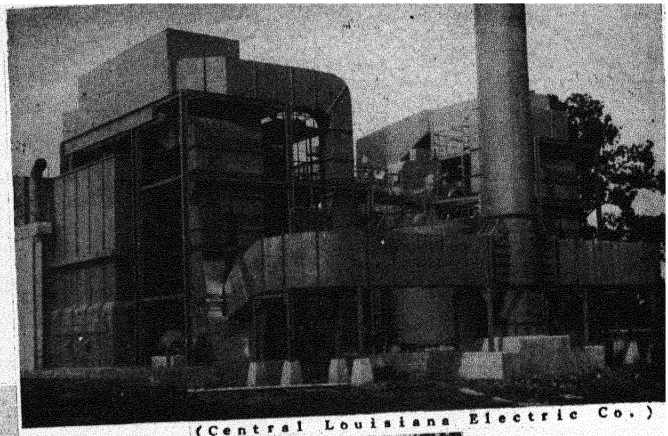
(Long Island Lighting Co.)

Fig. XV-8. Semi-outdoor plant, exterior.



(Diamond Alkali Co.)

Fig. XV-9. Semi outdoor plant, interior.



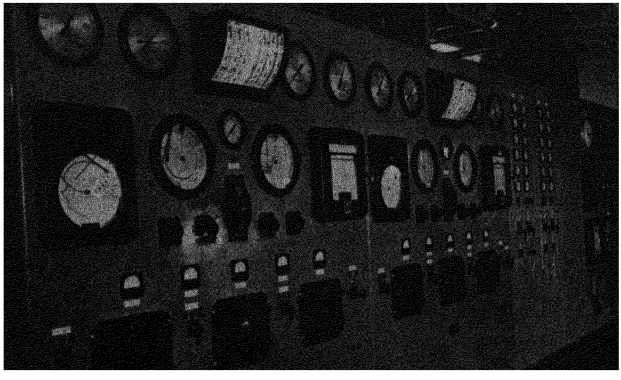
(Central Louisiana Electric Co.)

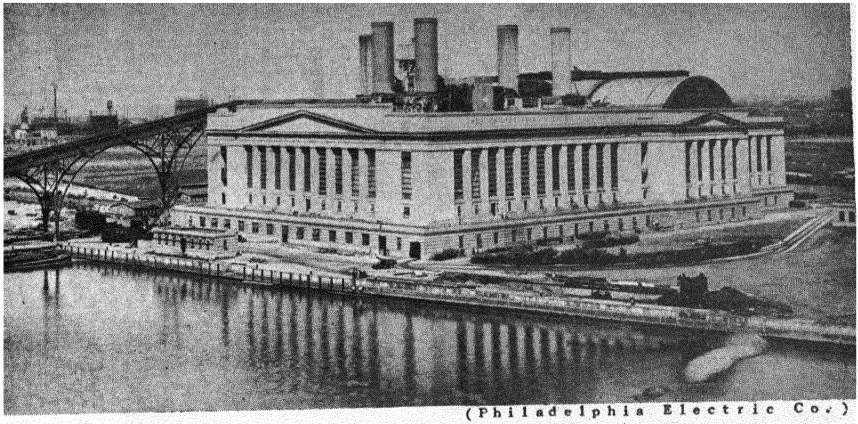
Fig. XV-10. (right) Outdoor plant, exterior.



(Central Louisiana Electric Co.)

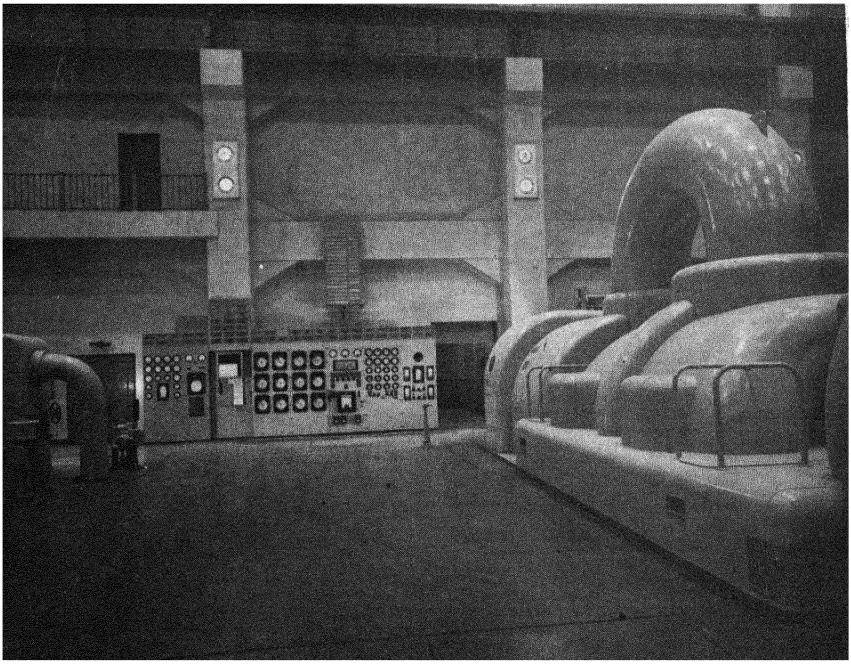
Fig. XV-11. (left) Outdoor plant, exterior.





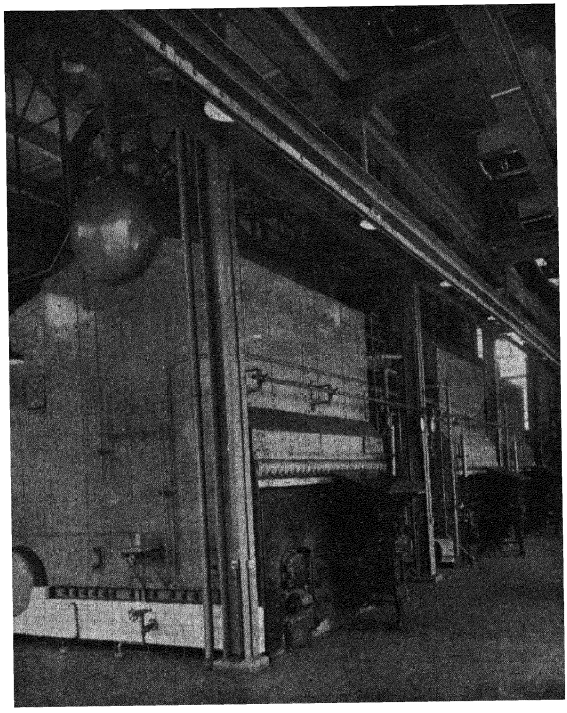
(Philadelphia Electric Co.)

Fig. XV-13. Enclosed plant, exterior.



(Los Angeles Dept. of Water & Power)

Fig. XV-14. Enclosed plant, interior.



(Fairmont Coal Bureau)

Fig. XV-15. Enclosed plant, interior.

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Sanderson, J. C., "Power Plant Substructure Problems," *Transactions A.S.M.E.*, Volume 51, 1929.

PROJECT IV

1. Specify the head, capacity and motor size for the following pumps (assume ordinary entrances and exits):

(a) Circulating water: No static lift.

(b) Condensate: Static lift 40 feet.

(c) Boiler feed: Static lift 20 feet.

2. The analysis of the raw water for makeup is: Calcium bicarbonate, 150 ppm; magnesium bicarbonate, 85 ppm; calcium sulphate, 50 ppm; magnesium chloride, 30 ppm; sodium chloride, 60 ppm. How much 90 o/o hydrated lime, 95 o/o soda ash and 95 o/o filter alum (using 8 ppm) would be required per thousand gallons of water to soften the water by the cold process, leaving a residual hardness of 50 ppm as calcium carbonate?

3. Estimate the draft and pressure losses in the air and flue gas circuits of the steam generator, and specify the capacity, pressure and motor size for the following fans:

(a) Forced draft: Backward curved blades.

(b) Induced draft: Forward curved blades.

4. Calculate the dimensions of the most economical brick stack to produce a draft of 0.5 inches of water. Ambient temperature 90 F and barometer 29.5 inches of mercury.

5. Make a preliminary plant layout drawing.

Note: The preceeding calculations apply to the power plant of Projects I, II and III.

CHAPTER XVI

ECONOMICS OF LOAD DIVISION

111. In the intelligently operated power plant or power system the efforts of all operating and supervisory personnel are bent toward the production of power at the least possible cost. To a large extent the economy of operation is affected by the manner of division of load between units in a plant and plants in a system. It is the purpose of this chapter to discuss briefly the theory of the incremental rate method of load division and to show some of its applications.

112. The Incremental Rate Theory--The theory of incremental rates postulates that each succeeding block of load should be thrown on the plant or machine which exhibits the lowest incremental rate (slope of the input-output curve), regardless of the absolute efficiency of the machine or plant. This theory contradicts the widely held opinion that the most efficient plant or machine should be loaded fully and the less efficient plants or machines used to supply the balance of the demand. According to the incremental rate theory, this opinion is true only in the special case in which the incremental rate of the most efficient plant or machine is always less than that of the less efficient plant or machines. The theory can be substantiated by a very simple demonstration, as follows:

Figure XVI- (a) represents the input-output curves of two machines, A and B. For simplicity these curves are made parabolic so that equations for them can be differentiated algebraically to obtain the equations of the incremental rate curves. It is not necessary to the theory, however, that the curves be capable of being expressed in the form of simple equations because any curve can be differentiated by graphical or tabular methods. The input-output curves A and B can be expressed as:

$$I_a = 17 + O_a + 0.1\ O_a^2$$

$$I_b = 6 + O_b + 0.15\ O_b^2$$

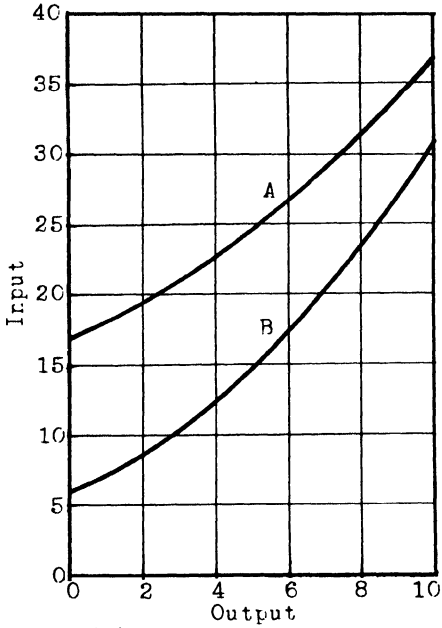
where: I and O = input and output in any desired units

The incremental rates for A and B are plotted in Figure XVI-1 (b), and can be expressed as:

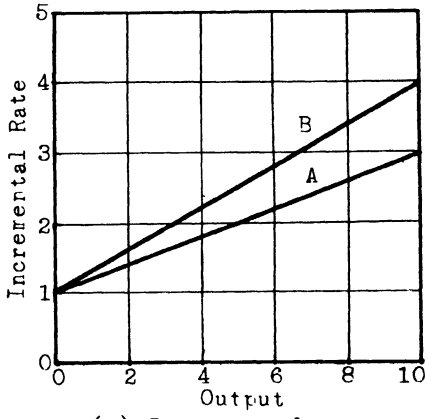
$$\frac{dI_a}{dO_a} = R_a = 1 + 0.2\ O_a$$

$$\frac{dI_b}{dO_b} = R_b = 1 + 0.2\ O_b$$

Examination of the curves of Figure XVI-1 will reveal that while machine B has a greater absolute efficiency than machine A at any load, the incremental rate is also greater at any load above zero load. This indicates that additional



(a) Input-output curves



(b) Incremental rate-output curves

Fig. XVI-1. Machine operating characteristics.

blocks of load, according to the theory, will be handled at greater efficiency by machine A than by machine B.

113. Division of Load--A correlary to the requirement that succeeding blocks of load be supplied by plants or machines with the lowest incremental rate is that, for maximum overall efficiency, all plants or machines must be loaded to

the point at which the incremental rates are equal. This correlary can be substantiated by a simple demonstration, using the data for the machines of Figure XVI-1, as follows:

Suppose it is desired to produce a total output of 14 with machine A and machine B running together. Without regard to efficiency, it would be possible to obtain this output with an infinite number of combinations between 10 on one machine and 4 on the other. However, examination of the following table will show that one combination alone will produce an output of 14 with a minimum input. By interpolation the minimum total input is found to be at an output of

Output		Input		
A	B	A	B	Total
10	4	37.0	12.4	49.4
9	5	34.1	14.8	48.9
8	6	31.4	17.4	48.8
7	7	28.9	20.4	49.3
6	8	26.6	23.6	50.2
5	9	24.5	27.1	51.6
4	10	22.6	31.0	53.6

5.8 from machine B and 8.2 from machine A. Examination of Figure XVI-1 (b) will show that the incremental rates for both machines are 2.64.

114. Loading Schedules--It is now possible to demonstrate the derivation of loading curves or schedules for maximum economy. The trend of loading of machines A and B of the previous discussion is such as to bring machine A to its maximum load first, and the load on machine B at which this occurs can be shown graphically by combination of the incremental rate curves of Figure XVI-1 (b), as shown in Figure XVI-2. Beyond this point machine B will supply the additional load to full plant capacity.

115. Applications of the Incremental Rate Method--The term "machine" has been used rather loosely in the previous discussions to indicate that the incremental rate theory is applicable to any piece of apparatus or collection of apparatus for which input-output curves can be drawn.

Input-output curves for turbines may have shapes similar to those shown in the previous discussions, or they may be of a variety of other shapes and slopes depending upon the valve arrangement, variation of efficiency with load and

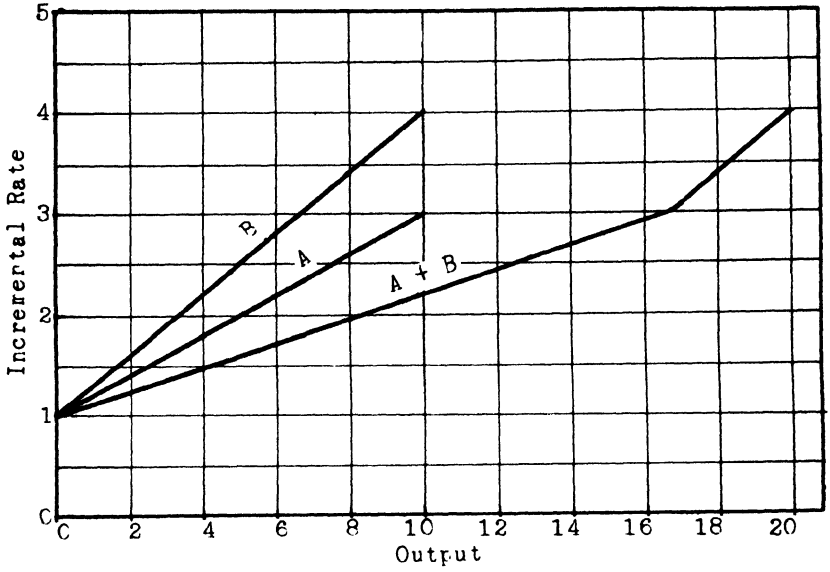


Fig. XVI-2. Plant loading curve.

the auxiliary power requirements. However, no matter what the shape, the basic theory is applicable to determination of the best load division.

The preceeding remarks apply equally well to steam generators. Input-output curves can be derived from steam generator efficiency data and the incremental rate curves derived in turn from the input-output curves.

For the purposes of the system load dispatcher, the plant loading curves can be integrated to give plant input-output curves. These curves will be of use in deciding upon the system loading schedule. The plant loading curve of Figure XVI-2 was based upon the operation of two machines at all times, however, due to the better absolute efficiency of machine B, best economy would dictate the use of machine B alone up to a plant load of 10. At this load machine A would be brought on the line and the load divided between the two machines. Figure XVI-3 shows the plant loading curve replotted on this basis. This curve can be integrated in three parts: from zero to 10; from 10 to 16.7; and from 16.7 to 20. The equations are:

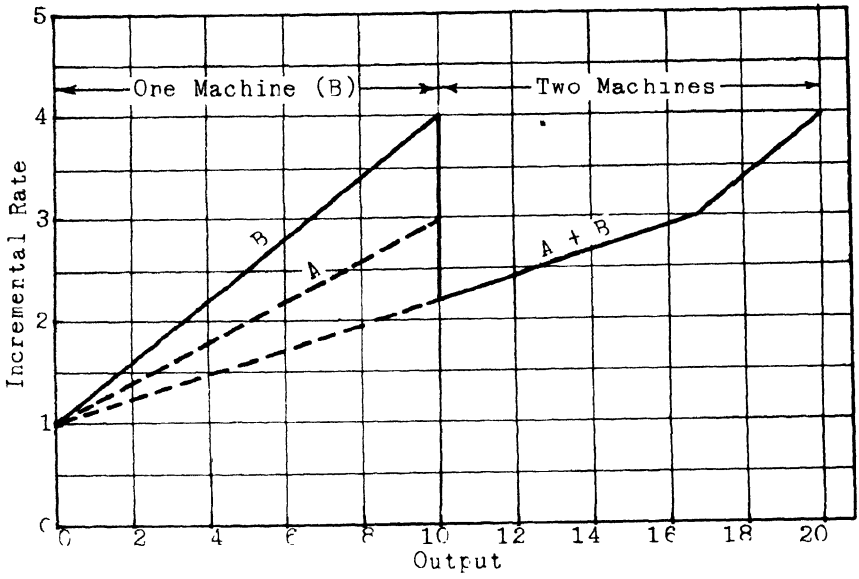


Fig. XVI-3. Plant loading curve.

$$I_{O=0}^{O=10} = \int (1 + 0.2\,O)dO = O + 0.1\,O^2 + C_1$$

$$I_{O=10}^{O=16.7} = \int \left(1 + \frac{2\,O}{16.7}\right)dO = O + 0.06\,O^2 + C_2$$

$$I_{O=16}^{O=20} = \int (-2 + 0.2\,O)dO = -2\,O + 0.1\,O^2 + C_3$$

When the constants are evaluated, the equations become:

$$I_{O=0}^{O=10} = 6 + O + 0.1\,O^2$$

$$I_{O=10}^{O=16.7} = 22 + O + 0.06\,O^2$$

$$I_{O=16}^{O=20} = 48 - 2\,O + 0.1\,O^2$$

The plant input-output curve is then plotted as shown in Figure XVI-4.

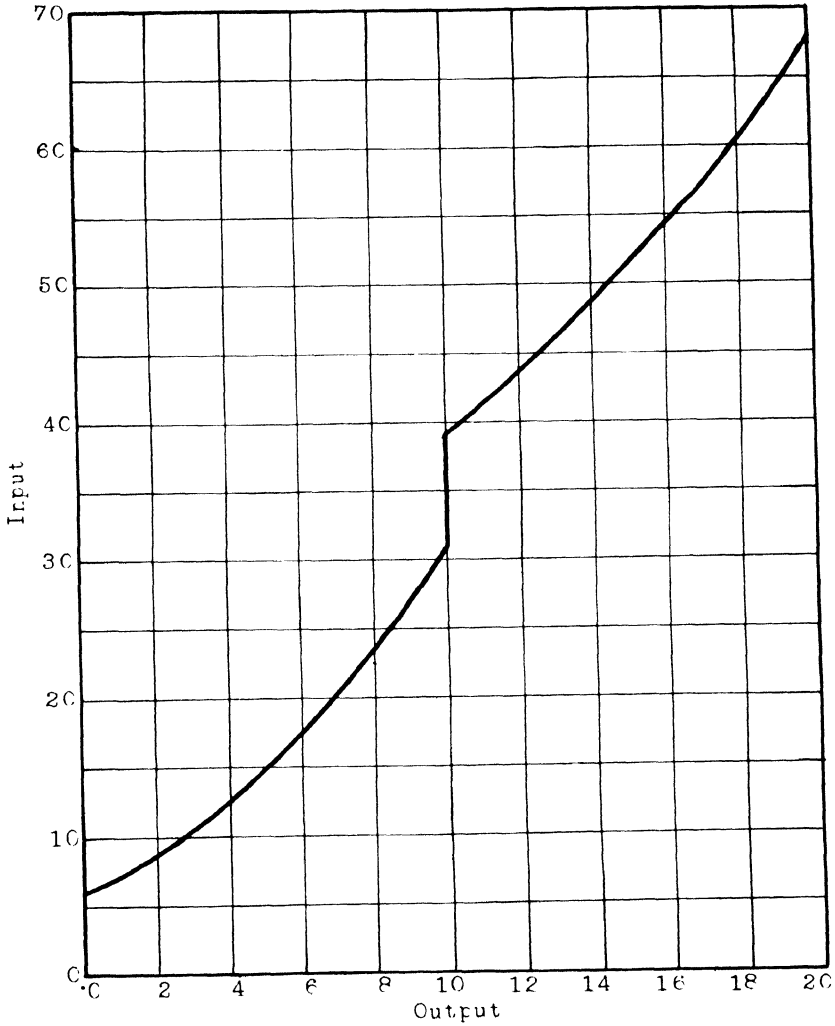


Fig. XVI-4. Plant input-output curve.

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CHAPTER XVII

DIESEL-ELECTRIC POWER PLANTS

116. The Diesel engine is at the present time the most efficient machine (with the exception of the mercury-steam binary vapor cycle) available for the conversion of the energy in fuel to a useful form. It is most unfortunate that the engines are limited in size to about 7000 horsepower. As mentioned in Chapter I, power plants with capacities up to about 7500 kw capacity may well contain Diesel engines, but above this capacity the steam turbine is supreme.

The Diesel engine takes its name from its inventor, Rudolph Diesel, who patented an engine in 1892 which was supposed to operate on the Carnot cycle. However, practical difficulties and development over the years has led to the modern Diesel engine which may be made to operate on the two-stroke or the four-stroke system. By far the greater number of modern Diesel engines operate on the two-stroke system because of the greater simplicity of the engine.

117. Two-Stroke Diesel Cycle--The two-stroke Diesel cycle, as the name implies, requires two strokes of the piston to complete a cycle. Referring to Figure XVII-1, it can be seen that with the piston at the bottom of the cylinder

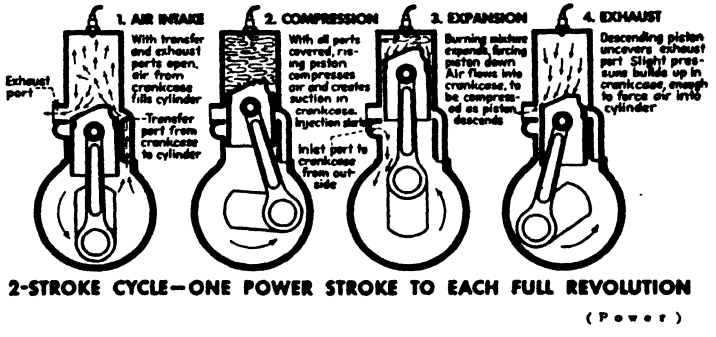
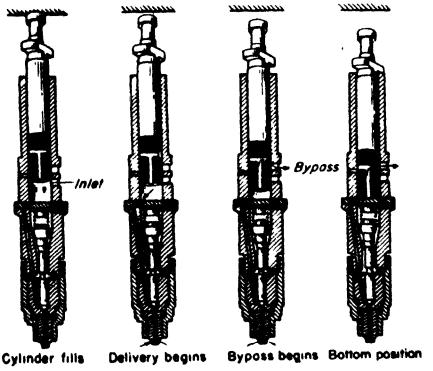


Fig. XVII-1. Two-stroke Diesel cycle.

scavenging air is blown in at one side of the cylinder and cut at the other side, purging the cylinder of exhaust gases and charging it with fresh air. As the piston moves upward the scavengirg and exhaust ports close and the air is compressed. When the piston reaches the top of its travel the

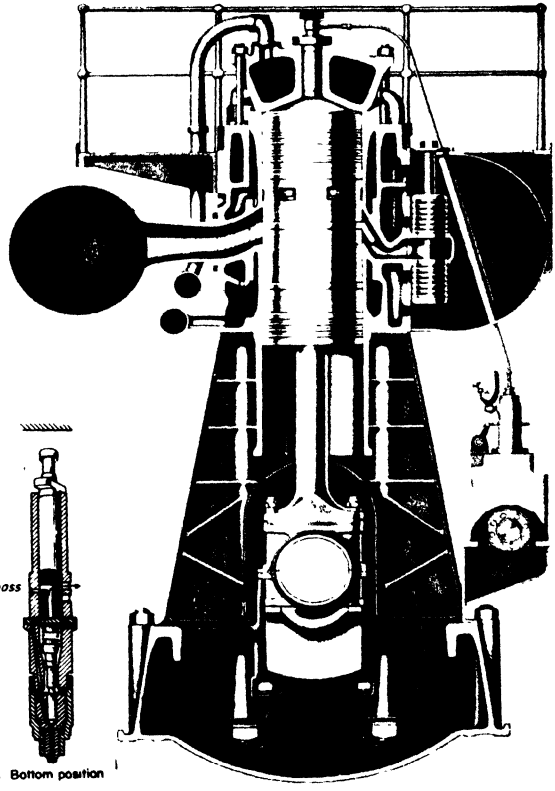
air temperature has risen to about 800 F, which is sufficient to cause ignition of the charge of fuel which is sprayed into the cylinder through an injector. The combustion of the fuel causes a further increase in temperature and the piston moves downward doing work. Sometimes the mechanical details are changed to employ a poppet valve in the cylinder head for the admission of scavenging air or for exhaust. Figure XVII-2 shows a fuel injector and Figures XVII-3 through XVII-5 show several two-stroke engines.

118. Four-Stroke Diesel Cycle--In this cycle, referring to Figure XVII-6, the first downward stroke of the piston is used for drawing in a charge of air through a poppet valve in the cylinder head. In the upward stroke the air charge is compressed. At the end of the compression stroke the fuel is sprayed into the cylinder through an injector and the piston moves downward on the power stroke. At the end of this stroke the exhaust valve in the cylinder



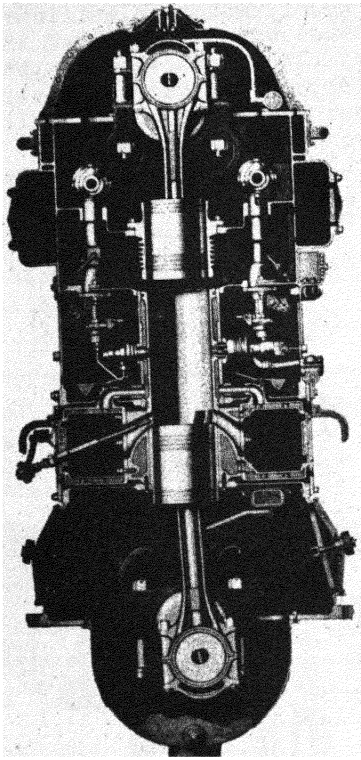
(Power)

Fig. XVII-2. Fuel injector.



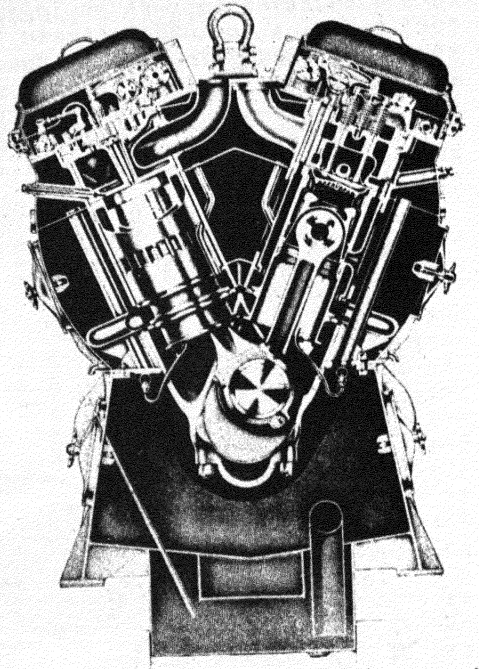
(Nordberg Mfg. Co.)

Fig. XVII-3. Large low speed two-stroke engine.



(Fairbanks, Morse & Co.)

Fig. XVII-4. High speed opposed piston two-stroke engine.



(General Motors Corp.)

Fig. XVII-5. High speed V-type two-stroke engine.

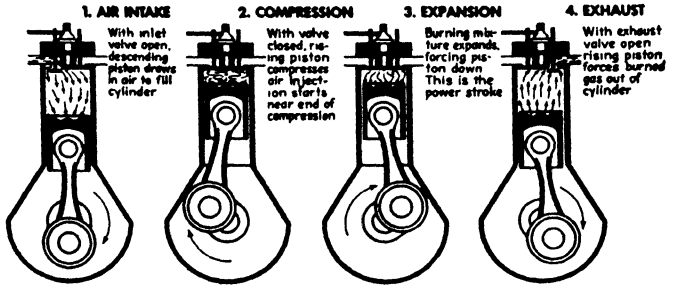
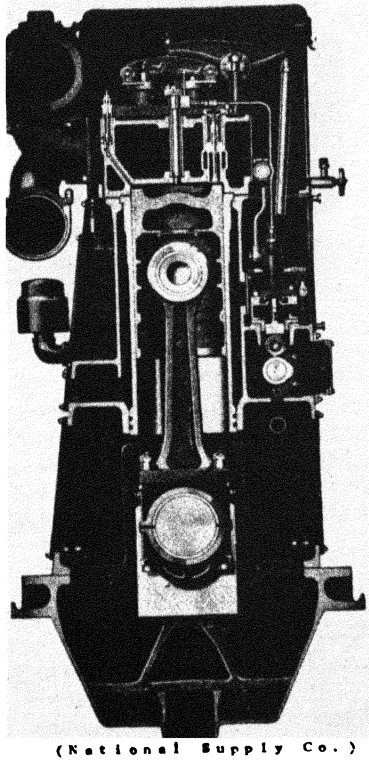


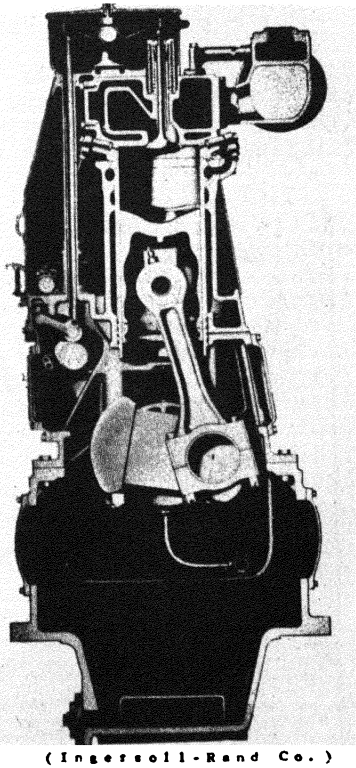
Fig. XVII-6. Four-stroke Diesel cycle.

head opens and on the upward stroke the exhaust gases are discharged from the cylinder. It would appear that the two-stroke engine would produce twice as much power for the same engine dimensions and speed as the four-stroke engine, but this is not true because the four-stroke engine has a much greater volumetric efficiency as an air compressor. Actually, the power produced per cylinder is almost the same, but the two-stroke cycle engine is preferred because of its greater simplicity. Figures XVII-7 through XVII-9 show several four-stroke cycle engines.



(National Supply Co.)

Fig. XVII-7. Medium speed four-stroke engine.



(Ingersoll-Rand Co.)

Fig. XVII-8. Medium speed four-stroke engine.

119. The Ideal Diesel Cycle--The ideal Diesel cycle, shown in Figure XVII-10, consists of a constant pressure addition of heat from A to B; an adiabatic expansion from B to C; a constant volume rejection of heat from C to D; and an adiabatic compression from D to A. The efficiency of the

ideal cycle can be expressed as follows:

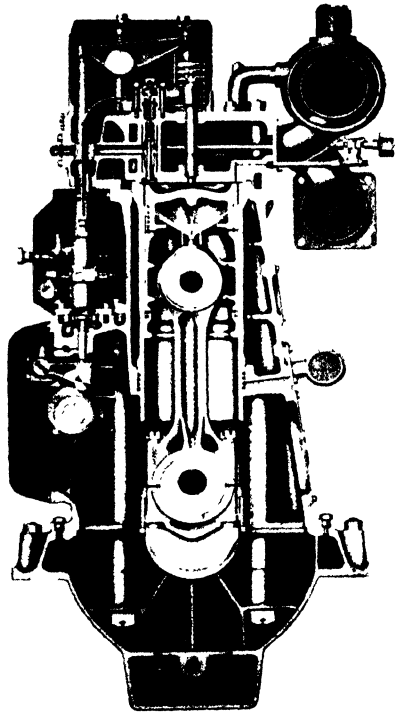
$$e_{t_c} = 1 - \frac{1}{r^n - 1} \frac{R^n - 1}{(n[R - 1])}$$

where: r = compression ratio, V_d/V_a (15 to 18)

R = fuel cutoff ratio, V_b/V_a

n = polytropic exponent

If n is given a value of 1.4, which would represent the adiabatic value for air, the efficiency obtained from the equation would be called the air standard efficiency. Actually, the value of n averages about 1.35.



(Worthington Pump & Machinery Co.)

Fig. XVII-9. Medium speed four-stroke engine.

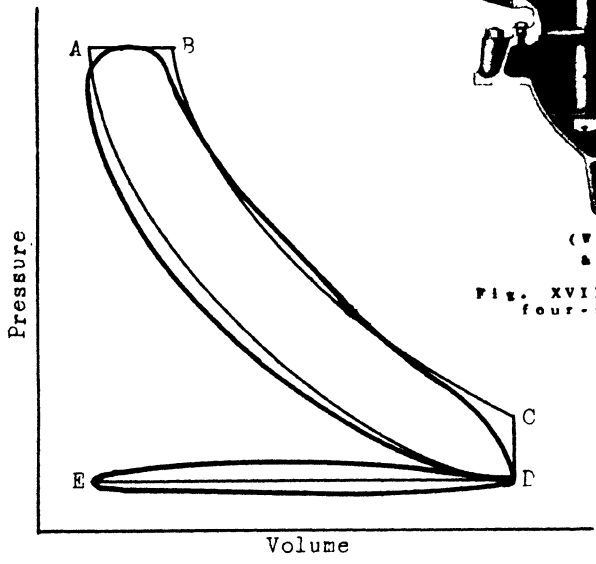


Fig. XVII-10. Ideal Diesel cycle.

The two-stroke engine will follow the shape of the air standard quite closely except for the difference in the value of n. The four-stroke engine, however, will exhibit a negative work loop DED due to losses in discharging the products of combustion and drawing in a fresh

air charge. The departure of n from the adiabatic value is due to the necessity of providing the cylinders with water jackets to prevent overheating.

120. Supercharging--The power output of Diesel engires can be increased by providing means for forcing more air into the cylinders, which in turn makes it possible to burn more fuel. The process involves increasing the initial air pressure, and the term applied is *supercharging*. Several systems of supercharging are used, as follows:

1. Positive displacement blowers or compressors.
   a. Direct connected.
   b. Motor driven.

2. Centrifugal or axial compressors.
   a. Exhaust gas turbine driven.
   b. Direct connected.
   c. Motor driven.

The advantage of the supercharger lies in its ability to cause an increase in power of the engire which is greater than the power required to drive the supercharger. As a matter of fact, supercharging is necessary for any Diesel engine when it is operated at considerable distances above sea level because of the decrease in atmospheric pressure which results in lower peak cylinder pressures. The decrease in power of an unsupercharged engine with increasing altitude is such as to cause the engine to have only 70 per cent of its sea level power at 8000 feet and 50 per cent at 14000 feet. Figures XVII-11 through XVII-13 show several types of supercharger and scavenging blower.

121. Diesel Engine Efficiencies--The thermal efficiency of most Diesel engines will be about 30 per cent, and the heat balance will be about as follows:

Shaft output	30 o/o
Cooling water	30 o/o
Exhaust gas	30 o/o
Friction, radiation compressor	10 o/o

A not inconsiderable item in the operation of a Diesel engine is the lubri-

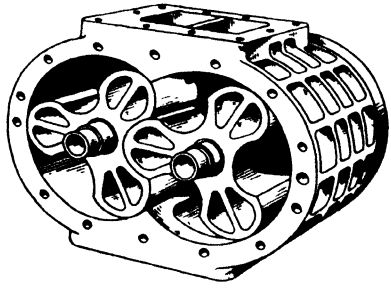
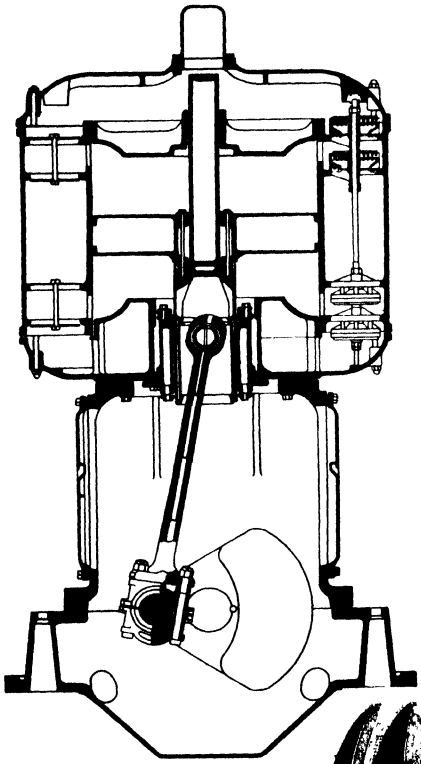


Fig. XVII-11. Positive displacement blower.

