FLUID HANDLING

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PREFACE

To the layman the word fluid denotes a liquid—water—but to the chemist a vast field is embraced by this generic term. The word embraces not only liquids but also gases, in fact any substance that takes the form or shape of its container. From such a definition it immediately becomes apparent how large a subject is covered by the simple word fluid. Consequently, in view of the many varying characteristics of liquids and gases, the problems of treating, handling and storing are immense. The chemist and engineer alike must each take a share in solving the difficulties encountered; to ensure that the fluid or fluids they deal with will not be contaminated by the equipment or apparatus conveying it, and at the same time it must be passive, or as nearly so as possible, towards such pipes and containers, thereby having no deleterious effect on them.

To-day, because of world economic conditions, and also the advent of many new materials, it is more than ever necessary that the right approach to all problems of fluid handling is made the first time, instead of by trial and error methods that are costly in time and wasteful of valuable materials. The need to keep production costs down but yet improve the quality of the final product has led to factors, such as initial treatment of process water, the metering of water, steam and other gaseous elements and their subsequent elimination by filtration or centrifugation, being given added importance in all chemical processes.

Thus whilst it is true to say that to-day there is a wealth of knowledge on these matters, much of it has been gained only as a result of bitter experience. At the same time published information is scattered and often only to be found, after much time consuming effort, in searching technical papers and manufacturers literature.

It is hoped that bringing together in book form all the most important and up-to-date information on fluid handling will contribute in some small measure to a better understanding of the problems involved, and thereby lessen the difficulty of their solution.

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SECTION 1

INDUSTRIAL WATER TREATMENT

By H. E. T. COMPTON, M.I.C.E., M.I.W.E.

WITH the advent of the industrial age one of the primary considerations of the selection of a site for any new works was the presence of a water supply of suitable quality and quantity to meet present and future needs; we can trace the origin of many industries in a particular district to the first of the above reasons. With developments in the knowledge of industrial chemistry it became ever clearer that however good a supply of water is, few indeed remain consistent throughout the year, and many require improving. Often the product being produced was greatly improved when a water of the correct characteristics which remain consistent became available, hence we have over the past century seen a number of processes developed to enable man to produce a water to his exact requirements. In 1841 a Scottish Professor, Thomas Clark, was granted one of the earliest patents of "A new mode of rendering certain waters less impure and less hard," and a more recent invention is that of Messrs. Adams and Holmes regarding the use of a Resin Zeolite.

Equipment is now available to produce a water to most requirements, and to-day one can produce a water equal to distilled water, and in some cases at only a fraction of the cost of distilling.

Notwithstanding the above development, one can only decide on the correct treatment for any water if one possesses a complete knowledge of chemistry for water treatment, and also the exact chemical requirements of the water to be produced. It is not within the scope of this article to deal with this side of the problem, but to review the various methods of treatment and also to give some details of the type of water produced by different processes.

In Figs. 1, 2 and 3 the principle water treatment processes are shown, but in order to keep the charts within reasonable limits

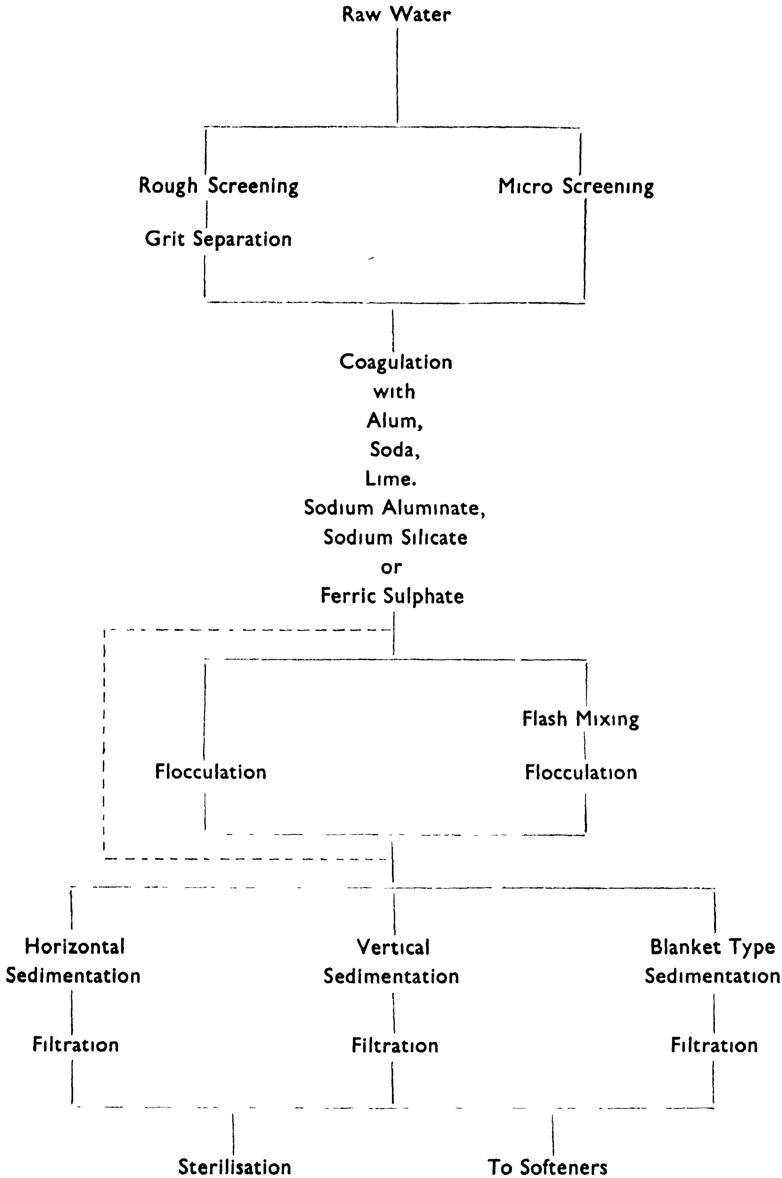


FIG. 1.—SEQUENCE OF TREATMENT FOLLOWED WHEN RAW WATER REQUIRES PURIFICATION.

the removal of iron, manganese and silica, all of which can be readily performed, have been omitted.

In considering the water requirements of an industrial plant, it may be found that some sections can manage with less exacting demands on the quality, it is, therefore, prudent to work out the running cost to produce a water of the required standards for each section. Thus it may be found that the capital cost of two plants can be more than justified when the running costs are taken into account.

An advance has been made which often greatly affects the ultimate selection of any particular form of equipment. This is the introduction of the automatically controlled plants which reduce labour costs and may, therefore, be of even greater importance in the near future. Automatic Filter plants, Zeolite Softening units and Demineralisation plants have now been put in operation and have proved very satisfactory.

Water Supplies

Where large supplies of water are required by industry they are usually obtained from a river or upland reservoir, a few exceptions are those with deep wells. The river and upland water will contain in varying degrees:

1. Turbidity and sediment.
2. Dissolved mineral matter.
3. Dissolved gases.
4. Colour and organic matter.
5. Taste and odours.
6. Micro-organisms.

Whether or not these impurities are in excess of the allowable maximums will decide the final forms of treatment, but most river water will require rough straining, the type of strainer depending upon the quantity of water to be handled and the type of debris in the river. After straining, a grit separation tank often serves a useful purpose.

In the case of upland waters these often only require fine or Micro screening to remove algae and fine suspended matter.

After such screening some river and upland waters are suitable for cooling purposes without further treatment; this will depend to a large extent if the water is free from scale-forming tendencies at the temperature to which the water will be finally raised. The Langelier index is often used to determine this point.

River and Upland Water Purification

The water as prepared above is often further purified in the following manner.

The first stage is to coagulate the water in order to produce a floc which will attract together such small particles of turbidity and colour that they will settle in suitably designed sedimentation tanks, or will be large enough not to pass through the interstices of a filter bed.

To produce flocculation, sulphate of alumina is the most common coagulant used, but a number of other chemicals are used for this purpose, either singly or in combination, depending upon the chemical characteristics of the water.

Some waters, after addition of the coagulant, re-act much faster if the chemicals are mixed with the incoming water by means of rapidly revolving stirrers, whilst others form better settling characteristics if they are flocculated for some ten to fifteen minutes before they are allowed to settle.

The design of sedimentation tanks has been the subject of much research and excellent results have been achieved. With many waters the vertical sedimentation tank with its suspended blanket has produced some very good results, whilst the introduction of Silica Gel as a coagulant with some waters has reduced the time allowed for complete sedimentation by over 100 per cent, but its use is still very limited.

The period of retention in sedimentation tanks varies according to the character of the water to be treated, but with good sedimentation in vertical tanks, designed to embody a blanket filter, the period can be reduced to about 2½ hours, whilst in some instances it is necessary to give as long as 6–12 hours for complete sedimentation without blanket filter. In many plants it is considered that the sedimentation tank is operating satisfactorily if it will remove 90 per cent of the settleable solids, but with the more recently designed tanks the water leaving the tanks has been so improved that it has only a turbidity of 10–15 p.p.m., although the raw water was heavily charged with suspended matter and colouring.

After settling, most waters for industrial use are passed on to filters of either the gravity or pressure type where the speed of filtration may vary from 70/150 gallons/sq. ft./hr., depending upon the quality of the filtrate required. After filtration the water will be free from all suspended matter, and will, with correct coagulation and previous treatment, have little or no colour. Those waters with low total solid content can be generally used for boilers working at pressures of up to 120 p.s.i., but advice should always be sought before using water without treatment, or for higher boiler working pressures.

Waters having been purified to this stage are suitable for passing for other forms of treatment, several of which are shown in Figs. 2 and 3.

In cases where the water is used for domestic purposes as well as process a full chemical and bacteriological analysis must be made to determine what treatment is necessary to render the domestic supply potable and free from bacterial contamination.

Zeolite (Sodium Cation Exchanger)

This form of plant is a simple means of removing calcium and magnesium ions from the water, but the resultant water will however have its sodium ions increased by an equivalent amount to the hardness removed. Hence the total solids remain the same, i.e. the same amount of anions, bi-carbonate, sulphate and chloride plus sodium cation equal those originally present and those gained by exchange.

The water obtained by this process is very useful for many industrial processes, especially where washing and scouring operations are of importance.

With the introduction of resin exchangers the rate of exchange per cubic foot of mineral has increased considerably, but the equivalent salt consumption per 1,000 grains of hardness removed has remained very much the same.

As an alternative to the carbonaceous mineral, the resin mineral has made it possible to soften waters with a pH much higher than was previously possible, and it is possible to pass water to the exchanger without the acid correction.

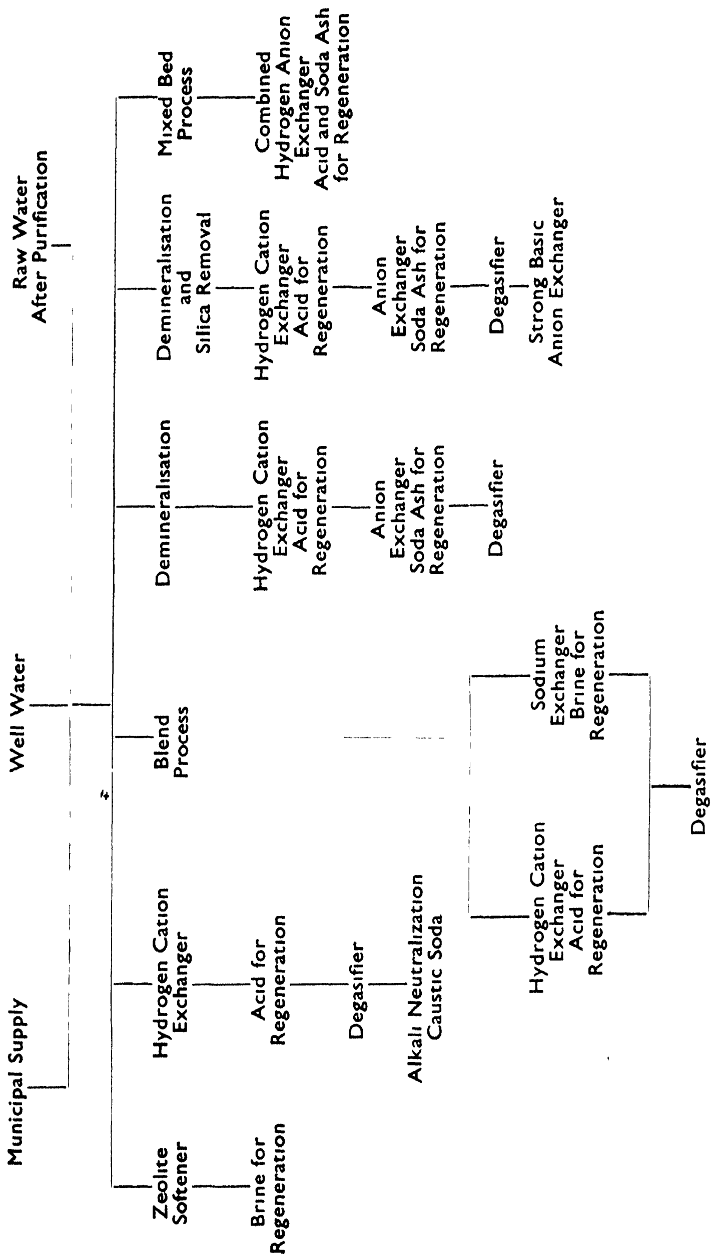


Fig. 2.—Sequence of Treatment Followed when Exchange Mineral is Used for Water Softening or Removal of Natural Salts.

Hydrogen Cation Exchanger

In the Hydrogen Cation Exchanger plant the Hydrogen ions are exchanged for the calcium magnesium and sodium ions, thus we have a water free from metallic ions but containing CO_2 and sulphuric and hydrochloric acid corresponding to the amount of sulphates and chlorides present in the raw water. It is, therefore, necessary to pass the effluent through a degaser tower where the CO_2 is easily removed, followed by the addition of caustic soda to neutralise the Sulphuric and Hydrochloric acid, and to increase the alkalinity to approximately 15 p.p.m. according to the purpose for which the treated water is to be used. The value of the Hydrogen cation exchange process is in removing the bi-carbonates and thus reducing the total solids. With those waters having a higher content of Sulphates and/or chlorides the next process is more economical.

Blend Process (Hydrogen Cation Exchange and Sodium Cation Exchange

In this system part of the water passes through a Sodium Cation Exchanger, the other portion is passed through a Hydrogen Cation Exchanger; if the correct proportions are passed through each it is possible to obtain a mixed water free from hardness and containing any required alkalinity, usually about 15 p.p.m. The mixed effluents should pass through a degaser to reduce CO_2 to the desired limit, for most purposes 15 p.p.m./5 p.p.m. is considered satisfactory.

Demineralisation

For water with reasonably low salinity this process is replacing the distillation plant, but the cost of treatment rises with the salinity, whereas distillation costs remain almost constant for all waters. It will be seen therefore that for some waters distillation is more economical.

With the demineralisation plant the water first passes through a Hydrogen Cation Exchanger which removes the Ca Mg and Na and forms CO_2, H_2, SO_4 plus HCl, this water is then passed to an Anion Exchanger which removes the H_2, SO_4 and HCl, but the CO_2 is not removed, so the effluent is then passed through a degaser to remove the CO_2.

Silica is not greatly reduced by this process, but it can however

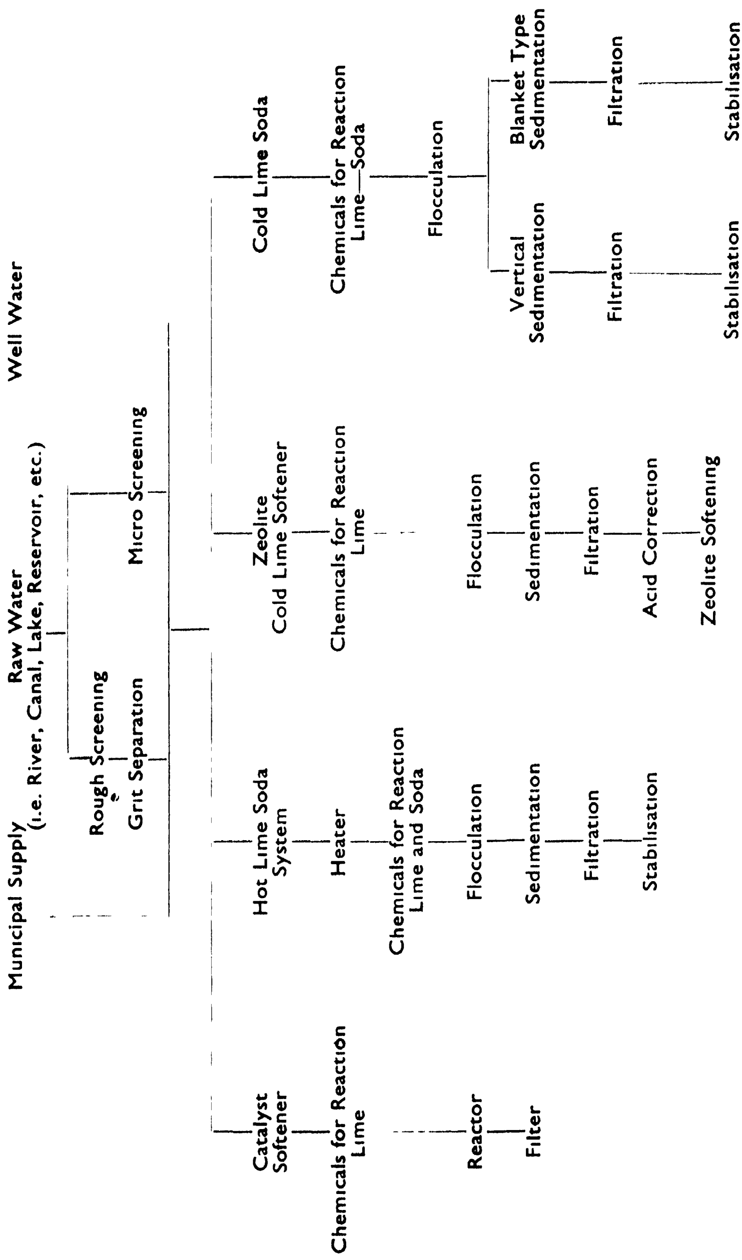


FIG. 3.—SEQUENCE OF TREATMENT FOLLOWED WHEN LIME IS USED FOR WATER SOFTENING.

be removed by a further anion exchanger with a highly basic resin after the degaser.

Instrumentation has enabled demineralisation plants to be run much more economically and also to prevent over running.

Demineralisation (Mixed or "Monobed" Process)

With the development of resins of controlled specific gravity, it is possible to place within one cylinder both Cation Exchange mineral and Anion Exchange mineral. It has been found that to pass a water through such a bed it is possible to obtain an effluent with an electrical resistance of from 2/10,000,000 Ohms/cm. as compared with 500,000 Ohms/cm. for ordinary demineralisation plants. To regenerate such a bed the Anion and Cation Exchanger minerals have to be separated and remixed after regeneration.

With the development of further resins it can be expected that the mixed bed will be further developed and that installation will not be limited to small units.

Cold Lime Soda Water Softening

1. CONTINUOUS TYPE.—This does not employ a sludge blanket but allows the sludge to settle at the bottom of the re-action tank.

With the continuous type the raw water is either controlled to be delivered at a constant rate, or if the flow has to vary then the chemical dose which is added to the raw water has to be varied in direct ratio to the flow of water, and it is in the design of the proportioning chemical dosing equipment that the many makers differ, and on which the efficiency of the plant greatly depends.

In the sequence of operation the raw water is mixed with lime and soda or one of the other chemicals, which are either prepared in a solution or fed from a dry feeder into the inlet channel plus either Sodium Aluminate or Sulphate of Alumina as a coagulant if necessary, to ensure that after flocculation and sedimentation for several hours, the finely divided precipitate is settled out of the water. The period of settlement is usually not less than 3 hours and is often longer. The water after this period of settlement usually contains too much suspended matter for industrial use. Thus some softeners are fitted with filters at the top of the re-action tank, this consists of a bed of wood wool which will last many months without renewal, but the more modern practice is to provide independent sand or anthracite filters. The re-action is not however completely finished in the re-action tank, and after, precipitation will occur, unless recarbonation can be carried out by one of the following methods.

(*a*) By passing scrubbed flue gases from a coke burner through the water.

(*b*) By the addition of sulphuric acid enough to bring the effluent into chemical balance.

When the effluent is to be used for boiler feed, or Zeolite treatment follows, sufficient acid is added to bring the akalinity down to the desired figure. The cold lime soda plant is used for many industrial plants with low pressure boilers and other processes where a large supply of water is required, and the process does not require a completely soft water. When not using an excess of lime and soda one can completely remove the CO_2, and reduce the hardness to 2·5 to 3 degrees.

2. CONTINUOUS SLUDGE BLANKET SOFTENER.—This type was originally developed in U.S.A., and the plant differs from the previous type in the following features.

The speed of vertical rise decreases as the water ascends in the re-action tank, and the precipitate is held in suspension in the form of a blanket at a given level, and thus the water with its chemical added has to pass through the blanket. In so doing the lime is completely used up and one obtains an effluent with from 10/15 p.p.m. of turbidity, and as the re-action is completed no recarbonation is necessary, also, due to the rapid re-action the time of retention is often reduced from 3 to 1½ hours, thus saving considerably on space. In most installations filters are provided in order to remove the final turbidity, but the run between cleansing is considerably greater than with the continuous type. The resultant effluent however is of the same character as for the continuous lime soda softener and can be used for the same purpose.

3. BATCH PROCESS.—This process is seldom installed in modern plants except where only small quantities of water are required, and usually consists of three or more tanks with one tank being filled, a second being settled and the third tank being drawn down for use. This type of plant gives excellent results

when correctly operated, but types No. 1 and No. 2 are usually much smaller in size for an equal capacity.

4. Catalyst Softener.—This is a distinct type of Cold Softener and has only a limited but very useful place in water treatment in so far that it will only remove the carbonate hardness, but the effluent is very free from suspended matter, although the period of retention is usually only 12 minutes. Another very interesting point in its favour is that there is no wet sludge to dispose of, but the sludge adheres to fine sand particles which have to be continuously added to the softener; when they are heavily coated the grains have to be withdrawn and disposed of. The advantage of this method is that it is clean and can be installed where the other types would be impossible, due to the disposal problem.

Hot Lime Soda Softening

This process is similar to the Continuous Cold Softener except that a heater is installed between the inlet and the point of injection of chemical, the temperature is raised to 180° F. or above. This increases the rate of chemical re-action considerably, also the precipitate formed is larger and heavier and thus settles more rapidly without the use of a coagulant; also there is no CO_2 left after heating, and the quantities of lime required are less. The hot process is almost only used for boiler feed water, or those processes requiring the maximum removal of the calcium and magnesium hardness from the water.

Lime Zeolite Softening

The Lime Zeolite system is often installed because of its economical running costs, and also that the treated water is of zero hardness instead of 3 degrees as with the lime soda method, and the sodium ions are not increased by the same amount as with the zeolite plant only.

Aeration

A review of this nature cannot be concluded without a brief reference to the following; Aeration, Iron Removal, and Chlorination.

Aeration is used to remove excess CO_2 from raw water and thus reduce the corrosive nature of raw waters, while with others it is used to remove odours. It can also be used for oxidation of Iron and Manganese. Aerators of the fountain type are the most common, but Mechanical Aeration towers are used in many cases and with such a definite and controlled Aeration can be achieved.

Iron Removal

Iron is present in many raw waters to some degree, and is very objectionable to many industries when the iron content is above 0·2 p.p.m. The methods of Iron Removal may be summarised as follows:

Aeration followed by filtration,
Re-action with lime in a Cold Softener,
Filtration through an Iron-removing Zeolite or Media.

Chlorination

Chlorination is used extensively as a sterilisation agent with most water supplies where food is in contact with the water, and where the water may be used for domestic uses; in these cases break point chlorination has been found to be very useful where taste is of importance.

Power stations use chlorination in a large way by introducing a very heavy injection at regular intervals into the inlet cooling water main to the condensers thus preventing coating of condenser tubes with algae, which otherwise would reduce the efficiency of heat exchange.

It is hoped that the information given in this section will enable those studying the problem of industrial water supply to appreciate the uses to which the various processes can be applied.

SECTION 2

METERING OF LIQUIDS

By P. SCANES

In modern chemical plants and processes the measurement of liquids is essential to the correct running of the plant, not only to assist in accounting but to ensure that the product quality is continuously maintained by correct proportioning of the various flows. In addition, by measurement of liquids which do not form part of the final product such as cooling water, hot water, fuel oils and so on, a constant check on operating efficiency of the plant can be maintained.

Although there appears to be a considerable variety in the types of flow meters available for measuring liquids in closed pipes, they can be classified into two very broad divisions, those which are inserted into the pipe-line measuring directly the volume passing through the mechanism, and those which measure pressure differentials which are related to the flow in the line. The former are generally termed broadly mechanical meters, and the latter differential meters, and are further subdivided under these headings.

MECHANICAL METERS

These fall into two groups, the first in which one or more moving elements perform a cyclic operation displacing a fixed volume of liquid at each cycle, and the other group in which a rotor is caused to rotate at a speed proportional to the velocity of the flow stream.

The first group may be divided into two classes which are termed "positive" and "semi-positive." In the former the moving elements are so sealed that no fluid can pass without displacing them, while in the latter the moving members have a small but definite clearance which can permit the passage of a small proportion of fluid without being measured.

The second group are generally termed "inferential" meters,

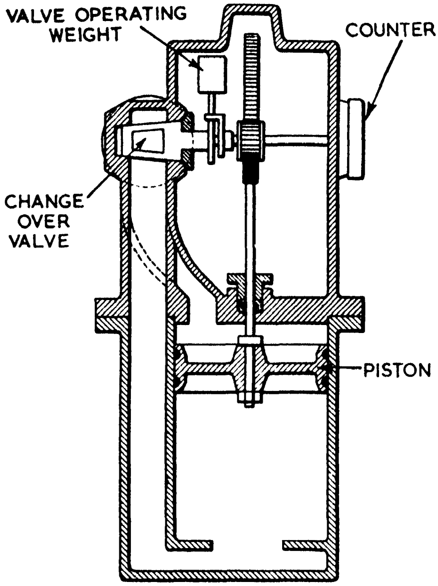


FIG. 1—SINGLE CYLINDER POSITIVE METER

and the rotor carries blades against which the fluid impinges causing rotation.

Positive Meters

These consist of a meter casing containing one or more pistons in cylinders, with a change-over valve to reverse the inlet and outlet of the meter from one side to the other of the piston or pistons at the end of the piston stroke. The pistons have a packing ring to prevent leakage, and the valve mechanism is so designed that it permits no leakage from inlet to outlet at the pressure difference which exists in operating the pistons. Various mechanical arrangements are used to translate the reciprocating movement of the pistons into a rotary motion for the purpose of driving a counter which gives the total flow passed by the meter. A single piston meter is shown diagrammatically in Fig. 1.

This type of meter can give a high order of accuracy down to virtually zero flow, and while the normal accuracy tolerances are given as $\pm$ 1 per cent, they can be made to give accuracies of $\pm$ ¼ per cent for special applications. The meter will measure accurately the volume passed independent of pipe-line condition such as proximity of bends or valves, and accuracy is unaffected by viscosity. The meter head loss is increased, however, with increased viscosity due to the greater resistance to the movement of the piston.

The meter size varies according to the maximum flow to be handled. Typical conditions are about 600 gallons per hour for a ½ in. meter at 10 ft. head loss, to 50,000 gallons per hour for an 8 in. meter at 5 ft. head loss.

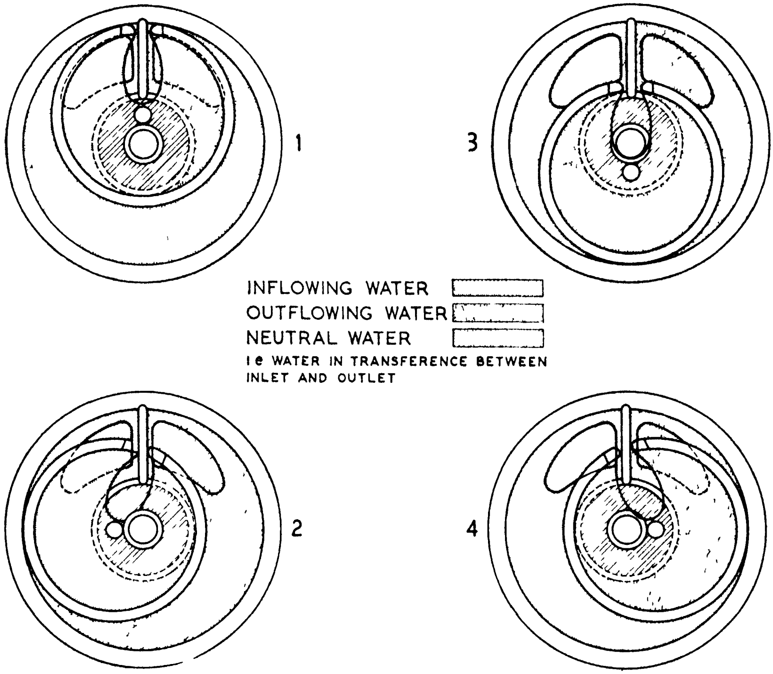


Fig. 2—Rotary Piston Principle.

The range of liquids which can be handled is limited only by choice of materials available to withstand the chemical action of the liquid, its pressure and its temperature. The cost of manufacture in special materials is normally high.

Semi-Positive Meters

This class of meter consists of a moving element or elements contained in a casing which has ports communicating with the meter inlet and outlet. The moving elements are termed pistons, and these move cyclically in such a manner that the volume between the pistons and their casings or chambers in communication with the inlet is always increasing and that volume in communication with the outlet is always decreasing. The piston seals off communication between inlet and outlet ports by fitting closely in the chamber, but with sufficient clearance to ensure freedom of movement. These clearances are kept to a minimum

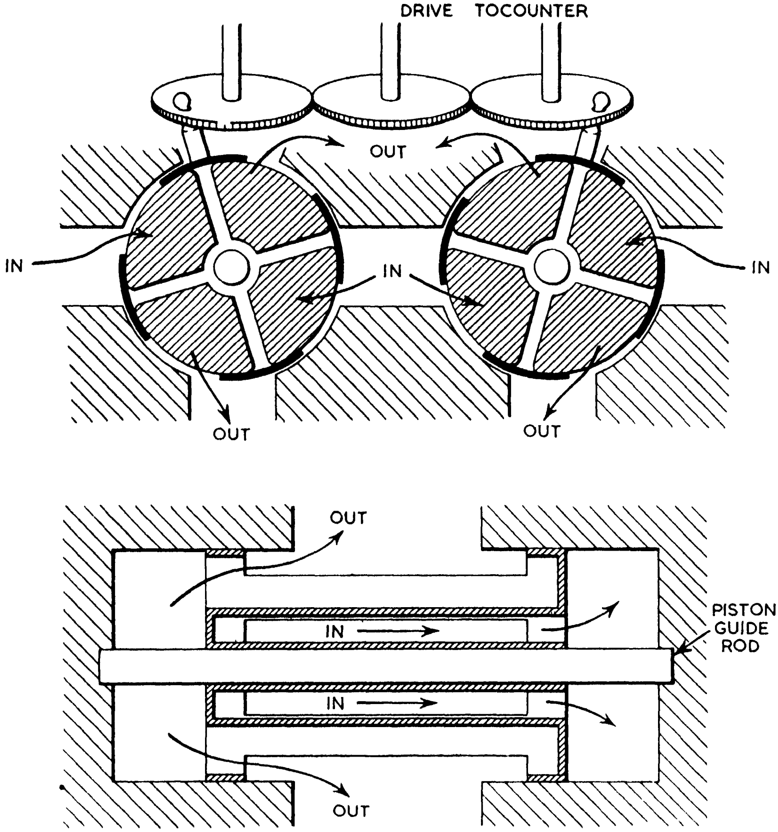
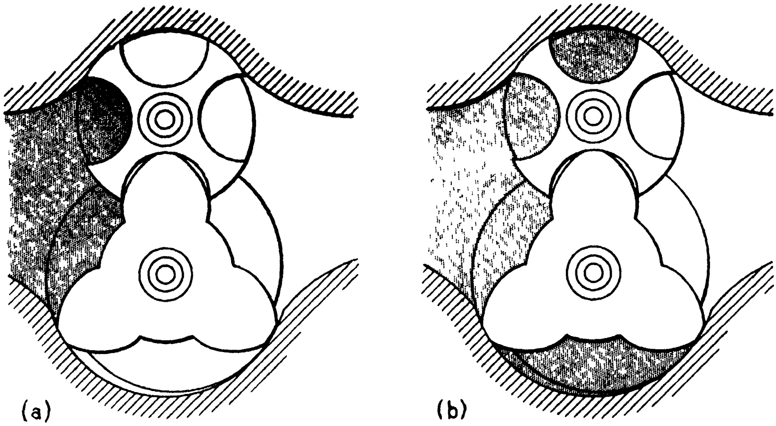


FIG. 3—TWO-PISTON SEMI-POSITIVE METER

Ports change over as piston rotates, and fluid displacement occurs as piston slides along guide rods The pistons are displaced 90° one from the other to obtain continuity of liquid displacement

in manufacture, and enable accurate registration to be achieved over a wide flow range, but they impose a lower limit of flow at which this accuracy can be maintained.

Several varieties of this type of measuring system are illustrated in Figs. 2, 3 and 4 which show the principle. In all of these meters, the cyclic operation of the piston is very simply translated into a circular motion for operating a counter mechanism, but as the latter must for convenience be outside the liquid, the drive



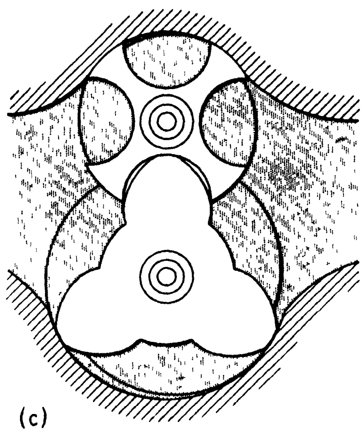


Fig. 4.—Two Rotor Semi-Positive Meter

(*a*) *Filling* Fluid enters spiral flutes of the rotors, causing them to turn

(*b*) *Measuring* An exact volume of liquid is momentarily isolated from the inlet and outlet

(*c*) *Discharging* Liquid flows freely out of rotors into the downstream line

must pass through a gland which will inevitably impose some load on the piston. This gland load will tend to reduce the accuracy at low flows, and to reduce this effect a reduction gear is placed between the piston drive and the gland, bringing the gland spindle speed down to a convenient figure for the counter unit. This reduction gear is normally known as the "under-gear."

These meters can deal with a wide range of liquids by suitable choice of materials, but quite apart from the resistance to chemical attack by the liquid the materials must possess a very high degree of dimensional stability and similarity of thermal expansion where temperature changes occur in service due to the very small clearances between pistons and chambers.

Furthermore, the weight of the piston has a marked influence in the performance at low flow rates so that some sacrifice of accuracy or flow range may be experienced in providing a suitable chemically resistant material.

Where the liquid contains solid particles which would tend to prevent operation of the piston, a strainer must be provided either internally or as a separate unit.

Viscosity has a small effect on the accuracy of registration due to the change in leakage through the small clearance. As an example, a meter which is accurate on cold water can increase its registration per unit volume passed by about 2 per cent if passing a liquid of viscosity 0·5 poises. As the viscosity increases, the head loss across the meter also increases.

Choice of Semi-Positive Meters

The capacities of the various types for a given nominal meter size vary considerably, but the following table gives a rough guide. A meter should be selected by its ability to deal with the actual flows required in preference to the size of pipe into which it is to be fitted.

Nominal Size	*Maximum Flow (g.p.h.)*
½ in.	Up to 700
¾ ,,	1100
1 ,,	1800
1½ ,,	3500
2 ,,	8000

The head loss on maximum flow may be up to about 15 p.s.i. for meters for water and similar liquids, where the flow range for accurate registration exceeds 40 to 1. For lower flow ranges, the head loss may be as low as 3 to 4 p.s.i. at maximum flow.

The head loss across semi-positive meters varies approximately as the square of the flow, but except in special circumstances the meters should not be used where the total available supply pressure is less than about 5 p.s.i., as a temporary increase in friction which may occur due to particles of foreign matter may tend to stop the piston, and the pressure across it may be insufficient to maintain its motion.

Installation of Positive and Semi-Positive Meters

The meters are provided either with screwed connections or flanges, depending on size, and are fitted direct into the pipe line. No levelling is required, and in general the meters will operate accurately in any position. Excessive vibration should be avoided as this can cause failure of the pipe joints and wear of the mechanism.

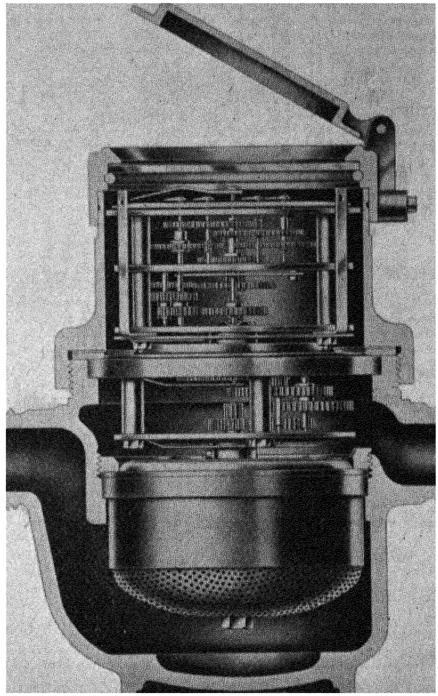


FIG. 5.—ROTARY PISTON METER WITH CIRCULAR READING COUNTER.
(*George Kent, Ltd*)

PRECAUTIONS.—Air or gases contained in the liquid will be measured as liquid, and such conditions sometimes occur in pump circuits, either due to gas coming out of solution or becoming sucked in at the pump inlet. In such cases an air or gas separator is necessary prior to the meter. A similar effect may occur in measuring liquids near their boiling point, as these may boil due to fall in pressure through the measuring chamber and increase the volume passing.

A section of a complete meter is shown in Fig. 5.

Inferential Meters

These are generally used for water measurement and in the larger sizes have a greater capacity for a given head loss than the positive or semi-positive meters size for size, but a lower flow range.

In the smaller size, one type, Fig. 6, consists of a rotor having flat radial blades, which is mounted vertically on a jewelled

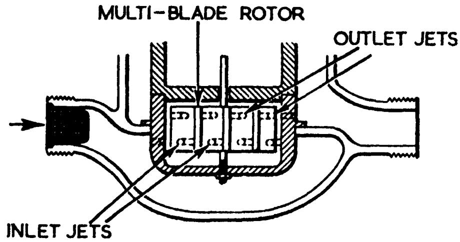


FIG. 6 — MULTI-JET INFERENTIAL METER
This is a multi-blade rotor type, having five radial blades, vertically mounted.

thrust to maintain minimum friction, and the liquid is directed by a single jet, or by multiple jets spaced round the periphery of the meter chamber on to the blades normal to their surfaces.

An alternative design consists of a rotor which is hollow and contains inclined jets in its circumference. The liquid is directed downwards into the rotor, and the reaction as it emerges from the jets causes rotation of the rotor.

Inferential Meters—Helical-Bladed Rotor

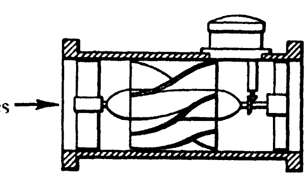
For larger sizes, generally above 1½ in., the rotor blades are helical in form, and the liquid is directed parallel to the rotor shaft. Minimum head loss and overall size is achieved with the rotor shaft axial in the pipe line, Fig. 7, but in general this means that the rotor axis is horizontal and bearing friction limits the minimum flow at which accurate registration is obtained. An alternative with the rotor shaft vertical, Fig. 8, permits the rotor weight to be taken on a low friction thrust, permitting registration at a lower flow, but increasing somewhat the head loss due to changes in direction of the stream.

The head loss at normal flow rates for these meters is about 1 ft., and the flow range 15 : 1 to 20 : 1, but these vary considerably from manufacturer to manufacturer.

The rotor movement is transmitted to a counter through a reduction gear and gland as for the semi-positive meters.

Although the principle of measurement would be equally

FIG 7.—INFERENTIAL METER WITH HELICAL-BLADED ROTOR—HORIZONTAL AXIS
This type of construction is used on the larger sizes of inferential meters (i e above 1½ in)



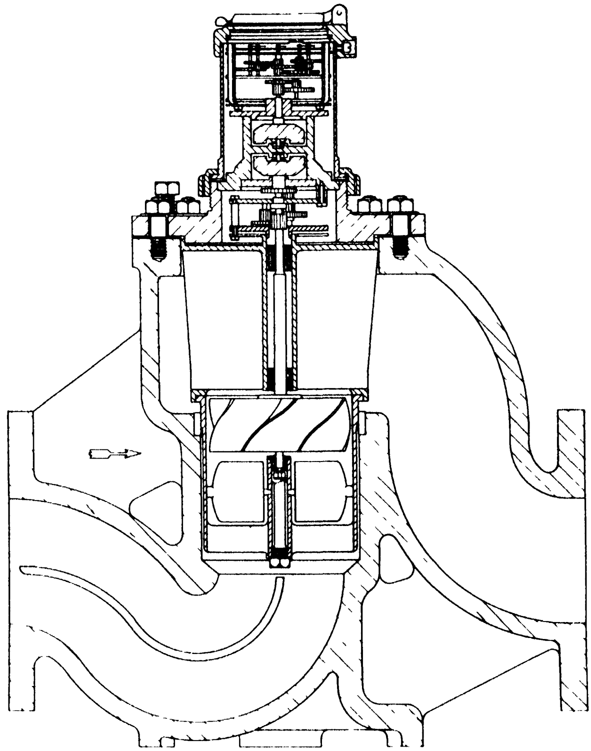


FIG 8.—INFERENTIAL METER.—HELICAL-BLADED ROTOR, VERTICAL AXIS.
(*George Kent, Ltd.*)

satisfactory for liquids other than water, provided the viscosity is low, the choice of suitable materials is more restricted, as the rotor must be light and bearings of extremely low friction to obtain accurate measurement.

Inferential Meters—Shunt Flow Type

A somewhat different type of inferential meter, Fig. 9, utilises a rotor which is driven by two nozzles through which part only of the main flow is directed. The proportion of the flow which is by-passed is determined by an orifice in the main flow, and this permits a wide range of maximum flows to be chosen using the same meter and varying orifice diameter.

Damping blades attached to the rotor shaft reduce the rotor

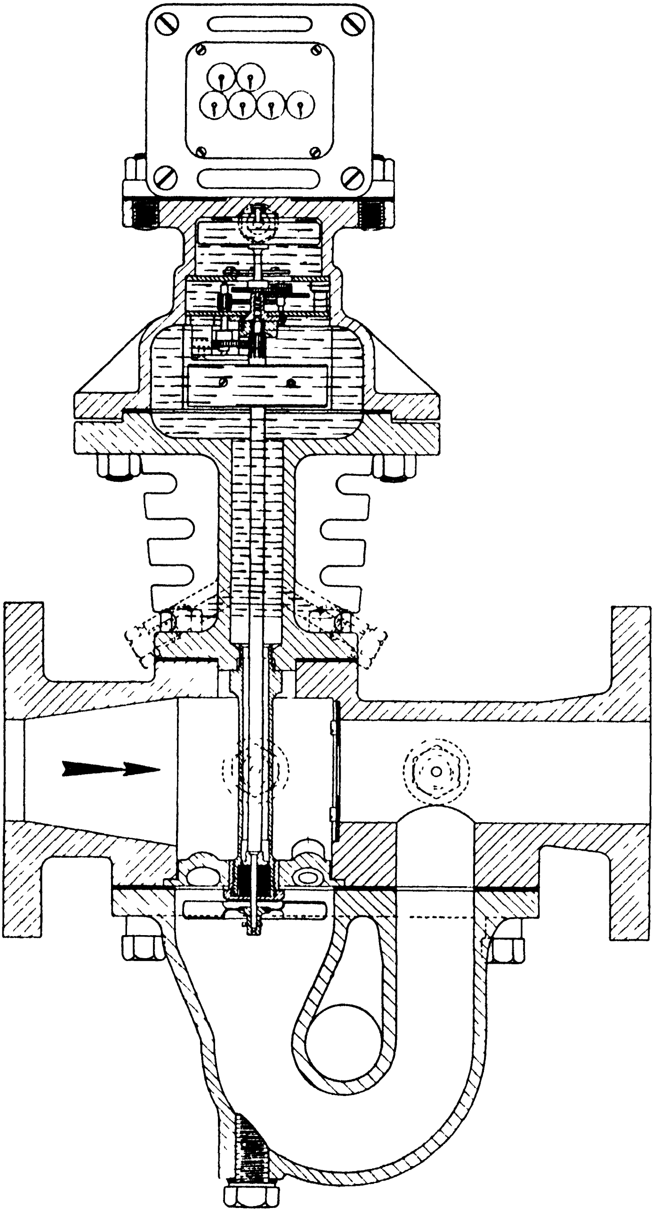


FIG. 9.—INFERENTIAL METER—SHUNT FLOW TYPE.
In order to illustrate the nozzles and filling plugs, these parts are shown out of their true relative positions.

speed and give enhanced life. In addition, the response to fast variations in flow is improved, enabling the meter to deal accurately with pulsating flows.

Inferential meters are considerably affected by viscosity due to changes of deflection of the stream by the rotor blades with changes in viscosity.

Installation of Inferential Meters

These meters in general are suitable for screwing or bolting directly in a horizontal section of pipe and require no special arrangements. The shunt type meter requires a straight section of uniform pipe upstream and downstream as described later for differential meters.

Counters and Accessories

These meters provide a measure of the total volume of liquid which is shown either by a counter fitted with pointers or circular dials, or by straight reading or cyclometer type or a combination of the two. The minimum quantity registered by the fastest moving pointer or figure wheel may be varied over wide limits and is restricted only by the torque which must be exerted to drive it. Additional counter units, capable of resetting to zero by lever or knob may be added enabling selected quantities of liquid to be passed without requiring subtraction of total meter readings. Additional mechanism is often provided to give automatic tripping of a valve in the line after pre-determined quantities have passed through the meter.

All accessories tend to add load to the metering unit and will obviously reduce the accuracy of the meter especially at the lower end of its flow range. For fairly constant operating conditions, this additional load can be compensated by adjustment, but it should be recognised that the meter cannot be expected to have the same accuracy flow range as a meter with a simple counter.

Maintenance of Counters

In the simple counter type, little maintenance is required. This will generally consist of cleaning the strainer and working parts, when necessary, to remove accumulated foreign matter, presence of which in any quantity will show due to increasing head loss through the meter. Periodic tests against known volumetric standards are advisable where highest accuracy is required and these should be carried out at the rates of flow at which the meter is operating. Where adjustment is provided for registration, advantage may be taken of this to prolong the life of the meter working parts to allow for wear which may have taken place, since although the meter may not be accurate of the whole of its original range of flows, it may be perfectly satisfactory for the normal operating conditions. The periods between overhauls and cleaning vary considerably with the duty, and can be found only by experience. A log sheet for each meter and the fixing of regular routine attention based on experience is the key to accurate and trouble free operation.

Where additional mechanism is involved in the counter unit, manufacturers' instructions on maintenance should be followed, varied as necessary by experience gained during operation. All such apparatus however will give better service if kept clean.

DIFFERENTIAL METERS

In this type of meter, the principle of measurement is based on the relationship between the flow in a pipe line and the pressure difference across a restriction placed in the flow stream. For general industrial use, the restrictor consists of an orifice, a nozzle or a Venturi tube and the theory underlying the pressure difference obtained in relation to the flow has been described in many publications. The basic formula for liquids in a horizontal pipe line is given below.

Formula for Liquids in a Horizontal Pipe line

If P = pressure difference across the restriction
Q = volume of flow in the pipe
ρ = fluid density
C = constant
W = weight flow in the pipe

$$Q = C\sqrt{\frac{P}{\rho}} \quad \text{or} \quad P = \frac{Q^2.\rho}{C}$$

$$W = C\sqrt{P/\rho} \qquad P = \frac{W^2}{C\rho}$$

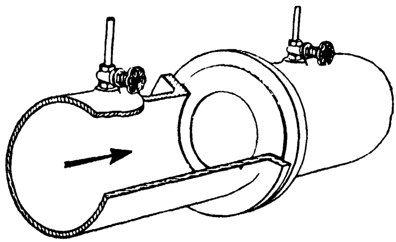


FIG 10 —ORIFICE FITTING FOR AIR, GAS OR LIQUID FLOW MEASUREMENT

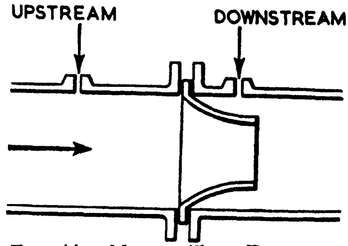


FIG 11 —NOZZLE-TYPE DIFFERENTIAL METER.

The simple formula shows that the pressure difference is proportional to the square of the flow (volume or weight) which has a considerable influence on the design of the instrument used for measuring the pressure difference. It shows also that the pressure difference for a given flow is dependent on the density of the liquid, so that an instrument measuring the differential pressure and translating this directly into flow is correct only for one particular density.

