MINISTRY OF SUPPLY

ROYAL ORDNANCE FACTORIES
(EXPLOSIVES)

THE TRANSPORT AND HANDLING OF ACIDS

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No. 10

THE TRANSPORT AND HANDLING OF ACIDS

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TRANSPORT AND HANDLING OF ACID

INTRODUCTION

The manufacture of explosives involves the use of large quantities of sulphuric and nitric acid and efficient working of the factory depends upon the right quantities being at the right place at the right time. An adequate and reliable transport system is therefore essential. Acid may be transported either in suitable containers such as carboys or tank wagons or through pipe lines.

The use of containers is necessary when transporting acid to or from the factory or within the factory when comparatively small quantities are to be despatched over a route not provided for in the normal running of the factory. Evidently a continuous pipe-line system is more efficient, safer and more expeditious than the use of containers which in effect merely involves inserting several manual operations between the ends of two pipe lines.

The motive power for transport through a pipe line is provided either by compressed air or some form of pump and the power required depends upon the amount of liquid to be moved in a given time, the height to which it must be raised its viscosity and the resistance due to the pipe line.

The resistance of the pipe line depends upon:-

(1) the material of which it is made;
(2) the internal diameter;
(3) the number and nature of the bends in it;
(4) the obstructions which may occur in it.

Finally the various valves necessary for the control of the movement of the acid must be considered.

Apart from these purely technical considerations the corrosive nature of the liquids dealt with necessitates careful consideration for the personal safety of the operatives. The use of compressed air, for example, should be avoided whenever possible when dealing with corrosive liquids.

A discussion of the subject of transporting and handling acids therefore involves the following items for consideration:-

Acid Transport and Handling

(1) the nature and quantity of material to be transported which determines the materials of construction to be used;
(2) the service required - continuous or discontinuous;
(3) the choice of method - container or pipe line;
(4) the motive power to be used - compressed air or pump;
(5) the choice of pump or compressed air plant;
(6) design of pipe line;
(7) choice and positioning of valves;
(8) special safety precautions.

Safety precautions must of course be considered at every stage of the process and may sometimes exercise a determining influence upon choice and design of plant.

Having designed and erected the transport system it is of course essential that it should be maintained in a highly efficient and safe condition for the longest possible time. The ease and speed with which this can be done depends primarily upon the foresight and skill with which the system was originally designed so that though the chemist is mainly concerned with maintenance and is apt to regard design and erection as the engineers job it is essential that he take a lively and intelligent interest in these matters if he is to perform his functions efficiently. It is much easier to alter things on a drawing board than on the plant.

MATERIALS

Materials to be handled

The corrosive action of sulphuric and nitric acid separately or mixed depends upon concentration and temperature. In addition spent acids invariably contain small proportions of nitrous acid. Nitric acid produced from salt-petre (retort process) invariably contains small amounts of hydrochloric acid (about 0.5%) which has a highly corrosive action.

Corrosion in most cases increases rapidly with temperature and it is therefore desirable to keep liquids as cool as possible particularly when iron and ferrous alloys generally are involved.

Materials of Construction

No metal or metallic alloy is completely immune from corrosive attack by the acids under consideration but within fairly well defined limits suitable types can be obtained to meet most cases which arise in practice. Where this is not possible one has to fall back on chemical stoneware.

(1) Chemical Stoneware

Chemical stoneware consists essentially of an aggregate bonded by a vitrifying clay. The properties vary with the particle size of the aggregate and the properties of the binder. In general the coarser the particles the more porous the stoneware but the greater resistance to changes of temperature.

TABLE I

Mechanical and Physical Properties

Tensile Strength	100-2500 lbs.sq.in.
Modulus of elasticity	6×10^6 x to $x \; 10^6$
Compression strength	25000 - 80000 lb./sq. in.
Thermal conductivity	0.6 - 0.9 B.T.U.
Specific Heat	0.185 - 0.19
Coefficient of expansion	0.000041 to 0.000049 per°C.
Specific Gravity	2.06 - 2.36

Ordinary salt glaze stoneware has a water obsorption of 6 to 10% but a good chemical stoneware should not exceed 3%.

In practice the objections to stoneware are its fragility and lack of adaptability. The pipe line must be made up of sections as obtained from the makers - they cannot be bent nor can the line accommodate itself to the minor irregularities always to be found in practice along the proposed route. This involves a large number of packed joints and the slightest movement or vibration inevitably causes leaking joints and cracked sections in course of time.

Stoneware however is the only satisfactory material for such things as nitric acid fume mains, in which very weak acid may condense, and for lines conveying nitric acid containing traces of hydrochloric acid.

Stoneware is used for containers of limited size - a few hundred gallons at most. It is also used to a lesser extent for pumps and slow speed fans.

The tendency however is to avoid stoneware as in spite of their higher cost and greater susceptibility to corrosion metallic materials are more adaptable and give less trouble in maintenance.

(2) Cast Iron and Mild Steel

Mild steel is generally used for containers, pipe lines and pumps for sulphuric acid, of over 75% strength and for mixed acids not containing more that 20% water. Corrosion however increases rapidly with temperature and therefore acid should be kept cool. If possible below 25°C.

In this respect cast iron is rather better than mild steel, and is to be preferred for oleum and for mixed acids containing not less than 14% H_2SO_4.

The corrosion of mild steel by mixed sulphuric and nitric acid has been the subject of a recent report by I.C.I. (F. and S.P.) Ltd. 3rd July, 1943. Corrosion is of two kinds, (a) in the vapour space where the action will be due to the volatile nitric acid and nitrous fumes, and (b) in the portion filled with liquid where it will be due to the mixed acid.

Mild steel may be passive to pure nitric acid, but as very slight disturbance (e.g. a scratch) may destroy the passivity, this cannot be relied upon. The presence of at least 2% H_2SO_4 is necessary for safety. The formation of a layer of ferric sulphate acts as a protective coating. In general, a reduction in thickness of the metal at the rate of 0.2 m.m. per annum may be taken as a safe limit.

It is found that in most cases corrosion is either violent with evolution of nitrous fumes or is below the suggested limit and that the presence of nitrous acid tends to accelerate corrosion.

Corrosion in the vapour space varies greatly and depends upon local condition. The entry of air, and with it, moisture, into the container is a major factor in promoting corrosion. In some cases top plates require replacement in a few weeks even with acid containing less than 0.5% water. With sulphuric acid alone 68% H_2SO_4 is the accepted lower limit of concentration for mild steel vessels.

(3) Stainless Steel

The addition of up to 14% chromium renders steel resistant to corrosion by nitric acid but the alloy is so hard as to be practically unworkable. Martensitic steels containing from 12 - 14% chromium are air hardening and if of low carbon content develops a coarse grain structure on welding. The addition of nickel also increases the resistance to corrosion but does not so harden the steel that it cannot be welded.

Present day practice is to use a mixture of chromium and nickel with small amounts of other metals. A steel alloy of 18% chromium and 8% nickel is resistant to both weak and strong nitric acid but does not weld satisfactorily as the joint suffers decay due to stresses set up in the welding.

The addition of 1% Titanium and 1% Tungsten improves matters in this respect and satisfactory joints can be made by a skilled welder. According to some authorities the improvement is due to the titanium, and tungston can be omitted.

The "18/8/1/1" alloy is resistant to both weak and strong nitric acid in the cold but is slightly attacked by warm acid especially if oxides of nitrogen are present. With weak nitric acid corrosion becomes serious above 60°C.