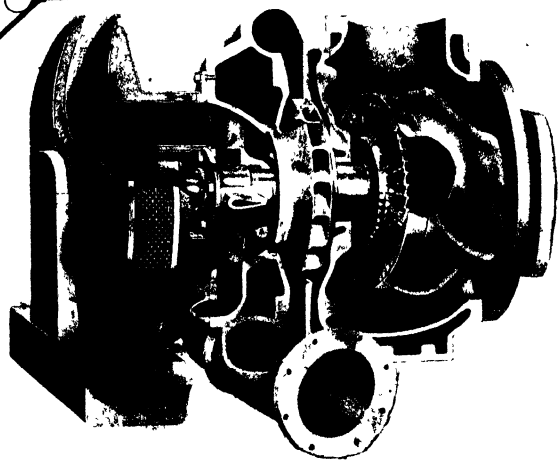


(Power)

Fig. XVII-12. Reciprocating scavenging pump.

cating oil will be consumed because at each combustion the lubricating oil film burns from the cylinder wall. Figure XVII-14 shows some data on fuel and lubricating oil economy for Diesel-electric plants.

Power output is directly proportional to speed, so that high speed engines will be more economical of space for a given output than will low speed engines. However, high speed engines (600 to 1200 rpm) have shorter lives and require higher grade fuel oils (number 2 or 3), so that a careful economic analysis with respect to expected life and cost must be made before deciding upon the particular type of engine for any given installation.



(Elliot Co.)

Fig. XVII-13. Exhaust gas turbine driven centrifugal blower.

122. Diesel Engine Auxiliaries--The auxiliaries for a Diesel engine installation may be placed in several classifications, as follows:

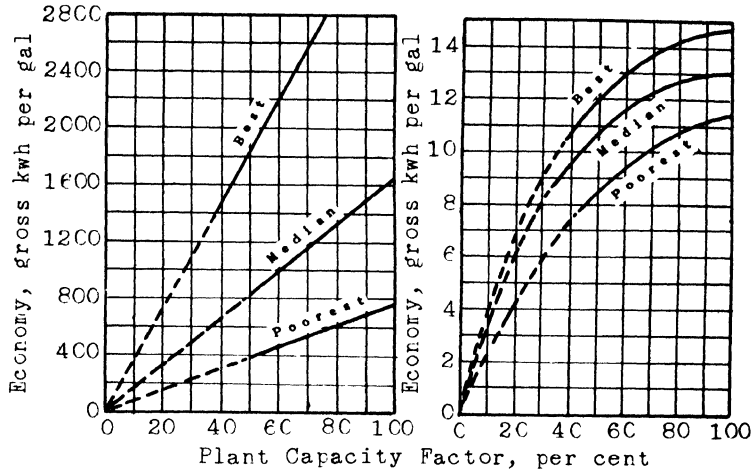


Fig. XVII-14. Diesel engine fuel and lubricating oil economy.

1. Fuel oil system.
2. Lubricating oil system.
3. Cooling water system.
4. Air intake system.
5. Exhaust system.
6. Starting air system.

Figure XVII–15 shows the arrangement of the various systems in relation to an engine. The systems can be designed in accordance with the fundamentals of fluid flow presented elsewhere in this book, but especial attention will have to be given to the air intake and exhaust systems in order to avoid conditions which would lead to resonance in the ducts.

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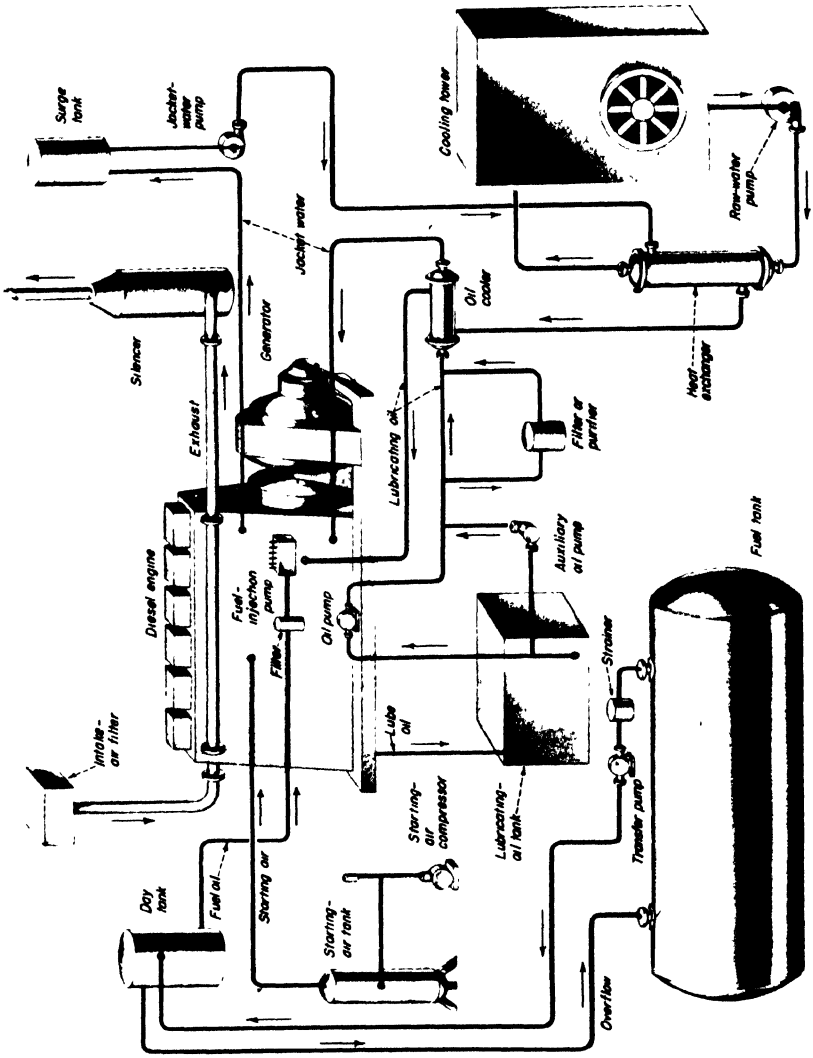


Fig. XVII-15. Diesel engine auxiliaries. (Power)

Kates, E. J., *Diesel Electric Plants*, Amer. Tech. Society, Chicago, 1945.

Ward, R. H., "The Diesel Engine and Public Utilities," *Transactions A.S.M.E.*, Volume 50, 1927–28.

CHAPTER XVIII

HYDRO-ELECTRIC POWER PLANTS

123. Hydro-electric power plants can be classified in two ways, as follows:

1. Water impoundment volume.
   a. Storage plants.
   b. Run-of-river plants.

2. Head on turbines.
   a. High head (over 500 feet).
   b. Medium head (50 to 500 feet).
   c. Low head (under 50 feet).

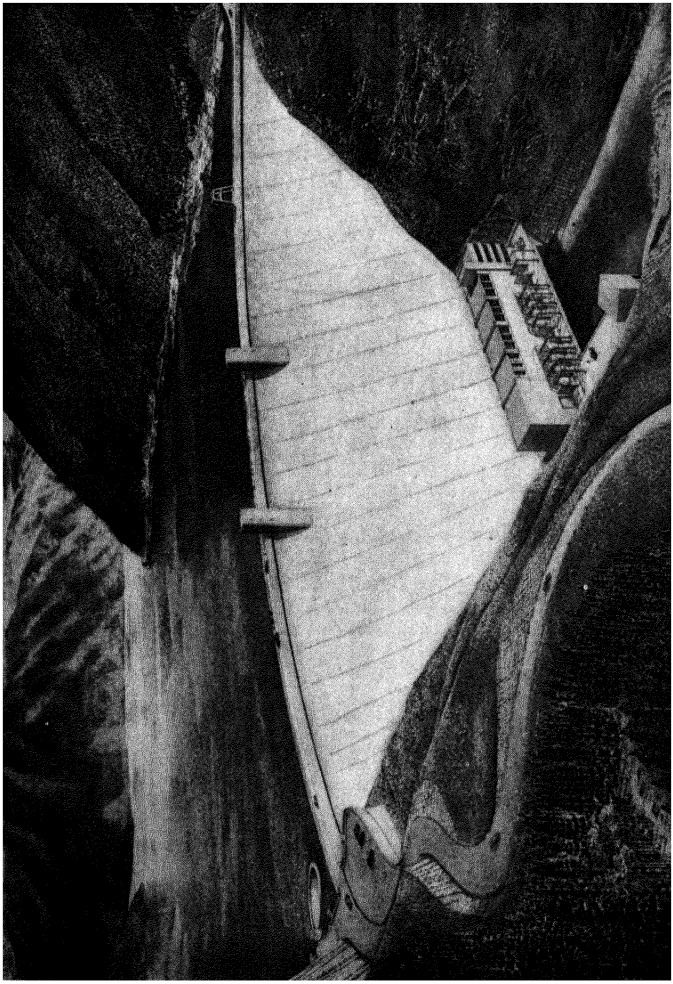
The impoundment volume will affect the amount of power available at any particular time, that is, the *storage plant* will be able to supply a swinging load with little or no water loss, while the *run-of-river plant* operates best on base load status (the base load, of course, varying with seasonal stream flow). The head available will affect the choice of type of prime mover. *High head plants* characteristically use small water volumes and high rotational speeds with impulse types of turbines, while *medium and low head plants* use larger water volumes and lower rotational speeds with reaction type machines. Any of the types are available in sizes from 750 to 75,000 kilowatts capacity.

124. Impoundment Methods--Any hydro-electric plant will require a dam which may be high or low depending upon the topography of the dam site and the surrounding water-shed. Each case is unique and requires its own solution.

High dams (over 100 feet) may be of the arch type or of the gravity type. The arch dam depends upon the shape of the dam to transfer the water load to the enclosing rock walls which serve as abutments. Hoover Dam on the Colorado River is of this type. The gravity dam depends upon the mass of the dam itself to resist the water load and the enclosing rock walls merely serve to confine the water laterally. Grand Coulee Dam on the Columbia River is of the gravity type. The TVA system contains both types of dams.

Low dams (under 100 feet) are usually of the gravity type and may be of masonry construction, as with high dams, or they may be of earth fill with cores of rock, clay or concrete.

Figure XVIII-1 shows a concrete arch dam.



(U.S.Bureau of Reclamation)

Fig. XVIII-1. Concrete arch dam.

125. **Water Storage**--The run-of-river plant requires little or no impoundment volume and the essential information for estimating the power capabilities of the site can

be obtained from a river flow duration curve. The flow duration curve can be constructed from a hydrograph, which is similar to an electrical load curve. Figure XVIII-2 shows a river hydrograph, and Figure XVIII-3 shows the flow duration curve derived from it. The minimum power available and the yearly power output can be estimated from these curves.

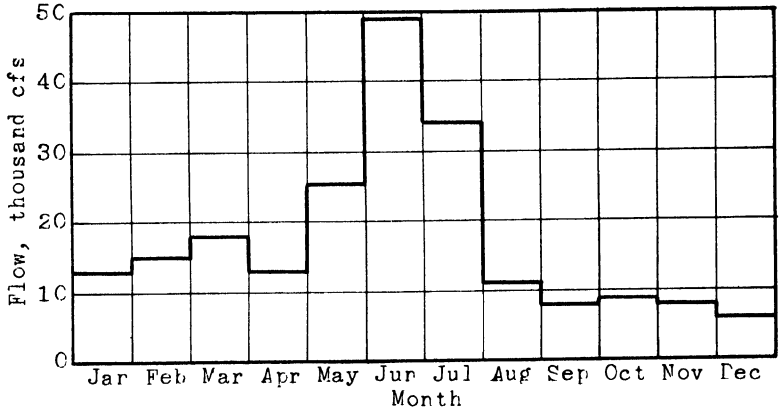


Fig. XVIII-2. River hydrograph.

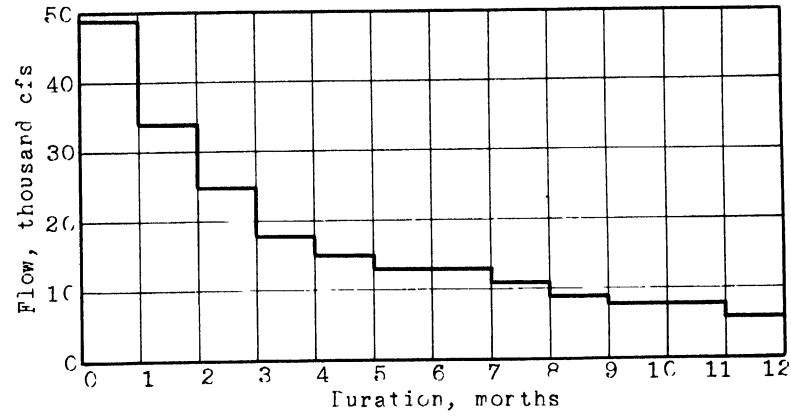


Fig. XVIII-3. River flow duration curve.

The storage plant makes use of a river mass flow curve in which cumulative water-shed runoff is plotted versus time

during the year. Such a curve, derived from Figure XVIII-2, is shown in Figure XVIII-4. Using this curve it is possible to estimate the maximum possible sustained flow to base load turbines by calculating the slope of the line drawn tangent to two similar yearly peaks (A and B in Figure XVIII-4). Wherever the slope of the mass flow curve is less than that of the tangent, the reservoir level will be decreasing, and vice versa. The total impoundment volume should be sufficient to maintain a minimum head on the turbines when the reservoir level is at its lowest, which would be at point C.

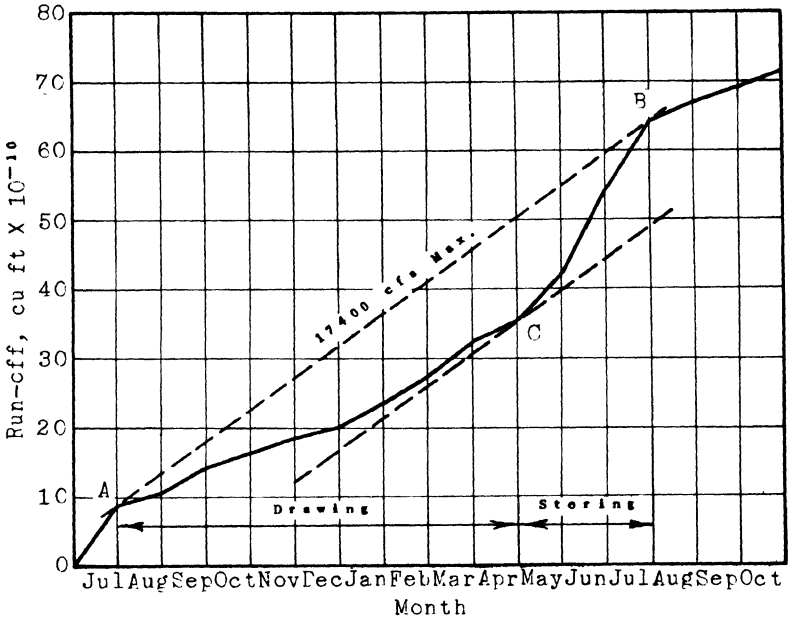


Fig. XVIII-4. River mass flow curve.

126. Hydraulic Turbines--The hydraulic impulse turbine is similar to the steam impulse turbine in that all of the pressure drop takes place in the nozzles. If it is assumed that the initial velocity is zero, the jet velocity is (assuming a perfect nozzle):

$$V = \sqrt{2gH} = \sqrt{2g(P_1 - P_2)v}$$

where: V = jet velocity, ft/sec
H = head at jet inlet, ft of water

P_1 and P_2 = jet inlet and outlet pressures, lbs/sq ft

v = specific volume of water, cu ft/lb

The power in the jet is:

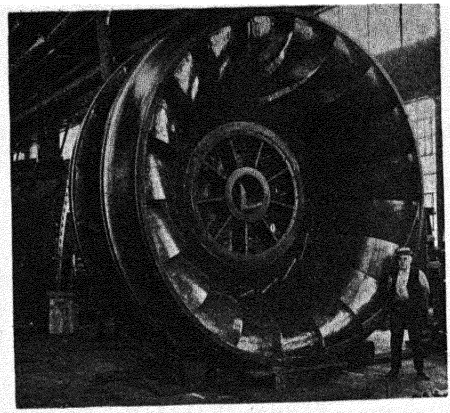
$$whp = \frac{M\ H}{550} = \frac{M(P_1 - P_2)v}{550}$$

where: M = water flow, lbs/sec

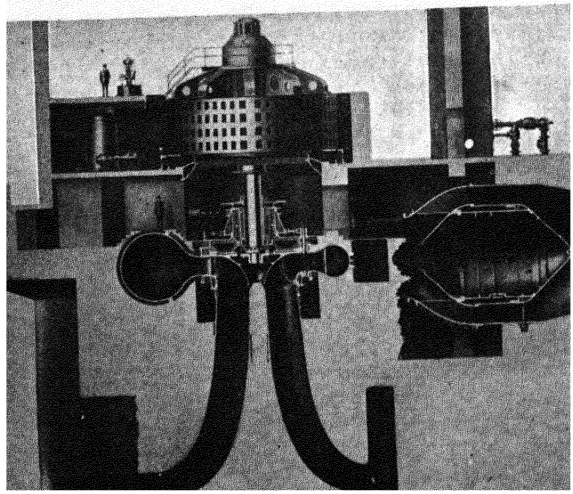
but due to the fact that it is not possible to slow the jet down to zero velocity, and due to mechanical friction, the shaft horsepower will only amount to about 85 to 90 per cent of the jet horsepower. The impulse turbine is for very high head developments (over 900 feet) and operates at speeds between 300 and 400 rpm. Figure XVIII-7 shows an impulse turbine runner of the Pelton type with its needle nozzles. Two of the runners are overhung on one generator and the nozzles are so arranged that one per runner is the power nozzle and identical nozzles are used for surge relief. That is, as the power nozzle closes on a load decrease the relief nozzle opens an equal amount and then automatically closes slowly to prevent surges in the penstock (which is the name given to the pipe which delivers water to the nozzles from the reservoir. As an extra safety measure, the penstocks are equipped with surge tanks near the turbines.

For heads between 65 and 900 feet the Francis type of reaction turbine is used. The wheel, or runner, has curved blades which receive water through control gates from a volute chamber and discharge the water vertically downward. The action is very similar to that in a reaction steam turbine, some pressure drop taking place in the control gates giving some impulse effect, while the remainder of the pressure drop takes place in the runner. The water horsepower is the same as the jet horsepower for the impulse turbine, but the efficiency is higher, usually between 90 and 95 per cent. Figure XVIII-5 shows a Francis type turbine with an umbrella generator. These machines operate at speeds between 100 and 300 rpm.

For heads less than 65 feet the axial flow propeller type of reaction turbine is used. The runner may be of the Nagler type with fixed pitch blades or of the Kaplan type with adjustable pitch blades. The Kaplan runner is very well suited to run-of-river plants because the power output and efficiency can be maintained under reduced head condi-



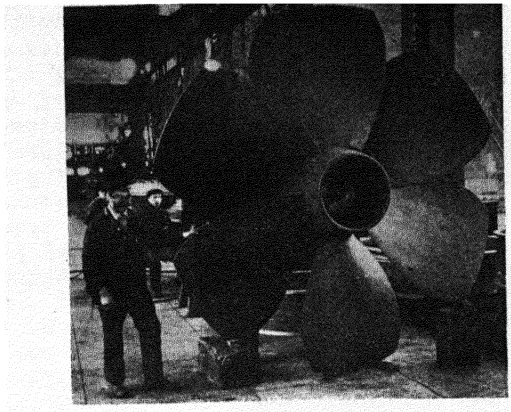
(a) Runner



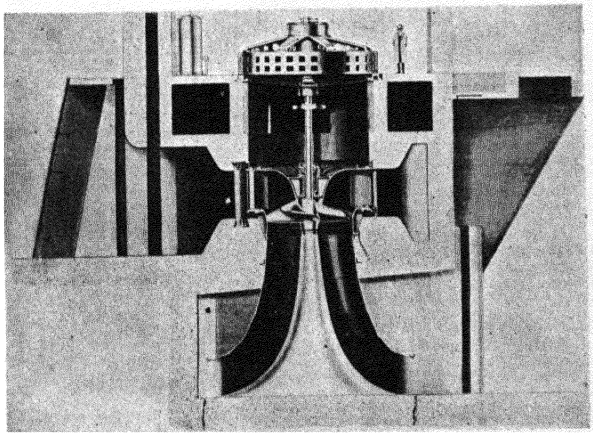
(b) General arrangement

(Wm. Cramp & Sons)

Fig. XVIII-5. Francis turbine.



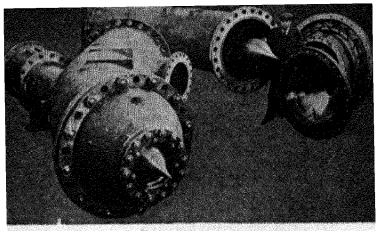
(a) Runner



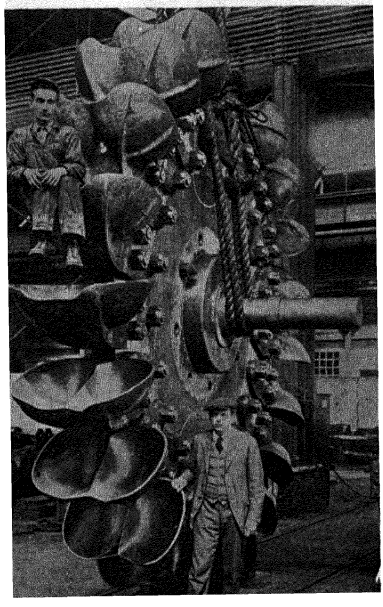
(b) General Arrangement

(Wm. Cramp & Sons)

Fig. XVIII-6. Nagler turbine.



(a) Needle nozzles



(b) Runner

(Allis-Chalmers Mfg. Co.)

Fig. XVIII-7. Pelton turbine.

tions. Water is supplied to the propeller through control gates in a manner similar to that used with the Francis runner. Efficiencies vary between 85 and 90 per cent and speeds between 60 and 100 rpm. Figure XVIII-6 shows a typical Nagler turbine connected to an umbrella type generator.

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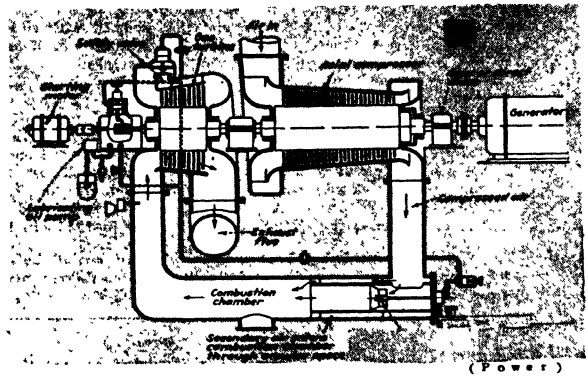
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CHAPTER XIX

GAS TURBINE POWER PLANTS

127. In the last war the development of the gas turbine was given great impetus and at the present time several manufacturers are offering 5000 kilowatt units for use with heavy fuel oil or natural gas. Research is being conducted on pulverized coal burning units but difficulty is being experienced with flyash erosion in the turbines.

128. Gas Turbine Cycles--The simplest gas turbine cycle corresponds to the open Rankine vapor cycle, as shown in Figure XIX-1. Referring to the figure, air at atmospheric pressure and temperature is drawn in by the compressor, compressed and led to the combustion chamber where fuel is burned at constant pressure. The resulting high temperature combustion gases then expand to atmospheric pressure through a turbine and the unavailable energy is rejected to the atmosphere. Part of the turbine work is used to drive the compressor and the remainder is available for doing useful work. Due to the fact that present turbine blading materials will withstand temperatures of only about 1200 F for long periods, secondary air in sufficient quantity to cool the combustion gases to a safe temperature must be supplied. The total air supplied amounts to between 100 and 150 pounds per pound of fuel oil. This large amount of excess air results in lowered cycle efficiency due to the increase in compressor power, but overall thermal efficiencies of 18 to 20 per cent are obtainable. An enthalpy-entropy diagram for the simple open cycle is shown in Figure XIX-2.



(Power)

Fig. XIX-1. Simple open gas turbine cycle

The simple open cycle may have a regenerator added to improve efficiency where the air temperature leaving the

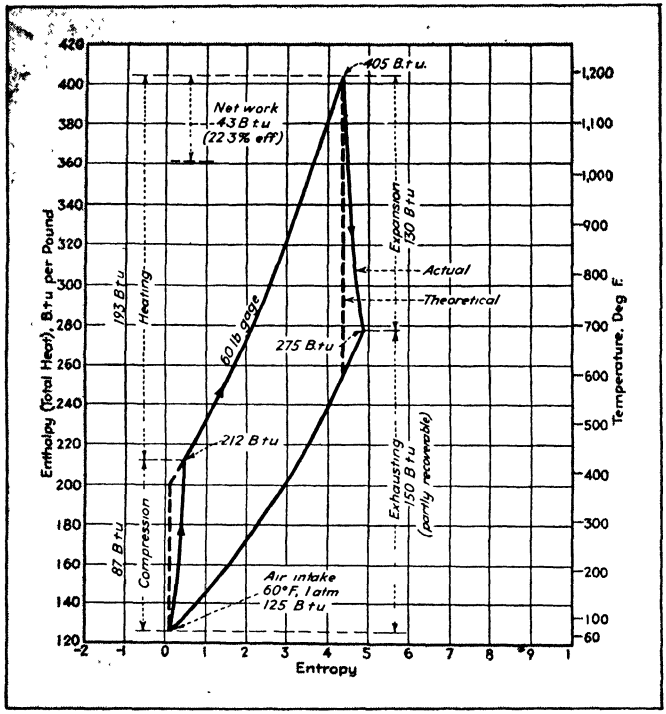


Fig. XIX-2. Simple open gas turbine cycle.

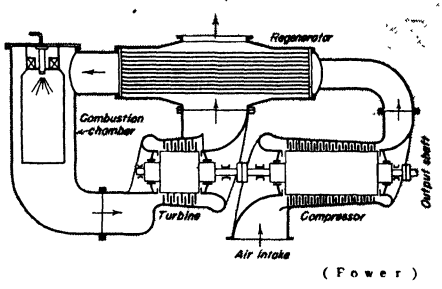


Fig. XIX-3. Open gas turbine cycle with regenerator.

compressor is less than the turbine exhaust temperature. Such an arrangement is shown in Figure XIX-3.

Other combirations with regeneration, multiple stage compression with intercooling and reheating will have higher efficiencies. Two of the various types of these more complex cycles are shown in Figures XIX-4 and XIX-5.

A closed gas turbine cycle has been proposed which makes use of a heat exchanger in the combustion chamber to make it possible to separate the combustion gases from the working fluid which can be made to operate at higher pressures

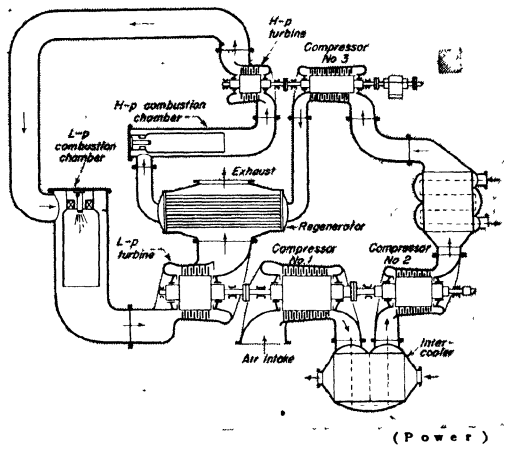
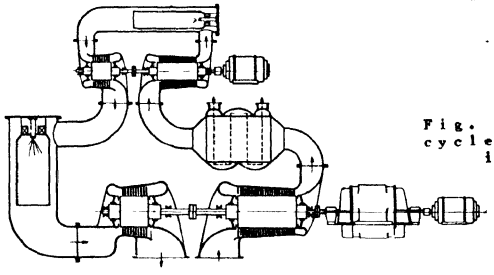


Fig. XIX-5. Open gas turbine cycle with reheat, intercooling and regeneration.



(Mechanical Engineering)

Fig. XIX-4. Open gas turbine cycle with reheat and intercooling.

where the density is greater, thus allowing smaller machines for the same output. Figure XIX-6 shows a diagram of the cycle. It will be noted that the

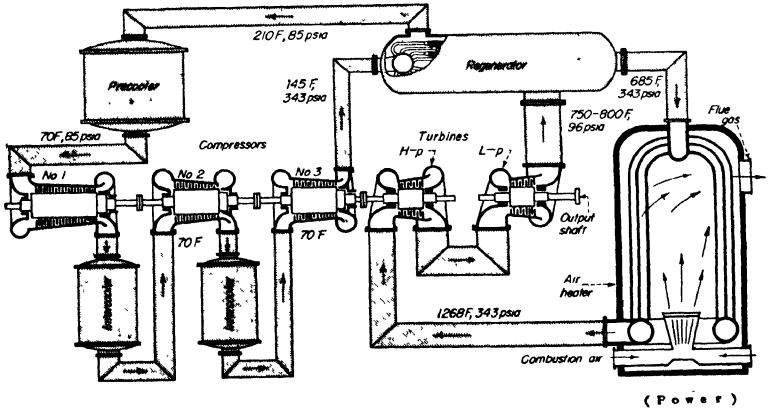
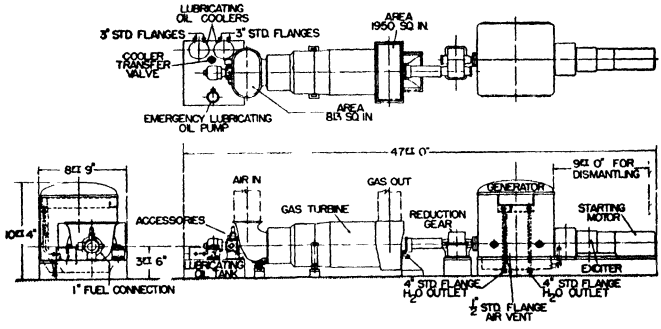


Fig. XIX-6. Closed gas turbine cycle.

cycle contains a precooler in which the unavailable energy is rejected. The efficiency of the closed cycle is slightly less than that of an equivalent open cycle, but the smaller size for the same output may overbalance the smaller efficiency.

129. Gas Turbine Plants--Up to the present time the principal application of the gas turbine in industry has been in the Houdry process of gasoline production where large quantities of compressed air are required. In these machines the excess turbine power is used to drive an oversized compressor and the extra air which is not needed for combustion goes to the process.

In the last few years several commercial gas turbo-generator installations with capacities up to 5000 kilowatts have been made. One of them is shown in Figure XIX-7. This particular machine is similar, except for the generator, to the units developed for use in locomotives.



(General Electric Co.)

Fig. XIX-7. Locomotive type gas turbo-generator.

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TABLE XVII
continued

300-Pound Malleable Iron Fittings

WORKING PRESSURES

300 pounds steam or oil, **550°** F

¼ to 1-inch — **2000** pounds cold water, oil, or gas, non-shock
1¼ to 2-inch — **1500** pounds cold water, oil, or gas, non-shock
2½ and 3-inch — **1000** pounds cold water, oil, or gas, non-shock

Dimensions, in Inches



90° Elbow



Tee



Cross



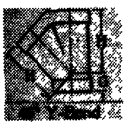
45° Elbow



90° Street Elbow



45° Street Elbow





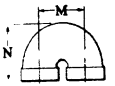
Reducer



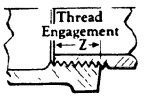
Cap



Coupling



Return Bend



Size	¼	⅜	½	¾	1	1¼	1½	2	2½	3
A—Center to end	15/16	11/16	1¼	17/16	1⅝	1 15/16	2⅛	2½	2 15/16	3⅜
B—Center to end, 45° Elbows	13/16	⅞	1	1⅛	15/16	1½	1 11/16	2	2¼	2½
C—Center to end, 90° Street Elbows	13/16	15/16	1¼	17/16	1⅝	1 15/16	2⅛	2½	2 15/16	3⅜
D—Center to end, 90° Street Elbows	17/16	1⅝	2	2 3/16	2 9/16	2⅞	3⅛	3 11/16	4½	5⅛
E—Center to end, 45° Street Elbows	¾	13/16	1	1⅛	15/16	1½	1 11/16	2		
F—Center to end, 45° Street Elbows	1⅛	1¼	1⅜	1 9/16	1 13/16	2⅛	2 5/16	2 11/16		
G—Center to end, 45° Y-Bends			⅝	⅞	1	1 1/16	1⅛	1 3/16	1⅜	1
K—Center to end, 45° Y-Bends			2	2⅜	3¼	3 11/16	1⅛	4 1/16	4⅜	5
J—End to end, Reducers		17/16	1 11/16	1¾	2	2⅜	2 11/16	3 3/16	3 11/16	4 1/16
K—Height, Caps	25/32	⅞	1 1/16	1¼	1⅜	1½	1 11/16	1 13/16	2⅛	2¼
L—End to end, Couplings	1⅜	1⅝	1⅞	2⅛	2⅜	2⅞	2⅞	3⅝	4⅛	4⅛
Z—Thread Engagement	⅜	⅜	½	9/16	11/16	11/16	11/16	¾	15/16	1

Return Bends

Size	1	1	1	1¼	1¼	1¼	1½	1½	1½	1½	2	2	2	2	2	2
M—Center to center	1¾	2½	3	2¼	2½	3	3	3½	6	8	3	3½	4	4⅝	6	8
N—Height	2⅞	3¼	3½	3 9/16	3 11/16	3 15/16	4 5/16	4 7/16	5	5⅛	4 3/16	3 15/16	5 11/16	6 13/16	4⅝	4⅞	5⅛	5 5/16	6⅛	7⅛

TABLE XVII
continued

Standard Cast Iron Fittings

WORKING PRESSURES
125 pounds steam
175 pounds cold water, oil, or gas, non-shock

Dimensions, in Inches



90° Elbow



45° Elbow



60° Elbow



30° Elbow



22½° Elbow



Cap


Reducer



Eccentric Reducer



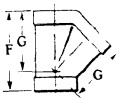
Side Outlet Elbow



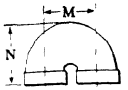
Tee



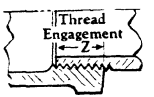
Cross



45° Y-Bend



Return Bend



Size	A	B	C	D	E	F	G	J	K	H	Z
1/4	13/16	3/4									3/8
3/8	15/16	13/16									3/8
1/2	1 1/8	7/8	1	1 3/16	3/4	2 1/2	1 1/8				1/2
3/4	1 5/16	1	1 1/16	1 5/16	7/8	3	2 1/4	1 1/2			9/16
1	1 1/2	1 1/8	1 1/4	1	1	3 1/2	2 3/4	*1 7/8			11/16
1 1/4	1 3/4	1 5/16	1 7/16	1 3/16	1 1/8	4 1/4	3 1/4	2 1/8	2 1/8		11/16
1 1/2	1 15/16	1 7/16	1 5/8	1 5/16	1 1/4	4 7/8	3 13/16	2 1/4	2 1/4		11/16
2	2 1/4	1 11/16	1 7/8	1 3/4	1 7/16	5 3/4	4 1/2	2 7/16	2 7/16		3/4
2 1/2	2 11/16	1 15/16	2 1/16	1 15/16	1 9/16	6 3/4	5 3/16	2 5/8	2 11/16		15/16
3	3 1/8	2 3/16	2 1/2	2 1/16	1 3/4	7 7/8	6 1/8	2 7/8	2 15/16		1
3 1/2	3 7/16	2 3/8				8 3/4	6 7/8	3 1/16	3 1/8		1 1/16
4	3 3/4	2 5/8	3	2 3/8	2 1/16	9 3/4	7 5/8	3 3/8	3 3/8	2 1/16	1 1/8
5	4 1/2	3 1/16	3 1/2	2 3/8	2 3/4	11 3/8	9 1/4	3 7/8	3 7/8	2 3/8	1 1/4
6	5 1/8	3 7/16	4 1/16	2 7/8	2 7/16	13 7/16	10 3/4	4 3/8	4 3/8	2 5/8	1 5/16
8	6 9/16	4 1/4				16 15/16	13 5/8	5 1/4	5 1/4	3 1/8	1 7/16

Return Bends								
Size	M	N	Size	M	N	Size	M	N
Close Pattern			Open Pattern			Wide Pattern		
1/2	1 1/4	1 23/32	3/4	1 7/8	2 7/32	1	3	3
3/4	1 1/2	2 1/32	1	2 1/2	2 11/16	1	4	3 1/2
1	1 3/4	2 3/8	1 1/4	3	3 9/32	1	5	4
1 1/4	2 1/4	2 29/32	1 1/2	3 1/2	3 3/4	1	6	4 1/2
1 1/2	2 1/2	3 1/4	2	4 1/2	4 19/32	1	8	5 1/2
2	3 1/4	3 31/32	2 1/2	5 1/2	5 7/16	1 1/4	4	3 3/4
2 1/2	3 3/4	4 5/16	3	6 1/2	6 5/16	1 1/4	6	4 3/4
3	4 1/4	5 1/16	4	7 1/2	7 5/16	1 1/4	8	5 3/4
4	6	6 13/16				1 1/2	4 1/4	4 1/16
						1 1/2	6	5
						1 1/2	8	6
						2	4 1/8	4 1/16
						2	6	5 5/16

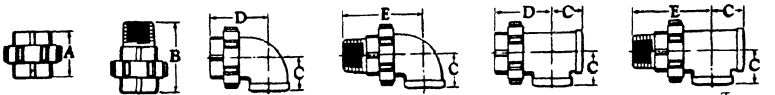
TABLE XVII
continued

Malleable Iron Unions and Union Fittings

WORKING PRESSURES

150 pounds steam

300 pounds cold water, oil, gas or gasoline, non-shock



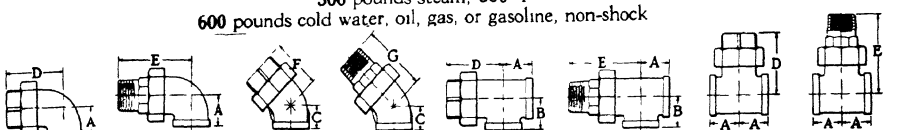
Union Female | Union Male and Female | 90° Elbow Female Union | 90° Elbow Male Union | Tee Female Union on Run | Tee Male Union on Run