Further, the constant C depends on a number of factors such as the size of pipe line, the type of restriction and the position at which the connections are made for measuring the differential pressure. The values of the constant for particular conditions may be ascertained by reference to B.S. 1042: 1943 *Code for Flow Measurement.*

The important point in measurement is that for the range of conditions which a particular installation is to deal with, this value shall remain constant within the limits of accuracy required. Provided that the particulars of the differential pressure element have been suitably chosen for the rates of flow and density involved, the only other variable which can affect the constant is the viscosity of the liquid. The effect is negligible above a certain critical value of the expression $\frac{W}{D_2\mu}$ termed the Reynold's Number where:

W = weight flow
D_2 = diameter of the bore of the restriction
} all units being consistent.
μ = viscosity.

The critical values below which the constant C becomes variable have been obtained experimentally for most types of measuring elements, and generally no difficulty is experienced in choosing a differential pressure element to avoid the critical value except when dealing with highly viscous liquids at low flow rates, i.e. when μ is large and W is small.

Differential Generating Devices

For industrial use, the "orifice type," the "nozzle" and the "Venturi tube" are most commonly used to produce a differential pressure.

Reference to Figs. 10, 11 and 12 shows the main features of these, and the curves, Fig. 13, indicate the form of pressure loss. It will be apparent that in the case of the orifice the final pressure

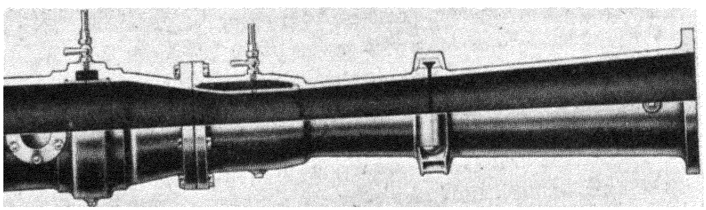


FIG 12—SECTIONAL VIEW OF VENTURI TUBE.
(George Kent, Ltd)

downstream, termed the "recovery" pressure, is less than the upstream by a greater amount than in the Venturi tube, and this is the main difference in their behaviour. The orifice type is, however, cheaper, much smaller and easier to install so that unless the loss in pressure presents a serious problem in the installation, or involves heavy expenditure in power, the orifice normally has an advantage. The nozzle is similar to the orifice but has some advantage in dealing with erosive liquids.

The differential pressure created with a given liquid is dependent on the size of the main, the flow, and the "bore" of the orifice or "throat" of the Venturi. For a given size of pipe line, the differential pressure for the maximum flow to be measured may be adjusted by varying the bore or throat, but there are limits in the ratio of pipe bore to orifice bore or Venturi throat, both maximum and minimum, beyond which accuracy is not maintained over the normal flow range. This requires that the

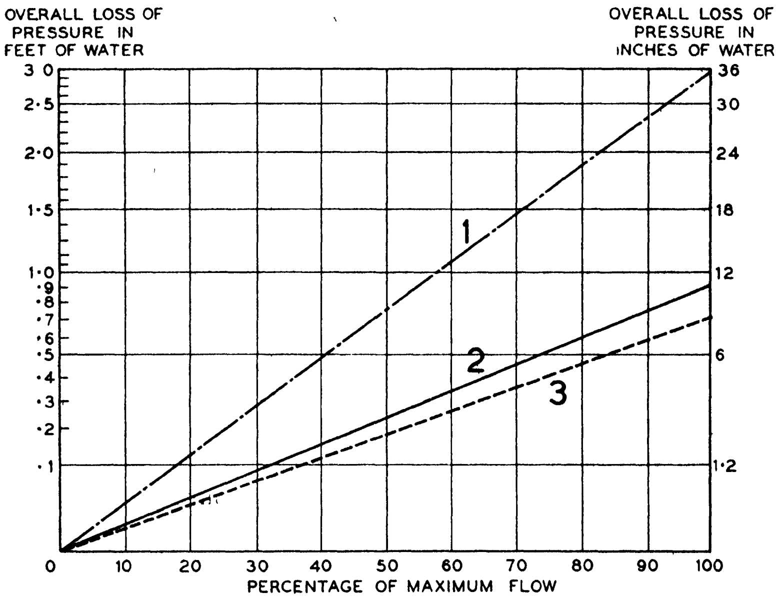


FIG 13.—CURVES SHOWING OVERALL PRESSURE LOSS FOR A GENERATED DIFFERENTIAL OF 60-in WATER GAUGE AT MAXIMUM FLOW

(1) Orifice and nozzle. (2) Short venturi tube. (3) Long venturi tube.

instruments used for measuring the differential pressure must be available with a range of maxima.

Installation of Differential Meters

It is essential that the velocity distribution in the pipe adjacent to the orifice or Venturi tube should be consistent and similar to the conditions under which their constants have been established. Pipe bends, elbows, shut-off or throttle valves in the vicinity have a considerable effect on the differential pressure created, and it is essential to provide a straight uniform portion of the pipe line on either side of the measuring element to ensure normal velocity distribution. The minimum required length upstream varies, according to the type of fittings causing the disturbance and also to the ratio of the orifice bore or Venturi throat to the pipe diameter, from ten pipe diameters to forty diameters. Details of these requirements are given in B.S. 1042: 1943, and where any doubts arise on a particular installation it is better to exceed these values. The downstream portion should be, in general, a minimum of five pipe diameters in length of similar uniform straight pipe.

In the case of orifices, two tappings are provided, one upstream and one downstream, across which the differential pressure is measured. These are either close to the orifice and are termed corner taps, or are spaced one pipe diameter upstream and one half diameter downstream. The former are normally used where the orifice is provided with a carrier as shown in Fig. 14, which has certain advantages as the carrier forms part of the pipe line and has an accurately controlled bore. The latter are convenient where it is desired to fit an orifice between existing flanges in a pipe line, and the tappings may be drilled in the pipe line, bosses being welded on if necessary. The flow constants are different for the two methods.

In the case of the Venturi tubes, tapping points are provided as shown in Fig. 12.

In all cases protrusions into the bore at the tappings must be removed, and joints must be slightly larger in the bore than the pipe internal diameter.

DIFFERENTIAL PRESSURE MEASURING INSTRUMENTS

These are used to measure the differential pressure and hence provide an indication, a record or integrated total, or combinations of these, in units of flow. They may be remote from the orifice or Venturi tube, being connected by means of suitable piping to the tapping points.

Mercury U-tube Type

The differential manometer is the simplest device in which a transparent U-tube is sealed with a liquid of greater specific gravity than the liquid being measured and immiscible with it, and capable of balancing the maximum differential pressure generated when the two columns are at the maximum difference in level. For liquid flow measurement the U-tube will generally contain mercury, due to its high density and immiscibility.

The same principle is used for the recording flow meter which is very widely used in industry. In this case, Fig. 15, the mercury

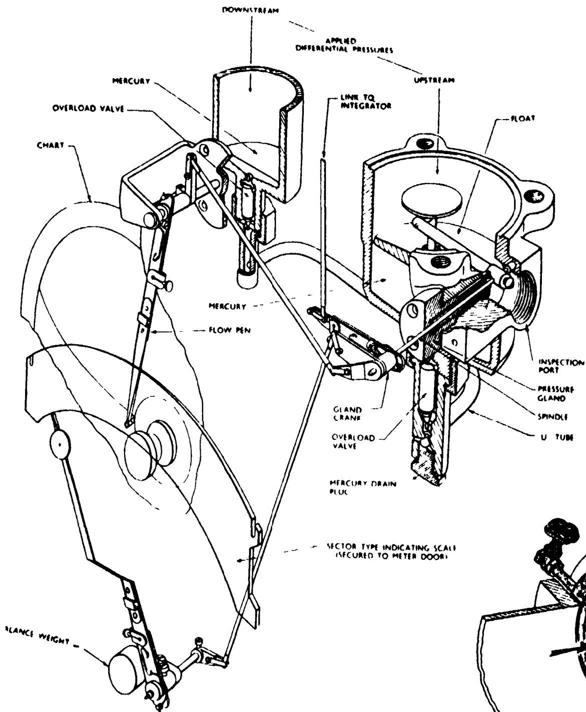


FIG. 15 —MERCURY U-TUBE DIFFERENTIAL UNIT
(*George Kent, Ltd*)

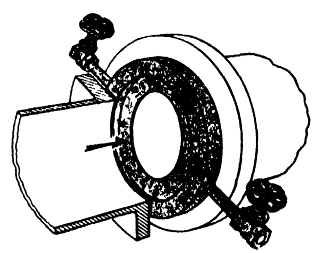


FIG. 14 —ORIFICE FITTING FOR AIR, GAS OR LIQUID FLOW MEASUREMENT.

is contained in a larger diameter tube which forms part of one limb of the U-tube, and a float of ferrous material resting on the mercury follows the variations in level due to differential pressure variations. The other limb may be similar in diameter so that the total variation in the height of the mercury levels is twice that of the float, or it may be different in order to produce a greater or less change in the levels for the same float movement. Thus for a standard float travel the corresponding total differential pressure can be modified at will. The movement of the float is transmitted by connecting rod and lever, or by chain and pulley or similar device to a spindle passing through the meter body via a gland and from this point, indicating pointers, recording devices and so on can be operated. To prevent

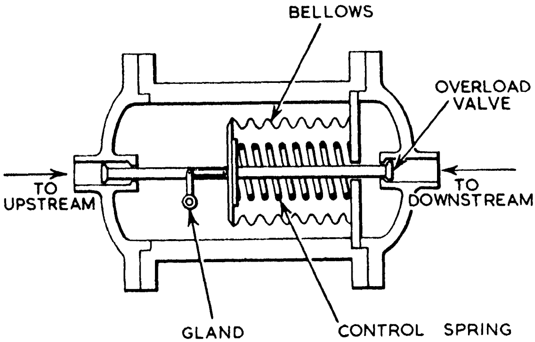


FIG 16 —BELLOWS-OPERATED DIFFERENTIAL UNIT.

mercury being disturbed beyond the designed maximum difference in level, overload valves are fitted which normally float in the mercury to the open position, but when the mercury leaves them they close and prevent further level change.

The maximum differential pressures provided in this type of device are arranged in convenient steps termed "heads" for use with orifices and Venturi tubes, as for example 30, 60, 120, 240 in. water gauge. It should be noted that the effective specific gravity for a mercury manometer used for differential pressure measurement is "specific gravity of mercury minus

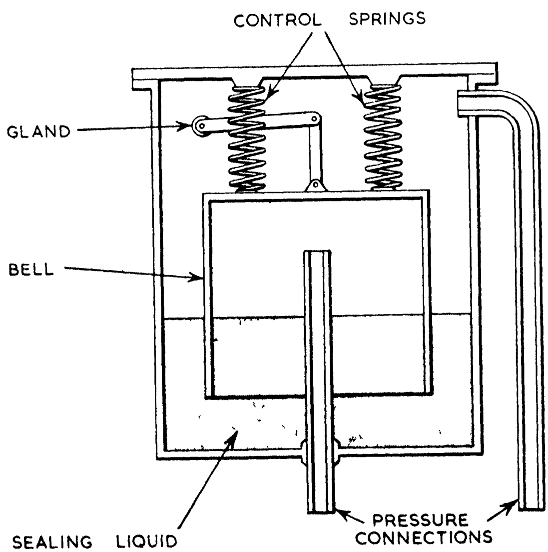


FIG. 17 —BELL-TYPE DIFFERENTIAL UNIT.

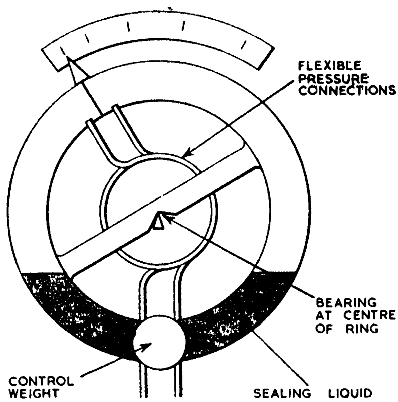


Fig 18.—Ring-type Differential Unit.

In this type, the differential pressure connections are joined to the ring by means of flexible tubes, and the ring itself rotates due to the force on the particles.

specific gravity of the liquid being measured." It is thus normal to give the maximum head of a meter unit as a figure in inches water gauge followed by a statement "air on mercury," or "water on mercury," depending on the condition for which this head is valid.

Other Meters for Differential Pressure Measurement

Differential pressure may also be measured by the deflection of diaphragms or extensible bellows which are controlled by springs; by inverted bells partially immersed in a sealing liquid of appropriate density and supported by springs, or controlled by variation in buoyancy; also by hollow rings with a partition at the top and sealing liquid at the bottom, supported at the centre of the ring and free to rotate, the rotation being controlled by a weight.

These are illustrated in Figs. 16, 17 and 18, and as in the case of the mercury meter described above the moving member is connected via a gland or similar seal to a recording mechanism, except in the ring type element.

In all liquid sealed meters, the maximum differential which can be measured is dependent on the height which the liquid column can read prior to the breaking of the seal, while in the diaphragm or bellows type it is dependent on the strength of the springs which control the deflection. In most such meters, the output is an angular rotation of some 40° and is linearly proportional to the differential pressure.

Recording Mechanism

The angular rotation of the output spindle is connected by linkwork to an indicating pointer, an arm carrying a marking device for recording on a chart, or to an integrating mechanism, or to combinations of these. As the operating forces are small due to the comparatively small differential pressures being measured, the additional mechanism must be light and frictionless in order to avoid errors due to unregistered movement of the sealing liquid or to restraint of diaphragm movement according to the principle involved.

In the case of indicating pointers and recording mechanisms, the scale spacing is normally square root to give a direct measure-zero and "opened out" towards maximum. This permits of the simplest mechanism, with minimum friction losses and very accurate and definite zero settings.

In integrating mechanisms it is inevitable that some magnification of the initial movement from zero must occur to give linear movement at the integration device proper, and this demands considerable care in design and execution to avoid undue friction leading to lost motion. The "zero" setting of the integrating device is also critical for accurate registration over the lower part of the flow range.

Indicating Scales

For indication only a circular scale is widely available, in which the angular movement from the measuring element is stepped up by quadrant and pinion to give about 300° rotation of a light pointer, as shown in Fig. 19. In other cases, a sector scale is provided with a long pointer giving a scale length of about one-third to one-half that of the circular scale.

Recording Devices

These are divided into two types, the disc chart and the strip chart. An arm carrying an inking device is normally used which follows an arc on the chart face. The chart is rotated or driven forward at constant speed by a spring or synchronous electric clock, the speed being chosen to suit the application, and is marked off with accurate time lines to correspond with the pen

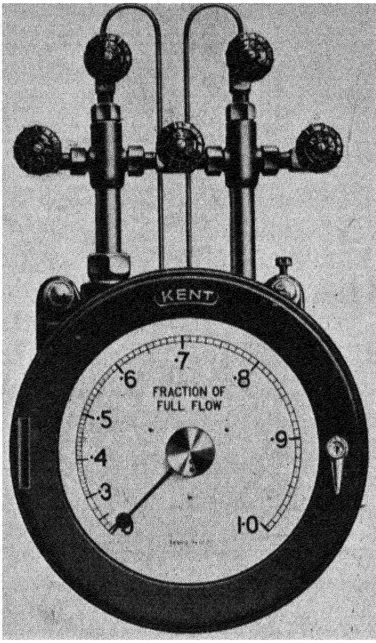


FIG 19 —FLOW INDICATOR

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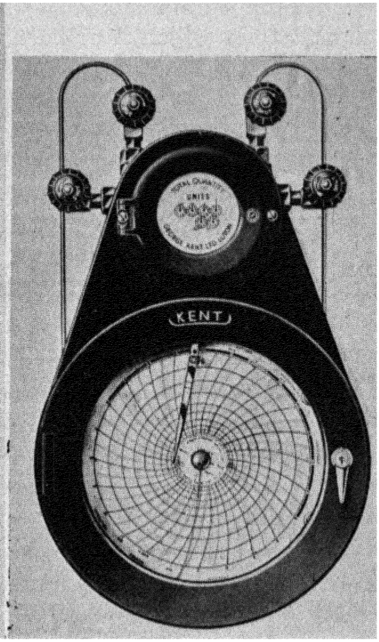


FIG. 20 —RECORDING AND INTEGRATING METER.

(*George Kent, Ltd*)

arc. For normal process work, the disc chart is generally used with a speed of one revolution per day, as this gives adequate records of plant behaviour for control, shows the whole record at a glance, is convenient for routine chart changing, and can then be used for accounting or study of process performance. The chart is normally about 11 in. diameter, with calibrated portion of about 4–5 in. wide.

Strip charts are used where records can conveniently be left unexamined for longer periods and are only required in cases of investigation. They are not available on many of the standard flow meters made in this country.

The inking device normally consists of a light pen with capillary feed to a nib. Designs vary considerably, but the trend is towards simplicity and ease of maintenance. Easy removal for cleaning, simple replenishment without removal, foolproof positioning and self adjustment of pen pressure are the objectives which have been achieved by careful design.

Integrators

The basic principle common to all these is a constant speed movement by which an amount proportional to the flow rate is added to a totalising counter during a fixed interval of time. The interval varies according to the design of the mechanism, but is made sufficiently short to ensure accurate registration for the average rates of flow changes experienced in service. In the continuous integrators, the time interval is infinitely small. The constant speed movement is derived from a spring clock or synchronous electric clock and in some designs is the same unit which drives the recorder chart.

A typical recording and integrating meter is shown in Fig. 20.

CHOICE OF METERS

A considerable number of factors are involved in the best choice for a specific purpose, and some of these can only be settled by consultation with the meter manufacturer. The following is a guide to the type of information which must be available however.

(*a*) What liquid is being measured? This will affect the differential generating device, mainly its materials, and also whether the liquid is likely to affect the meter to which it is connected.

(*b*) What is the line pressure? Working pressures above 1000 p.s.i. may call for special attention.

(*c*) What flow rates are to be handled? It is important to be reasonably precise, as although meters of this type have a recording range of about 10:1, the overall accuracy of the installation is greatest down to 50 per cent of maximum, and the legibility considerably better due to the more open spacing. The normal flows to be handled should, therefore, fall into the top half of the scale, and allowances for unexpected demands or future demands should not be permitted to influence this.

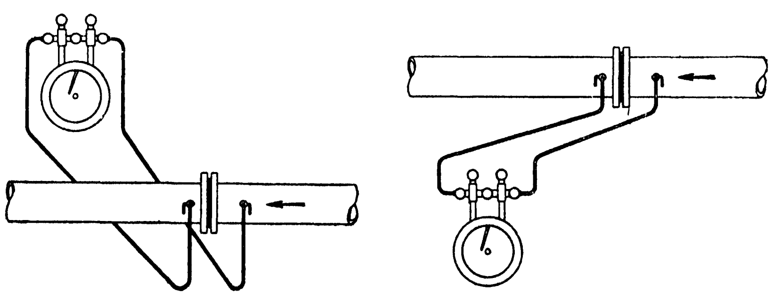
(*d*) What is the density or specific gravity and temperature under operating conditions? This is required to obtain the orifice or Venturi dimensions to suit the flows required.

(*e*) What is the pipe diameter, and if not uniform in size and straight for forty diameters upstream and ten diameters downstream of the intended location for measurement, what are the conditions?

(*f*) Is the pipe line horizontal or vertical?

(*g*) What type of record is required? This requires consideration of its duty. Where a flow is to be held at a predetermined value for short periods under constant supervision, or an occasional check is required at a glance, an indicating type may be all that is necessary. Where a flow is concerned with an important part of a process, it may be necessary to have a record to show any deviations that may have occurred to permit investigating falls in output, or variations in quality. It is also easier to detect tendencies to depart from normal operation on a record than by means of an indicator. For such requirements, a chart speed of one revolution per day is desirable. For less important duties, but where a record of daily maximum and minimum demand is required, or a check is necessary on unexpected abnormal flows a weekly rotation will normally give a clear display of the information.

(*h*) Is an integrator required? Where it is desired to know the total amount of liquid passed, this is of considerable value and saves computation from the record. Where an indicating pointer only is used, it is the only means of obtaining total quantity. The normal range of an integrator is from maximum down to $\frac{1}{7}$ or $\frac{1}{8}$ of maximum below which a cut-out prevents rotation of the counter.



FIGS. 21 and 22.—METHODS OF RUNNING THE PRESSURE PIPES FROM THE MAIN TO RECORDER. (*left*) WITH RECORDER ABOVE MAIN. (*right*) WITH RECORDER BELOW MAIN.

Installation

This should be carried out in accordance with manufacturers' recommendations issued with the equipment, and consists of inserting the orifice or Venturi meter in the line, mounting the meter in the position required, and connecting the tapping points to the meter connections. Certain precautions which must be taken to avoid errors in measurement are common to all these meters and cannot be overstressed.

The tapping points if made in the line itself must be free from burrs and protrusions where they break through.

The joints each side of the differential pressure generator must not project into the line, so that the bores should be slightly larger than the internal pipe diameter and accurately centralised.

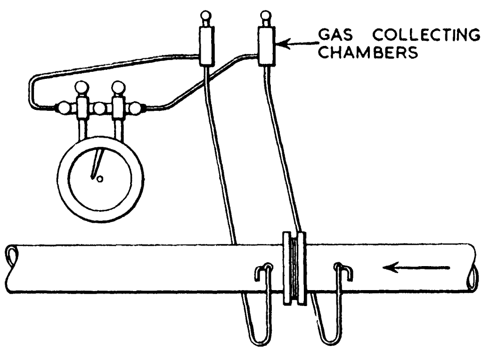


FIG 23 —METHOD OF INSTALLATION FOR METERING LIQUIDS

The connections from the tapping points to the meter must be so arranged that air or gas cannot collect in them, as these cause false differential pressures at the meter. Figs. 21 and 22 show typical pipe runs designed to avoid this. Where it is not possible due to the plant layout to adhere to simple pipe runs, collecting vessels may be used at appropriate points provided with vents (as shown in Fig. 23) to enable the air or gas to be blown off as often as necessary.

Means are required at the meter to shut off the connecting pipes, and to equalise the pressure across the meter in order to check the "zero" of indicators, charts and integrators. In many cases these are built in to the meter head, together with air or gas collecting chambers with vents, as indicated in Fig. 24.

Routine Maintenance

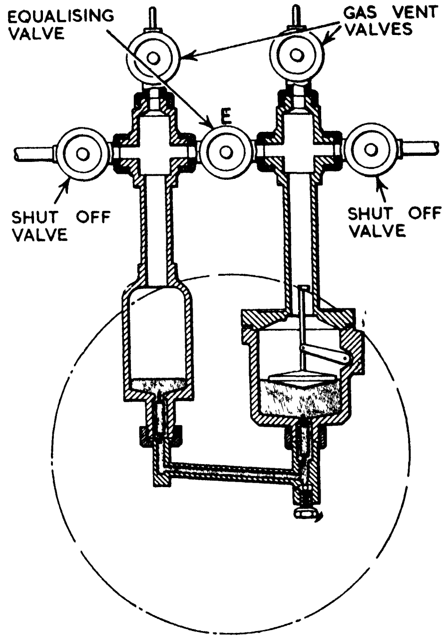


FIG 24—VALVE ARRANGEMENT BUILT INTO THE METER HEAD

Manufacturers' instruction manuals give complete details of maintenance required for the particular mechanism. A planned routine will give the best results and optimum value from the meter. For example, as the chart is changed, the inking device should be checked, the air vents opened to discharge collected gases, the meter equalised and the pen zero reset to agree with the chart zero. Where a spring driven clock is used, which will probably run for a week, this should be wound regularly to avoid unwelcome stoppages. These are particularly likely where an integrator is employed without a recording chart.

Special Applications

Certain liquids which can be satisfactorily handled in a pipe line present difficulties when passing into the connecting pipes and the meter. Cooling of hot heavy oils may cause lack of response due to increased viscosity; corrosion may occur in the meter where it may not be possible or economical to use the necessary resistant materials demanded by a liquid; foreign matter carried in the liquid may deposit in the connecting pipes and meter and cause blockage.

Two methods are commonly used to deal with these problems. One method is to fit seal pots adjacent to the tapping points in the pipe line which contain liquid which is immiscible with and chemically resistant to the liquid being measured. The size of the seal pots is chosen so that the volume of sealing liquid is

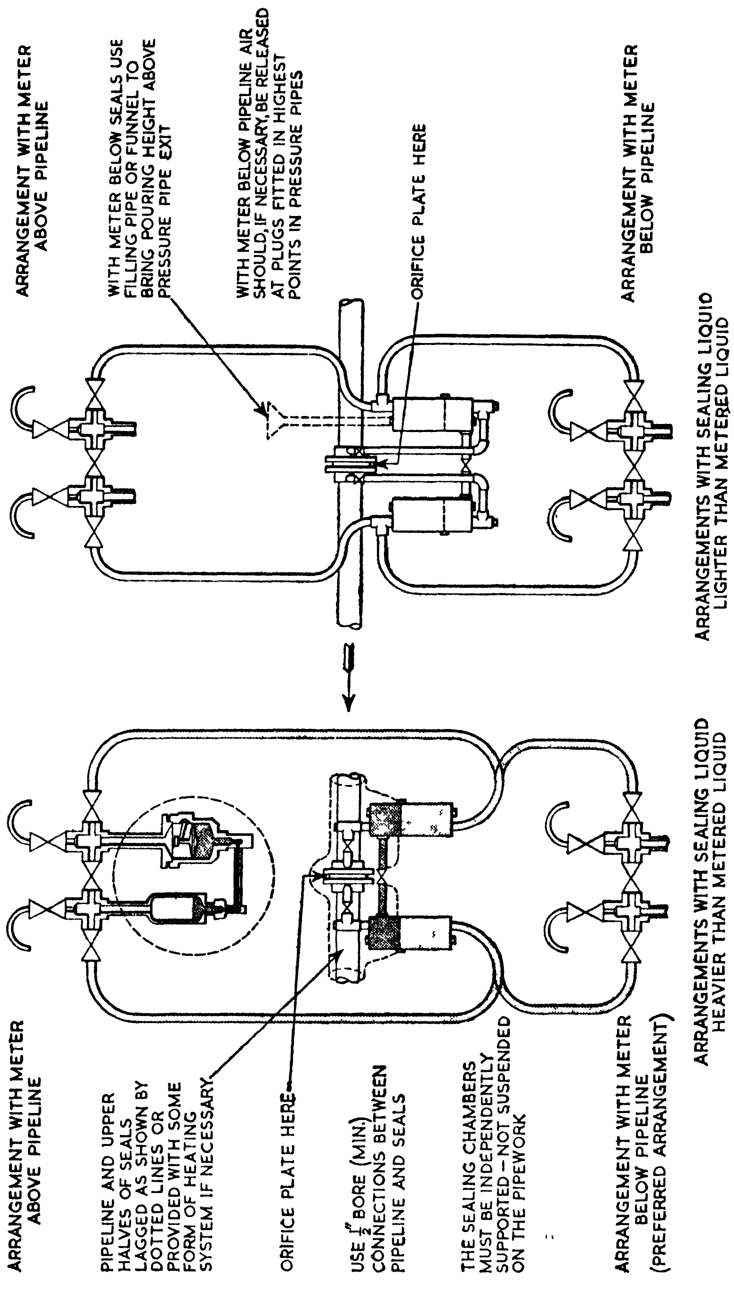


FIG. 25.—ARRANGEMENT OF METERS TO MEET SPECIAL APPLICATIONS

greater than the displacement of the measuring unit during its maximum movement so that the sealing liquid level always remains within the sealing vessel. The meter and connecting pipes thus contain only the sealing liquid. The arrangement is shown in Fig. 25.

The second method is to inject into the main at the tapping points a gas or liquid which has no detrimental effect on the liquid being measured, the same gas or liquid also filling the connecting pipes and the meter. The injection fluid must always be at a higher pressure than the pipe line and some form of flow indicator is often used to show that its flow is being maintained, as in Fig. 26. An alternative method when using liquid injection is to use a motor driven positive pump which injects a known quantity per stroke independent of the pressure in the line.

VARIABLE APERTURE FLOW METERS

This class of meter, like the differential meter, gives initially a mechanical movement proportional to the rate of flow, but the moving member is immersed in the flow stream. The moving member at zero flow completely obstructs the stream, and as the flow rate increases, moves with the flow to expose a larger and larger area of opening.

The movement is restrained by weight or spring, and the distance moved from the zero position is a measure of the rate of flow. The most common of this type is the "rotameter" shown in Figs. 27 and 28, in which the float forms the control weight and indicator, and the aperture is formed between the disc at the top of the float and the tapered glass tube.

By suitable choice of materials, these can be made to handle a wide range of corrosive liquids, and although in the simple form the liquid must be clear in order to view the float, various forms of detection of the float position from outside the tube are employed which offer virtually no restraint, and permit recording of the position. A typical example is shown in Fig. 29.

For many applications, all metal construction is employed using the same principle.

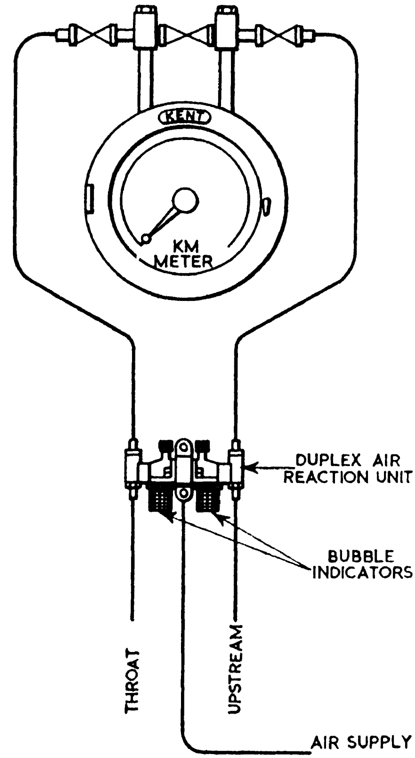
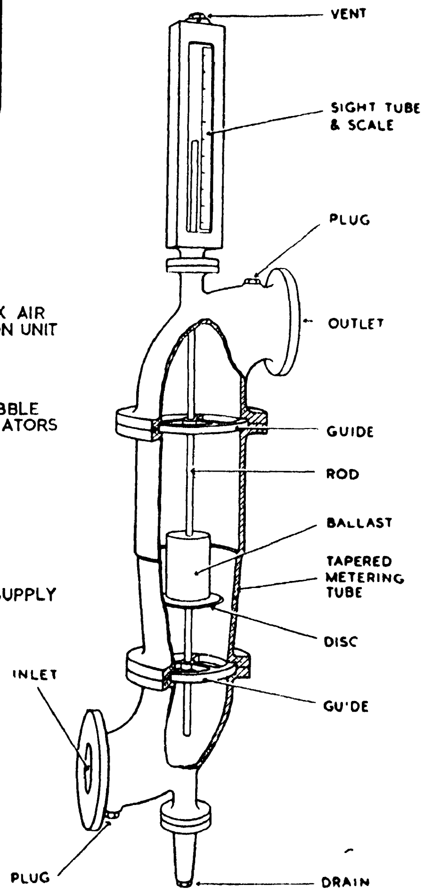


FIG 26 —(*left*)—ARRANGEMENT OF METER WITH AIR REACTION



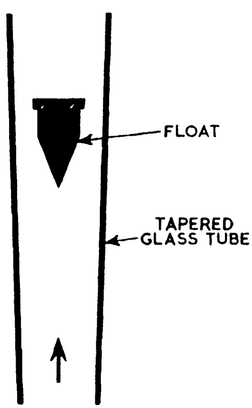


FIG 27 (*left*)—PRINCIPLE OF THE ROTAMETER.

FIG 28 (*above*)—SECTIONAL VIEW OF METAL TUBE ROTAMETER

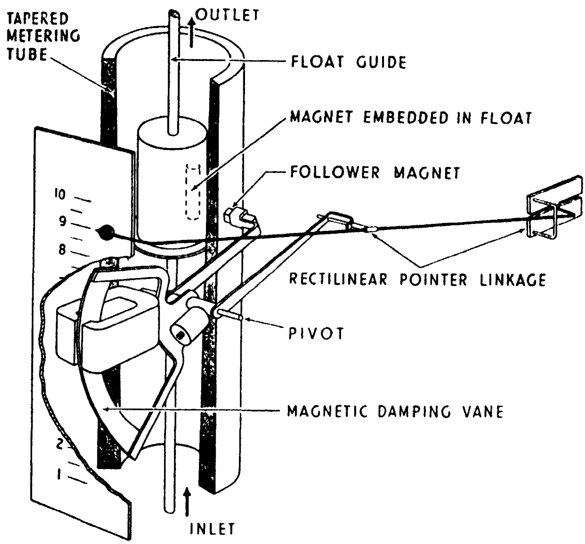


FIG 29.—ROTAMETER WITH MAGNETIC FOLLOWER

REMOTE CONTROL MECHANISMS

In order to meet modern industrial requirements, the instrument industry has designed systems of remote transmission to enable the measurement to be transmitted by electrical or pneumatic means to instruments at a central control point. This is an advantage where hazardous liquids are involved, avoids long pressure pipes and simplifies installation.

Additional mechanism can be added also in the instrument to provide automatic control of the flow.

FLOW MEASUREMENT IN OPEN CHANNELS

This problem occasionally arises in industry in dealing with effluent flows. In such cases, a sill across the flow with an opening of a particular shape and dimensions, or a restriction similar to the contour of a Venturi may be used in the channel and the upstream level measured by means of a float connected to a recording mechanism. The theory underlying the relationship between this level and the rate of flow is complex and each application normally requires individual consideration to obtain

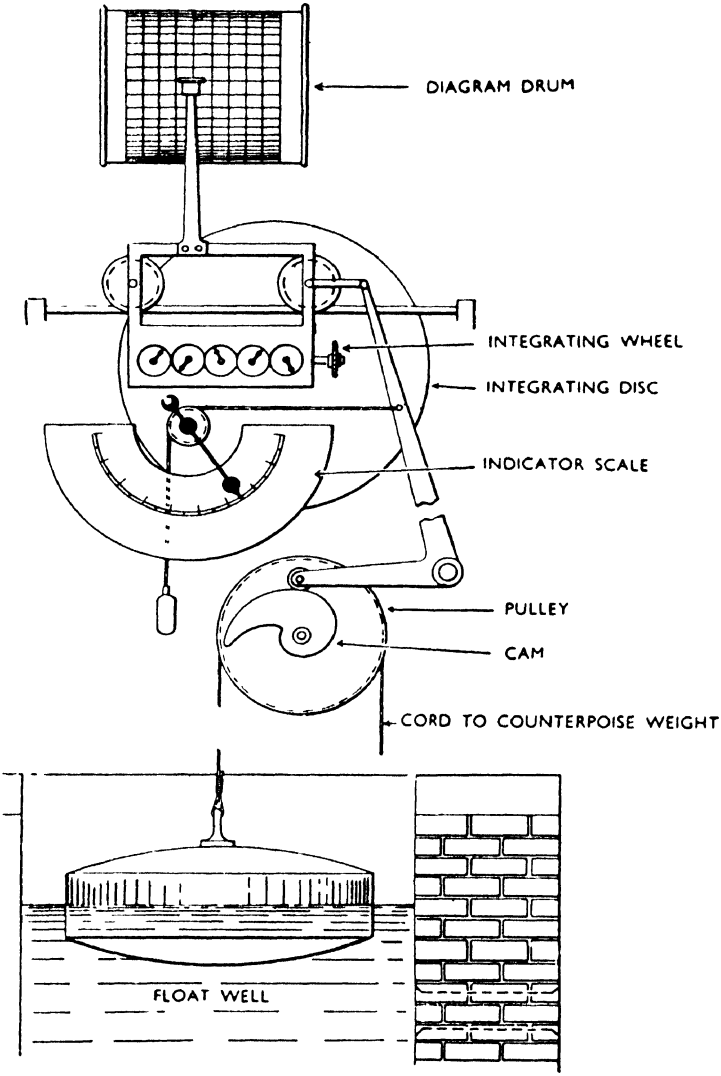


FIG. 30.—INSTALLATION FOR MEASUREMENT OF FLOW FROM WEIR OR VENTURI FLUME.

the required conditions. The float is connected by a cord passing over a circular cord wheel to provide an angular movement for operating, indicating, recording and integrating devices, as described for differential flow meters.

An example of this type of measurement is the weir consisting of a plate provided with a rectangular or 'V' opening through which the liquid flows. The height of the liquid above the lowest point of the opening is a measure of the rate of flow.

While the basic formulae can be simply expressed by

$Q = CH^{3/2}$ for rectangular openings,

and $Q = CH^{5/2}$ for 'V' notch openings

where Q = rate of flow

C = constant

H = Head of water above the crest of the opening

the practical formula for a given installation depends upon a variety of factors. B.S. 599: 1939 *Pump Tests* gives recommended conditions for weirs and the appropriate formulae which ensure reliable measurements.

A restriction formed by reducing the width of an open channel in a form similar to the contour of a Venturi tube can also be used under specified conditions to indicate rate of flow by measurement of the liquid level upstream of the throat. The shaped portion of the channel is described as a Venturi flume and the relationship of head of liquid to rate of flow is similar to that for a rectangular weir.

A typical instrument which is used for recording and integrating the rate of flow is shown in Fig. 30.

For a more detailed treatise on flow measurement, the reader is recommended to study *Flow Measurement and Meters* by Linford and published by Messrs. E. and F. N. Spon Ltd. Formulae and coefficients for orifices and Venturi tubes may be found in B.S. 1042: 1943 *Code for Flow Measurement.*

SECTION 3

METERING OF STEAM AND GASES

By P. SCANES

In industrial plants the measurement of gases which form part of the product process has become essential to the operation, especially where the process is continuous, and accurate flow rates must be maintained in order to obtain the required quality of the final product. Records obtained enable a close check to be maintained on plant operation, assist in investigation of cause of deviations in output or quality, and may be used for accounting. Similar measurements of flows of services such as steam and compressed air used in the plant, but not directly in the product, are of the utmost value in assessing operating costs and indicating ways of improving efficiency.

As in the case of liquids, meters for this purpose may be broadly divided into two classes, one in which the meter is installed directly into the line and measures volume, and the other in which the pressure difference across a restriction in the line is measured and translated into flow. The former are normally termed "mechanical" meters, and the latter "differential" meters. There are certain basic differences between meters for liquids and those for gases due to the very low viscosity, the compressibility, low density and often high velocities met with in gas flow measurement. Steam due to its liquid state at normal ambient temperatures and pressures requires somewhat different treatment from gases in general, although while in its gaseous state it behaves as a gas for the purpose of measurement. In the descriptions of the meters and methods which follow, therefore, attention will be called to those which are not suitable for or require special application for steam.

MECHANICAL METERS

These may be divided broadly into two classes, one class being virtually a positive, or semi-positive, type in which a definite volume is displaced per cycle of the mechanism, and the other

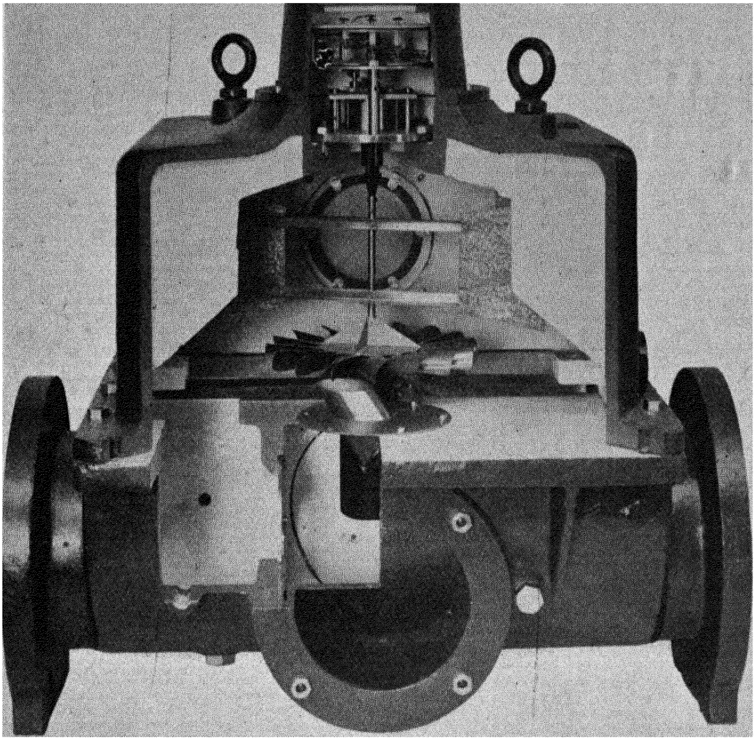


FIG. 1.—LOW PRESSURE SHUNT GAS METER
(*George Kent Ltd.*)

being an inferential type, in which the energy of the stream is used to rotate the moving member at a speed proportional to the stream velocity. While these general classifications are similar to mechanical meters for liquids, the meter construction differs considerably as the volumes to be handled are normally considerable due to the low density, and the pressure drop over the meter must be kept small to avoid velocity or volume variations of the gas in the meter, due to its compressibility.

Positive or Semi-Positive Meters

Positive or semi-positive meters are normally used in the measurement of clean gas supplied to consumers. They are of large dimensions in order to obtain the necessary power to

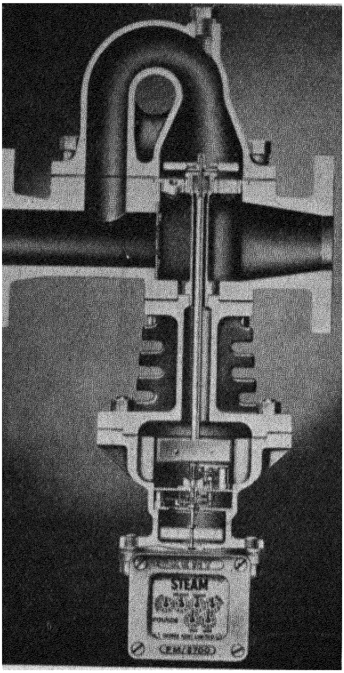


FIG. 2—INFERENTIAL METER, SHUNT FLOW TYPE
(*George Kent, Ltd*)

overcome friction with low pressure loss and to reduce the velocity of the moving parts. Their application is very limited in industrial plants and a more detailed description is therefore omitted. Positive or semi-positive types are not suitable for steam flow measurement.

Inferential Meters

The use of a simple turbine or rotor in the gas stream is not practicable due to the high speeds which would be obtained with the normal range of gas flows or to the low power to friction ratio which would occur at low gas flows.

The addition of damping vanes to the rotor shaft minimises both of these problems, and the provision of a shunt path round the measuring element enables a wide range of flows to be handled, using the same rotor and mechanism with the utmost economy in size.

The low pressure (about 10 p.s.i.) shunt gas meter shown in Fig. 1 employs damping blades immersed in the gas being measured, and the bearing friction and load due to the registering mechanism is reduced to a minimum. The gas flow is directed by means of nozzles on to the rotor blades, and by selection of the correct orifice and body size for the by-pass flow, the maximum flow for the meter can be varied over a wide range to suit gas mains from 3–30 in. The pressure loss at the rated maximum flow is about 2 in. water gauge and the operating range is about 10 : 1. The meter can deal with dirty gases provided that routine cleaning of the nozzles is carried out, for which easy access is provided. For tarry gases, steam jets may be incorporated to clean the interior without opening the meter. The meter measures volume of gas at the pressure and temperature actually in the meter.

Shunt Flow Inferential Meters

The shunt meter shown in Fig. 2 employs damping blades immersed in a liquid which enables it to deal with the higher velocities met with at higher pressures. Part of the gas is directed by two nozzles on to the rotor blades, while the orifice controls the proportion which is by-passed. By selection of the appropriate orifice size, and the body diameter, a wide range of maximum flows can be obtained. The bodies are chosen to match 2-, 3- and 4-in. pipes, while for large mains the meter may be used in a by-pass itself as shown in Fig. 3. Due to the constant density of the damping liquid, the registration varies with the density of the gas and in fact obeys a similar law to that of the orifice meter.

If Q be the volume of gas passed under the working condition of the meter

P_W the density of the gas at the working condition

P_C the density for which the meter is calibrated

R the quantity registered by the meter,

Then

$$Q = R\sqrt{\frac{P_C}{P_W}}$$

and in weight units

If W be quantity passed under working conditions

R_1 be quantity registered in weight units

$$W = R_1\sqrt{\frac{P_W}{P_C}}$$

For a given gas (including steam) the density varies with absolute pressure and absolute temperature, so that corrections may be applied from measurements of these two variables.

The registration is affected by a change of density of the damping liquid, and the same liquid must therefore be used as that specified in the original meter calibration. The actual damping liquid is varied according to the duty.

The meter is designed for measuring at high temperatures and pressures up to 250 p.s.i. and can be used for steam measurement. The damping chamber is cooled by means of fins and

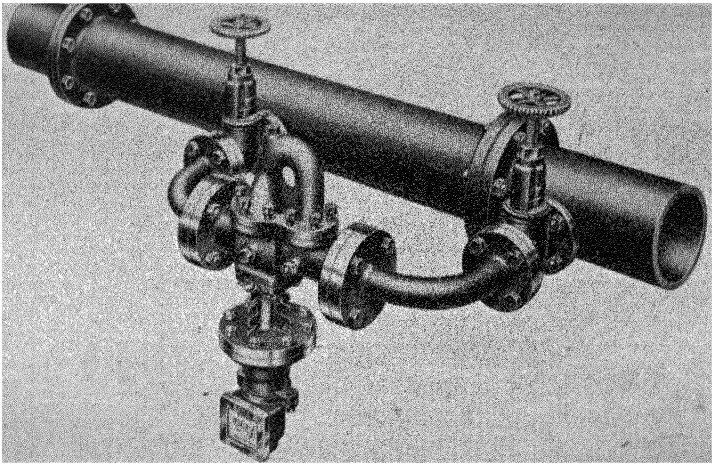


FIG 3.—SHUNT STEAM METER ON BY-PASS.
(*George Kent, Ltd*

condensation of the steam provides the damping liquid, and maintains its level automatically.

Installation and Maintenance of Inferential Meters

These meters require a horizontal straight section of pipe line of uniform diameter in the same manner as orifice meters, as the accuracy of measurement is dependent on the coefficient of the orifice with which the measuring element is incorporated. Joints must not protrude into the pipe bore.

The meters can withstand considerable short period overloads.

MAINTENANCE.—In the low pressure gas meter, accumulation of deposits in the nozzles affects the accuracy and should be removed as soon as any build-up is evident. This will normally occur only with dirty gases.

In the liquid damped meter when used with gases, periodic replenishment of the damping liquid is required to maintain the level.

DIFFERENTIAL METERS

The basic principles underlying the use of orifices and Venturi tubes to produce a differential pressure are similar to those

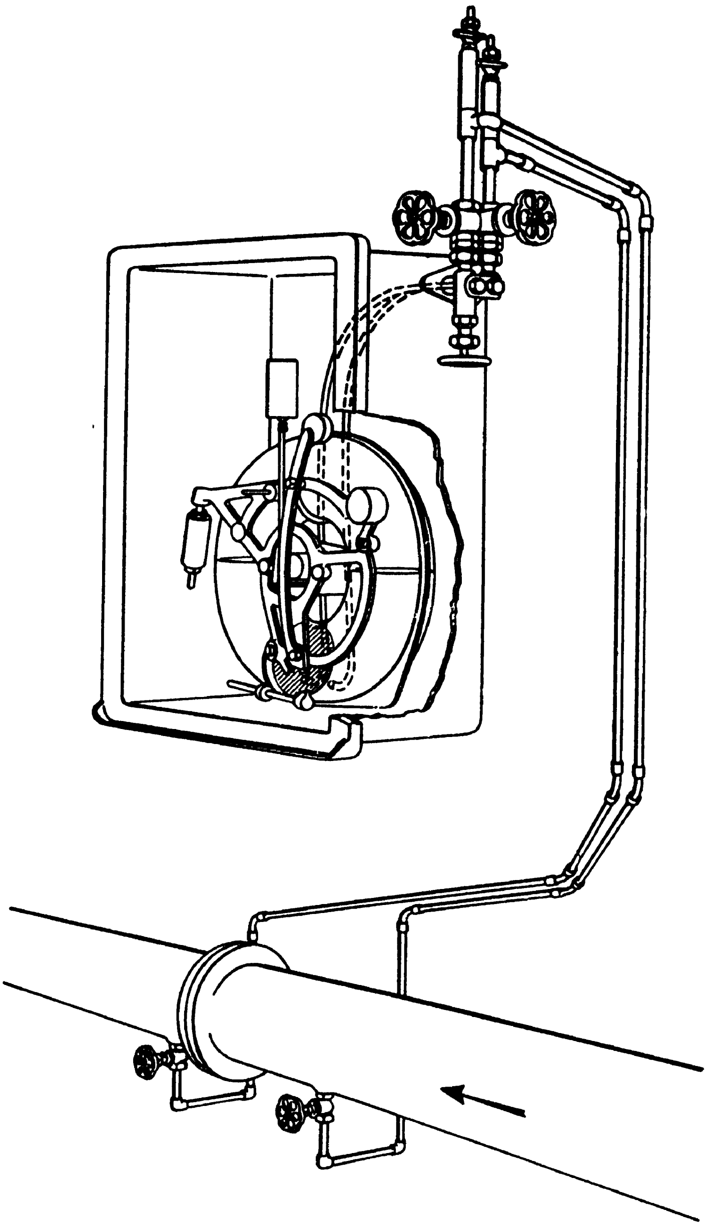


FIG. 4.—LOW DIFFERENTIAL HEAD RING BALANCE METERING UNIT.
(*George Kent, Ltd.*)

described for liquids, and the differential measuring devices are in many cases identical. Attention will therefore be called to certain differences in the methods which arise due to the compressibility of gases and their low densities compared with liquids.