Chlorine and hydrochloric acid, even in traces, increase corrosion greatly so that these alloys cannot be used for nitric acid made from salt petre by the retort process.

Various other alloys containing from 18 to 25% chromium are also used; for example "Weldanka" a low carbon alloy containing 18% to 25% chromium with some silica and 12% nickel (Brown Bayleys, Sheffield).

It is important when welding stainless steels of these types with oxy-acetylene that the flame be kept neutral. Excess of either oxygen or acetylene adversely affects the quality of the weld and except for very thin sheet (less than 0.08 ins) it is preferable to use electric welding.

(4) R.55 Alloy

Is a more complex alloy which has given good results but is difficult to obtain under present conditions. It is a proprietary alloy of the La Bour Company. The composition is reported as:-

Nickel 53.25%; Chromium 23%; Copper 5%; Molybdenum 4%;
Tungsten 2%; Iron 8%; Silicon 4%; Manganese 0.4%; Carbon 0.2%

It has been found satisfactory for the impellors and volutes of La Bour Pumps for all purposes-- weak and strong nitric acids and sulphuric acids.

(5) Everdure

An alloy of a different type which has been found highly resistant to 60 to 65% H_2SO_4 up to 100° is "Everdure" which is a copper alloy containing:-

Copper 94.4 - 96%
Silicon 3.0 - 4.5%
Manganese 1.0 - 1.1%

(6) Silicon Iron

The composition of a series of typical alloys is given below.

TABLE II

Origin	Si.	C.	P.	S.	Mn.	Ni.	Cu.
BRAYFOS	15.0	0.55	0.05	0.01	0.60	0.25	0.01
DURIRON	15.5	0.70	0.12	0.01	0.66	-	-
TANTIRON	15.0	0.70	0.40	-	0.60	-	-
IRONAC	15.5	0.80	0.80	0.05	0.40	0.05	0.03
KRUPP THERMISILID	15.0	0.50	0.04	0.005	0.30	-	-
LE CREUSOT	15.0	0.50	0.05	0.04	0.90	-	-
METILLURE	16.0	0.60	0.17	0.01	0.88	-	-
ELIANITE	15.0	0.80	0.06	0.03	0.50	2.25	-
PEJNITZ HUTTE	15.0	0.08	0.06	0.02	0.20	-	-
AUDLEY ENGINEERING CO.	14.5	0.30	0.11	-	0.50	0.25	0.05

For comparison the average physical characteristics of silicon iron are given below with typical figures for cast iron and chemical stoneware.

TABLE III

	Silicon Iron	Cast Iron	Stoneware
Weight pounds per cubic foot	440	445	112
Melting Point °C.	1,250	1,200	1,450
Coef. Expansion x 10^{-6}	28.2	12.1	0.15
Thermal Conductivity = Ag = 100	12.5	14.3	0.00023
Hardness Brinell	390	180	-
Tensile Strength Tons/sq.ins.	6.7	12.0	2.3
Compression Strength Sq.ins.	20.0	32.0	36.0
Modulus of Rupture	14.0	28.0	4.0

Silicon iron is resistant to hot nitric and hot sulphuric acid and to all concentrations of nitric and sulphuric acid. The silicon content should be about 14%. Below this the susceptibility to corrosion increased but the metal is more easily worked.

It therefore approaches chemical stoneware in its range of application but unfortunately the resemblance also extends to physical properties.

It is very hard and brittle and therefore cannot be worked though it can be ground with difficulty. Considerable improvement has been and, still is, being made in the quality of silicon iron, particularly as regards freedom from blowholes and porosity, with consequent general improvement in reliability of service. Recent investigations (R.V. Riley, M. of S. Silicon Iron Factory Research Lab. Report No. 43/17) indicate that the sensitivity of silicon iron to thermal shock and the tendency to crack when subject to high temperatures is due to the formation of a brittle phase (eta) which normally occurs only in silicon irons with 16% Si. and over. Under certain conditions, however, it may be formed where as little as 15.2% is present which at ordinary temperatures is the critical boundary. It is proposed, therefore that until other means of avoiding the formation of the brittle "eta" phase be discovered that the silicon content be limited to 14.2% which is the lower limit of the generally accepted specification (14.2 - 15.2% Si.) although admittedly 15% Si. is the more satisfactory from the point of view of resistance to corrosion. It still remains, however, a fragile material and generally speaking should be treated as carefully, as earthenware with due regard to its much greater weight per cubic foot which makes it the more important that it should be adequately and rigidly supported.

Silicon iron is used in certain types of pump, for example, the Tantiron Lennox pumps which have given satisfactory service in some R.O.Fs for weak and strong gun cotton, waste acid, R.D.X. strong nitric acid (98% HNO_3) and C.O.V. (92-94% H_2SO_4).

(7) Aluminium

Aluminium of at least 99.5% purity is generally used in R.O.Fs for nitric acid of over 90% strength. It can be used for concentrations as low as 80% but corrosion becomes increasingly serious below 90%. In the opinion of some acid factories aluminium cannot be absolutely relied upon with nitric acid below 96% and even at 96% the life is distinctly shorter than with 98%. There is an increasing tendency to replace it by stainless steel where possible possible. Where stainless steel has been used in preference to aluminium for C.N.A. pipe lines the results have been successful but the lightness of aluminium and, in war time at least, its greater availability makes it the more generally used.

The corrosion resistance of aluminium is due to the formation of a very thin, firmly adherent layer of oxide. Anything which tends to rupture the film or prevent its formation increases the probability of corrosion which usually takes the form of pin-holes.

Welded joints are only satisfactory if carefully made by a skilled worker. Badly made joints are porous and are rapidly perforated. Pin-holes in overhead lines conveying strong acid are extremely dangerous, and for this reason it is preferred in many factories to use screw flanges rather than welded joints at connections.

(8) Lead

Lead of over 99.9% purity is the much used metal in chemical works. Apart from its excellent resistivity to corrosion over a wide range of acids and concentration, the great ease of working and the way in which old material can be purified, recast and reused is a most valuable characteristic. This, however, is also a danger as the properties of the lead are greatly influenced by the presence of impurities and irregularities due to faulty methods in the plumbers shop. This is particularly the case where antimony is used in some of the lead work. Plumbers often add "a little antimony to make up for loss" with the result that in course of time much of the lead work in the factory is of very indefinite composition. Great care should be taken to segregate "Pure", "antimonial" and "tellurium" leads when old plant is returned to the plumbers shop for melting down.

Apart from antimony, other impurities may accumulate. Too high a casting temperature results in a coarse crystalline structure and the formation of oxides. Impurities tend to collect in the centre of the ingot and consequently when rolled the sheet produced is not of uniform composition and erratic performance as regards corrosion results.

The susceptibility of lead to corrosion is greatly increased by traces of Bismuth as little as 0.005% having a perceptible effect. Some specifications now include a clause stipulating Bismuth less than 0.005%.

Acid Transport and Handling

With mixtures of sulphuric and nitric acid lead is satisfactory with all the normal mixed and spent acids produced in explosives work.

The resistivity of lead to corrosion depends upon the formation of a thin layer of insoluble salt. In the case of sulphuric acid the solubility of the sulphate increases considerably above 75% H_2SO_4 whereas in the case of nitric the nitrate becomes more soluble with dilution and below 40% HNO_3 corrosion is very rapid.