Dimensions, in Inches

Size	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3
A	1 3/8	1 1/2	1 11/16	1 7/8	2 1/4	2 5/16	2 5/8	2 9/16	3 1/4	3 9/16
B	2 3/16	2 3/8	2 5/8	3	3 5/16	3 5/8	3 15/16	4 1/4	4 13/16	5 1/8
C	13/16	15/16	1 1/8	1 5/16	1 1/2	1 3/4	1 15/16	2 1/4		
D	1 11/16	1 7/8	2 1/8	2 7/16	2 7/8	3 3/16	3 5/8	3 7/8		
E	2 7/16	2 7/8	3	3 9/16	3 15/16	4 7/16	4 7/8	5 1/2		

300 pounds steam, 550° F

600 pounds cold water, oil, gas, or gasoline, non-shock



90° Elbow Female Union | 90° Elbow Male Union | 45° Elbow Female Union | 45° Elbow Male Union | Tee Female Union on Run | Tee Male Union on Run | Tee Female Union on Outlet | Tee Male Union on Outlet

Dimensions, in Inches

Size	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	1 x 3/8	1 x 1/2	1 x 3/4
A	15/16	1 1/16	1 1/4	1 7/16	1 5/8	1 15/16	2 1/8	2 1/2	2 15/16	3 3/8	1 5/16	1 7/16	1 1/2
B	15/16	1 1/16	1 1/4	1 7/16	1 5/8	1 15/16	2 1/8	2 1/2	2 15/16	3 3/8	1 7/16	1 1/2	1 9/16
C	13/16	7/8	1	1 1/8	1 5/16	1 1/2	1 11/16	2	2 1/4				
D	2	2 1/4	2 7/16	2 7/8	3 3/16	3 11/16	3 15/16	4 1/2	5 7/16	5 15/16	2 3/4	2 7/8	3
E	2 9/16	2 7/8	3 3/16	3 3/4	4 1/16	4 5/8	4 7/8	5 3/8	6 7/16	7 3/16	3 11/16	3 13/16	3 15/16
F	1 5/8	1 3/4	1 15/16	2 3/16	2 1/2	2 7/8	3 3/16	3 11/16	4 3/16				
G	2 3/16	2 7/16	2 11/16	3 1/16	3 7/16	3 13/16	4 1/8	4 9/16	5 3/16				

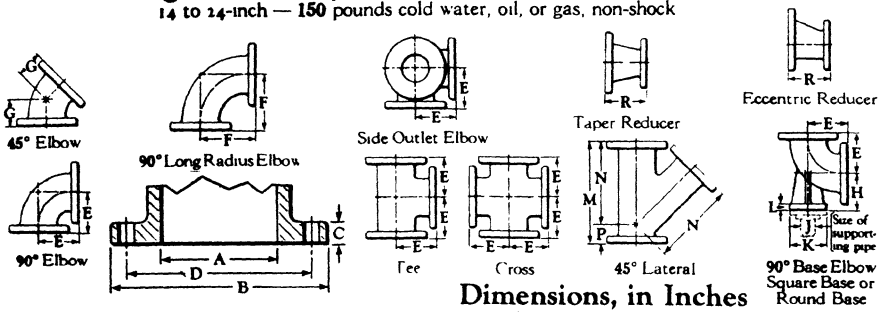
TABLE XVII
continued

125-Pound Cast Iron Flanged Fittings

WORKING PRESSURES

1 1/2 to 12-inch — 125 pounds steam
14 to 24-inch — 100 pounds steam

1 1/2 to 12-inch — 175 pounds cold water, oil, or gas, non-shock
14 to 24-inch — 150 pounds cold water, oil, or gas, non-shock



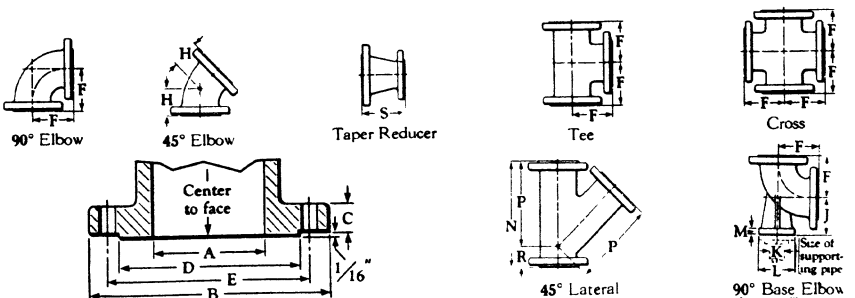
Dimensions, in Inches

Size	A	B	C	D	No of bolts	Dia. of bolts	E	EE	F	G	H	J	K	L	M	N	P	R
1 1/2	1 1/2	5	9/16	3 7/8	4	1/2	4	8	5	2 1/4	3 3/4	1	4 1/4	7/16	9	7	2	
2	2	6	5/8	4 3/4	4	5/8	4 1/2	9	6 1/2	2 1/2	4 1/8	1 1/4	4 5/8	1/2	10 1/2	8	2 1/2	5
2 1/2	2 1/2	7	11/16	5 1/2	4	5/8	5	10	7	3	4 5/8	1 1/4	4 5/8	1/2	12	9 1/2	2 1/2	5 1/2
3	3	7 1/2	3/4	6	4	5/8	5 1/2	11	7 3/4	3	4 7/8	1 1/2	5	9/16	13	10	3	6
3 1/2	3 1/2	8 1/2	13/16	7	8	5/8	6	12	8 1/2	3 1/2	5 1/8	1 1/4	5	9/16	14 1/2	11 1/2	3	6 1/2
4	4	9	15/16	7 1/2	8	5/8	6 1/2	13	9	4	5 1/2	2	6	5/8	15	12	3	7
5	5	10	15/16	8 1/2	8	3/4	7 1/2	15	10 1/4	4 1/2	6 1/4	2 1/2	7	11/16	17	13 1/2	3 1/2	8
6	6	11	1	9 1/2	8	3/4	8	16	11 1/2	5	7	2 1/2	7	11/16	18	14 1/2	3 1/2	9
8	8	13 1/2	1 1/8	11 3/4	8	3/4	9	18	14	5 1/2	8 3/8	4	9	15/16	22	17 1/2	4 1/2	11
10	10	16	1 3/16	14 1/4	12	7/8	11	22	16 1/2	6 1/2	9 3/4	4	9	15/16	25 1/2	20 1/2	5	12
12	12	19	1 1/4	17	12	7/8	12	24	19	7 1/2	11 1/4	6	11	1	30	24 1/2	5 1/2	14
14	14	21	1 3/8	18 3/4	12	1	14	28	21 1/2	7 1/2	12 1/2	6	11	1	33	27	6	16
16	16	23 1/2	1 7/16	21 1/4	16	1	15	30	24	8	13 3/4	6	11	1	36 1/2	30	6 1/2	18
18	18	25	1 9/16	22 3/4	16	1 1/8	16 1/2	33	26 1/2	8 1/2	15	8	13 1/2	1 1/8	39	32	7	19
20	20	27 1/2	1 11/16	25	20	1 1/8	18	36	29	9 1/2	16	8	13 1/2	1 1/8	43	35	8	20
24	24	32	1 7/8	29 1/2	20	1 1/4	22	44	34	11	18 1/2	8	13 1/2	1 1/4	49 1/2	40 1/2	9	24

TABLE XVII
continued

250-Pound Cast Iron Flanged Fittings

WORKING PRESSURES
250 pounds steam
400 pounds cold water, oil, or gas, non-shock



Dimensions, in Inches

Size	A	B	C	D	E	No. of bolts	Dia. of bolts	F	FF	G	H	J	K	L	M	N	P	R	S
2	2	6½	⅞	4 3/16	5	8	⅝	5	10	6½	3	4½	1¼	5¼	¾	11½	8	2¾	8
2½	2½	7½	1	4 15/16	5⅞	8	¾	5½	11	7	3½	4¾	1⅜	5¼	¾	13	10½	2¾	5½
3	3	8¼	1⅛	5 11/16	6⅝	8	¾	6	12	7¼	3½	5¼	1⅜	6⅛	1 5/16	14	11	3	6
3½	3½	9	1 3/16	6 5/16	7¼	8	¾	6½	13	8½	4	5⅝	1½	6⅛	1 3/16	15½	12½	3	6½
4	4	10	1¼	6 15/16	7⅞	8	¾	7	14	9	4½	6	2	6½	⅞	16½	13½	3	7
5	5	11	1⅜	8 5/16	9¼	8	¾	8	16	10½	5	6¾	2½	7½	1	18½	15	3½	8
6	6	12½	1 7/16	9 11/16	10⅝	12	¾	8½	17	11⅛	5½	7½	2½	7½	1	21½	17½	4	9
8	8	15	1⅝	11 5/16	13	12	⅞	10	20	14	6	9	4	10	1¼	25½	20½	5	11
10	10	17½	1⅞	14 1/16	15¼	16	1	11½	23	16¾	7	10½	4	10	1¼	29½	24	5½	12
12	12	20½	2	16 7/16	17¾	16	1⅛	13	26	19	8	12	6	12¼	1 7/16	33½	27¼	6	14

TABLE XVII
continued

Cast Iron Flanges

125-Pound

WORKING PRESSURES

1 to 12-inch — **125** pounds steam
14 to 24-inch — **100** pounds steam
1 to 12-inch — **175** pounds cold water, oil, or gas, non-shock
14 to 24-inch — **150** pounds cold water, oil, or gas, non-shock

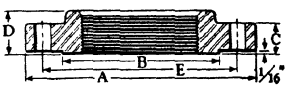


Size of pipe	Dimensions, in Inches					
	A	B	C	D	No of Bolts	Dia. of Bolts
Inches						
1	4 1/4	7/16	11/16	3 1/8	4	1/2
1 1/4	4 5/8	1/2	13/16	3 1/2	4	1/2
1 1/2	5	9/16	7/8	3 7/8	4	1/2
2	6	5/8	1	4 3/4	4	5/8
2 1/2	7	11/16	1 3/16	5 1/2	4	5/8
3	7 1/2	3/4	1 1/4	6	4	5/8
3 1/2	8 1/2	13/16	1 1/4	7	8	5/8
4	9	15/16	1 5/16	7 1/2	8	5/8
5	10	15/16	1 7/16	8 1/2	8	3/4
6	11	1	1 9/16	9 1/2	8	3/4
8	13 1/2	1 1/8	1 3/4	11 3/4	8	3/4
10	16	1 3/16	1 15/16	14 1/4	12	7/8
12	19	1 1/4	2 3/16	17	12	7/8
14 OD	21	1 3/8	2 1/4	18 3/4	12	1
16 OD	23 1/2	1 7/16	2 1/2	21 1/4	16	1
18 OD	25	1 9/16	2 11/16	22 3/4	16	1 1/8
20 OD	27 1/2	1 11/16	2 7/8	25	20	1 1/8
24 OD	32	1 7/8	3 1/4	29 1/2	20	1 1/4

250-Pound

WORKING PRESSURES

250 pounds steam
400 pounds cold water, oil, or gas, non-shock



Dimensions, in Inches						
A	B	C	D	E	No. of Bolts	Dia. of Bolts
4 7/8	2 11/16	11/16	7/8	3 1/2	4	5/8
5 1/8	3 1/16	3/4	1	3 7/8	4	5/8
6 1/8	3 9/16	13/16	1 1/8	4 1/2	4	3/4
6 1/2	4 3/16	7/8	1 1/4	5	8	5/8
7 1/2	4 15/16	1	1 7/16	5 7/8	8	3/4
8 1/4	5 11/16	1 1/8	1 9/16	6 5/8	8	3/4
9	6 5/16	1 3/16	1 5/8	7 1/4	8	3/4
10	6 15/16	1 1/4	1 3/4	7 7/8	8	3/4
11	8 5/16	1 3/8	1 7/8	9 1/4	8	3/4
12 1/2	9 11/16	1 7/16	2	10 5/8	12	3/4
15	11 15/16	1 5/8	2 3/16	13	12	7/8
17 1/2	14 1/16	1 7/8	2 3/8	15 1/4	16	1
20 1/2	16 7/16	2	2 9/16	17 3/4	16	1 1/8
23	18 13/16	2 1/8	2 11/16	20 1/4	20	1 1/8
25 1/2	21 1/16	2 1/4	2 7/8	22 1/2	20	1 1/4
28	23 5/16	2 3/8	3 1/8	24 3/4	24	1 1/4
30 1/2	25 9/16	2 1/2	3 5/16	27	24	1 3/8
36	30 1/16	2 7/8	3 11/16	32	24	1 1/2

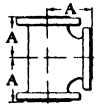
TABLE XVII
continued

Cast Steel Flanged Fittings

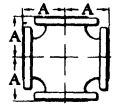
Dimensions, in Inches



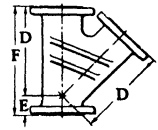
90° Elbow



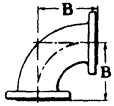
Tee



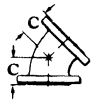
Cross



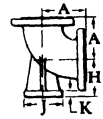
45° Lateral



90° Long
Radius Elbow



45° Elbow



90° Base Elbow



Taper
Reducer

Class	Size	A	B	C	D	E	F	G	H	J	K
150 Pound	1	3½	5	1¾	5⅞	1⅝	7⅛				
	1¼	3¾	5½	2	6¼	1⅝	8				
	1½	4	6	2¼	7	2	9				
	2	4½	6½	2½	8	2½	10½	5	4⅝	4⅝	½
	2½	5	7	3	9½	2½	12	5½	4⅝	4⅝	½
	3	5½	7¾	3	10	3	13	6	4⅝	5	9/16
	3½	6	8½	3½	11½	3	14½	6½	5⅛	5	9/16
	4	6½	9	4	12	3	15	7	5½	6	⅝
	5	7½	10¼	4½	13½	3½	17	8	6¼	7	11/16
	6	8	11½	5	14½	3½	18	9	7	7	11/16
	8	9	14	5½	17½	4½	22	11	8⅜	9	15/16
	10	11	16½	6½	20½	5	25½	12	9¾	9	15/16
	12	12	19	7½	24½	5½	30	14	11¼	11	1
	14	14	21½	7½	27	6	33	16	12½	11	1
	16	15	24	8	30	6½	36½	18	13⅝	11	1
	18	16½	26½	8½	32	7	39	19	15	13½	1⅛
	20	18	29	9½	35	8	43	20	16	13½	1⅛
	24	22	34	11	40½	9	49½	24	18½	13½	1⅛
300 Pound	1	4	5	2¼	6½	2	8½	4½			
	1¼	4¼	5½	2½	7¼	2¼	9½	4½			
	1½	4½	6	2¾	8½	2½	11	4½			
	2	5	6½	3	9	2½	11½	5	4½	5¼	¾
	2½	5½	7	3½	10½	2½	13	5½	4¾	5¼	¾
	3	6	7¾	3½	11	3	14	6	5¼	6½	13/16
	3½	6½	8½	4	12½	3	15½	6½	5⅝	6½	13/16
	4	7	9	4½	13½	3	16½	7	6	6½	⅞
	5	8	10¼	5	15	3½	18½	8	6¾	7½	1
	6	8½	11½	5½	17½	4	21½	9	7½	7½	1
	8	10	14	6	20½	5	25½	11	9	10	1¼
	10	11½	16½	7	24	5½	29½	12	10½	10	1¼
	12	13	19	8	27½	6	33½	14	12	12½	17/16

TABLE XVII
continued

Cast Steel Flanged Fittings

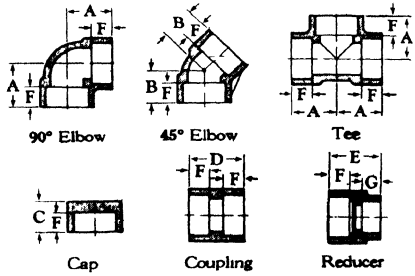
Dimensions, in Inches (Cont.)

Class	Size	A	C	D	E	F	G
600 Pound	½	3¼	2	5¾	1¾	7½	5
	¾	3¾	2½	6¾	2	8⅝	5
	1	4¼	2½	7¼	2¼	9½	5
	1¼	4½	2¾	8	2½	10½	5
	1½	4¾	3	9	2¾	11¾	5
	2	5¾	4¼	10¼	3½	13¾	6
	2½	6½	4½	11½	3½	15	6¾
	3	7	5	12¾	4	16¾	7¼
	3½	7½	5½	14	4½	18¼	7¾
	4	8½	6	16½	4½	21	8¾
	5	10	7	19½	6	25½	10¼
	6	11	7½	21	6½	27½	11¾
	8	13	8½	24½	7	31½	13¼
	10	15½	9½	29½	8	37½	15¾
	12	16½	10	31½	8½	40	16¾
900 Pound	3	7½	5½	14½	4½	19	7¾
	3½	8½	6	16½	4½	21	8¾
	4	9	6½	17½	5½	23	9¼
	5	11	7½	21	6½	27½	11¼
	6	12	8	22½	6½	29	12¼
	8	14½	9	27½	7½	35	14¾

Class	Size	A	C	D	E	F	G
1500 Pound	1½	6	4½	11	3½	14½	6¼
	2	7¼	4¾	13¼	4	17¼	7¼
	2½	8¼	5¼	15½	4½	19¾	8¼
	3	9¼	5¾	17½	5	22¼	9¼
	3½	9¾	6½	18¼	5½	23¾	9¾
	4	10¾	7⅛	19¼	6	25½	10¾
	5	13¼	8¾	23¼	7½	30¾	13¼
	6	13⅞	9⅜	24⅞	8⅛	33	14½
	8	16⅜	10⅞	29⅞	9⅛	39	17
2500 Pound	½	5⅜					
	¾	5⅜					
	1	6 1/16	4				
	1¼	6⅞	4¼				
	1½	7⅜	4¾				
	2	8⅞	5¾	15¼	5¼	20½	9½
	2½	10	6¼	17¼	5¾	23	10½
	3	11⅜	7¼	19¾	6¾	26½	11¾
	4	13¼	8½	23	7¾	30¾	13½
	5	15⅝	10	27¼	9¼	36½	15¾
	6	18	11½	31¼	10½	41¾	18
	8	20⅛	12¾	35¼	11¾	47	20½
	10	25	16	43¼	14¾	58	25½
	12	28	17¾	49¼	16¼	65½	29

FORGED STEEL SOCKET WELDING FITTINGS

DIMENSIONS, IN INCHES
(For Standard and Extra Strong Fittings)



Size	¼	⅜	½	¾	1	1¼	1½	2
A	13/16	31/32	1⅛	1 5/16	1½	1¾	2	2⅜
B	11/16	13/16	⅞	1	1⅛	1 5/16	1 7/16	1 11/16
C	¾	⅞	1	1⅛	1⅛	1¼	1⅜	1½
D	1⅜	1⅝	1¾	1⅞	2	2⅛	2¼	2¾
E		1⅜	1½	1⅝	1¾	2	2⅛	2¼
F	7/16	9/16	⅝	11/16	¾	13/16	⅞	1
G		Depth same as "F", depending on pipe size, e g ¼" has socket ⅜" deep						

WORKING PRESSURES

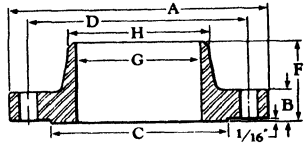
Pounds per Square Inch — Non-Shock

Temp Deg. F.	Crane Carbon Steel Fittings: Standard	Crane Carbon Steel Fittings: Extra Strong	No. 4 Carbon-Molybdenum Steel Fittings (Made to order): Standard	No. 4 Carbon-Molybdenum Steel Fittings (Made to order): Extra Strong
100	2000	3000	2000	3000
150	1900	2850	1900	2850
200	1800	2700	1800	2700
250	1700	2550	1700	2550
300	1600	2400	1600	2400
350	1500	2250	1500	2250
400	1400	2100	1400	2100
450	1300	1950	1300	1950
500	1200	1800	1200	1800
550	1120	1680	1150	1725
600	1040	1560	1100	1650
650	960	1440	1050	1575
700	880	1320	1000	1500
750	800	1200	950	1425
800	740	1100	900	1350
850	670	1000	850	1275
900	600	900	800	1200
950	530	795	640	960
1000	380	570	540	810

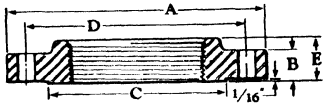
TABLE XVII
continued

Forged Steel Flanges

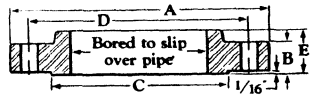
Dimensions, in Inches



Welding Neck Flange
150 and 300-Pound



Screwed Flange
150 and 300-Pound



Slip-On Welding Flange
150 and 300-Pound

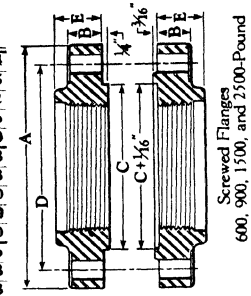
Class	Pipe Size	A	B	C	D	Bolts No.	Bolts Dia.	E	F	G	H
150 Pound	1	4 1/4	9/16	2	3 1/8	4	1/2	3/4	2 3/16	1.05	1.32
	1 1/4	4 5/8	5/8	2 1/2	3 1/2	4	1/2	13/16	2 1/4	1.38	1.66
	1 1/2	5	11/16	2 7/8	3 7/8	4	1/2	7/8	2 7/16	1.61	1.90
	2	6	3/4	3 5/8	4 3/4	4	5/8	1	2 1/2	2.07	2.38
	2 1/2	7	7/8	4 1/8	5 1/2	4	5/8	1 1/8	2 3/4	2.47	2.88
	3	7 1/2	15/16	5	6	4	5/8	13/16	2 3/4	3.07	3.50
	3 1/2	8 1/2	15/16	5 5/8	7	8	5/8	1 1/4	2 15/16	3.60	4.00
	4	9	15/16	6 3/16	7 1/2	8	5/8	15/16	3	4.03	4.50
	5	10	15/16	7 5/16	8 1/2	8	3/4	1 7/16	3 1/2	5.05	5.56
	6	11	1	8 1/2	9 1/2	8	3/4	1 9/16	3 1/2	6.07	6.63
	8	13 1/2	1 1/8	10 5/8	11 3/4	8	3/4	1 3/4	4	7.98	8.63
	10	16	1 3/16	12 3/4	14 1/4	12	7/8	1 15/16	4	10.02	10.75
	12	19	1 1/4	15	17	12	7/8	2 3/16	4 1/2	12.00	12.75
	14 OD	21	1 3/8	16 1/4	18 3/4	12	1	2 1/4	5	Bore as ordered	14.00
	16 OD	23 1/2	1 7/16	18 1/2	21 1/4	16	1	2 1/2	5		16.00
	18 OD	25	1 5/16	21	22 3/4	16	1 1/8	2 11/16	5 1/2		18.00
	20 OD	27 1/2	1 11/16	23	25	20	1 1/8	2 7/8	5 11/16		20.00
	24 OD	32	1 7/8	27 1/4	29 1/2	20	1 1/4	3 1/4	6		24.00
300 Pound	1	4 7/8	11/16	2	3 1/2	4	5/8	1 1/16	2 7/16	1.05	1.32
	1 1/4	5 1/4	3/4	2 1/2	3 7/8	4	5/8	1 1/16	2 9/16	1.38	1.66
	1 1/2	6 1/8	13/16	2 7/8	4 1/2	4	3/4	1 3/16	2 11/16	1.61	1.90
	2	6 1/2	7/8	3 5/8	5	8	5/8	1 5/16	2 3/4	2.07	2.38
	2 1/2	7 1/2	1	4 1/8	5 7/8	8	3/4	1 1/2	3	2.47	2.88
	3	8 1/4	1 1/8	5	6 5/8	8	3/4	1 11/16	3 1/2	3.07	3.50
	3 1/2	9	1 3/16	5 1/2	7 1/4	8	3/4	1 3/4	3 15/16	3.60	4.00
	4	10	1 1/4	6 3/16	7 7/8	8	3/4	1 7/8	3 3/8	4.03	4.50
	5	11	1 3/8	7 5/16	9 1/4	8	3/4	2	3 7/8	5.05	5.56
	6	12 1/2	1 7/16	8 1/2	10 3/8	12	3/4	2 1/16	3 7/8	6.07	6.63
	8	15	1 5/8	10 5/8	13	12	7/8	2 7/16	4 3/8	7.98	8.63
	10	17 1/2	1 7/8	12 3/4	15 1/4	16	1	2 5/8	4 5/8	10.02	10.75
	12	20 1/4	2	15	17 3/4	16	1 1/8	2 7/8	5 1/8	12.00	12.75

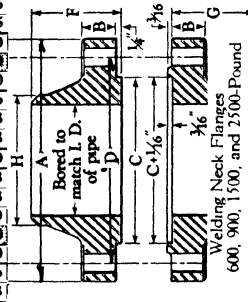
TABLE XVII
continued

Forged Steel Flanges

Dimensions, in Inches (Cont.)

Class	Pipe Size	A	B	C	D	Bolts No.	Bolts Dia.	E	F	G	H
600 Pound	½	3¾	9/16	1⅜	2⅝	4	½	⅞	25/16	21/16	0.84
	¾	4⅝	⅝	111/16	3¼	4	⅝	1	2½	2¼	1.05
	1	4⅞	11/16	2	3½	4	⅝	111/16	211/16	27/16	1.32
	1¼	5¼	13/16	2½	3⅞	4	⅝	1⅛	2⅞	2⅝	1.66
	1½	6⅛	⅞	2⅞	4½	4	¾	1¼	3	2¾	1.90
	2	6½	1	3⅝	5	8	⅝	17/16	3⅛	2⅞	2.38
	2½	7½	1⅛	4⅛	57/8	8	¾	1⅝	3⅜	3⅛	2.88
	3	8¼	1¼	5	6⅝	8	¾	113/16	3½	3¼	3.50
	3½	9	1⅜	5½	7¼	8	⅞	111/16	3⅝	3⅜	4.00
	4	10¾	1½	63/16	8½	8	⅞	2⅛	4¼	4	4.50
	5	13	1¾	75/16	10½	8	1	2⅜	4¾	4½	5.56
	6	14	1⅞	8½	11½	12	1	2⅝	4⅞	4⅝	6.63
	8	16½	23/16	10⅝	13¾	12	1⅛	3	5½	5¼	8.63
	10	20	2½	12¾	17	16	1¼	3⅜	6¼	6	10.75
	12	22	2⅝	15	19¼	20	1¼	3⅝	6⅜	6⅛	12.75
900 Pound	3	9½	1½	5	7½	8	⅞	2⅛	4¼	4	3.50
	3½	10¾	1⅝	5½	8½	8	1	29/16	4½	4⅛	4.00
	4	11½	1¾	63/16	9¼	8	1⅛	2¾	4¾	4½	4.50
	5	13¾	2	75/16	11	8	1¼	3⅛	5¼	5	5.56
	6	15	23/16	8½	12½	12	1⅛	3⅜	5¾	5½	6.63
	8	18½	2½	10⅝	15½	12	1⅜	4	6⅝	6⅜	8.63
1500 Pound	1½	7	1¼	2⅞	4⅞	4	1	1¾	3½	3¼	1.90
	2	8½	1½	3⅝	6½	8	⅞	2¼	4¼	4	2.38
	2½	9⅝	1⅝	4⅛	7½	8	1	2½	4⅜	4⅛	2.88
	3	10½	1⅞	5	8	8	1⅛	2⅞	4⅞	4⅝	3.50
	3½	11	2	5¼	8½	8	1⅛	31/16	5	4¾	4.00
	4	12¼	2⅛	63/16	9½	8	1¼	39/16	5⅛	4⅞	4.50
	5	14¾	2⅞	75/16	11½	8	1½	4⅛	6⅜	6⅛	5.56
	6	15½	3¼	8½	12½	12	1⅜	411/16	7	6¾	6.63
	8	19	3⅝	10⅝	15½	12	1⅝	5⅝	8⅝	8⅜	8.63
2500 Pound	½	5¼	13/16	1⅜	3½	4	¾	19/16	3⅛	2⅞	0.84
	¾	5½	1¼	111/16	3¾	4	¾	111/16	3⅜	3⅛	1.05
	1	6¼	1⅜	2	4¼	4	⅞	1⅞	3¾	3½	1.32
	1¼	7¼	1½	2½	5⅛	4	1	21/16	4	3¾	1.66
	1½	8	1¾	2⅞	5¾	4	1⅛	2⅜	4⅝	4⅜	1.90
	2	9¼	2	3⅝	6¾	8	1	2¾	5¼	5	2.38
	2½	10½	2¼	4⅛	7¾	8	1⅛	3⅛	5⅞	5⅝	2.88
	3	12	2⅝	5	9	8	1¼	3⅝	6⅞	6⅝	3.50
	4	14	3	63/16	10¾	8	1½	4¼	7¾	7½	4.50
	5	16½	3⅝	75/16	123/4	8	1¾	5⅛	9¼	9	5.56
	6	19	4¼	8½	14½	8	2	6	11	10¾	6.63
	8	21¾	5	10⅝	17¼	12	2	7	12¾	12½	8.63
	10	26½	6½	12¾	21¼	12	2½	9	16¾	16½	10.75
	12	30	7¼	15	24⅜	12	2¾	10	18½	18¼	12.75





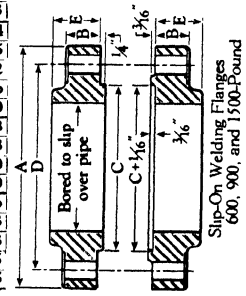
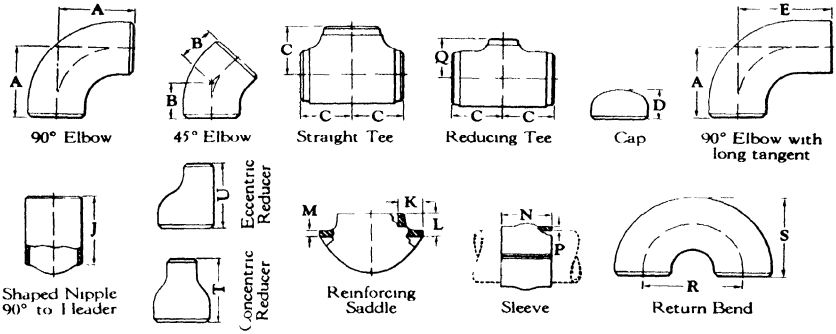


TABLE XVII
continued

Steel Butt-Welding Fittings

Dimensions, in Inches

Standard and Extra Strong Fittings have the same outside dimensions.



Elbows, Straight Tees, Caps, Nipples, Saddles, and Sleeves

Size	A	B	C	D	E	J	K	L	M	N	P
¾	1⅛										
1	1½	⅞	1½	1⅛							
1¼	1⅞	1	1⅞	1¼		6					
1½	2¼	1⅛	2¼	1½		6					
2	3	1⅜	2½	1½	4¼	6	1¾	1¼	½	3	¼
2½	3¾	1¾	3	1½	5	6	1¾	1½	½	3	¼
3	4½	2	3⅜	2	5¾	6	2	1¾	½	3	⅜
~~3½~~	~~5¼~~	~~2½~~	~~3¾~~	~~2½~~	~~6¾~~	~~6~~	~~2~~	~~1¾~~	~~½~~	~~3½~~	~~⅜~~
4	6	2½	4⅛	2½	7½	6	2	2	½	4	⅜
5	7½	3⅛	4⅞	3	9	8	2	2	½	5	⅜
6	9	3¾	5⅝	3½	10¾	8	2½	2¼	½	6	⅜
8	12	5	7	4	13¾	8	3	3	⅝	8	½
10	15	6¼	8½	5	17	10	3½	3½	⅝	10	½
12	18	7½	10	6	20½	10	4	4	⅝	12	½
14 OD	16	7¾		6½			4	4	⅝	14	½
16 OD	18	8½		7			4	4	⅝	16	½
18 OD	20	9½		8			4	4	⅝	18	½
20 OD	25			9			5	5	⅝	20	½
24 OD	30			10½			5	5	⅝	24	½

Return Bends

Size of pipe	R	S
1	3	2 3/16
1¼	2½	2 5/16
1¼	3¾	2¾
1½	3	2 11/16
1½	4½	3¼
2	4	3 7/16
2	6	4 3/16
2½	7½	5 3/16
3	6	5
3	9	6½
~~3½~~	~~10½~~	~~7¼~~
4	8	6½
4	12	8¼
5	15	10 5/16
6	18	12 5/16
8	24	16 5/16
10	30	20 3/8
12	36	24 3/8

Reducing Tees

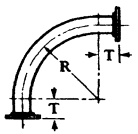
Size	C	Q	Size	C	Q
1¼ x 1¼ x ¾	1⅞	1⅞	4 x 4 x 3	4⅛	3⅞
1½ x 1½ x 1¼	2¼	2¼	4 x 4 x 2½	4⅛	3¾
1½ x 1½ x 1	2¼	2¼	4 x 4 x 2	4⅛	3½
1½ x 1½ x ¾	2¼	2¼	5 x 5 x 4	4⅞	4⅝
2 x 2 x 1½	2½	2⅜	5 x 5 x 3	4⅞	4⅜
2 x 2 x 1¼	2½	2¼	5 x 5 x 2½	4⅞	4¼
2 x 2 x 1	2½	2	6 x 6 x 5	5⅝	5⅜
2½ x 2½ x 2	3	2¾	6 x 6 x 4	5⅝	5⅛
2½ x 2½ x 1½	3	2⅝	6 x 6 x 3	5⅝	4⅞
2½ x 2½ x 1¼	3	2½	8 x 8 x 6	7	6⅝
3 x 3 x 2½	3⅜	3¼	8 x 8 x 5	7	6⅜
3 x 3 x 2	3⅜	3	8 x 8 x 4	7	6⅛
3 x 3 x 1½	3⅜	2⅞	10 x 10 x 8	8½	8
			10 x 10 x 6	8½	7⅝
			12 x 12 x 10	10	9½
			12 x 12 x 8	10	9
			12 x 12 x 6	10	8⅝

Reducers

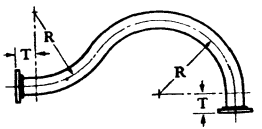
Size	T	U	Size	T	U	Size	T	U
1¼ x ¾	2	2	3 x 2½	3½	3½	6 x 5	5½	5½
1½ x 1¼	2½	2½	3 x 2			6 x 4		
1½ x 1			3 x 1½			~~6 x 3½~~		
1½ x ¾			4 x 3			6 x 3		
2 x 1½	3	3	4 x 2½	4	4	8 x 6	6	6
2 x 1¼			4 x 2			8 x 5		
2 x 1			5 x 4	5	5	8 x 4		
2½ x 2	3½	3½	5 x 3			10 x 8	7	7
2½ x 1½			5 x 2½			10 x 6		
2½ x 1¼						~~10 x 5~~		
						~~10 x 4~~		
						12 x 10	8	8
						12 x 8		
						12 x 6		

TABLE XVII
continued

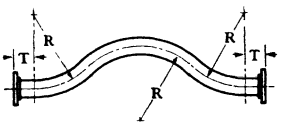
Standard Types of Pipe Bends



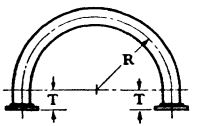
No. 1
Quarter Bend, 90°



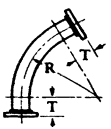
No. 2, Single Offset Quarter Bend



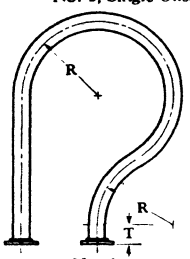
No 4, Crossover Bend



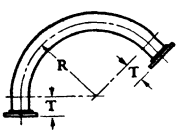
No. 7, U-Bend — 180°



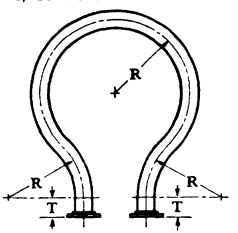
No. 1½
Angle Bend, 46° to 89°



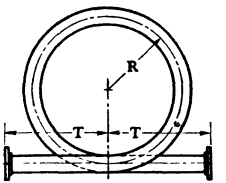
No. 6
Single Offset U-Bend



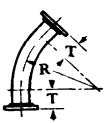
No. 7½
Angle Bend
91° to 179°



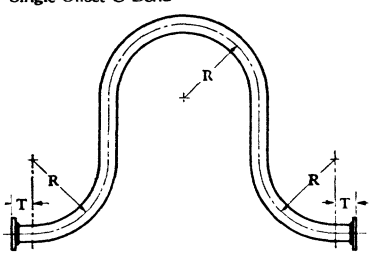
No. 8
Double Offset U-Bend



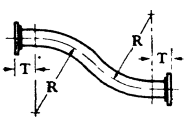
No. 11
Circle Bend



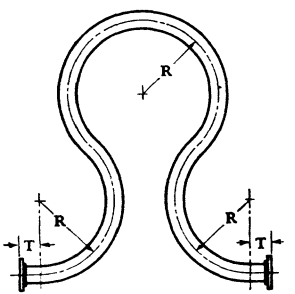
No. 3
45° Bend



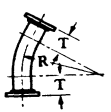
No 9
Expansion U-Bend



No 5
Offset Bend



No. 10
Double Offset Expansion U-Bend



No. 3½
Angle Bend, Under 45°

TABLE XVII
continued

Standard Types of Pipe Bends

Radii and Tangents of Pipe Bends, in Inches

Size of Pipe	Column "A" R Minimum Recommended Radius Steel or Genuine Wrought Iron Pipe Standard or Extra Strong Weight	Column "B" R Shortest Radii to which pipe can be bent								Column "C" T Minimum Length of Tangent Steel or Genuine Wrought Iron Pipe Standard or Extra Strong Weight	
		Steel Pipe Only				Genuine Wrought Iron Pipe					
		Threaded Ends, Screwed, or Welded Flanges		Cranelap Joints		Threaded Ends, Screwed, or Welded Flanges		Cranelap Joints			
		Standard Weight Pipe	Extra Strong Weight Pipe	Standard Weight Pipe	Extra Strong Weight Pipe	Standard Weight Pipe	Extra Strong Weight Pipe	Standard Weight Pipe	Extra Strong Weight Pipe	Threaded Ends or Screwed Flanges	Cranelap Joints
1/4	1 1/4	1	5/8			1 1/4	1			1	
3/8	1 7/8	1 1/4	3/4			1 7/8	1 1/2			1 1/4	
1/2	2 1/2	1 1/2	1	2	2	2 1/2	2	2 1/2	2	1 1/2	2
3/4	3 3/4	1 3/4	1 1/4	3	3	3	2 1/2	3	3	1 3/4	2
1	5	2	1 1/2	4	4	4	3	4	4	2	2
1 1/4	6 1/4	2 1/4	1 3/4	4	4	5	4	5	4	2	2 1/2
1 1/2	7 1/2	2 1/2	2	5	5	6	5	6	5	2 1/2	3
2	10	3	2 1/2	6	6	8	5	8	6	3	4
2 1/2	12 1/2	5	4 1/4	10	10	10	8	10	10	4	5
3	15	8	6	12	12	12	10	12	12	4	6
3 1/2	17 1/2	10	8	12	12	14	12	14	12	5	6
4	20	12	10	14	14	16	12	16	14	5	6
5	25	18	14	18	14	20	15	20	15	6	7
6	30	22	15	22	15	26	18	26	18	7	7
8	40	30	23	30	23	30	28	30	28	9	8
10	50	36	30	36	30	36	32	36	32	12	10
12	60	46	36	46	36	46	42	46	42	14	10
*14 OD	70	60	48	60	48	60	54	60	54	16	14
*16 OD	96	80	60	80	60	80	70	80	70	18	16
*18 OD	108	90	66	90	66	90	80	90	80	18	18
*20 OD	120	100	72	100	72	100	90	100	90	18	18
*24 OD	144	144	108	144	108	144	122	144	122	18	20

*For sizes 14-inch O D and larger, the radii shown are based upon pipe with a wall thickness of 3/8-inch or lighter under the "Standard Weight Pipe column, and a wall thickness of 1/2-inch or heavier under the "Extra Strong Weight Pipe column

TABLE XXIV

FORMULAS AND MOLECULAR AND EQUIVALENT WEIGHTS OF SUBSTANCES FREQUENTLY APPEARING IN THE CHEMISTRY OF WATER CONDITIONING

Substance	*Formula*	*Weight of Molecule or Radical*	*Eq. Wt.*
Aluminum	Al	27.0	9.00
Aluminum chloride (crystal)	$AlCl_3$	133.0	44.33
Aluminum chloride (anhydrous)	$AlCl_3 \cdot 6H_2O$	241.0	80.33
Aluminum sulphate (crystal)	$Al_2(SO_4)_3$ $18H_2O$	666.4	111.06
Aluminum sulphate (anhydrous)	$Al_2(SO_4)_3$	342.1	57.01
Ammonia	NH_3	17.0	17 00
Ammonium alum	$Al_2(SO_4)_3(NH_4)_2SO_4 \cdot 24H_2O$	906.6	151.10
Potassium alum	$Al_2(SO_4)_3K_2SO_4 \cdot 24H_2O$	948 8	158.13
Aluminum hydrate	$Al(OH)_3$	78.0	26.00
Ammonium chloride	NH_4Cl	53.5	53.50
Ammonium (ion)	NH_4	18.0	18.00
Ammonia water	NH_4OH	35.1	35.10
*Alumina	Al_2O_3	102.0	17.00
Sodium aluminate	$Na_2Al_2O_4$	164.0	27.33
Ammonium sulphate	$(NH_4)_2SO_4$	132.0	66.00
Barium	Ba	137.4	68.70
Barium carbonate	$BaCO_3$	197.4	98.70
Barium chloride	$BaCl_2 \cdot 2H_2O$	244.3	122.15
Barium sulphate	$BaSO_4$	233.4	116.70
Barium hydrate	$Ba(OH)_2$	171.0	85.50
Barium oxide	BaO	153.0	76.50
Calcium	Ca	40.1	20.05
Calcium bicarbonate	$Ca(HCO_3)_2$	162.1	81.05
Calcium carbonate	$CaCO_3$	100.1	50.05
Calcium chloride	$CaCl_2$	111.0	55.50
Calcium hydrate (pure)	$Ca(OH)_2$	74.1	37.05
Calcium hydrate (90%)	$Ca(OH)_2$	.	41.10
Calcium oxide (pure)	CaO	56.1	28.05
Calcium oxide (90%)	CaO	....	31.17
Calcium sulphate (anhydrous)	$CaSO_4$	136.2	68.08
Calcium sulphate (gypsum)	$CaSO_4 \cdot 2H_2O$	172.2	861.0
Calcium nitrate	$Ca(NO_3)_2$	164.1	82.05
Calcium phosphate	$Ca_3(PO_4)_2$	310.3	51.71
Carbon	C	12.0	3.00
Chloride (gas)	Cl_2	70.9	35.45

Courtesy of the Cochrane Corp.