The value C given for the differential generating devices in the simple formula

$$W = C\sqrt{\frac{P}{\rho}}$$

is constant only if the change of density in the restriction is small. Since the density varies with absolute pressure, the gas must suffer some density change in producing the differential pressure, and this must be kept to a small proportion of the absolute pressure of the gas. For this reason in many applications very low differential heads must be used and a correspondingly more sensitive differential measuring device must be employed.

In the formula the density term indicates that, as in the case of liquids, the differential pressure is affected by the gas density, but unlike liquids the gas density is considerably influenced by pressure and temperature in the pipe line. A meter is, therefore, accurate for one specific ratio of absolute pressure to absolute temperature and one specific density at this condition.

The simple formula may be modified to show this dependence, and becomes for a given gas:

$$Q = C_1\sqrt{P_d\frac{P_A}{T_A}}$$

$$W = C_2\sqrt{P_d\frac{P_A}{T_A}}$$

where P_A = absolute pressure, and
T_a = absolute temperature
P_d = pressure diff.

Q is the volume of gas at a specified temperature and pressure and is often expressed by "free gas," which means the volume it would take up if allowed to assume the pressure and temperature of the atmosphere (taken as 14·7 p.s.i. absolute and 60° F.). Thus for accurate measurement variations in pressure and temperature

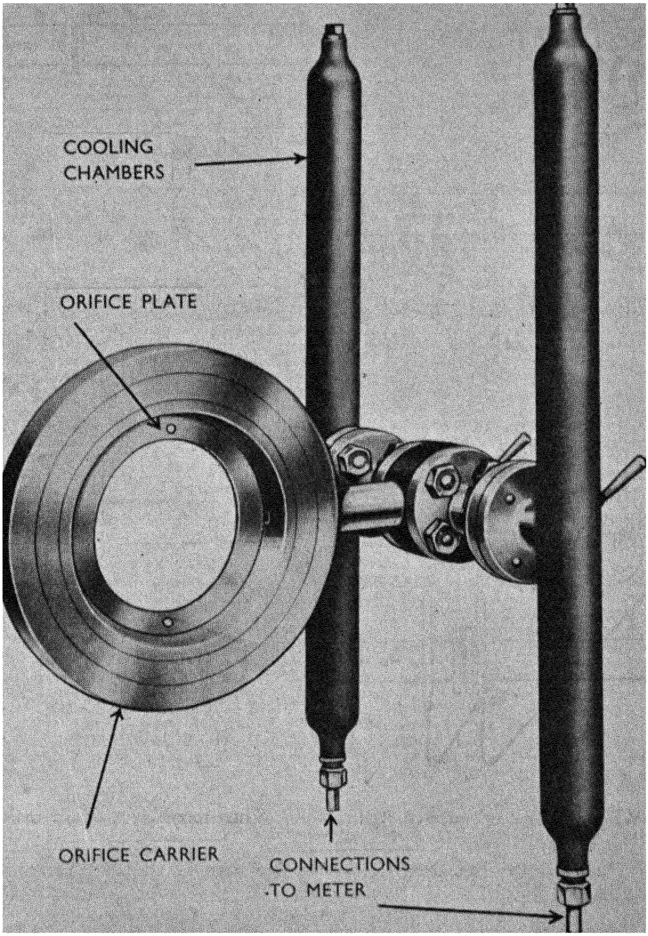
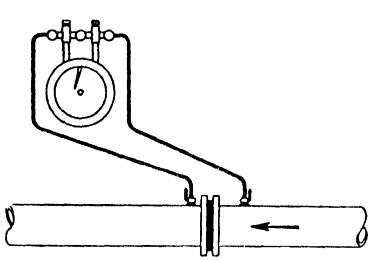
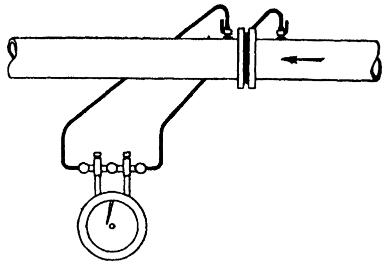


FIG 5 —CONNECTIONS FOR DIFFERENTAL METERS.
(*George Kent, Ltd*)

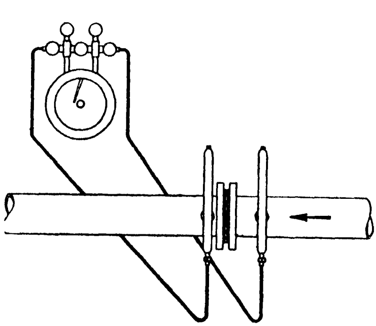
must be taken into account, although in practice if the mean values are carefully chosen and the meter is calibrated for these, a reasonable overall accuracy is obtained. Due to the square root relationship, the error introduced is approximately one-half only of the percentage change in the absolute pressure or the absolute temperature.



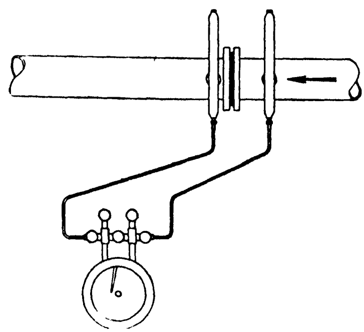
AIR AND GASES
When recorder is above main



AIR AND GASES.
When recorder is below main



STEAM
When recorder is above main



STEAM
When recorder is below main.

Fig. 6.—Typical Pipe Runs for Air and Gases and Steam.

Differential Pressure Measuring Instruments

Where gas pressures are high (and this applies almost invariably in steam measurement) the differential pressure can be made sufficiently large to operate any of the measuring units described for liquids.

For low pressure gases in which the permissible differential may be as low as 0·5 in. water gauge at maximum flow, some changes must be made in the unit in order to obtain sufficient power to operate recording and indicating devices, which entails increasing the area on which this differential pressure operates.

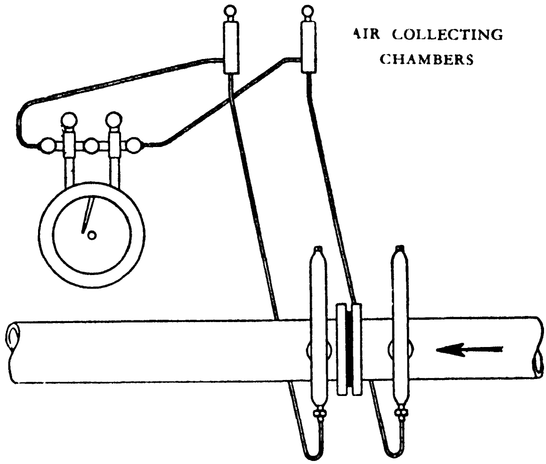


Fig. 7 (*right*)—Pipe Run for Steam, Using Air Collecting Chambers

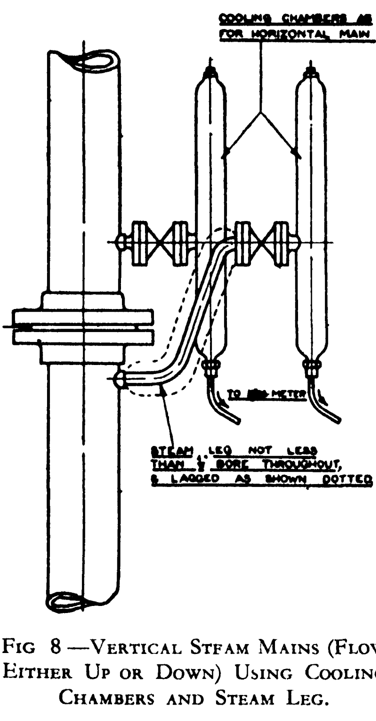


Fig 8—Vertical Steam Mains (Flow Either Up or Down) Using Cooling Chambers and Steam Leg.

Fig. 4 shows a low differential head ring balance metering unit. The sealing liquid for air and most gas measurements is paraffin, as this is capable of sealing against differential heads up to about 8 in. water gauge in the dimensions of the ring, and does not materially add to the weight of the ring on its knife edge bearings.

The bell-type unit, in which the bell is suspended by springs, and the open base is immersed in the sealing liquid has already been referred to (see Section 2, Fig. 17). In this device the bell movement is brought out of the casing by a lever and gland.

These low differential types are not suitable for steam.

Installation of Differential Meters

In the case of gases, the connections from orifice or \ tappings to the measuring unit must be so disposed that m which may accumulate can run back into the pipe line ‹ collecting vessels where it can be drawn off.

For steam measurement, this is deliberately condensed pipe line so that water is present in the connecting pipes the meter. In order to assist the condensation, and to p a reservoir of liquid for displacements occurring in the during flow changes, a cooling chamber is fitted at each t point as shown in Fig. 5. In the case of a vertical pipe short lagged portion of pipe is required to one cooling cl in order to keep the liquid level the same in each.

Typical pipe runs for gases and steam are shown in Fig and 8.

Recording Devices

These are similar to those described for liquid mete page 32), and in many cases the identical mechanisms are e ed. Where necessary on very low head meters, the mecl is made lighter in view of the lower power available, a combinations of the various features may be limited.

VARIABLE APERTURE FLOW METERS

The principle described for liquids is equally applic gases and similar corrections for gas density variatio required as in the case of the differential meter. The t glass tube and float are eminently suitable for indicating fl clean gases and can be manufactured to handle a wide ra corrosive gases. These meters are not used for steam m ment.

CHOICE OF METERS

As in the case of meters for liquids, a number of factor ence the best choice for a particular duty. For mea quantities of air, steam or gas supplies to various sectio plant in order to allocate costs of production, totalising such as the inferential meter provide an economical and a means. For process work where rates of flow are important and centralised grouping of essential measurements is desirable, the differential meter is necessary. The information required by the manufacturer in order to specify the type of instrument considered best suited to the application is similar to that indicated under the same heading in the section on liquid meters (see page 34).

SECTION 4

THE DRYING OF GASES

By J. R. HOWARD, A.M.I MECH.E.

ALTHOUGH the general term "fluids" is most often taken to connote liquids, it does in fact cover all those substances which take the shape of the vessel in which they are contained.

Fluid Handling must, in its widest sense, include the drying of gases and vapours. The metering of steam and gases has been dealt with in the preceding section. The present section is devoted to the important subject of the Drying of Gases and the control of humidity.

Moisture Content of Gas

Under normal conditions, moisture is always present in air and gases. It is not visible unless the concentration is so heavy that moisture separates out as fog, mist, or actual droplets, and this fact can be used as a means of measuring the liquid content.

At saturation point, a bright metal surface in contact with the gas will be coated with finely divided moisture, or "dew," and apparatus is available which will define this "dewpoint" with accuracy.

The liquid present in a gas can vary between absolute dryness and saturation, and the percentage of moisture is usually referred to as the "relative humidity," taking full saturation as 100 per cent. Change of temperature or pressure will change dewpoint and relative humidity. These variables, and the heat content, are inter-dependent, and have been tabulated by various experimenters.

Relative humidity can be read directly from such a psychrometric chart, which gives the relation between wet and dry bulb temperature as read on a standard two-bulb thermometer, the wet bulb always showing a lower temperature than surrounding air or gas, owing to the effect of evaporation. For example, in perfectly dry air, maximum difference would be shown, and in saturated air the minimum difference. A typical

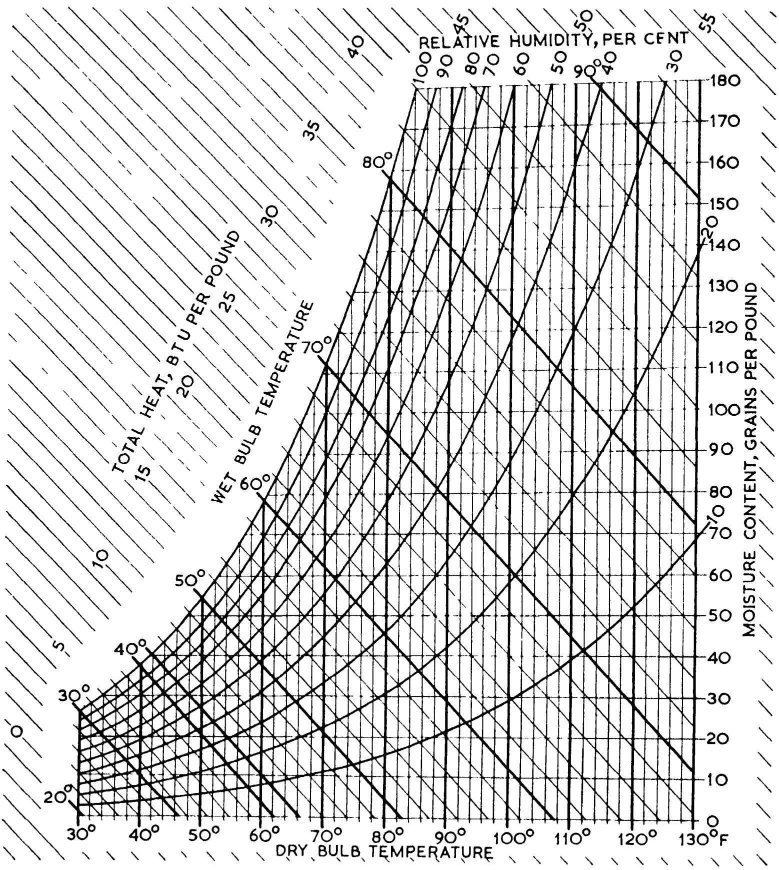


FIG. 1—PSYCHOMETRIC CHART

chart is shown in Fig. 1. To find the relative humidity for any conditions, follow diagonally downwards to the right from the wet bulb reading, until the line cuts the vertical line from the dry bulb reading. This point will lie on or between lines curving upwards to the right, these showing the relative humidity as a percentage of the total moisture content at saturation or "dew-point" conditions.

It naturally follows that all variables in the physical conditions connected with moisture in gases are inter-dependent, so that a change in temperature, pressure, humidity or total heat,

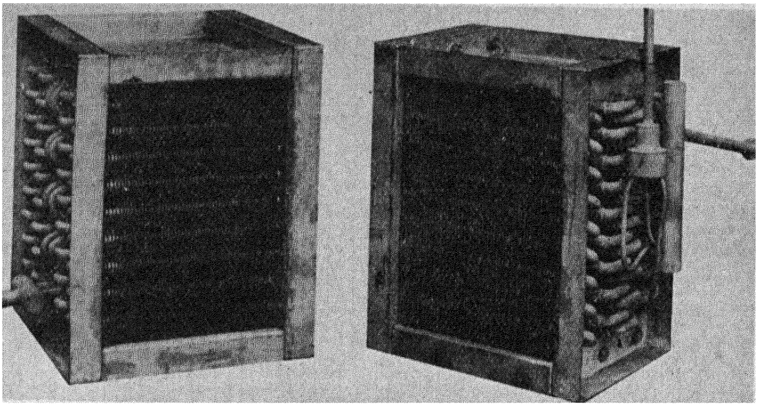


Fig. 2.—Typical Finned Dehumidification Coils.
(*Carter Refrigeration & Airconditioning, Ltd.*)

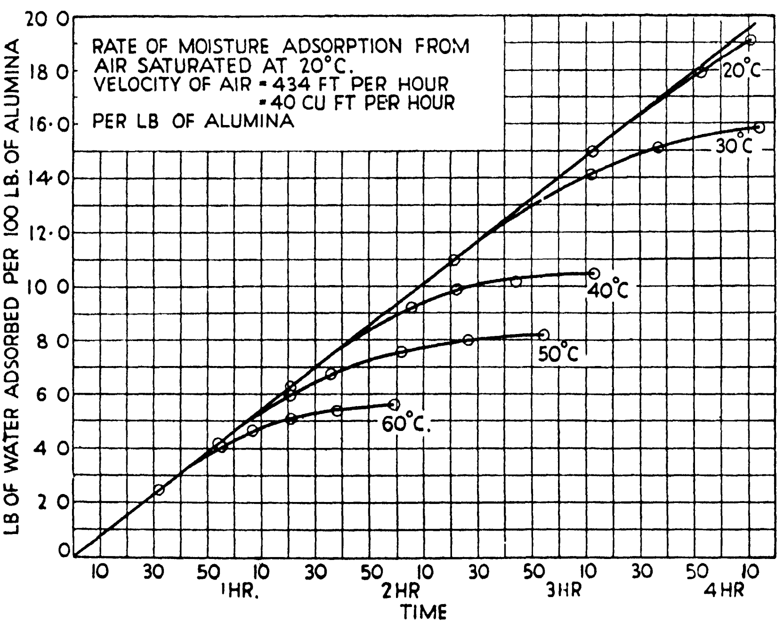


Fig. 3.—Effect of Bed Temperature on Adsorption Efficiency.

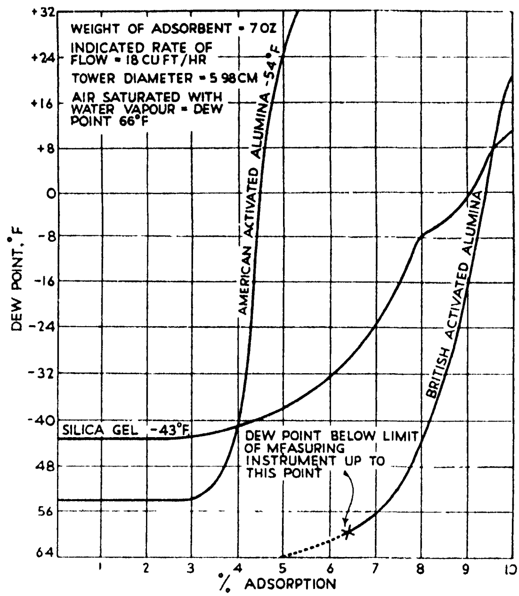


Fig. 4 —Comparative Dew Points Obtained at a Fixed Drying Rate

will affect all the other factors, and a process can be devised which will produce any desired condition.

"Air conditioning" is applied to maintain moisture content and temperature in offices, shops and factories, which is acceptable for comfort, stock maintenance, or special processes, using, as may be most suitable for local conditions, spray chilling, refrigeration, or heating, or a combination of these, as, for example:

1. Contact with water sprays, will give a saturation or dewpoint approximating to the temperature of the spray.
2. Mechanical carry over of liquid from the sprays is separated by contact with surfaces, or by change of direction, etc., etc.
3. Reheating to the desired temperature will lower the relative humidity, as may be read directly from the chart. (Fig. 1.)

Alternatively:

1. Refrigeration will reject moisture by cooling below the "dewpoint."
2. Reheating will lower the relative humidity, as in the first example.

Reduction of Relative Humidity

It is necessary to clearly understand the change of physical state which is involved in drying or reducing relative humidity above the dewpoint, before deciding which method is commercially economic for any particular application.

Partial drying by refrigeration is used to treat large volumes of gas where dewpoints below or near freezing point are not required, using heat exchangers or gilled tubes, around and across which the gas to be cooled is guided by baffles, or by suitable arrangement of the tubes. Makers of such plant have brought the system to a high standard of efficiency. Typical examples are illustrated in Fig. 2.

When drying to a dewpoint lower than freezing conditions, refrigeration is limited because the moisture will be deposited on the cooling tubes as ice, which will rapidly seal off the spaces between the gills on the pipes and choke the apparatus—so that for practical purposes it is not advisable to use this method below 36° F. except where special conditions allow the expense involved in compressing, cooling, and release of pressure, as for example in preparing gases for processing or liquefaction, a subject outside the scope of this article.

Partial drying by refrigeration is economical as a preparation for the drying of gases by adsorptive methods, using solid adsorbents which are sponge-like in structure, hard, granular, and chemically inert, the water being contained in the minute cells and passages of the material by a process which is not completely understood, and which is accompanied by a rise in temperature.

The action is probably connected with capillary attraction, and the water can be rejected by heating above the boiling point, this being termed "reactivation."

Adsorbtion Elements

The two adsorbent media principally used are silica gel—($Si\ O_2$) and activated alumina ($Al_2\ O_3\ H_2\ O$). Both are capable of repeated cycles of adsorption and drying out or reactivation.

It is stated that, due to the sponge-like structure, one pound of this alumina contains 1,600,000 sq. ft. of pore area.

Advantages of silica gel and alumina are: ease of handling, non-corrosive nature, capacity for repeated regeneration, stability

TABLE I

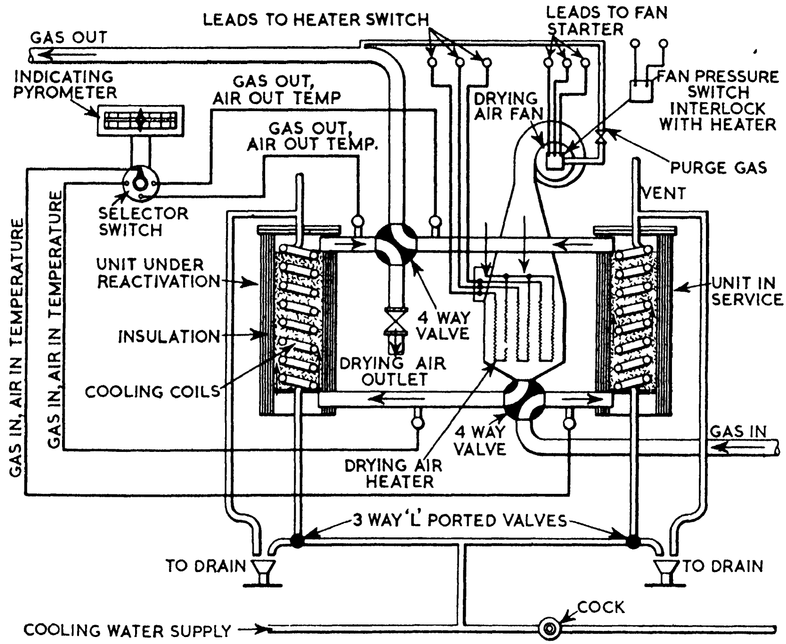
DESCRIPTION AND TABLE OF PHYSICAL CHARACTERISTICS OF ACTIVATED ALUMINA

Property	*Numerical Value*	*Units*
Physical structure . . .	$Al_2O_3H_2O$	
Specific heat . . .	0 21	cal./g /°C. at 30° C.
Thermal conductivity . .	0·75	B Th.U./sq.ft./hr. /in./°F. temperature, difference at 20–30° C.
Thermal conductivity with 15 per cent adsorbed water .	0 85	
Bulk density	40	lb./cu.ft.
Apparent specific gravity . .	1 10	
True specific gravity . .	3 60	
Porosity . . .	60	per cent
Surface area . . .	350	Sq. m /g.
Water adsorption at 100 per cent efficiency . . .	17–18	per cent by weight

to heat to fairly high temperatures, low resistance to gas flow, great mechanical strength, and the low dewpoints which can be obtained.

These very low dewpoints are illustrated in Fig. 4 in which the percentage adsorption is plotted against dewpoints at a fixed flow rate for activated alumina (British and American materials) and for silica gel. In general, silica gel has a higher total adsorption capacity, which is of advantage for purposes in which dewpoints of less than 6° F. are not required, but the breakdown in service of silica gel is greater and it disintegrates if it comes into contact with liquid water.

Both materials work equally well under high pressure, and large units can be made to treat compressed air or gas directly by passage through suitable containers. A specific time of contact is necessary, but this depends upon temperature, the time increasing as the temperature rises until adsorptive action ceases.



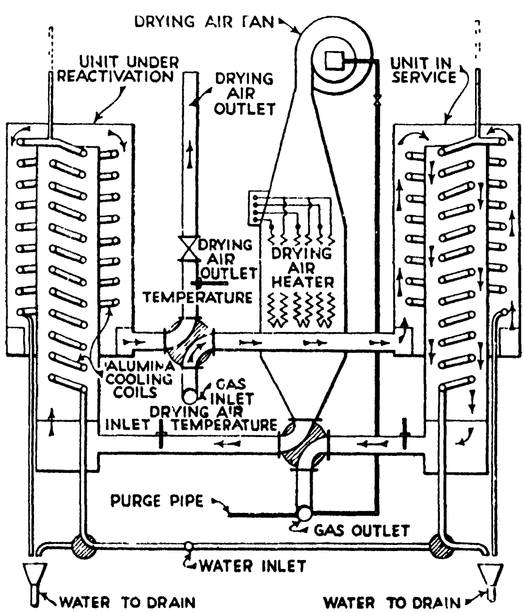


FIG 5 (*above*) — DIAGRAM OF SIMPLE TWO-CHAMBER ALUMINA DRIER.

FIG. 6 (*left*).— DIAGRAMMATIC LAYOUT OF ANNULAR RING DRIER.

TABLE II

MINIMUM CONTACT TIME FOR COMPLETE DEHYDRATION

Volumetric flow rate cu. ft./hr.	Time of contact seconds	Dewpoint ° F.
8	1·9	below –62
18	0·9	–63
20	0·8	–62
29	0·5	–52
35	0·4	–30

This action is naturally reflected in the performance figures at normal pressures, and here exact figures have been taken by the principal suppliers.

Fig. 3 demonstrates the reduction in adsorption capacity with reduction in relative humidity. Over the range 15–50° C. the adsorptive capacity is substantially constant for constant relative humidity.

Reactivation

Opinion differs as to the best method of supplying heat for reactivation; it can be done by:

(*a*) Heating the alumina beyond adsorption point and blowing cold air through.

(*b*) Heating the blowing air.

In the first case (*a*), reactivation or removal of moisture does not commence until the mass has reached approximately 250° F. and in the second case (*b*), reactivation commences as soon as local heating exceeds 250° F. but in both systems, the entire mass must eventually be heated. A definite guide as to condition can be given by the exit temperature of the air, as heat will be taken up so long as any moisture remains. Obviously the same quantity of heat must be supplied as the adsorption has evolved during drying, plus heat loss by radiation and exit of the air, plus also the heat required to raise the weight of material, containers, etc., to 250° F. during reactivation.

Adsorptive efficiency varies. The quality and characteristics of the material to be used must be known, and weighed

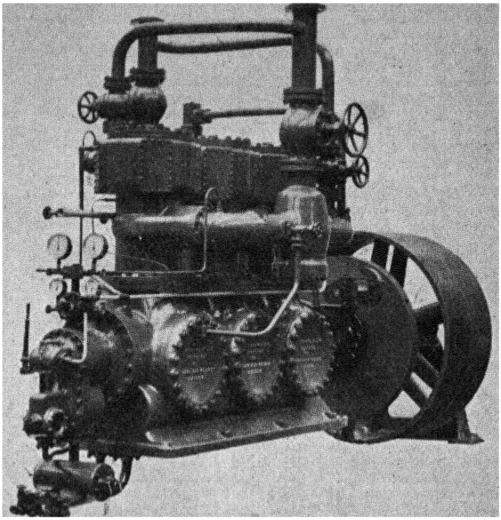


FIG 7.—AMMONIA COMPRESSOR BY L STERNE & CO, LTD.

This has three cylinders (14 in. bore 12 in stroke) and is suitable for running up to a maximum speed of 300 r p m. When running at this speed it can develop 225 t.r and 300 h p is required to drive it

(*Carter Refrigeration & Airconditioning, Ltd*)

against the duty required. Silica gel will give dewpoints down to — 43° F. American Alumina will give dewpoints down to — 54° F. Alumina manufactured for the purpose of drying, will give as low as — 60° F. consistently, or lower with special precautions.

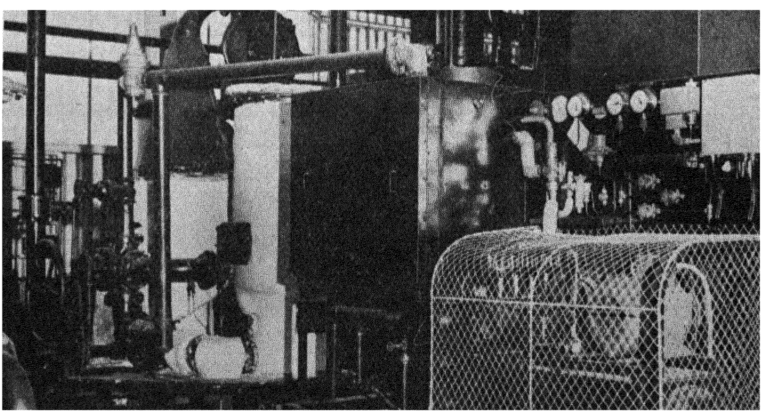


FIG 8—NITROGEN GAS DRIER
(*Incandescent Heat Co, Ltd*)

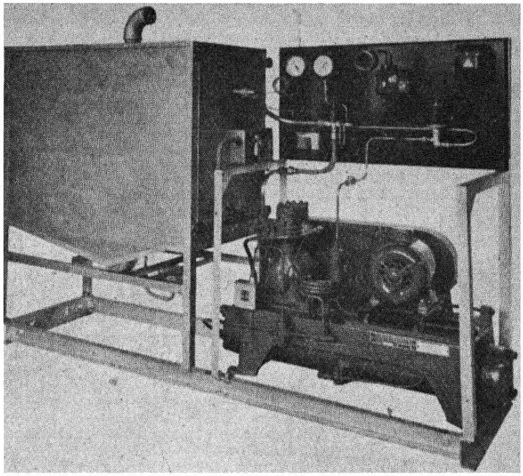


FIG. 9.—DIRECT EXPANSION GAS COOLING AND DEHUMIDIFYING UNIT.
Capable to reducing 400 cu. ft per hour of Nitrogen from 100° F saturated to 40° F saturated
(Carter Refrigeration & Airconditioning, Ltd.)

The life of prepared alumina is not affected by liquid saturation, but saturation point is reached suddenly, and exact timing of the duty cycle is necessary. For this reason, and also on grounds of economy, a refrigerator to hold a standard dewpoint of 38–42° F. is of advantage before the dryer.

Given a knowledge of adsorptive efficiency, the weight of water which the material will accept can be calculated, and a fixed time cycle arranged. This also governs the amount of alumina to be used, and the type of drier, heater, fan capacity, etc.

Types of Alumina Driers

The usual type of simple dual chamber drier is shown in Fig. 5.

Gas to be dried enters from the right-hand and can be directed into either chamber by the lower four-way valve, leaving by the upper four-way valve. Reactivation of the other chamber may proceed simultaneously as the fan can blow heated air or gas via the other ports in the four-way valves. Temperatures at entry and exit of each chamber are shown by the pyrometer, which can be connected to any of the four points by a selective switch. The valves are linked to give simultaneous action.

An improvement on the simple design is the double pass arrangement shown in Fig. 1 and is especially suitable for large

TABLE III

WATER VAPOUR IN ONE CUBIC FOOT OF GAS

Dew-point Fah.	*Dew-point Cent.*	*Weight of H_2O Vapour lb. per C. ft.*	*H_2O per cent of Vol.*
− 40	−40	0·0000082	0 014
− 36	−38	0·000012	0 0205
− 32	−35	0·000016	0·0275
− 28	−33	0·000021	0 0367
− 24	−31	0·000025	0·0441
− 20	−28	0 000031	0·0552
− 16	−26	0·000038	0·0682
− 12	−24	0·000045	0·0817
− 8	−22	0·000055	0·1005
− 4	−19	0·000065	0·1195
0	−18	0 000077	0·143
+ 4	−16	0 000092	0 173
+ 8	−13	0 000110	0·208
+ 12	−11	0·000130	0 248
+ 16	− 9	0·000154	0 279
+ 20	− 7	0·000182	0·353
+ 24	− 4·4	0 000215	0·42
+ 28	− 2·2	0·000255	0·502
+ 32	0	0·000300	0 597
+ 40	+ 4·4	0·000405	0·818
+ 50	+10	0·000580	1·195
+ 60	+16	0·000820	1·72
+ 70	+21	0·00114	2·44
+ 80	+27	0·00157	3·43
+ 90	+32	0·00212	4·72
+100	+38	0·00283	6·40

(*From "Carbon Dioxide" by W. P. Heath*) capacities where it is difficult to thoroughly reactivate in the time available.

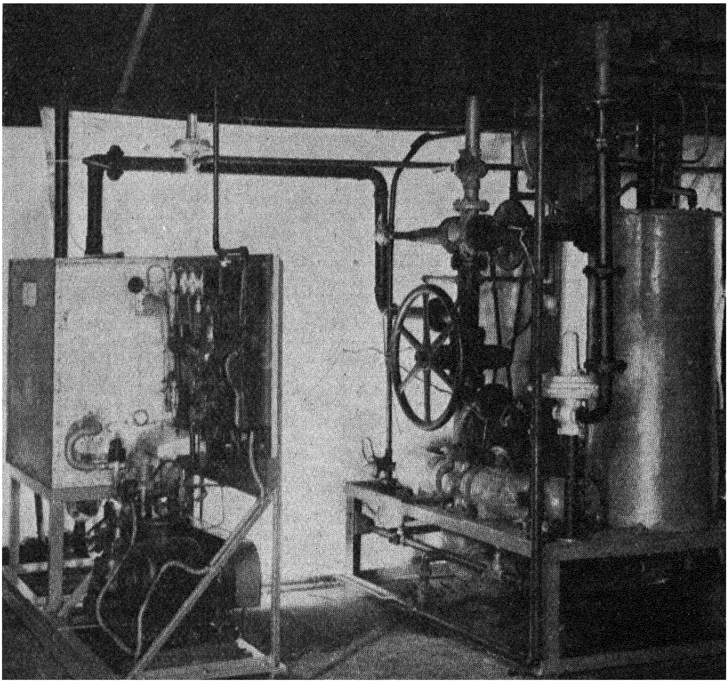
This drier uses contra-flow for the drying and reactivation processes. Upon commencing reactivation, the small diameter inner chamber rapidly heats up, and materially assists in heating the annular outer chamber, so shortening reactivation time. Also the reactivation of this small volume of alumina is very thorough.

When drying service is resumed, the gas leaves by this small completely dry chamber, after partial drying in the larger annulus, this tending to give lower and more consistent dewpoint figures. Actually −60° F. is readily maintained over an 8-hour cycle. If activated alumina is used, drying service can be longer with this type of drier, which is equal to a column of twice the normal depth, without risk of carry-over of liquid water. Upon changing over from drying to reactivating it is not unusual to drain off a quantity of liquid from the outer chamber, this liquid having been rejected because the alumina at the entry has passed saturation point. This technique is not suitable for silica gel, for, as already stated, contact with water will disintegrate it.

Note the inclusion of cooling coils in both driers to give control of drying temperature, and assist in cooling after reactivation.

Precautions to be taken in the Design of Drying Plant

Although it would seem that the tables and illustrations given supply sufficient information to design a complete drying plant, experience shows that, in practice, it is difficult to completely sweep the contents of a container with gas, owing to selective flow or channelling, settling of material, etc. Some allowance must be made for this and also for gradual poisoning of the material, choking of the fine interstices, insufficient time or heat to reactivate, accidental or careless overheating and other contingencies. The material supplied by the principal makers is very reliable and regular in performance, but eventually it does break up and the resulting "fines" adversely affect performance by choking, and increasing the resistance to flow. This may take months or years according to the treatment given to the driers. It is strongly recommended that the containers be filled



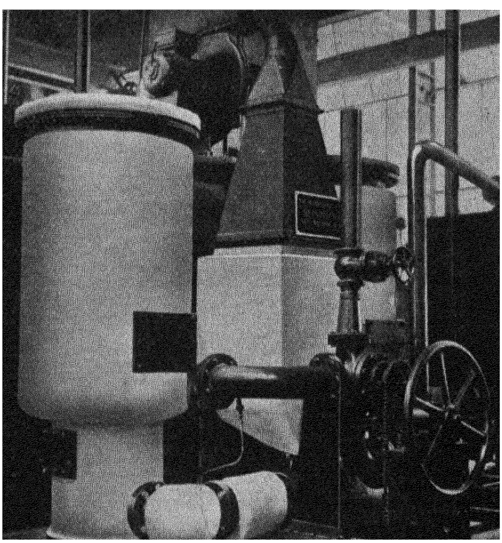


FIG. 10 (*above*) — COOLING UNIT BY J & E HALL, LTD, FOLLOWED BY SIMPLE GAS DRIER (*Incandescent Heat Co, Ltd.*)

FIG 11 (*left*) — LARGE DOUBLE PASS DRIER (*Incandescent Heat Co, Ltd*) at site (not before shipment), and that regular inspection be given at about six-month intervals.

Information on moisture content of natural gas and light hydrocarbons was given in *The Petroleum Engineer,* May, 1952 (published by the Petroleum Engineer Publishing Co., Texas, U.S.A.). This paper refers to saturation at high pressures, adsorption by activated alumina, and the poisoning of the alumina by oil, and also to the use of ethylene glycols as dehydrating agents.

Metal alloys, liquid at room temperature, and containing metallic sodium and potassium, have been used for drying gases, on a small scale, and the system is very effective, due to the affinity of the metals for moisture. This would be unsuitable for heavy commercial usages of gas, as the constituents are expensive and expendable, but where purification from oxygen is also required, such a system might repay further research.

Acknowledgements are due to Messrs. Peter Spence & Sons, Ltd., of Widnes, for permission to publish the details relative to the properties of Activated Alumina.

SECTION 5

PRINCIPLES OF CHEMICAL PUMPING

By I. N. MERRILL, M.I.CHEM.E., M.INST.F.

PUMPS are machines designed for the purpose of raising liquid from a low to a higher level. The circulation of water and air on the surface of the earth is a "pumping" function of the solar machine. The development of agriculture has been closely linked with irrigation. A very recent surgical achievement has been to replace the heart (man's natural pumping machine), with an artificial pump made from plastics. It is no overstatement to say that the development of pumps, or machines for the purpose of moving liquids, has been a factor of major importance in the part which science has played in the advance of civilisation.

Of all liquids handled by pumps water is still the most important and the improvement and development of water pumps is still the major activity of pump designers and manufacturers. The pumping of chemicals, or liquids other than water, involves handling the widest possible range of fluids, often under extreme conditions of temperature and pressure. The properties of these fluids, their corrosive and erosive effects on available materials of construction and the mechanical properties of the available materials of construction all require special study to enable chemical problems to be dealt with.

Whereas designers of pumps for handling water can largely ignore the factors of corrosion and erosion and concentrate on obtaining high mechanical efficiency and reliability at a low initial cost, the designer of chemical pumps often has to subordinate fine clearances and high mechanical efficiencies to considerations of rugged construction and ability to go on doing heavy duty work without failure. The rate of corrosion of materials of construction, deliberately chosen on economic grounds, has an important bearing on the design of a chemical pump. Initial cost is usually a secondary consideration to reliability.

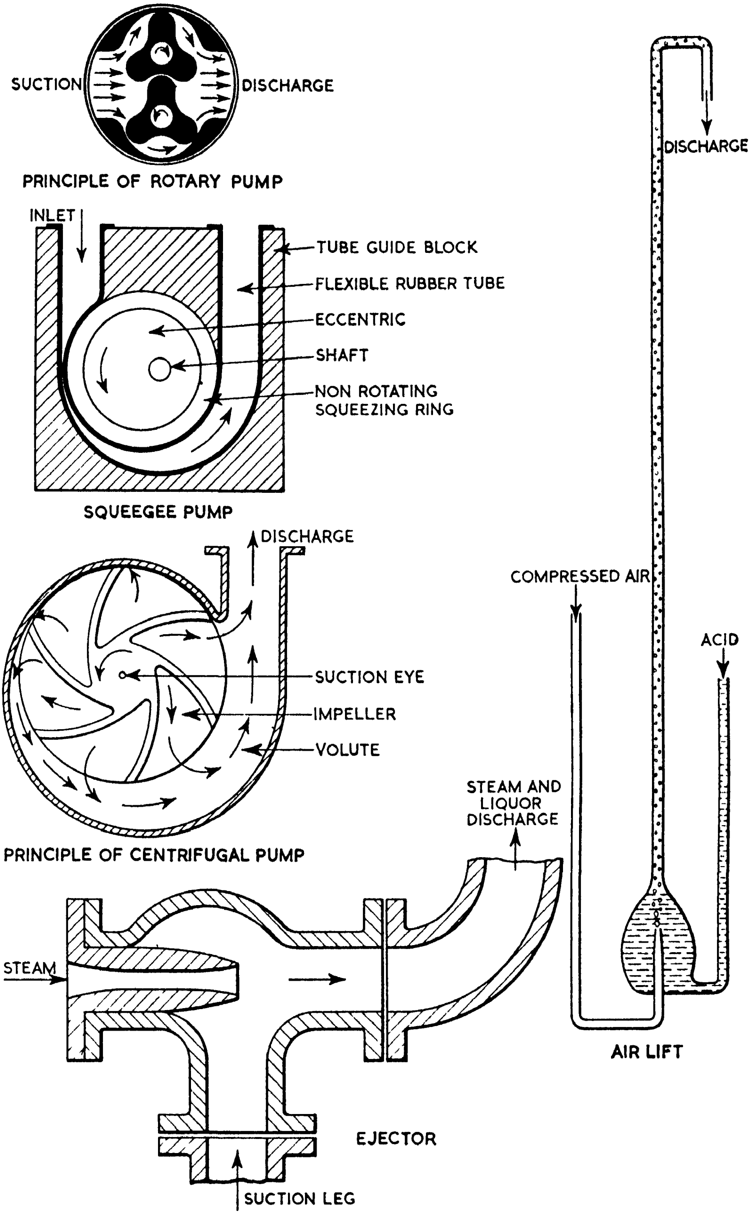


FIG. 1.—SHOWING PRINCIPLE OF OPERATION FOR ROTARY PUMP, AIR LIFT PUMP, SQUEEGEE PUMP, EJECTOR AND CENTRIFUGAL PUMP.

Leakage in Pumps

In the case of water pumps the problem of leakages at glands can usually be fairly readily dealt with by conventional stuffing boxes and mechanical seals of various types. In the case of chemical pumps leakages from glands are often serious hazards to be guarded against with the greatest care. The simple case of acid slinging from a rotating shaft is a potential cause of accident and injury. The prevention of leakages into and out of chemical pumps requires very careful consideration and the exercise of the greatest ingenuity. Indeed, the three most important factors influencing chemical pump design are corrosion, erosion, and internal and external leakage.

Classification

The majority of the very wide range of pumps available for handling chemicals readily fall into three fairly well defined groups, leaving numbers of miscellaneous liquid handling devices, not so easily classified, to form a fourth group. These four groups, namely Centrifugal Pumps, Reciprocating Pumps, Rotary Pumps and Special Pumping Devices are dealt with separately.

CENTRIFUGAL PUMPS

Centrifugal pumps function by imparting velocity to the liquid handled by the whirling blades of a rotating impeller, and subsequently converting this *velocity* energy to *pressure* energy. Ignoring friction and mechanical losses, the pressure energy available from a centrifugal pump is directly proportional to the velocity imparted to the liquid.

This velocity is directly proportional to the tip speed of the impeller and is consequently dependent on the diameter of the impeller and the speed at which it is rotated.

Impellers used in centrifugal pumps vary considerably as regards the number of blades, the shape and the curvature of the blades. They may be fully open, half shrouded, or fully shrouded. They may be "overhung" with bearings at one end of the shaft only or they may be centrally fixed with bearings at both ends of the shaft. They may be vertical, horizontal or inclined. Centrifugal pump casings vary considerably in design. They may have a volute or, alternatively, be circular. They may have single

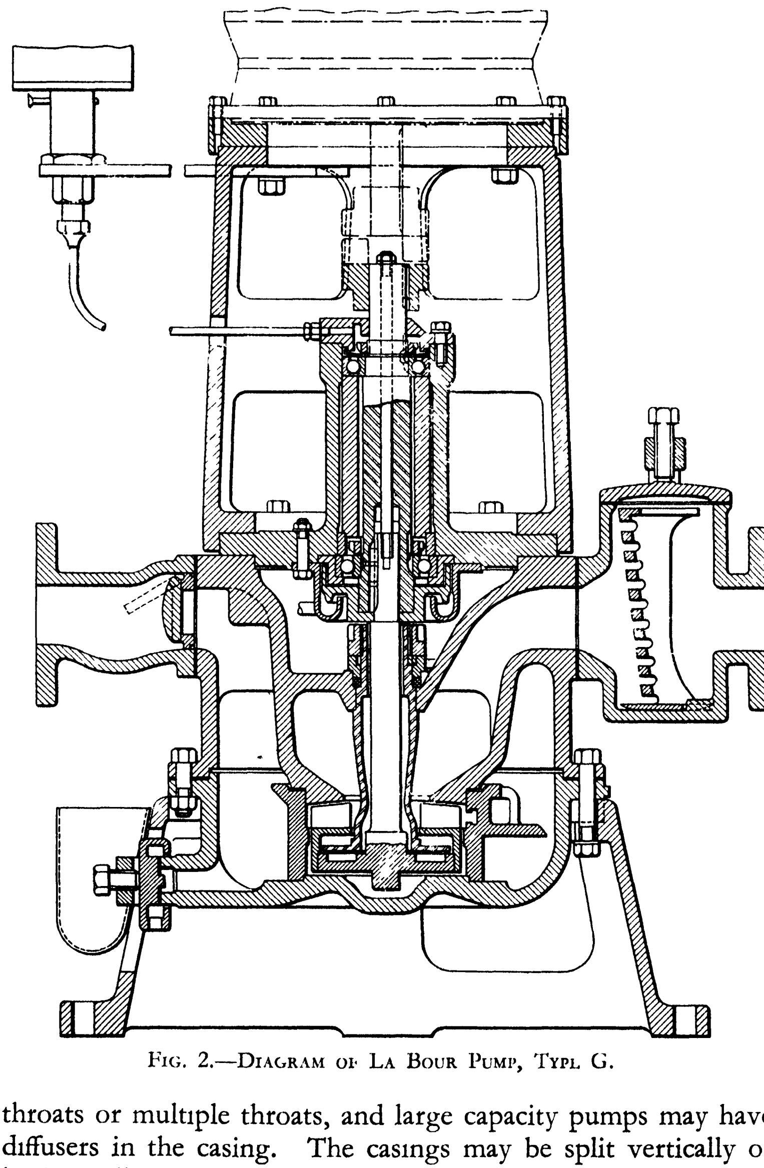


FIG. 2.—DIAGRAM OF LA BOUR PUMP, TYPE G.

throats or multiple throats, and large capacity pumps may have diffusers in the casing. The casings may be split vertically or horizontally and have single or double suction connections.

There are several types of vertical spindle centrifugal pumps which avoid the use of stuffing boxes by providing an annular space around the impeller shaft to contain a column of

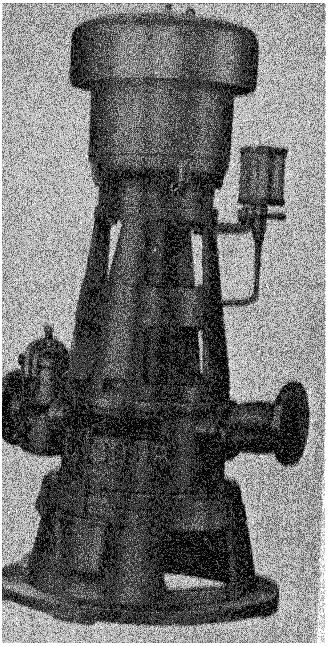


FIG. 3.—VERTICAL SELF-PRIMING CENTRIFUGAL PUMP.
(*British La Bour Pump Co., Ltd*)

the liquid which is being pumped. This type of pump is usually required to work with a minimum positive suction head of five or six feet and a maximum positive suction head which must be less than the height of the column of liquid. The height of this column of liquid and the separate provision of an overflow make this type of pump cumbersome; but it is nevertheless growing in popularity. There is no rubbing contact inside the pump and is therefore no mechanical wear.

La Bour Type "G" Pump

Perhaps the most interesting of the vertical spindle glandless centrifugal pumps is the La Bour type "G" (Figs. 2 and 3). This pump has all the advantages of other types of vertical spindle glandless pumps plus the important additional advantages of being self-priming and compact in construction. The type "G" employs the basic self-priming principle originated by La Bour twenty-five years ago. It is a hyrdobalance pump and automatically stops the recirculation necessary during priming by the counterplay of hydraulic pressures. It is short and compact because it is sealed against internal and external leakage around the impeller shaft by an ingenious application of the principle that "when a liquid is subjected to centrifugal force its effective weight increases as the square of its velocity."

The pump is open to atmosphere via the generous clearance space in the sleeve around the impeller shaft and in consequence it must be located above the liquid to be pumped. The open end of the sleeve around the impeller shaft is located slightly higher than the suction connection so that when the pump is stopped liquid in the delivery pipe runs back into the suction

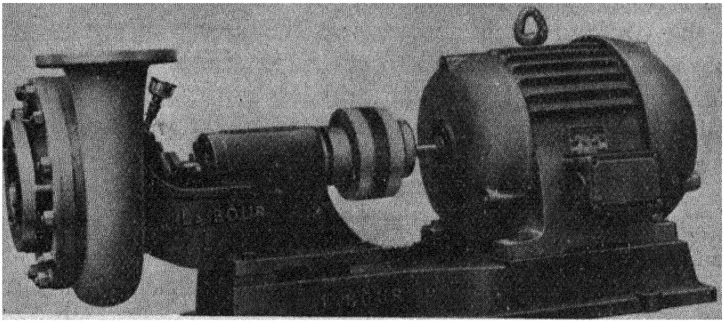


FIG 3a —HORIZONTAL SELF-PRIMING CENTRIFUGAL PUMP TYPE "Q".
(*British La Bour Pump Co , Ltd*)

pipe and to the source of supply. Liquid necessary for priming and repriming is retained in the pump by locating the suction connection well above the centre of the pump. The impeller shaft enters at the suction side and in consequence the "seal" around it is unaffected by discharge pressures. Sealing against internal and external leakages therefore requires the consideration of only atmospheric pressures.