Corrosion is accelerated by anything which tends to break down the protective film as, for example, the agitation of the contents of a mixer or the impingment of a stream of acid upon one point. It is advisable, therefore, to protect such positions by a lead shield which can easily be replaced.

(9) Regulus Metal

Regulus metal contains from 12 to 15% antimony, and is used where hardness is desirable as for pump casings and impellors. The resistance to acid corrosion is slightly reduced, but this is more than balanced by the increased strength, and surface hardness. As little as 1 or 2% antimony has a perceptible effect on the hardness and amounts of this order are added to lead for stator tubes in Gaillard tower precipitators.

(10) Tellurium Lead

The addition of tellurium in small quantities increases the tensile strength and yield value and reduces the tendency to crystallisation under the influence of vibration. Tellurium lead is therefore used in mixers and plant where vibration is considerable. There appears to be little change in the resistivity to corrosion. Improvement due to tellurium is only evident over a very small range. The optimum appears to be at about 0.045 Te. With more or less than this the beneficial effect is not obtained and the general opinion of plumbers seems to be that tellurium lead offers little advantage to compensate for increased difficulty of working.

THE STORAGE OF ACIDS

Boiler Tanks

These have long been accepted as standard storage vessels for acids which do not corrode iron or mild steel. They are readily obtainable under normal conditions and their shape and construction is such that, especially in the case of the larger sizes they are most easily transported and installed. Placed horizontally the weight is well distributed and there is little danger of leaking at the bottom. At the same time they do not require a great amount of head room and with large volumes of acid the pressure head behind the valve is kept within reasonable limits. A tank about 28 feet long and 8 feet diameter hold about 9,000 gallons - 80 tons of C.O.V. Tanks of this type are sometimes lead lined but this is open to the objection that should the lead be perforated corrosion occurs and the gas generated soon lifts the whole of the sheeting and troubles are intensified rather than reduced by its presence.

The fact that the tank is totally enclosed is an advantage as regards the preservation of the contents but involves the dangers due to the accumulation of gases and renders necessary the precautions concerning the use of naked flame and safeguards for workers who have to enter them. A further consideration of importance is the accumulation of sludge especially nitrobody. If strong nitric acid is allowed to enter a tank containing such sludge there is danger of a serious explosion (see Safety Precautions Page No. 55.

The tank should be placed with a slight slope towards the sludge hole and the outlet valve and a plug operated from the top of the tank should be placed behind the outlet valve. The tank is provided with a man-hole and a dip-stick hole. It is advisable to protect the area round the dip-stick hole with a lead apron so that drips from the dip-stick do not fall on the iron and cause corrosion.

Calibration

The "dip" and volume of horizontal tanks can be correlated by use of rather complex mathematical formulae but as they are seldom perfectly symmetrical direct calibration throughout the whole depth is to be recommended. As the volume is not proportional to the dip, the error is not constant throughout and this is a defect when accurate measurement is required.

Lead Lined Tanks

Lead lining is used both for iron and wooden tanks. In the acid of iron tanks the danger of perforation and corrosion allowing the acid to attack the iron under the lead may lead to even more trouble than straightforward corrosion. The work, must, therefore, be done very carefully and first class lead be used. The choice of lead and the thickness is a matter of importance. The thinner the lead the more rapidly it will be perforated whilst on vertical surfaces thick lead tends to creep especially with warm acids. Practical considerations also limit the choice. Below 10 lb. lead the plumber finds it difficult to avoid perforating it when welding and over 16 lbs. handling on vertical surfaces is difficult. 6 lb. lead is however used for lead chambers and over 30 lb. lead for the saucers of Glover towers

It is stated by some that tellurium lead is more satisfactory as regards "creep" but evidence on this point is not conclusive.

Homogeneous Lead Lining

In this process, the iron surface is thoroughly cleaned and coated with a thin layer of tin. Lead is then run on to the desired thickness by the lead burner.

Properly applied the lead coating affords satisfactory protection and is superior to the ordinary lead lining in that the lead does not creep. The process is therefore well adapted for application to vessels subjected to considerable changes of temperature.

Success in the process depends primarily upon the preparation of the surface before the application of the lead and very careful working on the part of the lead burner is necessary to ensure that satisfactory adhesion of the lead is achieved particularly because, in general, defects cannot be detected by subsequent inspection.

The process is slow and tedious. Even with straightforward flat surfaces the application of a lead layer 3/16" thick takes about $4\frac{1}{2}$ hours per square foot. Thicker coats and more complicated surfaces take correspondingly longer times. It is therefore expensive and the introduction of various metals and alloys capable of affording equally effective resistance to corrosion has reduced the necessity of using it. Homogenous lead lining has been used with satisfactory results on the air lifts and cyclones of T.N.T. plants and for lining T.N.T. sulphiting and washing tanks and also for making unions between lead and iron pipes. For reasons indicated, however, the process has somewhat restricted application and appears likely to become even less important in the future.

Aluminium Tanks

Aluminium tanks are used largely for strong nitric acid. For reasons stated the bottoms should not be welded. Where joints are unavoidable they should be rivetted.

Brick and tile tanks

So far as resistance to corrosion is concerned the bricks and tiles used behave much the same as chemical stoneware. The chief difficulty lies in the cement and the jointing. In addition the low mechanical strength of the material necessitates the use of a very thick wall and hence a great weight of material. As the materials are also of low resistance to shock and stress, it is necessary to have a very firm foundation free from vibration and to provide ample protection against shock. All this again increases the bulk and weight of material. The most satisfactory foundation is a large concrete raft with a protective apron of sheet lead (at least 16 lb.) under the tank. As the sides of such tanks cannot be pierced, it is necessary to use suction pumps drawing over the top of the tank.

A fairly satisfactory cement is made up with sodium silicate and brick dust, though difficulty is sometimes experienced due to its failures to set uniformly throughout the mass (N.B. This may be due to variation in the Na_2O/SiO_2 ratio). There are many different grades of sodium silicate on the market and without information as to the composition of that used, no conclusions of technical value can be drawn. A grade known as P84 in which the SiO_2/Na_2O ratio is 3.3 has been found satisfactory.

At one factory a tank has recently been constructed for containing weak sulphuric acid contaminated with organic matter. It consists of a concrete box into which a wolvic stone run-off pipe is built. The box is lined with two layers of Astos (a bituminous asbestos felting material supplied by the Rubberoid Company) which is attached by means of a bituminous solution.

Inside this the brick lining is built up in the usual way.

The permanence and satisfactory behaviour of a brick tank depends primarily upon the skill and care with which it is erected. The somewhat unhappy experience in war-time with such tanks is largely due to the shortage of skilled labour.

It is essential that perfectly dry conditions should be maintained throughout the erection and that the materials, particularly the type of cement, be properly selected and used. The bricks or tiles should fit closely and the jointing material be just too thick to be trowelled. It should be applied either by dipping or spreading in an even layer and the tile then hammered into position.

As regards the outer casing, wood is not satisfactory because it has not sufficient rigidity to ensure proper support of the stoneware. A brick casing with a thick layer of bituminous material between it and the inner tile lining is most satisfactory.

Generally speaking, however, brick or tile lined tanks are to be avoided when other suitable materials are available.

General

All tanks should be placed squarely on good foundations so that the weight is taken uniformly by the bottom.

They should be raised off the ground in at least two courses of acid proof brick, and it is desirable that the floor and surrounding area should be paved with acid proof brick and raised slightly above general ground level. In general practice all acid floors should have a slope of 1 in 30.