TABLE XXIV
continued

Substance	*Formula*	*Weight of Molecule or Radical*	*Eq. Wt*
Copper	Cu	63.6	31.80
Copper sulphate	$CuSO_4$	160.0	80.00
Iron (ferric)	Fe'''	55.8	18.60
Iron (ferrous)	Fe''	55 8	27.90
*Ferric oxide	Fe_2O_3	159.6	26 60
*Iron oxide and alumina	R_2O_3	109.0	18.20
Ferrous sulphate (copperas)	$FeSO_4\ 7H_2O$	278.0	139 00
Ferric chloride	$FeCl_3$	162.0	54.00
Ferric hydrate	$Fe(OH)_3$	107 0	35 66
Ferric sulphate	$Fe_2(SO_4)_3$	400.0	66.66
Ferrous carbonate	$FeCO_3$	116.0	58.00
Ferrous hydrate	$Fe(OH)_2$	89.9	44.95
Ferrous oxide	FeO	71.8	35.90
Fluorine (gas)	F_2	19 0	19.00
Hydrogen (gas)	H_2	2.02	1.01
Hydrogen sulphide (gas)	H_2S	34.1	
Lead	Pb	207.0	103.50
Magnesium	Mg	24 3	12.15
Magnesium oxide	MgO	40.3	20.15
Magnesium bicarbonate	$Mg(HCO_3)_2$	146 3	73.15
Magnesium carbonate	$MgCO_3$	84.3	42.15
Magnesium chloride	$MgCl_2$	95.2	47.60
Magnesium hydrate	$Mg(OH)_2$	58.3	29.15
Magnesium nitrate	$Mg(NO_3)_2$	148.3	74.15
Magnesium phosphate	$Mg_3(PO_4)_2$	263.0	43.83
Magnesium sulphate	$MgSO_4$	120.4	60.20
Nitrogen (gas)	N_2	28.0	
Oxygen (gas)	O_2	32.0	8.00
Potassium	K	39.1	39.10
Potassium carbonate	K_2CO_3	138.0	69.00
Potassium chloride	KCl	74 6	74.60
Potassium hydrate	KOH	56.1	56.10
Potassium iodide	KI	166.0	166.00
Potassium nitrate	KNO_3	101.0	101.00
Potassium oxide	K_2O	94.2	47.10
Potassium permanganate	$KMnO_4$	158.0	158.00
Potassium sulphate	K_2SO_4	174.0	87.00
Silicon	Si	28.1	7.03
Silver	Ag	108.0	108.00
Silver chloride	AgCl	143.3	143.30
Silver nitrate	$AgNO_3$	169.9	169.90
Silica	SiO_2	60.1	30.05
Sodium	Na	23.0	23.00
Sodium bicarbonate	$NaHCO_3$	84.0	84.00

TABLE XXIV
continued

Substance	*Formula*	*Weight of Molecule or Radical*	*Eq. Wt.*
Sodium carbonate	Na_2CO_3	106.0	53.00
Sodium chloride	NaCl	58.5	58.50
Sodium hydrate	NaOH	40.0	40.00
Sodium nitrate	$NaNO_3$	85.0	85.00
Sodium oxide	Na_2O	62.0	31.00
Sodium sulphite	Na_2SO_3	126.0	63.00
Sulphur dioxide (gas)	SO_2	64.1	32.05
Trisodium phosphate	$Na_3PO_4 \cdot 12H_2O$ (18.7% P_2O_5)	380.2	126.73
Trisodium phosphate (anhydrous)	Na_3PO_4 (43.3% P_2O_5)	164.0	54.66
Disodium phosphate	$Na_2HPO_4 \cdot 12H_2O$ (19.8% P_2O_5)	358.2	119.40
Disodium phosphate (anhydrous)	Na_2HPO_4 (50.0% P_2O_5)	142.0	47.33
Monosodium phosphate	$NaH_2PO_4 \cdot H_2O$ (51.4% P_2O_5)	138.1	46.03
Monosodium phosphate (anhydrous)	NaH_2PO_4 (59.1% P_2O_5)	120.1	40.03
Metaphosphate (Hagan)	$NaPO_3$ (69.5% P_2O_5)	102.0	34.00
Sodium sulphate	Na_2SO_4	142.0	71.00
Water	H_2O	18.0	9.00
	ACID RADICALS		
Bicarbonate	HCO_3	61.0	61.00
Carbonate	CO_3	60.0	30.00
Carbon dioxide	CO_2	44.0	22.00
Chloride	Cl	35.46	35.46
Nitrate	NO_3	62.0	62.00
Hydrate	OH	17.0	17.00
Phosphate	PO_4	95.0	31.66
Phosphorous oxide	P_2O_5	142.0	23.67
Sulphate	SO_4	96.06	48.03
Sulphite	SO_3	80.1	40.05
	ACIDS		
Hydrogen	H_2	2.0	1.00
Acetic acid	$HC_2H_3O_2$	60.0	60.00
Carbonic acid	H_2CO_3	62.0	31.00
Hydrochloric acid	HCl	36.46	36.46
Phosphoric acid	H_3PO_4	98.0	32.67
Sulphuric acid	H_2SO_4	98.1	49.05
Nitric acid	HNO_3	63.0	63.00
Sulpurous acid	H_2SO_3	82.1	41.05

* Al_2O_3 and Fe_2O_3 are commonly reported together as R_2O_3, which for purpose of computation is given a mol. wt. of 109 and eq. wt. of 18.2 on the basis of 88% Al_2O_3 and 12% Fe_2O_3.

TABLE XXV

STEAM TABLES

Courtesy of Combustion Engineering-Superheater, Inc.

Saturated Steam: Temperature Table

Temp Fahr. t	Absolute Pressure Lb per Sq. In p	In Hg 32 F.	Specific Volume Sat Liquid v_f	Evap v_{fg}	Sat Vapor v_g	Enthalpy Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Entropy Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapor s_g	Temp. Fahr. t
32	0 0886	0 1806	0 01602	3305 7	3305 7	0	1075 1	1075 1	0	2 1865	2 1865	32
34	0 0961	0 1957	0 01602	3060 4	3060 4	2 01	1074 0	1076 0	0 0041	2 1755	2 1796	34
36	0 1041	0 2120	0 01602	2836 6	2836 6	4 03	1072 9	1076 9	0 0082	2 1645	2 1727	36
38	0 1126	0 2292	0 01602	2632 2	2632 2	6 04	1071 7	1077 7	0 0122	2 1533	2 1655	38
40	0 1217	0 2478	0 01602	2445 1	2445 1	8 05	1070 5	1078 6	0 0162	2 1423	2.1585	40
42	0 1315	0 2677	0 01602	2271 8	2271 8	10 06	1069 3	1079 4	0 0203	2 1314	2 1517	42
44	0 1420	0 2891	0 01602	2112 2	2112 2	12 06	1068 2	1080 3	0 0242	2 1207	2 1449	44
46	0 1532	0 3119	0 01602	1965 5	1965 5	14 07	1067 1	1081 2	0 0282	2 1102	2 1384	46
48	0 1652	0 3364	0 01602	1829 9	1829 9	16 07	1065 9	1082 0	0 0322	2 0995	2 1317	48
50	0 1780	0 3624	0 01602	1704 9	1704 9	18 07	1064 8	1082 9	0 0361	2 0891	2 1252*	50
52	0 1918	0 3905	0 01603	1588 4	1588 4	20 07	1063 6	1083 7	0 0400	2 0786	2 1186	52
54	0,2063	0 4200	0 01603	1482 4	1482 4	22 07	1062 5	1084 6	0 0439	2 0684	2 1123	54
56	0 2219	0 4518	0 01603	1383 5	1383 5	24 07	1061 4	1085 5	0 0478	2 0582	2 1060	56
58	0 2384	0 4854	0 01603	1292 7	1292 7	26.07	1060 2	1086.3	0 0517	2 0479	2 0996	58
60	0 2561	0 5214	0 01603	1208 1	1208 1	28 07	1059 1	1087 2	0 0555	2 0379	2 0934	60
62	0 2749	0 5597	0 01604	1129 7	1129 7	30 06	1057 9	1088 0	0 0594	2 0278	2 0872	62
64	0 2949	0 6004	0 01604	1057 1	1057 1	32 06	1056 8	1088 9	0 0632	2 0180	2 0812	64
66	0 3162	0 6438	0 01604	989 6	989 6	34 06	1055 7	1089 8	0 0670	2 0082	2 0752	66
68	0 3388	0 6898	0 01605	927 0	927 0	36 05	1054 5	1090 6	0 0708	1 9983	2.0691	68
70	0 3628	0 7387	0 01605	868 9	868 9	38 05	1053 4	1091 5	0 0745	1.9887	2 0632	70
72	0 3883	0 7906	0 01606	814 9	814 9	40 04	1052 3	1092 3	0 0783	1 9792	2 0575	72
74	0 4153	0 8456	0 01606	764 7	764 7	42 04	1051 2	1093 2	0 0820	1.9697	2 0517	74
76	0 4440	0 9040	0 01607	718 0	718 0	44 03	1050 1	1094 1	0 0858	1 9603	2 0461	76
78	0 4744	0 9659	0 01607	674 4	674 4	46 03	1048 9	1094 9	0 0895	1 9508	2 0403	78
80	0 5067	1 032	0 01607	633 7	633 7	48 02	1047 8	1095 8	0 0932	1 9415	2 0347	80
82	0 5409	1 101	0 01608	595 8	595 8	50 02	1046 6	1096 6	0 0969	1 9321	2 0290	82
84	0 5772	1 175	0 01608	560 4	560 4	52 01	1045 5	1097 5	0 1006	1 9230	2 0236	84
86	0 6153	1 253	0 01609	527 6	527 6	54 01	1044 4	1098 4	0 1042	1 9139	2 0181	86
88	0 6555	1 335	0 01609	497 0	497 0	56 00	1043 2	1099 2	0 1079	1 9047	2 0126	88
90	0 6980	1 421	0 01610	468 4	468 4	58 00	1042 1	1100 1	0 1115	1 8958	2 0073	90
92	0 7429	1 513	0 01611	441 7	441 7	59 99	1040 9	1100 9	0 1151	1 8867	2 0018	92
94	0 7902	1 609	0 01611	416 7	416 7	61 98	1039 8	1101 8	0 1187	1 8779	1 9966	94
96	0 8403	1 711	0 01612	393 2	393 2	63 98	1038 7	1102 7	0 1223	1 8692	1 9915	96
98	0 8930	1 818	0 01613	371 3	371 3	65 98	1037 5	1103 5	0 1259	1 8604	1 9863	98
100	0 9487	1 932	0 01613	350 8	350 8	67 97	1036 4	1104 4	0 1295	1 8517	1 9812	100
102	1 0072	2 051	0 01614	331 5	331 5	69 96	1035 2	1105 2	0 1330	1 8430	1 9760	102
104	1 0689	2 176	0 01614	313 5	313 5	71 96	1034 1	1106 1	0 1366	1 8345	1 9711	104
106	1 1338	2 308	0 01615	296 5	296 5	73 95	1033 0	1107 0	0 1401	1 8261	1 9662	106
108	1 2020	2 447	0 01616	280 7	280 7	75 94	1032 0	1107 9	0 1436	1 8179	1.9615	108
110	1 274	2 594	0 01617	265 7	265 7	77 94	1030 9	1108.8	0 1471	1.8096	1 9567	110
112	1 350	2 749	0 01617	251 6	251 6	79 93	1029 7	1109 6	0 1506	1 8012	1 9518	112
114	1 429	2 909	0 01618	238 5	238 5	81 93	1028 6	1110 5	0 1541	1 7930	1 9471	114
116	1 512	3 078	0 01619	226 2	226 2	83 92	1027 5	1111 4	0 1576	1 7848	1 9424	116
118	1 600	3 258	0 01620	214 5	214 5	85 92	1026 4	1112 3	0 1610	1 7767	1 9377	118
120	1 692	3 445	0 01620	203 45	203 47	87 91	1025.3	1113 2	0 1645	1 7687	1 9332	120
122	1 788	3 640	0 01621	193 16	193 18	89 91	1024 1	1114 0	0 1679	1 7606	1 9285	122
124	1 889	3 846	0 01622	183 44	183 46	91 90	1023 0	1114 9	0 1714	1 7526	1 9240	124
126	1 995	4 062	0 01623	174 26	174 28	93 90	1021.8	1115 7	0 1748	1 7446	1 9194	126
128	2 105	4 286	0 01624	165 70	165 72	95 90	1020 7	1116 6	0 1782	1 7368	1.9150	128
130	2 221	4 522	0 01625	157.55	157 57	97 89	1019.5	1117 4	0 1816	1 7289	1 9105	130
132	2 343	4 770	0 01626	149 83	149 85	99 89	1018.3	1118.2	0 1849	1 7210	1 9059	132
134	2 470	5 029	0 01626	142 59	142 61	101 89	1017 2	1119.1	0 1883	1 7134	1 9017	134
136	2 603	5 300	0 01627	135 73	135 75	103 88	1016 0	1119 9	0 1917	1 7056	1.8973	136
138	2 742	5 583	0 01628	129 26	129 28	105 88	1014.9	1120 8	0 1950	1.6980	1.8930	138
140	2 887	5 878	0 01629	123 16	123 18	107 88	1013 7	1121.6	0 1984	1 6904	1.8888	140
142	3 039	6 187	0 01630	117 37	117 39	109.88	1012 5	1122 4	0 2017	1 6828	1.8845	142
144	3 198	6 511	0 01631	111 88	111 90	111.88	1011.3	1123 2	0 2050	1 6752	1 8802	144
146	3 363	6 847	0 01632	106 72	106 74	113.88	1010 2	1124 1	0 2083	1 6678	1 8761	146
148	3 536	7 199	0 01633	101 82	101.84	115 87	1009 0	1124 9	0 2116	1 6604	1 8720	148
150	3 716	7 566	0 01634	97.18	97 20	117.87	1007 8	1125 7	0 2149	1 6530	1.8679	150
152	3 904	7 948	0 01635	92 79	92 81	119.87	1006.7	1126 6	0 2181	1 6458	1.8639	152
154	4 100	8 348	0 01636	88.62	88 64	121.87	1005.5	1127 4	0 2214	1 6384	1 8598	154
156	4 305	8 765	0 01637	84 66	84 68	123 87	1004.4	1128 3	0 2247	1 6313	1 8560	156
158	4 518	9.199	0 01638	80 90	80.92	125,87	1003 2	1129.1	Q 2279	1 6241	1 8520	158
160	4 739	9 649	0 01639	77 37	77 39	127 87	1002.0	1129 9	0 2311	1 6169.	1 8480	160
162	4 970	10 12	0 01640	74 00	74 02	129 88	1000.8	1130 7	0 2343	1 6098	1 8441	162
164	5 210	10 61	0 01642	70 79	70 81	131 88	999 7	1131 6	0 2376	1 6029	1 8405	164
166	5 460	11 12	0 01643	67 76	67 78	133.88	998 5	1132 4	0 2408	1 5958	1 8366	166

TABLE XXV
continued

Saturated Steam: Temperature Table—(Continued)

Temp. Fahr. t	Absolute Pressure Lb per Sq. In. p	Absolute Pressure In. Hg. 32 F.	Specific Volume Sat. Liquid v_f	Specific Volume Evap. v_{fg}	Specific Volume Sat. Vapor v_g	Enthalpy Sat Liquid h_f	Enthalpy Evap. h_{fg}	Enthalpy Sat Vapor h_g	Entropy Sat Liquid s_f	Entropy Evap. s_{fg}	Entropy Sat. Vapor s_g	Temp. Fahr. t
170	5 990	12 20	0 01645	62 12	62 14	137 89	996 1	1134 0	0 2471	1 5319	1 8290	170
172	6 272	12 77	0 01646	59 50	59 52	139 89	995 0	1134 9	0 2503	1 5751	1 8254	172
174	6 565	13 37	0 01647	57 01	57 03	141 89	993 8	1135 7	0 2535	1 5683	1 8218	174
176	6 869	13 99	0 01648	54 64	54 66	143 90	992 6	1136 5	0 2566	1 5615	1 8181	176
178	7 184	14 63	0 01650	52 39	52 41	145 90	991.4	1137 3	0 2598	1 5547	1 8145	178
180	7.510	15 29	0 01651	50 26	50 28	147 91	990 2	1138 1	0 2629	1 5479	1 8108	180
182	7 849	15 98	0 01652	48 22	48 24	149 92	989 0	1138 9	0 2661	1 5412	1 8073	182
184	8 201	16 70	0 01653	46 28	46 30	151 92	987 8	1139 7	0 2692	1 5346	1 8038	184
186	8 565	17 44	0 01654	44 43	44 45	153 93	986 6	1140 5	0 2723	1 5280	1 8003	186
188	8.944	18 21	0 01656	42 67	42 69	155 94	985.3	1141 3	0 2754	1 5213	1 7967	188
190	9 336	19 01	0 01657	40 99	41 01	157 95	984 1	1142 1	0 2785	1 5147	1 7932	190
192	9 744	19 84	0 01658	39 38	39 40	159 95	982.8	1142 8	0 2816	1 5081	1 7897	192
194	10 168	20 70	0 01659	37 84	37 86	161 96	981 5	1143 5	0 2847	1 5015	1 7862	194
196	10 605	21 59	0 01661	36 38	36 40	163 97	980 3	1144 3	0 2877	1 4951	1 7828	196
198	11 057	22 51	0 01662	34 98	35 00	165 98	979 0	1145 0	0 2908	1 4885	1 7793	198
200	11 525	23 46	0 01663	33 65	33 67	167 99	977 8	1145 8	0 2938	1 4822	1 7760	200
202	12 010	24 45	0 01665	32.37	32.39	170 01	976 6	1146 6	0 2969	1 4759	1 7728	202
204	12 512	25 47	0 01666	31 15	31 17	172 02	975 3	1147 3	0 2999	1 4695	1 7694	204
206	13 031	26 53	0 01667	29 99	30 01	174 03	974 1	1148 1	0 3029	1 4633	1 7662	206
208	13 568	27 62	0 01669	28 88	28 90	176 04	972 8	1148 8	0 3059	1 4570	1 7629	208
210	14.123	28 75	0 01670	27 81	27 83	178 06	971 5	1149 6	0 3090	1 4507	1 7597	210
212	14 696	29 92	0 01672	26 81	26 83	180 07	970 3	1150 4	0 3120	1 4446	1 7566	212
215	15 591		0 01674	25 35	25 37	183 10	968 3	1151 4	0 3165	1 4352	1 7517	215
220	17 188		0 01677	23 14	23 16	188 14	965 2	1153 3	0 3239	1 4201	1 7440	220
225	18 915		0 01681	21.15	21.17	193 18	961.9	1155 1	0 3313	1 4049	1 7362	225
230	20 78		0 01684	19 371	19 388	198 22	958 7	1156 9	0 3386	1 3900	1 7286	230
235	22 80		0 01688	17 761	17.778	203 28	955 3	1158 6	0 3459	1 3751	1 7210	235
240	24 97		0 01692	16 307	16 324	208 34	952 1	1160 4	0 3531	1 3607	1 7138	240
245	27 31		0 01696	15 010	15 027	213 41	948 7	1162 1	0 3604	1 3462	1 7066	245
250	29.82		0 01700	13.824	13 841	218 48	945 3	1163 8	0 3675	1 3320	1 6995	250
255	32.53		0 01704	12 735	12 752	223 56	942 0	1165 6	0 3747	1 3181	1 6928	255
260	35 43		0 01708	11 754	11 771	228 65	938 6	1167 3	0 3817	1 3042	1 6859	260
265	38 54		0 01713	10 861	10.878	233 74	935 3	1169 0	0 3888	1 2906	1 6794	265
270	41.85		0 01717	10 053	10 070	238 84	931 8	1170 6	0 3958	1 2770	1 6728	270
275	45.40		0 01721	9 313	9.330	243 94	928 2	1172 1	0 4027	1 2634	1 6661	275
280	49 20		0 01726	8.634	8 651	249 06	924 6	1173 7	0 4096	1 2500	1 6596	280
285	53 25		0 01731	8 015	8 032	254 18	921 0	1175 2	0 4165	1 2368	1 6533	285
290	57.55		0 01735	7 448	7 465	259 31	917 4	1176 7	0 4234	1 2237	1 6471	290
295	62 13		0 01740	6.931	6.948	264 45	913 7	1178 2	0 4302	1 2107	1 6409	295
300	67.01		0 01745	6.454	6 471	269 60	910 1	1179 7	0 4370	1 1980	1 6350	300
305	72 18		0 01750	6 014	6.032	274 76	906 3	1181 1	0 4437	1 1852	1 6289	305
310	77.68		0 01755	5 610	5 628	279 92	902 6	1182 5	0 4505	1 1727	1 6232	310
315	83.50		0 01760	5 239	5 257	285 10	898 8	1183 9	0 4571	1 1587	1 6158	315
320	89 65		0 01765	4.897	4 915	290 29	895 0	1185 3	0 4637	1 1479	1 6116	320
325	96 16		0 01771	4.583	4 601	295 49	891 1	1186 6	0 4703	1 1356	1 6059	325
330	103 03		0 01776	4 292	4 310	300.69	887 1	1187 8	0 4769	1 1234	1 6003	330
335	110 31		0 01782	4 021	4 039	305 91	883 2	1189 1	0 4835	1 1114	1 5949	335
340	117 99		0 01788	3 771	3 789	311 14	879 2	1190 3	0 4900	1 0994	1 5894	340
345	126.10		0 01793	3 539	3 557	316 38	875 1	1191 5	0 4966	1 0875	1 5841	345
350	134 62		0 01799	3 324	3 342	321 64	871 0	1192 6	0 5030	1 0757	1 5787	350
355	143 58		0 01805	3 126	3 144	326 91	866 8	1193 7	0 5094	1 0640	1 5734	355
360	153 01		0 01811	2 940	2 958	332 19	862 5	1194 7	0 5159	1 0522	1 5681	360
365	162.93		0 01817	2 768	2 786	337 48	858 2	1195 7	0 5223	1 0406	1 5629	365
370	173 33		0 01823	2 607	2 625	342 79	853 8	1196 6	0 5286	1 0291	1 5577	370
375	184 23		0 01830	2.458	2.476	348 11	849 4	1197 5	0 5350	1 0176	1 5526	375
380	195 70		0.01836	2.318	2 336	353.45	844.9	1198 4	0 5413	1 0062	1 5475	380
385	207 71		0 01843	2.189	2.207	358 80	840 4	1199 2	0 5476	0 9949	1 5425	385
390	220.29		0 01850	2.064	2 083	364 17	835 7	1199.9	0 5540	0 9835	1 5375	390
395	233 47		0 01857	1.9512	1 9698	369 56	831 0	1200.6	0 5602	0 9723	1.5325	395
400	247.25		0.01864	1.8446	1.8632	374.97	826.2	1201.2	0 5664	0.9610	1.5274	400
405	261.67		0.01871	1.7445	1.7632	380.40	821.4	1201 8	0 5727	0 9499	1 5226	405
410	276 72		0 01878	1.6508	1 6696	385.83	816.6	1202 4	0 5789	0.9390	1.5179	410
415	292 44		0.01886	1 5630	1 5819	391.30	811 7	1203 0	0 5851	0.9280	1.5131	415
420	308.82		0.01894	1 4806	1 4995	396.78	806.7	1203.5	0.5912	0.9170	1.5082	420
425	325 91		0.01902	1.4031	1 4221	402.28	801 6	1203.9	0 5974	0 9061	1.5035	425
430	343 71		0 01910	1 3303	1 3494	407.80	796 5	1204.3	0 6036	0 8953	1.4989	430
435	362 27		0 01918	1.2617	1 2809	413 35	791 2	1204 6	0.6097	0 8843	1 4940	435
440	381 59		0.01926	1 1973	1 2166	418 91	785 9	1204.8	0 6159	0 8735	1.4894	440
445	401 70		0.01934	1 1367	1 1560	424 49	780 4	1204 9	0 6220	0 8626	1 4846	445
450	422 61		0.01943	1.0796	1 0990	430.11	774.9	1205 0	0 6281	0 8518	1.4799	450
455	444.35		0.0195	1 0256	1 0451	435.74	769.3	1205 0	0 6342	0 8410	1.4752	455
460	466 97		0.0196	0 9745	0.9941	441.42	763 6	1205 0	0 6403	0 8303	1.4706	460
465	490.43		0.0197	0 9262	0 9459	447.10	757.8	1204 9	0 6463	0 8195	1 4658	465
470	514 70		0 0198	0 8808	0 9006	452 84	751.9	1204.7	0 6524	0 8088	1.4612	470
									0 6585	0 7980	1.4565	475

TABLE XXV
continued

Saturated Steam: Temperature Table—(Concluded)

Temp. Fahr t	Abs. Press Lb./Sq In p	Specific Volume Sat Liquid v_f	Evap v_{fg}	Sat. Vapor v_g	Enthalpy Sat Liquid h_f	Evap h_{fg}	Sat. Vapor h_g	Entropy Sat Liquid s_f	Evap. s_{fg}	Sat Vapor s_g	Temp Fahr t
480	566 12	0 0200	0 7972	0 8172	464 37	739 8	1204 2	0 6646	0 7873	1 4519	480
485	593 28	0 0201	0 7585	0 7786	470 18	733 6	1203 8	0 6706	0 7766	1 4472	485
490	621 44	0 0202	0 7219	0 7421	476 01	727 3	1203 3	0 6767	0 7658	1 4425	490
495	650 59	0 0203	0 6872	0 7075	481 90	720 8	1202 7	0 6827	0 7550	1 4377	495
500	680 80	0 0204	0 6544	0 6748	487 80	714 2	1202 0	0 6888	0 7442	1 4330	500
505	712 19	0 0206	0 6230	0 6436	493 8	707 5	1201 3	0 6949	0 7334	1 4283	505
510	744 55	0 0207	0 5932	0 6139	499 8	700 6	1200 4	0 7009	0 7225	1 4234	510
515	777 96	0 0208	0 5651	0 5859	505.8	693 6	1199 4	0 7070	0 7116	1 4186	515
520	812 68	0 0209	0 5382	0 5591	511 9	686 5	1198 4	0.7132	0 7007	1 4139	520
525	848 37	0 0210	0 5128	0 5338	518 0	679 2	1197.2	0 7192	0 6898	1.4090	525
530	885 20	0 0212	0 4885	0 5097	524 2	671 9	1196 1	0 7253	0 6789	1 4042	530
535	923 45	0 0213	0 4654	0 4867	530 4	664 4	1194 8	0 7314	0 6679	1 3993	535
540	962 80	0 0214	0 4433	0 4647	536 6	656 7	1193 3	0 7375	0 6569	1.3944	540
545	1003 6	0 0216	0 4222	0 4438	542 9	648 9	1191 8	0 7436	0 6459	1 3895	545
550	1045 6	0 0218	0 4021	0 4239	549 3	640 9	1190 2	0 7498	0 6347	1 3845	550
555	1088 8	0 0219	0 3830	0 4049	555 7	632 6	1188 3	0 7559	0 6234	1 3793	555
560	1133 4	0 0221	0 3648	0 3869	562.2	624 1	1186 3	0 7622	0 6120	1 3742	560
565	1179 3	0 0222	0 3472	0 3694	568 8	615 4	1184 2	0 7684	0 6006	1 3690	565
570	1226.7	0 0224	0 3304	0 3528	575 4	606 5	1181 9	0 7737	0 5890	1 3627	570
575	1275 7	0 0226	0 3143	0 3369	582 1	597 4	1179 5	0 7810	0 5774	1 3584	575
580	1326 1	0 0228	0 2989	0 3217	588 9	588 1	1177 0	0 7872	0 5656	1 3528	580
585	1378 1	0 0230	0 2840	0 3070	595 7	578.6	1174 3	0 7936	0 5538	1 3474	585
590	1431 5	0 0232	0 2699	0 2931	602 6	568 8	1171 4	0 8000	0 5419	1 3419	590
595	1486.5	0 0234	0 2563	0 2797	609 7	558 7	1168 4	0 8065	0 5297	1.3362	595
600	1543 2	0 0236	0 2432	0 2668	616 8	548 4	1165 2	0 8130	0 5175	1.3305	600
605	1601 5	0 0239	0 2306	0 2545	624 1	537 7	1161 8	0 8196	0 5050	1 3246	605
610	1661 6	0 0241	0 2185	0 2426	631 5	526 6	1158 1	0 8263	0 4923	1 3186	610
615	1723 4	0 0244	0 2068	0 2312	638 9	515 3	1154 2	0 8330	0 4795	1 3125	615
620	1787 0	0 0247	0 1955	0 2202	646 5	503 7	1150 2	0.8398	0 4665	1 3063	620
625	1852 4	0 0250	0 1845	0 2095	654 3	491 5	1145 8	0 8467	0 4531	1 2998	625
630	1919 8	0 0253	0 1740	0 1993	662 2	478.8	1141 0	0 8537	0 4394	1 2931	630
635	1989 0	0 0256	0 1638	0 1894	670 4	465.5	1135 9	0 8609	0 4252	1 2861	635
640	2060.3	0 0260	0 1539	0 1799	678 7	452 0	1130 7	0 8681	0 4110	1 2791	640
645	2133 5	0 0264	0 1441	0 1705	687 3	437.6	1124 9	0 8756	0.3961	1 2717	645
650	2208 8	0 0268	0 1348	0 1616	696 0	422 7	1118.7	0 8832	0 3809	1.2641	650
655	2286 4	0 0273	0 1256	0 1529	705 2	407 0	1112 2	0 8910	0 3651	1 2561	655
660	2366 2	0 0278	0 1167	0 1445	714 4	390 5	1104 9	0 8991	0 3488	1.2479	660
665	2448 0	0 0283	0 1079	0 1362	724 5	372 1	1096.6	0 9074	0 3308	1.2382	665
670	2532.4	0 0290	0 0991	0 1281	734 6	353 3	1087.9	0 9161	0.3127	1.2288	670
675	2619 2	0 0297	0 0904	0 1201	745 5	332 8	1078 3	0 9253	0 2933	1.2186	675
680	2708 4	0 0305	0 0810	0 1115	757 2	310 0	1067.2	0 9352	0 2720	1 2072	680
685	2800 4	0 0316	0 0716	0 1032	770 1	284 5	1054.6	0 9459	0 2485	1 1944	685
690	2895.0	0 0328	0 0617	0 0945	784 2	254 9	1039 1	0 9579	0 2217	1 1796	690
695	2992.7	0.0345	0 0511	0 0856	801 3	219 1	1020.4	0 9720	0.1897	1 1617	695
700	3094.1	0 0369	0 0389	0 0758	823 9	171 7	995 6	0 9904	0 1481	1 1385	700
705	3199 1	0 0440	0.0157	0 0597	870 2	77 6	947.8	1 0305	0 0661	1 0966	705
706 24*	3206.2	0 0541	0	0 0541	910.3	0	910 3	1 0645	0	1 0645	706 24*