A composite impeller, shaft, centrifugal chamber and flanged sleeve assembly is built up as an integral unit before being fixed into the pump. The bottom part of the half-shrouded impeller takes the form of a short cylindrical chamber which rotates with the impeller around the flange of the sleeve which forms the stationary member of the assembly. The flange of the fixed member divides the centrifugal chamber at the bottom of the impeller and provides the effect of a "U" tube rotating in a horizontal plane with the openings towards the axis. At one end the "U" tube is open via the stationary sleeve around the impeller shaft to atmosphere; at the other end, the "U" tube is open to the liquid retained in the pump. When the impeller is rotated, the reduced pressure at the eye permits atmospheric pressure to push liquid from the source of supply into the pump.

The centrifugal seal incorporated in the impeller assembly prevents the atmospheric pressure from pushing air into the pump via the clearance around the impeller shaft and around the stationary flange which divides the centrifugal chamber. It needs the equivalent of the pressure of a 34-feet column of water to seal against atmospheric pressure. The centrifugal seal formed by the rotating "U," in which the effective weight of the whirling liquid increases as the square of the velocity, provides ample pressure to meet this requirement. The centrifugal seal described above absorbs less power than the friction which has to be overcome in a conventional stuffing-box.

H. M. D. Centrifugal Pump

This is a glandless pump and is probably the only centrifugal pump in which the liquid handled is positively sealed inside the pump casing with no possibility of liquid or gas leaking in or out. It utilises a magnetic coupling working through a diaphragm which separates the driven member (the impeller assembly) from the source of power. Although the impeller shaft bearings have to operate in the liquor being pumped, a wide range of construction materials are available and the pump has a considerable range of application. It is particularly useful where volatile liquids and explosion hazards have to be dealt with. The efficiency of the pump is high and the principle lends itself to considerable adaptation.

The stuffing boxes and mechanical seals which are used on centrifugal pumps require special consideration. Short stuffing boxes and a few turns of graphited greasy packing are sufficient to seal against leakages from a water pump. Such leakages, if they actually occur, are not usually serious. On chemical pumps stuffing boxes should be of generous proportions. They should provide room for five or six turns of packing. In many cases it is desirable to provide a jacket round the stuffing box so that the packing can be kept cool by flowing water through the jacket. An internal lantern or logging ring should be interposed between the rings of packing to provide for liquid sealing or grease sealing the running clearance round the impeller shaft.

If grease impregnated packings are used without provision for independent grease sealing, then they must be replaced at regular intervals, because once the grease has worked out of the packing the woven fabric of the packing—often asbestos—has an extremely abrasive effect on the shaft. It is much cheaper to replace packings rather than impeller shafts. The quality of the packings used must be carefully considered together with the suitability of the sealing greases. It is worth while going to a lot of trouble to find a suitable sealing grease for any particular service. When pumps are required to work under conditions of high vacuum it is usually desirable to liquid seal the stuffing box by running liquid round the shaft or by submerging the stuffing box completely in a trough of sealing liquid. Liquid sealing is the only positive way to seal a stuffing box under vacuum conditions.

Mechanical Seals

Mechanical seals are being manufactured in a number of construction materials and their application on chemical pumps is steadily increasing. They rely on precision fits and rubbing contact with such materials as carbon and neoprene, etc. They often incorporate springs and in consequence their suitability for use under corrosive conditions has to be carefully considered. On a wide range of clean chemical fluids they have proved highly satisfactory and their popularity is likely to increase.

Advantages of Centrifugal Pumps

The simple construction of centrifugal pumps makes practicable their manufacture in most available construction materials, e.g. all metals and alloys which can be machined or ground and a wide range of non-metallic materials such as chemical stoneware, glass, carbon, rubber, plastics, etc.

Since the development of the electric motor which forms an ideal power unit for direct coupling to centrifugal pumps, the latter have enjoyed rapidly increasing popularity. Other features of centrifugal pumps make them extremely attractive and they usually receive first consideration when a pumping problem has to be dealt with. They are of low weight and simple construction and consequently relatively low initial cost. They take up very little floor space. The only rubbing contact in a conventional centrifugal pump is at that part of the impeller shaft which moves against the packing in the stuffing box. The effect of mechanical wear is consequently extremely small. In vertical-spindle glandless centrifugal pumps there is no mechanical rubbing contact whatever. Centrifugal pumps are valveless. They build up pressures according to their hydraulic characteristics and no more. There is no danger of pressure accidentally rising above safe limits and they require very little maintenance beyond periodical attention to stuffing boxes and the lubrication of bearings.

The output is in the form of a continuous steady stream so that the piping is free from shock and vibration, and pipe friction losses are correspondingly reduced. The output of a centrifugal pump can be *doubled* by increasing the speed by a mere 12½ per cent, whereas to double the output of a piston or rotary pump the speed would have to be at least doubled, if indeed it were practicable to run either of these positive types of pump at a higher speed.

Centrifugal pumps will readily handle solids in suspension, and are not dependent on fine clearances. Whilst they are broadly limited to low-pressure work and handling fluids with relatively low viscosities, they will handle a very wide range of chemical services. Their characteristics make them ideally suitable for filter press work—they give maximum capacity and minimum head at the commencement of feeding the press and maximum head and minimum capacity at the "finishing off" of the press. The maximum pressure attainable is limited by the hydraulic characteristics of the particular pump and there is no danger of bursting filter cloths. For certain types of evaporator and vacuum extraction work self-priming pumps with liquid-sealed submerged glands make extremely economical and reliable units.

RECIPROCATING PUMPS

Reciprocating pumps function by positively displacing the liquid to be handled, by a backwards and forwards motion of a piston, ram or diaphragm. On the suction stroke liquor enters the pump through a non-return inlet valve. On the pressure stroke liquid is pushed out through the non-return outlet valve to the point of delivery.

They may be directly driven by steam, air or hydraulic pressure applied to a double-acting piston at the other end of the piston rod. Alternatively they may be driven by any external source of power, through cranks or eccentrics.

Reciprocating pumps operate with a high overall efficiency over a wide range of speeds, capacities and pressures. They will work satisfactorily with high suction lifts and/or against high-pressure heads. They take up a relatively large amount of space, are relatively high in initial cost and give a pulsating flow. They are positive in action and must be protected by means of pressure relief valves against pressure build-up.

Piston Pumps

These may be horizontal, vertical or inclined. They may have any number of cylinders and may be single or double acting. Pistons may be plain, fitted with rings, incorporate packing grooves or work through stuffing boxes. Length of stroke and speed may be fixed or variable. Valve boxes and valve design vary considerably.

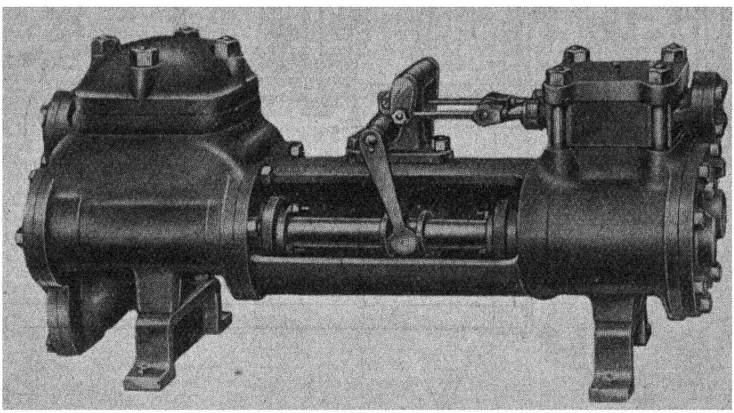


FIG 4—HORIZONTAL DUPLEX PUMP.
For capacities up to 200 g p.m. Maximum working pressure at the liquid end is 250 lb /sq. in , and at the steam end 200 lb /sq. in.
(*Worthington-Simpson, Ltd*)

Cast iron, steel and bronze are the usual materials of construction for piston pumps which work with fine clearances and high efficiencies. They are generally limited to handling relatively clean, non-corrosive fluids, free from solids in suspension and are used extensively in the oil industry, as well as for handling both highly viscous and highly volatile liquids. They are also used for pumping such materials as hot pitch, tar, bitumen, paint, soap, molasses, etc., and for evaporator work, vacuum extraction work, filter-press work and many other applications. Their feature of positive displacement makes them suitable for metering and proportionating pumps.

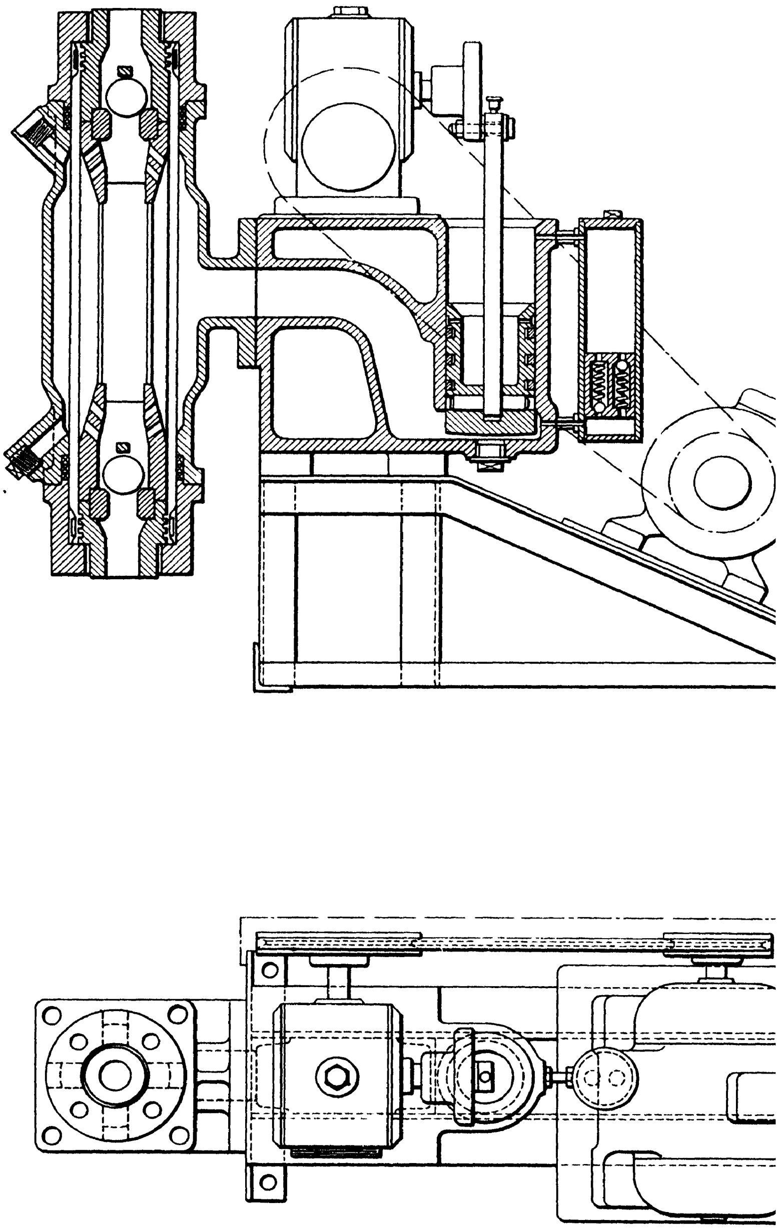


FIG. 5.—MERRILL TUBE DIAPHRAGM PUMP.

Ram Pumps

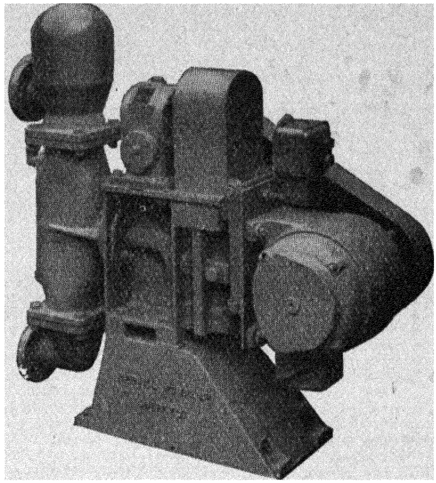


FIG. 6.—TUBI DIAPHRAGM PUMP WITH AIR VESSEL
Capacity 12·5 g p m
(*Merrill Pumps, Ltd*)

The ram or plunger pump is a special type of piston pump in which the "piston" takes the form of a relatively long closed or solid cylinder which moves through a stuffing box instead of in a close-fitting cylinder. Ram pumps usually work at slower speeds than piston pumps. They may be horizontal or vertical and have one or more rams or plungers. They are suitable for very high pressure work or where a very long stroke is required. Usually they are small-volume pumps, but large-volume ram pumps have certain special applications in the chemical industry for the slow moving of liquids which tend to foam.

Ram pumps are extensively used on hydraulic work and in this connection they find more incidental application in the chemical industry than they do on actual chemical pumping

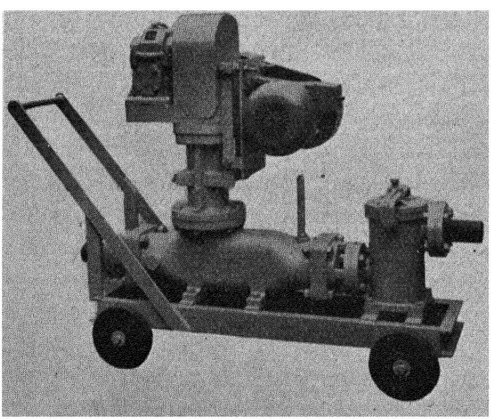


FIG 6A —MOBILE HORIZONTAL HYDRAULIC TUBE DIAPHRAGM PUMP
This pump may be used for emptying pickling tanks, plating baths, acid sumps, etc , Capacity 25 g p m
(*Merrill Pumps, Ltd*)

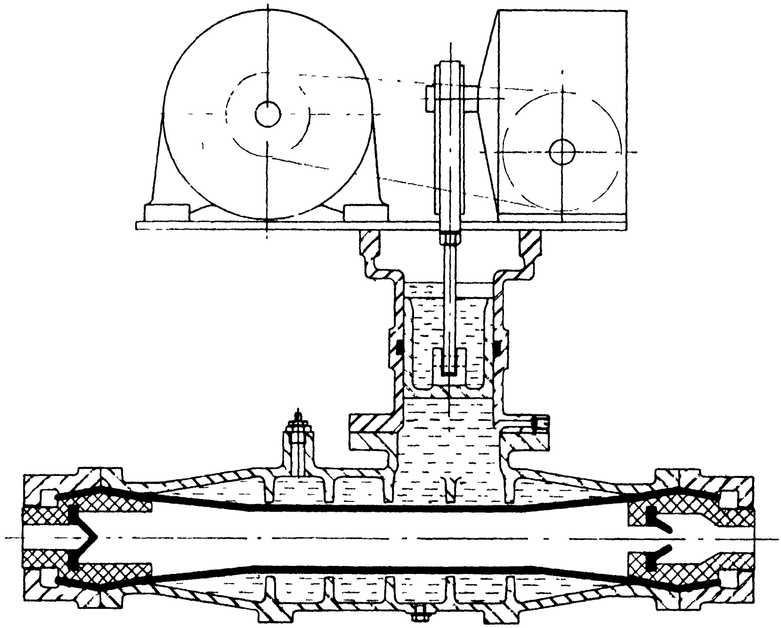


FIG. 7.—HYDRAULICALLY-OPERATED TUBE DIAPHRAGM PUMP.

duties. It might be mentioned that a special type of ram pump termed a "dead" weight ram pump has very useful application for feeding filter presses, particularly in the pottery industry.

Diaphragm Pumps

The diaphragm pump (see Fig. 5) is a reciprocating pump in which the corrosive or abrasive fluid to be handled is isolated from the pumping element by a diaphragm. The hydraulically operated diaphragm pump functions generally in the manner of a reciprocating pump, the diaphragm merely acting as a membrane to separate the fluid passing through the pump from the clean fluid which transmits positive suction and pressure strokes, through the diaphragm, to the liquid to be pumped. The question of fine clearances or rubbing contacts no longer pertains in the pumping chamber, isolated by the diaphragm, and it is possible to use a wide range of construction materials and to handle solids in suspension and even slurries with this type of pump. A wide range of flexible materials such as rubber, neoprene, butyl, polyvinylchloride, silicone rubber, thiokol, polythene, polytetrafluorethylene, etc., is available for diaphragms. Almost any machineable metal or alloy and non-metallic materials such as carbon, rubber, porcelain, plastics, etc., can be used for non-return valves and seatings and the pumping chamber.

Diaphragm pumps are *glandless* and *self priming*. They are sealed against the possibility of external or internal leakage. Large effective diaphragm areas can be obtained by using tubular diaphragms. Double-acting piston pumps of simple design and low cost are manufactured for the specific purpose of hydraulically operating diaphragm pumps with capacities up to 100 g.p.m. and at operating pressures up to 50 p.s.i.

Diaphragm pumps have a very wide range of application on difficult chemical services. They are particularly suitable for use on such services as hydrochloric acid, acetic acid, chlorides and chlorine liquors, plating solutions, pickling acids, dye liquors, formaldehyde, sodium hypochlorite, bonderising fluids, acid and alkaline slurries, etc.

Figs. 6 and 6a show tube diaphragm pumps suitable for use in the chemical industry. The pump illustrated in Fig. 6 has a capacity of 12·5 g.p.m., whilst Fig. 6a shows a 25 g.p.m. capacity pump.

ROTARY PUMPS

Rotary pumps have a rotating member which as it turns in relation to auxiliary parts, creates cavities, which move from suction to discharge, forcing the liquid along. The seal between the suction and discharge is formed by close running clearances or by rubbing contact. The liquid being pumped itself seals the space between the running clearances.

Some types of rotary pump can be driven at direct coupled electric motor speeds, e.g. 760 r.p.m., 960 r.p.m., or 1450 r.p.m., but are usually run at slower speeds, e.g. 100 r.p.m. to 300 r.p.m. Rotary pumps can be driven by almost any prime mover. The construction of a Rootes blower rotary pump is shown in Fig. 7.

Both the rotating element and the auxiliary parts in rotary pumps vary considerably in each of the many different types made. The commonest type of rotary pump is the external

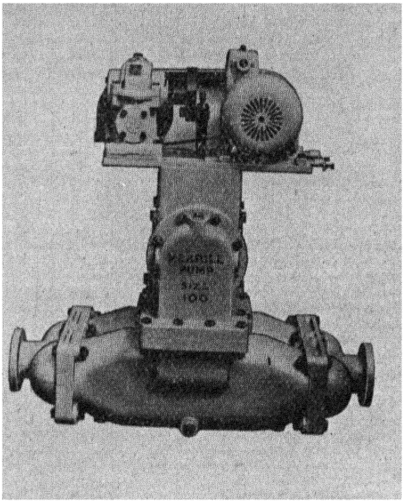


FIG 8.—MERRILL ROTARY PUMP, SIZE 100
(*Merrill Pumps, Ltd.*)

gear type in which spur or helical gears are usually used. However there are many other types such as: lobe gear, screw displacement, internal gear, sliding vane, cam, radial piston, swash plate type, etc.

Rotary pumps are usually made from machineable metals or alloys such as cast iron, bronze, stainless steel, etc. Laminated and reinforced plastic materials are also quite extensively used for the rotating elements and auxiliary parts. They are also made from special materials such as carbon, rubber, nylon, polytetrafluorethylene, etc. Rubbing contact and close clearances are the two important factors to be borne in mind when selecting construction materials. Rotary pumps can be steam-jacketed to handle such materials as tar and pitch.

Advantages of Rotary Pumps

Rotary pumps have a big advantage over reciprocating pumps in that they are valveless, but they are at a disadvantage as regards the problems of sealing against internal and external leakage and bearings. Many types of rotary pump have the bearings inside the pump and in consequence they have to be self-lubricating or lubricated by the fluid which is being pumped. The advance of powder metallurgy and the availability of graphite impregnated and other types of self-lubricating bearings are of considerable assistance in dealing with this problem. Many laminated plastics are self-lubricating in aqueous liquids and can be advantageously used in internal bearing rotary pumps. When the material to be pumped prohibits the use of internal bearings the rotor shafts can be run in external bearings, the only complication being the introduction of an extra stuffing box or stuffing boxes.

A disadvantage of rotary pumps is the attention required to stuffing boxes. Packing manufacturers have carried out exhaustive research to develop suitable packing for use in rotary pumps and the problem is met in a variety of ways, e.g. "U" packings, woven metallic packings, plastic metallic packings, fully metallic packings, "O" rings in various synthetic materials and the conventional woven and braided packings made from cotton, asbestos, hemp, etc., and impregnated with graphite, grease, mica and other materials. Mechanical seals of various types have been successfully applied to the sealing of rotary pump shafts and the use of this type of seal is steadily increasing.

Applications of Rotary Pumps

These pumps are relatively low in initial cost and occupy very little space. They will handle viscous fluids and work against high pressures, and will operate with high suction lifts and handle entrained air or gas. Because they are positive in action they must be protected against build-up of pressure. They will handle a wide range of fluids from mobile solvents to highly viscous greases providing they are non-corrosive and do not carry solids in suspension to cause erosion of the closely-fitting parts of the pump. Ignoring slip, capacity is proportional to speed and generally they have a wide range of capacity. Overall efficiency is rather low.

Rotary pumps are extensively used for handling heat transfer mediums such as diphenyl oxide, transformer oil, etc., and in this connection are used on a great variety of chemical processes, such as handling oils, greases, tar, pitch, soap, paint, varnish, etc. They lend themselves readily to being built into internal combustion engines and many different types of machine and are widely used outside the chemical industry proper.

Rotary pumps with overhung simple lobe-type rotors are made with wing-nut detachable fronts to facilitate easy cleaning and sterilising. This type is very popular in the food industries for handling such things as milk, sauces and chocolate. They are also extensively used in the rayon industry for feeding the cellulose solution to the spinnerets.

SPECIAL PUMPING DEVICES

Air Lifts

Air lifts usually consist of a "U" tube in which one leg is at least twice the length of the other. The liquid to be raised is run by gravity into the short leg. Compressed air (or other gas) is admitted into the long leg at a point just above the bottom of the "U" tube. Air bubbles mix with the liquid and also divide the column into liquid spaces and gas spaces. The liquid column in the short leg becomes heavier than the broken column of liquid and air in the long leg and there is a steady discharge of liquid and air at the higher level.

Air lifts have a number of useful applications. A typical application on which they are regularly used is the circulation of scrubbing liquor on absorption towers which deal with nitrous and nitric oxides and nitric acid fumes. For such applications only a small volume of circulating liquor is required. Air lifts made in chemical stoneware are immune from corrosion by the acid and are a successful device for this purpose.

Blow Eggs

A blow egg is a closed vessel, usually of an egg-like shape suitable for withstanding pressure. It is fitted with a standpipe reaching to the bottom of the "egg" and extending to the point at which the liquid is required to be delivered. The liquor to be pumped is run in through a valve, which is then closed. A compressed-air line brings air to the top of the vessel. Air pressure acting on the surface of the liquid forces it up the standpipe.

Blow eggs can be made automatic by the use of a float, and they are quite extensively used in industry. A cast iron, lead lined, rubber lined or chemical stoneware blow egg will often last as long as twenty years without maintenance attention. Whereas, generally speaking, blow eggs are being rapidly superseded by chemical pumps, there are certain applications for which they are eminently suitable. For instance, molten sodium is moved by blow eggs using compressed nitrogen.

Ejectors

Ejectors operate with compressed air, water or steam on the well-known Venturi throat principle. They can be manufactured in a wide range of construction materials, e.g. cast iron, bronze, stainless steel, high silicon iron, lead, carbon, porcelain, etc. They can be used for lifting, lifting and forcing, or forcing. Steam-operated ejectors have a popular application in industry for emptying sumps, etc.

Ejectors have very variable application in chemical processes for vacuum work on evaporators, vacuum distillation plants and on vacuum filters and are useful for priming syphons and creating a suction on fume systems.

Ejectopumps

The ejectopump makes ingenious use of the principles of both the ejector and the blow egg. By combining the application of these principles it is self priming and can work with a suction lift. Ejector action draws a charge of liquid into the pump, after which pressure on the surface of the liquid discharges it to the point of delivery.

The ejectopump has an advantage over the blow egg in that it can operate with a suction lift and it has an advantage over the ejector in that it operates without aeration or churning of the liquid.

Tungstone Pump

The tungstone pump was especially designed for pumping corrosive chemical slurries to filter presses. It makes use of compressed-air displacement in a very practical way. The pump consists of a chamber with non-return valves for suction and delivery. A motor-driven multiport valve controls the supply of compressed air or steam to the pumping chamber. The pump must be located below the source of supply and it is desirable to have a positive suction head of three or four feet. At the beginning of the cycle the control valve vents the pump chamber to atmosphere; the liquor flows by gravity into the pump past the inlet valve; the control valve then admits compressed air or steam which blows a charge of liquid past a delivery valve to the point of supply. The cycle is then repeated.

The tungstone pump has proved extremely popular on the application for which it was designed, namely feeding filter presses. It has also proved very successful for handling corrosive acids, viscous fluids and a fairly wide range of chemical services.

Squeegee Pumps

The squeegee pump is an ingenious small pump which has a capacity range of up to six or seven gallons per hour. A rubber tube is bent into the form of a "U" and located by guide plates. A compressor ring, moved by an eccentric rotor inside it, bears against the tubing to compress it, and as the compressor ring moves it pushes a charge of liquid (or gas) towards the outlet. The flattened tube expands when pressure is released from it and draws in liquid (or gas) to restart the cycle. The compressor ring does not rotate.

The pump is very quiet, and there is no churning of the liquid. The tube is easily cleaned and sterilised and very cheap to replace.

Diaphragm Type Compressor

An interesting new item of compressed air equipment is the diaphragm-type compressor manufactured by The Hymatic Engineering Co., Ltd., which is designed to provide small quantities of low-pressure air completely free from oil and other impurities. It is intended for such duties as food processing, raising consumable liquids, pressurising instruments or special equipment and for many special processes in medical or industrial laboratories.

The new compressor possesses (Fig. 9) simplicity of design having a three-ply diaphragm in place of the usual cylinder and piston, thus avoiding the necessity for the presence of oil in the compression chamber. The connecting rod is an aluminium alloy casting shaped into a circular disc at the upper end upon which the diaphragm is seated. At the top of the compression stroke, the disc conforms to the contour of the diaphragm which has its outer extremities nipped between the main casting and the compression head. The plate holding the diaphragm in position on the disc also carries the diaphragm-type inlet valve, the ports being carried through the diaphragm and the connecting-rod head. The connecting rod is split at the bottom to accommodate the sealed grease-packed ball race constituting the

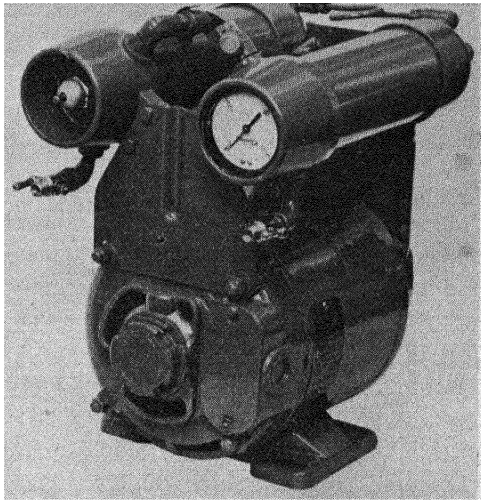


FIG. 9.—DIAPHRAGM-TYPE COMPRESSOR
Suitable for use in food processing, raising consumable liquids, pressurising instruments and laboratory work.
(The Hymatic Engineering Co., Ltd.)

big end bearing and the hollow overhung crankshaft is located on the rigid driving shaft of the $\frac{1}{6}$ h.p. B.T.H. motor by a key and central bolt. The main bearings are again grease packed and an activated carbon air intake filter furnishes an additional safeguard to purity.

The aluminium alloy head sealing the compression space houses the ring-type delivery valve and a special chamber designed to damp out pulsation. Fitted with twin cylinder air receivers, each with its own drain cock, built-in relief valve and recessed pressure gauge, the compressor unit is mounted on the spigot of the electric motor. A pressure switch is available as an extra, and can be adjusted for controlling both the working pressure and the cut in and cut out differential. Adjustment in the first case is between 0 and 50 p.s.i. and the differential for more than normal control accuracy can be as low as 2 p.s.i. This factor is especially valuable in instrument or laboratory work.

The maximum working pressure is 50 p.s.i. at 1,450 r.p.m. Delivery is 1 c.f.m. of free air at 10 p.s.i.—the equivalent of 200 gallons an hour liquid displacement.

The compressor is silent in operation and there is no perceptible vibration as both crankshaft and connection rod are carefully balanced. Servicing is rarely necessary during the life of the unit since no lubrication is required at any point and there are no moving parts in rubbing contact.

MONO PUMPS FOR THE HANDLING AND FILTRATION OF LIQUIDS

Efficient processing in the fine chemical, pharmaceutical and medicinal producing industries usually requires a continuous movement of fluids from the raw material stage to the finished product store. The equipment used for conveying the fluids form an important part of the manufacturing plant. The fluids may be either hot, cold, viscous, acidic, caustic or liquors containing solids in suspension or solution. Therefore, although one of the factors which should be considered when making the choice of pump for any specific duty, would be the mechanical properties of the material used for its construction, the ability of the pump to perform the duty involved will also influence the decision of the chemical engineer.

Although the Mono pump is constructed on very robust lines, the total weight is moderate and the unit as a whole is handy and can be moved about with ease. It is designed to run at standard motor speeds so that it can be direct-coupled to electric or compressed air motors without the complication and added weight of intermediate gearing. The unit consumes minimum horse-power for the work done, and this efficiency is maintained over a wide range of speeds and pressures.

The Mono pump is of the rotary positive displacement type. It has, however, several interesting features and a brief description of its construction may be of interest. Fig. 10 shows a cut-away view of the pump, which comprises a stator, or sleeve, and a single rotating element. It has only one gland, which is generally arranged on the suction side, so that it does not have to be packed against pressure. There are no valves or gearing, and no lubrication is required.

It will be seen from the illustration that the stator is undulating having two humps; also, the rotor assumes a helical or twisted form and is designed to revolve in the grooves of the stator. The rotor and stator engage with each other with perfect accuracy and in such a way that, when the rotor is turned, its circular cross-section at every point in its length travels back and forth

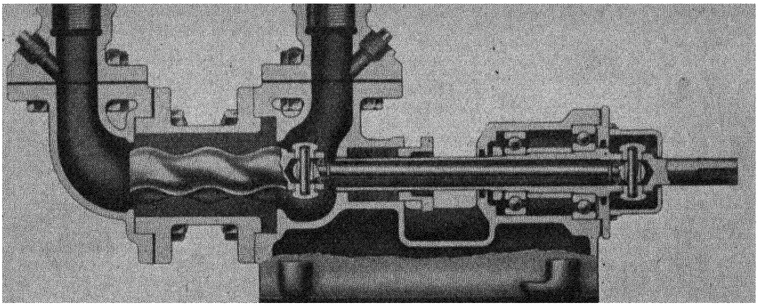


FIG 10 — SECTIONAL ARRANGEMENT OF TYPE "D" SUCTION-ON-GLAND MONO PUMP.
(*Mono Pumps, Ltd*)

in a straight line across the corresponding section of the stator. This gives the effect of a "ripple" proceeding along the rotor and pushing the liquid before it.

The straight-line path of each cross-section of the rotor is, in fact, accomplished by a compounding of two motions: the driving mechanism of the pump turns the rotor about its axis, and, due to the meshing of the rotor with the stator, the axis itself simultaneously describes a small circle in the opposite direction. The line of contact between the rotor and the stator forms a complete seal between the suction and the discharge sides of the pump, and the seal is continuously moving at uniform velocity through the stator and re-creating itself at the inlet or suction end.

Self-Priming and Positive Displacement Features

For normal purposes the stator of the Mono pump is made of rubber. The resilient nature of this material makes it possible for the rotor to be actually an interference fit in the stator so that there is extremely close contact along the whole of the seal line. This feature, together with the absence of valves and cylinder clearances, renders the pump an extremely effective air exhauster, provided only that sufficient water is present to maintain a lubricating film between the stator and rotor. It works with equal facility with any proportion of air and water. It can thus prime itself with a suction lift as high as 27 ft. of water and will run from zero inflow up to the full capacity of the pump, provided that the suction pipe is of a suitable diameter to carry the required mixture of air and water.

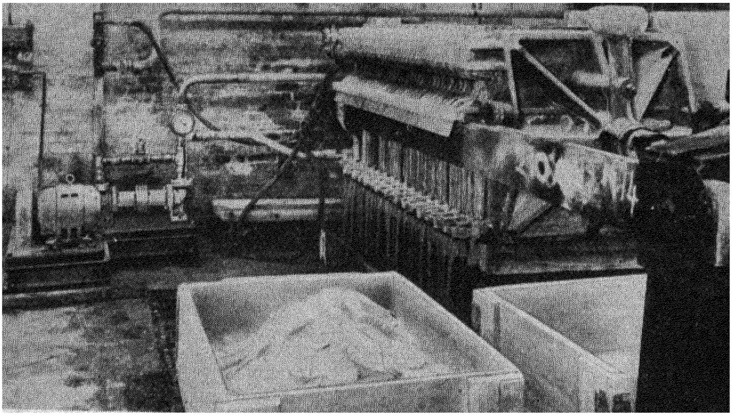


FIG 11 —TYPE D6D PUMP USED IN FILTERING WHITE OXIDE AT A MAXIMUM PRESSURE OF 50 lb /sq in
The maximum pressure of this Mono pump is 130 lb /sq in
(*Mono Pumps, Ltd*)

Since the pump gives a positive displacement, the head developed is independent of the speed and the capacity is approximately proportional to the speed. The pump has a uniformly high efficiency over a wide range of heads, which is of assistance in meeting the varying conditions of industrial service. Combining the characteristics with the rotary motion and continuous flow it will be seen that the Mono pump incorporates the advantages of both the reciprocating and centrifugal type of pump.

Applications in Chemical Processing

The powerful suction capabilities and the self-priming feature of the Mono pump are of particular interest to the chemical engineer, and the steady flow given by the pump is also of considerable assistance to chemical processing especially where filtration is essential.

The uniform delivery from the pump under varying heads or pressures helps to maintain an uninterrupted flow for duties associated with continuous process plants. For pilot plants a low capacity pump is available. Fig. 12 illustrates a portable Mono pump on transfer duties in a chemical works.

Filtration Applications

In most filters the function of the porous medium is that of a foundation or framework on which to build a structure of solid particles arranged in such a way as to form a barrier or cake. The structure of the barrier or cake is gradually built up by trapping the solid particles on the porous medium as the liquid being filtered flows through the apparatus. The barrier is the true filtering medium and the aim is to produce a rigid but uniform granular cake so that minimum resistance will be offered to the passage of the liquid.

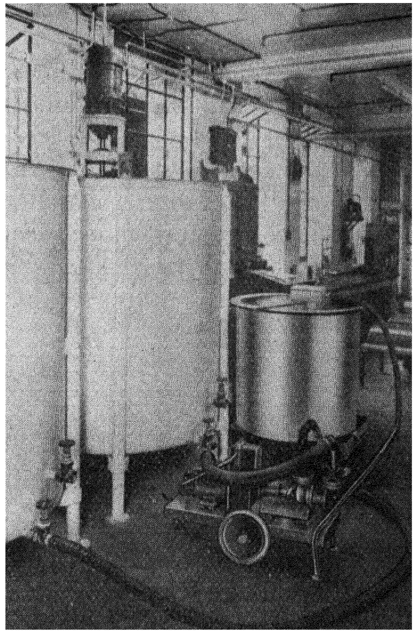


FIG. 12—PORTABLE UNIT DELIVERING A SUSPENSION TO A STORAGE TANK VIA A FILTER HEAD

This application is only one of the many and varied uses to which Mono pumps can be put in a chemical processing works

(*Mono Pumps, Ltd*)

Where the solid particles in the fluid being filtered are of such a nature that difficulty may be experienced in the formation of a porous cake, a filter-aid such as kieselguhr (a small solid, with an open structure) might be mixed with the fluid, or a prefabricated barrier such as a filter mat or sheet might be used. To overcome the resistance of the cake or barrier and to maintain a satisfactory rate of filtration, it is necessary, for most industrial filtering, to apply an external pressure by pumping the fluid to the filter. These pressures will slowly build up as the filtering operation progresses. Many of the difficulties encountered in industrial filtration can be caused by the improper use of this pressure. If the process is efficiently carried out, only relatively low pressures, which are within the limits of the Mono pump, are most frequently required. The use of too high a pressure will act detrimentally by destroying the open structure of a cake, thus forming a barrier much more difficult for the liquid to penetrate and needing a longer and uneconomic time cycle to complete the filtering operation.

A pulsating flow will also destroy the structure of the cake and the physical properties of the individual particles will not perform the function required. It follows, therefore, that the inherent low velocity of the Mono pump with its steady performance against varying pressures enables it to be ideally applied to the duty. In addition it has the great advantages of being self-priming and possessing ability to handle free-flowing liquids, viscous fluids and slurries or solids suspended in liquid.

A filter frequently encountered in industry is that referred to as the filter press. It consists of a number of filter plates or frames, usually covered with filter cloth, arranged between two heads to form a tight square or cylindrical vessel consisting of a number of filtering chambers. This is the usual type of filter employed where the cake is retained for use. The Mono pump is usually employed on filter presses operating between 10 lb.–120 lb. per square inch. Fig. 12 illustrates a Mono pump feeding a filter press with colour slurry. A further type uses a specially prepared filter-aid powder which forms a filter-bed keyed firmly into position by the pump before the liquid is filtered. Another type uses filter mats, woven fabric, wire cloth or plastic, as a filtering medium. Pressures on this type of filter vary up to 50 lb. p.s.i.

The publishers are indebted to Messrs. Mono Pumps Ltd., for supplying the information upon which this article has been based.

SECTION 6

CENTRIFUGAL SEPARATORS

By G. A. FRAMPTON, A.R.C.S., B.Sc., F.R.I.C., M.I.Chem.E.

THE use of the centrifuge as an industrial tool may be said for all practical purposes to date from the period immediately following the first world war. Prior to that time centrifuges were employed for the separation of cream from milk and also for the drying of crystals, but the former application was almost the sole example of the use of this type of machine in what might loosely be called the "high speed" form. During the last thirty years the high-speed centrifuge has developed very rapidly into an extremely useful piece of equipment, finding applications in almost every branch of industrial activity, and today centrifuging may be regarded as a fairly well-defined unit process, comparable in scope to such unit processes as filtration, comminution, fluid transfer, heat exchange, etc.

Principle of the Centrifugal Separator

The broad term "centrifuging" covers all those varied forms of centrifugal machine making use of centrifugal force for the separation of poly-phase mixtures into their single phase components, but high-speed centrifuging is concerned with that section of centrifugal machines which operates with a centrifugal field of force in the range of 6,000–15,000 times gravity, wherein the mixture of phases is passed in continuous flow through a rotor of the imperforate type, spinning at such a speed as to develop a field of force of that order.

Generally speaking, the efficiency of such a machine for separation purposes may be said to depend almost directly upon the magnitude of the centrifugal force developed and as this force is a function of the speed of rotation the aim is to operate such machines at the maximum permissible speed within the limitation imposed by the physical strength of the available materials of construction.

The centrifugal force developed within a rotating body

Efficiency of Separators

In general, the problem presented to the high-speed centrifuge is that of separating finely divided particles of solid matter from a liquid medium in which they are dispersed, or alternatively, separating two liquid phases which are intimately mixed together, or a combination of both of these operations. Such separations are theoretically possible only when a difference in density exists between the materials to be separated and the efficiency of separation is a direct function of this density difference. It is usual to assess the efficiency of a given machine in terms of the continuous through-put at which the machine can retain all of the suspended particles which exceed a given limiting size. This will be made clear by the following formula relating the capacity of a centrifuge to the said limiting size of particles which can positively be removed:

$$Q_{gph} = K. \left[\frac{R_1^2 - R_2^2}{\log_{10} R^1/R_2} L.\omega^2\right] \left(\frac{s - \sigma}{\eta}\right) D^2$$

where Q = Flow rate in g.p.h.

K = Mathematical constant

R_1 = Inner radius of bowl wall in cms.

R_2 = Liquid Surface Radius in cms.

L = Bowl length in cms.

ω = Angular velocity in radians/second.

s = Specific gravity of particle.

σ = Specific gravity of liquid medium.

η = Viscosity of liquid medium, in poises.

D = Equivalent diameter of particle in microns.

In this expression it will be noticed that there are two parameters. The parameter within the square bracket is the one depending upon the mechanical characteristics of the machine itself, whereas the parameter within the round bracket is that governed by the physical characteristics of the liquid medium and the solid particles which are to be separated from it.

Applications

The applications for which the high-speed centrifuge has become accepted as the most appropriate industrial tool are now so numerous and diversified that they cover almost every

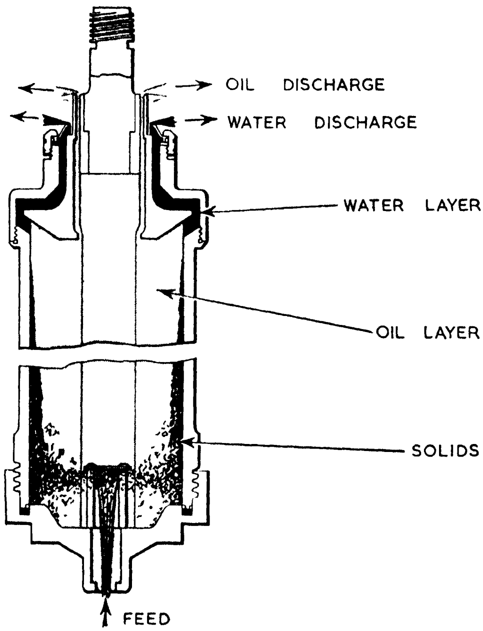


FIG 2.—SHARPLES SUPER-EFFICIENCY PURIFIER.

industrial field of production in the chemical and engineering world. For example, the cleansing of every variety of mineral oil, including diesel fuels, I.C.E. lubricants of all types, steam and gas turbine lubricating oils, insulating oil, coolants and lubricants for machining operations, hydraulic actuating oils, etc., represent types of materials which are continuously and automatically purified while in service by the simple procedure of passing them through a high-speed centrifuge placed at some convenient point in the circuit.

Improvements in Design of Separators

The detail design of the centrifuges employed is subject to continuous modification and improvement, not only to increase the efficiency of the machine as a separator, but also to meet the new demands imposed by changes in the nature and duties of the liquids in question.

A good example of this is to be found in the development during the last few years of the use of heavy residual oils as a fuel for large Marine diesel engines. High-speed centrifuges have been employed for the purification of distillate fuels for such diesel engines for very many years, but since the end of the late war there has been a very decided move to employ for this purpose oil of the type which was formerly used for firing boilers, due to its very marked lower cost. This heavy residual oil from its very nature requires more stringent purification than the distillate oils, in order to make it a satisfactory diesel fuel, and yet its purification is a matter of much greater difficulty, due to its higher density on the one hand and its greater viscosity on the other. In consequence, great efforts have been made by the manufacturers of centrifugal oil purifiers to meet these new conditions and they have now produced machines and methods of treatment which make it possible for Marine diesel engines to operate reliably and economically on these cheaper grades of fuel.

Continuous Separators

A most interesting example of the way in which high-speed centrifuges have influenced production trends in industry is the way in which they have enabled certain batch processes to be replaced by continuous processes. The refining of vegetable and fish oils is a case in point where it is customary to carry out

FIGS. 3 and 4 (*see pages* 100 *amd* 101)—HIGH CAPACITY VAPORTITE OIL PURIFIER.

KEY

1.	Frame	250.	Pulley collet
21.	Coupling nut	251.	Pulley collet nut
25.	Cover lid	305	Idler elbow set screw
26	Upper cover	306.	Idler weight spring
37.	Three wing	307.	Idler weight screw
45.	Brake hinge nut	308.	Idler weight ball
60.	Brake hinge screw	326.	Bearing assembly
61.	Brake hinge washer	327.	Brake assembly
64.	Lower cover	379	Drag assembly
77.	Belt	380.	Drag stud nut
80.	Idler Pulley arm	381	Drag stud
81.	Idler elbow	386	Bearing base nut
82.	Motor pulley	393.	Feed tube assembly
83.	Idler weight arm	394.	Bearing base stud
84.	Idler weight	395.	Drag gasket
85	Motor bracket	407.	Vaportite sleeve
86.	Motor bolt	408.	Small cover gasket
87.	Motor shim	423.	Bowl assembly
88.	Motor	431.	Idler shaft collar
89.	Idler shaft	565.	Idler pulley assembly
98.	Motor bracket bolt	696.	Discharge plate
112.	Idler weight arm pin	775.	Funnel lid
154.	Bowl bottom gasket	776.	Funnel hinge pin
247.	Idler stop	996.	Brake seal felt
248.	Idler stop set screw	1272.	Funnel body gasket

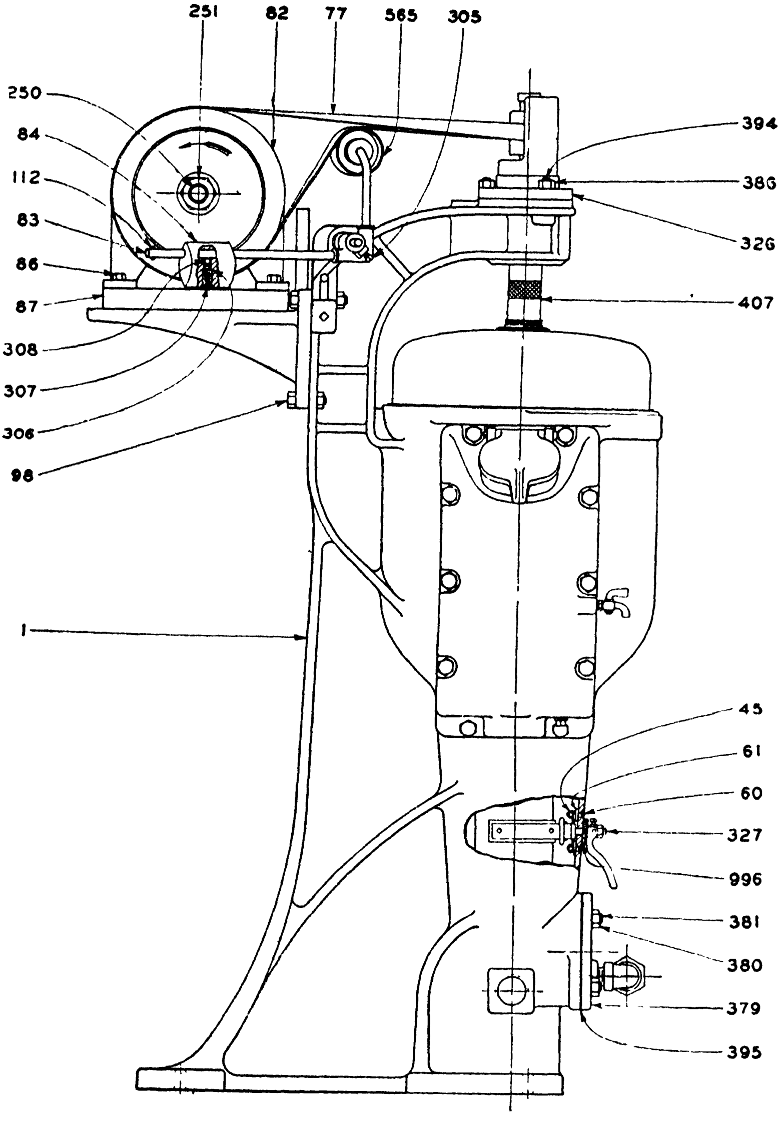


FIG. 3.—FRONT VIEW OF HIGH CAPACITY VAPORTITE OIL PURIFIER.
(*Sharples Centrifuges, Ltd.*)

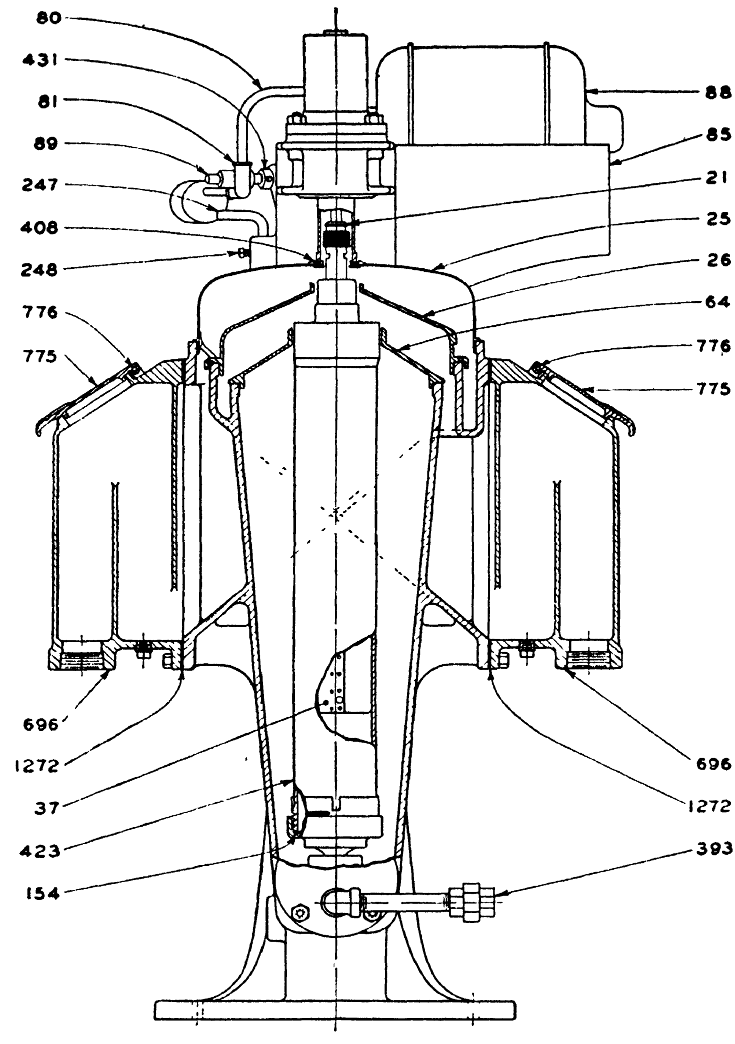


FIG. 4.—REAR VIEW OF HIGH CAPACITY VAPORTITE OIL PURIFIER.
(*Sharples Centrifuges, Ltd.*)

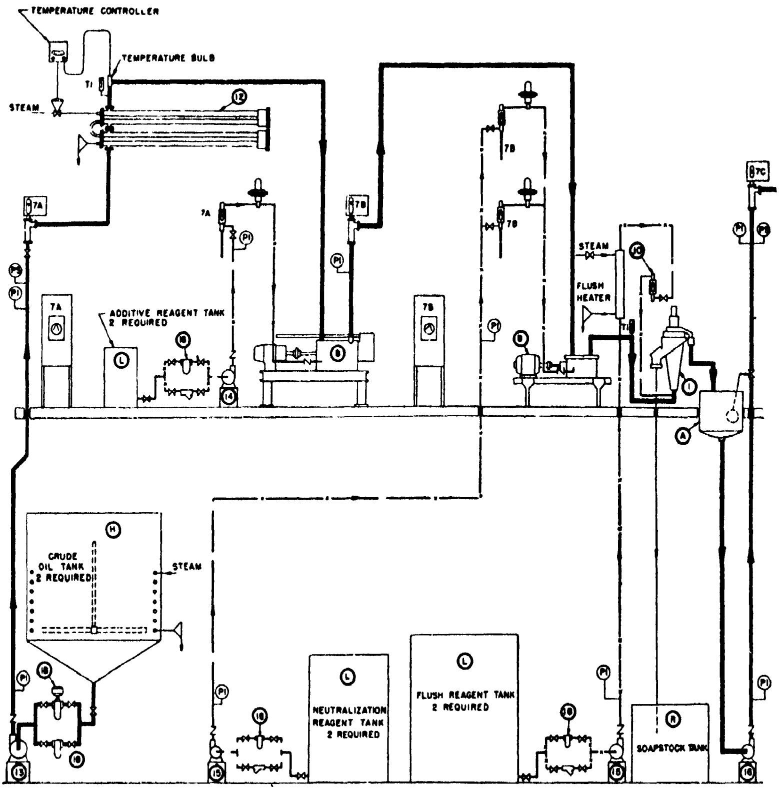


FIG. 5.—FLOW SHEET VEGETABLE OIL REFINING LOW LOSS PROCESS WITH DOUBLE WATER WASH AND VACUUM DRYING.