There should be a definite slope towards a gully so that acid spills and leaks can easily be washed away. All valves at the bottom of the tank should have a plug behind them operated from the top of the tank.

EXPERIENCE IN ROYAL ORDNANCE FACTORIES

TANKS

Sulphuric Acid (Concentrated)

Mild steel tanks are generally used. When packing is required, "Sulphestio" is satisfactory.

Sulphuric Acid (Weak)

Wooden or mild steel tanks, lead lined, are used. With warm acid there is a tendency for the lead to creep.

Tellurium lead is being tried at some factories but there appears, so far, to be no definite decision as to whether it constituted an improvement.

Nitric Acid (Concentrated)

Aluminium tanks are used. Brick lined tanks have been tried at some factories but do not appear to have created a good impression. When traces of hydrochloric acid are present (as in retort acid) brick or tile built tanks appear the most satisfactory solution of the problem at present. For smaller tanks stainless steel has been used with satisfactory results.

Nitric Acid (Weak)

Stainless steel is apparently the only satisfactory metal for tanks. For smaller containers chemical stoneware is used.

Spent and Mixed Acid with more than 20% water

Wood or mild steel tanks, lead lined, are used.

Acids may be transported in some form of container or through a pipe line. Both on the ground of economy and of safety, the pipe line is obviously to be preferred. When, however, circumstances demand the use of containers, the choice depends upon the nature of the liquid and the amount to be transported.

I. CARBOYS

The carboy is defined as a globular bottle of not more than 12 gallons for liquids over 1.2 specific gravity, or 14 gallons for liquids under 1.2.

The glass must not be less than 1/8 inch thick and practically free from bubbles or striae. It must be annealed and clearly marked on the neck with the distinguishing mark of the maker.

For acceptance for transport by rail it must be packed in an iron or wooden hamper with at least ½ inch of straw packing between bottle and hamper. The straw must be in good condition and when handed to the railway, sufficiently damp to prevent fire.

When large numbers are to be transported they must be loaded so that movement is impossible and must be securely stoppered.

Although the use of carboys for acid transport by rail or road is not the practice of R.O.Fs and the development of tank cars has much reduced their use in industry, they are still very largely used. In R.O.Fs their use is confined to transporting small quantities, mainly for experimental purposes, when the erection of a pipe line would be impracticable or uneconomical. The practice should, however, be avoided so far is possible and the safety precautions referred to on p. 55 carefully observed.

When occasion necessitates the despatch of acid in carboys or other glass containers by rail, the relevant railway regulations should be carefully observed

II. TANK CARS

The typical British Tank Car for sulphuric acid is of from 12 to 14 tons capacity and of the following approximate dimensions:-

Length over buffers	18 ft. 4 inches
Overall height above rails	10 " 6 "
Wheel base	9 " 0 "

Acid Transport and Handling

Length of tank (inside)	15 ft. 3 inches
Diameter	4 " 8 "
Capacity	1,560 gallons
at 17.5 lbs. per gall.	12 tons 14 cwt.
Tare (empty)	8 to 9 tons.

Materials of construction:

Shell of tank	- 3 mild steel plates $\frac{3}{8}$"
ends	- self flanged $\frac{1}{2}$" steel plate
Woodwork	- Best English or American white oak. Tank bearers and stanchions Pitch pine.

Fittings

(1) Direct acting internal valve with regulus metal plug.

(2) 2 inch cast iron outlet discharging on either side of tank - 2 inch cocks.

(3) Cast iron manhole with mild steel lid.

(4) Cast iron syphon block fitted on top of tank at one end for discharging by compressed air or syphoning. When not in use this is covered by a blank flange.

Trucks must be thoroughly inspected at regular intervals and sediment washed out. Care must be taken to remove all water after washing out.

So far as possible, trucks should be filled and emptied by gravity.

When compressed air is used, 30 lbs. per sq. inch is sufficient to raise acid 1.7 gravity 840 ft.

It should be noted however that tank cars invariably have the maximum permissible pressure clearly marked upon them and this should never be exceeded. It is sometimes as low as 25 lbs/sq. inch

Generally whenever possible, tank cars should be off-loaded by gravity or by pumping. If necessary the pump can be primed by applying just sufficient air pressure to start up.

It is important that the connections should be carefully inspected before starting blowing and any pressure in the tank vented before the pipe connections on the tank are uncovered or the bottom discharge valves opened. The air pressure line should not be connected until the discharge line is satisfactorily completed. A pressure gauge should be provided in such a position that it can easily be read by the operator.

Whenever possible tank cars should be discharged by pump. When only top discharge is available, the pump may be primed by applying the minimum air pressure to carry the acid over to the pump. In any case the air pressure used on tank cars should be kept to the minimum necessary for complete discharge. Serious accidents have occurred in the use of compressed air for "blowing over" corrosive liquids and the method should be avoided so far as possible. In any case the greatest care should be taken and the operations be conducted under expert supervision.

Filling Tank Cars

Unless provided with special splash plates, tank cars must be filled to the loading bar fixed 5 inches from the crown. They must not be filled beyond the official capacity.

General

Whether full or empty, the manhole cover and other openings must be closed water tight before dispatch.

Tank cars used for acids are liable to accumulate hydrogen. Naked lights should therefore not be brought near a tank until it has been properly vented and if necessary purged.

III. DRUMS

Mild steel drums are used for sulphuric acid as they are much safer than carboys in every respect.

The Railway Clearing House specification includes the following items of importance:-

1. Material - best quality mild steel at least 12 B.G. (2.517 m.m.) and 10 B.G. (3.175 m.m.) for ends.

Acid Transport and Handling

2. Construction - (a) Drums may be rivetted or welded.
(b) Ends may be flanged and let into the body 1 to $1\frac{1}{2}$ inches and strengthened by welded hoops.
(c) 3 solid rolling hoops must be shrunk on the body.
(d) The drum must be closed by a screwed steel plug and boss and plug must not project beyond the chime when screwed home.

3. Tests - The drum must be tested at an internal pressure of 20 lbs. per sq. inch and the test repeated at least every six months.

4. Leaks - Leaks must not be stopped by soldering - all repair must be made with the materials of construction.

Transport

Empty drums must be securely closed and air-tight.

Weight and Size

The gross weight of drum and contents must not exceed 1400 lbs. The standard drum is about 2 ft. diameter and 3 ft. overall length and weighs about 1 cwt. It holds approximately 9 cwt. of C.O.V.

Transport of Nitric Acid

Nitric Acid can be transported in special tank cars or drums - aluminium for C.N.A. and stainless steel for W.N.A. or C.N.A.

Mixed Acid

Mixed acid with less than 20% water content can be transported in ordinary mild steel tank cars or drums.

PIPE LINES

A pipe line must be adequate to the needs of the case and offer as little resistance to the flow of the liquid as possible. It must be durable and give the minimum amount of trouble in maintenance

Under any given set of conditions the capacity of a pipe line depends upon its dimensions and the resistance it offers to the flow of liquid. Apart from the nature of the liquid the resistance to flow depends upon the dimensions of the pipe (length and diameter), its "roughness" or frictional resistance, and the nature and number of bends in it - the sharper the bend the greater the resistance.