* Critical temperature

TABLE XXV
continued

Saturated Steam: Pressure Table

Abs Press Lb /Sq In p	Temp Fahr t	Specific Volume Sat Liquid v_f	Evap v_{fg}	Sat Vapor v_g	Enthalpy Sat Liquid h_f	Evap h_{fg}	Sat Vapor h_g	Entropy Sat Liquid s_f	Evap s_{fg}	Sat Vapor s_g	Abs Press Lb /Sq. In p
0 0886	32 00	0 01602	3303 7	3303 7	0	1075 1	1075 1	0	2 1865	2 1865	0 0886
0 125	40 69	0 01602	2383 7	2383 7	8 74	1070 2	1078 9	0 0176	2 1388	2 1564	0 125
0 250	59 31	0 01603	1235 8	1235 8	27 38	1059 5	1086 9	0 0542	2 0414	2 0956	0 250
0 500	79 58	0 01607	641 71	641 73	47 60	1048 0	1095 6	0 0924	1 9434	2 0358	0 500
1	101 76	0 01614	333 77	333 79	69 72	1035 5	1105 2	0 1326	1 8443	1 9769	1
5	162 25	0 01641	73 584	73 600	130 13	1000 7	1130 8	0 2347	1 6090	1 8437	5
10	193 21	0 01659	38 445	38 462	161 17	982 1	1143 3	0 2834	1 5042	1 7876	10
14 696	212 00	0 01672	26 811	26 828	180 07	970 3	1150 4	0 3120	1 4446	1 7566	14 696
15	213 03	0 01672	26 303	26 320	181 11	969 6	1150 7	0 3135	1 4413	1 7548	15
20	227 96	0 01683	20 093	20 110	196 16	959 9	1156 1	0 3356	1 3959	1 7315	20
30	250 34	0 01700	13 746	13 763	218 83	945 2	1164 0	0 3680	1 3312	1 6992	30
40	267 24	0 01715	10 489	10 506	236 02	934 7	1169 7	0 3919	1 2844	1 6763	40
50	281 01	0 01727	8 505	8 522	250 09	925 9	1174 0	0 4110	1 2473	1 6583	50
60	292 71	0 01738	7 162	7 179	262 10	915 4	1177 5	0 4271	1 2166	1 6437	60
70	302 92	0 01748	6 193	6 210	272 61	907 9	1180 5	0 4409	1 1905	1 6314	70
80	312 03	0 01757	5 458	5 476	282 02	901 1	1183 1	0 4532	1 1677	1 6209	80
90	320 27	0 01766	4 880	4 898	290 57	894 8	1185 4	0 4641	1 1472	1 6113	90
100	327 83	0 01774	4 415	4 433	298 43	889 9	1187 3	0 4741	1 1287	1 6028	100
110	334 79	0 01782	4 032	4 050	305 69	883 3	1189 0	0 4832	1 1118	1 5950	110
120	341 26	0 01789	3 710	3 728	312 46	879 1	1190 6	0 4916	1 0963	1 5879	120
130	347 31	0 01796	3 437	3 455	318 81	873 2	1192 0	0 4995	1 0820	1 5815	130
140	353 03	0 01803	3 202	3 220	324 83	868 5	1193 3	0 5069	1 0686	1 5755	140
150	358 43	0 01809	2 998	3 016	330 53	863 9	1194 4	0 5138	1 0560	1 5698	150
160	363 55	0 01815	2 816	2 834	335 95	858 6	1195 5	0 5204	1 0442	1 5646	160
170	368 42	0 01821	2 656	2 674	341 11	855 2	1196 3	0 5266	1 0327	1 5593	170
180	373 08	0 01827	2 514	2 532	346 07	851 1	1197 2	0 5325	1 0220	1 5545	180
190	377 55	0 01833	2 386	2 404	350 83	847 2	1198 0	0 5382	1 0119	1 5501	190
200	381 82	0 01839	2 270	2 288	355 40	843 3	1198 7	0 5436	1 0021	1 5457	200
210	385 93	0 01844	2 165	2 183	359 80	839 6	1199 4	0 5488	0 9929	1 5417	210
220	389 89	0 01850	2 067	2 086	364 05	835 8	1199 9	0 5538	0 9838	1 5376	220
230	393 70	0 01855	1 980 1	1 999	368 16	832 2	1200 4	0 5585	0 9752	1 5337	230
240	397 40	0 01860	1 8990	1 9176	372 16	828 7	1200 9	0 5632	0 9669	1 5301	240
250	400 97	0 01866	1 8244	1 8431	376 04	825 4	1201 4	0 5677	0 9590	1 5267	250
260	404 43	0 01870	1 7553	1 7742	379 78	822 0	1201 8	0 5720	0 9513	1 5233	260
270	407 79	0 01875	1 6913	1 7101	383 43	818 8	1202 2	0 5761	0 9439	1 5200	270
280	411 06	0 01880	1 6316	1 6504	386 99	815 5	1202 5	0 5802	0 9365	1 5167	280
290	414 24	0 01885	1 5758	1 5947	390 47	812 4	1202 9	0 5841	0 9296	1 5137	290
300	417 33	0 01890	1 5237	1 5426	393 85	809 3	1203 2	0 5879	0 9228	1 5107	300
350	431 71	0 01912	1 3064	1 3255	409 70	794 7	1204 4	0 6057	0 8915	1 4972	350
400	444 58	0 0193	1 1416	1 1609	424 02	780 9	1204 9	0 6215	0 8635	1 4850	400
450	456 27	0 0195	1 0123	1 0318	437 18	767 8	1205 0	0 6357	0 8382	1 4739	450
500	467 00	0 0197	0 9077	0 9274	449 40	755 5	1204 9	0 6488	0 8153	1 4641	500
550	476 94	0 0199	0 8217	0 8416	460 83	743 6	1204 4	0 6609	0 7939	1 4548	550
600	486 21	0 0201	0 7494	0 7695	471 59	732 0	1203 6	0 6721	0 7739	1 4460	600
650	494 90	0 0203	0 6879	0 7082	481 73	721 0	1202 7	0 6826	0 7553	1 4379	650
700	503 09	0 0205	0 6347	0 6552	491 49	710 1	1201 6	0 6925	0 7376	1 4301	700
750	510 83	0 0207	0 5884	0 6091	500 8	699 4	1200 2	0 7019	0 7206	1 4225	750
800	518 20	0 0209	0 5476	0 5685	509 7	689 1	1198 8	0 7104	0 7047	1 4155	800
850	525 23	0 0210	0 5116	0 5326	518 3	678 9	1197 2	0 7194	0 6893	1 4087	850
900	531 94	0 0212	0 4794	0 5006	526 6	669 0	1195 6	0 7276	0 6746	1 4022	900
950	538 38	0 0214	0 4503	0 4717	534 6	659 2	1193 8	0 7355	0 6605	1 3960	950
1000	544 56	0 0216	0 4240	0 4456	542 4	649 5	1191 9	0 7431	0 6468	1 3899	1000
1050	550 52	0 0218	0 4001	0 4219	550 0	640 0	1190 0	0 7504	0 6335	1 3839	1050
1100	556 26	0 0219	0 3783	0 4002	557 4	630 4	1187 8	0 7575	0 6205	1 3780	1100
1150	561 81	0 0221	0 3583	0 3804	564 6	621 0	1185 6	0 7644	0 6079	1 3723	1150
1200	567 19	0 0223	0 3397	0 3620	571 7	611 5	1183 2	0 7712	0 5955	1 3667	1200
1250	572 39	0 0225	0 3228	0 3453	578 6	602 2	1180 8	0 7777	0 5835	1 3612	1250
1300	577 43	0 0227	0 3067	0 3294	585 4	592 9	1178 3	0 7840	0 5717	1 3557	1300
1350	582 32	0 0229	0 2918	0 3147	592 1	583 7	1175 8	0 7902	0 5602	1 3504	1350
1400	587 07	0 0231	0 2780	0 3011	598 6	574 6	1173 2	0 7963	0 5489	1 3452	1400
1450	591 70	0 0233	0 2652	0 2885	605 0	565 5	1170 5	0 8022	0 5379	1 3401	1450
1500	596 20	0 0235	0 2530	0 2765	611 4	556 3	1167 7	0 8081	0 5269	1 3350	1500
1550	600 59	0 0237	0 2416	0 2653	617 7	547 1	1164 8	0 8138	0 5160	1 3298	1550
1600	604 87	0 0239	0 2309	0 2548	623 9	538 0	1161 9	0 8195	0 5054	1 3249	1600
1650	609 05	0 0241	0 2207	0 2448	630 0	528 8	1158 8	0 8250	0 4948	1 3198	1650
1700	613 12	0 0243	0 2111	0 2354	636 1	519 6	1155 7	0 8304	0 4843	1 3147	1700
1750	617 11	0 0245	0 2020	0 2265	642 1	510 4	1152 5	0 8359	0 4740	1 3099	1750
1800	621 00	0 0247	0 1933	0 2180	648 0	501 3	1149 3	0 8412	0 4639	1 3051	1800
1850	624 82	0 0249	0 1850	0 2099	653 9	492 0	1145 9	0 8465	0 4537	1 3002	1850
1900	628 55	0 0252	0 1770	0 2022	659 9	482 5	1142 4	0 8517	0 4434	1 2951	1900
1950	632 20	0 0254	0 1695	0 1949	665 8	473 0	1138 8	0 8569	0 4332	1 2901	1950
2000	635 78	0 0257	0 1622	0 1879	671 7	463 5	1135 2	0 8620	0 4231	1 2851	2000
2100	642 73	0 0262	0 1486	0 1748	683 4	444 2	1127 6	0 8722	0 4029	1 2751	2100
2200	649 42	0 0267	0 1359	0 1626	695 0	424 4	1119 4	0 8823	0 3826	1 2649	2200
2300	655 87	0 0274	0 1240	0 1514	706 7	404 3	1111 0	0 8923	0 3624	1 2547	2300
2400	662 09	0 0280	0 1130	0 1410	718 5	392 9	1101 4	0 9025	0 3413	1 2438	2400
2500	668 10	0 0287	0 1026	0 1313	730 7	360 3	1091 0	0 9127	0 3195	1 2322	2500
2600	673 91	0 0295	0 0924	0 1219	743 1	337 0	1080 1	0 9232	0 2973	1 2205	2600
2700	679 54	0 0305	0 0818	0 1123	756 1	312 2	1068 3	0 9342	0 2740	1 2082	2700
2800	684 98	0 0316	0 0716	0 1032	770 0	284 6	1054 6	0 9458	0 2486	1 1944	2800
2900	690 26	0 0329	0 0612	0 0941	785 2	252 9	1038 1	0 9586	0 2199	1 1785	2900
3000	695 37	0 0346	0 0503	0 0349	802 6	218 7	1019 3	0 9731	0 1876	1 1607	3000
3100	700 29	0 0372	0 0380	0 0752	824 6	169 4	994 0	0 9916	0 1460	1 1376	3100
3200	705 04	0 0443	0 0153	0 0596	871 3	75 3	946 6	1 0311	0 0647	1 0958	3200
3206 2*	705 34	0 0541	0	0 0541	910 3	0	910 3	1 0645	0	1 0645	3206 2*

*Critical pressure

TABLE XXV
continued

Superheated Steam

Abs Press Lb/Sq In. (Sat Temp.)		Sat Water	Sat Steam	Temperature—Degrees Fahrenheit 200°	250°	300°	350°	400°	450°	500°	600°	700°	800°	900°	1000°	1100°	1200°
	Sh			98 24	148 24	198 24	248 24	298 24	348 24	398 24	498 24	598 24	698 24	798 24	898 24	998 24	1098 24
1	v	0 0161	333 79	392 5	422 5	452 1	482 1	511 7	541 8	571 3	630 9	690 6	750 2	809 8	869 4	929 1	988 7
(101 76)	h	69 72	1105 2	1149 2	1171 9	1194 4	1217 3	1240 2	1263 5	1286 7	1333 9	1382 1	1431 0	1480 8	1531 4	1583 0	1635 4
	s	0 1326	1 9769	2 0491	2 0822	2 1128	2 1420	2 1694	2 1957	2 2206	2 2673	2 3107	2 3512	2 3892	2 4251	2 4592	2 4918
	Sh			37 75	87 75	137 75	187 75	237 75	287 75	337 75	437 75	537 75	637 75	737 75	837 75	937 75	1037 75
5	v	0 0164	73 600	78 17	84 24	90 21	96 26	102 19	108 23	114 16	126 11	138 05	149 99	161 91	173 83	185 80	197 72
(162 25)	h	130 13	1130 8	1148 3	1171 1	1193 6	1216 6	1239 8	1263 0	1286 1	1333 5	1381 8	1430 8	1480 6	1531 3	1582 9	1635 3
	s	0 2347	1 8437	1 8710	1 9043	1 9349	1 9642	1 9920	2 0182	2 0429	2 0898	2 1333	2 1738	2 2118	2 2478	2 2820	2 3146
	Sh			6 79	56 79	106 79	156 79	206 79	256 79	306 79	406 79	506 79	606 79	706 79	806 79	906 79	1006 79
10	v	0 0166	38 462	38 88	41 96	44 98	48 02	51 01	54 04	57 02	63 01	68 99	74 96	80 92	86 89	92 88	98 85
(193 21)	h	161 17	1143 3	1146 7	1170 2	1192 8	1216 0	1239 3	1262 5	1285 8	1333 3	1381 6	1430 6	1480 5	1531 2	1582 8	1635 2
	s	0 2834	1 7876	1 7928	1 8271	1 8579	1 8875	1 9154	1 9416	1 9665	2 0135	2 0570	2 0975	2 1356	2 1716	2 2058	2 2384
	Sh				38 00	88 00	138 00	188 00	238 00	288 00	388 00	488 00	588 00	688 00	788 00	888 00	988 00
14 696	v	0 0167	26 828		28 44	30 52	32 61	34 65	36 73	38 75	42 83	46 91	50 97	55 03	59 09	63 19	67 25
(212 00)	h	180 07	1150 4		1169 2	1192 0	1215 4	1238 9	1262 1	1285 4	1333 0	1381 4	1430 5	1480 4	1531 1	1582 7	1635 1
	s	0 3120	1 7566		1 7838	1 8148	1 8446	1 8727	1 8989	1 9238	1 9709	2 0145	2 0551	2 0932	2 1292	2 1634	2 1960
	Sh				36 97	86 97	136 97	186 97	236 97	286 97	386 97	486 97	586 97	686 97	786 97	886 97	986 97
15	v	0 0167	26 320		27 86	29 90	31 94	33 95	35 98	37 97	41 98	45 97	49 95	53 93	57 91	61 91	65 89
(213 03)	h	181 11	1150 7		1169 2	1192 0	1215 4	1238 9	1262 1	1285 4	1333 0	1381 4	1430 5	1480 4	1531 1	1582 7	1635 1
	s	0 3135	1 7548		1 7816	1 8126	1 8424	1 8705	1 8967	1 9216	1 9687	2 0123	2 0529	2 0910	2 1270	2 1612	2 1938
	Sh				22 04	72 04	122 04	172 04	222 04	272 04	372 04	472 04	572 04	672 04	772 04	872 04	972 04
20	v	0 0168	20 110		20 81	22 36	23 91	25 43	26 95	28 45	31 46	34 46	37 44	40 43	43 42	46 43	49 41
(227 96)	h	196 16	1156 1		1168 0	1191 1	1214 8	1238 4	1261 6	1285 0	1332 7	1381 2	1430 3	1480 2	1531 0	1582 6	1635 1
	s	0 3356	1 7315		1 7485	1 7799	1 8101	1 8384	1 8646	1 8896	1 9368	1 9805	2 0211	2 0592	2 0952	2 1294	2 1620
	Sh				9 93	59 93	109 93	159 93	209 93	259 93	359 93	459 93	559 93	659 93	759 93	859 93	959 93
25	v	0 0169	16 321		16 58	17 84	19 08	20 30	21 53	22 73	25 15	27 55	29 94	32 33	34 73	37 14	39 52
(240 07)	h	208 41	1160 4		1166 3	1190 2	1214 1	1237 9	1261 1	1284 6	1332 4	1381 0	1430 1	1480 0	1530 9	1582 5	1635 0
	s	0 3532	1 7137		1 7221	1 7570	1 7875	1 8160	1 8422	1 8673	1 9146	1 9584	1 9990	2 0371	2 0732	2 1074	2 1400
	Sh					49 66	99 66	149 66	199 66	249 66	349 66	449 66	549 66	649 66	749 66	849 66	949 66
30	v	0 0170	13 763			14 82	15 87	16 89	17 91	18 92	20 94	22 94	24 94	26 93	28 93	30 94	32 93
(250 34)	h	218 83	1164 0			1189 2	1213 4	1237 4	1260 6	1284 2	1332 1	1380 8	1429 9	1479 9	1530 8	1582 4	1634 9
	s	0 3680	1 6992			1 7335	1 7643	1 7930	1 8192	1 8444	1 8918	1 9357	1 9763	2 0145	2 0508	2 0848	2 1174
	Sh					40 72	90 72	140 72	190 72	240 72	340 72	440 72	540 72	640 72	740 72	840 72	940 72
35	v	0 0171	11 907			12 66	13 57	14 45	15 33	16 20	17 94	19 66	21 36	23 08	24 79	26 52	28 22
(259 28)	h	227 92	1167 0			1188 2	1212 7	1236 9	1260 1	1283 8	1331 9	1380 6	1429 8	1479 8	1530 7	1582 3	1634 8
	s	0 3807	1 6869			1 7156	1 7468	1 7758	1 8020	1 8274	1 8750	1 9189	1 9596	1 9978	2 0339	2 0681	2 1007
	Sh					32 76	82 76	132 76	182 76	232 76	332 76	432 76	532 76	632 76	732 76	832 76	932 76
40	v	0 0172	10 506			11 04	11 84	12 62	13 40	14 16	15 68	17 19	18 69	20 18	21 68	23 20	24 69
(267 24)	h	236 02	1169 7			1187 1	1211 9	1236 4	1259 6	1283 4	1331 6	1380 4	1429 6	1479 6	1530 6	1582 2	1634 8
	s	0 3919	1 6763			1 6997	1 7313	1 7606	1 7868	1 8123	1 8600	1 9040	1 9447	1 9829	2 0191	2 0533	2 0860
	Sh					25 55	75 55	125 55	175 55	225 55	325 55	425 55	525 55	625 55	725 55	825 55	925 55
45	v	0 0172	9 408			9 785	10 50	11 20	11 89	12 57	13 93	15 27	16 60	17 94	19 27	20 62	21 95
(274 45)	h	243 38	1172 0			1185 9	1211 1	1235 8	1259 1	1283 0	1331 3	1380 1	1429 4	1479 4	1530 5	1582 1	1634 7
	s	0 4019	1 6668			1 6854	1 7175	1 7471	1 7734	1 7990	1 8468	1 8908	1 9315	1 9697	2 0059	2 0401	2 0728
	Sh					18 99	68 99	118 99	168 99	218 99	318 99	418 99	518 99	618 99	718 99	818 99	918 99
50	v	0 0173	8 522			8 777	9 430	10 06	10 69	11 30	12 53	13 74	14 93	16 14	17 34	18 55	19 75
(281 01)	h	250 09	1174 0			1184 6	1210 3	1235 2	1258 6	1282 6	1331 0	1379 9	1429 3	1479 3	1530 4	1582 0	1634 6
	s	0 4110	1 6583			1 6724	1 7051	1 7349	1 7613	1 7870	1 8349	1 8790	1 9198	1 9580	1 9942	2 0284	2 0611
	Sh					12 93	62 93	112 93	162 93	212 93	312 93	412 93	512 93	612 93	712 93	812 93	912 93
55	v	0 0173	7 792			7 950	8 553	9 130	9 703	10 26	11 38	12 48	13 57	14 67	15 76	16 86	17 95
(287 07)	h	256 30	1175 8			1183 2	1209 4	1234 6	1258 2	1282 2	1330 7	1379 7	1429 1	1479 2	1530 3	1581 9	1634 5
	s	0 4193	1 6506			1 6604	1 6938	1 7240	1 7507	1 7764	1 8244	1 8685	1 9093	1 9475	1 9837	2 0179	2 0512
	Sh					7 29	57 29	107 29	157 29	207 29	307 29	407 29	507 29	607 29	707 29	807 29	907 29
60	v	0 0174	7 179			7 260	7 821	8 353	8 882	9 398	10 42	11 44	12 44	13 44	14 44	15 45	16 45
(292 71)	h	262 10	1177 5			1181 8	1208 5	1234 0	1257 7	1281 8	1330 4	1379 5	1428 9	1479 0	1530 2	1581 8	1634 4
	s	0 4271	1 6437			1 6494	1 6834	1 7139	1 7407	1 7665	1 8146	1 8588	1 8996	1 9378	1 9741	2 0083	2 0410
	Sh					2 03	52 03	102 03	152 03	202 03	302 03	402 03	502 03	602 03	702 03	802 03	902.03
65	v	0 0174	6 654			6 674	7 202	7 696	8 187	8 665	9 614	10 55	11 48	12 40	13 33	14 26	15 19
(297 97)	h	267 51	1179 1			1180 4	1207 6	1233 4	1257 2	1281 4	1330 1	1379 3	1428 8	1478 9	1530 1	1581.7	1634 4
	s	0 4342	1 6374			1 6391	1 6738	1 7047	1 7316	1 7575	1 8057	1 8500	1 8909	1 9291	1 9654	1 9996	2 0323
	Sh						47 08	97 08	147 08	197 08	297 08	397 08	497 08	597 08	697 08	797 08	897 08
70	v	0 0175	6 210				6 671	7 132	7 592	8 036	8 920	9 791	10 65	11 51	12 37	13 24	14 10
(302 92)	h	272 61	1180 5				1206 7	1232 8	1256 7	1281 0	1329 9	1379 0	1428 6	1478 7	1530 0	1581 6	1634 3
	s	0 4409	1 6314				1 6647	1 6960	1 7230	1 7490	1 7974	1 8416	1 8826	1 9208	1 9572	1 9914	2 0241
	Sh						42 40	92 40	142 40	192 40	292 40	392 40	492 40	592 40	692 40	792 40	892 40
75	v	0 0175	5 820				6 210	6 644	7 076	7 492	8 319	9 133	9 938	10 74	11 54	12 36	13 16
(307 60)	h	277 44	1181 9				1205 8	1232 2	1256 2	1280 6	1329 6	1378 8	1428 4	1478 6	1529 8	1581 5	1634 2
	s	0 4472	1 6260				1 6563	1 6879	1 7150	1 7411	1 7896	1 8339	1 8749	1 9132	1 9495	1 9837	2 0164

Sh = superheat, deg F
v = specific volume, cu. ft per lb
h = enthalpy, B t u per lb
s = entropy, B t u. per deg. F. per lb.

TABLE XXV
continued

Superheated Steam—(Continued)

Abs Press Lb /Sq In (Sat Temp)		Sat Water	Sat Steam	Temperature—Degrees Fahrenheit 340°	360°	380°	400°	420°	450°	500°	600°	700°	800°	900°	1000°	1100°	1200°
	Sh			27 97	47 97	67 97	87 97	107 97	137 97	187 97	287 97	387 97	487 97	587 97	687 97	787 97	887 97
80	v	0 0176	5 476	5 720	5 889	6 055	6 217	6 384	6 623	7 015	7 793	8 558	9 313	10 07	10 82	11 58	12 33
(312 03)	h	282 02	1187 1	1200 0	1211 0	1221 2	1231 5	1240 3	1255 7	1280 2	1329 3	1378 5	1428 2	1478 4	1529 7	1581 4	1634 1
	s	0 4532	1 6209	1 6424	1 6560	1 6683	1 6804	1 6905	1 7077	1 7339	1 7825	1 8268	1 8679	1 9062	1 9426	1 9768	2 0095
	Sh			23 75	43 75	63 75	83 75	103 75	133 75	183 75	283 75	383 75	483 75	583 75	683 75	783 75	883 75
85	v	0 0176	5 169	5 368	5 528	5 685	5 839	5 995	6 226	6 594	7 329	8 050	8 762	9 472	10 18	10 90	11 61
(316 25)	h	286 40	1184 3	1198 5	1210 0	1220 5	1230 7	1239 7	1255 1	1279 7	1329 0	1378 3	1428 0	1478 2	1529 6	1581 3	1634 0
	s	0 4587	1 6159	1 6339	1 6481	1 6608	1 6728	1 6831	1 7003	1 7266	1 7754	1 8198	1 8609	1 8992	1 9357	1 9699	2 0026
	Sh			19 73	39 73	59 73	79 73	99 73	129 73	179 73	279 73	379 73	479 73	579 73	679 73	779 73	879 73
90	v	0 0177	4 808	5 055	5 208	5 357	5 504	5 653	5 869	6 220	6 916	7 599	8 272	8 943	9 626	10 29	10 96
(320 27)	h	290 57	1185 4	1197 3	1209 0	1219 8	1230 0	1239 1	1254 5	1279 3	1328 7	1378 1	1427 9	1478 1	1529 5	1581 2	1634 0
	s	0 4641	1 6113	1 6264	1 6408	1 6538	1 6658	1 6763	1 6935	1 7200	1 7689	1 8134	1 8546	1 8929	1 9294	1 9636	1 9964
	Sh			15 87	35 87	55 87	75 87	95 87	125 87	175 87	275 87	375 87	475 87	575 87	675 87	775 87	875 87
95	v	0 0177	4 653	4 773	4 921	5 063	5 205	5 346	5 552	5 886	6 547	7 195	7 834	8 481	9 117	9 751	10 38
(324 13)	h	294 58	1186 4	1196 0	1208 0	1219 0	1229 3	1238 6	1254 0	1278 9	1328 4	1377 8	1427 7	1478 0	1529 4	1581 1	1633 9
	s	0 4692	1 6070	1 6191	1 6339	1 6472	1 6593	1 6700	1 6872	1 7138	1 7623	1 8073	1 8485	1 8869	1 9234	1 9576	1 9904
	Sh			12 17	32 17	52 17	72 17	92 17	122 17	172 17	272 17	372 17	472 17	572 17	672 17	772 17	872 17
100	v	0 0177	4 431	4 520	4 663	4 801	4 936	5 070	5 266	5 589	6 217	6 836	7 448	8 055	8 659	9 262	9 862
(327 83)	h	298 43	1187 3	1194 9	1207 0	1218 3	1228 4	1238 6	1253 7	1278 6	1327 9	1377 5	1427 5	1478 0	1529 2	1581 0	1633 7
	s	0 4741	1 6028	1 6124	1 6273	1 6409	1 6528	1 6645	1 6814	1 7080	1 7568	1 8015	1 8428	1 8814	1 9177	1 9520	1 9847
	Sh			8 62	28 62	48 62	68 62	88 62	118 62	168 62	268 62	368 62	468 62	568 62	668 62	768 62	868 62
105	v	0 0178	4 232	4 292	4 429	4 563	4 691	4 820	5 007	5 316	5 916	6 507	7 090	7 670	8 245	8 819	9 391
(331 38)	h	302 13	1188 2	1193 5	1205 9	1217 2	1227 6	1237 5	1252 9	1278 0	1327 6	1377 4	1427 3	1477 7	1529 2	1580 9	1633 7
	s	0 4787	1 5988	1 6055	1 6208	1 6344	1 6466	1 6580	1 6752	1 7020	1 7511	1 7960	1 8372	1 8757	1 9122	1 9464	1 9791
	Sh			5 21	25 21	45 21	65 21	85 21	115 21	165 21	265 21	365 21	465 21	565 21	665 21	765 21	865 21
110	v	0 0178	4 050	4 084	4 217	4 345	4 469	4 592	4 773	5 069	5 643	6 208	6 765	7 319	7 869	8 417	8 963
(334 79)	h	305 69	1189 0	1192 2	1204 9	1216 4	1226 9	1236 9	1252 4	1277 5	1327 4	1377 1	1427 1	1477 5	1529 1	1580 8	1633 6
	s	0 4832	1 5950	1 5990	1 6147	1 6286	1 6410	1 6525	1 6698	1 6966	1 7460	1 7909	1 8321	1 8706	1 9072	1 9414	1 9742
	Sh				21 92	41 92	61 92	81 92	111 92	161 92	261 92	361 92	461 92	561 92	661 92	761 92	861 92
115	v	0 0179	3 882		4 022	4 146	4 266	4 384	4 558	4 843	5 393	5 935	6 469	6 999	7 525	8 049	8 572
(338 08)	h	309 13	1189 8		1203 8	1215 6	1226 2	1236 3	1251 9	1277 1	1327 1	1376 9	1427 0	1477 4	1528 9	1580 7	1633 6
	s	0 4875	1 5915		1 6088	1 6230	1 6355	1 6471	1 6645	1 6915	1 7410	1 7859	1 8273	1 8658	1 9023	1 9366	1 9695
	Sh				18 74	38 74	58 74	78 74	108 74	158 74	258 74	358 74	458 74	558 74	658 74	758 74	858 74
120	v	0 0179	3 728		3 845	3 963	4 079	4 194	4 361	4 635	5 165	5 685	6 197	6 705	7 210	7 713	8 215
(341 26)	h	312 46	1190 6		1202 7	1214 7	1225 4	1235 7	1251 4	1276 7	1326 8	1376 7	1426 8	1477 2	1528 8	1580 6	1633 5
	s	0 4916	1 5879		1 6028	1 6173	1 6299	1 6417	1 6592	1 6863	1 7359	1 7809	1 8223	1 8608	1 8974	1 9317	1 9646
	Sh				15 66	35 66	55 66	75 66	105 66	155 66	255 66	355 66	455 66	555 66	655 66	755 66	855 66
125	v	0 0179	3 586		3 680	3 796	3 908	4 019	4 181	4 445	4 954	5 454	5 947	6 435	6 920	7 403	7 885
(344 34)	h	315 69	1191 3		1201 6	1213 7	1224 5	1235 0	1250 8	1276 3	1326 5	1376 4	1426 6	1477 1	1528 7	1580 5	1633 4
	s	0 4956	1 5846		1 5973	1 6119	1 6246	1 6367	1 6544	1 6817	1 7314	1 7764	1 8179	1 8565	1 8931	1 9274	1 9603
	Sh				12 69	32 69	52 69	72 69	102 69	152 69	252 69	352 69	452 69	552 69	652 69	752 69	852 69
130	v	0 0180	3 455		3 528	3 641	3 750	3 857	4 013	4 268	4 760	5 242	5 716	6 186	6 653	7 117	7 581
(347 31)	h	318 81	1192 0		1200 4	1212 7	1223 6	1234 3	1250 3	1275 8	1326 1	1376 1	1426 4	1476 9	1528 6	1580 4	1633 3
	s	0 4995	1 5815		1 5918	1 6066	1 6194	1 6317	1 6496	1 6769	1 7267	1 7718	1 8134	1 8520	1 8887	1 9230	1 9559
	Sh				9 79	29 79	49 79	69 79	99 79	149 79	249 79	349 79	449 79	549 79	649 79	749 79	849 79
135	v	0 0180	3 333		3 388	3 497	3 603	3 707	3 859	4 105	4 580	5 045	5 502	5 955	6 405	6 853	7,303
(350 21)	h	321 96	1192 7		1199 2	1211 7	1222 7	1233 6	1249 7	1275 4	1325 8	1375 9	1426 2	1476 8	1528 5	1580 3	1633 2
	s	0 5032	1 5784		1 5864	1 6015	1 6144	1 6269	1 6449	1 6724	1 7223	1 7674	1 8090	1 8476	1 8843	1 9186	1 9515
	Sh				6 97	26 97	46 97	66 97	96 97	146 97	246 97	346 97	446 97	546 97	646 97	746 97	846 97
140	v	0 0180	3 220		3 258	3 364	3 467	3 567	3 715	3 956	4 413	4 862	5 303	5 741	6 176	6 607	7 037
(353 03)	h	324 83	1193 3		1198 0	1210 6	1221 8	1232 9	1249 1	1275 0	1325 5	1375 7	1426 0	1476 6	1528 4	1580 2	1633 2
	s	0 5069	1 5755		1 5813	1 5965	1 6097	1 6225	1 6406	1 6683	1 7183	1 7635	1 8051	1 8437	1 8804	1 9147	1 9476
	Sh				4 24	24 24	44 24	64 24	94 24	144 24	244 24	344 24	444 24	544 24	644 24	744 24	844 24
145	v	0 0181	3 114		3 136	3 240	3 340	3 438	3 581	3 812	4 257	4 692	5 119	5 541	5 961	6 378	6 794
(355 76)	h	327 71	1193 9		1196 7	1209 5	1220 9	1232 2	1248 5	1274 5	1325 1	1375 4	1425 8	1476 5	1528 3	1580 1	1633 1
	s	0 5104	1 5726		1 5760	1 5914	1 6048	1 6178	1 6360	1 6638	1 7139	1 7592	1 8009	1 8396	1 8763	1 9106	1 9435
	Sh					21 57	41 57	61 57	91 57	141 57	241 57	341 57	441 57	541 57	641 57	741 57	841 57
150	v	0 0181	3 016			3 124	3 221	3 317	3 456	3 681	4 112	4 533	4 946	5 355	5 761	6 164	6 567
(358 43)	h	330 53	1194 4			1208 4	1220 0	1231 4	1248 0	1274 1	1324 9	1375 1	1425 6	1476 3	1528 1	1580 0	1633 0
	s	0 5138	1 5698			1 5865	1 6002	1 6133	1 6319	1 6598	1 7101	1 7553	1 7970	1 8357	1 8724	1 9068	1 9397
	Sh					18 98	38 98	58 98	88 98	138 98	238 98	338 98	438 98	538 98	638 98	738 98	838 98
155	v	0 0181	2 921			3 015	3 110	3 203	3 340	3 558	3 976	4 384	4 785	5 181	5 574	5 964	6 354
(361 02)	h	333 27	1195 0			1207 2	1219 1	1230 7	1247 5	1273 6	1324 5	1374 9	1425 4	1476 2	1528 0	1579 9	1632 9
	s	0 5172	1 5671			1 5818	1 5958	1 6091	1 6279	1 6558	1 7062	1 7516	1 7933	1 8321	1 8688	1 9032	1 9361
	Sh					16 45	36 45	56 45	86 45	136 45	236 45	336 45	436 45	536 45	636 45	736 45	836 45
160	v	0 0182	2 834			2 913	3 006	3 097	3 230	3 443	3 849	4 245	4 633	5 018	5 398	5 777	6 155
(363 55)	h	335 95	1195 5			1206 0	1218 3	1230 0	1246 9	1273 2	1324 1	1374 7	1425 2	1476 0	1527 9	1579 8	1632 8
	s	0 5204	1 5646			1 5772	1 5917	1 C052	1 6241	1 6522	1 7026	1 7482	1 7899	1 8287	1 8655	1 8999	1 9328

Sh = superheat, deg F
v = specific volume, cu. ft. per lb.
h = enthalpy, B t u per lb
s = entropy, B t u. per deg. F. per lb.