(*Sharples Centrifuges, Ltd.*)

1. Refining centrifuge
2. Re-refining centrifuge
3 Water wash centrifuge
7A. Additive treat ratio controller
7B Neutralisation treat ratio controller
7C. Re-refining treat ratio controller
8. Additive treat mixer
8. Neutralisation treat mixer
8. Re-refining treat mixer
10 Flowmeters
11. Vacuum Dryer
11. Condenser and ejector
12. Heater
13. Crude oil pump
14. Additive reagent pump
15. Caustic pump
16. Refined oil pump
17. Dry oil pump
18. Strainers

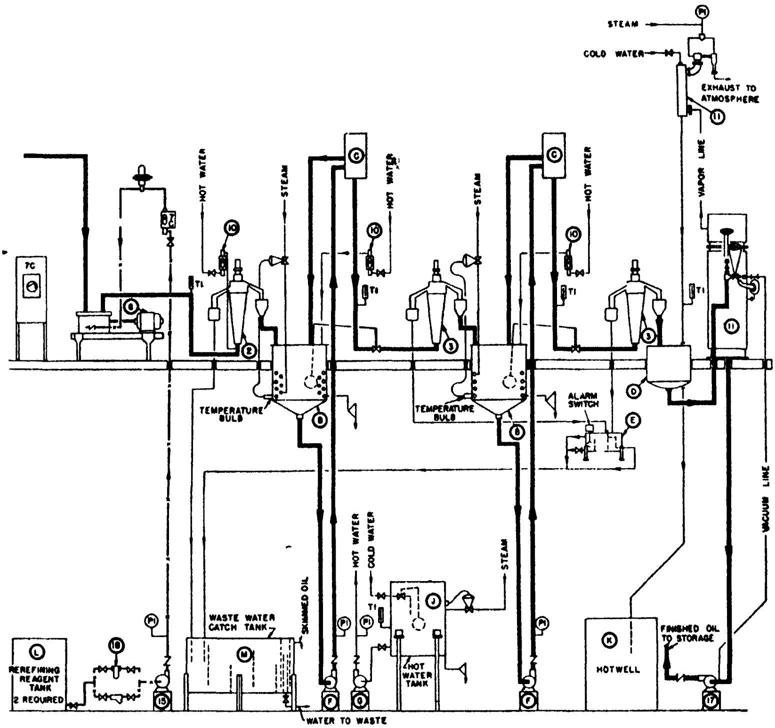


FIG. 6.—FLOW SHEET (*Continued*)

A. Refined oil tank
B Water wash tanks
C. Head tanks
D. Dryer supply tank
E. Wash water weir tank
F Water wash pumps
G. Hot water pump
H. Crude oil tank
J. Hot water tank
K. Hotwell
L. Reagent tanks
M. Waste water catch tank
R. Soapstock tank
PI Pressure indicator
PS. Pressure switch
T1. Thermometer

the refining of the crude oil by a treatment with caustic alkali followed by separation of the soap-stock from the oil. This was formerly performed batch-wise in large vessels holding a charge of anything from 5 to 40 tons and the actual separation was, of course, performed by gravity.

As soon as a suitable design of centrifuge was available which could effectively separate the soap-stock from the oil in a continuous manner at an economic through-put the road was opened for a continuous refining process wherein the refining reagent is proportioned in a continuous stream into the crude oil, the mixture given the requisite degree of contact and agitation, conditioned as to temperature, and then passed through a battery of centrifuges which deliver the refined oil product on the one hand and the soap-stock on the other.

Apart from the improved yield and reduced operating costs which mean increased economy of such a continuous process as compared with the older batch method, this advance conferred numerous other advantages, the chief of which is the ease of control and the ability to make changes in the treatment during the continuous operation as dictated by the analysis of the products issuing from the machine. It may be said that such a continuous centrifugal process converted what was formerly an art into a science, under the control of laboratory technicians

A similar example is the modern continuous method of soap manufacture, whereby the former batch process which tied up materials in large kettles for anything up to five or six days was converted into a continuous process, with the neat soap leaving the process in a continuous stream at a capacity of anything from 1 to 10 tons per hour, the material itself being in process only a matter of minutes. Such a process would not have been possible prior to the war and became a practical possibility only due to the advance in design of a centrifuge which could handle such a material as neat soap at a temperature of anything from 80–100° C.

Construction of Centrifuges

Another advance which materially widened the scope of the high-speed centrifuge was the production of these machines in materials of construction which could withstand the corrosive attack of liquids which cannot normally be handled in the common metals. Here, of course, much of the credit must be given to metallurgy, which has produced the special steels possessing adequate corrosion-resisting properties and yet retaining physical characteristics which will withstand the stresses imposed by very high centrifugal force. Much progress has been made in this field within the last few years, but more remains to be done, and work is being actively pursued along this particular line.

At the present time it may be said that apart from a limited number of highly corrosive media, almost any commercial liquid can now be handled by an industrial high-speed centrifuge at capacities ranging from 50 up to 1,000 g.p.h., for the removal of particles larger than about 1 micron, and for the separation of components which differ in specific gravity by 0·05 or more. This has meant that centrifuges are now used to a much greater extent than formerly in the chemical and the food processing industries.

In a comparable way it is interesting to note how the employment of high-speed centrifuges for clarifying and improving surface finish materials such as varnishes, enamels, lacquers, etc., has increased due to the improvements of the last few years in these machines in respect of solvent-tight enclosures and flameproof driving equipment.

Non-aerating Centrifuges

In conclusion, it should be remarked that a recent field of development of high-speed centrifuges is concerned with eliminating the undesirable feature of aeration, which characterises all such normal operations. Non-aerating centrifuges are now available, in particular for milk clarification and separation; and so the wheel may be said to have turned full circle, advances in industrial centrifuging technique having been applied back to the old original example of the use of centrifugal force, i.e. the cream separator.

SECTION 7

HIGH-SPEED CENTRIFUGES AND THEIR INDUSTRIAL APPLICATION

By D. G. GILLIES

CENTRIFUGAL SEPARATORS which form one of the most important items in continuous separation equipment, are normally classified into low-speed and high-speed machines. B.S. 767: 1951 *Hydro-extractors and Centrifugal Machines* describes centrifuges having bowl speeds from 400–3,000 r.p.m., and these are normally termed low-speed machines. High-speed centrifuges which are considered in this article have speeds from 3,000–17,000 r.p.m.

Historically, high-speed centrifuges were first developed for milk separation and a Patent was granted to the Swedish inventor De Laval, in 1878. Since that date, the application of "cream separators" has now become universal in dairies and the use of such machines rapidly spread to the industrial processing field.

High-speed centrifugal separators are used for the following types of separation.

1. Liquid/liquid separation (purification)
2. Liquid/solid separation (clarification)
3. Liquid/liquid/solids separation.

Further, high-speed machines may be classified under the following headings depending upon the way in which the solids are handled in the centrifuge bowl.

(*a*) Continuous feed, intermittent manual cleaning.

(*b*) Continuous feed, automatic discharge of solids.

Table I shows the general classification of the types of centrifuges available in this field and it is now necessary to examine how these various machines can be applied to specific separation problems met in industry.

LIQUID/LIQUID SEPARATORS

When liquids only are to be separated, the choice of the correct centrifuge is less complicated than when solids are present. For liquid/liquid separations, two basic types of

TABLE I. HIGH-SPEED CENTRIFUGES

Speeds 3,000–17,000 *r p m.*

Continuous Feed Intermittent Manual Cleaning			*Continuous Feed Automatic Discharge of Solids*			
				Nozzle Bowls		
Tubular Bowls	*Disc Bowls*	*Cylinder Bowls*	*Valve Bowls*	*Peripheral Discharge*	*Yeast Separators*	*Conveyor-Type Bowls*
L S , L L , L.L.S. Hollow tubular bowl open or vapour-tight construction. B D. 4 in. B S.15,000–17,000 r.p m.	L.S., L.L , L L.S. Bowl fitted conical discs open or vapour-tight construction. B D. 5–15 in. B S. 5,000–10,000 r p.m.	L S. Bowl fitted 3 or 5 vertical cylinders, gravity or pump feed, pressure non-aerated discharge B.D. 5–27 in. B S. 4,000–6,000 r p m.	L S , L L S Disc bowls fitted automatic peripheral opening device for solids ejection. B S. 5,500-6,200 r p m.	L.S., L.L.S. Disc bowls fitted with 4, 6, 8, or 12 nozzles in periphery for solids discharge B.S. 4,000–6,000 r p m.	L S. Disc bowl nozzles in base of bowl for readily flowable solids. B S 4,000–6,000 r p m.	L.S., L.L S. Hollow, horizontal, conical or cylindrical bowl, fitted internal helical screw for continuous discharge of solids. B.S. 3,000–3,300 r.p.m.
	Capacities L.S. 5-4,000g.p.h. L.L 5-2,400g.p.h.	*Capacities* L.S. 5-3,350g p h.	*Capacities* L S up to 2,000 g p h.	*Capacities* 600–5,000 g p h	*Capacities* Up to 6,000 g p h.	*Capacities* 100–1,500 g p h

L.S. Liquid/solid separation
L.L. Liquid/Liquid separation
L.L S Liquid/Liquid/Solid separation
B.D. Bowl diameters
B S. Bowl speeds

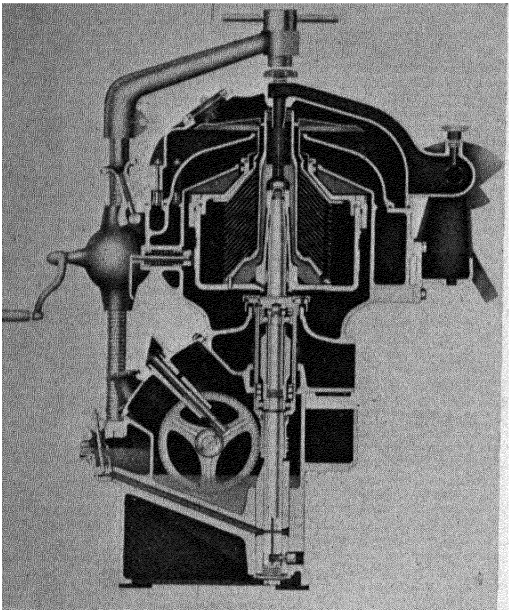


FIG. 1.—TYPICAL DISC TYPE BOWL CENTRIFUGE OF ENCLOSED FUME-PROOF CONSTRUCTION.
(*Alfa-Laval Co, Ltd*)

high-speed centrifuge are available, namely the tubular-bowl type and the disc-bowl type. Either of these types of machine can be used for the separation of two immiscible liquids, and in the absence of any solid matter in these liquids the machines will operate continuously.

Tubular Bowl Centrifuge

The first of these two types, the tubular bowl, is well represented by the Sharples type of centrifuge (Fig. 2). It comprises basically a hollow tube 24–30 in. long and 4 in. in diameter. The feed is at the base of the bowl which is rotating on a vertical axis. In the head at the top of the bowl are separate discharges for the two liquids and the degree of separation can be controlled by varying the diameter of the heavy phase discharge outlet by the insertion of gravity rings. These discharge outlets may be of the open type or vapour sealed for handling volatile liquids. Internally, the bowls are fitted with three vanes to prevent liquid slip.

In order to obtain the required degree of efficiency, such bowls are rotated at 15,000–17,000 r.p.m. on commercial machines and this gives a peripheral centrifugal force of 13,000–15,000 times gravity.

Maximum through-put capacities on liquid/liquid separations are quoted up to 1,000 g.p.h., but through-puts will vary very considerably with the types of liquids being separated, as is illustrated in Table II.

Disadvantages of this type of bowl are the relatively large settling distances through which particles must pass before they are completely separated and the consequent need of high rotational speed to give adequate separation effect. The liquid nearer the centre of the bowl, in view of the small diameter, will be subjected to a very much reduced centrifugal force.

Disc-Type Bowl

The disc-type bowl was introduced at an early date and is typified by the De Laval design (Fig. 1). Modern disc-type bowls have larger diameters which are usually slightly greater than their heights and this gives the bowls very good operation stability. Bowls of this type are made with diameters from 5–15 in. These bowls are fitted with a series of conical discs having a ½° angle to 30–50°, and spaced 0 5–2 mms. apart. The conical discs divide the liquids passing through the bowl into very fine layers and in this way the distances the particles must travel before they are separated is reduced to an absolute minimum and, consequently, the efficiency of separation is greatly increased.

Bowls of this type run at speeds of 5,000 to 10,000 r.p.m. and develop peripheral centrifugal forces of 5,500–7,500 times gravity. It is interesting to note, however, that it has been shown that the use of discs will increase the separating efficiency by 5–10 times. Consequently, in determining the efficiency of the centrifuge bowl, it must be remembered that this efficiency does not only depend purely on the centrifugal force developed at the periphery, but is very closely allied with the travel distances for the particles before separation. Consequently, with the disc design of bowl, it is possible to obtain the required separating efficiency at very much lower bowl speeds.

Machines of this type are normally gravity or pump fed and the liquids enter the bowl through a central tubular shaft or distributor which feeds them evenly into the stack of discs. The two liquid discharges are at the top of the bowl and, again, separation is controlled by gravity discs of differing diameters on the heavy phase discharge. The discharge outlets are either open or vapour tight.

Advantages of the disc-type bowl are the high separating

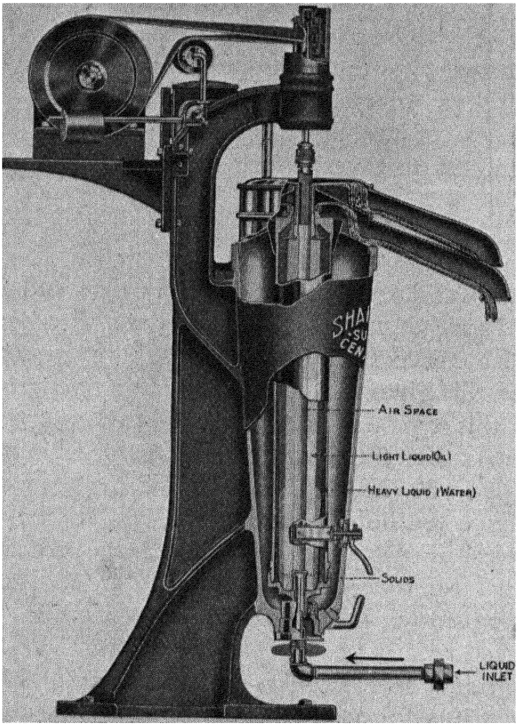


FIG. 2 (*left*) — TUBULAR BOWL CENTRIFUGE.
(*Sharples Centrifuges, Ltd*)

FIG 3 (*below*)— DE LAVAL SHORT MIX REFINING PLANT INSTALLATION FOR REFINING 40 TONS PER 24 HOURS OF VEGETABLE OILS.

The illustration shows a three-stage plant with three liquid/liquid disc type centrifuges for degumming, neutralising and water wash separations. The central separator for soap-stock separation is of hermetic design.

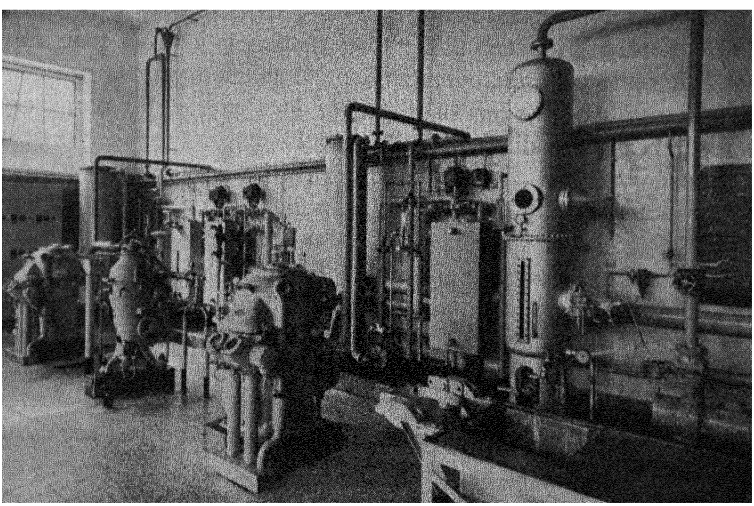


TABLE II

TYPICAL THROUGH-PUT RATES USING 15 IN. DISC-TYPE BOWLS

Problem	*Approximate Through-put G.P.H.*
White Spirit Clarification	4,000
White Spirit/Water separation	2,500
Diesel Oil (light)/Water separation	1,500
Palm Oil/Water separation	1,000
Beer Clarification (Hermetic)	400–700
Vegetable Oil degumming or soap-stock separation	250–500
Thin oil varnish clarification	100–400
Rubber Latex Concentration	100
Bacteria separation—media clarification	20–50

efficiency at relatively low operating speeds. In this design, it is possible to make the bowls of much larger diameter which permits construction of machines having higher through-put capacities. For example, a larger machine with a 15 in. diameter bowl has a maximum capacity on liquid/liquid separation of approximately 2,500 g.p.h.

Capacities of Tubular and Disc Bowls

In the case of both tubular and disc bowls, it is difficult to calculate performance from the basic designs of the bowls. When any new separation problem is met, it is invariably necessary to make a practical test to determine the degree of separation which can be obtained and the capacity for the various sizes of machine.

It is, of course, possible to develop factors whereby results obtained on one size of machine of a particular construction, can be translated to another size of machine. Through-put capacities will also vary very greatly with the types of liquids being handled depending upon the gravity difference, viscosity, emulsibility, etc. To show the effect of this, Table II illustrates some typical through-put capacities on different problems which can be expected on a 15 in. disc-type bowl.

Disc and tubular purifiers already described, are designed for separating two immiscible liquids and can handle a feed in which the ratios of the liquids may be constantly varying between 0 and 100 per cent. For problems such as milk separation, however, a complete separation is not possible and it is, of course, desired in this case, to concentrate all the fat in the light liquid phase which is discharged as the cream emulsion. Special "concentrator" disc bowls are used for this type of processing. They are designed to handle a feed of constant composition at a fixed rate of flow. They have two pre-determined outlets at fixed diameters for the two liquid phases. In this case, the liquids are fed into the disc-pack near the centre of the bowl so that the greater length of disc towards the periphery of the bowl is available for separating the light phase from the heavy phase.

Typical Applications of Liquid/Liquid Separators

1. VEGETABLE OIL REFINING.—Both tubular and disc bowls are used for the continuous separation of gums, soap-stock and wash-water from vegetable oils. Such continuous separations have led to the adoption of fully continuous refining processes both by De Laval and Sharples. Not only does centrifugal separation offer better de-oiling of gums, soap-stock, etc., thereby reducing losses, but controlled mixing and separation cycles give the possibility of accurately controlled chemical dosage, reaction times, etc. This also greatly assists in lowering process losses. It is possible to reduce refining losses by 25 per cent when compared with batch methods.

A typical vegetable oil refining installation is shown in Fig. 3.

2. CONCENTRATION OF RUBBER LATEX.—The problem here is rather similar to milk separation. Field rubber latex contains about 32 per cent dry rubber content (D.R.C.). By using centrifugal latex concentrators with disc bowls, it is possible to increase the D.R.C. to 60 per cent, thereby greatly reducing shipping space, etc. At the same time, water soluble proteins are separated in the skim. A somewhat special design of disc centrifuge is necessary in this case, in view of the tendency for the rubber particles to coagulate.

3. BENZOL AND MINERAL OIL REFINING.—In acid refining of benzol, mineral oil, etc., centrifuges are used in continuous processes for the separation of acid sludge, and also at the neutralising stages when required. As in the case of vegetable oil refining, yields can be increased and chemical consumption

reduced. For example, in benzol refining, it is possible to reduce the acid consumption by as much as 60 per cent, and losses by 66 per cent.

4. Penicillin and other Pharmaceutical Products.—Centrifuges are widely used for solvent/solvent and solvent/aqueous liquor extraction processes. The liquid/liquid separators are particularly applicable to counter current extraction systems using two or three machines for multi-stage extraction.

5. Blood Separation.—Another typical liquid/liquid separation is blood separation, in which the centrifuge gives a continuous separation of a concentrate of corpuscles and plasma.

LIQUID/SOLID AND LIQUID/LIQUID/SOLID SEPARATIONS

In separations where solids are involved, a much wider variety of centrifugal separators must be considered, primarily depending upon the type and percentage of solids involved.

The straight tubular and disc bowls already described, are designed for high efficiency and as such only a very limited sludge-holding space is available in the bowl. In a larger disc bowl for example, there is a sludge-holding space outside the disc area and, consequently, the build up of solids does not interfere with the separating efficiency. This sludge space is, however, limited to a maximum of about 14 litres. In a tubular bowl, as sludge builds up on the bowl peripheral wall the effective centrifugal force must drop, and for this reason the sludge-holding capacity is very limited unless decreased separating efficiency can be allowed.

Typical Applications

Machines for liquid/solid and liquid/liquid/solid separation are used for problems where a high separating efficiency is required but where the percentage of solids is small. However, some of the main centrifuge applications come in this category, i.e. purification of many types of oils including the following:

1. Diesel Fuel Oil.—Centrifugal purification is the most generally accepted method of treating diesel fuel oil. Before burning oil in diesels, it is necessary to remove moisture to prevent engine misfire and to remove solids to prevent liner wear. Both these impurities can very well be removed in

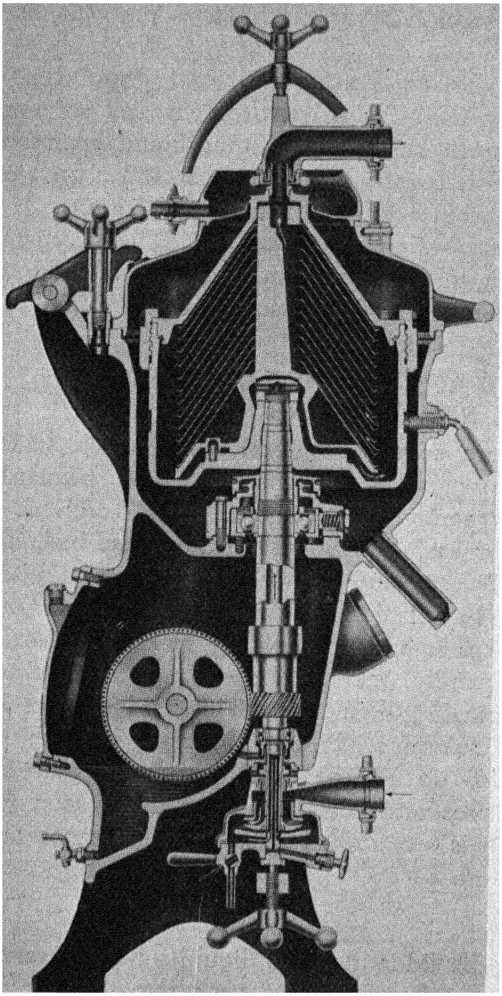


FIG 4.—TYPICAL DE LAVAL CENTRIFUGAL CLARIFIER WITH INLET THROUGH THE HOLLOW DRIVING SPINDLE
The illustration shows a machine with built-in feed pump. A similar outlet pump can also be incorporated at the outlet.
(*Alfa-Laval Co., Ltd.*)

centrifugal purifiers. High-speed centrifuging has more recently become the accepted method of purifying fuel oils of higher viscosities up to 3,500 secs. R. 1., which are now being widely used in particular for marine use. With this type of oil it is necessary to ensure the maximum possible removal of insoluble and soluble ash, and the highest efficiency of centrifuging is, therefore, required, and disc bowls are widely used.

2. DIESEL AND TURBINE LUBRICATING OIL.—These are further applications for which centrifuges are used extensively. Lubricating oil must be kept free from moisture and solids and it is common practice to treat such sump oils on a continuous by-pass system through the centrifuge. Capacity is then arranged so that the whole oil is treated every few hours.

The above are, of course, typical liquid/liquid/solid separations, but standard tubular and disc bowls have many applications as liquid/solid separators, i.e. clarification of varnishes and lacquers, dry-cleaning solvents, pharmaceutical liquors, etc. Generally speaking, unless very low throughput rates are used, the percentage of insoluble solids should not exceed 0·1–0 5 per cent, so as to make economic length of runs possible before bowl cleaning.

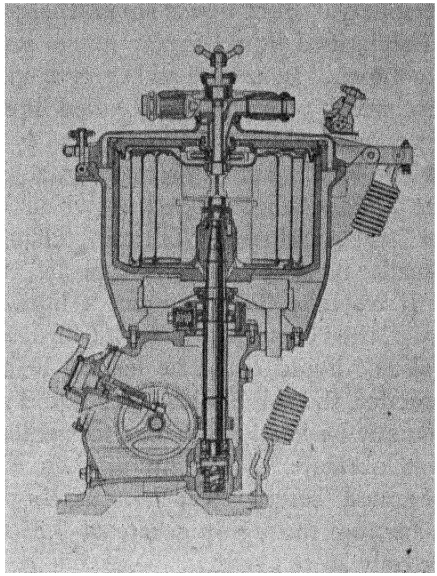


FIG. 5.—DE LAVAL CYLINDER-TYPE CLARIFIER BOWL
Capacity 64 litres
(*Alfa-Laval Co. Ltd*)

Hermetic Centrifuges

Hermetic centrifuges, of De Laval design (see Fig. 4), have disc-type bowls, and the feed is through the bowl-driving spindle which is hollow. Inlet and outlets are sealed by special glands so that the liquids passing through at no time come in contact with the air. As liquid/solid separators, such machines find wide use in breweries, for the clarification of carbonated beer. Cider is similarly treated. They are also used for clarifying such liquids as caustic lye in artificial-silk factories and for separating bacteria in the preparation of anti-toxins. Typical capacities are given in Table II.

Cylinder Bowls

Cylinder bowls are wide diameter bowls in which a number of vertical cylinders are used in the place of discs. The liquid is fed into the centre of the bowl and then travels alternatively from the bottom to the top, and from the top to the bottom of the bowl between the cylinders. There are normally, 3 or 5 cylinders which virtually give the effect of several concentric tubular bowls, with increasing effective centrifugal force towards the periphery. Such bowls are normally liquid/solid separators only. The clarified liquid finally passes into a chamber at the top of the bowl. In this chamber is a stationary impellor or paring disc which picks up the clarified liquid and discharges it against a pressure of up to 40 p.s.i., and in a non-aerated condition.

The bowls have larger sludge-holding spaces as, for example, the 27 in. diameter bowl shown in Fig. 5 has a sludge space of 64 litres, and the maximum through-put rate is 3,350 g.p.h. Smaller bowls of the same type are, however, available.

If we take, for example, a liquid containing say 1 per cent solid, then using a bowl with 64 litres sludge-holding space, 1,400 gals. of liquid could be treated before cleaning the bowl. (In practice, the solid holds some liquid so the amount treated would actually be less.) If it was found that a satisfactory clarification was obtained at 700 g.p.h., then a two hours' run would be obtained before cleaning. If, however, we were using the maximum through-put rate of 3,350 g.p.h. then the run would be only 25 minutes.

It will be seen, therefore, that when high capacities are being considered 1–2 per cent solids is perhaps the upper limit for cylinder bowls. In certain cases, however, when the value of the liquids or solids is high, e.g. pharmaceutical preparations, etc., small batches containing up to say 5 per cent solids can be handled.

Typical applications of cylinder bowls are:

1. Beer Wort.—Clarification of beer wort to remove hot or cold sludge prior to fermentation. When clarifying hot wort the pressure discharge of the clarifier transfers the wort through the subsequent plate-type cooler and to the fermentation tank without further pumping. Through-put capacities up to 2,000 g.p.h.

2. Fruit Juices, etc.—Clarification of juices—apple, black-currant, etc.

Other applications include the clarification of molasses in yeast factories, pharmaceutical extracts, etc., i.e. liquorice, liver extracts, etc.

CONTINUOUS FEED—AUTOMATIC DISCHARGE OF SOLIDS

It has been seen that the types of high-speed centrifuge so far described, are only suitable when the percentages of solids in the materials being treated are relatively low. When feed rates are higher and the percentage of solids much over 1 per cent it is necessary to consider machines with arrangements for the automatic discharge of solids.

Valve Bowls

Valve bowls follow more or less the standard disc-bowl design with the exception that they have either mechanical or hydraulic opening devices in the bowl periphery. By operating these mechanisms the contents of the bowl can be ejected at any required interval.

In such bowls the sludge-holding space is slightly less than the corresponding straight disc bowl, to allow room for the opening mechanism. Sludge-holding spaces are normally between 5 and 10 litres, and obviously, when this amount of sludge is accumulated in the bowl, the opening device must be operated. Consequently, solid contents must be moderate or the opening will be too frequent. For example, on a liquid with 2·0 per cent solid a 10 litre sludge space would be full after treating 111 gallons. At 1,000 g.p.h. input the bowl would, therefore, have to be opened every 6·6 mins. This type of machine is preferably used for liquids containing solids of a soft non-gritty nature which cause no difficulties in re-closing the bowl.

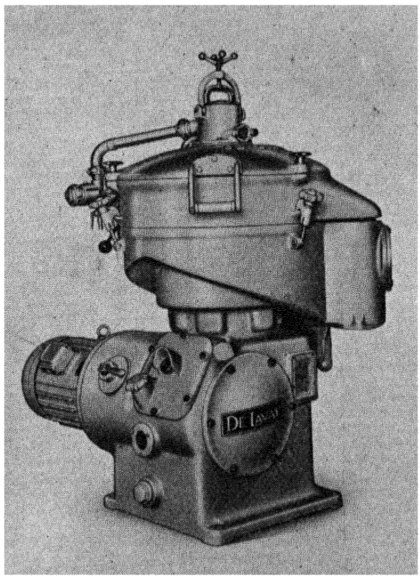


FIG 6.—PERIPHERAL DISCHARGE NOZZLE SEPARATOR FITTED WITH RECIRCULATOR DEVICE FOR THE NOZZLE DISCHARGE.
(Alfa Laval Co , Ltd)

These machines, therefore, suit the intermediate type of solid problem very well, i.e. where the solid content is too high for

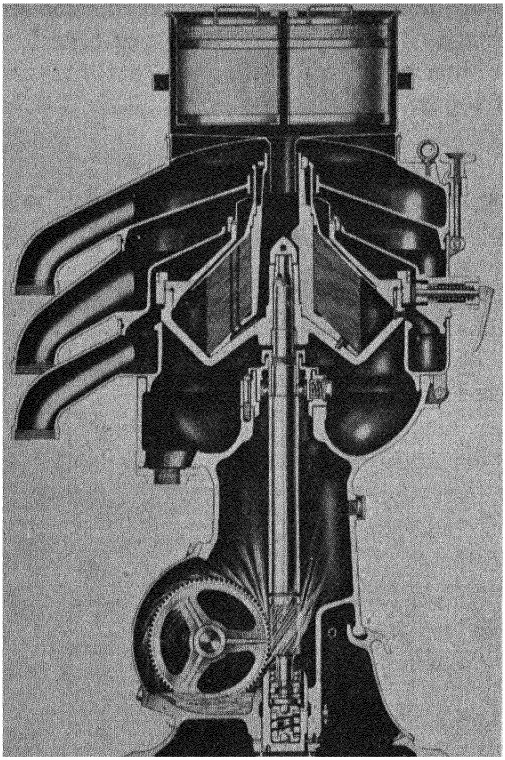


FIG. 7.—CROSS-SECTION OF A DE LAVAL PERIPHERAL DISCHARGE NOZZLE SEPARATOR USED FOR FISH OIL SEPARATION
Three separate discharges for oil, water and sludge are shown.
(*Alfa-Laval Co., Ltd.*)

the non-discharging bowl, but rather low for the continuously discharging type. They are used for separation problems in connection with animal fat or liver residue separation, etc.

Nozzle Separators

Nozzle separators are normally disc-type bowls fitted with a number of nozzles through which solids can be discharged continuously. Such nozzles are normally of 0·5–2·0 mm. in diameter, and, consequently, pre-screening is frequently necessary to prevent nozzle chokage. The position of the nozzles in the bowls depends upon the type of solids being separated, but there are two normal positions. The first type has the nozzles placed at the periphery of the bowl and the bowl wall is in the form of an apex to assist the sliding of the solids towards the nozzles. Solids in this case are, therefore, ejected at the point of greatest force, and such bowls are then used for the type of solids which do not flow too readily. Peripheral discharge bowls have 4, 6, 8 or 12 nozzles, depending on the type of solid.

The second type, for solids which flow more readily, i.e. yeast cream, etc., has nozzles placed in the base of the bowl. Under centrifugal force the solids are forced to the periphery, and to discharge they flow back a certain distance through tubes against the centrifugal force before discharging through the nozzles. In this way, a greater concentration of the solids can be obtained as less liquid will escape through the nozzles with the solids, due to the lower centrifugal force at the radius of discharge.

Applications of Peripheral Discharge Bowls

These have, possibly, the widest application. They are being used for an ever-increasing number of liquid/solid and liquid/liquid/solid separations. Some of the typical liquid/solid applications are as follows:

1. For the concentration of mill flows in the preparation of starches of many kinds. Starch suspensions are fed into the centrifuge, the starch separated and concentrated in the nozzle discharge. Special starch separators for this problem often have independent fresh-water feeds through a hollow bowl driving spindle and with either a special washing ring in the bowl itself near the nozzles, or by a special double nozzle discharge device, which washes the concentrated starch before it is discharged from the bowl. Starches handled include corn, wheat, rice, cassava, potato, etc.
2. For gluten stripping and concentration in corn starch manufacture.
3. For china clay and whiting separation and concentration. With this type of processing it is also possible, by controlling the nozzle flows and input rates, to adjust the separation so that smaller particles below a certain size will be carried over with the 'clarified' liquor, while the larger particles discharge through the nozzles. It is thus possible to classify solids and obtain fractions of well defined particle size, say below 1 μ and above, or below 2 μ and above, etc.
4. For the clarification of crude vegetable oils, etc., containing fine protein matter, also the separation and concentration of insoluble proteins from aqueous suspensions.

Some of the typical liquid/liquid/solid separations for which peripheral discharge nozzle bowls are used are as follows:

1. Separation of fish oils, etc., from stick water resulting from the cooking and pressing of fish. This liquor contains oil, glue water and possibly between 4–10 per cent of fine protein solids, from which oil has to be recovered.

2. Wool-scouring liquors. Liquors used for the washing of wool contain the valuable wool grease, water, and varying quantities of sand, dirt, etc.

Other processes include the recovery of animal fats, palm oil, etc.

Operation of Peripheral Discharge Bowls

Let us now consider the way in which these machines are operated. Feed rates naturally again depend upon the particular problem but generally speaking, such machines are intended for the higher through-put problem. Further, the rate of flow through the nozzles will depend upon their number and size. Normally, it is hardly possible to work with nozzles of less than 0·75 mm. in diameter without chokage, and 1 mm. is more common. Eight 1 mm. nozzles in a larger bowl will discharge some 425 g.p.h. of water, depending upon bowl speed. Consequently, if for example, we take a liquid/solid separator being fed at 1,500 g.p.h., only 1,075 g.p.h. of clarified liquor will be discharged and the rest will pass through the nozzles. Say the ingoing feed had 5 per cent solids, i.e. 75 g.p.h., then the nozzle discharge concentration would only be 17·6 per cent dry solid.

Naturally, if the feed rate was increased to 2,000 g.p.h., and the same nozzles used, the total nozzle flow would remain the same and the concentration be increased to 23·5 per cent. In some cases this may be adequate and in others not so. In a three-way separation of oil, water and solids, the oil would be discharged separately and the concentration of solids in the nozzle discharge would not usually be so critical.

Recirculation Fitting for Peripheral Discharge Bowls

Very often in a two-way separation the subsequent stage to separation will be to dry the solids and then the maximum concentration of solids is necessary. A special new feature of some peripheral discharge nozzle machines is a recirculation device. By this means, it is possible to recycle a proportion of the nozzle discharge back into the bowl close to the nozzle discharge without interfering with the main flow through the

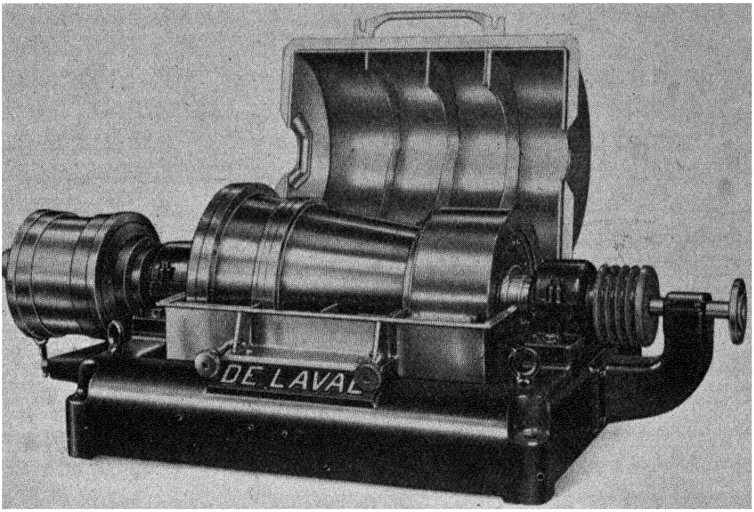


FIG 8 —CONVEYOR TYPE CENTRIFUGE WITH COVER OPEN
Showing the horizontal bowl and gear box for driving the helical screw at a different speed to the bowl
(*Alfa-Laval Co , Ltd*)

bowl. In this manner, the concentration of the solids can be built up further, and by recycling more liquid and using larger nozzles, risk of bowl chokage is reduced.

Continuing the above example, it has been seen that a concentration of 23·5 per cent was achieved by a single passage through the machine when operating at 2,000 g.p.h. If, however, 50 per cent of the nozzle flow was recycled the total nozzle flow would remain at 425 g.p.h. but 212·5 gallons of this would be a concentration of 23·5 per cent solids, i.e. 50 gallons solids. The full 5 per cent of solids from a fresh feed, i.e. 100 gallons, would then bring the total amount of solids in the nozzle discharge to 150 g.p.h., i.e. a concentration of 35 3 per cent. The concentration of solids can in this way be built up to a maximum such that the sludge will flow out of the bowl. To give an indication of what this figure may be for different solids the following may be quoted: The limit of concentration for most starches is about 40 per cent; for China Clay 65 per cent; while for solids of the protein type 25 per cent. These all refer to dry solids.

It is interesting to note that through-put capacities up to the order of 2,000 g.p.h. are normal for three-way separators of this type and higher up to 5,000 g.p.h. for two-way separators. There are very many variations in design to suit particular problems and machines are offered by De Laval and other manufacturers.

In the case of machines of the yeast separator design, these are universally used in yeast factories for both concentrating and washing yeast in the production of bakers yeast. Maximum concentration of yeast in the nozzle discharge is 16 per cent dry yeast, and through-put capacities up to 6,000 g.p.h. are possible on the larger machines offered by De Laval.

Conveyor-Type Bowls

One final type of centrifuge which is designed for the continuous separation of solids and which comes within the range of high-speed machines, should be mentioned. This is the horizontal, conical or cylindrical bowl machine (Fig. 8), fitted with an internal helical screw rotating at a slightly different speed to the bowl. By means of the screw, solids which are separated from the periphery of the bowl are conveyed along the bowl wall and discharged continuously. Machines of these types are put forward by Sharples and De Laval, having bowls of approximately 18 in. diameter and rotating at speeds between 3,000 and 3,500 r.p.m. They have, therefore, a relatively low separating efficiency when compared with the machines just described, but nevertheless are well suited to processes where a very high separating force is not necessary. They are, therefore, used when solids of a somewhat coarser nature are to be separated and in fact are often used as a pre-treater before a nozzle machine. This is often the case, for example, in treating fish press liquors to remove the coarser solids. In this instance, it has been shown that the solids separated in this way are drier than from a vibrating screen. Normal moisture contents of the discharged solids are of the order of 50 per cent. Normal through-put capacities are up to a maximum of 1,500 g.p.h.

The use of this type of machine is restricted to the firmer type of solid which will be conveyed by the screw, as it is found that soft solids of the yeasty type cannot readily be handled.

SECTION 8

CONTINUOUS-OPERATION CENTRIFUGES FOR THE SUGAR INDUSTRY

By E. RUEGG

FOR some years past the sugar industry has used the vertical type of centrifuge, and during the period this machine has been developed to give high outputs. Its method of operation is, however, not continuous and despite automatic arrangements, manual attention is still required. Also, the increased outputs were achieved at the expense of considerable peak loading and wear of the machine, caused by frequent starting-up and braking.

For these reasons experiments have been going on for some years with continuous-operation centrifuges for the sugar industry. The call for this machine has been further increased by the fact that such continuous-operation centrifuges have been most successfully applied in many other industries where they have proved their economy.

A difficulty in adopting continuous-operation centrifuges for the sugar industry was chiefly found to be the relatively high viscosity of the syrups and the fact that exacting requirements

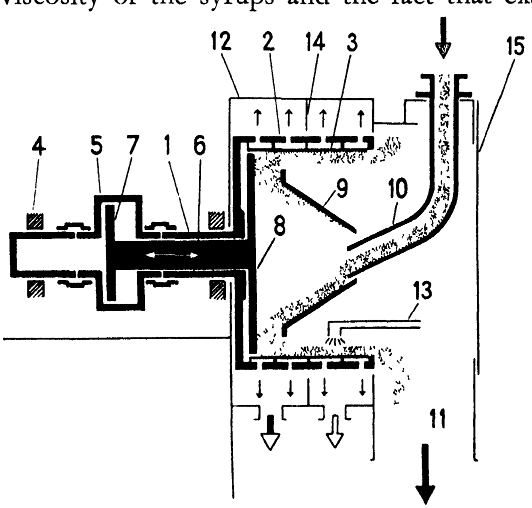


FIG. 1 —DIAGRAM OF PUSH-TYPE CENTRIFUGE.

apply to the final product, depending on the stage of manufacture concerned.

Amongst the best-known continuous-operation machines are the so-called "worm" and "pusher" centrifuges.

This section deals with the push-type machine, since, as a result of repeated endeavours, it has now proved possible to adopt this type for the sugar industry and, moreover, for dealing with different qualities of sugar.

The pushing or discharging action itself was adopted at an early date, but only in conjunction with a non-continuous method. It came into operation only after a completed centrifuge process, namely, for discharging the contents of the basket in a single stroke. The design of a continuous-operation push-type centrifuge dates back to the year 1908, having been introduced by an engineer named Eckstein.

Development of the Continuous-operation Centrifuge

In 1930 the firm of Escher Wyss took up the development of this system of centrifugation as a supplement to the scraper-type machines that were already being manufactured by the department concerned. Centrifuges of the push type were well suited to the Company's manufacturing programme which for a long time had been particularly devoted to turbo-machines.

After unavoidable initial difficulties, a wide market was opened up for the new machine. The continuous operation, practically without attendance, encountered widespread interest. With increasing experience it was found possible to deal with more and more new products in these special machines and furthermore to increase the outputs. Such machines are now encountered in the whole chemical industry and in its related fields. They are of various sizes with discharge capacities up to 30 tons/hr. or more.

Since centrifuges are usually required for very exacting duty, the push-type machine is likewise characterised by a simple but sturdy design and a minimum number of parts subject to wear, coupled with the very limited needs as to attendance already referred to. Those parts of the machines coming in contact with the material to be centrifugated can, in practice, be made of almost any alloy that may be employed for the particular

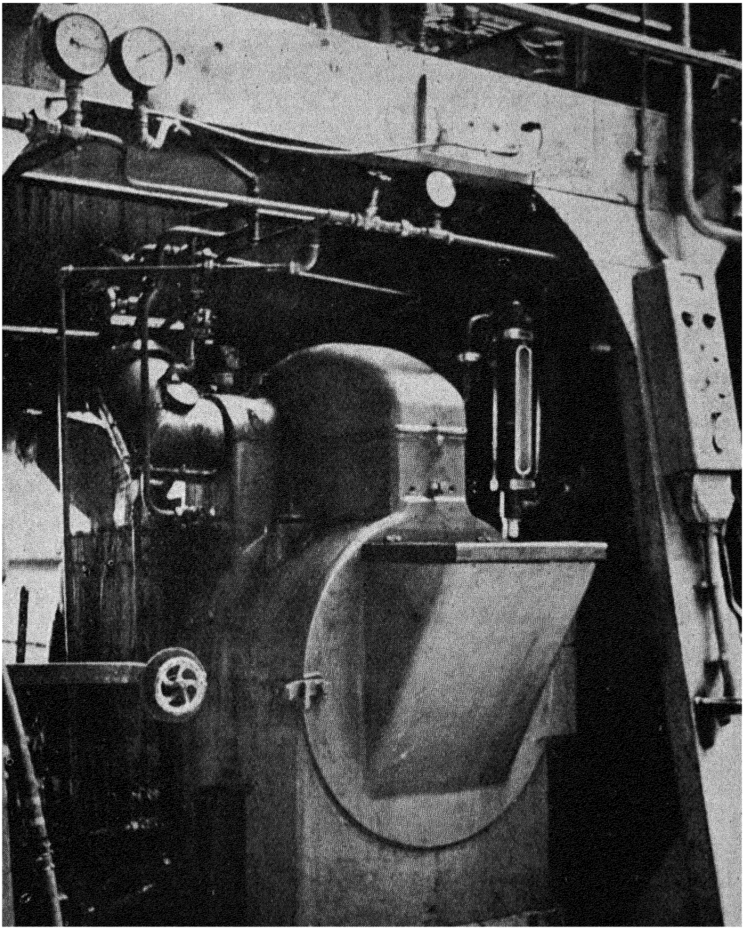


FIG. 2.—EXPERIMENTAL PUSH-TYPE CENTRIFUGE FOR SUGAR IN INDUSTRIAL OPERATION

purpose. The power consumption of the machine is low and constant.

The first trials to employ these machines for sugar took place at the end of the thirties in the Swiss Sugar Factory at Aarberg. Subsequently Escher Wyss worked according to a systematic programme of trials with continually improved machines that were gradually increased in size. The Aarberg Sugar Factory kindly assisted in these endeavours by making available their installations, equipment and experience. Although a certain likelihood of success was apparent from the commencement, this development work nevertheless proved difficult and involved considerable time. The short operating periods, necessarily connected with the sugar campaigns, and also the delays occasioned by the war years, all hindered speedy progress. But the many prerequisites for centrifugating sugar were thoroughly explored. The requirements of uninterrupted operation, possibility of spraying with water and/or steam, separate discharge of green syrup and wash syrup, careful treatment of the crystals, acceptable power consumptions, etc., were continually opposed by the difficult characteristics for centrifugation of the viscid massecuites. When cooling down was effected either encrustation occurred, the product was not pure enough, the crystals were damaged, the syrup contained too much sugar, or the power consumption of the machines was not in accordance with expectations.