Bends necessarily involve a certain amount of distortion and hence strain in the metal which invariably increases susceptibility to corrosion. Accelerated corrosion at bends has been specially noted with mild steel pipes carrying C.O.V. at temperatures above 50 - 60°C. (at Irvine). Suspended matter also tends to accumulate at sharp bends and thus increases the tendency to choking.

On all grounds therefore it is desirable to make pipe lines as direct as possible and, in order to avoid the formation of air locks, the slope should be continuous in one direction.

Permanence

The permanence of a pipe line depends upon:-

1. Correct choice of material.
2. Adequate support.
3. Protection from external corrosive actions such as drips of condensate, or leaks from overhead structures.
4. Freedom from strain due to movement of the structures to which it is attached.

The relative importance of these items depends largely upon the nature of the materials involved.

1. Chemical stoneware is resistant to corrosion but very sensitive to shock and strain.

Acid Transport and Handling

Stoneware lines must therefore be very well supported and protected from strain and vibration. Each section should be individually supported and the joints so made that whilst there is sufficient freedom of movement to take up changes due to variation of temperature there is no possibility of individual movement which may cause cracked sections and leaky joints. Joints are of three types:- (Fig.1.)

(i) "Socket and spigot" and conical joints

This the usual type for ordinary pipe lines not subjected to any exceptional internal pressure. Where pressures are likely to develop the conical joint is better. It is also useful when corrosive liquid (for example the vapours from a nitric acid retort) are involved. Whichever type is used the joint must be so arranged as to face the stream of liquid so that liquid does not collect behind the packing.

(ii) Butt Joints

This joint has the advantage that a single section can be replaced without disturbing the adjacent ones but it has the disadvantage that it is difficult to adjust the clamp so as to form a sufficiently tight joint between the sections without causing excessive strain and hence cracked sections or leaking joints. The packing between the butt ends is usually in the form of washers or rings cut to size by the maker but may be made up in the factory from the usual materials such as asbestos millboard depending upon the service conditions under which the pipe is to be used.

Packing Stoneware Joints

For acid pipe lines the basic material is asbestos. Joints of the "spigot and socket" and "conical types" are first packed with one or more asbestos rings fitting snugly in the jointing channel followed by a layer of asbestos putty.

The formulae for these putties varies considerably, each packer having his own preference.

A typical formulae is:-

20	lbs.	asbestos powder
3	"	blue asbestos
10	"	clay
$2\frac{1}{2}$	"	Russian tallow
10	"	boiled linseed oil

The ingredients are warmed, well kneaded and packed into the joints above the first rings of asbestos and followed by alternate layers of asbestos rings and putty. This putty does not set hard and therefore admits a certain amount of movement with temperature change. Where temperature changes are frequent and considerable e.g. in retort mains at least a $\frac{1}{4}$" clearance between the ends of the pipe should be allowed.

This packing is not suitable for highly reactive acid e.g. hot concentrated nitric acid. In such cases the Russian Tallow and linseed oil may be replaced by petroleum jelly and the asbestos rings except the one directly in contact with the acid should be well soaked in petroleum jelly - preferably soaked in it for at least two hours at about 100°C.

Lead pipe lines should be continuously supported. With very long pipe lines, satisfactory results can be obtained by placing the lead pipe inside an iron pipe and then expanding the lead to fit tightly by air pressure.

Aluminium pipe lines should be flanged as welded joints are unreliable for reasons already mentioned (see p.).

Flanges

Where flange joints are used a suitable packing material must be used and with the softer metals an iron backing ring is advisable. These are split in two so that they can be removed without removing the flange. They are of standard dimensions to correspond with the flanges. The split should be made to pass through the diametrically opposite bolt holes so that when screwed down there is no possibility of the free ends springing.

Flanges for 18/8/1/1 stainless steel are preferably screwed on with a light weld at the back of the flange. It is important that the welding be carefully done. If an axy-acetylene flame be used the flame must be kept neutral. An excess of either gas has an adverse effect on the metal and increases its susceptibility to corrosion particularly with nitric acid.

EXPERIENCE IN ROYAL ORDNANCE FACTORIES

PIPE LINES

Sulphuric Acid (Concentrated)

Mild steel or cast iron is generally used. The only adverse comment is that with warm acid (50^o- 60^o) mild steel piping wears out rather quickly at the bends as might be expected. Where packing at flanges is required, "Sulphesto" gives satisfactory results.

Sulphuric Acid Weak (60 - 70%)

Lead pipe with "Bellite" or "Lionite" packing at the flanges is generally used.

Nitric Acid (Concentrated)

Aluminium piping with "Bellite" packing and lead piping with "Lionite" packing are used and there appears little to choose between them. Aluminium is lighter and more rigid but unless of good quality and carefully welded, is liable to pin-hole corrosion. Screwed flanges are therefore preferred.

If lead is coupled with aluminium, corrosion occurs due to electrolytic action. The introduction of a soft lead packing which can easily be replaced is therefore recommended. Earthenware piping is occasionally used but the trouble with joints is considerable and this practice is not recommended.

Nitric Acid (Weak)

Stainless steel piping with "Nitresto" packing is used.

Spent and Mixed Acids

Lead piping is used except for Mixed Acids containing less than 20% water where mild steel or cast iron can be used.

VALVES

For satisfactory operation in a chemical works a valve must:-

1. resist the corrosive action of the materials;
2. operate reliably, quickly and easily;
3. be free from any tendency to accumulate sediment and choke;
4. require the minimum of attention.

Failure to resist corrosion results results in leaks and sticking which are a source of danger to operatives, damage to plant and loss of material. A drip of 2 drops a second is equal to about a ton a day of C.O.V. The typical acid factory of a R.O.F. contains several hundred valves and therefore losses due to defective valves may easily amount to a very considerable tonnage of acid within a short period.

The main types of valve in use for controlling the flow of liquids are represented in Figs. 2 to 9.

1. Plug cocks
2. Globe valves
3. Gate valves
4. Check or non-return valves
5. Reducing valves

Many varieties of each type are available and the choice depends upon the nature of the material to be dealt with, the size of the pipe line and the service required.

For the ordinary operations of an acid factory some form of plug valve is invariably used except when flow must be restricted to one direction in which case a check or non-return valve is used.

1. The plug cocks (Fig. 2)

The operation of the plug valve is evident from the diagram which shows the self lubricated type.

The essential feature is a solid body casting with a conical plug pierced with a hole corresponding to the throughway of the body.

A quarter turn of the spindle therefore completely opens or closes the valve.

The advantages of the valve are:-

1. Simplicity - there are no complicated parts, obstructions to the flow of liquid nor dead spaces where sediment may accumulate or eddies be formed.
2. Quick action.
3. Absence of exposed surfaces which may corrode.

The disadvantages are:-

1. The rate of increase of flow varies with the position of the valve consequently it is not suitable when a precise control of flow is required.
2. In its simplest form it is difficult to combine a tight fit with ease of operation If the sides of the plug are too nearly parallel the valve tends to stick, whereas if they are too conical pressure on the valve tends to raise the plug and cause leaks. If the valve is not sufficiently tight it tends to leak and corrosion between the plug and body causes sticking and rapid deterioration.

The self lubricated valve represents an effort to remove most of the troubles under heading (2).

The valve plug is held in position by a top plate and the bottom seating is slightly hollowed.

Lubricant, usually in the form of a "stick" made to fit the valve is contained in a lubricant chamber above the plug and forced down through vertical grooves in the sides of the plug into the space made by the hollow seating and also between the surfaces of the plug and the body. Pressure is thus transmitted to the plug forcing it upwards against the resiliant packing between the top of the plug and the upper cover plate.