TABLE XXV
continued

Superheated Steam—(Continued)

Abs Press Lb/Sq In (Sat Temp)		Sat Water	Sat Steam	Temperature—Degrees Fahrenheit 400°	420°	440°	460°	480°	500°	550°	600°	700°	800°	900°	1000°	1100°	1200°
	Sh			33 99	53 99	73 99	93 99	113 99	133 99	183 99	233 99	333 99	433 99	533 99	633 99	733 99	833.99
145	v	0 0182	2 752	2 909	2 997	3 084	3 170	3 251	3 334	3 533	3 729	4 114	4 491	4 864	5 234	5 601	5 967
(360 01)	h	338 55	1195 9	1217 4	1229 3	1241 1	1251 8	1262 4	1272 8	1298 5	1323 8	1374 5	1425 0	1475 9	1527 8	1579 7	1632.7
	s	0 5236	1 5619	1 5874	1 6011	1 6144	1 6262	1 6376	1 6486	1 6747	1 6991	1 7448	1 7865	1.8254	1 8622	1 8966	1.9295
	Sh			31 58	51 58	71 58	91 58	111 58	131 58	181 58	231 58	331 58	431 58	531 58	631 58	731 58	831 58
150	v	0 0182	2 674	2 816	2 903	2 988	3 071	3 151	3 232	3 426	3 617	3 991	4 357	4 720	5 079	5 436	5 791
(368 42)	h	341 11	1196 3	1216 5	1228 4	1240 5	1251 3	1261 8	1272 3	1298 2	1323 5	1374 2	1424 9	1475 7	1527 6	1579 6	1632.7
	s	0 5266	1 5593	1 5832	1 5969	1 6105	1 6224	1 6337	1 6448	1 6711	1 6955	1 7412	1 7831	1 8219	1 8587	1 8931	1 9261
	Sh			29 23	49 23	69 23	89 23	109 23	129 23	179 23	229 23	329 23	429 23	529 23	629.23	729 23	829.23
155	v	0 0182	2 601	2 730	2 814	2 897	2 979	3 057	3 136	3 325	3 510	3 875	4 231	4 584	4 932	5 279	5 625
(370 77)	h	343 61	1196 7	1215 6	1227 6	1239 9	1250 8	1261 3	1271 9	1297 8	1323 2	1374 0	1424 7	1475 6	1527 5	1579 5	1632.6
	s	0 5296	1 5569	1 5793	1 5931	1 6069	1 6189	1 6302	1 6414	1 6677	1 6922	1 7380	1 7799	1 8185	1.8553	1 8897	1 9227
	Sh			26 92	46 92	66 92	86 92	106 92	126 92	176 92	226 92	326 92	426 92	526 92	626 92	726 92	826.92
160	v	0 0183	2 532	2 648	2 731	2 812	2 892	2 968	3 045	3 229	3 410	3 765	4 112	4 455	4 794	5 132	5 468
(373 08)	h	346 07	1197 2	1214 6	1226 8	1239 2	1250 2	1260 8	1271 5	1297 4	1322 8	1373 7	1424 5	1475 5	1527.4	1579 4	1632 5
	s	0 5325	1 5545	1 5751	1 5891	1 6030	1 6151	1 6265	1 6378	1 6641	1 6886	1 7345	1 7765	1 8154	1.8522	1 8866	1 9196
	Sh			24 66	44 66	64 66	84 66	104 66	124 66	174 66	224.66	324 66	424 66	524 66	624 66	724 66	824.66
165	v	0 0183	2 466	2 570	2 651	2 731	2 809	2 884	2 958	3 139	3.315	3 661	3 999	4 333	4 664	4 992	5.319
(3,5 34)	h	348 47	1197 6	1213 7	1226 0	1238 4	1249 6	1260 3	1271 0	1297 4	1322 4	1373 4	1424 3	1475 3	1527 3	1579.3	1632.4
	s	0 5354	1 5522	1 5712	1 5853	1 5992	1.6115	1 6230	1 6343	1 6611	1 6853	1 7312	1 7733	1 8122	1 8491	1 8835	1.9165
	Sh			22 45	42 45	62 45	82 45	102 45	122 45	172 45	222 45	322 45	422 45	522 45	622 45	722 45	822 45
170	v	0 0183	2 404	2 496	2 576	2 654	2 731	2 804	2 877	3 053	3 225	3 563	3 893	4 218	4 540	4 860	5 179
(377 55)	h	350 83	1198 0	1212 7	1225 1	1237 7	1249 0	1259 8	1270 5	1296 6	1322 1	1373 1	1424 1	1475 2	1527.1	1579 2	1632.3
	s	0 5382	1 5501	1 5674	1 5817	1 5959	1 6083	1 6199	1 6312	1 6577	1 6823	1 7282	1 7703	1 8093	1 8461	1 8806	1 9136
	Sh			20 30	40 30	60 30	80 30	100 30	120 30	170 30	220 30	320 30	420 30	520 30	620 30	720 30	820 30
175	v	0 0184	2 344	2 426	2 505	2 581	2 656	2 728	2 799	2 972	3 140	3 470	3 791	4 109	4 423	4 735	5 046
(379 70)	h	353 13	1198 4	1211 7	1224 2	1237 0	1248 3	1259 3	1270 0	1296 2	1321 8	1372 9	1423 9	1475 0	1527 0	1579 1	1632 2
	s	0 5409	1 5479	1 5636	1 5780	1 5924	1 6048	1 6166	1 6279	1 6545	1 6792	1 7252	1 7673	1 8063	1.8432	1.8777	1 9107
	Sh			18 18	38 18	58 18	78 18	98 18	118 18	168 18	218 18	318 18	418 18	518 18	618 18	718 18	818 18
180	v	0 0184	2 288	2 360	2 437	2 512	2 585	2 656	2 726	2 895	3 059	3 381	3 697	4 005	4 311	4 616	4 919
(381 82)	h	355 40	1198 7	1210 8	1223 7	1236 3	1247 9	1258 7	1269 4	1295 6	1321 4	1372 5	1423 9	1474 9	1526 6	1579 0	1632.1
	s	0 5436	1 5457	1 5599	1 5748	1 5889	1 6017	1 6133	1 6245	1.6511	1 6761	1.7221	1 7646	1 8035	1.8402	1.8749	1 9079
	Sh			16 11	36 11	56 11	76 11	96 11	116 11	166 11	216 11	316 11	416 11	516 11	616 11	716 11	816.11
185	v	0 0184	2 235	2 297	2 372	2 446	2 518	2 587	2 656	2 821	2 982	3 297	3 604	3 906	4 205	4 502	4 798
(383 89)	h	357 61	1199 0	1209 7	1222 5	1235 4	1247 1	1258 2	1269 0	1295 4	1321 0	1372 4	1423 5	1474 7	1526 8	1578 9	1632 1
	s	0 5462	1 5436	1 5562	1 5709	1 5854	1 5983	1 6102	1 6216	1 6484	1 6731	1 7194	1 7616	1.8007	1.8377	1.8722	1.9053
	Sh			14 07	34 07	54 07	74 07	94 07	114 07	164 07	214 07	314 07	414 07	514 07	614 07	714 07	814 07
190	v	0 0184	2 183	2 237	2 311	2 384	2 454	2 522	2 589	2 751	2 909	3 216	3 516	3 812	4 104	4 395	4 683
(385 93)	h	359 80	1199 4	1208 8	1221 8	1234 7	1246 5	1257 7	1268 5	1295 0	1320 7	1372 1	1423 3	1474 6	1526 6	1578 8	1632 0
	s	0 5488	1.5417	1 5527	1 5676	1 5821	1 5951	1 6071	1 6185	1 6454	1 6702	1 7165	1 7588	1 7980	1 8349	1 8695	1.9022
	Sh			12 07	32 07	52 07	72 07	92 07	112 07	162 07	212 07	312 07	412.07	512 07	612 07	712 07	812 07
195	v	0 0185	2 134	2 179	2 252	2 324	2 393	2 460	2 526	2 685	2 839	3 140	3 433	3 722	4 008	4 292	4 574
(387.93)	h	361 95	1199 6	1207 8	1221 0	1234 0	1245 9	1257 2	1268 0	1294 6	1320 4	1371 9	1423 1	1474 4	1526 5	1578 7	1631 9
	s	0.5513	1.5395	1.5491	1 5643	1 5789	1 5920	1 6042	1 6156	1 6426	1.6675	1 7139	1 7562	1 7954	1 8324	1.8670	1.9000
	Sh			10 11	30 11	50 11	70 11	90 11	110 11	160 11	210 11	310 11	410 11	510 11	610 11	710 11	810 11
200	v	0 0185	2 086	2 124	2 196	2 267	2 335	2 400	2 465	2 621	2 772	3 067	3 354	3 637	3 916	4 193	4 469
(389.89)	h	364 05	1199 9	1206 8	1220 1	1233 2	1245 2	1256 7	1267 5	1294 1	1320 0	1371 6	1422 9	1474 2	1526 4	1578 6	1631 8
	s	0 5538	1.5376	1 5457	1 5610	1 5757	1 5889	1 6013	1 6127	1 6397	1 6647	1 7112	1 7536	1 7928	1 8298	1 8644	1.8974
	Sh			8 19	28 19	48 19	68 19	88 19	108 19	158 19	208 19	308 19	408 19	508 19	608 19	708 19	808.19
205	v	0 0185	2 042	2 072	2 142	2 212	2 279	2 344	2 407	2 560	2 708	2 997	3 278	3 555	3 828	4 100	4 369
(391 81)	h	366 11	1200 2	1205 8	1219 2	1232 3	1244 5	1256 2	1267 1	1293 7	1319 6	1371 4	1422 7	1474 1	1526 3	1578 5	1631
	s	0 5562	1 5358	1 5423	1 5577	1 5724	1 5858	1 5984	1 6099	1 6369	1 6619	1 7086	1 7510	1 7902	1 8272	1 8618	1 894
	Sh			6 30	26 30	46 30	66 30	86 30	106 30	156 30	206 30	306 30	406 30	506 30	606 30	706 30	806 3
210	v	0 0186	1 9989	2 021	2 091	2 160	2 226	2 289	2 352	2 502	2 647	2 930	3 205	3 477	3 744	4 010	4.27
(393 70)	h	368 16	1200 4	1204 9	1218 3	1231 6	1243 8	1255 6	1266 7	1293 3	1319 3	1371 1	1422 5	1474 0	1526 2	1578 4	1631.
	s	0 5585	1 5337	1 5390	1 5514	1 5693	1 5827	1 5954	1 6071	1 6341	1 6592	1 7059	1 7484	1 7877	1 8247	1.8593	1.892
	Sh			4 44	24 44	44 44	64 44	84 44	104 44	154 44	204 44	304 44	404 44	504 44	604 44	704 44	804 4
215	v	0 0186	1 9573	1 973	2 042	2 110	2 175	2 237	2 298	2 446	2 589	2 866	3 136	3 402	3 664	3.924	4 18
(395.56)	h	370 17	1200 7	1203 9	1217 5	1230 8	1243 2	1255 0	1266 2	1292 9	1319 0	1370 9	1422 3	1473 8	1526 0	1578 3	1631.
	s	0 5609	1 5320	1 5357	1 5513	1 5662	1 5798	1 5925	1 6043	1.6314	1.6566	1.7034	1 7459	1 7852	1 8222	1.8568	1 889
	Sh				22 60	42 60	62 60	82 60	102 60	152 60	202 60	302 60	402 60	502 60	602 60	702 60	802.6
220	v	0 0186	1 9176		1 995	2 062	2 126	2 187	2 247	2 392	2 532	2 805	3 069	3 330	3 586	3 841	4 09
(397 40)	h	372 16	1200 9		1216 6	1230 0	1242 5	1254 4	1265 7	1292 5	1318 6	1370 5	1422 1	1473 6	1525 9	1578 2	1631
	s	0 5632	1.5301		1.5482	1 5633	1 5770	1 5898	1.6017	1 6289	1 6541	1 7009	1 7435	1.7828	1 8199	1.8545	1.887
	Sh				20 80	40 80	60 80	80 80	100 80	150 80	200 80	300 80	400 80	500 80	600 80	700 80	800 8
225	v	0.0186	1 8797		1 950	2 015	2 078	2 139	2 198	2 341	2 479	2 746	3 006	3 261	3 513	3 762	4.01
(399 20)	h	374 11	1201 1		1215 6	1229 1	1241 8	1253 8	1265 2	1292 0	1318 3	1370 3	1421 9	1473 5	1525 8	1578 1	1631
	s	0 5654	1 5283		1 5450	1 5602	1 5742	1 5871	1 5991	1 6263	1 6517	1 6985	1 7411	1 7805	1 8176	1 8522	1 885

Sh = superheat, deg. F.
v = specific volume, cu. ft. per lb.
h = enthalpy, B t u per lb
s = entropy, B t.u per deg. F. per lb.

TABLE XXV
continued

Superheated Steam—(Continued)

Abs Press. Lb /Sq In (Sat Temp)		Sat Water	Sat Steam	Temperature—Degrees Fahrenheit 420°	440°	460°	480°	500°	520°	550°	600°	700°	800°	900°	1000°	1100°	1200°
	Sh			19 03	39 03	59 03	79 03	99 03	119 03	149 03	199 03	299 03	399 03	499 03	599 03	699 03	799 03
250	v	0 0187	1 8431	1 9065	1 9711	2 0334	2 0932	2 1515	2 2085	2 2920	2 4272	2 6897	2 9444	3 1949	3 4416	3 6867	3 9299
(400.97)	h	376 04	1201 4	1214 6	1228 3	1241 0	1253 2	1264 7	1274 5	1291 6	1317 9	1370 0	1421 7	1473 3	1525 6	1578 0	1631 3
	s	0 5677	1 5267	1 5419	1 5573	1 5713	1 5844	1 5965	1 6066	1 6238	1 6492	1 6961	1 7388	1.7782	1 8153	1 8500	1 8831
	Sh			17 29	37 29	57 29	77 29	97 29	117 29	147 29	197 29	297 29	397 29	497 29	597 29	697 29	797 29
255	v	0 0187	1 8079	1 8686	1 9286	1 9899	2 0489	2 1065	2 1626	2 2447	2 3776	2 6354	2 8855	3 1313	3 3733	3 6128	3 8524
(402 71)	h	377 91	1201 6	1213 7	1227 5	1240 3	1252 6	1264 2	1274 2	1291 2	1317 5	1369 8	1421 5	1473 2	1525 5	1577 9	1631 2
	s	0 5698	1 5249	1 5388	1 5543	1 5684	1 5816	1 5938	1 6041	1 6212	1 6466	1 6937	1 7364	1 7759	1 8130	1 8477	1 8808
	Sh			15 57	35 57	55 57	75 57	95 57	115 57	145 57	195 57	295 57	395 57	495 57	595 57	695 57	795 57
260	v	0 0187	1 7742	1 8246	1 8876	1 9482	2 0063	2 0631	2 1185	2 1991	2 3299	2 5833	2 8289	3 0701	3 3077	3 5437	3 7778
(404 43)	h	379 78	1201 8	1212 8	1226 6	1239 5	1252 0	1263 6	1273 8	1290 8	1317 1	1369 5	1421 3	1473 0	1525 4	1577 8	1631 1
	s	0 5720	1 5233	1 5359	1 5514	1.5656	1 5790	1 5912	1 6017	1 6188	1 6442	1 6914	1 7342	1 7737	1 8109	1 8456	1 8787
	Sh			13 88	33 88	53 88	73 88	93 88	113 88	143 88	193 88	293 88	393 88	493 88	593 88	693 88	793 88
265	v	0 0187	1 7416	1 7858	1 8481	1 9080	1 9654	2 0213	2 0759	2 1554	2 2840	2 5331	2 7744	3 0114	3 2446	3 4761	3 7061
(406 12)	h	381 62	1202 0	1211 9	1225 7	1239 7	1251 2	1263 0	1273 4	1290 4	1316 8	1369 3	1421 1	1472 9	1525 3	1577 7	1631 1
	s	0 5741	1 5217	1 5330	1 5485	1 5628	1 5762	1 5886	1 5993	1 6164	1 6419	1 6892	1 7320	1 7715	1 8087	1 8434	1 8765
	Sh			12 21	32 21	52 21	72 21	92 21	112 21	142 21	192 21	292 21	392 21	492 21	592 21	692 21	792 21
270	v	0 0188	1 7101	1 7486	1 8101	1 8692	1 9259	1 9810	2 0350	2 1131	2 2399	2 4847	2 7219	2 9548	3 1838	3 4112	3 6370
(407 79)	h	383 43	1202 2	1211 0	1224 9	1238 0	1250 6	1262 5	1273 0	1290 0	1316 4	1369 0	1420 9	1472 7	1525 1	1577 6	1631 0
	s	0 5761	1.5200	1 5301	1 5457	1 5601	1 5736	1 5861	1 5969	1 6140	1 6395	1 6869	1 7298	1 7693	1 8065	1 8413	1 8744
	Sh			10 56	30 56	50 56	70 56	90 56	110 56	140 56	190 56	290 56	390 56	490 56	590 56	690 56	790 56
275	v	0 0188	1.6798	1 7127	1 7735	1 8318	1 8879	1 9422	1 9956	2 0725	2 1973	2 4382	2 6714	2 9002	3 1253	3 3486	3 5704
(409 44)	h	385 22	1202 3	1210 0	1224 1	1237 3	1250 0	1262 0	1272 6	1289 5	1316 1	1368 7	1420 7	1472 6	1525 0	1577 5	1630 9
	s	0 5782	1 5183	1 5271	1 5429	1 5574	1 5711	1 5837	1 5946	1 6116	1 6373	1 6847	1 7277	1 7673	1 8045	1 8393	1 8724
	Sh			8 94	28 94	48 94	68 94	88 94	108 94	138 94	188 94	288 94	388 94	488 94	588 94	688 94	788 94
280	v	0 0188	1 6504	1 6780	1 7381	1 7957	1 8512	1 9048	1 9575	2 0334	2 1562	2 3932	2 6226	2 8475	3 0688	3 2883	3 5062
(411.06)	h	386 99	1202 5	1209 0	1223 2	1236 5	1249 4	1261 5	1272 2	1289 1	1315 7	1368 5	1420 5	1472 4	1524 9	1577 4	1630 8
	s	0 5802	1 5167	1 5241	1 5401	1 5547	1 5686	1 5813	1 5923	1 6093	1 6350	1 6826	1 256	1 7652	1 8024	1 8372	1 8703
	Sh			7 34	27 34	47 34	67 34	87 34	107 34	137 34	187 34	287 34	387 34	487 34	587 34	687 34	787 34
285	v	0 0188	1 6232	1 6446	1 7040	1 7610	1 8157	1 8687	1 9207	1 9955	2 1165	2 3499	2 5756	2 7968	3 0143	3 2300	3 4443
(412 66)	h	388 74	1202 7	1208 0	1222 3	1235 6	1248 7	1260 9	1271 8	1288 6	1315 4	1368 2	1420 3	1472 2	1524 7	1577 3	1630 7
	s	0 5822	1 5153	1 5214	1 5375	1 5521	1 5662	1 5790	1 5902	1 6071	1 6330	1 6806	1 7237	1 7633	1 8005	1 8353	1 8684
	Sh			5 76	25 76	45 76	65 76	85 76	105 76	135 76	185 76	285 76	385 76	485 76	585 76	685 76	785 76
290	v	0 0189	1 5947	1 6122	1 6710	1 7273	1 7815	1 8338	1 8853	1 9590	2 0783	2 3080	2 5302	2 7478	2 9616	3 1738	3 3844
(414 24)	h	390 47	1202 9	1207 0	1221 4	1234 8	1248 0	1260 4	1271 4	1288 2	1315 0	1367 9	1420 1	1472 1	1524 6	1577 2	1630 6
	s	0 5841	1 5137	1 5184	1 5346	1 5493	1 5635	1 5766	1 5879	1 6048	1 6307	1 6784	1 7215	1 7612	1 7984	1 8332	1 8663
	Sh			4 20	24 20	44 20	64 20	84 20	104 20	134 20	184 20	284 20	384 20	484 20	584 20	684 20	784 20
295	v	0 0189	1 5684	1 5809	1 6391	1 6948	1 7484	1 8001	1 8510	1 9236	2 0413	2 2677	2 4863	2 7004	2 9103	3 1195	3 3267
(415 80)	h	392 17	1203 0	1206 1	1220 5	1234 0	1247 4	1259 8	1271 0	1287 8	1314 7	1367 6	1419 9	1472 0	1524 5	1577 1	1630 5
	s	0 5861	1 5122	1 5157	1 5319	1 5467	1 5611	1 5742	1 5857	1 6026	1 6286	1 6763	1 7195	1 7593	1 7965	1 8313	1 8644
	Sh			2 67	22 67	42 67	62 67	82 67	102 67	132 67	182 67	282 67	382 67	482 67	582 67	682 67	782 67
300	v	0 0189	1 5426	1 5506	1 6082	1 6634	1 7164	1 7677	1 8172	1 8896	2 0056	2 2286	2 4447	2 6547	2 8634	3 0670	3 2707
(417 33)	h	393 85	1203 2	1205 2	1219 5	1233 4	1246 6	1259 2	1270 5	1287 4	1314 4	1367 4	1419 7	1471 8	1524 4	1577 0	1630 4
	s	0 5879	1 5107	1 5130	1 5291	1 5443	1 5585	1 5718	1 5834	1 6004	1 6265	1 6742	1 7175	1 7572	1 7945	1 8294	1 8625
	Sh				19 65	39 65	59 65	79 65	99 65	129 65	179 65	279 65	379 65	479 65	579 65	679 65	779 65
310	v	0 0189	1 4933		1 5495	1 6036	1 6555	1 7054	1 7546	1 8246	1 9375	2 1541	2 3631	2 5675	2 7682	2 9671	3 1645
(420 35)	h	397 16	1203 5		1217 8	1231 5	1245 3	1258 0	1269 6	1286 4	1313 5	1366 9	1419 3	1471 5	1524 1	1576 8	1630 3
	s	0 5917	1 5079		1 5240	1 5391	1 5539	1 5673	1 5793	1 5962	1 6224	1 6705	1 7138	1 7536	1 7909	1 8258	1 8590
	Sh				16 71	36 71	56 71	76 71	96 71	126 71	176 71	276 71	376 71	476 71	576 71	676 71	776 71
320	v	0 0190	1 4479		1 4943	1 5473	1 5982	1 6472	1 6954	1 7637	1 8737	2 0844	2 2874	2 4857	2 6804	2 8735	3 0643
(423 29)	h	400 40	1203 8		1216 0	1229 9	1244 0	1256 8	1268 6	1285 6	1312 8	1366 3	1418 9	1471 2	1523 8	1576 6	1630 1
	s	0 5953	1.5052		1 5189	1 5342	1 5494	1 5629	1 5751	1 5922	1 6185	1 6667	1 7102	1 7501	1 7874	1 8224	1 8556
	Sh				13 84	33 84	53 84	73 84	93 84	123 84	173 84	273 84	373 84	473 84	573 84	673 84	773 84
330	v	0 0190	1 4048		1 4424	1 4944	1 5445	1 5925	1 6397	1 7064	1 8138	2 0189	2 2163	2 4090	2 5981	2 7855	2 9712
(426 16)	h	403 56	1204 0		1214 1	1228 2	1242 5	1255 5	1267 6	1284 7	1312 1	1365 8	1418.4	1470 8	1523 6	1576 4	1630 0
	s	0 5988	1 5023		1 5136	1 5291	1 5445	1 5582	1 5707	1 5879	1 6144	1 6628	1 7063	1 7463	1 7837	1 8187	1 8520
	Sh				11 04	31 04	51 04	71 04	91 04	121 04	171 04	271 04	371 04	471 04	571 04	671 04	771 04
340	v	0 0191	1 3640		1 3935	1 4446	1 4936	1 5409	1 5872	1 6525	1 7573	1 9572	2 1493	2 3368	2 5206	2 7027	2 8831
(428 96)	h	406 65	1204 2		1212 2	1226 5	1241 0	1254 2	1266 6	1283 8	1311 4	1365 2	1418 0	1470 5	1523 3	1576 2	1629 8
	s	0.6023	1 4997		1 5086	1 5243	1 5399	1 5538	1 5666	1 5839	1 6106	1 6591	1 7027	1 7428	1 7802	1 8152	1 8485
	Sh				8 29	28 29	48 29	68 29	88 29	118 29	168 29	268 29	368 29	468 29	568 29	668 29	768 29
350	v	0 0191	1 3255		1 3472	1 3976	1 4460	1 4923	1 5377	1 6016	1 7041	1 8991	2 0863	2 2687	2 4475	2 6246	2 8000
(431.71)	h	409 70	1204 4		1210 3	1224 8	1239 5	1252 9	1265 5	1282 9	1310 6	1364 7	1417 6	1470 2	1523 0	1576 0	1629 6
	s	0.6057	1.4972		1 5038	1 5197	1 5355	1 5496	1 5626	1.5801	1 6069	1.6556	1 6993	1.7395	1 7769	1 8120	1 8453
	Sh				5 61	25 61	45 61	65 61	85 61	115 61	165 61	265 61	365 61	465 61	565 61	665 61	765 61
360	v	0 0192	1 2889		1 3035	1 3532	1 4008	1 4463	1 4909	1 5536	1 6538	1 8441	2 0266	2 2044	2 3784	2 5506	2 7213
(434 39)	h	412 67	1204 5		1208 5	1223 1	1238 0	1251 5	1264 5	1282 0	1309 9	1364 1	1417 2	1469 9	1522 8	1575 8	1629 4
	s	0.6080	1.4946		1.4991	1 5151	1 5311	1 5453	1 5587	1 5763	1 6033	1 6521	1 6960	1 7362	1.7737	1 8088	1.8421

Sh = superheat, deg F
v = specific volume, cu. ft. per lb.
h = enthalpy, B t u per lb
s = entropy, B.t.u. per deg. F. per lb.

TABLE XXV
continued

Superheated Steam—(Continued)

Abs Press. Lb./Sq. In. (Sat. Temp.)		Sat. Water	Sat Steam	Temperature—Degrees Fahrenheit 460°	480°	500°	520°	540°	560°	580°	600°	700°	800°	900°	1000°	1100°	1200°
	Sh			22 99	42 99	62 99	82 99	102 99	122 99	142 99	162 99	262 99	362 99	462 99	562 99	662 99	762 99
370	v	0 0192	1 2545	1 3111	1 3579	1 4028	1 4466	1 4881	1 5286	1 5675	1 6063	1 7921	1 9703	2 1435	2 3131	2 4809	2 6471
(437.01)	h	415 58	1204 6	1221 4	1236 5	1250 2	1263 4	1275 2	1286 7	1298 3	1309 1	1363 6	1416 8	1469 6	1522 5	1575 6	1629 2
	s	0 6122	1 4921	1 5106	1 5268	1 5412	1 5548	1 5667	1 5781	1 5894	1 5997	1 6488	1 6928	1 7331	1 7706	1 8058	1 8391
	Sh			20 41	40 41	60 41	80 41	100 41	120 41	140 41	160 41	260 41	360 41	460 41	560 41	660 41	760 41
380	v	0 0193	1 2217	1 2711	1 3173	1 3614	1 4045	1 4452	1 4850	1 5232	1 5612	1 7428	1 9168	2 0859	2 2512	2 4148	2 5768
(439.59)	h	418 45	1204 7	1219 8	1235 0	1248 8	1262 3	1274 2	1286 0	1297 5	1308 4	1363 0	1416 4	1469 2	1522 2	1575 4	1629 1
	s	0 6154	1 4897	1 5063	1 5226	1 5371	1 5510	1 5630	1 5747	1 5859	1 5963	1 6455	1 6896	1 7299	1 7675	1 8027	1 8361
	Sh			17 89	37 89	57 89	77 89	97 89	117 89	137 89	157 89	257 89	357 89	457 89	557 89	657 89	757 89
390	v	0 0193	1 1904	1 2332	1 2788	1 3222	1 3647	1 4046	1 4436	1 4812	1 5184	1 6961	1 8661	2 0311	2 1925	2 3521	2 5101
442.11)	h	421 27	1204 8	1218 0	1233 4	1247.4	1261 2	1273 2	1285 1	1296 7	1307 7	1362 5	1416 0	1468 9	1522 0	1575 2	1628 9
	s	0 6184	1 4872	1 5017	1 5183	1 5330	1 5472	1 5593	1 5711	1 5824	1 5929	1 6423	1 6365	1 7269	1 7646	1 7998	1 8332
	Sh			15 42	35 42	55 42	75 42	95 42	115 42	135 42	155 42	255 42	355 42	455 42	555 42	655 42	755 42
400	v	0 0193	1 1609	1 1972	1 2422	1 2849	1 3269	1 3660	1 4042	1 4413	1 4777	1 6522	1 8179	1 9796	2 1367	2 2926	2 4475
(444 58)	h	424 02	1204 9	1216 5	1231 6	1245 9	1259 9	1272 4	1284 3	1295 8	1307.0	1362 1	1415 5	1468 6	1521 5	1574 8	1628.8
	s	0 6215	1.4850	1 4977	1 5140	1 5290	1 5434	1 5561	1 5678	1 5790	1 5897	1 6393	1 6835	1 7240	1 7615	1 7968	1 8304
	Sh			13 00	33 00	53 00	73 00	93 00	113 00	133 00	153 00	253 00	353 00	453 00	553 00	653 00	753 00
410	v	0 0194	1 1327	1 1628	1 2071	1 2494	1 2906	1 3291	1 3669	1 4033	1 4390	1 6095	1 7722	1 9297	2 0887	2.2359	2 3864
(447.00)	h	426 74	1205 0	1214 6	1230 2	1244 5	1258 8	1271.2	1283 5	1295 1	1306 2	1361 4	1415 1	1468 3	1521 4	1574 8	1628 6
	s	0 6244	1.4828	1.4933	1.5101	1 5252	1 5399	1 5524	1 5646	1 5759	1 5865	1 6362	1 6806	1 7212	1 7589	1 7943	1 8277
	Sh			10 62	30 62	50 62	70 62	90 62	110 62	130 62	150 62	250 62	350 62	450 62	550 62	650 62	750 62
420	v	0 0194	1 1058	1 1300	1 1738	1 2156	1 2561	1 2942	1 3312	1 3671	1 4021	1 5693	1 7285	1 8826	2 0332	2 1819	2 3290
(449 38)	h	429 42	1205 0	1213 0	1228 6	1243 1	1257 5	1270 2	1282 6	1294 3	1305 4	1360 8	1414 6	1468 0	1521 2	1574 6	1628 4
	s	0 6273	1 4805	1 4892	1 5060	1 5213	1 5361	1 5489	1 5612	1 5726	1 5832	1 6331	1 6776	1 7184	1 7561	1 7915	1 8249
	Sh			8 28	28 28	48 28	68 28	88 28	108 28	128 28	148 28	248 28	348 28	448 28	548 28	648 28	748 28
430	v	0 0195	1 0800	1 0986	1 1419	1 1834	1 2233	1 2607	1 2972	1 3326	1 3670	1 5309	1 6869	1 8377	1 9850	2 1305	2 2742
(451.72)	h	432 05	1205 0	1211 2	1227 0	1241 7	1256 3	1269 1	1281 8	1293 5	1304 6	1360 3	1414 2	1467 6	1520 9	1574 4	1628 2
	s	0.6302	1 4782	1 4850	1 5020	1 5175	1 5326	1 5455	1 5581	1 5695	1 5801	1 6303	1 6748	1.7156	1 7534	1 7888	1 8222
	Sh			5 99	25 99	45 99	65 99	85 99	105 99	125 99	145 99	245 99	345 99	445 99	545 99	645 99	745.99
440	v	0 0195	1 0554	1 0688	1 1116	1 1524	1 1918	1 2288	1 2648	1 2996	1 3334	1 4943	1 6472	1 7949	1 9390	2 0814	2 2220
(454.01)	h	434 63	1205 0	1209 6	1225 3	1240 2	1255 0	1268 0	1280 9	1292 6	1303 9	1359 7	1413 8	1467 3	1520 6	1574 1	1628 0
	s	0 6330	1 4762	1 4812	1 4981	1 5138	1 5291	1 5422	1 5550	1 5664	1 5772	1 6275	1 6722	1 7130	1 7508	1 7862	1 8197
	Sh			3 73	23 73	43 73	63 73	83 73	103 73	123 73	143 73	243 73	343 73	443 73	543 73	643 73	743 73
450	v	0 0195	1 0318	1 0401	1 0824	1 1230	1 1617	1 1982	1 2337	1 2681	1 3013	1 4593	1.6092	1 7539	1 8951	2 0345	2 1720
(456 27)	h	437 18	1205 0	1207 9	1223 7	1238 7	1253 8	1266 9	1280 0	1291 8	1303 1	1359 1	1413 4	1467 0	1520 3	1573 9	1627 8
	s	0 6357	1.4739	1.4771	1 4941	1 5099	1 5255	1 5387	1 5517	1 5632	1 5740	1 6245	1 6694	1 7103	1 7481	1.7836	1 8171
	Sh				21 52	41 52	61 52	81 52	101 52	121 52	141 52	241 52	341 52	441 52	541 52	641 52	741.52
460	v	0 0196	1 0092		1 0545	1 0946	1 1329	1 1690	1 2039	1 2379	1 2706	1 4258	1 5729	1 7147	1 8530	1 9896	2 1243
(458.48)	h	439 69	1205 0		1222 0	1237 2	1252 5	1265 8	1279 0	1291 0	1302 3	1358 6	1413 0	1466 6	1520 0	1573 7	1627 7
	s	0 6384	1.4719		1 4902	1 5062	1 5220	1 5354	1 5485	1 5602	1 5710	1 6217	1.6667	1 7076	1 7455	1.7811	1 8146
	Sh				19 34	39 34	59 34	79 34	99 34	119 34	139 34	239 34	339 34	439 34	539 34	639 34	739 34
470	v	0 0196	0 9875		1 0278	1 0676	1 1053	1 1410	1 1755	1 2091	1 2412	1 3937	1 5381	1 6772	1 8127	1 9466	2 0785
(460.66)	h	442 17	1205 0		1220 2	1235 7	1251 2	1264 7	1278 0	1290 0	1301 5	1358 0	1412 5	1466 3	1519 8	1573 5	1627 5
	s	0 6411	1.4699		1 4862	1 5025	1 5185	1 5321	1 5453	1 5570	1 5680	1 6189	1 6639	1 7050	1 7429	1.7785	1 8120
	Sh				17 20	37 20	57 20	77 20	97 20	117 20	137 20	237 20	337 20	437 20	537 20	637 20	737 20
480	v	0 0197	0 9668		1 0021	1 0416	1 0789	1 1141	1 1482	1 1813	1 2131	1 3630	1 5049	1 6413	1 7742	1 9054	2 0347
(462 80)	h	444 60	1205 0		1218 6	1234 2	1249 9	1263 5	1277 0	1289 1	1300 8	1357 5	1412 1	1466 0	1519 5	1573 3	1627.3
	s	0 6436	1 4679		1 4825	1 4989	1 5151	1 5288	1 5422	1 5539	1 5650	1 6161	1 6612	1 7023	1 7402	1 7758	1 8093
	Sh				15 09	35 09	55 09	75 09	95 09	115 09	135 09	235 09	335 09	435 09	535 09	635 09	735 09
490	v	0 0197	0 9466		0 9774	1 0166	1 0535	1 0884	1 1220	1 1548	1 1860	1 3335	1 4729	1 5067	1 7371	1 8659	1 9927
(464.91)	h	447 00	1204 9		1217 0	1232 7	1248 4	1262 3	1276 0	1288 3	1300 0	1356 9	1411 7	1465 6	1519 2	1573 1	1627 1
	s	0 6462	1 4659		1 4789	1 4954	1 5116	1 5256	1 5392	1 5511	1 5622	1 6135	1 6588	1 6999	1 7379	1 7736	1.8071
	Sh				13 00	33 00	53 00	73 00	93 00	113 00	133 00	233 00	333 00	433 00	533 00	633 00	733 00
500	v	0.0197	0 9274		0 9538	0 9926	1 0290	1 0636	1 0969	1 1292	1 1600	1 3051	1 4417	1 5735	1 7016	1 8280	1.9532
(467 00)	h	449 40	1204 9		1215 3	1231 4	1246 6	1261 1	1275 0	1287 3	1299 3	1356 3	1411 2	1465 1	1518 8	1572 9	1627 3
	s	0 6488	1.4641		1 4752	1 4922	1 5079	1 5225	1 5363	1 5482	1 5596	1 6110	1 6564	1 6975	1 7356	1 7714	1.8052
	Sh				10 95	30 95	50 95	70 95	90 95	110 95	130 95	230 95	330 95	430 95	530 95	630 95	730 95
510	v	0 0198	0 9090		0 9310	0 9695	1 0056	1 0397	1 0727	1 1046	1 1350	1 2780	1 4127	1.5418	1 6675	1 7915	1 9135
(469.05)	h	451 75	1204 8		1213 5	1229 6	1245 6	1259 9	1274 0	1286 6	1298 4	1355 7	1410 9	1465 0	1518 7	1572 6	1626 8
	s	0 6513	1.4621		1 4714	1.4883	1 5048	1 5192	1 5332	1 5454	1.5566	1 6082	1 6538	1 6951	1 7332	1 7689	1 8026
	Sh				8 93	28 93	48 93	68 93	88 93	108 93	128 93	228 93	328 93	428 93	528 93	628 93	728 93
520	v	0 0198	0 8812		0 9091	0 9472	0 9829	1 0169	1 0494	1 0810	1 1110	1 2519	1 3844	1 5113	1 6347	1.7565	1 8763
(471.07)	h	454 07	1204.7		1211 8	1228 1	1244 2	1258 6	1272 9	1285 6	1297 6	1355 1	1410 4	1464 6	1518 4	1572 4	1626 6
	s	0 6537	1 4601		1 4677	1 4849	1 5015	1 5160	1 5302	1 5425	1 5539	1 6057	1 6514	1 6928	1 7310	1.7668	1 8005
	Sh				6 95	26 95	46 95	66 95	86 95	106 95	126 95	226 95	326 95	426 95	526 95	626 95	726 95
530	v	0 0199	0 8741		0 8879	0.9258	0 9612	0.9948	1 0269	1 0582	1 0878	1 2267	1 3571	1 4818	1 6031	1 7228	1 8402
(473.05)	h	456 35	1204 6		1210 0	1226 5	1242.8	1257 3	1271 8	1284 8	1296 8	1354 6	1410 0	1464 3	1518.1	1572 2	1626.4
	s	0 6562	1.4584		1 4642	1 4816	1 4984	1 5130	1 5274	1 5400	1 5514	1 6035	1 6493	1 6908	1 7290	1 7648	1 7985

Sh = superheat, deg. F.
v = specific volume, cu. ft. per lb.
h = enthalpy, B.t.u. per lb.
s = entropy, B.t.u. per deg. F. per lb.