Finally in 1948 the results obtained with vertical centrifuges were met and it became possible to install operational units in various stages of the process. The successes in continuous operation were confirmed by the Aarberg Sugar Factory, who, in 1951, converted their raw sugar station for use with push-type centrifuges. The two units employed for this purpose together deal with 750 tons of massecuite per day, corresponding to a discharge of about 400 tons of sugar.

In this connection reference may be made to the congress at Pyrmont in 1951 and also to the one at Bad Ems in 1952, on which occasions Mr. Reichen, Manager of the Aarberg Plant, as also Mr. Boss of the same company, reported about the positive results obtained in operation with push-type centrifuges.

Operation of the Push-type Centrifuge

The design of the push-type centrifuge is shown, in principle, by the schematic drawing, Fig. 1. On the hollow shaft (1) the basket (2) of the machine is overhung, being equipped with a grate-type sieve (3). The pressure cylinder (5) is accommodated in the hollow shaft (1), in which former the piston (7) is fitted, being connected by rod (6) to the so-called pusher (8). The pusher in its turn supports the inlet funnel (9) and the feed pipe (10) discharges into the latter.

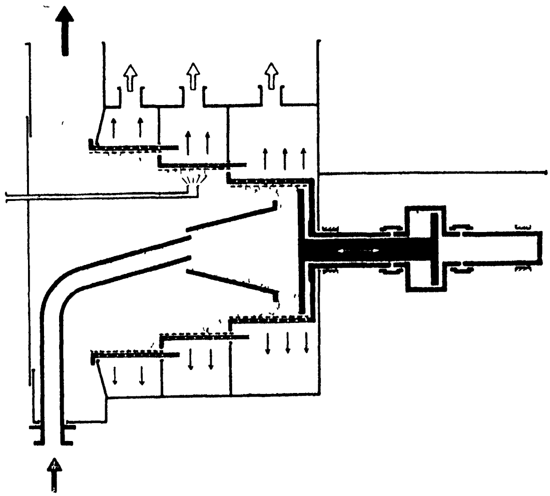


FIG 3.—DIAGRAM OF MULTI-STAGE PUSH-TYPE CENTRIFUGE.

By alternate admission of liquid under pressure, piston (7) is caused to move to and fro and with it the pusher (8), also the inlet funnel (9), this takes place continuously during rotation of the machine. The product to be centrifugated flows continuously through the inlet pipe (10) into the machine. The funnel (9) gradually accelerates it and brings about distribution in the basket of the centrifuge. Under the action of centrifugal force the liquid in this mixture is discharged through the sieves (3). As a result of the uninterrupted axial movements of the pusher, a successive pushing along of the solid matter accumulating on the sieves takes place, namely in the direction of the edge of the basket. The product is thus discharged into the collector (11) and reaches the conveyor through a pit.

The liquid is led from the casing through the corresponding branches. If required, washing, impregnation, steaming or the like, of the solid matter can take place in these push-type centrifuges in a continuous manner by adopting suitable spraying means, nozzles, etc. These devices are adjustable, so that they can be brought into the desired zone during operation. Walls in the casing permit separation to a considerable degree of the various liquid components.

Construction

The overhung supporting of the rotor ensures very good accessibility to the basket and its accessories from the large doors

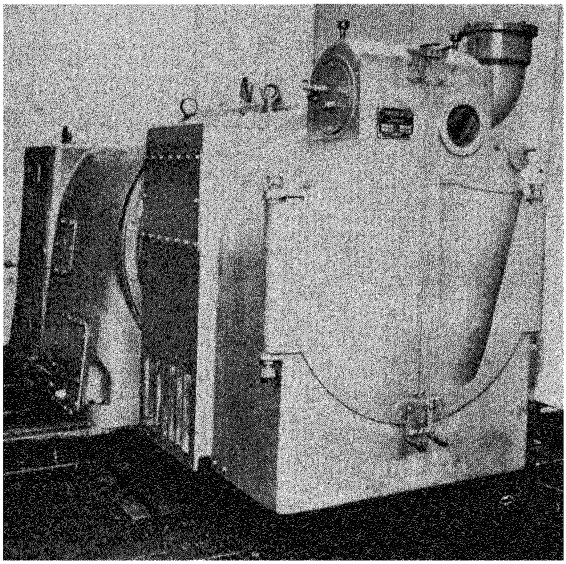


FIG. 4—PUSH-TYPE CENTRIFUGE FOR SUGAR, MODEL C.

provided in front of the machine, so that the process of operation can be observed through suitable openings.

The hydraulic operation of the pusher gives rise to ideal conditions as regards the lubrication and life of the moving parts, few spares are needed and overhauls, as also repairs, are easy to carry out.

The multi-stage designing of the basket was one of the main factors in the adoption of these machines in the sugar industry (see Fig. 3). Whilst maintaining the same design and method of operation, basing on the pusher principle, the multi-stage machine is characterised by separate baskets of differing diameters which follow one another successively. In this way it is ensured not only that the sugar cake is retained in the machine for a longer period, but also that the product is repeatedly loosened and stirred. Moreover, this design brings about an even better separation of the separate fractions of the syrup. The number of stages depends on the quality of the sugar to be centrifugated. A multi-stage machine was shown by Escher Wyss for the first time at the ACHEMA X exhibition held in 1952 at Frankfurt.

Model "C" Continuous-Operation Centrifuge

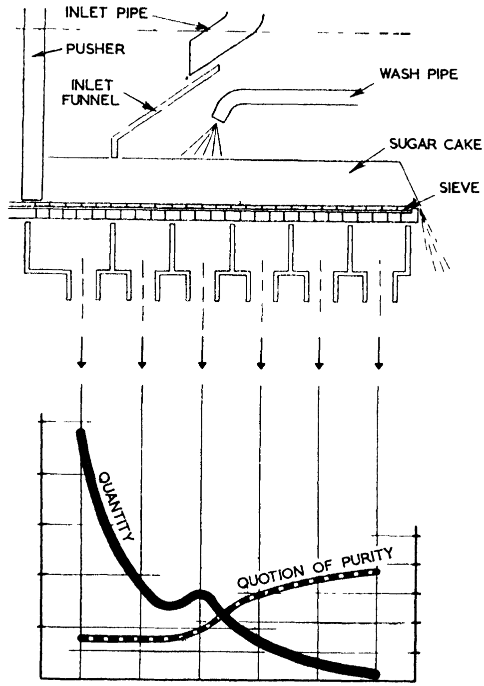


FIG. 5 — CENTRIFUGATION PROCESS WITH CAKE OF SUGAR BEING PUSHED FORWARD.

As regards the capacity of the push-type centrifuge for the purpose of affination, it is claimed that the output is greater than that of the vertical centrifuge being, in the case of the machine model "C," 8–10 tons of raw sugar, or 7–8 tons of medium product sugar per hour.

Also, the quality of the discharged sugar is, for the above output, extremely good; the consumption of wash water is less, and the components of the syrup can be separated more reliably and into finer stages of quality.

Fig. 5 shows the course of the centrifugation process. As the layer of sugar is pushed towards the edge of the basket the quantity of syrup to be discharged decreases; on the other hand, from the commencement of the washing process the coefficient of purity increases. Since the casing is subdivided into various chambers, whilst an ingenious battery of distributors is arranged at the outlet, the possibility exists of differentiating to a considerable degree during operation, especially as the washer nozzles can be differently adjusted at any time.

The power consumption of the centrifuge model "C" is about 1·5–2·5 h.p. per ton of discharged sugar, depending on the quality of the latter and the characteristics of the massecuite. This power consumption is constant and permits the adoption of ordinary squirrel-cage motors since there is a current peak only when starting up the machine. Starting of the plant can be either direct or with a star-delta arrangement. Consequently the electrical equipment is of simple design and reliable in operation.

The machine does not require attendance, so that a whole battery of these centrifuges can be entrusted to a single supervisor. The occasional actions required during the process connected with feeding, i.e. the affination, etc., take place with the aid of a few hand-wheels, cranks and levers. As a rule these centrifuges can be operated during a number of consecutive shifts, without it being necessary to wash out the machine.

The external appearance of the Model "C" centrifuge for sugar may be noted from Fig. 4. In front the two large hinged doors are shown; whilst on the right at the top is the bend for connecting the pipe from the trough; the casing, air-extraction branch, inspection cover and flange with separate discharges from the chambers, are shown on the left of the illustration. (The distributing battery is not shown.)

As a protection against sugar dust, spray water and vapours, all components such as motors, belt drives, control devices, etc., are encased in the stator, as with standard machines. Large erection doors ensure easy access, and the dimensions of the machine are such that it can be installed within the same space as a standard vertical centrifuge.

According to the stage of production for which they are adopted it is possible that some further improvements will be made to push-type centrifuges working with sugar, but centrifugation by the continuous process can now be easily effected.

Acknowledgement

The illustrations which have been used in this section are reproduced by permission of Messrs. Escher Wyss, Ltd.

SECTION 9

CONTINUOUS FILTRATION

By S. HOPTON

THE Rotary Vacuum Filter has been developed to achieve continuous processing instead of batch manufacture. Within a short time after introduction, the basic principles of modern rotary vacuum filters became stabilised and the continuous vacuum filter remained basically unchanged for a number of years. During the last few years, however, there have been considerable developments in this field.

Drum Filters

This type of filter is most commonly used as it offers a simple solution to continuous filtration. The method of discharge of the "cake" is by blade or strings but essentially the principles are the same. The essentials of modern rotary vacuum filters are (1) a sump which carries the slurry to be filtered and (2) a rotating drum which revolves with a variable degree of submergence in the slurry. Since a large number of liquids would tend to deposit solids in the slurry tank, it is normal practice to employ an agitator, either of the oscillating or rotary-screw type for maintaining the undissolved solids in suspension.

The surface of the drum is divided into segments which are connected by pipework to an automatic valve located in the centre of rotation (see Fig. 3). This valve applies vacuum to the various sections in the cycle of operation. As the drum rotates each compartment in turn undergoes filtering, de-watering, and discharging of the cake, these sequences being under continuous control by the automatic valve. The periphery of the drum is covered with a permeable filter medium of cotton, wool or synthetic fibre and, as the filtered material is drawn through the medium by the differential pressure produced by the vacuum the cake is left on the outside of the cloth. Beneath the cloth there are annular spaces which convey the liquor away

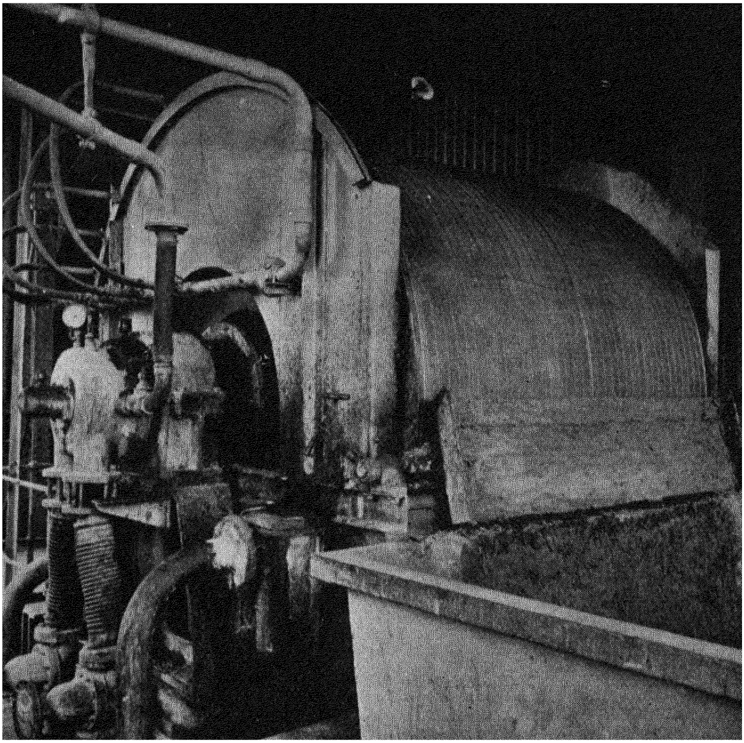


FIG. 1.—ROTARY VACUUM FILTER WITH KNIFE DISCHARGE OPERATING ON CAUSTIC LIME FILTRATION.
(Davey, Paxman & Co., Ltd.)

from the cloth and then through the drain lines to the automatic valve.

In the case of rotary vacuum filters fitted with blade-type discharge, the blade presses on wires which run completely round the drum circumference. Normally, compressed air comes into operation and lifts the cake from the cloth before the cake reaches the scraper. A typical rotary vacuum filter with knife discharge is shown in Fig. 1.

In the case of string discharge, the strings are spaced together at approximately $\frac{1}{4}$ to $\frac{1}{2}$ in. spacing, and these cling to the drum periphery until, when nearing the point of cake discharge, they leave the drum at a tangent, returning to the drum after being driven around a small side roller. This ensures that the cake is lifted from the cloth by the strings as they leave the drum at a tangent. The strings actually lift the cake from the cloth in a continuous sheet. The makers claim that, since string discharge does not subject the filter cloth to any severe mechanical strain or abrasive action, it is possible to operate rotary filters with cloth of light fabrics, and at the same time secure long operating life.

The efficiency of filtration is dependent upon the filtration characteristics of the cake itself, and it thus follows that the thinner the cloth the more efficient will filtration conditions be. Light fabrics having physical properties very close to those of the theoretical desired media, allow the cake, rather than the cloth, to act as the filter medium. One advantage of string discharge is that no compressed air blow-back is required for cake loosening prior to removal. Fig. 2 shows the "Feinc" rotary vacuum filter which has a string discharge arrangement.

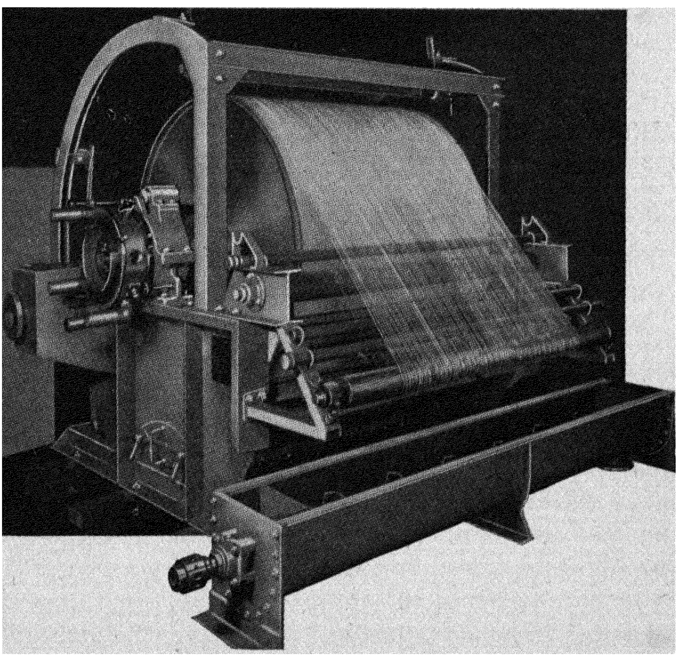


FIG 2.—"FEINC" ROTARY VACUUM FILTER WITH STRING DISCHARGE ARRANGEMENT

(Stockdale Engineering, Ltd.)

Drum Pre-Coat Filters

In a number of industrial filtration applications, the liquor requiring to be filtered is unsuitable for direct filtration, as the insoluble contents of the liquor may only be present as small proportions of the liquor, and consequently, no "cake" is formed in the short period of drum rotation. Since efficient filtration

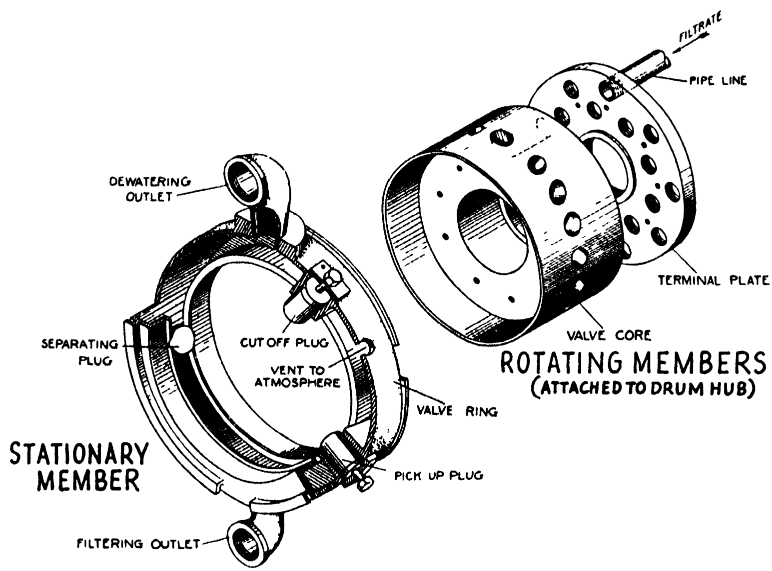


FIG. 3—AUTOMATIC VALVE FOR ROTARY VACUUM FILTER

is accomplished by the filter cake itself acting as the filter, it is essential for an initial thickness of cake to be present.

In the rotary vacuum filter known as the Drum Pre-coat type (Fig. 4), a pre-coat cake is allowed to form on the surface of the drum by feeding a pre-coat slurry which forms the initial filter cake. Usually, this initial pre-coat forms to a depth of about $2\frac{1}{2}$ in. This pre-coat cake operates as the filtration medium and, after its formation on the drum periphery, the slurry tank is cleared of the filter aid liquor, and the "process" slurry fed in the usual way. With this system, micro-scraper knife control is necessary so that the blade moves inwards and continuously removes a layer of the deposited solids plus an extremely thin section of the pre-coat cake. The pre-coat cake can be applied quickly and often this will last for sixteen hours and upwards depending upon the particular material under filtration. It is clear that, with this particular type, string discharge is not possible.

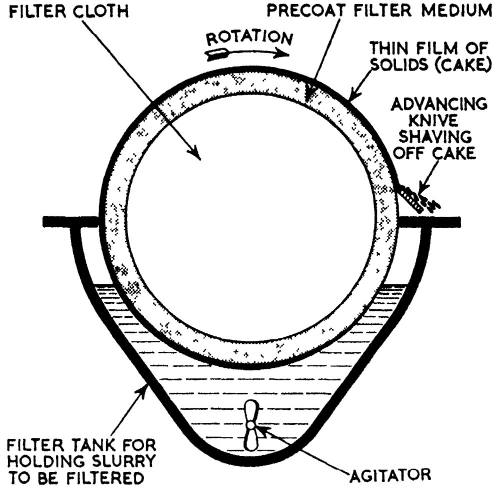


FIG. 4.—DIAGRAMMATIC ARRANGEMENT OF DORR OLIVER PRE-COAT FILTER.

The advantage of the pre-coat filter over the normal drum design is that slurries with low sediment content or liquors with sediment of small particle size can be filtered with reasonable ease.

Rotary-Disc Filters

These operate on the same principle as the drum filter with knife discharge with the exception that the filtration is carried out on radial co-axial discs, each of which is covered individually by cloth on both sides. This filter finds a ready application in coal slurry filtration. A large filtration area is possible per unit of floor area in comparison with the orthodox drum-type filter. A rotary-disc filter is illustrated in Fig. 5.

Rotary-Table Filters

This type of filter finds a successful application on problems where a high degree of washing of the cake is necessary, and it is possible with crystalline and coarse materials to obtain extremely high filtration rates with this design. Slurry is fed continuously to a horizontal rotating filter bed and vacuum is applied from beneath. The rotating table is divided in compartments similar to the drum filter, and each is connected separately to a central automatic control valve.

An interesting application of this filter is the solvent extraction of oil from seeds such as cotton-seed oil and soya bean. In this

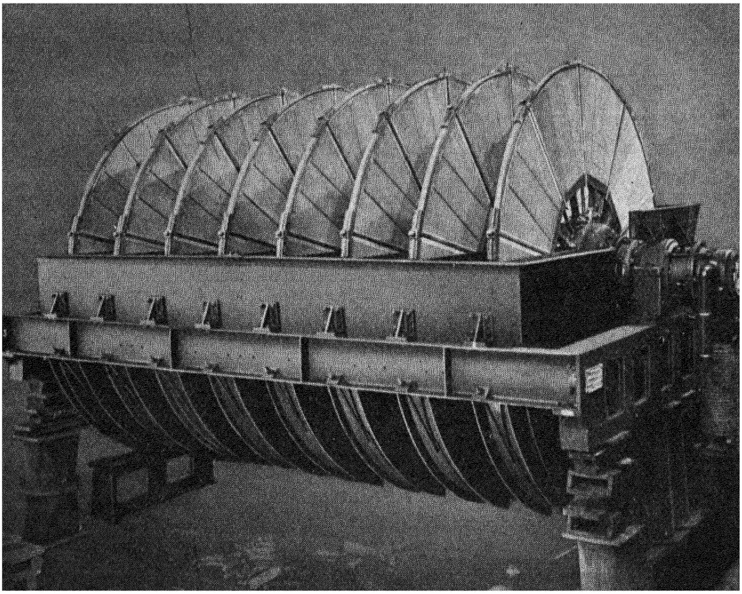


FIG 5 —ROVAC DISC FILTER.
(International Combustion, Ltd)

application, the meal is applied to the rotating table in the form of a slurry. This allows counter-current washing to be carried out with the solvent and the myscella is extracted in the normal way by vacuum through the automatic valve.

Accessory Equipment

The degree of vacuum necessary for filtration varies according to the material of the filter cake and can vary between 5 in. Hg and 22 in. Hg vacuum. The filtrate liquor percolates through the filter cloth and thence to the automatic vacuum valve which controls the application of vacuum during the cycle. The pump is separated from the filter by a liquid receiver. The collected liquor is removed from this receiver either by an extraction pump or by the employment of a simple barometric leg. The extraction pump is usually of the centrifugal or rotary-screw type which is designed to operate under the appropriate vacuum on its suction side.

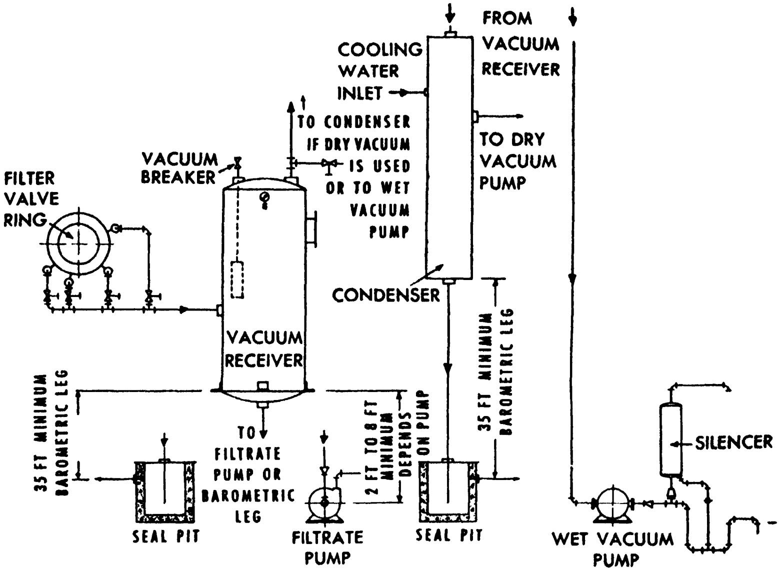


FIG. 6.—TYPICAL ARRANGEMENT OF ACCESSORIES WHEN SAME VACUUM IS USED FOR FORMING FILTER COKE, WASHING AND DE-WATERING

It is often quite satisfactory to employ the same vacuum conditions for the different functions of (1) forming filter cake, (2) washing, and (3) de-watering after washing, and Fig. 6 shows this arrangement.

Where, however, the cake formed is of an impermeable nature, it is often necessary to apply differential vacuum to the various parts of the cycle, and Fig. 7 shows this arrangement. In some instances the wash liquors need to be collected separately from the filtrate liquors and this arrangement is shown in Fig. 8.

Filtration Rates

The key to the sizing of any rotary vacuum filter is the determination of filtration rates and, as these can vary between 2 lbs./sq. ft./hr. and 120 lbs./sq. ft./hr., it can be seen that an accurate laboratory determination of this is important. For comparison, Table I shows relative filtration rates for a few commonly known materials which have been satisfactorily dealt with by filters of the rotary type.

TABLE I

TYPICAL FILTRATION RATES

Materia	*Filtration Rate in Lbs./ft²/hr.*
Clays	5–16
Minerals	7–50
Zinc and Calcium Carbonate . . .	2–50
Flour and Starch	50–300
Fatty Acids and Waxes	6–80
Paper Pulp	3–20
Sewage	1–200
Neutralised Acid Sludges	5–70

Typical Applications

PENICILLIN.—Rotary vacuum filters are now well established as the accepted way of separating the mycellia from the broth. Both scraper and knife discharge filters have been used successfully on this application but the present tendency is to use string discharge for this material.

RECLAIMED RUBBER TAILINGS.—Reclaimed rubber tailings are being successfully handled on drum filters in both the U.S.A. and the United Kingdom.

PETROLEUM INDUSTRY.—The use of rotary vacuum filters in solvent de-waxing processes is becoming increasingly important.

SEWAGE.—An increasing number of sewage disposal authorities are using rotary vacuum filters either on normal sewage treatment or as experimental units. The London County Council have pioneered in the freezing of sewage with the addition of small quantities of certain chemicals. After thawing out it is found that remarkably increased filtration rates are possible and this application gives promise of being an ideal application for a rotary vacuum filter.

RAYON SPINNING SOLUTION.—In order, for economic reasons, to avoid excess consumption of sulphuric acid in the spinning bath, the excess sodium sulphate formed in the spinning process is crystallised and removed by filtration on a special rotary filter. The drum operates on about 5 in. Hg vacuum.

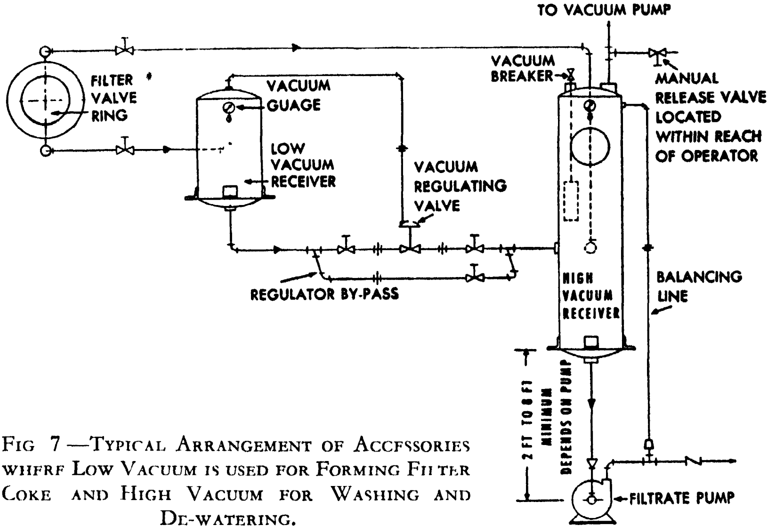


FIG 7.—TYPICAL ARRANGEMENT OF ACCESSORIES WHERE LOW VACUUM IS USED FOR FORMING FILTER COKE AND HIGH VACUUM FOR WASHING AND DE-WATERING.

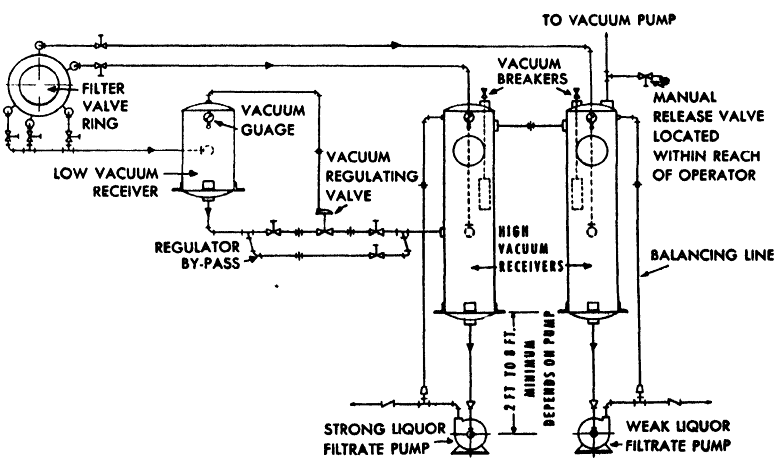


FIG. 8.—TYPICAL ARRANGEMENT OF ACCESSORIES WHERE LOW VACUUM IS USED FOR FORMING FILTER COKE, AND HIGH VACUUM FOR WASHING, DE-WATERING AND SEPARATION OF WEAK AND STRONG LIQUIDS

TABLE II

Material	*Suitable for Temp. °C.*	*Suitable for Liquors*
COTTON . .	90° C. Max.	Volatile organic acids
WOOL . .	80° C. Max.	Dilute acids
NYLON . .	Up to 150° C.	Alkalis and organic solvents Petroleum Products
TERYLENE . .	Up to 100° C.	Acids. Common organic solvents
GLASS FIBRE .	Up to 250° C.	Concentrated hot acids
DYNEL . .	Up to 110° C.	Both acids and alkalis. Solvents. Petroleum Products
ORLON . .	Over 150° C.	Hydrochloric, Nitric Chromic, Oxalic Acids and Petrolem Products
VINYON . .	Up to 110° C.	Similar to Dynel
WOVEN METALS .	Nickel, Stainless Steel, Monel, Hastelloy. (No temperature limits)	Suitable for various liquors as determined by normal chemical engineering experience

Filter Aids and Filter Cloths

A number of filtration problems, hitherto unsuccessfully dealt with by rotary vacuum filters, have now yielded to treatment by the addition of a suitable filter aid to the mother liquors. This is usually diatomaceous earth and, by this means, a suitable cake is obtainable on the drum.

It is necessary for the operator and designer to investigate the relative values of different cloths, and a brief list is given in Table II to show respective uses.

SECTION 10

TYPES OF COMMERCIAL FILTERS

THE METAFILTRATION PROCESS

By J. A. PICKARD

THE Metafiltration process was first introduced in 1928. It has very wide fields of application in the filtration of any liquids from which the removal of very fine suspended matter is required. It is possible to remove particles down to 1 micron ($\frac{1}{25000}$ in.) in a practical manner. Metafiltration is, therefore, applicable to such diverse needs as sterilisation, the filtration of varnish, conferring brilliancy on beverages, reclaiming lubricating oil, and preserving the efficiency of electro-plating baths.

Basic Principles

The basis of the Metafiltration process is the filtration of liquids through very fine filter beds carried on the surface of edge filters. The edge filter itself is built up from a number of Metafilter rings as illustrated in Fig. 1. These rings are $\frac{7}{8}$ in. outside diameter, $\frac{5}{8}$ in. inside diameter, and $\frac{1}{30}$ in. thick. The lower side of each ring is flat and the upper side is provided with scallop-shaped raised parts which are usually 0·003 in. above the general level of the upper surface. When these rings are piled one on top of another all the same way up, they form what is in effect a very strong metal pipe provided with very fine circumferential slits. This assemblage is mounted on a fluted drainage rod, as shown

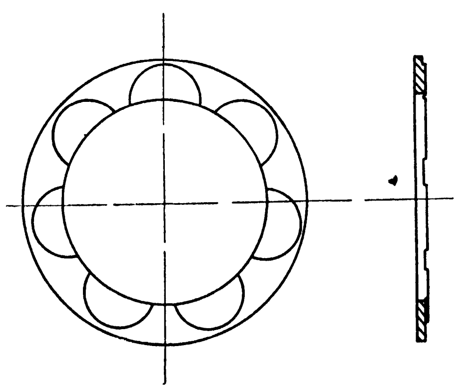


FIG. 1—SECTIONAL VIEW OF FILTER RING.

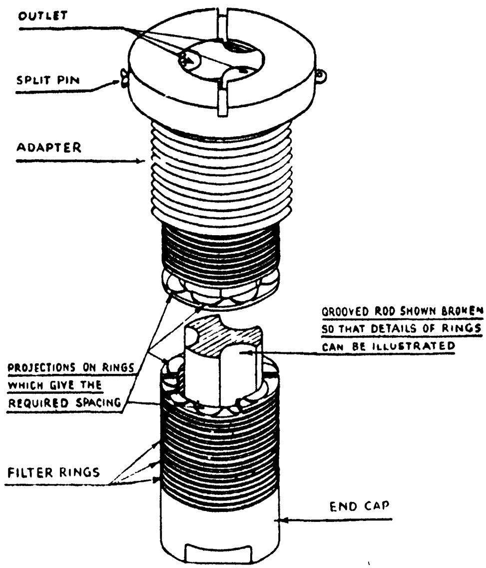


FIG. 2.—METAFILTER ASSEMBLY.

in Fig. 2, where the rings are held in close contact by screwing down the cap.

An important feature is that the area of the scallops which support the tightening pressure is great enough to prevent any flattening out, so that the edges of the rings are always 0·003 in. apart and the overall porosity of the column is maintained.

Filter Powder

The filter beds, which are laid down on this strong foundation, are powders, of which a great many different varieties are available and applicable to different needs. The wide choice of filtering materials available makes the process extremely flexible and enables it to be employed for a multiplicity of uses.

A Metafilter pack with a filter bed upon it is shown in Fig. 3. The method of depositing the filter bed is to suspend the desired filtering medium in some of the liquid to be filtered, and then to pump the mixture into the body of the filter in which the filter pack is fitted. The liquid finds it way between the rings, and away by means of the drainage flute, but the powder is strained out and forms on the surface a very compact but highly porous bed. The liquid to be filtered is subsequently passed through and the clear filtrate collected.

The final step which makes the Metafilter highly practical and convenient in use is the cleaning. This is accomplished merely by reverse flow without opening the filter. This detaches the filter bed and the collected dirt from the packs as shown, which leaves the filter by a sludge door at the bottom of the body and all is then ready for a new run. Some 10 or 15 minutes

TABLE I

TYPES AND APPLICATIONS OF "METASIL" FILTER AIDS

Variety of Metasil	*Size of Smallest Particles Normally Removed*	*Applications*
'A' Plus	25 microns (·001 inch)	Clarification of coarse suspensions
'A'	10 ,, (·0004 ,,)	Production of brilliant filtrates in syrups, beer, vegetable oils. Chemical manufacture
'B'	4 ,, (·00016 ,,)	Vinegar. Sterilisation
'C'	1 ,, (·00004 ,,)	Removal of colloids. Ultra-filtration
'ALAG'	2 ,, (·00008 ,,)	Drinking water
'FER'	5 ,, (·0002 ,,)	Removal of iron from drinking water
'AW'	2 ,, (·00008 ,,)	Transformer and Switch oil maintenance
'W'	1 ,, (·00004 ,,)	Decolorisation

are quite sufficient to clean and restart a Metafilter of any size.

Water Filtration

Metafiltration was employed for the purification of water for military requirements in the late war. Filters of 100 to 10,000 g.p.h. are available and Fig. 4 shows a 5,000 g.p.h. model.

The construction of the filter is shown in Fig. 5. The body of the filter is cylindrical with a conical end leading down to the sludge door. The upper end is closed by a division plate in which the Metafilter packs are mounted and the filter is completed by a domed head. The outlet pipe takes the water from a level close to the upper surface of the division plate and the remainder of the head constitutes an air chamber. This is standard design and provides for extremely efficient cleaning by the following means.

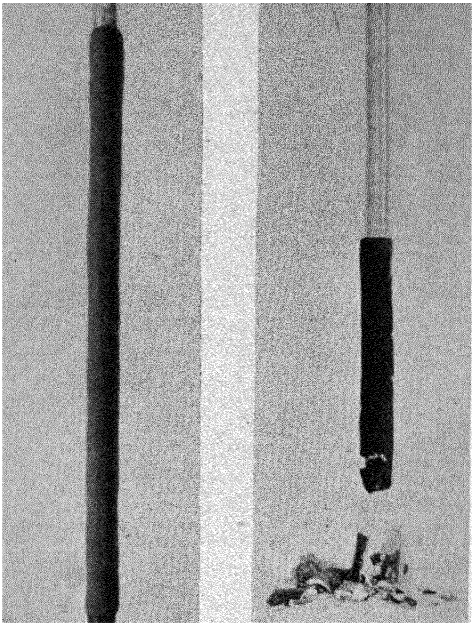


FIG. 3.—METAFILTER PACK WITH FILTER BED IN PLACE AND WITH BED DETACHED WHEN CLEANING

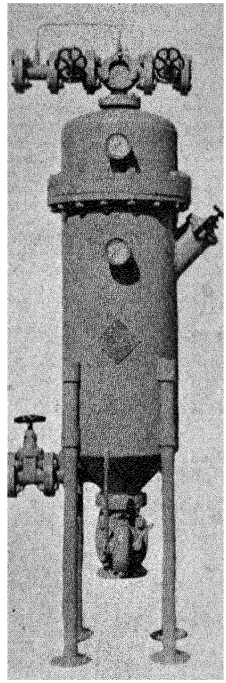


FIG. 4.—FILTER FOR WATER PURIFICATION.
Capacity 5,000 g p.h.

When the filtration is over the outlet is closed but pumping is continued, thus forcing water into the head, where it mounts until the pressure in the head is the same as in the body. Should the pressure mount to 100 p.s.i. the head will then be about seven-eighths full of water with a cushion of compressed air above it. On stopping pumping and suddenly opening a drain valve from the body, the whole of this water is discharged with great velocity backwards through the packs whence it instantly removes the bed and dirt, and carries all away to the drain outlet.

According to the degree of purification required, different qualities of filtering powder (Metasil) are used. A perfectly bright clear filtrate is produced with an open free-flowing variety, which also removes the bulk of any bacteria or pathogenic organisms. If sterilisation is needed a finer grade is used and the flow through the filter is somewhat reduced.

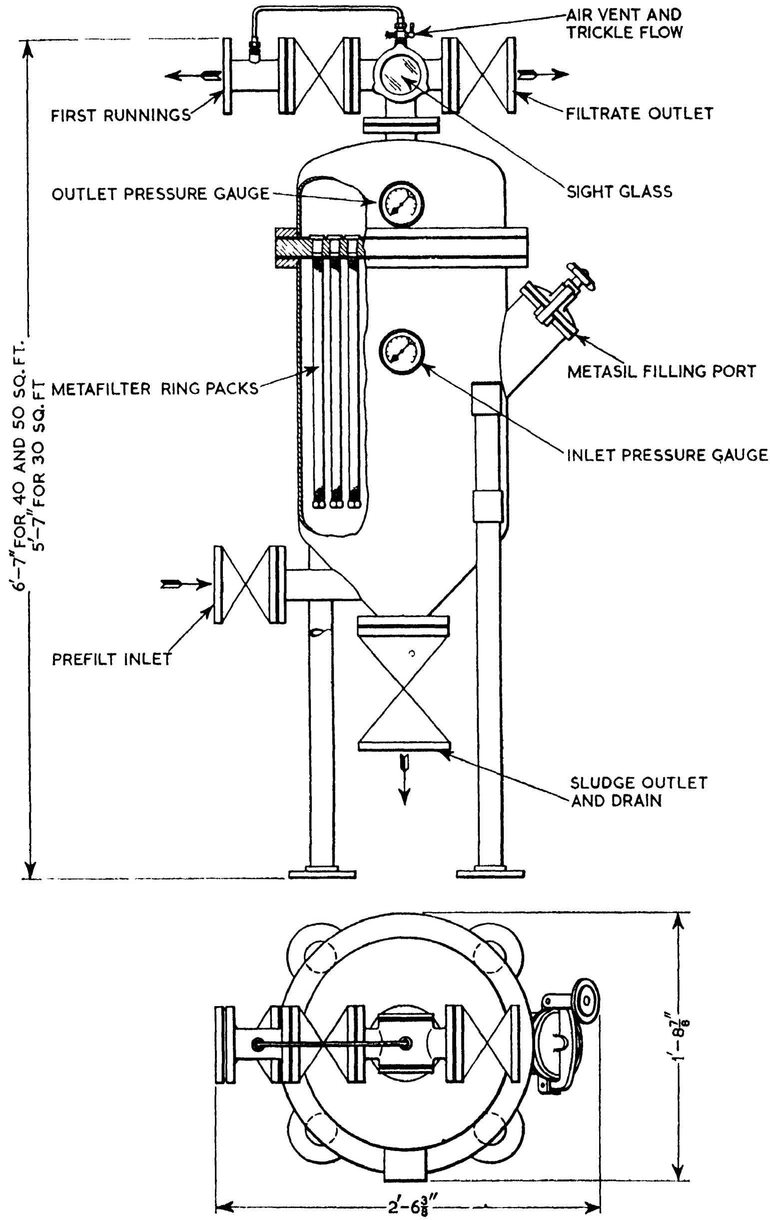
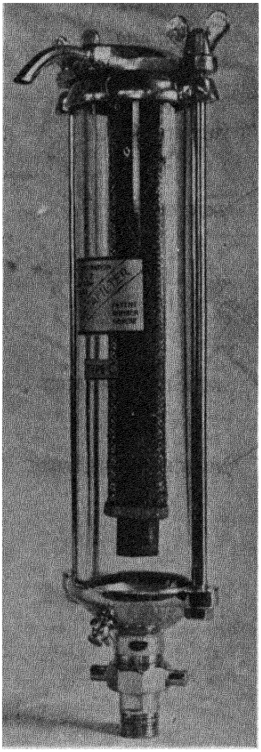


FIG 5.—SECTIONAL VIEW OF THE METAFILTER.



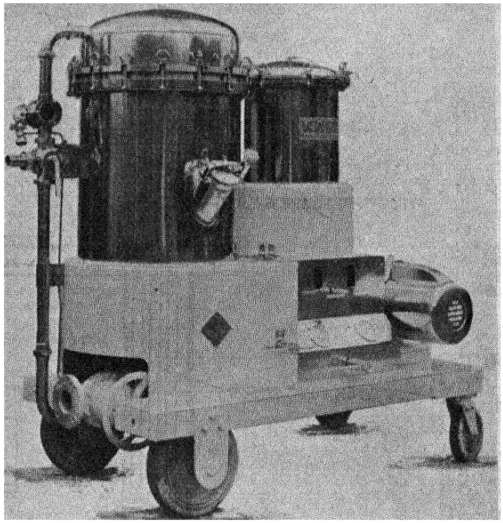


FIG 6 (*left*)—SMALL WATER PURIFYING FILTER FOR DOMESTIC USE.

FIG. 7 (*above*).—PORTABLE FILTER FOR USE IN BREWERIES.

For household use a small model as shown in Fig. 6, somewhat different in construction, is widely used in tropical countries and the Commonwealth.

Beer Filtration

Metafilters can be used for all the filtrations needed in a brewery—roughing, polishing, sterilizing, and recovery of waste. Standard sizes deal with anything up to 2 barrels a minute and a typical filter, built entirely in stainless steel, is shown in Fig. 7.

A special feature which may be used in conjunction with any filter from which the maximum quantity of filtrate possible is required is the Injector. This is shown in Fig. 8 and its function is to introduce into the liquid as it flows to the filter body an extra quantity of Metasil.

The injector consists of a chamber containing Metasil, with a

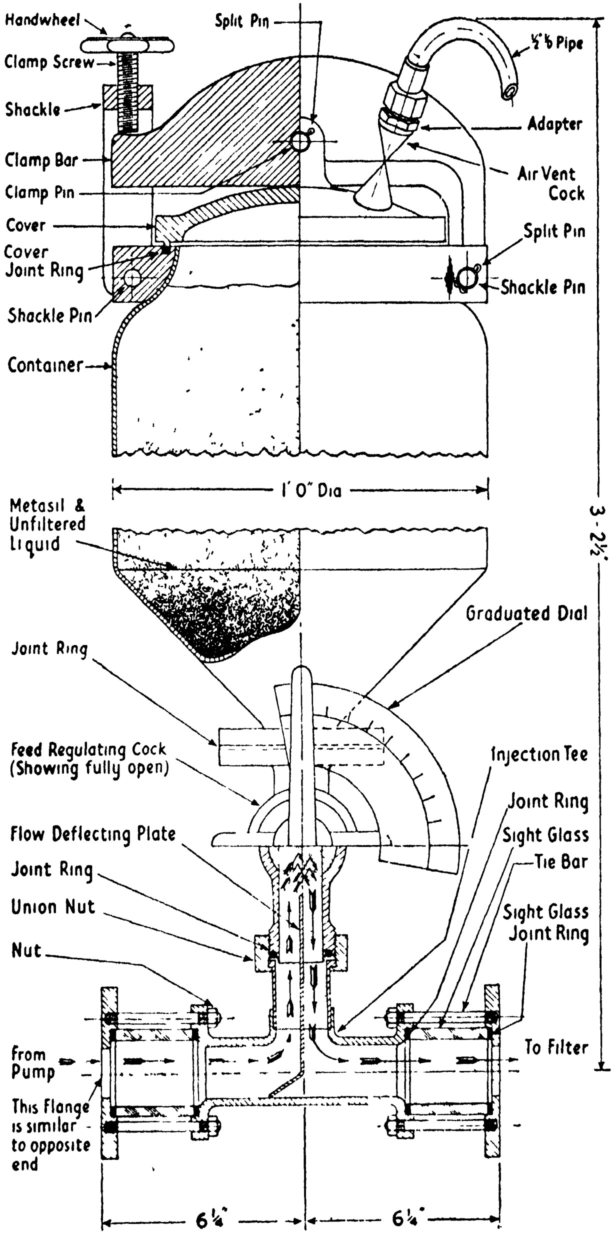


FIG. 8.—THE INJECTOR UNIT FOR GIVING THE MAXIMUM QUANTITY OF FILTRATE.

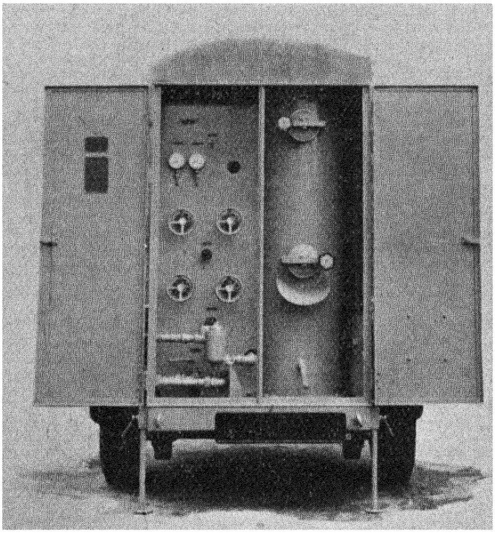


FIG. 9.—PORTABLE TRANSFORMER OIL FILTRATION PLANT
Output 300 g p h.

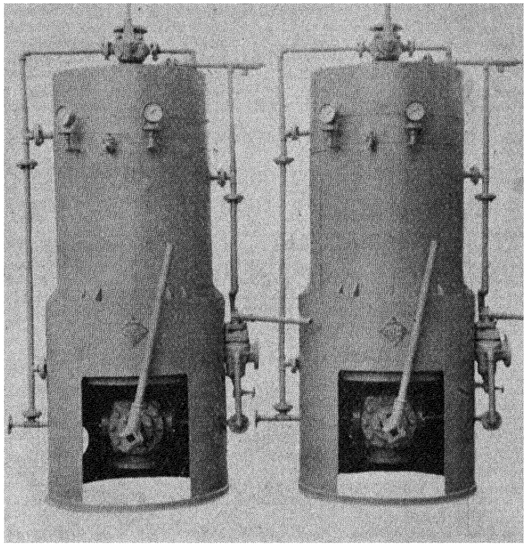
cock at the bottom. It is mounted on the vertical limb of a tee, the side branches containing sight glasses. The powder settles to the bottom of the chamber and the liquid, caused by a division to flow up one side and down the other of the tee, impinges on the lower surface of the cock. As this is opened more or less a larger or smaller surface of settled Metasil is exposed to the washing action of the liquid, and is borne into the current. One sight glass shows the condition of the raw liquid before filtering, and the other permits the amount of Metasil added to be judged and the setting of the cock arranged accordingly.

Transformer Oil

Metafilters are regulation equipment for the purification and preservation of transformer oil. They are employed to maintain the highest possible breakdown value of insulating oil contained in transformers and contact breakers in generating and transformer stations.

They are particularly suited for this duty, not only in view of the perfection of the filtration, which removes colloidal carbon, dissolved water, and other impurities, but because the filtration is conducted at atmospheric temperature. This avoids the necessity to employ heaters which are extremely wasteful in current and introduce a considerable fire risk. They may be

FIG. 10 —PLANT EMPLOYED FOR THE FILTRATION OF LIQUID SULPHUR



used in both stationary and portable forms. A portable plant with an output of 300 g.p.h. is shown in Fig. 9.

Chemical Manufacture

The Metafilter has much to recommend it in this field in view of the fact that it can be built in practically any metal. The solidity of the construction of the Metafilter packs, which provide the utmost fineness without corresponding weakness, and the absence of brazing, soldering, or welding which can promote corrosion, are most important points. In addition the fact that the filtering elements, should they become clogged through maltreatment or accident, can be effectively cleaned and restored to normal by dismantling, is a great point in their favour.

A special model indicating the wide range of their application is shown in Fig. 10 which is employed for the filtration of liquid sulphur. As will be seen this filter is steam jacketed in every part to maintain the sulphur in a liquid condition. It is built entirely in stainless steel and the steps in its operation are the same as in the case of more straightforward filtrations.