Given the right lubricant therefore leaking is stopped. Screwing down the lubricating head at once increases the supply of lubricant and loosens the plug key forcing it upwards. In this way sticking is reduced to a minimum and when it occurs can usually be remedied by adjustment of the lubricant head.

The two most important matters are choice and supply of lubricant and care of the valve packing. Use of the wrong type of lubricant or neglect to keep the valve well supplied of course renders the whole arrangement useless. If the packing is detroyed or loses its resilence the valve cannot be loosened by adjusting the lubricating head and increasing the pressure on the lubricant merely increases sticking and eventually permanently injures the valve by scoring and distortion of the seating.

Globe Valves (Fig. 3)

In this type of valve the flow of liquid is easily controlled. The number of turns between "ON" and "OFF" can be varied within wide limits and the area of the aperture is practically proportional to the turning of the spindle throughout the whole range.

The objections to the globe valve are:-

(i) the flow through the valve is not direct, hence there is considerable resistance to flow and dead space in which sediment can collect;

(ii) the proper closing of the valve depends upon the accurate fit of the moving disc on the seating and a very small amount of corrosion or distortion is therefore sufficient to cause leaking through the valve even if not out of the glands;

(iii) the surfaces of the controlling parts are permanently exposed to the corrosive action and pressure of the liquid.

Consequently this type of valve is not suitable for acid lines.

Above 2" it is difficult to make the globe valve operate successfully and for greater diameters some form of Gate valve is invariably used.

Gate Valve (Fig.4)

This type is always used for large valves. The operation is simple and, as in the globe valve, the fineness of control can be adjusted by altering the pitch of the spindle thread. Except in the vary rare case of rectangular cross-section, howvver, the rate of increase of flow is not proportional to the degree of opening.

At high pressures the valve becomes difficult to operate due to the pressure on the gate and small bye pass valves are fitted to equalise the pressure before opening the main valve. Bye pass valves are necessary on all gate valves of 8" and over.
In the illustrations a wedge shaped gate is shown. Parallel sided gates have the advantage that they are not so liable to jam in the seating.

The presence of sludge in the liquid causes trouble as it tends to accumulate in the guides of the gate and therefore this type of valve is not to be recommended for use in acid lines.

Check Valves (Fig. 5)

These are used when the flow of liquid must be confined to one direction. The ball type is satisfactory up to about $\frac{1}{2}$" - beyond this it is difficult to get satisfactory results because of the weight of the ball and the difficulty of attaining sufficiently accurate sphericity. The swing or clock type is therefore used, or a modified form of the ball type in which the ball is replaced by a specially shaped piece.

Non-rotative Valve

This valve is designed to reduce the wear on the contacting parts. The bottom portion of the plug which comes in contact with the seating is detached from the spindle which therefore merely presses it against the seating without any grinding action. Valves of this type (e.g. the Cortin and Corking pattern) have given satisfactory service in R.O.F. acid factories.

Needle Valves (Fig. 6)

This type of valve is used where very accurate control of flow is necessary, the mode of operation is clear from the drawing.

Reducing Valves (Figs. 7 and 8)

This type of valve is designed to deliver at a constant pressure below that of the supply.

Entering at (1) liquid passed out through the main valve opening 4. At the same time some passes through the port 6 to the chamber 5 where it operates on the underside of piston 7.

When the pressure exerted exceeds the down thrust of the spring (10) the piston is raised and so closes the main passage by raising the seating 3. Similarly when the pressure falls in chamber 5 piston 7 falls again and the main valve is opened. The pressure at which the valve operates is determined by adjusting the screw 10.

For steam, such valves are made of cast iron for initial pressures up to 100 lb. sq. in. - for higher pressures and for water, air or gas, gun metal is preferable.

(Fig.(8) shows a simpler design made in gun metal for use with steam.

It is important that reducing valves should not be used as "dead stop" valves, an ordinary valve should be placed on the high pressure side of the valve and be kept either fully closed or fully open- all regulations being done by the reducing valve.

Diaphragm Valves (Fig. 9)

The characteristic feature of this type is that the working parts of the valve are protected from the liquids by means of a flexible diaphragm usually of rubber.

The mode of operation is clearly seen in the diagram which shows a "Saunders" valve of the type generally used in the T.N.T. factories where molten T.N.T. is handled and metal to metal contact must therefore be avoided.

For this purpose, the main trouble is the accumulation of solidified T.N.T. which causes sticking. In cases where this problem does not arise the limitations of the valve lie in the ability of the flexible diaphragm to maintain its resilience and impermeability over a long period. This varies with the severity of service and the nature of the liquid handled and, although the diaphragm can be easily and quickly replaced, the use of this type is only resorted to when some special consideration makes the use of the all metal valve undesirable or impossible.

By selecting suitable types of composition for the flexible diaphragm this type of valve can be adapted for use with a variety of liquids or gases.

The simplicity of the design of the metallic portion makes this type of valve specially suitable for application of glass and other protective linings. Such valves are largely used in handling food products.

Materials for valve construction

Valves for steam or water lines are usually made of brass or gun metal. Cast iron is not used for pressures over 250 lbs. sq. in. or temperatures above 450°C. (230°C.). Steel may be used up to 1350 lbs. sq. in.

For acids choice of materials is determined by the same consideration as those already discussed.

EXPERIENCE IN ROYAL ORDNANCE FACTORIES

2. VALVES

For general purposes the plug valve is used. The lubricated type has proved satisfactory but one factory prefers the "gate" type for handling hot C.O.V. The use of lubricated valves is limited by their high cost to cases where the ordinary type has proved unsatisfactory.

The "non rotative" type of valve is recommended by some factories as there is less wear on the seating.

Sulphuric Acid (Concentrated)

Cast iron valves are satisfactory and "Ironac" is used on some lines at one factory.

Where packing is required "Chlornite" is reported as satisfactory

Weak Sulphuric Acid

Non-rotative valves preferably those of Appleton and Howard or Houghton are recommended. Packing appears to be troublesome Blue Asbestos soaked in petroleum jelly is used but is not regarded as wholly satisfactory.

Nitric Acid (Concentrated)

Stainless steel plug valves or Ludgate vertical spindle valves are satisfactory and "Chlornite" packing is used.

Weak Nitric Acid

Similar to strong Nitric Acid.

Mixed and Spent Acids

Stainless steel non rotative plug valves with "Chlornite" packing are satisfactory. With hot acid, packing is a difficulty and no packing material seems wholly satisfactory.

THE MOVEMENTS OF LIQUID THROUGH PIPE LINES

In the absence of gravity flow the power required to force a liquid through a system is supplied by some form of pump which may act directly upon the liquid or indirectly through the medium of compressed air.

The indirect method is possibly the simplest and until comparatively recent times was very largely used for the transport of acids.

Transport by Compressed Air

(1) Acid Eggs

The acid egg in its simplest form consists essentially of a vessel sufficiently strong to withstand the required pressure and resistant to corrosive action of the liquid under consideration.

It is provided with an inlet for the liquid and an outlet pipe which reaches to the bottom of the vessel. Air is admitted through a pipe line provided with a pressure gauge and a check valve.

Such a method has the advantage of simplicity and the fact that the liquid does not come in contact with the pump eliminates many mechanical and corrosion difficulties. At the same time the head against which the liquid can be moved is limited only by the air pressure available and strength of the system.