TABLE XXV
continued

Superheated Steam—(Continued)

Abs Press Lb /Sq In (Sat Temp)		Sat Water	Sat Steam	Temperature—Degrees Fahrenheit 500°	520°	540°	560°	580°	600°	650°	700°	750°	800°	900°	1000°	1100°	1200°
	Sh			24 98	44 98	64 98	84 98	104 98	124 98	174 98	224 98	274 98	324 98	424 98	524 98	624 98	724 98
540	v	0 0199	0 8576	0 9051	0 9401	0 9736	1 0054	1 0363	1 0665	1 1356	1 2025	1 2671	1 3309	1 4535	1 5727	1 6903	1 8056
(475 02)	h	458 62	1204 5	1225 0	1241 4	1256 1	1270 7	1283 8	1296 0	1325 6	1354 0	1382 1	1409 6	1463 9	1517 8	1572 0	1626 2
	s	0 6585	1 4565	1 4781	1 4950	1 5098	1 5243	1 5370	1 5486	1 5759	1 6009	1 6246	1 6469	1 6884	1 7266	1 7625	1 7962
	Sh			23 06	43 06	63 06	83 06	103 06	123 06	173 06	223 06	273 06	323 06	423 06	523 06	623 06	723 06
550	v	0 0199	0 8416	0 8851	0 9198	0 9530	0 9846	1 0151	1 0441	1 1132	1 1791	1 2428	1 3055	1 4262	1 5434	1 6590	1 7724
(476 94)	h	460 83	1204 4	1223 4	1240 0	1254 8	1269 6	1282 9	1295 2	1324 9	1353 5	1381 6	1409 2	1463 6	1517 5	1571 7	1626 0
	s	0 6609	1 4548	1 4748	1 4919	1 5068	1 5215	1 5344	1 5461	1 5735	1 5987	1 6224	1 6447	1 6862	1 7244	1 7603	1 7940
	Sh			21 15	41 15	61 15	81 15	101 15	121 15	171 15	221 15	271 15	321 15	421 15	521 15	621 15	721 15
560	v	0 0200	0 8253	0 8658	0 9003	0 9332	0 9644	0 9947	1 0233	1 0917	1 1566	1 2193	1 2810	1 3998	1 5151	1 6289	1 7403
(478 85)	h	463 04	1204 3	1221 8	1238 5	1253 5	1268 5	1282 0	1294 4	1324 2	1352 9	1381 1	1408 7	1463 2	1517 2	1571 5	1625 8
	s	0 6632	1 4530	1 4714	1 4886	1 5034	1 5187	1 5318	1 5436	1 5711	1 5964	1 6202	1 6425	1 6841	1 7224	1 7584	1 7921
	Sh			19 27	39 27	59 27	79 27	99 27	119 27	169 27	219 27	269 27	319 27	419 27	519 27	619 27	719 27
570	v	0 0200	0 8114	0 8472	0 8814	0 9141	0 9450	0 9749	1 0033	1 0708	1 1348	1 1966	1 2575	1 3744	1 4879	1 5998	1 7093
(480 73)	h	465 22	1204 1	1220 2	1236 9	1252 2	1267 3	1281 0	1293 5	1323 5	1352 3	1380 6	1408 3	1462 9	1517 0	1571 3	1625 6
	s	0 6655	1 4512	1 4681	1 4853	1 5008	1 5156	1 5291	1 5410	1 5686	1 5940	1 6179	1 6403	1 6820	1 7204	1 7564	1 7901
	Sh			17 42	37 42	57 42	77 42	97 42	117 42	167 42	217 42	267 42	317 42	417 42	517 42	617 42	717 42
580	v	0 0201	0 7968	0 8291	0 8631	0 8956	0 9263	0 9558	0 9839	1 0506	1 1137	1 1747	1 2347	1 3498	1 4616	1 5714	1 6794
(482 58)	h	467 37	1204 0	1218 6	1235 5	1250 9	1266 1	1280 0	1292 6	1322 8	1351 6	1380 0	1407 8	1462 5	1516 7	1571 0	1625 4
	s	0 6677	1 4494	1 4648	1 4822	1 4978	1 5128	1 5264	1 5384	1 5662	1 5916	1 6156	1 6381	1 6799	1 7183	1 7543	1 7881
	Sh			15 59	35 59	55 59	75 59	95 59	115 59	165 59	215 59	265 59	315 59	415 59	515 59	615 59	715 59
590	v	0 0201	0 7831	0 8116	0 8455	0 8778	0 9082	0 9373	0 9653	1 0310	1 0934	1 1535	1 2128	1 3262	1 4360	1 5442	1 6505
(484 41)	h	469 50	1203 8	1217 0	1234 0	1249 6	1265 0	1278 9	1291 8	1322 1	1351 1	1379 5	1407 4	1462 2	1516 4	1570 8	1625 3
	s	0 6699	1 4477	1 4616	1 4791	1 4949	1 5101	1 5236	1 5359	1 5638	1 5894	1 6134	1 6360	1 6778	1 7162	1 7522	1 7861
	Sh			13 79	33 79	53 79	73 79	93 79	113 79	163 79	213 79	263 79	313 79	413 79	513 79	613 79	713 79
600	v	0 0201	0 7695	0 7945	0 8284	0 8605	0 8907	0 9194	0 9471	1 0123	1 0738	1 1332	1 1915	1 3032	1 4115	1 5179	1 6224
(486 21)	h	471 59	1203 6	1215 6	1232 5	1248 3	1263 7	1278 1	1290 9	1321 4	1350 5	1379 0	1407 0	1461 8	1516 0	1570 5	1625 0
	s	0 6721	1 4460	1 4586	1 4760	1 4920	1 5072	1 5212	1 5334	1 5615	1 5871	1 6112	1 6339	1 6757	1 7141	1 7502	1 7841
	Sh			12 01	32 01	52 01	72 01	92 01	112 01	162 01	212 01	262 01	312 01	412 01	512 01	612 01	712 01
610	v	0 0202	0 7565	0 7781	0 8120	0 8436	0 8736	0 9022	0 9296	0 9942	1 0548	1 1135	1 1708	1 2809	1 3878	1 4928	1 5964
(487 99)	h	473 67	1203 5	1213 8	1230 9	1246 9	1262 5	1276 8	1290 0	1320 6	1350 0	1378 5	1406 5	1461 5	1515 8	1570 3	1624 9
	s	0 6743	1 4444	1 4552	1 4728	1 4890	1 5044	1 5183	1 5309	1 5591	1 5850	1 6091	1 6318	1 6738	1 7123	1 7484	1 7823
	Sh			10 25	30 25	50 25	70 25	90 25	110 25	160 25	210 25	260 25	310 25	410 25	510 25	610 25	710 25
620	v	0 0202	0 7438	0 7622	0 7960	0 8275	0 8572	0 8856	0 9127	0 9765	1 0364	1 0943	1 1505	1 2598	1 3648	1 4677	1 5707
(489 75)	h	475 72	1203 3	1212 2	1229 5	1245 5	1261 3	1275 8	1289 1	1319 9	1349 3	1377 9	1406 1	1461 2	1515 5	1570 1	1624 7
	s	0 6764	1 4427	1 4520	1 4698	1 4860	1 5016	1 5157	1 5284	1 5568	1 5827	1 6068	1 6296	1 6717	1 7102	1 7464	1 7803
	Sh			8 51	28 51	48 51	68 51	88 51	108 51	158 51	208 51	258 51	308 51	408 51	508 51	608 51	708 51
630	v	0 0202	0 7316	0 7466	0 7802	0 8117	0 8413	0 8694	0 8963	0 9595	1 0187	1 0757	1 1312	1 2387	1 3423	1 4445	1 5449
(491 49)	h	477 75	1203 1	1210 6	1227 8	1244 1	1260 1	1274 7	1288 3	1319 2	1348 7	1377 4	1405 7	1460 8	1515 2	1569 9	1624 5
	s	0 6785	1 4410	1 4488	1 4665	1 4830	1 4988	1 5130	1 5260	1 5545	1 5805	1 6047	1 6276	1 6697	1 7083	1 7445	1.7784
	Sh			6 79	26 79	46 79	66 79	86 79	106 79	156 79	206 79	256 79	306 79	406 79	506 79	606 79	706 79
640	v	0 0203	0 7197	0 7317	0 7651	0 7963	0 8258	0 8537	0 8804	0 9429	1 0015	1 0578	1 1124	1 2187	1 3210	1 4213	1 5193
(493 21)	h	479 79	1202 9	1209 0	1226 3	1242 7	1258 9	1273 6	1287 4	1318 5	1348 2	1376 8	1405 2	1460 5	1515 0	1569 7	1624 3
	s	0 6806	1 4394	1 4458	1 4636	1 4802	1 4962	1 5105	1 5236	1 5523	1 5785	1 6026	1 6256	1 6678	1 7065	1 7427	1 7766
	Sh			5 10	25 10	45 10	65 10	85 10	105 10	155 10	205 10	255 10	305 10	405 10	505 10	605 10	705 10
650	v	0 0203	0 7082	0 7171	0 7504	0 7816	0 8107	0 8384	0 8648	0 9269	0 9846	1 0404	1 0944	1 1988	1 2999	1 3987	1 4958
(494 90)	h	481 73	1202 7	1207 3	1224 8	1241 3	1257 6	1272 5	1286 5	1317 8	1347 6	1376 3	1404 7	1460 1	1514 7	1569 4	1624 1
	s	0 6826	1 4379	1 4427	1 4607	1 4774	1 4935	1 5080	1 5213	1 5501	1 5764	1 6006	1 6236	1 6659	1 7046	1 7408	1 7748
	Sh			3 42	23 42	43 42	63 42	83 42	103 42	153 42	203 42	253 42	303 42	403 42	503 42	603 42	703 42
660	v	0 0204	0 6969	0 7031	0 7361	0 7672	0 7962	0 8237	0 8499	0 9113	0 9686	1 0234	1 0769	1 1803	1 2797	1 3774	1 4727
(496 58)	h	483 77	1202 5	1205 7	1223 2	1240 0	1256 4	1271 4	1285 5	1317 1	1347 0	1375 8	1404 3	1459 7	1514 4	1569 2	1624 0
	s	0 6847	1 4363	1 4396	1 4576	1 4746	1 4908	1 5054	1 5188	1 5479	1 5742	1 5985	1 6216	1 6639	1 7027	1 7390	1.7730
	Sh			1 77	21 77	41 77	61 77	81 77	101 77	151 77	201 77	251 77	301 77	401 77	501 77	601 77	701 77
670	v	0 0204	0 6861	0 6892	0 7224	0 7531	0 7820	0 8093	0 8354	0 8963	0 9527	1 0072	1 0599	1 1617	1 2600	1 3560	1 4503
(498.23)	h	485 61	1202 3	1204 0	1221 7	1238 7	1255 1	1270 2	1284 5	1316 3	1346 3	1375 3	1403 9	1459 4	1514 1	1569 0	1623 8
	s	0 6867	1 4349	1 4367	1 4549	1 4721	1 4883	1 5030	1 5166	1 5459	1 5723	1 5968	1 6200	1 6624	1 7012	1 7376	1 7716
	Sh				20 13	40 13	60 13	80 13	100 13	150 13	200 13	250 13	300 13	400 13	500 13	600 13	700 13
680	v	0 0204	0 6757		0 7089	0 7397	0 7683	0 7954	0 8212	0 8814	0 9375	0 9912	1 0432	1 1440	1 2408	1 3357	1 4287
(499 87)	h	487 64	1202 1		1220 2	1237 3	1253 9	1269 1	1283 6	1315 6	1345 8	1374 7	1403 4	1459 0	1513 8	1568 7	1623 6
	s	0 6886	1 4332		1 4519	1 4692	1 4856	1 5004	1 5142	1 5437	1 5703	1 5947	1 6179	1 6603	1 6992	1 7356	1 7697
	Sh				18 51	38 51	58 51	78 51	98 51	148 51	198 51	248 51	298 51	398 51	498 51	598 51	698 51
690	v	0 0205	0 6652		0 6956	0 7263	0 7549	0 7818	0 8075	0 8675	0 9225	0 9758	1 0272	1 1267	1 2223	1 3162	1 4087
(501 49)	h	489 56	1201 8		1218 5	1235 8	1252 5	1268 0	1282 7	1314 9	1345 1	1374 2	1402 8	1458 7	1513 6	1568 5	1623 4
	s	0 6906	1 4316		1 4488	1 4663	1 4828	1 4978	1 5118	1 5415	1 5681	1 5927	1 6159	1 6586	1.6975	1 7339	1 7689
	Sh				16 91	36 91	56 91	76 91	96 91	146 91	196 91	246 91	296 91	396 91	496 91	596 91	696 91
700	v	0 0205	0 6552		0 6830	0 7133	0 7419	0 7687	0 7941	0 8534	0 9084	0 9608	1 0117	1 1096	1 2043	1 2965	1 3871
(503 09)	h	491 49	1201 6		1217 1	1234 7	1251 3	1266 8	1281 9	1314 3	1344 6	1373 7	1402 5	1458 2	1513 4	1568 2	1623 1
	s	0 6925	1 4301		1 4461	1 4638	1 4803	1 4953	1 5097	1 5396	1 5663	1 5908	1 6141	1 6567	1 6958	1 7321	1 7665

Sh = superheat, deg F
v = specific volume, cu ft. per lb.
h = enthalpy, B t u per lb
s = entropy, B t u per deg. F. per lb.

TABLE XXV
continued

Superheated Steam—(Continued)

Abs Press. Lb/Sq In (Sat. Temp)		Sat Water	Sat Steam	Temperature—Degrees Fahrenheit 520°	540°	560°	580°	600°	620°	650°	700°	750°	800°	900°	1000°	1100°	1200°
	Sh			12 99	32 99	52 99	72 99	92 99	112 99	142 99	192 99	242 99	292 99	392 99	492 99	592 99	692 99
725	v	0 0206	0 6314	0 6524	0 6827	0 7109	0 7373	0 7624	0 7864	0 8203	0 8740	0 9250	0 9745	1 0697	1 1612	1 2511	1 3393
(507 01)	h	496 2	1200 9	1212 8	1230 9	1248 0	1264 0	1279 1	1293 8	1312 3	1343 0	1372 3	1401 3	1457 4	1512 5	1567 7	1622 7
	s	0 6973	1 4263	1 4385	1 4568	1 4737	1 4892	1 5036	1 5173	1 5342	1 5612	1 5859	1 6094	1 6522	1 6913	1 7279	1 7621
	Sh			9 17	29 17	49 17	69 17	89 17	109 17	139 17	189 17	239 17	289 17	389 17	489 17	589 17	689 17
750	v	0 0207	0 6091	0 6237	0 6538	0 6818	0 7080	0 7326	0 7561	0 7896	0 8419	0 8918	0 9399	1 0326	1 1212	1 2078	1 2928
(510 83)	h	500 8	1200 2	1208 8	1227 4	1244 9	1261 0	1276 6	1291 4	1310 5	1341 5	1371 0	1400 2	1456 5	1511 8	1567 1	1622 3
	s	0 7019	1 4225	1 4313	1 4501	1 4674	1 4830	1 4979	1 5117	1 5291	1 5564	1 5813	1 6049	1 6479	1 6871	1 7237	1 7580
	Sh			5 43	25 43	45 43	65 43	85 43	105 43	135 43	185 43	235 43	285 43	385 43	485 43	585 43	685 43
775	v	0 0208	0 5882	0 5969	0 6268	0 6545	0 6803	0 7047	0 7278	0 7607	0 8119	0 8606	0 9073	0 9977	1 0838	1 1676	1 2505
(514.57)	h	505 3	1199 5	1204 7	1223 7	1241 5	1258 2	1271 9	1285 0	1308 6	1340 0	1369 7	1399 0	1455 6	1511 1	1566 6	1621 8
	s	0 7064	1 4189	1 4242	1 4434	1 4610	1 4772	1 4902	1 5062	1 5241	1 5518	1 5769	1 6006	1 6438	1 6832	1 7200	1 7543
	Sh			1 80	21 80	41 80	61 80	81 80	101 80	131 80	181 80	231 80	281 80	381 80	481 80	581 80	681 80
800	v	0 0209	0 5685	0 5714	0 6013	0 6288	0 6545	0 6785	0 7013	0 7336	0 7838	0 8313	0 8770	0 9648	1 0486	1 1302	1 2105
(518.20)	h	509 7	1198 8	1200 3	1220 0	1238 2	1255 3	1271 4	1286 5	1306 8	1338 4	1368 5	1397 8	1454 9	1510 5	1566 0	1621 4
	s	0 7108	1 4155	1 4170	1 4369	1 4549	1 4715	1 4868	1 5009	1 5195	1 5473	1 5727	1 5964	1 6400	1 6794	1 7162	1 7506
	Sh				18 25	38 25	58 25	78 25	98 25	128 25	178 25	228 25	278 25	378 25	478 25	578 25	678 25
825	v	0 0210	0 5500		0 5774	0 6046	0 6300	0 6539	0 6763	0 7081	0 7573	0 8038	0 8483	0 9338	1 0155	1 0950	1 1727
(521.75)	h	514 0	1198 0		1216 1	1234 9	1252 1	1268 5	1284 0	1304 8	1336 8	1367 0	1396 6	1453 8	1509 7	1565 4	1620 8
	s	0 7152	1 4121		1 4304	1 4490	1 4657	1 4813	1 4958	1 5148	1 5430	1 5685	1 5925	1 6362	1 6758	1 7127	1 7471
	Sh				14 77	34 77	54 77	74 77	94 77	124 77	174 77	224 77	274 77	374 77	474 77	574 77	674 77
850	v	0 0210	0 5326		0 5545	0 5817	0 6070	0 6306	0 6528	0 6841	0 7323	0 7779	0 8213	0 9048	0 9845	1 0619	1 1375
(525 23)	h	518.3	1197 2		1212 4	1231 5	1249 1	1265 7	1281 4	1302 9	1335 2	1365 7	1395 4	1452 8	1509 0	1564 8	1620 4
	s	0 7194	1 4087		1 4240	1 4429	1 4600	1 4758	1 4905	1 5101	1 5386	1 5643	1 5883	1 6321	1 6720	1 7090	1 7435
	Sh				11 38	31 38	51 38	71 38	91 38	121 38	171 38	221 38	271 38	371 38	471 38	571 38	671 38
875	v	0 0211	0 5162		0 5327	0 5601	0 5851	0 6085	0 6305	0 6615	0 7087	0 7535	0 7960	0 8773	0 9554	1 0306	1 1045
(528.62)	h	522 4	1196 4		1208 4	1228 0	1246 0	1263 0	1279 0	1300 9	1333 5	1364 4	1394 2	1451 9	1508 3	1564 3	1619 9
	s	0 7236	1 4056		1 4177	1 4371	1 4546	1 4708	1 4858	1 5058	1 5345	1 5606	1 5847	1 6287	1 6687	1 7058	1 7403
	Sh				8 06	28 06	48 06	68 06	88 06	118 06	168 06	218 06	268 06	368 06	468 06	568 06	668 06
900	v	0 0212	0 5006		0 5123	0 5394	0 5644	0 5876	0 6094	0 6399	0 6866	0 7304	0 7720	0 8516	0 9277	1 0010	1 0727
(531 94)	h	526 6	1195 6		1204 0	1224 2	1242 6	1260 0	1276 5	1298 6	1331 8	1363 0	1392 9	1451 1	1507 8	1563 7	1619 3
	s	0 7276	1 4022		1 4106	1 4306	1 4484	1 4649	1 4803	1 5004	1 5296	1 5559	1 5801	1 6245	1 6647	1 7017	1 7362
	Sh				4 80	24 80	44 80	64 80	84 80	114 80	164 80	214 80	264 80	364 80	464 80	564 80	664 80
925	v	0 0213	0 4858		0 4927	0 5199	0 5448	0 5678	0 5894	0 6196	0 6655	0 7085	0 7494	0 8272	0 9014	0 9731	1 0432
(535 20)	h	530 6	1194 7		1200 0	1220 8	1239 6	1257 0	1273 9	1296 7	1330 2	1361 7	1391 7	1450 0	1506 9	1563 1	1618 9
	s	0 7316	1 3991		1 4044	1 4250	1 4433	1 4599	1 4757	1 4965	1 5260	1 5526	1 5769	1 6214	1 6618	1 6990	1 7337
	Sh				1 62	21 62	41 62	61 62	81 62	111 62	161 62	211 62	261 62	361 62	461 62	561 62	661 62
950	v	0 0214	0 4717		0 4741	0 5014	0 5262	0 5491	0 5705	0 6003	0 6456	0 6877	0 7277	0 8039	0 8766	0 9465	1 0148
(538 38)	h	534 6	1193 8		1195 8	1217 0	1236 4	1254 1	1271 3	1294 5	1328 5	1360 3	1390 5	1449 1	1506 1	1562 6	1618 5
	s	0 7355	1 3960		1 3980	1 4190	1 4378	1 4547	1 4708	1 4920	1 5220	1 5488	1 5733	1 6180	1 6584	1 6958	1 7305
	Sh					18 50	38 50	58 50	78 50	108 50	158 50	208 50	258 50	358 50	458 50	558 50	658 50
975	v	0 0215	0 4583			0 4835	0 5083	0 5311	0 5524	0 5820	0 6266	0 6680	0 7073	0 7820	0 8533	0 9214	0 9880
(541 50)	h	538 5	1192 9			1213 0	1233 0	1251 2	1268 7	1292 1	1326 7	1358 8	1389 2	1448 2	1505 4	1562 0	1618 0
	s	0 7393	1 3929			1 4128	1 4322	1 4495	1 4659	1 4873	1 5178	1 5449	1 5695	1 6145	1 6551	1 6926	1 7274
	Sh					15 44	35 44	55 44	75 44	105 44	155 44	205 44	255 44	355 44	455 44	555 44	655 44
1000	v	0 0216	0 4456			0 4665	0 4914	0 5141	0 5351	0 5639	0 6085	0 6492	0 6879	0 7611	0 8306	0 8974	0 9626
(544 56)	h	542 4	1191 9			1208 8	1229 4	1248 2	1265 8	1289 6	1324 9	1357 2	1388 0	1447 3	1504 7	1561 3	1617 5
	s	0 7431	1 3899			1 4066	1 4266	1 4445	1 4610	1 4827	1 5138	1 5411	1 5660	1 6113	1 6520	1 6895	1 7244
	Sh					12 43	32 43	52 43	72 43	102 43	152 43	202 43	252 43	352 43	452 43	552 43	652 43
1025	v	0 0217	0 4334			0 4498	0 4751	0 4978	0 5188	0 5479	0 5913	0 6314	0 6695	0 7413	0 8095	0 8746	0 9384
(547 57)	h	546.1	1191.0			1204 5	1225 9	1245 2	1263 0	1287 6	1323 1	1355 7	1386 8	1446 4	1504 1	1560 6	1617 0
	s	0 7468	1 3871			1 4004	1 4212	1 4396	1 4562	1 4787	1 5100	1 5375	1 5627	1 6082	1 6491	1 6866	1 7216
	Sh					9 48	29 48	49 48	69 48	99 48	149 46	199 48	249 48	349 48	449 48	549 48	649 48
1050	v	0 0218	0 4219			0 4345	0 4596	0 4822	0 5031	0 5320	0 5749	0 6143	0 6519	0 7223	0 7892	0 8531	0 9154
(550 52)	h	550 0	1190 0			1200 5	1222 4	1241 9	1260 2	1285 1	1321 3	1354 2	1385 8	1445 4	1503 4	1560 3	1616 5
	s	0 7504	1 3839			1 3942	1 4155	1 4341	1 4512	1 4739	1 5058	1 5336	1 5590	1 6047	1 6458	1 6833	1 7184
	Sh					6 58	26 58	46 58	66 58	96 58	146 58	196 58	246 58	346 58	446 58	546 58	646 58
1075	v	0 0219	0 4108			0 4195	0 4446	0 4672	0 4879	0 5169	0 5592	0 5980	0 6349	0 7042	0 7696	0 8322	0 8933
(553.42)	h	553.7	1188.9			1196 3	1218 7	1238 8	1257 2	1282 8	1319 4	1352 6	1384 1	1444 3	1502 5	1559 3	1615 9
	s	0 7540	1 3810			1 3883	1 4100	1 4292	1 4464	1 4698	1 5020	1 5300	1 5555	1 6015	1 6428	1 6804	1 7156
	Sh					3 74	23 74	43 74	63 74	93 74	143 74	193 74	243 74	343 74	443 74	543 74	643 74
1100	v	0 0219	0 4002			0 4054	0 4304	0 4530	0 4736	0 5027	0 5445	0 5828	0 6190	0 6871	0 7511	0 8125	0 8724
(556.26)	h	557.4	1187.8			1192 3	1214 9	1235 6	1254 5	1280 6	1317 8	1351 3	1383 0	1443 6	1501 7	1558 7	1615 4
	s	0 7575	1 3780			1 3824	1 4044	1 4241	1 4418	1 4656	1 4984	1 5267	1 5523	1 5986	1 6398	1 6776	1 7128
	Sh						20 93	40 93	60 93	90 93	140 93	190 93	240 93	340 93	440 93	540 93	640 93
1125	v	0 0220	0 3902				0 4167	0 4392	0 4598	0 4883	0 5301	0 5678	0 6036	0 6706	0 7333	0 7938	0 8524
(559.07)	h	561.0	1186 7				1211 3	1232.2	1251 5	1277 7	1315 9	1349 6	1381 7	1442 6	1500 8	1558 2	1614 9
	s	0 7610	1 3752				1 3991	1 4190	1 4370	1 4610	1 4946	1 5231	1 5491	1 5956	1 6369	1 6749	1 7101

Sh = superheat, deg. F.
v = specific volume, cu. ft. per lb.
h = enthalpy, B t u. per lb
s = entropy, B t u per deg F. per lb.

TABLE XXV
continued

Superheated Steam (Continued)

Abs Press Lb/Sq In (Sat Temp)		Sat Water	Sat Steam	Temperature—Degrees Fahrenheit 580°	600°	620°	640°	660°	680°	700°	720°	750°	800°	900°	1000°	1100°	1200°
	Sh			18 19	38 19	58 19	78 19	98 19	118 19	138 19	158 19	188 19	238 19	338 19	438 19	538 19	638 19
1150	v	0 0221	0 3804	0 4035	0 4259	0 4468	0 4659	0 4839	0 5005	0 5165	0 5317	0 5537	0 5889	0 6549	0 7166	0 7760	0 8333
(561.81)	h	564 6	1185 6	1207 4	1228 7	1248 6	1266 9	1284 4	1299 5	1314 1	1327 9	1348 1	1380 4	1441 7	1500 2	1557 8	1614 5
	s	0 7644	1 3723	1 3934	1 4137	1 4323	1 4491	1 4649	1 4783	1 4910	1 5028	1 5197	1 5458	1 5926	1 6341	1 6723	1 7075
	Sh			15 46	35 46	55 46	75 46	95 46	115 46	135 46	155 46	185 46	235 46	335 46	435 46	535 46	635 46
1175	v	0 0222	0 3710	0 3911	0 4133	0 4339	0 4530	0 4708	0 4874	0 5032	0 5183	0 5400	0 5747	0 6396	0 7005	0 7586	0 8149
(564 54)	h	568 2	1184 4	1203 6	1225 4	1245 4	1264 6	1281 5	1297 3	1312 1	1326 1	1346 4	1379 0	1440 6	1499 4	1557 0	1614 0
	s	0 7678	1 3694	1 3880	1 4088	1 4275	1 4451	1 4603	1 4743	1 4872	1 4991	1 5161	1 5425	1 5896	1 6313	1 6694	1 7048
	Sh			12 81	32 81	52 81	72 81	92 81	112 81	132 81	152 81	182 81	232 81	332 81	432 81	532 81	632 81
1200	v	0 0223	0 3620	0 3793	0 4013	0 4219	0 4408	0 4585	0 4750	0 4907	0 5056	0 5271	0 5613	0 6251	0 6853	0 7423	0 7971
(567 19)	h	571 7	1183 2	1200 2	1222 1	1242 6	1261 5	1279 2	1295 3	1310 3	1324 4	1345 0	1377 7	1439 5	1499 0	1556 6	1613 6
	s	0 7712	1 3667	1 3831	1 4040	1 4232	1 4405	1 4565	1 4707	1 4838	1 4958	1 5131	1 5395	1 5867	1 6289	1 6671	1 7025
	Sh			10 18	30 18	50 18	70 18	90 18	110 18	130 18	150 18	180 18	230 18	330 18	430 18	530 18	630 18
1225	v	0 0224	0 3534	0 3669	0 3895	0 4102	0 4290	0 4466	0 4631	0 4786	0 4934	0 5146	0 5483	0 6113	0 6702	0 7264	0 7806
(569 82)	h	575 1	1182 0	1195 6	1218 6	1239 7	1258 8	1276 7	1293 3	1308 3	1322 7	1343 3	1376 4	1438 6	1498 0	1556 0	1613 0
	s	0 7745	1 3640	1 3771	1 3990	1 4188	1 4363	1 4524	1 4671	1 4802	1 4925	1 5097	1 5365	1 5840	1 6262	1 6646	1 7006
	Sh			7 61	27 61	47 61	67 61	87 61	107 61	127 61	147 61	177 61	227 61	327 61	427 61	527 61	627 61
1250	v	0 0225	0 3453	0 3549	0 3782	0 3991	0 4177	0 4354	0 4517	0 4672	0 4817	0 5027	0 5360	0 5980	0 6558	0 7113	0 7646
(572 39)	h	578 6	1180 8	1190 9	1215 0	1236 7	1256 0	1274 5	1291 2	1306 6	1321 0	1341 9	1375 2	1437 7	1497 2	1555 4	1612 6
	s	0 7777	1 3612	1 3710	1 3939	1 4142	1 4319	1 4486	1 4634	1 4768	1 4891	1 5066	1 5335	1 5813	1 6235	1 6620	1 6979
	Sh			5 07	25 07	45 07	65 07	85 07	105 07	125 07	145 07	175 07	225 07	325 07	425 07	525 07	625 07
1275	v	0 0226	0 3371	0 3437	0 3672	0 3881	0 4068	0 4244	0 4406	0 4560	0 4705	0 4912	0 5241	0 5852	0 6420	0 6966	0 7488
(574 93)	h	582 0	1179 5	1186 5	1211 2	1233 5	1253 3	1272 0	1289 0	1304 6	1319 4	1340 3	1373 9	1436 7	1496 3	1554 7	1612 0
	s	0 7809	1 3584	1 3651	1 3887	1 4095	1 4277	1 4445	1 4596	1 4732	1 4858	1 5033	1 5305	1 5785	1 6207	1 6594	1 6951
	Sh			2 57	22 57	42 57	62 57	82 57	102 57	122 57	142 57	172 57	222 57	322 57	422 57	522 57	622 57
1300	v	0 0227	0 3294	0 3329	0 3567	0 3776	0 3965	0 4140	0 4301	0 4453	0 4598	0 4803	0 5127	0 5730	0 6290	0 6826	0 7340
(577 43)	h	585 4	1178 3	1182 0	1207 7	1230 3	1250 6	1269 6	1287 0	1302 8	1317 8	1338 9	1372 6	1435 8	1495 7	1554 2	1611
	s	0 7840	1 3557	1 3593	1 3837	1 4049	1 4235	1 4406	1 4560	1 4698	1 4826	1 5002	1 5275	1 5758	1 6183	1 6570	1 6929
	Sh				20 11	40 11	60 11	80 11	100 11	120 11	140 11	170 11	220 11	320 11	420 11	520 11	620 11
1325	v	0 0228	0 3220		0 3463	0 3673	0 3863	0 4037	0 4200	0 4350	0 4493	0 4696	0 5016	0 5611	0 6162	0 6689	0 7196
(579 89)	h	588 7	1177 0		1203 8	1227 0	1247 8	1267 0	1285 0	1300 8	1315 9	1337 3	1371 2	1434 8	1494 9	1553 4	1611 1
	s	0 7871	1 3530		1 3789	1 4002	1 4193	1 4366	1 4525	1 4663	1 4792	1 4971	1 5246	1 5731	1 6158	1 6545	1 6904
	Sh				17 68	37 68	57 68	77 68	97 68	117 68	137 68	167 68	217 68	317 68	417 68	517 68	617 68
1350	v	0 0229	0 3147		0 3363	0 3576	0 3766	0 3940	0 4105	0 4252	0 4393	0 4594	0 4911	0 5497	0 6042	0 6559	0 7056
(582 32)	h	592 1	1175 8		1200 0	1223 8	1245 0	1264 6	1283 2	1299 1	1314 2	1335 8	1370 0	1433 8	1494 3	1552 8	1610
	s	0 7902	1 3504		1 3734	1 3957	1 4151	1 4328	1 4492	1 4631	1 4760	1 4941	1 5218	1 5705	1 6134	1 6521	1 6884
	Sh				15 29	35 29	55 29	75 29	95 29	115 29	135 29	165 29	215 29	315 29	415 29	515 29	615 29
1375	v	0 0230	0 3078		0 3266	0 3480	0 3670	0 3847	0 4007	0 4154	0 4295	0 4494	0 4808	0 5387	0 5922	0 6432	0 6926
(584 71)	h	595 3	1174 5		1195 8	1220 2	1242 0	1262 1	1280 7	1296 8	1312 3	1334 1	1368 6	1432 8	1493 2	1552 0	1609
	s	0 7932	1 3477		1 3680	1 3908	1 4108	1 4289	1 4453	1 4593	1 4726	1 4908	1 5188	1 5678	1 6107	1 6496	1 6859
	Sh				12 93	32 93	52 93	72 93	92 93	112 93	132 93	162 93	212 93	312 93	412 93	512 93	612 93
1400	v	0 0231	0 3011		0 3172	0 3388	0 3581	0 3760	0 3914	0 4063	0 4203	0 4401	0 4711	0 5283	0 5811	0 6313	0 6795
(587 07)	h	598 6	1173 2		1191 8	1216 9	1239 2	1260 1	1278 2	1294 9	1310 6	1332 8	1367 4	1431 9	1492 7	1551 7	1609
	s	0 7963	1 3452		1 3629	1 3863	1 4068	1 4256	1 4416	1 4562	1 4696	1 4882	1 5162	1 5654	1 6086	1 6476	1 6839
	Sh				10 60	30 60	50 60	70 60	90 60	110 60	130 60	160 60	210 60	310 60	410 60	510 60	610 60
1425	v	0 0232	0 2947		0 3081	0 3297	0 3491	0 3668	0 3825	0 3972	0 4112	0 4308	0 4616	0 5180	0 5701	0 6195	0 6667
(589 40)	h	601 8	1171 8		1187 7	1213 2	1236 2	1257 2	1275 8	1292 9	1308 9	1331 1	1366 1	1431 0	1491 8	1551 0	1609
	s	0 7992	1 3425		1 3576	1 3814	1 4025	1 4215	1 4379	1 4528	1 4665	1 4850	1 5134	1 5629	1 6061	1 6453	1 6818
	Sh				8 30	28 30	48 30	68 30	88 30	108 30	128 30	158 30	208 30	308 30	408 30	508 30	608 30
1450	v	0 0233	0 2885		0 2991	0 3211	0 3405	0 3580	0 3739	0 3885	0 4025	0 4220	0 4524	0 5082	0 5597	0 6083	0 6547
(591 70)	h	605 0	1170 5		1183 2	1209 7	1233 1	1254 3	1273 5	1290 8	1307 0	1329 7	1364 8	1430 1	1491 3	1550 4	1608
	s	0 8022	1 3401		1 3521	1 3769	1 3984	1 4175	1 4345	1 4493	1 4634	1 4824	1 5108	1 5606	1 6041	1 6432	1 6797
	Sh				6 03	26 03	46 03	66 03	86 03	106 03	126 03	156 03	206 03	306 03	406 03	506 03	606 03
1475	v	0 0234	0 2824		0 2903	0 3126	0 3318	0 3495	0 3654	0 3801	0 3939	0 4129	0 4435	0 4986	0 5493	0 5973	0 6431
(593 97)	h	608 2	1169 1		1178 7	1206 2	1229 7	1251 5	1271 0	1288 8	1305 0	1327 4	1363 5	1429 1	1490 3	1549 8	1608
	s	0 8052	1 3375		1 3466	1 3723	1 3939	1 4135	1 4308	1 4463	1 4601	1 4789	1 5081	1 5582	1 6016	1 6410	1 6775
	Sh				3 80	23 80	43 80	63 80	83 80	103 80	123 80	153 80	203 80	303 80	403 80	503 80	603 80
1500	v	0 0235	0 2765		0 2817	0 3044	0 3236	0 3413	0 3573	0 3721	0 3856	0 4042	0 4349	0 4894	0 5396	0 5869	0 6321
(596 20)	h	611 4	1167 7		1174 2	1202 5	1226 4	1248 5	1268 6	1286 8	1303 0	1325 4	1362 1	1428 1	1489 8	1549 3	1608
	s	0 8081	1 3350		1 3411	1 3676	1 3895	1 4094	1 4272	1 4431	1 4569	1 4757	1 5054	1 5558	1 5995	1 6390	1 6757
	Sh					21 59	41 59	61 59	81 59	101 59	121 59	151 59	201 59	301 59	401 59	501 59	601 59
1525	v	0 0236	0 2708			0 2962	0 3158	0 3335	0 3495	0 3642	0 3777	0 3965	0 4265	0 4804	0 5299	0 5766	0 6217
(598 41)	h	614 5	1166 2			1198 6	1223 5	1245 8	1266 2	1284 7	1301 2	1324 1	1360 7	1427 0	1488 9	1548 6	1607
	s	0 8109	1 3323			1 3626	1 3855	1 4055	1 4236	1 4397	1 4538	1 4730	1 5026	1 5532	1 5971	1 6367	1 6737
	Sh					19 41	39 41	59 41	79 41	99 41	119 41	149 41	199 41	299 41	399 41	499 41	599 41
1550	v	0 0237	0 2653			0 2883	0 3084	0 3261	0 3420	0 3567	0 3702	0 3891	0 4185	0 4719	0 5208	0 5669	0 6111
(600 59)	h	617 7	1164 8			1194 5	1220 5	1243 3	1264 0	1282 7	1299 6	1323 0	1359 4	1426 2	1488 3	1548 2	1607
	s	0 8138	1 3298			1 3576	1 3814	1 4020	1 4203	1 4365	1 4510	1 4706	1 5001	1 5511	1 5951	1 6348	1 6717

Sh = superheat, deg F
v = specific volume, cu ft. per lb
h = enthalpy, B t u per lb.
s = entropy, B t.u. per deg F per lb.