The absence of perishable material such as paper or cloth is important, and Metafilters will stand up to the corrosive action of nitric and sulphuric acids, the strongest alkalis, and very high temperatures. They are in fact employed to filter molten caustic soda. Where volatile or poisonous liquids are concerned the totally enclosed form of the filter enables it to be used without inconvenience. It can be used under pressures up to 1 ton per sq. in., and probably more if required.

Space cannot be found to mention all the applications but the following is a list of some liquids dealt with commercially.

Cutting Oil	Sugar Syrup
Essential Oils	Varnishes
Linseed Oil	Ascorbic Acid
Lubricating Oil	Cod Oil
Petrol	Liver Extract
Whale Oil	Oxymel of Squills
Fats	Saline Solutions
Glucose	Serum
Honey	Rose-Hip Syrup
Lysol	Beer
Lacquers	Cider
Plating Solutions	Vinegar
Soap Solutions	Whisky and Wines

Filter Pockets

Metafilters are also made in the form of filtering pockets. These are formed of two circles of special filtering paper enclosing a thin metal extending and draining element. Mounted together on a drainage member they present a large filtering surface in a very small volume and are widely used in filters to deal with lubricating oil on internal combustion engines. They are usually mounted in association with the engine itself as a by-pass filter. They maintain the oil in the crankcase clear and transparent by removing all suspended carbon, water, and grit, by purely mechanical means. As they do not employ chemicals or adsorption they are equally satisfactory with detergent and straight mineral lubricating oils.

The Author is indebted to the Metafiltration Co., Ltd., for permission to reproduce the illustrations used in this subsection.

THE SWEETLAND PRESSURE FILTER

By A. G. E. JOYCE, M.I.CHEM.E.

This filter comes under the classification of batch-operating leaf filters of the type in which a pressure differential above that obtainable by vacuum suction is available. It possesses advantages compared to the conventional plate-and-frame press, namely quick discharge of the cake, absence of leakage, high washing efficiency and long cloth life. The maximum operating pressure of the standard machine is 50 p.s.i.g., which is sufficient for the majority of industrial products (pressures of 20–40 p.s.i.g. are quite usual).

The filter is unsuitable for rapidly segregating products and, whilst it is difficult to generalise in filtration, may be said to deal usually with comparatively slow-filtering finely-divided materials compared to products normally handled by rotary vacuum filters. Since the percentage suspended solids content of a slurry is a principal factor in its filtration rate, the Sweetland Filter may be said to be suitable for products of comparatively low solid content.

The design of the filter permits the use of a wide range of metals in its construction, so that most corrosive liquors, hot or cold, can be accommodated. This filter has become increasingly popular in many branches of industry during the past 20 years, including sugar refining and mineral and vegetable oil refining, besides countless chemical products.

Design and Operation

The filter (Fig. 11) comprises a cylindrical pressure shell mounted upon two stools, with its axis horizontally disposed. The leaves comprise cloth-covered flat discs fabricated from stout mesh with a peripheral rim and a pipe connection at the top by which they are suspended transversely within the filter shell at regular spacings. The shell is split axially and the lower half swings open, upon hinges arranged along one side, to expose the leaves for cake discharge. Internal spacer bars, running longitudinally along each side of the upper half of the shell locate the leaves parallel to each other and prevent them from rotating when external retaining cap-nuts are tightened on the pipe connections at the top of the shell.

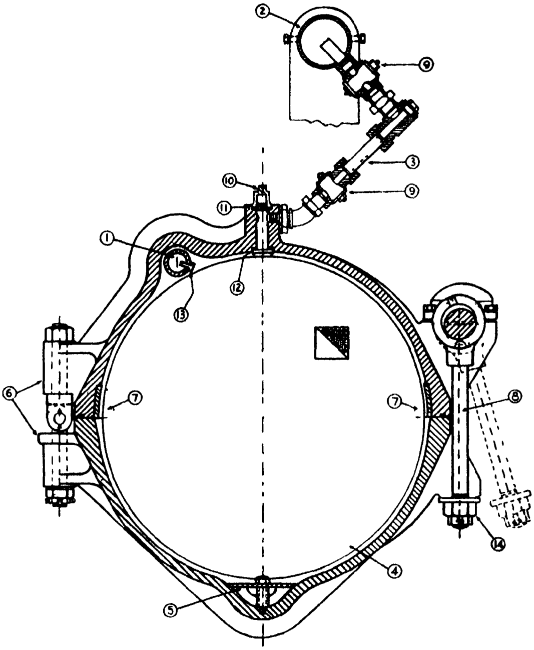


FIG 11 — CONSTRUCTION OF THE SWEETLAND PRESSURE FILTER

1. Internal manifold
2. Filtrate manifold
3. Sight glass
4. Filter leaf
5. Distributing plate
6. Hinge
7. Side leaf spacers
8. Swing bolt
9. Filtrate shut-off cock
10. Cap nut.
11. Lead washer
12. Rubber washer
13. Nozzle
14. Swing bolt castle nut

(*Dorr-Oliver Co, Ltd*)

The filtrate outlet connection from each leaf communicates with a separate sight glass, where the liquor flow can be observed. Cocks in the sight-glass fittings permit any leaf to be cut out, without interruption to the filter operation as a whole, in the event of cloudy flow due to a damaged cloth. All the sight glasses connect to a manifold pipe.

A pressure-tight joint is formed between the two halves of the shell by a square-section rubber gasket retained in a groove in the joint face of the upper half. This joint is secured by a quick-operating gear, comprising an eccentric shaft mounted upon the top half of the shell, with dependent "swing bolts" engaging with lugs on the lower half of the shell. The eccentric shaft is rotated by a geared handwheel (or a lever in the smaller sizes) and the swing bolts are thus caused either to engage the lugs, rise and pull up the joint or to lower and swing out from the lugs to free the lower half shell for opening.

Two arms carrying weights extend horizontally from the lower half shell to counterbalance its weight and assist opening and closing. In the larger sizes, an hydraulic cylinder is

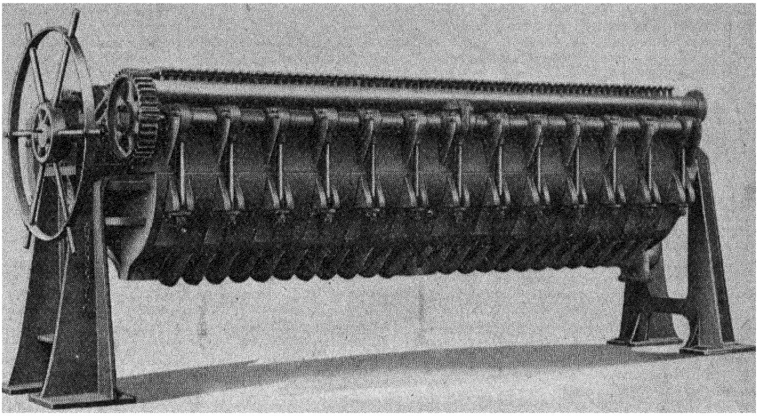


FIG. 12.—THE SWEETLAND PRESSURE FILTER IN CLOSED POSITION
(*Dorr Oliver Co., Ltd.*)

attached to one of the counterweight arms to replace the manual effort.

An internal sluicing mechanism, comprising a pipe with pressure-water nozzles, is installed longitudinally in the top of the shell in cases where wet cake discharge is required. This is notably the case when the leaves are precoated and the filtration involves a clarification in which only a very small amount of solid matter is filtered out of the liquor.

An external hand- or motor-operated ratchet gear is attached to this sluice pipe which gives to it both axial and lateral motion, so that the whole area of both sides of the leaves is effectively scoured by the water jets from the nozzles in the pipe.

Leaves are of two types, namely "upper drainage" and "lower drainage." The former are generally employed where a high moisture-content cake can be tolerated or where sluicing discharge is used: the latter (which include an internal drainage tube down the centre of the leaf, with bottom inlet for the liquor) are invariably used where the cake is air-blown before being discharged after opening the filter. The cloth covering on both sides of the leaves usually comprises a bag enveloping the leaf, but an alternative leaf design provides a rim with a circular dove-tailed groove in each face into which separate discs of cloth are caulked; this type of rim construction is used in particular

TABLE II. FILTER-LEAF SPACINGS FOR SWEETLAND PRESSURE FILTERS

Filter Nos.	Inside dia. (ins.)	Inside length (ins.)	Filter Leaf Spacing: 2 in.			3 in.			4 in.		
			Number of leaves	Filter area (sq ft.)	Nominal cake capacity cu. ft. ½ in. thick	Number of leaves	Filter area (sq ft.)	Nominal cake capacity cu. ft. 1 in. thick	Number of leaves	Filter area (sq ft.)	Nominal cake capacity cu ft. 1½ in. thick
1A	16	11	5	13	0·52	3	7·8	0·63	2	5·2	0·66
2	16	36½	18	47	1·9	12	31	2·5	9	24	3·0
5	25	61	30	196	8 1	20	131	10·9	15	98	12·2
7	25	82	41	268	11·1	27	177	14·7	20	131	16·3
10	31	109	54	546	22·7	36	364	30·3	27	273	34·1
12	37	145	72	1,044	43·5	48	695	57·9	36	522	65·2

for the attachment of woven wire cloths when such cloths are preferable to textiles.

Construction

In the standard machines the filter shell is of cast-iron construction of robust proportions and appropriately ribbed to ensure a rigid construction, especially necessary since the shell is split for opening. Other metals employed are cast bronze, stainless-steels, cast-iron lined with stainless-steel, monel, lead and other metal sheeting. The filter shell is also, when required, fabricated in plate.

The leaf frames and liquor outlet fittings are obtainable in a variety of metals such as mild steel, stainless steel, bronze and monel.

Determination of Filter Size

It will be noted that Table II shows leaf spacings at 2, 3 and 4 in. centres available with the various filter sizes. This variety of leaf spacing is a principal feature of the Sweetland pressure filter. Unlike the conventional plate-and-frame press, there is no space to be completely filled with cake; the slurry is pumped into the shell, completely submerging the leaves on both sides of which the cakes form, while the filtered liquor passes into the leaf interiors and is discharged through the top pipe connections, sight glasses and manifold.

As is well known, the filtration characteristics of different products vary enormously and the filtration rate of any product decreases as the cake forms. It is evident, therefore, that a particular optimum economic cake thickness applies to every product, beyond which it is better to discharge the filter and commence a fresh cycle than to continue building up the cake.

Unless the filter is to be installed in a process in which its use is already established, laboratory tests are necessary to determine the optimum cake thickness and thereby the leaf spacing. The tests will also include an investigation of washing and air-blowing, where these services are required. Thus, a complete cycle time will be established, governed by the particular characteristics of the product in question and the demands of the process. Such tests are, of course, required in the determination of other types of filters. In the case of the Sweetland, the phases of the cycle

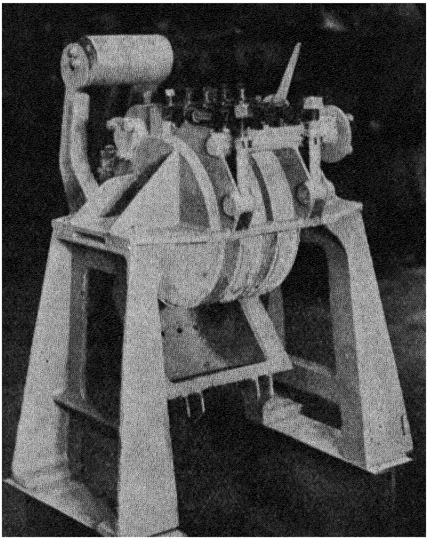


FIG. 13.—SMALL UNIT FOR PILOT PLANT WORK
(*Dorr-Oliver Co., Ltd*)

to be determined will, for example, comprise: filling the filter body, cake forming, draining slurry, washing, draining surplus wash liquor, air-blowing, draining dregs and cake discharging.

This cycle will, of course, be independent of the size of filter to be used. A capacity figure of dry weight of solids (or volume of liquor) per sq. ft. per total cycle time, in conjunction with a cake thickness and a given leaf spacing, will be obtained by the test; and from this the area of the full-scale filter can be calculated. Of course, some adjustment of cake thickness or leaf spacing may be necessary in order to employ a standard size of filter and the required data is given by a filtration curve (liquor through-put/time) drawn during the test.

The leaf spacing selected provides for the thickness of adjacent cakes, the leaf thickness and a space to permit of easy discharge, the latter being generally $\frac{1}{2}$–$\frac{3}{4}$ in. Thus, for example, it will be noted from the Table on page 154 that $1\frac{1}{2}$ in. cakes are associated with 4 in. centres leaf spacing. The majority of products fall within the range of leaf spacings given in the tabulation, but wider spacing, such as 6 in. or more, is occasionally required.

Cake discharge in the normal case is by reverse air-blow via the filtered liquor manifold. This causes the cloths to distend and the cakes to fall *en masse*.

Advantages

The advantages of the Sweetland pressure filter may be summarised as follows:

(i) Saving of labour, secured by the short time required to discharge the cake.

(ii) Economy in filter area, achieved by the short time occupied by cake discharge (compared to a plate-and-frame press) whereby a much larger proportion of the total cycle time is usefully employed.

(iii) High washing efficiency, due to the cakes being submerged in the wash liquor. A high degree of displacement washing is achieved, whereby the liquor strength is maintained with consequent evaporator economy (in appropriate cases) or high recovery of mother liquor.

(iv) Particular suitability for volatile products. In the common plate-and-frame press, in which the cloths are pinched between the plates, evaporation of liquor may occur through the cloth thickness. The one joint in the Sweetland filter is leak-proof.

(v) Long cloth life, since the cloths are not pinched as between the plates of an ordinary press.

(vi) Consistent results within a fairly wide range of batch size variations, since there is no space to be completely filled with cake, as in the ordinary plate-and-frame press. Thus considerable variation in cake thickness from batch to batch can be tolerated.

(vii) A totally closed circuit in the filtration step with, if desired, automatic lifting of the filtered liquor (so long as the head is reasonable compared to the filtration pressure).

THE STELLAR FILTER

The Stellar filter is designed to work with a deposited filter bed and to discharge the used filter bed without dismantling. It makes use of diatomite (kieselguhr) as the filtering medium and is specially suited to those applications which require fine filtration. As is usual with filters using diatomite, the filter bed or pre-coat is formed from a suspension of the powder in liquid deposited on a series of foundations or elements in the form of strainers as the liquid passes through.

The ideal foundation for a filter bed is a rigid strainer which offers as little resistance as possible to the flow of liquid in either direction and does not have large opposed surfaces at the point

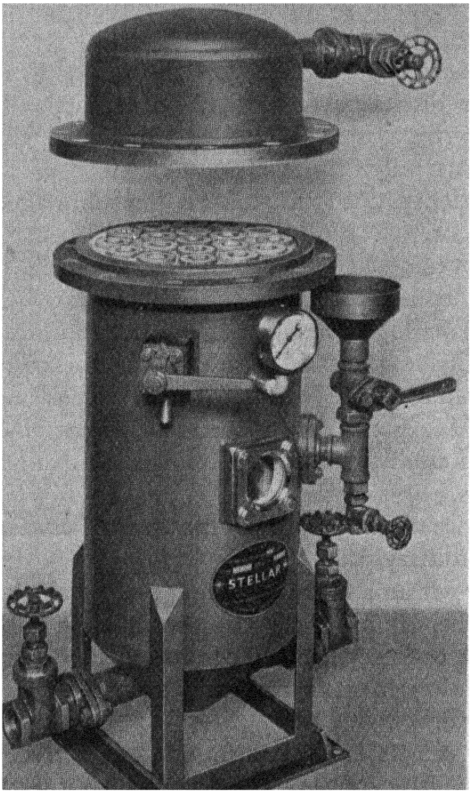


FIG. 14.—STELLAR FILTER WITH PATENT AUTOPACT CLEANING DEVICE. EXPLODED VIEW SHOWING DIAPHRAGM PLATE.
(The Paterson Engineering Co., Ltd)

where the gap is at its smallest, avoiding the consequent choking due to adherent deposits of slime or scale.

Construction

The filter element consists of a tube with equally spaced longitudinal ribs having a screw thread cut along the entire length, providing on each rib a series of grooves in which the consecutive turns of wire wound on the ribs is firmly located. The pitch of the helix is slightly greater than the diameter of the wire and the difference provides the free openings for the liquid to pass through the filter support. By this construction the openings over the whole area of the element are of regular size and the result is a rigid element with the shortest possible flow and the minimum gap, fulfilling the ideal conditions mentioned above. The regularity of the openings ensures an even coating of filter aid with no break which would permit unfiltered liquid to by-pass and ensures absolutely uniform filtration over the whole surface of the element.

A number of these elements are fixed to a rigid diaphragm plate separating the filter body from the filter head or outlet manifold. The usual form of construction is that the elements stand down from the plate vertically and the bed is formed by passing a liquid with kieselguhr in suspension through the filter. The kieselguhr is strained out, forming a complete cylindrical coating on the elements of a fine and uniform filter bed.

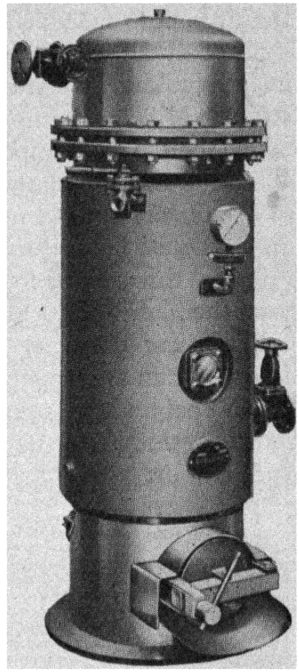


FIG 15 —STEAM JACKETTED STELLAR FILTER.
For use with resins, varnishes, etc
(*The Paterson Engineering Co , Ltd*)

Self-contained Cleaning System

Normally filters of the leaf type or plate and frame presses are dismantled for cleaning. With other candle-type filters when cleaning is required a flow of liquid is forced through the elements in the reverse direction and dislodges the filter bed and dirt which falls to the base of the filter body clear of the elements and can be removed by washing out or scraping out as may be applicable to the particular design. In the Stellar filter, however, the cleaning arrangements are such that the used filter bed is discharged from the elements by a self-contained arrangement, the patented Autopact cleaning system, and in all cases cleaning is effected in a very short time, involving a minimum of labour. This method uses a minimum of liquid and provides a self-contained arrangement whilst at the same time far more effective cleaning is obtained than by ordinary backwashing.

The Autopact feature is achieved by constructing the filter so as to have air spaces both in the filter head and the filter body;

the air in both spaces is compressed by the entering liquid against a closed outlet valve until a desired pressure is reached, when the inlet valve can also be closed. It will be apparent that if the air release valve on the filter body is opened suddenly the air contained therein will escape almost instantly, destroying the balanced condition and having the effect that liquid in the head is subjected to a suddenly applied pressure equivalent to an explosion which drives liquid back through the elements at a very high initial velocity, throwing off the bed and dirt. This discharge of air from the filter body is all important.

Filters for water and for liquids which cannot be discharged down a drain are usually required to be of the sludge-door type which enables the body liquid to be drained off, leaving fairly compact sludge to be removed through the quick opening sludge door.

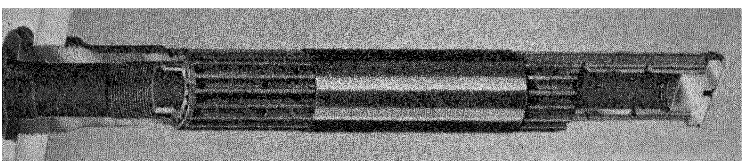


FIG. 16 CUTAWAY SECTION OF FILTER ELEMENT SHOWING WIRE WOUND CONSTRUCTION.
(The Paterson Engineering Co, Ltd)

Materials Used for Construction

As regards materials of construction, filter shells for general purposes with aqueous liquids are made of mild steel and lined when necessary with a hard plastic enamel. For foodstuffs and corrosive conditions stainless steel is used. The filter elements for water, oils and non-corrosive liquids are made with extruded brass tubular cores, electro tinned and wound with either monel or stainless steel wire. They can, however, be made with mild steel cores wound with stainless steel wire, ebonite cores wound with stainless steel wire, or stainless steel cores and winding throughout.

Where it is imperative that the residual liquid must be conserved, special arrangements can be made according to the

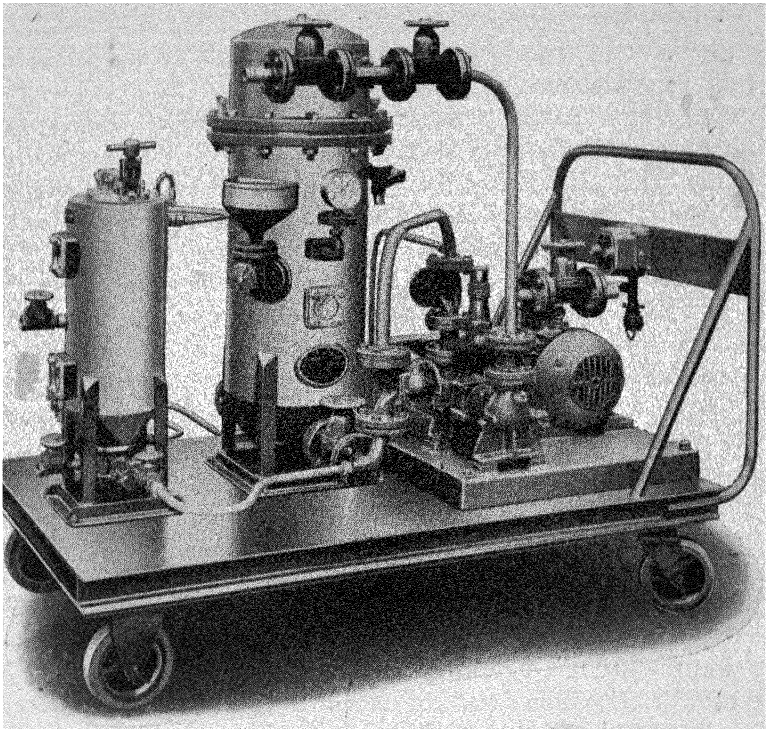


FIG. 17 —PORTABLE STELLAR FILTER FOR FRUIT JUICES, SYRUPS, ETC.
(The Paterson Engineering Co , Ltd)

nature of the application—siphon-type elements, a reversible filter on trunnions or a separate small filter for dealing with the contents of the main filter.

Filter Aids

The filtration of liquids containing other than a small amount of suspended matter, is usually facilitated by the use of filter aid as a continuous addition throughout filtration. This addition of filter aid inhibits the formation of a skin of dirt on the pre-coat and by the deposition of further porous material continuously maintains an open filter bed throughout the run. The Stellar Jet Filtraider enables this filter aid to be introduced proportionately into the stream of liquid immediately before the filter and the abrasive diatomite does not pass through the pump.

Applications

Some of the many applications of the Stellar filter for industrial purposes are given below.

WATER.—The Stellar filter is, of course, widely known as a filter for small water supplies on Army water-tank trucks and the trailer-mounted water purification sets, 3,000 g.p.h. In industry the Stellar filter can be used wherever a particularly fine filtration is required, e.g. to remove from a mains water adventitious matter picked up in pipes as for the aerated water trade, for photographic washing and for any other purposes where fine particles would be detrimental. A considerable reduction in bacteriological content of a contaminated water can also be achieved. The Stellar filter has also been very widely used in the recirculating filtration system for swimming pools where it has found favour because of the compactness of its installation, as it requires only approximately one-third of the space occupied by a normal sand filtration plant.

SYRUPS.—Syrups used in the manufacture of drinks and fruit juices can be filtered, removing suspended matter and organisms likely to cause fermentation.

FRUIT JUICES.—Filtration of bacteria and organisms likely to cause deterioration and fermentation, often preventing the products from becoming completely useless.

BEER, CIDER, WINES, VINEGAR.—All these liquids can be filtered through Stellar filters, removing all the products of fermentation, yeast cells, etc., so that a sterile product suitable for bottling is obtained without affecting the taste. The filter is a closed system and can be worked so that the liquid is always under pressure for dealing with carbonated liquids.

VARNISHES.—The filter has proved to be well suited for dealing with varnish and resin solutions. The ease of handling and cleaning makes it particularly attractive.

USED INSULATING OIL.—The sludge and moisture with which oil used in a transformer becomes contaminated can be filtered without the necessity for heating the oil before filtration. The oil is restored to a high dielectric strength. If the oil is cleaned at regular intervals the deposits of sludge and impurities are removed as they are formed and the rate of increase of acidity is retarded.

Lubricating Oils.—Fine filtration of rolling-mill oils producing highly finished aluminium plate and stainless steel strip. In these systems the oil is continuously re-circulated and by by-passing a suitable quantity through a system of Stellar filters the level of contamination in the main bulk of oil is kept to a very low figure.

Chemical Solutions.—Stellar filters are used in the production of fine chemicals. They are also used in the production of insulin and other injection solutions which must be completely free from suspended matter.

Vegetable Oils.—The final filtration of edible oils after catalyst hardening for the final brightening and removal of traces of nickel.

THE STREAM-LINE FILTER

By A. BEALE, M.I.Mech.E., M.I.N.A.

The Stream-Line filter falls into the general class of filters in which solid impurities are held back at the filtering surface instead of being trapped in the depths of a filter bed. In appearance it is not unlike an edge-type strainer, in which thin metal discs spaced a few thousandths of an inch apart make up a medium which holds back coarse impurities at the edges while allowing liquid and finer solid particles to go through. The materials and construction used in the Stream-Line filter, however, ensure that every trace of solid impurity is removed at the paper edges.

Discs of specially prepared and impregnated paper are mounted on rods passing through concentric holes within the discs, and are compressed together endwise by spring loading. Nothing is used to hold the papers apart, and the passages between them are infinitesimally small. With suitable end compression it may be ensured that any known particle can be removed, and there is no penetration whatever into the packs. The perfect cleanliness of the filtered liquid thus obtained is only one of the two great features of the principle, the other being that as all the impurities collect *outside* the medium they can be removed completely by a brief reverse flow either of compressed air or of filtered liquid. Thus the medium is cleanable and needs to be

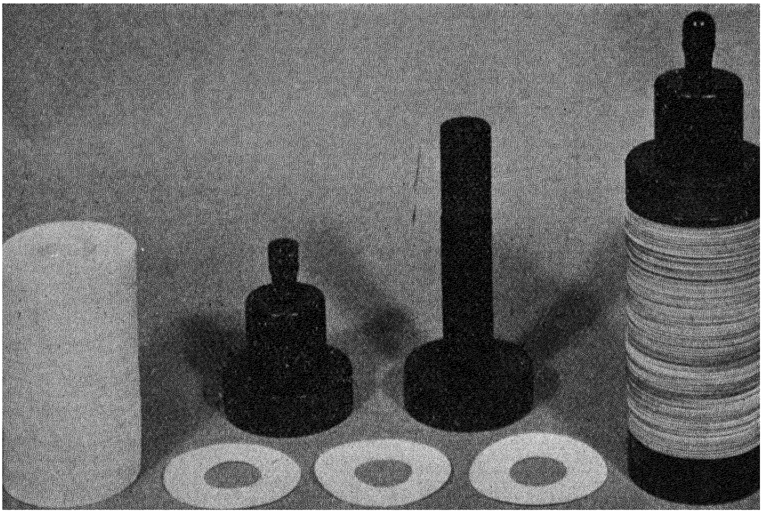


FIG. 18.—LABORATORY MODEL OF STREAM-LINE FILTER

renewed only when "worn out" by prolonged use, which in commercial applications proves to be once in from one year to twenty years.

Laboratory Models

A description of laboratory models serves also to illustrate the basic construction. Fig. 18 shows an inexpensive type in ebonite in which the end compression is applied by screwing up by hand. Of this it may be said that better results can be obtained in commercial installations, making use of spring loading. Fig. 21 shows a laboratory model with spring loading, such as is recommended for any precision tests. Fig. 19 shows how either of these is used in the laboratory, and Fig. 20 shows what happens when cleaning by reversal is carried out.

The foregoing models operate by applying suction to the filter, which is immersed in an open beaker. Fig. 22 shows a type with the filter unit itself enclosed so that it can be operated if preferred by applying pressure to the unfiltered liquid.

These laboratory models are useful both for cleaning up small batches of liquid required for laboratory purposes, and for checking the possibilities of larger scale operations. It is noteworthy that it is possible to proceed with confidence direct from

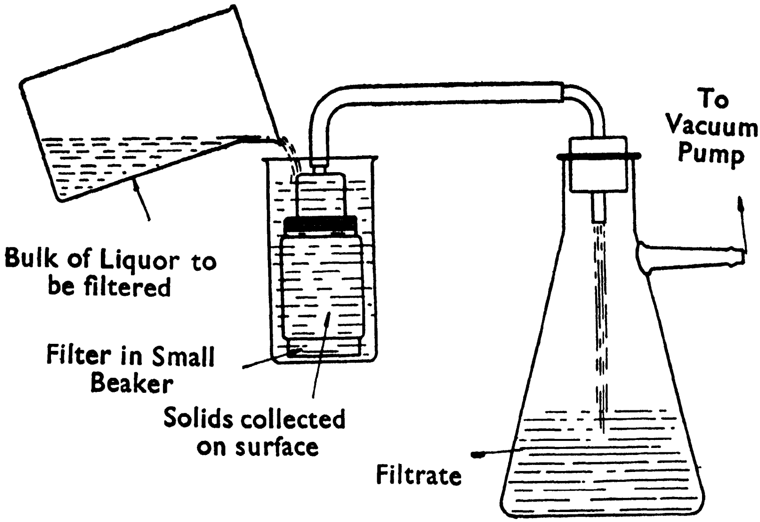


FIG. 19.—APPLICATIONS OF FILTER FOR LABORATORY USE.

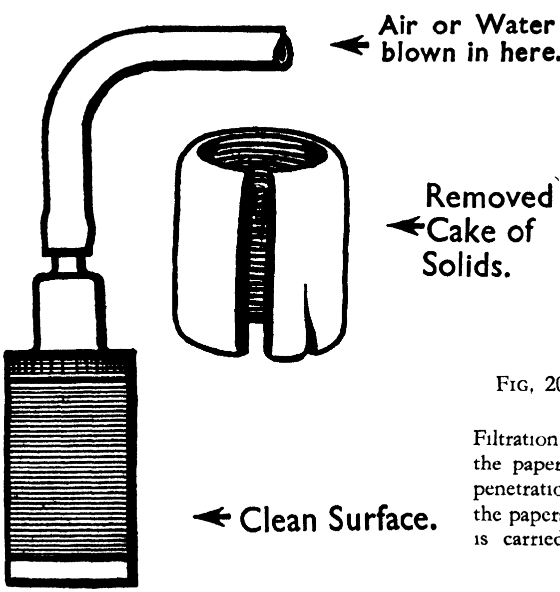


FIG. 20.—CLEANING THE FILTER.

Filtration takes place entirely at the paper edge. There is no penetration of solids between the papers and hence cleaning is carried out by reversal.

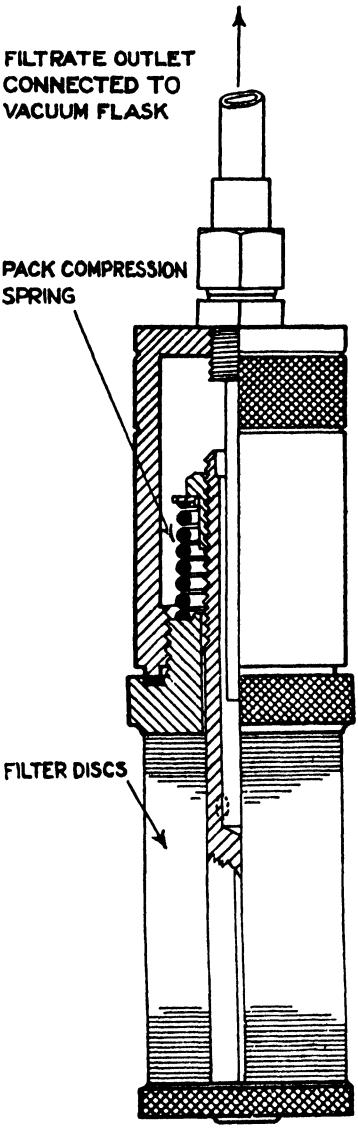


FIG. 21.—SPRING-LOADED VACUUM LABORATORY UNIT.

the laboratory to the commercial scale. Filter discs of the same dimensions are used for almost all applications. The laboratory filter may have, say, 3 in. run of discs on a single column. The commercial filter will consist of a multiplicity of columns of greater length, but its performance will be strictly pro rata. A commercial filter with 91 columns each 36 in. long will give $91 \times 36/3 = 1{,}092$ times the output of a 3 in. laboratory pack, and precisely the same quality of filtration. Incidentally, a commercial filter of this size contains about 800,000 discs. The flow through a Stream-Line filter is the summation of the very small flows between each pair of a very large number of discs.

Spheres of Application

For laboratory scale work, where the cost of renewing the pack is not an important consideration, the Stream-Line filter has innumerable applications, and its suitability should be investigated wherever it is important to secure absolutely clean filtrate from the very outset.

For larger scale applications, the following considerations are to be borne in mind:

1. The rate of flow is necessarily low compared with

that through a less efficient medium, so that its application is limited to the cleaning of intrinsically valuable liquids at moderate through-puts. From a few gallons a day of used lubricating oil up to a few tons *per minute* of

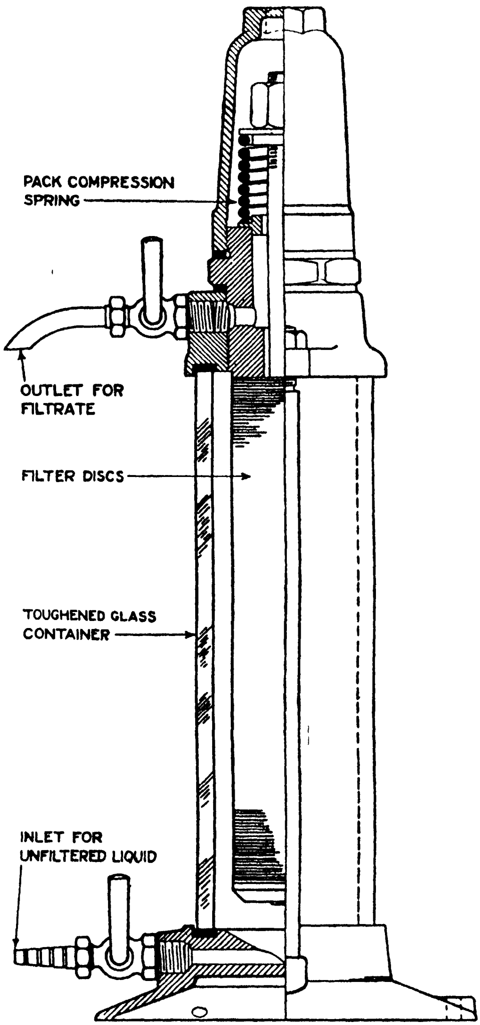


FIG. 22.—CONSTRUCTIONAL VIEW OF FILTER.

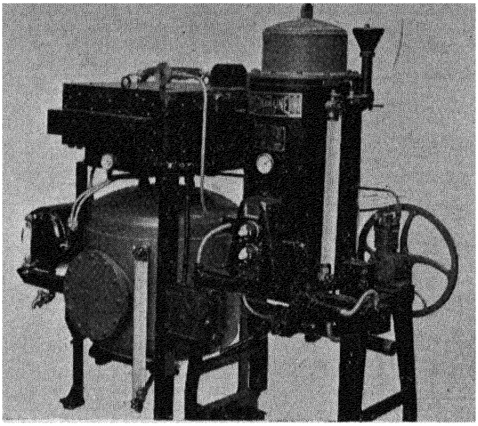


FIG 23 —STREAM-LINE FILTER WITH ELIMINATOR FOR VOLATILE PRODUCTS
(*Stream Line Filters Ltd*

gasoline are the limits for single commercial units in common use.

2. The medium used will give a long life when dealing with oils of all descriptions, but applications to aqueous liquids are limited and call for individual investigation.
3. The percentage of solid impurity handled with facility by this means is relatively small. Coarse or easily-settled impurities should be eliminated before filtration.

Methods of Application

The Stream-Line filter can be arranged to clean dirty liquids by batch treatment or by circulation on by-pass. As absolute cleanliness of filtration is assured from first to last, this filter is particularly useful when the object is to transfer a liquid from a contaminated source to a clean receiver, because there is no danger of in any way contaminating the clean receiver.

On the other hand, if circumstances dictate that cleaning of the liquid should be done by circulation the fact that the liquid leaving the filter is absolutely clean minimises the period for which circulation is necessary in order to bring the whole quantity up to a satisfactory standard.

Actual passage through the filter requires a pressure difference which can be produced by the application of either vacuum or pressure, and standard models are available in both forms. The

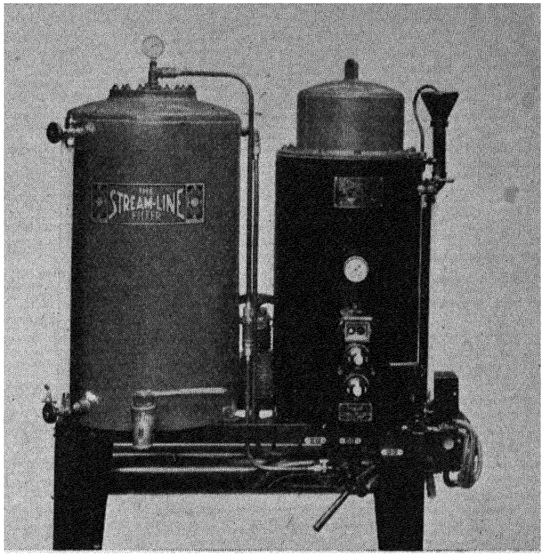


FIG 24.—TYPE 019 FILTER FOR DEALING WITH OIL FROM A FLEET OF 50–100 VEHICLES
(*Stream-Line Filters, Ltd*)

filter pack in a heated filter working under vacuum is self-drying, so that oils containing a trace of moisture can be filtered and dried by such a filter.

Applications in the Chemical Industry

INDUSTRIAL CHEMISTRY.—The following are some of the classes of product for which the Stream-Line filter is used

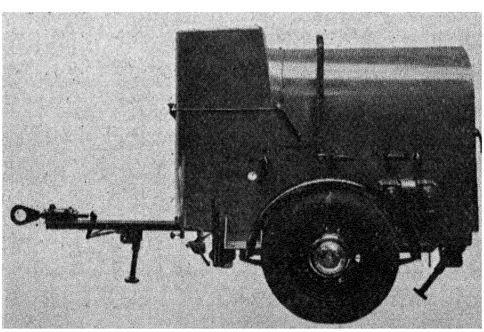


FIG. 25.—MOBILE FILTER FOR INSULATING OIL.
(*Stream-Line Filters, Ltd*)

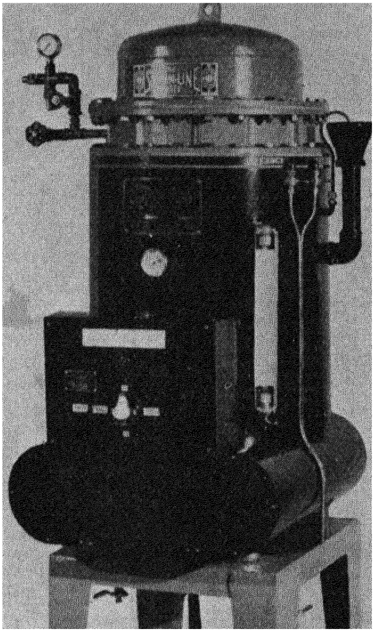


FIG. 26.—FILTER FOR ATTACHMENT TO A 1,200 b.h.p. DIESEL ENGINE.
(*Stream-Line Filters Ltd.*)

commercially by the chemist, either for basic cleaning or for providing a final polish before marketing:

Edible Oils
Cosmetics and Perfumes
De-icing fluids
Disinfectants
Light Fuel Oils
Insulating Oils
Impregnating Oils and Waxes
Gases so highly compressed that the volumetric rate of flow required is not prohibitive.

ENGINEERING ANCILLARY TO CHEMICAL PRODUCTION.—Chemical works, like any others, afford scope for Stream-Line filters in the following ways:

Lubricating oils for diesel engines, turbines, and road transport can be kept clean with negligible cost.

Insulating oils in works transformers and switchgear can be cleaned and dried periodically so that risk of breakdown is eliminated. This can be particularly helpful also in small high voltage equipment used, for instance, in X-ray installations.

Hydraulic oils used in presses and machinery can be kept clean with economy in oil cost and increased reliability in the operation of controls.

Machine oils, cutting oils, fuels and indeed all grades of oil used in the factory can with advantage be rendered absolutely clean before use or re-use.

Typical Installations

A filter used for pressure filtration of oil where heating is required is illustrated in Fig. 26. The actual model shown is an electrically heated type for attachment to a 1.200 b.h.p. diesel engine.

Fig. 24 shows a vacuum operated filter used for dealing with lubricating oil in batches. The model illustrated would be suitable for a fleet of 50 to 100 vehicles.

Fig. 23 shows an elaboration of the type shown in Fig. 24 with means for eliminating volatile products by heating under vacuum after filtration.

A fully mobile insulating oil filter suitable for towing from one transformer station to another is illustrated in Fig. 25. This filter removes moisture and dissolved gases by heating under vacuum, and is suitable also for dealing with turbine oil.

THE WATER-JET FILTER PUMP

By R. H. MORRIS

This type of pump is extremely useful when a moderate vacuum is required and the installation cost must be low. It finds its greatest use in assisting laboratory filtrations but there are many other possible applications when its vacuum of 10–15 mms. of mercury can be utilised.

The classic material of construction of the pump is glass, which is well able to resist the corrosive solutions which may be filtered in the laboratory. However, glass is fragile and there is difficulty in maintaining the exact sizes and relationship of the jet and Venturi required for the highest performance. This led to the introduction of pumps made from metal, in which the

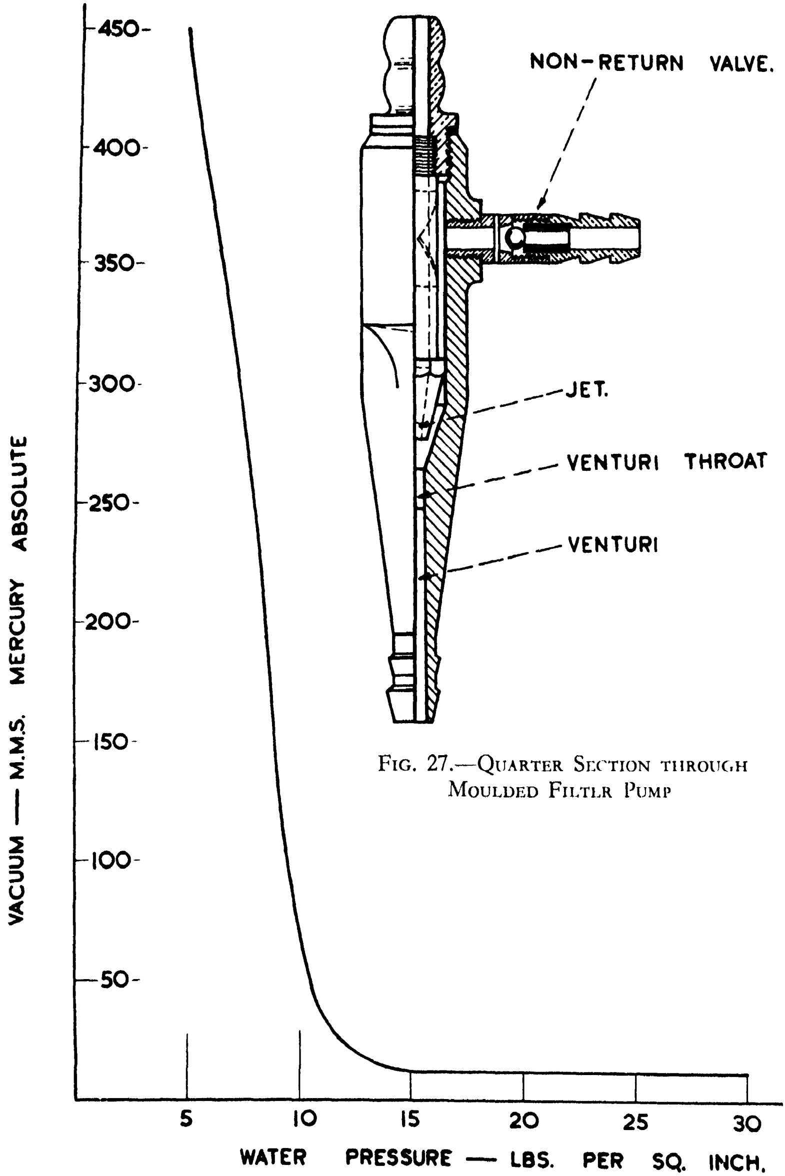


Fig. 27.—Quarter Section through Moulded Filter Pump

Fig. 28.—Performance Curve of Filter pump.

optimum dimensions can be held within close limits. The latest development is the introduction of pumps moulded from resistant thermosetting resins, and which combine to a large extent the corrosion resistance of glass with the reproducibility of metal parts.

Operation

Fig. 27 shows diagrammatically the typical arrangement of such a pump. Water from the mains enters down the central tube and emerges from the jet at a high speed—about 90–100 ft. per sec. Air in the immediate neighbourhood of the water stream is caught up and entrained in it, so that there is a continual removal of the air from the interior of the pump and, via the side nozzle, from any vessel to which it is connected. The angle of the Venturi is proportioned to ensure that the Venturi throat is the region of lowest pressure and that there is an increase in pressure towards the end of the pump which communicates with the atmosphere. Removal of air from the vessel connected to the pump implies a falling pressure in the vessel if this is otherwise sealed. If the pump is working efficiently the pressure will fall until it is roughly equal to the saturated vapour pressure of water at the temperature of the water jet. The pressure cannot fall below this value, and the water-jet pump vacuum is limited to the following values which give round figures for the vapour pressure of water at the stated temperature.

5° C.	10° C.	15° C.	20° C.	25° C.	
7	9	13	18	24	mms. of mercury

In practice the measured value will usually be found to be a few millimetres higher owing to small leakages which are almost inevitable under the usual laboratory conditions of use.

The vacuum obtained will not reach these values unless the mains water pressure exceeds a certain minimum value. Fig. 28 shows a typical performance curve for an efficient pump, from which it will be seen that the vacuum obtained falls away very rapidly below certain values of mains water pressure.

Non-Return Valve

Fluctuations in mains water pressure below this critical value after a good vacuum has been obtained can lead to "sucking back," in which case mains water will be carried through into

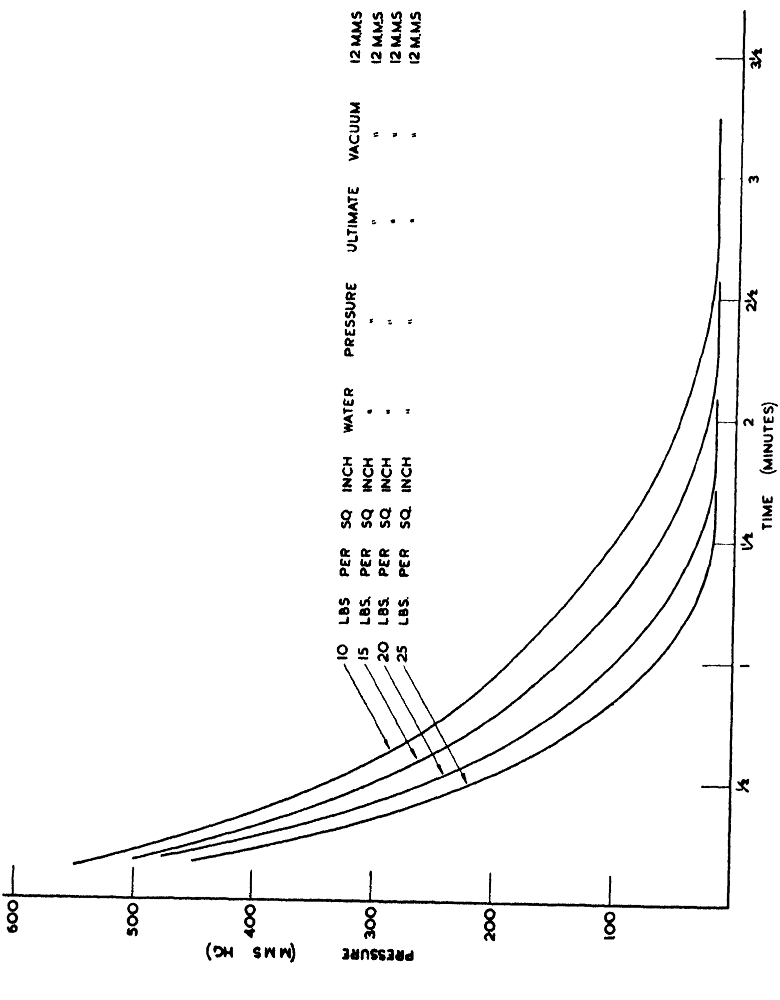


Fig. 29 — Pumping Speed of Filter Pump.

the filter flask. To guard against dilution and contamination of the filtrate a safety vessel is often introduced between the pump and the filter flask to receive any water sucked back. Unfortunately, the safety vessel must be fairly large (about as big as the filter flask) and this leads to serious loss in pumping speed. A simpler method of preventing sucking back is to introduce a valve in the side nozzle of the pump, arranged to seal off the vacuum space as soon as the water pressure falls. Such a valve must be simple and not affect the pumping speed; it must also be made from chemically resistant materials. A small ball valve, the ball being made from glass or other inert material, answers the requirements very well, and such valves are now fitted to a number of makes of pump.