It is, however open, to many criticisms:

1. The efficiency is low. When the egg is emptied of liquid it is full of compressed air which must be released and its energy content cannot be used.
2. Although it can be made semi-automatic it requires individual attention and is discontinuous in operation
3. Although corrosion troubles in connection with pumps are eliminated, the troubles with valves and valve packings under considerable and rapidly varying pressures still remain, and are a source of much danger. The egg itself is also subject to corrosion.

Improved pump design and the introduction of corrosion resist-resisting alloys has, therefore, led to the almost complete elimination of acid eggs for the movement of acids in R.C.Fs.

Acid Transport and Handling

As, however, some still remain in use, attention may be drawn to some of the more serious sources of danger and the importance of careful working and periodic inspection must be stressed.

1. Bursting of the egg - Where cast iron or steel is used there is sometimes a tendency for the acid to penetrate the shell and eventually weaken it to such an extent that the egg may collapse under even slight pressure. (See Appendix I).
2. When the liquid contains partially nitrated substances, e.g. M.N.T. or D.N.T. there is a danger of this gradually accumulating in the egg and in course of time the amount may become so great as to cause a serious explosion if the liquid comes in contact with concentrated nitric acid. (Appendix).
3. Unless the valves are very carefully packed and inspected at frequent intervals the frequent and sudden pressure changes cause breakdown of the packing. Acid leaks under high pressures are very dangerous.

(2) Air Lifts

The air lift is in constant use in most acid factories where a continuous circulation of an acid liquor is required, the most common example being the absorption towers for nitrous fumes.

It depends upon the fact that if compressed air is admitted through a submerged jet in the bottom of the air lift, the bubbles of air carry slugs of liquid with them up the tube (Fig 10). In the case of absorption towers this has the advantage that it ensures very intimate mixing of the liquid with air and, therefore, rapid oxidation of the nitrous fumes is effected.

The apparatus is simple in design, completely automatic and free from moving parts. On the other hand the efficiency is low (though probably higher than that of the acid egg) 30% being a very fair figure, but with small air lifts with a low submergence ratio efficiency may fall to 5% or 10%.

Although simple the action is too complicated for mathematical analysis.

From practice an empirical formula has been evolved. (Fig.11)

$$V = 0.8 \left(\frac{Ht}{C \log \left(\frac{HS + 34}{34} \right)} \right)$$

V = cubic feet of air required to lift one gallon water.
Ht= total lift (from surface of water to the point of discharge).
H_S= submergence (from water level to the point of air inlet).
C = a constant according to the table below.

Lift (Ht)	Constant C
10 - 60	245
61 - 200	233
201 - 500	216
501 - 650	185
651 - 750	156

The submergence ration $\left(\frac{H_S}{Ht + H_S} \right)$ varies from 0.66 for a lift of 20 feet to 0.41 for a lift of 500 feet.

The performance of an air lift depends very much upon the design of the air jet and particularly the throat of the inlet to the lift tube. Consequently, makers figures for performance must be taken, but a formula is a useful guide in estimating the probable size and number of lifts required and in checking performance.

Most of the trouble with air lifts is due to packing failures and choking due to suspended matter, e.g. nitrobody in denitration plants.

The submergence tube and the bottle are invariably of earthenware, but the lift tube may be of stainless steel or borosilicate glass. Stainless steel cannot be used for nitric acid containing traces of chlorine or hydrochloric acid, and in any case, glass has the advantage that one can see how the apparatus is working. When metal tubes are used it is advisable to use glass for the top section to permit visual inspection.

Acid Transport and Handling

In R.O.F's air lifts of the type shown in Fig.12 are largely used on absorption towers. The submergence ratio is about 30% and the total lift about 14 ft. Performance varies greatly according to circumstances. With 1 inch pipes the delivery is about 80 galls. per hour and with 1½ inch pipe about 200 galls. per hour. Efficiency is determined to a large extent by the proportions of the nozzle and the mouth of the delivery pipe. Experiments indicate that a ratio of 1 to 6.25 for the area of the nozzle discharge orifice and the throat area respectively gives satisfactory results even with low submergence ratios which is an obvious advantage under the circumstances obtaining in these plants.

The Tungston Pump (Fig. 13)

This was originally designed for handling corrosive liquids containing considerable quantities of solid matter in suspension. It consists essentially of two chambers which are alternately filled and emptied by compressed air. In principle of operation therefore the machine is related to the automatic acid egg but it does not come within the scope of the Factory Act Regulations (No.31) governing the operation and inspection of acid eggs and closed tanks. The valves controlling the air supply are situated at a height above the chambers sufficient to avoid the acid coming into contact with them. The system gives satisfactory results provided no corrosive fumes are involved as in the case of spent acid. The relation between air pressure and delivery is shown in Fig. 14.

PUMPS

Types of Pumps

Pumps may be divided into three groups:-

1. Reciprocating (plunger or piston).
2. Rotary.
3. Centrifugal.

Reciprocating pumps are seldom used in modern chemical plant and the present tendency is to use centrifugal pumps almost exclusively.

The rotary pump, however, has considerable merits and is a sturdy reliable machine. During the 1914-1918 war it was used very largely in the Government factories, the type most generally favoured being the Douglas Pump.

A detailed analysis of the performance of the Douglas Pump is included in the Ministry of Munitions (D.E.S.) Technical Records "Acid Mixing" (See p.).

CENTRIFUGAL PUMPS

In the present R.O. Factories the centrifugal pump has almost completely replaced the rotary, the chief types being the glandless acid pump and the LaBour self priming pump.

The centrifugal pump (Fig. 15) with a single impeller can operate with heads up to 75 or 100 feet.

Apart from the impeller, there are no moving parts so that, apart from renewing packing and wearing rings, they give little trouble provided they are properly used. They can handle liquids containing a considerable amount of suspended matter without choking or damage.

An important feature is that the impeller speed can be the same as that of the motor so that the pump may be coupled directly with the motor thus giving a compact efficient unit which, with suitable "flame proof" devices, is particularly suitable for use in explosives factories.

The Impeller

With the ordinary open impeller (Fig.16a) there is considerable leakage from the delivery to the suction side. This is prevented by enclosing the vanes between two discs of metal (Fig. 16b). It is then necessary only to ensure a close fit between the circumference of the impeller and the volute and between the hub of the impeller and the casing. This type of impeller is used in the Glandless Acid Pump largely used in R.O.Fs. In the Labour pump, however, the open impeller is sufficient, as there is no volute, the liquid being caught between the vanes of the impeller and discharged directly into the discharge ports.

A further refinement is to place two such impellers back to back thus eliminating the end thrust on the bearing caused by a single impeller.

When the flow of liquid is large and the head small the impeller can be made with inlets in both sides thus balancing the end thrust due to suction. With small quantities of liquid delivered at high head a small "eye" is desirable and the end thrust is then negligible.

GLANDLESS ACID PUMPS

This is the simplest form of centrifugal pump and is used in most R.O.Fs. for all kinds of acid where gravity feed is possible.

The general principle of the pump is clear from the diagram (Fig. 1) the main points being:-

(1). The impeller is suspended from the motor consequently no gland or packing is necessary, only the impeller comes into contact with the acid.

(2) The pump operates when the impeller is flooded with liquid by filling the sump to the required depth. Once started, pumping will continue whilst the liquid level is above the outlet of the sump.