TABLE XXV
continued

Superheated Steam—(Continued)

Abs Press Lb /Sq In (Sat Temp)		Sat Water	Sat Steam	Temperature—Degrees Fahrenheit 620°	640°	660°	680°	700°	720°	740°	760°	780°	800°	900°	1000°	1100°	1200°
	Sh			17 26	37 26	57 26	77 26	97 26	117 26	137 26	157 26	177 26	197 26	297 26	397 26	497 26	597 26
1575	v	0 0238	0 2599	0 2804	0 3008	0 3186	0 3345	0 3492	0 3627	0 3755	0 3877	0 3993	0 4105	0 4633	0 5117	0 5573	0 6010
(602 74)	h	620 8	1163 4	1190 3	1216 9	1240 3	1261 3	1280 5	1297 6	1313 5	1328 8	1343 5	1357 8	1424 9	1487 3	1547 4	1606 2
	s	0 8166	1 3273	1 3524	1,3768	1 3979	1 4165	1 4332	1 4478	1 4612	1 4738	1 4858	1 4972	1 5485	1 5927	1 6325	1 6691
	Sh			15 13	35 13	55 13	75 13	95 13	115 13	135 13	155 13	175 13	195 13	295 13	395 13	495 13	595 13
1600	v	0 0239	0 2548	0 2730	0 2935	0 3114	0 3274	0 3421	0 3555	0 3682	0 3802	0 3919	0 4031	0 4554	0 5032	0 5482	0 5914
(604 87)	h	623 9	1161 9	1186 3	1213 7	1237 6	1258 9	1278 4	1295 7	1311 8	1327 3	1342 2	1356 7	1424 1	1486 8	1547 0	1605 8
	s	0 8195	1 3249	1 3477	1 3728	1 3943	1 4132	1 4302	1 4449	1 4585	1 4713	1 4834	1 4950	1 5465	1 5909	1 6308	1 6674
	Sh			13 03	33 03	53 03	73 03	93 03	113 03	133 03	153 03	173 03	193 03	293 03	393 03	493 03	593 03
1625	v	0 0240	0 2497	0 2656	0 2864	0 3044	0 3203	0 3348	0 3484	0 3610	0 3729	0 3845	0 3957	0 4474	0 4948	0 5391	0 5816
(606 97)	h	627 0	1160 4	1182 1	1210 2	1234 5	1256 2	1275 9	1293 5	1310 0	1325 5	1340 6	1355 2	1423 0	1486 0	1546 3	1605 2
	s	0 8222	1 3223	1 3425	1 3683	1 3902	1 4094	1 4266	1 4416	1 4555	1 4683	1 4806	1 4923	1 5440	1 5887	1 6287	1 6652
	Sh			10 95	30 95	50 95	70 95	90 95	110 95	130 95	150 95	170 95	190 95	290 95	390 95	490 95	590 95
1650	v	0 0241	0 2448	0 2583	0 2794	0 2976	0 3136	0 3280	0 3417	0 3542	0 3661	0 3776	0 3887	0 4399	0 4867	0 5305	0 5724
(609 05)	h	630 0	1158 8	1177 6	1206 8	1231 7	1253 7	1273 6	1291 8	1308 4	1324 1	1339 3	1354 0	1422 1	1485 3	1545 7	1604 7
	s	0 8250	1 3198	1 3373	1 3641	1 3865	1 4060	1 4233	1 4389	1 4528	1 4658	1 4782	1 4899	1 5420	1 5867	1 6268	1 6634
	Sh			8 90	28 90	48 90	68 90	88 90	108 90	128 90	148 90	168 90	188 90	288 90	388 90	488 90	588 90
1675	v	0 0242	0 2401	0 2511	0 2726	0 2909	0 3069	0 3214	0 3350	0 3474	0 3592	0 3706	0 3817	0 4324	0 4787	0 5220	0 5634
(611 10)	h	633 1	1157 2	1173 1	1203 2	1228 7	1251 0	1271 5	1289 7	1306 4	1322 2	1337 5	1352 5	1420 9	1484 4	1545 0	1604 1
	s	0 8278	1 3173	1 3321	1 3597	1 3827	1 4024	1 4203	1 4358	1 4499	1 4629	1 4754	1 4874	1 5396	1 5846	1 6248	1 6615
	Sh			6 88	26 88	46 88	66 88	86 88	106 88	126 88	146 88	166 88	186 88	286 88	386 88	486 88	586 88
1700	v	0 0243	0 2354	0 2441	0 2659	0 2844	0 3006	0 3152	0 3286	0 3411	0 3528	0 3641	0 3750	0 4254	0 4711	0 5139	0 5549
(613 12)	h	636 1	1155 7	1168 1	1199 4	1225 7	1248 4	1269 4	1287 8	1304 7	1320 7	1336 2	1351 2	1420 1	1483 7	1544 4	1603 9
	s	0 8304	1 3147	1 3262	1 3549	1 3786	1 3987	1 4170	1 4327	1 4469	1 4602	1 4728	1 4848	1 5374	1 5825	1 6227	1 6597
	Sh			4 87	24 87	44 87	64 87	84 87	104 87	124 87	144 87	164 87	184 87	284 87	384 87	484 87	584 87
1725	v	0 0244	0 2309	0 2384	0 2593	0 2780	0 2943	0 3088	0 3222	0 3346	0 3463	0 3575	0 3684	0 4183	0 4636	0 5058	0 5464
(615 13)	h	639 1	1154 1	1165 2	1195 6	1222 4	1245 8	1266 8	1285 5	1302 7	1318 9	1334 5	1349 5	1419 0	1482 9	1543 7	1603 4
	s	0 8332	1 3123	1 3226	1 3505	1 3747	1 3954	1 4136	1 4296	1 4441	1 4575	1 4702	1 4822	1 5352	1 5806	1 6208	1 6579
	Sh			2 89	22 89	42 89	62 89	82 89	102 89	122 89	142 89	162 89	182 89	282 89	382 89	482 89	582 89
1750	v	0 0245	0 2265	0 2329	0 2529	0 2718	0 2882	0 3028	0 3162	0 3285	0 3402	0 3514	0 3622	0 4116	0 4564	0 4982	0 5383
(617 11)	h	642 1	1152 5	1162 0	1191 7	1219 2	1243 1	1264 5	1283 6	1300 9	1317 4	1333 1	1348 3	1418 1	1481 2	1543 3	1603 0
	s	0 8359	1 3099	1 3187	1 3460	1 3708	1 3919	1 4105	1 4269	1 4414	1 4550	1 4678	1 4800	1 5333	1 5780	1 6192	1 6562
	Sh				20 93	40 93	60 93	80 93	100 93	120 93	140 93	160 93	180 93	280 93	380 93	480 93	580 93
1775	v	0 0246	0 2222		0 2466	0 2657	0 2822	0 2968	0 3102	0 3225	0 3340	0 3452	0 3559	0 4049	0 4493	0 4906	0 5302
(619 07)	h	645 0	1150 9		1187 6	1216 0	1240 4	1262 1	1281 5	1299 0	1315 5	1331 5	1346 8	1416 9	1481 3	1542 5	1602 3
	s	0 8386	1 3076		1 3413	1 3669	1 3885	1 4074	1 4239	1 4387	1 4523	1 4653	1 4775	1 5311	1 5767	1 6173	1 6544
	Sh				19 00	39 00	59 00	79 00	99 00	119 00	139 00	159 00	179 00	279 00	379 00	479 00	579 00
1800	v	0 0247	0 2180		0 2405	0 2598	0 2764	0 2912	0 3045	0 3168	0 3283	0 3393	0 3499	0 3986	0 4425	0 4834	0 5224
(621 00)	h	648 0	1149 3		1183 7	1212 7	1237 6	1259 8	1279 6	1297 4	1313 9	1329 9	1345 3	1416 0	1480 6	1542 0	1601 8
	s	0 8412	1 3051		1 3367	1 3628	1 3848	1 4041	1 4211	1 4360	1 4497	1 4627	1 4750	1 5290	1 5748	1 6155	1 6526
	Sh				17 08	37 08	57 08	77 08	97 08	117 08	137 08	157 08	177 08	277 08	377 08	477 08	577 08
1825	v	0 0248	0 2139		0 2345	0 2540	0 2708	0 2855	0 2991	0 3112	0 3225	0 3335	0 3441	0 3924	0 4357	0 4763	0 5147
(622 92)	h	650 9	1147 7		1179 5	1209 4	1234 9	1257 3	1277 8	1295 6	1312 2	1328 3	1343 9	1415 0	1479 5	1541 3	1601 1
	s	0 8439	1 3028		1 3319	1 3589	1 3815	1 4009	1 4185	1 4334	1 4471	1 4602	1 4727	1 5270	1 5728	1 6137	1 6508
	Sh				15 18	35 18	55 18	75 18	95 18	115 18	135 18	155 18	175 18	275 18	375 18	475 18	575 18
1850	v	0 0249	0 2099		0 2285	0 2482	0 2651	0 2799	0 2936	0 3056	0 3170	0 3279	0 3384	0 3863	0 4293	0 4695	0 5075
(624 82)	h	653 9	1145 9		1175 1	1205 8	1231 8	1254 8	1275 6	1293 5	1310 5	1326 7	1342 4	1413 9	1479 0	1540 8	1600 8
	s	0 8465	1 3002		1 3269	1 3546	1 3776	1 3976	1 4154	1 4305	1 4445	1 4577	1 4705	1 5248	1 5710	1 6120	1 6492
	Sh				13 31	33 31	53 31	73 31	93 31	113 31	133 31	153 31	173 31	273 31	373 31	473 31	573 31
1875	v	0 0251	0 2060		0 2225	0 2427	0 2597	0 2746	0 2882	0 3003	0 3115	0 3224	0 3328	0 3804	0 4229	0 4626	0 5003
(626 69)	h	656 9	1144 2		1170 5	1202 3	1229 0	1252 3	1273 5	1291 8	1308 7	1325 2	1340 8	1412 9	1478 0	1540 2	1600 3
	s	0 8491	1 2977		1 3218	1 3504	1 3741	1 3943	1 4124	1 4278	1 4418	1 4552	1 4677	1 5227	1 5689	1 6101	1 6475
	Sh				11 45	31 45	51 45	71 45	91 45	111 45	131 45	151 45	171 45	271 45	371 45	471 45	571 45
1900	v	0 0252	0 2022		0 2165	0 2371	0 2543	0 2694	0 2828	0 2950	0 3063	0 3171	0 3274	0 3747	0 4170	0 4562	0 4934
(628 55)	h	659 9	1142 4		1165 6	1198 8	1225 9	1249 8	1271 0	1289 7	1307 0	1323 5	1339 4	1411 9	1477 5	1539 7	1599 8
	s	0 8517	1 2951		1 3163	1 3462	1 3702	1 3910	1 4091	1 4249	1 4392	1 4526	1 4653	1 5207	1 5672	1 6084	1 6457
	Sh				9 62	29 62	49 62	69 62	89 62	109 62	129 62	149 62	169 62	269 62	369 62	469 62	569 62
1925	v	0 0253	0 1985		0 2107	0 2317	0 2491	0 2642	0 2776	0 2898	0 3010	0 3118	0 3221	0 3690	0 4109	0 4497	0 4864
(630 38)	h	662 8	1140 6		1160 9	1195 0	1223 1	1247 3	1268 7	1287 7	1305 1	1321 8	1337 8	1410 7	1476 6	1538 9	1599 0
	s	0 8543	1 2926		1 3111	1 3419	1 3667	1 3878	1 4061	1 4221	1 4364	1 4500	1 4628	1 5185	1 5652	1 6065	1 6438
	Sh				7 80	27 80	47 80	67 80	87 80	107 80	127 80	147 80	167 80	267 80	367 80	467 80	567 80
1950	v	0 0254	0 1949		0 2049	0 2264	0 2440	0 2591	0 2726	0 2848	0 2960	0 3067	0 3170	0 3636	0 4052	0 4436	0 4800
(632 20)	h	665 8	1138 8		1155 8	1191 3	1220 0	1244 8	1266 5	1285 8	1303 4	1320 2	1336 3	1409 7	1476 0	1538 4	1598 8
	s	0 8569	1 2901		1 3056	1 3376	1 3630	1 3846	1 4031	1 4194	1 4339	1 4476	1 4604	1 5165	1 5635	1 6048	1 6424
	Sh				6 00	26 00	46 00	66 00	86 00	106 00	126 00	146 00	166 00	266 00	366 00	466 00	566 00
1975	v	0 0256	0 1913		0 1992	0 2212	0 2391	0 2544	0 2678	0 2798	0 2910	0 3016	0 3117	0 3581	0 3994	0 4376	0 4737
(634 00)	h	668 7	1137 0		1150 5	1187 5	1217 0	1242 4	1264 4	1283 6	1301 5	1318 3	1334 4	1408 4	1475 1	1537 8	1598 4
	s	0 8595	1 2877		1 3000	1 3334	1 3595	1 3816	1 4004	1 4165	1 4313	1 4450	1 4579	1 5144	1 5617	1 6032	1 6409

Sh = superheat, deg F
v = specific volume, cu. ft. per lb.
h = enthalpy, B t u per lb
s = entropy, B t u per deg F per lb

TABLE XXV
continued
Superheated Steam—(Continued)

Abs Press Lb/Sq In (Sat Temp)		Sat Water	Sat Steam	Temperature—Degrees Fahrenheit 660°	680°	700°	720°	740°	760°	780°	800°	820°	850°	900°	1000°	1100°	1200°
	Sh			24 22	44 22	64 22	84 22	104 22	124 22	144 22	164 22	184 22	214 22	264 22	364 22	464 22	564 22
2000	v	0 0257	0 1879	0 2162	0 2344	0 2498	0 2633	0 2752	0 2862	0 2966	0 3067	0 3165	0 3305	0 3528	0 3940	0 4319	0 4678
(635 78)	h	671 7	1135 2	1183 7	1214 3	1240 0	1262 4	1281 8	1299 6	1316 4	1332 7	1348 6	1371 1	1407 2	1473 5	1537 4	1598 6
	s	0 8620	1 2851	1 3289	1 3560	1 3783	1 3975	1 4138	1 4285	1 4422	1 4552	1 4677	1 4851	1 5122	1 5592	1 6015	1 6395
	Sh			22 46	42 46	62 46	82 46	102 46	122 46	142 46	162 46	182 46	212 46	262 46	362 46	462 46	562 46
2025	v	0 0258	0 1845	0 2112	0 2296	0 2452	0 2587	0 2707	0 2816	0 2919	0 3020	0 3116	0 3257	0 3478	0 3887	0 4262	0 4617
(637 54)	h	674 7	1133 3	1179 9	1211 1	1237 5	1260 3	1280 1	1297 9	1314 8	1331 3	1347 1	1370 1	1406 2	1473 8	1537 0	1598 1
	s	0 8646	1 2826	1 3246	1 3523	1 3752	1 3947	1 4114	1 4261	1 4398	1 4530	1 4654	1 4832	1 5103	1 5582	1 6001	1 6380
	Sh			20 71	40 71	60 71	80 71	100 71	120 71	140 71	160 71	180 71	210 71	260 71	360 71	460 71	560 71
2050	v	0 0259	0 1812	0 2062	0 2248	0 2405	0 2541	0 2661	0 2769	0 2872	0 2972	0 3067	0 3208	0 3428	0 3833	0 4205	0 4556
(639 29)	h	677 6	1131 4	1175 7	1207 7	1234 6	1257 9	1278 0	1295 9	1313 0	1329 5	1345 3	1368 6	1405 1	1472 8	1536 2	1597 4
	s	0 8671	1 2800	1 3199	1 3483	1 3717	1 3916	1 4085	1 4233	1 4372	1 4504	1 4628	1 4808	1 5082	1 5562	1 5982	1 6362
	Sh			18 98	38 98	58 98	78 98	98 98	118 98	138 98	158 98	178 98	208 98	258 98	358 98	458 98	558 98
2075	v	0 0261	0 1780	0 2013	0 2200	0 2358	0 2494	0 2615	0 2724	0 2828	0 2927	0 3022	0 3161	0 3374	0 3782	0 4151	0 4499
(641 02)	h	680 5	1129 5	1171 5	1204 3	1231 6	1255 2	1275 7	1294 0	1311 5	1328 1	1344 0	1367 3	1403 1	1472 1	1535 7	1597 0
	s	0 8697	1 2776	1 3154	1 3445	1 3682	1 3884	1 4056	1 4208	1 4350	1 4483	1 4608	1 4788	1 5056	1 5546	1 5967	1 6348
	Sh			17 27	37 27	57 27	77 27	97 27	117 27	137 27	157 27	177 27	207 27	257 27	357 27	457 27	557 27
2100	v	0 0262	0 1748	0 1964	0 2152	0 2310	0 2447	0 2568	0 2679	0 2783	0 2882	0 2977	0 3114	0 3319	0 3730	0 4096	0 4441
(642 73)	h	683 4	1127 6	1167 3	1200 4	1228 2	1252 2	1273 0	1292 0	1309 6	1326 4	1342 6	1365 8	1400 8	1471 0	1534 8	1596 4
	s	0 8722	1 2751	1 3108	1 3401	1 3643	1 3848	1 4023	1 4180	1 4323	1 4458	1 4585	1 4764	1 5027	1 5525	1 5947	1 6330
	Sh			15 57	35 57	55 57	75 57	95 57	115 57	135 57	155 57	175 57	205 57	255 57	355 57	455 57	555 57
2125	v	0 0263	0 1716	0 1918	0 2108	0 2268	0 2406	0 2527	0 2637	0 2739	0 2838	0 2933	0 3070	0 3280	0 3682	0 4045	0 4386
(644 43)	h	686 3	1125 6	1163 0	1197 3	1225 7	1250 2	1271 3	1290 2	1307 8	1324 8	1341 2	1364 7	1400 8	1470 5	1534 5	1596 0
	s	0 8747	1 2726	1 3060	1 3364	1 3611	1 3820	1 3994	1 4151	1 4294	1 4430	1 4559	1 4740	1 5011	1 5505	1 5929	1 6311
	Sh			13 89	33 89	53 89	73 89	93 89	113 89	133 89	153 89	173 89	203 89	253 89	353 89	453 89	553 89
2150	v	0 0265	0 1685	0 1872	0 2064	0 2225	0 2364	0 2485	0 2594	0 2695	0 2793	0 2889	0 3026	0 3240	0 3633	0 3993	0 4331
(646 11)	h	689 2	1123 5	1158 6	1193 7	1222 7	1247 7	1269 1	1288 1	1305 7	1322 7	1339 4	1363 2	1400 5	1469 4	1533 8	1595 3
	s	0 8773	1 2700	1 3015	1 3326	1 3578	1 3792	1 3972	1 4129	1 4272	1 4408	1 4540	1 4723	1 5003	1 5492	1 5918	1 6300
	Sh			12 23	32 23	52 23	72 23	92 23	112 23	132 23	152 23	172 23	202 23	252 23	352 23	452 23	552 23
2175	v	0 0266	0 1655	0 1828	0 2018	0 2182	0 2321	0 2442	0 2552	0 2654	0 2752	0 2847	0 2983	0 3196	0 3587	0 3943	0 4279
(647 77)	h	692 0	1121 5	1154 3	1189 7	1219 8	1244 9	1266 5	1286 1	1304 0	1321 3	1338 0	1361 9	1399 4	1468 9	1533 1	1595 0
	s	0 8798	1 2676	1 2971	1 3284	1 3546	1 3760	1 3942	1 4104	1 4250	1 4388	1 4519	1 4704	1 4985	1 5478	1 5903	1 6288
	Sh			10 58	30 58	50 58	70 58	90 58	110 58	130 58	150 58	170 58	200 58	250 58	350 58	450 58	550 58
2200	v	0 0267	0 1626	0 1773	0 1972	0 2138	0 2277	0 2399	0 2509	0 2612	0 2710	0 2804	0 2939	0 3151	0 3540	0 3893	0 4226
(649 42)	h	695 0	1119 4	1148 0	1185 8	1216 2	1241 8	1263 8	1283 6	1302 9	1319 5	1336 2	1360 3	1398 0	1467 9	1532 3	1594 3
	s	0 8823	1 2649	1 2906	1 3239	1 3504	1 3723	1 3907	1 4072	1 4229	1 4362	1 4494	1 4679	1 4962	1 5458	1 5884	1 6269
	Sh			8 94	28 94	48 94	68 94	88 94	108 94	128 94	148 94	168 94	198 94	248 94	348 94	448 94	548 94
2225	v	0 0269	0 1597	0 1727	0 1931	0 2097	0 2237	0 2360	0 2471	0 2574	0 2671	0 2765	0 2900	0 3109	0 3495	0 3847	0 4175
(651 06)	h	697 9	1117 4	1142 7	1182 1	1213 3	1239 1	1261 7	1282 0	1300 5	1318 0	1335 2	1359 2	1397 0	1467 0	1531 9	1593 7
	s	0 8848	1 2625	1 2852	1 3201	1 3472	1 3693	1 3883	1 4051	1 4201	1 4341	1 4476	1 4661	1 4944	1 5441	1 5871	1 6255
	Sh			7 33	27 33	47 33	67 33	87 33	107 33	127 33	147 33	167 33	197 33	247 33	347 33	447 33	547 33
2250	v	0 0270	0 1569	0 1680	0 1889	0 2055	0 2197	0 2320	0 2432	0 2535	0 2632	0 2726	0 2860	0 3066	0 3449	0 3800	0 4125
(652 67)	h	700 8	1115 3	1137 2	1178 0	1209 7	1236 5	1259 2	1279 8	1298 6	1318 3	1333 5	1357 8	1395 5	1465 8	1531 2	1593 1
	s	0 8873	1 2599	1 2795	1 3156	1 3432	1 3661	1 3852	1 4022	1 4175	1 4317	1 4452	1 4640	1 4922	1 5421	1 5854	1 6239
	Sh			5 73	25 73	45 73	65 73	85 73	105 73	125 73	145 73	165 73	195 73	245 73	345 73	445 73	545 73
2275	v	0 0272	0 1542	0 1630	0 1848	0 2018	0 2159	0 2281	0 2393	0 2496	0 2594	0 2688	0 2821	0 3026	0 3407	0 3755	0 4077
(654 27)	h	703 8	1113 2	1130 8	1174 3	1207 1	1233 9	1256 7	1277 6	1296 8	1314 8	1332 1	1356 5	1394 4	1465 1	1530 7	1592 8
	s	0 8898	1 2573	1 2731	1 3116	1 3401	1 3630	1 3822	1 3995	1 4151	1 4295	1 4431	1 4619	1 4903	1 5405	1 5839	1 6225
	Sh			4 13	24 13	44 13	64 13	84 13	104 13	124 13	144 13	164 13	194 13	244 13	344 13	444 13	544 13
2300	v	0 0274	0 1514	0 1580	0 1807	0 1980	0 2120	0 2241	0 2353	0 2457	0 2556	0 2649	0 2781	0 2986	0 3365	0 3709	0 4029
(655 87)	h	706 7	1111 0	1124 2	1169 9	1204 0	1230 9	1253 9	1275 0	1294 5	1312 9	1330 3	1354 9	1393 2	1464 3	1529 9	1592 2
	s	0 8923	1 2547	1 2665	1 3070	1 3366	1 3596	1 3790	1 3964	1 4123	1 4270	1 4407	1 4597	1 4884	1 5388	1 5823	1 6210
	Sh			2 26	22 26	42 26	62 26	82 26	102 26	122 26	142 26	162 26	192 26	242 26	342 26	442 26	542 26
2325	v	0 0275	0 1488	0 1530	0 1766	0 1941	0 2083	0 2207	0 2319	0 2423	0 2520	0 2613	0 2744	0 2948	0 3324	0 3665	0 3983
(657 74)	h	709 7	1108 8	1117 1	1165 7	1200 4	1228 2	1252 0	1273 2	1293 0	1311 5	1329 0	1353 6	1392 1	1463 5	1529 2	1591 7
	s	0 8948	1 2521	1 2595	1 3025	1 3327	1 3565	1 3765	1 3941	1 4101	1 4249	1 4387	1 4577	1 4866	1 5372	1 5807	1 6196
	Sh			1 00	21 00	41 00	61 00	81 00	101 00	121 00	141 00	161 00	191 00	241 00	341 00	441 00	541 00
2350	v	0 0277	0 1462	0 1479	0 1725	0 1901	0 2046	0 2172	0 2285	0 2389	0 2484	0 2576	0 2706	0 2910	0 3282	0 3621	0 3936
(659 00)	h	712 6	1106 5	1109 7	1161 2	1196 6	1225 2	1249 8	1271 7	1291 6	1309 8	1327 3	1352 1	1391 0	1462 3	1528 3	1590 9
	s	0 8974	1 2495	1 2524	1 2980	1 3287	1 3532	1 3739	1 3920	1 4082	1 4227	1 4365	1 4557	1 4848	1 5354	1 5791	1 6180
	Sh				19 45	39 45	59 45	79 45	99 45	119 45	139 45	159 45	189 45	239 45	339 45	439 45	539 45
2375	v	0 0278	0 1436		0 1686	0 1863	0 2010	0 2137	0 2250	0 2353	0 2450	0 2541	0 2671	0 2873	0 3244	0 3580	0 3892
(660 55)	h	715 6	1104 0		1156 9	1193 0	1222 4	1247 5	1269 5	1289 6	1308 3	1325 8	1350 8	1389 8	1461 7	1527 8	1590 4
	s	0 9000	1 2467		1 2935	1 3249	1 3501	1 3712	1 3893	1 4057	1 4207	1 4344	1 4537	1 4830	1 5340	1 5777	1 6166
	Sh				17 91	37 91	57 91	77 91	97 91	117 91	137 91	157 91	187 91	237 91	337 91	437 91	537 91
2400	v	0 0280	0 1410		0 1646	0 1824	0 1974	0 2101	0 2214	0 2317	0 2415	0 2506	0 2636	0 2836	0 3205	0 3538	0 3848
(662 09)	h	718 5	1101 4		1152 2	1189 1	1219 4	1244 7	1267 1	1287 3	1306 5	1324 2	1349 6	1388 5	1460 8	1526 9	1589 8
	s	0 9025	1 2438		1 2887	1 3208	1 3467	1 3680	1 3865	1 4030	1 4183	1 4323	1 4519	1 4810	1 5323	1 5761	1 6152

Sh = superheat, deg F
v = specific volume, cu. ft. per lb.
h = enthalpy, B t u per lb
s = entropy, B t u per deg F. per lb.

TABLE XXV
continued

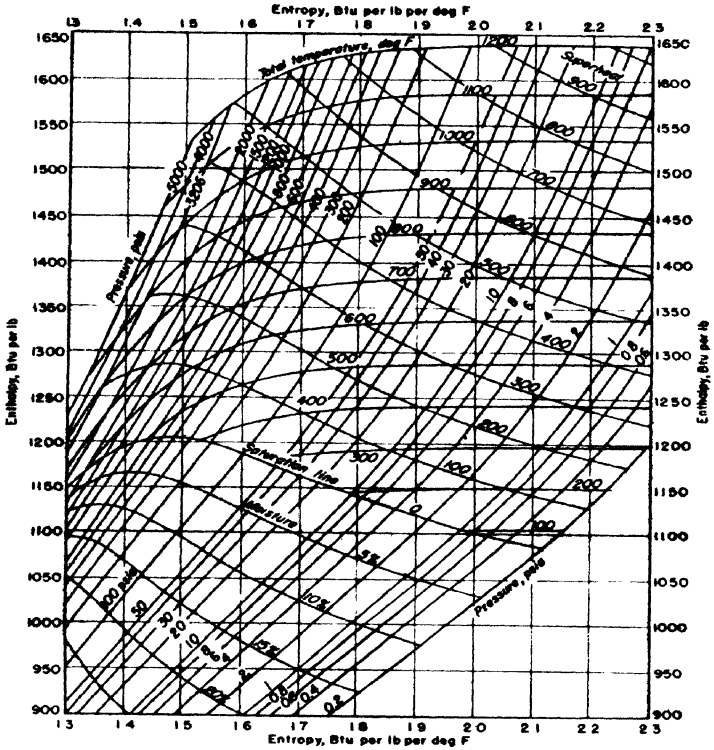
Superheated Steam—(Concluded)

Abs. Press. Lb./Sq. In. (Sat. Temp.)		Sat. Water	Sat. Steam	Temperature—Degrees Fahrenheit 650°	700°	750°	740°	750°	760°	800°	820°	850°	900°	950°	1000°	1100°	1200°
	Sh			14 88	34 88	54 88	74 88	94 88	114 88	134 88	154 88	184 88	234 88	284 88	334 88	434 88	534 88
2450	v	0 0283	0 1360	0 1567	0 1750	0 1902	0 2032	0 2147	0 2250	0 2347	0 2440	0 2569	0 2766	0 2954	0 3130	0 3458	0 3764
(665 12)	h	724 6	1096 3	1142 3	1181 3	1212 9	1239 5	1262 8	1283 5	1302 9	1321 4	1347 1	1386 3	1423 8	1459 0	1525 6	1588 9
	s	0 9076	1 2381	1 2787	1 3127	1 3397	1 3620	1 3813	1 3981	1 4138	1 4282	1 4481	1 4774	1 5045	1 5290	1 5732	1 6125
	Sh			11 90	31 90	51 90	71 90	91 90	111 90	131 90	151 90	181 90	231 90	281 90	331 90	431 90	531 90
2500	v	0 0287	0 1313	0 1488	0 1680	0 1834	0 1967	0 2083	0 2188	0 2285	0 2375	0 2503	0 2700	0 2884	0 3058	0 3381	0 3683
(668.10)	h	730 7	1091 0	1131 9	1173 9	1206 8	1234 5	1258 6	1280 1	1299 9	1318 3	1344 2	1384 3	1421 8	1457 3	1524 2	1587 9
	s	0 9127	1 2322	1 2683	1 3048	1 3329	1 3562	1 3761	1 3936	1 4095	1 4240	1 4440	1 4740	1 5011	1 5258	1 5701	1 6097
	Sh			8 97	28 97	48 97	68 97	88 97	108 97	128 97	148 97	178 97	228 97	278 97	328 97	428 97	528 97
2550	v	0 0291	0 1264	0 1408	0 1606	0 1766	0 1902	0 2020	0 2125	0 2223	0 2315	0 2440	0 2634	0 2817	0 2989	0 3308	0 3604
(671 03)	h	736 7	1085 6	1120 0	1164 7	1199 8	1228 9	1254 0	1276 0	1296 5	1315 6	1341 5	1381 8	1419 8	1455 6	1522 9	1586 7
	s	0 9179	1 2265	1 2568	1 2957	1 3257	1 3502	1 3709	1 3888	1 4052	1 4202	1 4402	1 4704	1 4979	1 5228	1 5674	1 6070
	Sh			6 09	26 09	46 09	66 09	86 09	106 09	126 09	146 09	176 09	226 09	276 09	326 09	426 09	526 09
2600	v	0 0295	0 1219	0 1323	0 1541	0 1706	0 1842	0 1961	0 2066	0 2164	0 2256	0 2380	0 2573	0 2754	0 2924	0 3237	0 3530
(673.91)	h	743 1	1080 1	1106 0	1157 0	1194 0	1223 9	1249 7	1272 2	1293 1	1312 6	1338 9	1379 7	1418 1	1454 2	1521 6	1585 8
	s	0 9232	1 2205	1 2433	1 2877	1 3193	1 3444	1 3657	1 3840	1 4008	1 4161	1 4364	1 4670	1 4947	1 5199	1 5645	1 6044
	Sh			3 25	23 25	43 25	63 25	83 25	103 25	123 25	143 25	173 25	223 25	273 25	323 25	423 25	523 25
2650	v	0 0300	0 1173	0 1235	0 1469	0 1640	0 1782	0 1903	0 2009	0 2108	0 2200	0 2322	0 2514	0 2691	0 2859	0 3169	0 3455
(676.75)	h	749 5	1074 5	1090 1	1146 8	1186 4	1218 3	1245 1	1268 3	1289 9	1309 9	1336 2	1377 5	1415 9	1452 2	1520 2	1584 7
	s	0 9287	1 2147	1 2284	1 2777	1 3116	1 3384	1 3606	1 3794	1 3967	1 4125	1 4328	1 4637	1 4914	1 5167	1 5618	1 6018
	Sh				20 46	40 46	60 46	80 46	100 46	120 46	140 46	170 46	220 46	270 46	320 46	420 46	520 46
2700	v	0 0305	0 1123		0 1402	0 1581	0 1725	0 1846	0 1954	0 2053	0 2147	0 2269	0 2458	0 2632	0 2798	0 3105	0 3389
(679 54)	h	756 1	1068 3		1137 5	1179 7	1213 0	1240 3	1264 5	1286 5	1307 2	1334 0	1375 7	1414 0	1450 6	1519 2	1583 8
	s	0 9342	1 2082		1 2684	1 3045	1 3325	1 3550	1 3747	1 3923	1 4086	1 4293	1 4606	1 4882	1 5137	1 5592	1 5993
	Sh				17 72	37 72	57 72	77 72	97 72	117 72	137 72	167 72	217 72	267 72	317 72	417 72	517 72
2750	v	0 0310	0 1077		0 1335	0 1520	0 1670	0 1794	0 1902	0 2000	0 2094	0 2215	0 2402	0 2578	0 2740	0 3043	0 3322
(682 28)	h	763 0	1061 8		1127 1	1172 2	1207 4	1236 0	1260 8	1283 0	1304 2	1331 4	1373 3	1412 2	1449 2	1518 0	1582 8
	s	0 9399	1 2016		1 2583	1 2969	1 3265	1 3501	1 3703	1 3881	1 4048	1 4258	1 4572	1 4853	1 5110	1 5566	1 5969
	Sh				15 02	35 02	55 02	75 02	95 02	115 02	135 02	165 02	215 02	265 02	315 02	415 02	515 02
2800	v	0 0316	0 1032		0 1267	0 1461	0 1615	0 1741	0 1851	0 1950	0 2045	0 2166	0 2351	0 2521	0 2685	0 2983	0 3258
(684 98)	h	770 0	1054 6		1115 9	1164 5	1201 5	1231 3	1257 0	1279 8	1301 7	1329 3	1371 5	1410 4	1447 9	1517 0	1581 9
	s	0 9458	1 1944		1 2478	1 2892	1 3203	1 3449	1 3658	1 3840	1 4013	1 4226	1 4542	1 4823	1 5084	1 5542	1 5945
	Sh				12 35	32 35	52 35	72 35	92 35	112 35	132 35	162 35	212 35	262 35	312 35	412 35	512 35
2850	v	0 0322	0 0986		0 1198	0 1404	0 1563	0 1690	0 1801	0 1901	0 1995	0 2117	0 2298	0 2469	0 2629	0 2925	0 3197
(687 65)	h	777 5	1046 6		1103 5	1156 6	1195 8	1226 5	1252 9	1276 9	1298 4	1326 8	1368 9	1408 7	1446 0	1515 8	1581 1
	s	0 9521	1 1866		1 2359	1 2813	1 3143	1 3397	1 3611	1 3803	1 3973	1 4192	1 4507	1 4795	1 5055	1 5517	1 5923
	Sh				9 74	29 74	49 74	69 74	89 74	109 74	129 74	159 74	209 74	259 74	309 74	409 74	509 74
2900	v	0 0329	0 0941		0 1126	0 1348	0 1511	0 1641	0 1754	0 1855	0 1949	0 2069	0 2250	0 2418	0 2578	0 2870	0 3138
(690 26)	h	785 2	1038 1		1089 2	1148 3	1189 5	1221 6	1249 1	1273 3	1295 7	1324 2	1367 1	1406 9	1444 8	1514 8	1580 2
	s	0 9586	1 1785		1 2228	1 2733	1 3080	1 3345	1 3569	1 3762	1 3939	1 4159	1 4480	1 4767	1 5032	1 5495	1 5903
	Sh				7 17	27 17	47 17	67 17	87 17	107 17	127 17	157 17	207 17	257 17	307 17	407 17	507 17
2950	v	0 0337	0 0895		0 1052	0 1292	0 1460	0 1593	0 1708	0 1809	0 1902	0 2023	0 2202	0 2369	0 2527	0 2815	0 3081
(692 83)	h	793 6	1028 9		1073 2	1139 5	1183 1	1216 6	1245 1	1269 8	1292 5	1321 7	1364 9	1405 1	1443 2	1513 5	1579 4
	s	0 9655	1 1697		1 2080	1 2647	1 3014	1 3290	1 3522	1 3720	1 3898	1 4124	1 4448	1 4738	1 5004	1 5469	1 5879
	Sh				4 63	24 63	44 63	64 63	84 63	104 63	124 63	154 63	204 63	254 63	304 63	404 63	504 63
3000	v	0 0346	0 0849		0 0972	0 1236	0 1410	0 1546	0 1661	0 1763	0 1856	0 1978	0 2155	0 2322	0 2478	0 2763	0 3024
(695 37)	h	802 6	1019 3		1054 0	1130 3	1176 4	1211 4	1240 6	1266 0	1289 0	1319 0	1362 5	1401 4	1441 7	1512 4	1578 4
	s	0 9731	1 1607		1 1907	1 2559	1 2947	1 3236	1 3474	1 3677	1 3858	1 4090	1 4416	1 4711	1 4978	1 5447	1 5866
	Sh				2 16	22 16	42 16	62 16	82 16	102 16	122 16	152 16	202 16	252 16	302 16	402 16	502 16
3050	v	0 0357	0 0804		0 0868	0 1183	0 1361	0 1499	0 1617	0 1719	0 1812	0 1935	0 2111	0 2275	0 2431	0 2712	0 2971
(697 84)	h	812 9	1007 7		1025 0	1121 2	1169 6	1205 9	1236 3	1262 4	1285 7	1316 4	1360 4	1401 3	1440 2	1511 1	1577 4
	s	0 9818	1 1501		1 1650	1 2472	1 2879	1 3179	1 3437	1 3655	1 3819	1 4056	1 4386	1 4681	1 4952	1 5422	1 5833
	Sh					19 71	39 71	59 71	79 71	99 71	119 71	149 71	199 71	249 71	299 71	399 71	499 7
3100	v	0 0372	0 0752			0 1128	0 1312	0 1456	0 1576	0 1680	0 1771	0 1891	0 2068	0 2231	0 2385	0 2663	0 2921
(700 29)	h	824 6	994 0			1110 8	1162 4	1200 9	1232 5	1259 4	1282 7	1313 4	1358 2	1399 5	1438 7	1509 9	1577 0
	s	0 9916	1 1376			1 2374	1 2808	1 3126	1 3383	1 3599	1 3782	1 4019	1 4355	1 4653	1 4926	1 5398	1 5815
	Sh					17 31	37 31	57 31	77 31	97 31	117 31	147 31	197 31	247 31	297 31	397 31	497 3
3150	v	0 0392	0 0691			0 1075	0 1266	0 1410	0 1532	0 1636	0 1729	0 1850	0 2024	0 2187	0 2341	0 2615	0 2873
(702 69)	h	841 3	976 3			1100 3	1155 3	1194 7	1227 6	1254 9	1279 2	1310 5	1355 5	1397 5	1437 2	1508 6	1576
	s	1 0056	1 1217			1 2276	1 2738	1 3064	1 3331	1 3550	1 3741	1 3983	1 4320	1 4623	1 4900	1 5373	1 5795
	Sh					14 96	34 96	54 96	74 96	94 96	114 96	144 96	194 96	244 96	294 96	394 96	494 9
3200	v	0 0443	0 0596			0 1024	0 1217	0 1368	0 1493	0 1596	0 1687	0 1810	0 1985	0 2145	0 2296	0 2570	0 2827
(705 04)	h	871 3	946 6			1089 8	1146 9	1189 3	1224 4	1251 1	1275 2	1307 7	1353 8	1395 7	1435 2	1507 6	1575
	s	1 0311	1 0958			1 2180	1 2660	1 3011	1 3288	1 3510	1 3699	1 3950	1 4296	1 4598	1 4874	1 5353	1 5777
	Sh					14 66	34 66	54 66	74 66	94 66	114 66	144 66	194 66	244 66	294 66	394 66	494 6
3206 8*	v	0 0541	0 0541			0 1018	0 1211	0 1363	0 1488	0 1591	0 1682	0 1805	0 1980	0 2140	0 2290	0 2564	0 2821
(705 34)	h	910 3	910 3			1088 5	1145 8	1188 5	1222 9	1250 6	1274 8	1307 3	1353 4	1395 3	1434 8	1507 3	1575
	s	1 0645	1 0645			1 2170	1 2652	1 3005	1 3284	1 3506	1 3696	1 3947	1 4293	1 4596	1 4872	1 5351	1 5777

* Critical pressure.

Sh = superheat, deg F
v = specific volume, cu. ft. per lb.
h = enthalpy, B t u per lb
s = entropy, B.t.u per deg. F. per lb.

TABLE XXV
continued
Mollier Diagram for Steam



(Power)

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