There is an additional advantage of the non-return valve. After full vacuum has been obtained quickly with the water flowing at full pressure, the flow may then be reduced to a value which will just maintain the vacuum. Occasional variations in the water pressure will be unimportant if the pump is fitted with a suitable valve, and there will be a considerable reduction in water consumption compared with that of a pump without valve which must be kept working continuously at high water pressure.

Effects of Increase of Water Pressure

Apart from difficulties which might arise from suck-back, low water pressures are also associated with low pumping speeds. Fig. 29 shows the effect of increase of water pressure on the pumping speeds of a typical filter pump. Surprising increases in effective pumping speed can be produced by keeping the sizes of the filter vessels to a minimum, and by using relatively wide bore tube in short lengths for all connections.

Although the water-jet pump can be a very efficient device in its own sphere, it is rather wasteful of water. A typical pump consumes about 100 g.p.h., and in a large laboratory where many pumps might be left running for long periods the actual cost of the water consumed can be quite high. Alternative vacuum arrangements should be made for such laboratories.

It is interesting to note that most proprietary filter pumps will also operate, with varying degrees of effectiveness, from a compressed air line. This is to be regarded as an emergency procedure, for the air consumption is high.

Some water supply authorities impose restrictions on the use of water-jet filter pumps, to provide against the extremely remote contingency of a filtrate being sucked back into the water mains. Confirmation of any local restrictions should therefore be obtained before any scheme involving a large number of pumps is decided upon.

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SECTION 11

ATOMISERS AND ATOMISING

By N. M. WATSON

ATOMISING of fluids plays an increasingly important part in industry and agriculture. The wide variety of fluids and conditions met with in both of the above fields, but more particularly in industry, makes necessary a large variety of spray nozzles and other devices to produce the multifarious spray characteristics required.

During recent years much work has been done and detailed information obtained on the design and performance of atomisers. Most of this work has been done by various research workers, each operating within a range of experimental conditions relevant to his particular investigation. The result is that though the basic mechanism of disintegration of a liquid jet is understood in a general way, so many variables are involved that the influence of each is difficult to estimate, for example, at very low velocities individual drops can be formed at an orifice (of say a laboratory tap), see Fig. 1. These drops are formed under the influence of gravity. When the tap is turned on further, i.e. the velocity is increased, the liquid is discharged as a continuous jet for quite a distance, whereupon its surface becomes irregular due to varying air disturbances which cause the "solid" jet to "neck down" and break up into droplets. At high velocities therefore, the effect of air resistance becomes most important. We thus have a group of forces operating in the high-velocity jet; on the one side the forces of surface tension and viscosity tending to hold the jet together, and on the other side the forces of turbulent flow and air pressures tending to break up the jet. This is the simplest type of atomiser. This type of atomiser finds wide but exclusive use in diesel nozzle manufacture where a high penetration of spray is of vital importance.

By far the greatest demand for atomisers is for those types giving greater spatial distribution of the droplets, i.e. where the spray droplets are distributed as a cone or fan shape.

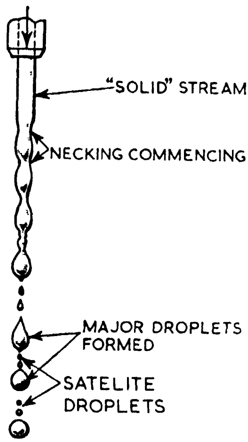

FIG. 1.—INDIVIDUAL DROPS MAY BE FORMED WHEN USING VERY LOW JET VELOCITIES

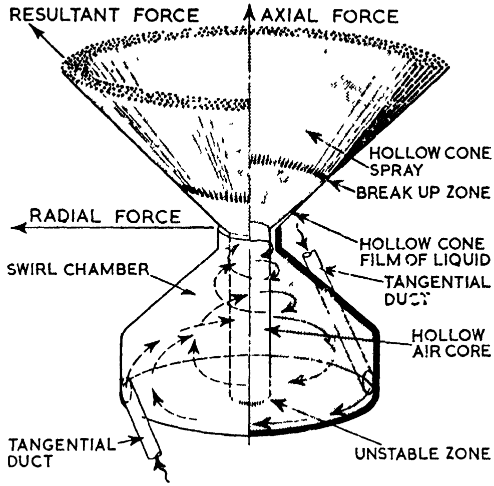

FIG. 2.—CONSTRUCTION OF SIMPLE SWIRL ATOMISER.

Cone Sprays

A cone-shaped distribution is produced by the simple expedient of causing the liquid to swirl or centrifuge within the nozzle prior to its leaving the orifice. Fig. 2 shows the essential features of a simple swirl atomiser. The liquid under pressure is fed tangentially into a circular swirl chamber via slots, ducts or channels and having entered at the periphery of the chamber, spins round rapidly, its angular velocity varying inversely as the radius of the vortex chamber. This implies an infinite velocity at the axis of the swirl chamber, but what in fact happens is that an air "core" is formed as shown.

The discharge orifice is usually much smaller in diameter than that of the swirl chamber. As more and more liquid enters the tangential passages the liquid already in the swirl chamber is forced forward to the orifice. This liquid is thus under the influence of two forces as it approaches the orifice.

1. The pressure force or axial velocity forcing the liquid along the axis of the chamber and
2. the centrifugal or spinning force tending to fling the liquid outwards radially.

The liquid leaves the orifice (not as a solid stream) but as a fast-spinning tube of liquid. Immediately this liquid is free of

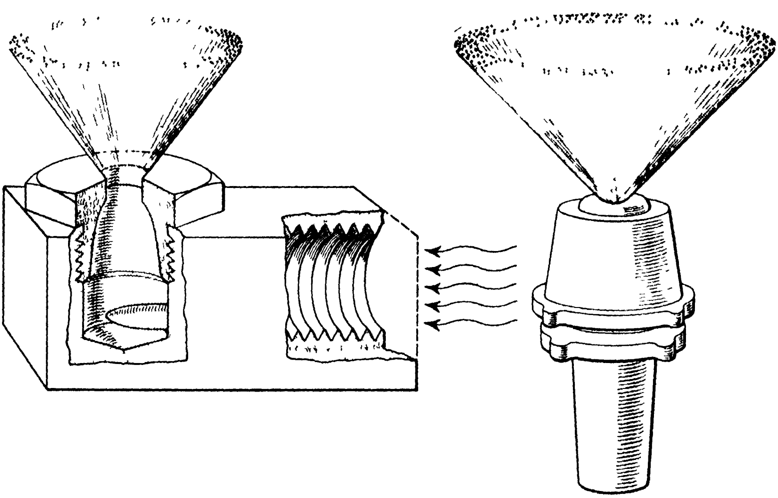

FIG. 3 (a) and (b) (*above*) —PRACTICAL NOZZLE DESIGNS OF HOLLOW CONE ATOMISERS.

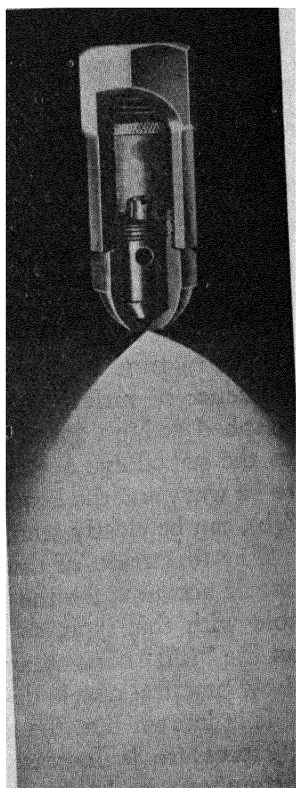

FIG 3 (c) (*right*) —FURTHER TYPE OF NOZZLE OF HOLLOW CONE ATOMISER SHOWING SPRAY CHARACTERISTIC

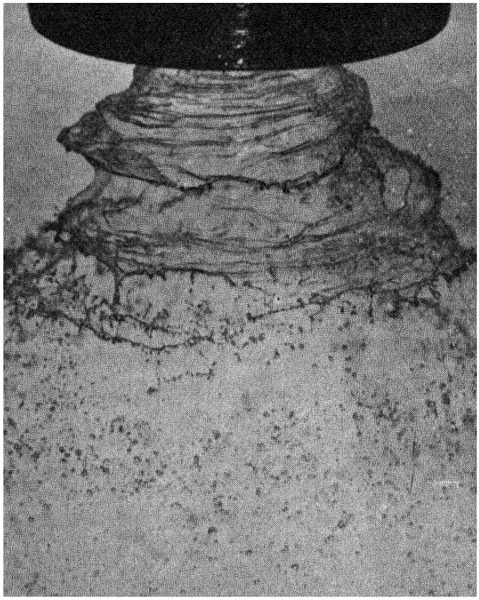

FIG. 4.—MAGNIFIED VIEW OF CONE SPRAY

the orifice wall it diverges conically into a rapidly thinning film. At a short distance from the orifice this liquid film cone breaks up due to its thinning down to a zone of instability. In this zone the film or sheet of liquid breaks up into strings or ligaments. These in turn break up into drops of varying size under the influence of surface tension. Fig. 4 shows a cone spray photographed at high speed and magnified. The cone sheet, which, to the naked eye appears smooth and perfectly conical, is seen to be wavy and the ligaments, with subsequent droplet formation, 3(b), can be clearly seen.

The formation of the air core in this hollow cone-type spray nozzle accounts for the low coefficient of discharge rate obtainable with this type, as distinct from the flow rates obtainable on the "full" cone-spray nozzles described later. Figs. 3(a) and show practical nozzle designs of hollow cone atomisers.

It is known that the air core tends to increase in diameter as the pressure is increased, and that it is substantially parallel throughout its length in the swirl chamber. The increase in diameter is limited by the viscose losses incurred by increasing the flow rate (increase of pressure). This often gives a slight reduction in spray angle at higher pressures, a phenomenon which can be quite puzzling at first sight. The angle of the spray cone is primarily governed by the ratio of the two forces acting on the liquid, axially and radially. These forces are, in turn, controlled by the nozzle ratio, a factor of great importance in good nozzle design. This ratio concerns the relationship of the internal dimensions to the orifice.

Full-Cone Nozzles

In a nozzle producing a "full" cone of spray, i.e. a spray characteristic in which the whole volume of the cone is filled with atomised droplets, the air core is replaced by a jet of liquid introduced axially through the back of the swirl chamber or nozzle core, Fig. 5(a). The diameter of this "lead hole" or "centre jet" is carefully determined in relation to the other internal dimensions of the nozzle to produce a flow of liquid

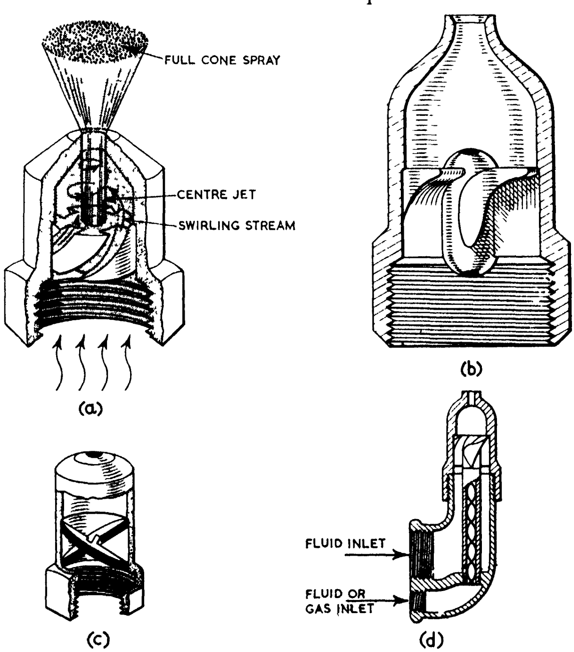

FIG. 5.—VARIOUS TYPES OF NOZZLE FOR PRODUCING FULL CONE SPRAY.

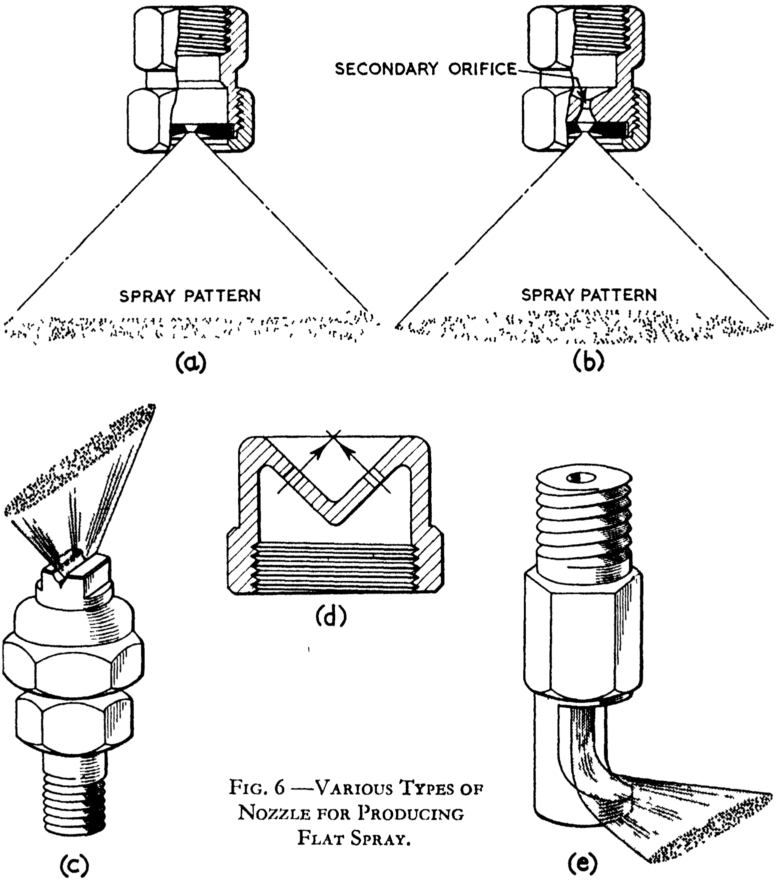

FIG. 6 —VARIOUS TYPES OF NOZZLE FOR PRODUCING FLAT SPRAY.

axially, such that the resultant spray density within the cone is as evenly distributed as possible.

A typical characteristic of the "full-cone" spray nozzle is the absence of the conical sheet or film at the orifice; the droplets seeming to form right at the orifice lip. The other distinguishing feature is the larger flow rate obtainable with a given orifice size and pressure than is the case with the "hollow-cone" atomiser nozzles. In most cases the flow of the full-cone nozzle is approximately twice that of an equivalent-sized hollow cone nozzle. Figs. 5(a), 5(b), 5(c), and 5(d) are practical designs of nozzles for producing full-cone spray characteristics. The type shown in Fig. 5(d) is designed to provide separate feed to the axial jet so that two liquids can be mixed intimately and sprayed simultaneously. The spray angle of a full-cone nozzle remains fairly constant over a wide pressure range. It is not always possible therefore, to obtain stock nozzles of a desired angle when both the through-put and pressure are fixed.

Flat-Spray Nozzles

The flat- or fan-shaped spray characteristic is not produced by swirl action but by the shape or contours made in the material of the nozzle just prior to and immediately beyond the actual orifice lip. Another method is to converge two "solid jets." Fig. 6(a) shows the type having a circular orifice with grooves milled at the back of the orifice and at the face. The particular contours and angular disposition of these two grooves produces the flat sheet of liquid which breaks up at some zone near the orifice into ligaments and thence to droplets. Unfortunately this type of flat-spray nozzle tends to produce sprays having heavy edges or "horns" as shown. These horns are particularly noticeable on low capacity wide-angle nozzles, and may comprise as much as one-half of the total through-put. This uneven distribution is a most undesirable feature, but it can be corrected by the insertion of a "plug" or alternatively a restricted orifice immediately at the back of the disc orifice as Fig. 6(b). The main feature of this nozzle design is the absence of "feather" or knife edges on the orifice lip, with consequent good wearing properties.

The second type of flat-spray nozzle is shown in Fig. 6(c). Here the orifice is elliptical by virtue of the contours machined in the nozzle immediately to the rear and to the face of the orifice. This type when accurately made gives very good spray distribution without the tendency to heavy ends. The spray pattern is elliptical as shown in Fig. 6(c), and to produce a "line" of spray of even density the spray patterns should overlap. The orifice lip on these nozzles must be fine-edged. This requirement makes the nozzle rather more susceptible to wear than the round orifice type. They do not require a plug or secondary orifice as when correctly designed and manufactured there are no heavy "horns" even with the low volume wide-angle nozzles. The absence of a plug or extra orifice provides greater freedom from blockage troubles.

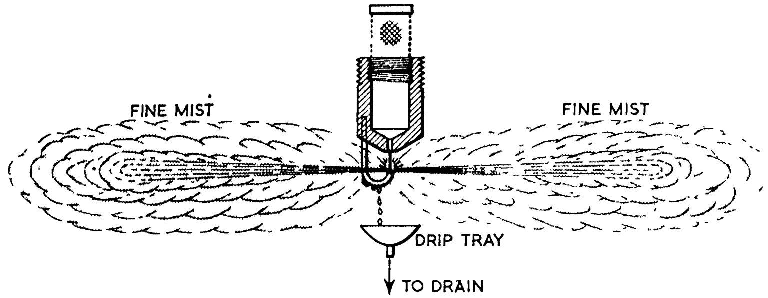

FIG 7.—IMPACT-TYPE NOZZLE

Impact Nozzles

The impinging jet type is shown in Fig. 6(d). The two streams of liquid are caused to hit each other a short distance from the nozzle and this results in a flat sheet being formed which in turn breaks down into droplets. The disadvantage of this type is that two orifices are required having full bore characteristics. Thus for a given volume of sprayed liquid, the holes must be quite small in diameter compared to the other types of nozzles. This necessitates accurate alignment and increases the blockage risk. The only favourable feature would be the resistance to wear due to the plain cylindrical shape of the orifices. If one orifice blocks however, the nozzle projects one solid stream of water, no fan spray being produced.

Impact types of nozzles Fig. 7 sometimes use one or more "solid" streams of liquid striking on a surface or another similar stream of liquid. By suitably positioning and shaping the impact surface a very fine atomisation can be obtained for a given pressure. In other cases the impact surface is designed to give a coarse break-up as in the sprinkler heads used for fire protection and flooding nozzles as Fig. 6(e). The fine atomisation type is sometimes used for humidifying work. It is important, however, to arrange for the large droplets, which collect on the support holding the impact plate, to be collected and drained away.

Rotating Nozzles

Rotating nozzles, or spinning-disc atomisers, provide yet another method of atomising fluids. They are essentially a spinning disc or cup into the centre of which liquid is caused to flow. The high speed of rotation of the cup or disc imparts a high radial velocity to the liquid, thus the spray produced is in all directions but in one plane at right angles to the axis of the disc or cup. This can be quite a disadvantage in certain cases, e.g. spray drying where large diameter drying chambers are required to accommodate the spray particles. Various types of disc shapes, some with vanes are used.

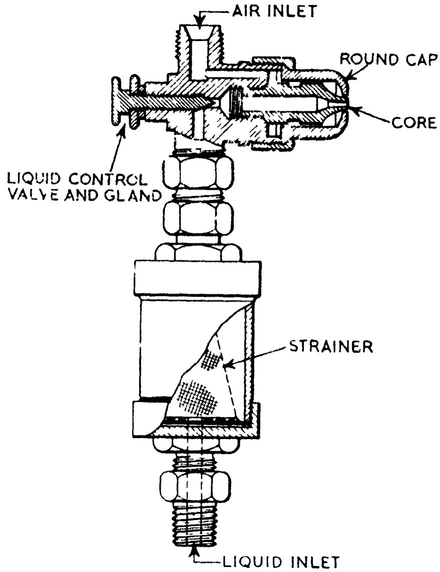

FIG 8—HUMIDIFYING SPRAY HEAD

The spinning-disc type atomiser is particularly useful for spraying viscose liquids, slurries and suspensions where the ordinary pressure-jet nozzle might tend to block. Disc speeds vary from a few hundred to several thousand r.p.m., depending on the particular application. The quantity of material sprayed can vary from zero to full flow, but the size of droplets would vary. The smallest size drops are produced by high speeds and low feed rates. Generally speaking, more power is consumed by rotating atomisers for a given through-put than is the case for pressure nozzles.

The rotating atomisers are used for very finely atomising small quantities of water for humidity work, spray drying of various materials, and in some oil burners. The rotating nozzle is usually rather expensive and is not used where pressure nozzles would meet the need.

Gas Atomising Nozzles

In this type of nozzle the atomisation of the liquid is achieved by impingement of a high-velocity air, gas or steam supply across an orifice to which liquid has been caused to flow. Common examples are fly sprayers, scent sprays, etc. In these cases the liquid is sucked into the air stream and this powerful stream tears the liquid into ligaments and breaks these into very fine drops. The relationship between the air or gas orifice and the liquid orifice varies with the design of nozzle and in many cases they are concentric.

Fig. 8 shows a humidifying spray head. The cap and centre core can be supplied with several different orifice sizes giving a range of flow from zero to 10 g.p.h. with an air pressure of say 50 p.s.i.g. This type of spray head will operate at lower air pressures (5 p.s.i.g.) with low viscosity liquids. The atomisation produced by this type of nozzle can be exceedingly fine. This is necessary where high humidities are required to be maintained without droplet deposition.

Air-atomising nozzles are used for paint spraying, insecticide spraying, oil burning, spray drying, etc.

Spray Particle Sizes

Various methods are available for measuring the type of atomisation of a given spray. Use has been made of glass microscope slides on to which small glass rings (cut from a glass tube) have been cemented. These cells have been half filled with castor oil when used for testing water sprays. This oil is immiscible with water but has a density such that droplets of water falling into the oil are just submerged below the surface of the oil. They retain a spherical shape and do not evaporate before measurement can be made.

The slides are placed beneath the nozzle and covered over with a strip of metal. The spray is started and allowed to settle down to steady conditions when the covering strip is removed for an interval of time to suit the spray rate and distance from nozzle. It is essential that the number of drops allowed to fall into the cells be limited by the "exposure" given, so as not to risk coalescence of the drops within the oil medium. By disposing a series of slides across the diameter of the spray cone, an analysis can be built up of the particle sizes in relation to the cross sectional area.

The droplets are measured in microns ($\frac{1}{1000}$ millimetre) and it is often found that considerable range of drop sizes occurs.

In one test they varied from 30–430 microns. In this case the greatest *number* of drops occurred at a group diameter of 30 microns but the maximum *volume* was found at about 130 microns. The question of the particle size analysis of sprays may not be of great importance in some fields of commercial nozzle application, but it is of very great importance in certain directions, e.g. the development of fuel-oil burner nozzles, fuel injection nozzles, insecticide spray nozzles, humidifying nozzles.

Author's Acknowledgement

Acknowledgements are due to The Shell Petroleum Co., Ltd., for permission to use Fig. 4 and certain information from a Technical Report; Mr. J. R. Joyce for helpful discussions and information; and Messrs. H. T. Watson, Ltd., for permission to publish the diagrams used in the article and the photograph used in Fig. 3(b).

SECTION 12

KARBATE IMPERVIOUS GRAPHITE PIPES, PIPE FITTINGS AND VALVES

KARBATE impervious Graphite pipes have the properties common with all Karbate equipment, in that they are resistant to the chemical attack of almost all corrosive liquors and gases. They are highly resistant to thermal shock, whilst the coefficient of thermal expansion is only about 20–25 per cent that of most steels, but the coefficient of thermal conductivity is much higher. Other advantages are, that they are light to handle compared to their physical strength, easily cut to length and can be threaded on site when installing pipe work.

The following table gives the range of Karbate pipe sizes which are normally processed in this country, although larger sizes can be produced.

Pipe Size	*Nominal I D Inches*	*Nominal O D Inches*	*Maximum Length Feet*	*Average Weight in lb per foot*		*Circumference*		*Area of Cross Section*	
				Carbon and Graphite	*"Karbate"*	*Outer Feet*	*Inner Feet*	*O D Sq. ft*	*I D Sq. ft.*
1	1	1½	9	0·66	0·74	0·393	0·262	·01227	·00545
1¼	1¼	2	9	0·97	1·1	0·524	0·393	·0218	·01227
2	2	2⅝	9	1·5	1·7	0·687	0·524	·0376	·0218
2½	2½	3	9	1·8	2·0	0·785	0·622	·0491	·0308
3	3	4	9	4·8	5·4	1·047	0·785	·0873	·0491
4	4	5¼	9	7·2	8·1	1·374	1·047	·1503	·0873

The maximum pressures for which pipes should be used are 75 p.s.i. for hydrostatic uses, and 50 p.s.i. when used for steam. The pipes are extruded and processed in such a manner that they are strong, and the above figures offer a considerable factor of safety, and whilst it is recommended that every care must be taken against subjecting the pipes to mechanical shock, surges of pressure up to two or three times these figures are not likely to cause failure.

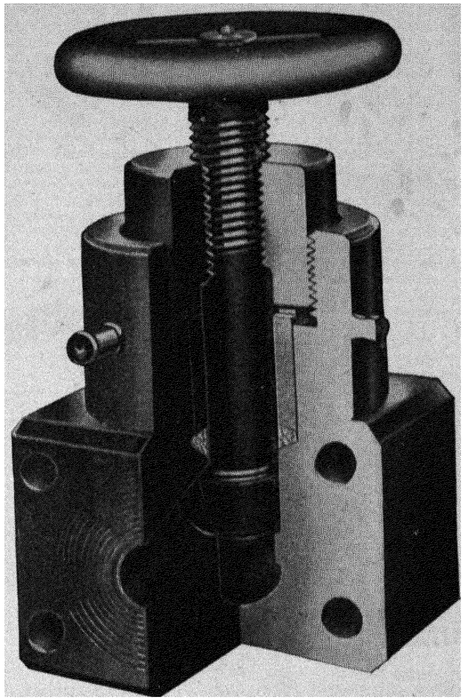

FIG. 1.—KARBATE GLOBE VALVE.

Applications of Karbate Pipes

Karbate pipes fall into two main uses, $\frac{7}{8}$ in. dia. and to a certain extent 1 in. dia. pipes are built into tube bundles for heat transfer purposes. From 1 in. dia. to 4 in. dia. pipes are used in pipe systems for conveying fluids, and also for heat transfer purposes when used in the construction of bayonet heaters, cascade coolers and kindred equipment, condensers, evaporators, etc. A wide range of pipe fittings including flanged connections, couplings, elbows, flexible couplings and valves are available for use in pipe networks.

As previously mentioned, the pipe can be easily sawn off to length and threaded on site when installing a pipe system, and by using standard 45° and 90° bends quite complicated layouts can easily be fabricated. The screwed joints are cemented with chemically suitable cements so that they are permanent, but where it is desirable to be able to dismantle sections at will, flanged joints can be introduced. In most pipe layouts there are sufficient bends and expansion joints are not required. Flexible joints, however, are available to compensate for thermal expansion, misalignments or excessive vibration.

Construction of Pipes, Fittings and Valves

In considering pipe friction, tests have shown that the resistance to fluid flow with Karbate pipe is very similar to that experienced with steel pipes of a similar diameter.

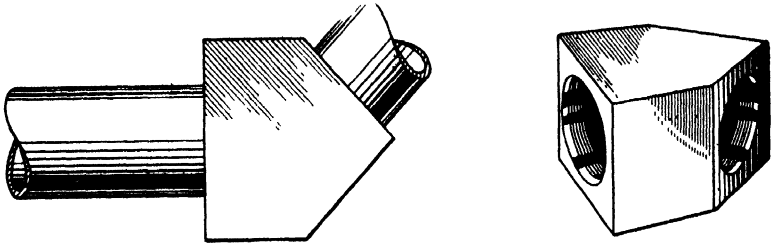

Fig. 2.—45° Elbow Fitting Produced in the Following Sizes: 1 in., 1½ in., 2 in., 2½ in., 3 in. and 4 in.

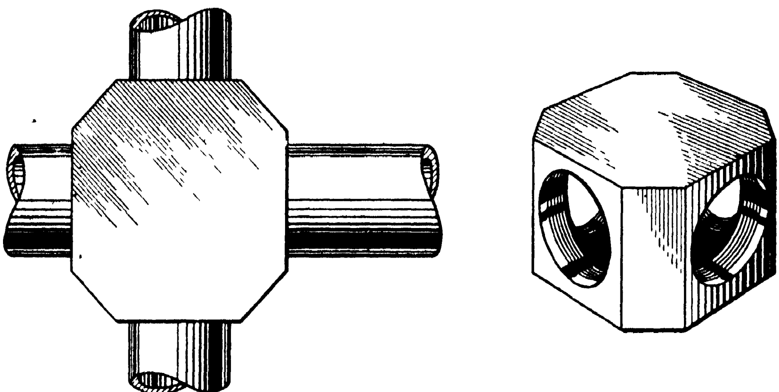

Fig. 3.—Cross Joint Produced in Sizes of 1 in., 1½ in., 2 in., 2½ in., 3 in. and 4 in.

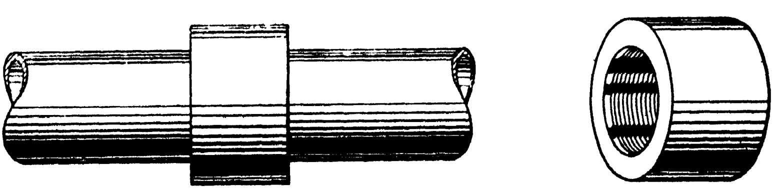

Fig. 4.—Coupling, Produced in Standard Sizes.

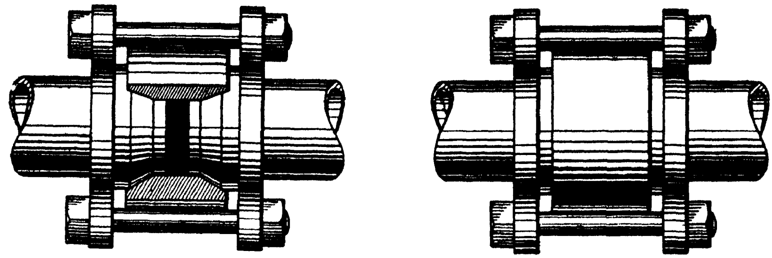

Fig. 5 —Type FC Flexible Coupling Assembly Produced in the Following Sizes 1 in, 1½ in, 2 in, 2½ in, 3 in. and 4 in.

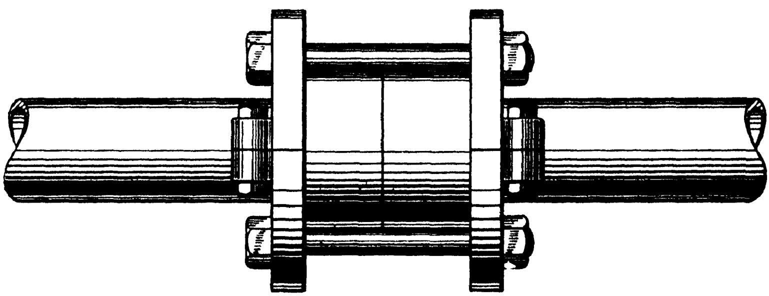

Fig 6.—Type "V" Flange Connection

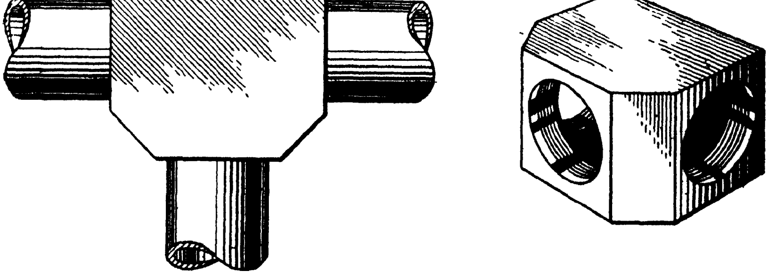

Fig. 7.—Tee Joint Produced in the Following Sizes: 1 in., 1½ in., 2 in., 2½ in., 3 in. and 4 in.

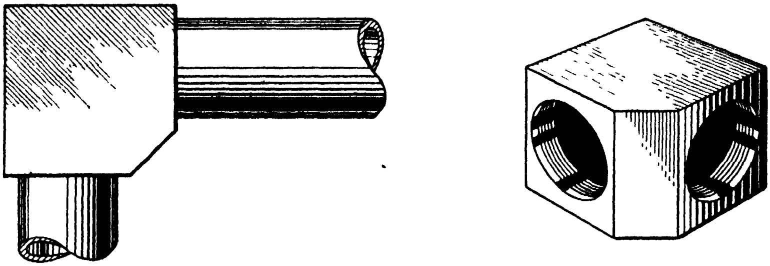

FIG. 8.—90° ELBOW FITTING PRODUCED IN THE FOLLOWING SIZES 1 in, 1½ in, 2 in, 2½ in, 3 in and 4 in

Details of various types of pipe fittings are shown in Fig. 1, and from these it can be seen that tees, crosses and elbows both 90° and 45° are machined from solid rectangular section stock, and they are of very sturdy design. As the fluid path is machined out the pressure losses at the bends are kept reasonably small.

The construction of the flexible coupling is clearly shown. Cast-iron follower plates are drawn up towards each other by the tie bolts compressing the synthetic rubber gaskets between the pipe ends and the special Karbate coupling. This coupling can be used up to at least 50 p.s.i. pressure.

In making flanged connections Karbate collars are threaded and cemented on the ends of the pipes, a synthetic rubber or other suitable gasket is placed between the collars and the split metal flanges are placed in position, the two halves of each being fastened together round the pipe, split pressure pads are placed round the pipe between the Karbate collars, and the metal flanges, and the tie bolts are tightened to make the joint. Two sizes of Karbate globe valves have been developed for use with 1 in. and 2 in. pipe layouts.

As seen from the cut-away view, the body of the valve is a substantial block of Karbate. The valve stem is also Karbate, but is reinforced down centre by a metal spindle to which is attached the handwheel. The valve packing which is made of Graphite and Fluon is compressed by the gland ring between it and the valve bonnet. All the material in contact with the corrosive liquids is Karbate, with the exception of the Fluon packing; in fact the only item not made of Karbate which is yet to be mentioned, is the bonnet lock-nut, and this is made from a Bakelite impregnated cotton material.

The valves are designed for shut-off and throttling duties with corrosive fluids which are free from abrasive solids. The maintenance of these valves is very small, and little wear takes place on either the stem, the threads, or the seatings of the valve. The spindle and seating are easily relapped, should this become necessary.

The publishers are indebted to British Acheson Electrodes, Ltd. for supplying the information and illustrations used in the above article.

LINATEX VALVES AND LININGS

"Linatex" is a substance which consists of 95 per cent pure rubber and is produced by a patented process of manufacture. This manufacturing process avoids the subjection of the rubber latex to the degree of heat normally associated with rubber manufacture.

A type of valve, specially constructed to meet the requirements of chemical engineering, has been produced incorporating this material and a brief summary of its applications and characteristics are given below. It may, however, also be mentioned that "Linatex" has many other applications including its use as linings in chemical pumps and pebble mills.

The "Linatex" Valve

This valve has been designed to perform all the complicated requirements in the control of abrasive and corrosive slurries, chemicals, and vapours. As will be seen from Fig. 9 the valve comprises a handwheel with brass working parts contained in a cast aluminium body. The slurries, chemicals or vapours are channelled straight-through in a tube of "Linatex." In cases where chemicals which act on rubber are to be used, the tube is made of other suitable synthetic material.

A sectional view of the "Linatex" valve is shown in Fig. 9. This shows the "Linatex" tube (A) which isolates the metal parts of the valve. An integral flange (B) made of the same material obviates the necessity for a pipe joint.

The valve is manufactured to British Standard flange diameters

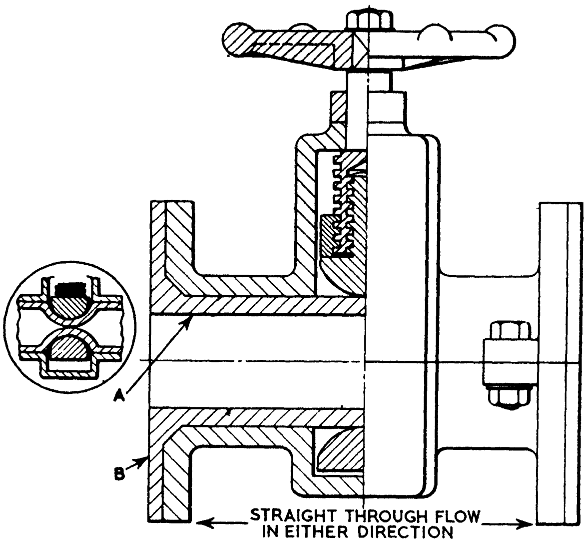

FIG. 9.—SECTIONAL VIEW OF THE "LINATEX" VALVE, (INCORPORATING WARREN MORRISON DESIGN).

and is available in the following sizes, ½ in., ¾ in., 1 in., 1½ in., 2 in., 3 in., 4 in., 6 in. and 8 in.

The main applications for which valves of this type are used are:

(*a*) The control of slurries of an abrasive and/or corrosive nature.
(*b*) As drain-off cocks for sludges.
(*c*) The control of fluids which must not be contaminated.
(*d*) Where several valves must be used in series with the minimum of head loss.
(*e*) The control of powders or fine solids, particularly those of an abrasive nature which wear the slides of the frequently adopted gate.
(*f*) The control of low pressure air or gases, particularly those with solids in suspension.

The above applications illustrate the more arduous types of duty for which the "Linatex" valve can be used, but it should be noted that the valves are equally suitable for the handling of other less difficult liquids, foodstuffs, delicate fluids, etc.

Before deciding on the use of a "Linatex" valve for any given application it is well to consider working characteristics of the valve, and, in this connection, a list of advantages and limitations of the valve are given below.

The advantages may be summarised as follows:

(1) The head loss is negligible.
(2) Valves will not normally clog when handling liquids with solids in suspension and any build-up of the slurry on the rubber will tend to be broken by the flexing when the valve is operated.
(3) Erosion when handling abrasives in suspension in gas or fluid is reduced to a minimum due to the easy flow through the valve even when throttled. The only wearing part is replaceable.
(4) The valve will give tight closure over small particles.
(5) There is no possibility of a gland leak. (This is particularly advantageous when handling noxious gases).
(6) The adoption by the makers of a wide range of natural and synthetic rubbers enables the basic valve to be used extensively in chemical works handling a variety of fluids; standardisation is therefore possible where otherwise a multiplicity of valve types would be needed.

The limitations of the type of valve, which should be borne in mind are (1) it is not suitable for operating at high pressures and is not recommended for over 50 lbs. per sq. in. working pressure; (2) although frequently considered for vacuum applications due to the absence of flow resistance, the design does not lend itself to operating with a negative head due to the tendency of the rubber tube to collapse; and (3) certain chemicals and gases, e.g. wet chlorine, which are otherwise handled by rubber tubing cannot be handled as the action of the chemical causes a surface hardening of the rubber which prevents further attack so long as the rubber is not flexed. Operation of the valve therefore causes progressive attack and ultimately destroys the tube.

The above information has been compiled from data received from Messrs. Warren Morrison Ltd., and Messrs. Wilkinson Rubber Linatex Ltd.

SECTION 13

TYPES OF JOINTINGS FOR CHEMICAL PLANT INSTALLATIONS

KLINGER JOINTINGS AND THEIR APPLICATION

By J. REASON

THE range of Klinger jointings covers all pressures and temperatures, superheated and saturated steam, chemicals, gases and hydrocarbons. Brief technical data relating to each type of jointing is given below and Table I shows the thermal conductivity values for these jointing materials.

"Klingerit" Compressed Asbestos Jointing

This jointing material is universally employed in power stations and operational experience has proved that it is entirely satisfactory for steam up to 5,000 p.s.i. working pressure and up to 500° C. (932° F.) superheat. It is not conducive in any way to electrolytic action.

It has also been established that "Klingerit" jointing gives excellent service under very severe and unusual conditions

TABLE I

THERMAL CONDUCTIVITY FOR KLINGER JOINTING MATERIALS

Material	*Density* lb./ft.^{3}	*Thermal Conductivity* (B. Th. U per sq. ft. per hour for inch thickness and 1° F. difference in temperature.)
Klingerit	118	3·4
Graphited Klingerit	118	3·3
Klingerit 1000	131	3·7
Klinger-Oilit	114	3·0
Klinger-Acidit	117	2·4

occurring in chemical works where working pressures up to 6,000 p.s.i. coupled with temperatures of up to 500° C. are frequently encountered. A typical example is given below.

A special apparatus had to be insulated against an electric current of 2,500 V and the insulation position was required, at the same time, to withstand a pressure of 5,200 p.s.i. at 300° C. "Klingerit" jointing of a thickness of $\frac{1}{16}$in. was tested for a long period under these conditions, which it withstood satisfactorily.

"Klingerit" is also used extensively for numerous purposes in the oil industry, particularly for oil-well, and refining installations, where the temperature of crude reaches 900° F.

Owing to its ability to withstand very high compressive loadings, this jointing is frequently used for insulation purposes, for instance, between steam chests and concrete foundations to prevent the heat from the steam chest from penetrating into the foundation block.

If specified the jointing can be issued under Release Notes conforming to M.o.S. Specification DTD 378a. It also conforms to Admiralty Specifications for compressed asbestos fibre jointing for steam and petrol, and to other U.K. and overseas specifications.

Details of "Klingerit" compressed asbestos jointing are given in Table II.

"Klinger-Acidit" Jointing

It is common practice to use standard "Klingerit" compressed asbestos jointing with many kinds of acids, but it is not suitable for strong nitric acid and for a few other concentrated acids. "Klinger-Acidit" is, therefore, produced as a compressed asbestos jointing specially designed for use with hot nitric acid and other inorganic and organic acids. It conforms to chemical industry and other authoritative specifications ruling at home and abroad.

"Klinger-Acidit" has been tested up to pressures of 1,000 p.s.i. and temperatures of 500° C. After 48 hours immersion in nitric acid (96 per cent) at room temperature, its tensile strength, in the weakest direction, is greater than 1,800 p.s.i.

This jointing material is slightly harder and less flexible than

Table II

"KLINGERIT" COMPRESSED ASBESTOS JOINTING

Sheet Size (in.)	*Weight of Sheets* (lb., approx.) *for the following thicknesses* (in.)						
	·008	$\frac{1}{64}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{1}{4}$
40 × 40	$\frac{7}{8}$	$1\frac{3}{4}$	$3\frac{1}{2}$	7	$10\frac{1}{2}$	14	28
40 × 60	$1\frac{1}{4}$	$2\frac{1}{2}$	5	10	15	20	40
48 × 48	$1\frac{1}{4}$	$2\frac{1}{2}$	5	10	15	20	40
60 × 80	$2\frac{1}{2}$	5	10	20	30	40	80
48 × 96	$2\frac{1}{2}$	5	10	20	30	40	80
80 × 80	$3\frac{1}{2}$	7	14	28	42	56	112
80 × 160	7	14	28	56	84	112	224
80 × 240	$10\frac{1}{2}$	21	42	84	126	168	336
96 × 240	$12\frac{1}{2}$	25	50	100	150	200	400

Table III

"KLINGER-ACIDIT" JOINTING

Sheet Size (in.)	*Weight of Sheets* (lb., approx.) *for the following thicknesses* (in.)			
	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$
40 × 60	5	10	15	20
60 × 80	10	20	30	40
60 × 120	15	30	45	60

TABLE IV

"KLINGER-OILIT" JOINTING

Sheet Size (in.)	*Weight of Sheets* (lb., approx.) *for the following thicknesses* (in.)						
	·008	$\frac{1}{64}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{1}{4}$
40 × 40	$\frac{7}{8}$	$1\frac{3}{4}$	$3\frac{1}{2}$	7	10	14	28
48 × 48	$1\frac{1}{4}$	$2\frac{1}{2}$	5	10	15	20	40
40 × 60	$1\frac{1}{4}$	$2\frac{1}{2}$	5	10	15	20	40
48 × 96	$2\frac{1}{2}$	5	10	20	30	40	80
60 × 80	$2\frac{1}{2}$	5	10	20	30	40	80
80 × 80	$3\frac{1}{2}$	7	14	28	42	56	112
80 × 160	7	14	28	56	84	112	224
80 × 240	$10\frac{1}{2}$	21	42	84	126	168	336
96 × 240	$12\frac{1}{2}$	25	50	100	150	200	400

"Klingerit" of the same thickness, but it is perfectly suitable for use between all types of flat surfaces including glass and ceramics, and it can be softened, to some extent, if desired, by immersion in boiling water prior to application.

"Klinger-Oilit" Jointing

"Klinger-Oilit" conforms to authoritative oil industry and other specifications ruling in the U.K. (including B.S. 1832: 1952, *Compressed Asbestos Jointing in the Petroleum Industry*) and overseas.

In contrast to the majority of oil-resisting jointings of other types, "Klinger-Oilit" is made from inorganic raw materials and therefore does not deteriorate with exposure or heat, but retains its resiliency and strength under the highest temperatures and pressures. It prevents seepages and does not soften, or squeeze out.

Tests have proved that "Klinger-Oilit" is a most reliable jointing material for use with hot crude oil at a temperature of 900° F., as well as with trichlorethylene, carbon-tetrachloride, naphtha, paraffin and many other chemicals. It has given highly satisfactory results for many years under working oil pressures ranging up to 4,000 p.s.i., thus proving its suitability for the most severe conditions encountered in the oil industry.

This type of jointing is also suitable for use with refrigerants, including methyl chloride, freons, sulphur dioxide, carbon dioxide and ammonia, and can also be used for steam and water joints. As a result, pipe-lines may be steamed out without any damage to the joint. It can be provided with graphited surfaces, which reduce sticking on to metal surfaces to a minimum.

"Klingerit 1000" Jointing

Richard Klinger, Ltd. also manufacture "Klingerit 1000," a wire-reinforced jointing, specially suitable for cylinder head and exhaust gaskets for internal combustion engines and for any joints subjected to fluctuating stresses.

"CONTROPOL" LIQUID JOINTING AND ITS APPLICATIONS

"Contropol" is a universal liquid jointing compound which, it is claimed, dispenses with the need for rings, washers and all supplementary packing in that it requires nothing else to effect a pressure-proof connection. The compound, when used for flanges, boilers, pipe connections, engines, casings, etc., eliminates the need for metal, rubber, asbestos and sheet packings of specific shapes and sizes.

Application

The compound, a thick, black fluid, may be applied thinly by a brush on to the surfaces of the fittings which are to be joined; and it should be allowed to become "tacky" before the faces of the fittings are either bolted or screwed together. Where uneven surfaces are encountered, the compound should be built up in a series of thin layers.

Should it be necessary to dismantle, [illegible] a portion of a pipe line or a boiler for either inspection or for replacement, it will be found that joints made with "Contropol" will part without difficulty, and as the compound will have spread itself evenly over the entire facings of the surfaces to which it was applied, it will afford visible proof of its protection against blow-bys.

Reliability under various Conditions

Due to its nature, a fine-mesh slate powder compounded with artificial resins and thinned with either methylated spirits or acetone (a choice of thinners is provided due to the reaction of certain plastics with acetone), "Contropol" can be effectively employed in the construction and maintenance of chemical manufacturing plant, in that its properties as a reagent are negative.

The compound is absolutely stable in petrol, benzole, oil, gas, water and steam. Dependent upon strength and temperatures, "Contropol" will resist acids and alkalis to varying degrees. For example, hydrochloric acids up to 100° C.; and a 20 per cent solution of sodium hydroxide up to 60° C. will have no effect on it at all, and it is perfectly reliable for cold solutions of caustic alkalis.

Characteristics of "Contropol" Liquid Jointing

"Contropol" has been subjected to the most stringent tests, carried out by impartial authorities, and its efficiency under all conditions has been fully established. This, particularly in the field of chemical engineering and manufacturing plant which was required to operate in cycles of extreme heat and which called for sudden large decreases in temperature. An actual example of one such process was that in which the plant was required to operate at a day temperature of 850° C. and which was required to cool completely overnight. The whole operation taking six days to complete. In this particular case not only were the joints made with "Contropol" satisfactory, but it was found that when other joints made with the conventional asbestos based sheet developed leaks these could be made tight by the application of "Contropol" to the outer edge of the joint.

In some branches of chemical engineering, and civil engineering is not without the same problem at times, it becomes necessary to either raise or lower to a somewhat drastic degree the temperature or pressure, or both, on a pipe line, valve, or boiler, etc. This operation often proves fatal from a maintenance engineer's point of view. On practically every occasion when such tactics have been employed, for good reason or for bad, it has been found that the sudden fluctuations have caused joints either to blow, or to have rendered them so ineffective when normal working resumes that a complete re-packing of many of the joints becomes necessary. This is most undesirable, not only from the production point of view, but also by the fact that in all probability many of the packings employed were of a specialised nature and as such cost a considerable amount of money to replace in material and labour.

An endeavour to overcome such problems has been made with "Contropol," in that its pressure and temperature elasticity is such that it is only in far removed cases that the temperatures and temperature variations employed in chemical manufacture will be outside the range of the compound. It can be safely stated that water pressure of 3,000 p.s.i. will have no effect on the efficiency of the joint; and the effective temperature range of "Contropol" is from between 1,000° C. to —50° C. Pressure of up to 200 atmospheres, and in steam pipes of up to 2,000 p.s.i. at temperatures up to 900° C. may be applied without any depreciation in the performance of the compound.

The above sub-section is based upon information kindly provided by Messrs. Stanley and Sanders who are the sole concessionaires for "Contropol" jointing.

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