(3) Some of the liquid escapes between the pump shaft and the backcasing into the overflow chamber and is returned to the sump.

(4) When starting the pump, the delivery valve is closed until a good flow of liquid back to the sump is attained and the pump running at full speed. The delivery pipe is then opened and pump proceeds normally.

(5) When pumping is finished the delivery valve is first closed and the liquid returns to the sump.

It is thus possible to keep the pump primed permanently whilst there is sufficient head of liquid on the suction side to flood the impeller and the construction of the pumps enables the full head of liquid on the delivery side to be attained gradually thus reducing wear and tear due to shock caused by rapid changes of pressure. Further as there is a free flow back to the sump no strain is imposed on the system if the valve is closed against the pump.

The most important advantage, however, is the absence of glands and stuffing boxes requiring accurate packing. The only portion subject to serious wear is the impeller though casings have sometimes proved deficient in wearing quality.

As there are no rubbing parts in the pump (a definite leakage clearance being provided round the shaft) it is possible to run these pumps empty as there are no parts requiring lubrication by liquid and the power consumption is negligible. The pump may be run continuously and thus automatically primes itself when the liquid rises in the sump to impeller level.

As the design is simple this type of pump can be made in a variety of materials.

For Spent Acid, Weak Sulphuric Acid, Denitrated Acid (60 - 70% H_2SO_4)	Regulus Metal
For C.O.V. (95% H_2SO_4)	Cast Iron
For Weak and Strong Nitric Acids (40 - 98%)	Stainless Steel

SELF PRIMING PUMPS

In order to operate efficiently the centrifugal pump must be full of liquid and completely free from air. When the feed to the pump is by gravity, this is easily achieved but otherwise some method of priming the pump is necessary.

THE LABOUR PUMP (Fig. 18)

This is effected in the LaBour self priming pump by means of a specially designed casing which includes a separating chamber and an impeller chamber without a volute. The liquid at first passes into the separating chamber (C) and flows back to the impeller chamber by channel (A), air escaping through the delivery pipe. When the impeller chamber and separating chamber are full of liquid the pump functions normally.

Packing LaBour Pumps

The design of the LaBour pump is such that the gland is on the suction side of the pump but a small amount of acid leaks back and in any case the entrance of air must be prevented. Special packings are supplied by the LaBour Company though some factories prefer those obtained from the Crane Company.

The frequency of packing depends upon the service required of the pump and the care with which it is used. Generally, about once a week seems the usual practice though in some cases fresh packing is required every two or three days. This, however, seems exceptional and, if persistent, a search should be made for the cause.

Where self priming pumps are used to raise liquid on the suction side, it is necessary to ensure that there are no air leaks because, however small the entrance of air prevents the pump operating at full capacity.

The design of the suction system should also be such that air locks cannot be formed and that the depth of liquid above the suction inlet is sufficient to guarantee that no air can be drawn in.

For LaBour pumps the impellors are generally made of R.55 alloy for all purposes; the casings are:-

For spent acid, weak sulphuric (60 - 70%) and denitrated acid	- Regulus Metal
For C.O.V. (95% H_2SO_4)	- Cast Iron
For nitric acid all strengths	- Stainless Steel.

Non-metallic Pumps

Chemical stoneware is not, from the engineering standpoint, a very suitable material for mechanical constructions involving moving parts or accurate dimensions.
Pumps can, however, be made satisfactorily of special earthenware and are used in some factories. As might be expected the main trouble is fracture of the impeller and the expense of replacing it as repair is not possible. A compromise is the

earthenware lined pump. Such pumps are used for liquids such as hydrochloric acid which attack any metallic substance but such conditions are seldom encountered in explosives factories and the general experience is that any advantage which superior resistance to corrosion may give is more than balanced by the lack of strength and the impossibility of repair on site with the consequent high cost of complete replacement of parts.

Care and Maintenance of Centrifugal Pumps

1. Erection

As pumps require frequent and careful attention, is is important that they should, so far as possible, be erected in well lighted positions convenient of access. The best workmanship can only be expected if the best facilities for its performance are provided.

2. The suction system should be arranged so that there is no risk of air being drawn in either through leaks or insufficient immersion of the suction end.

3. The pump should be firmly attached to its bed-plate and care taken that it is correctly aligned with the motor so that no strain is transmitted to any part of the pump from the system to which it is connected.

4. Where corrosive liquids are used, care must be taken that none falls upon the bed-plate or foundations as corrosion will eventually cause unevenness and throw the pump out of alignment.

5. Packing

It is extremely important that both the packing and the gland or stuffing box should be perfectly clean and the packing cut exactly to size. When rings are made up from strips, the ends should be cut square and the joints staggered. When packing is completed, the gland should be tightened up with a spanner and then loosened back and make finger tight. As the pump "runs in" the packing should be gradually tightened up. If packing is too tight and becomes hot the lubricant melts out and the packing becomes hard and may even char, with the result that the shaft is scored. Grit and dirt, of course, have the same disastrous effect.

Packing is too often regarded as an "odd job" whereas, in fact, there are few operations in which careful and clean workmanship yield such high dividends in increased life and reduced maintenance costs.

Although the centrifugal pump may be allowed to work against a closed valve without suffering direct injury, it must be remembered that, under such conditions, considerable heat is evolved. A centrifugal pump full of water working against a closed valve will raise the water to boiling point in about 15 minutes.

In the case of acids the rate of corrosion usually increases rapidly with temperature; consequently the wear on the pump is greatly increased.

Cavitation

Much of the trouble due to rapid wear of the pump casing is due to imperfect priming or leaks on the suction side of the pump. Bubbles of air caught by the impellor find lodgement in the casing and a high local pressure is developed when the bubble eventually collapses the casing receives a shock which often repeated wears a hole or springs a leak joint. Unduly rapid wear of the casing especially if it repeatedly recurs in the same place should be noted and the impellor and the suction motion carefully overhauled.

Cavitation is primarily caused by too sudden a change in direction-velocity of the fluid in its passage through the pump and may be due to faulty workmanship or design or to unsuitable operating conditions.

Cavitition may also occur in the passages of a control valve when too great a direction velocity change is caused for example when the valve is partly closed against a high pressure and delivers to a low pressure system.

The effect is that of a local "water hammer" of high frequency and produces a characteristic rattling sound. The pitting caused may aggravate the trouble by causing further changes in the velocity and direction of the liquid.

Inspection

All pumps should be inspected regularly by a workman specially trained for the work, particular attention being paid to :-

(a) the impeller and the shaft - note the extent and nature of wear and corrosion;
(b) the glands, stuffing boxes and packing - note whether they tend to get hot during a run and if there is any sign of scoring on the shaft due to dirty, or otherwise defective packing;
(c) casing and mounting - note if there are any signs of undue corrosion or strain. Where acid drips are frequent, it is advisable to protect the coupling between motor and pump by covering it with a shield of some resistant material.

Records

It is strongly recommended that each pump be given a distinctive number and a card index be kept of all repairs and maintenance. Only in this way can an accurate record be kept of the comparative performance of pumps under varying conditions and undue rapidity of deterioration be detected.

The Cost of Pumping

In chemical works - particularly acid factories - the actual cost of pumping is comparatively negligible. Efficiency of pumping is therefore less important than reliability, low maintenance costs and long life.

The following extract from the records of the Ministry of Munitions D.E.S. 1918, relates to Douglas Rotary pumps but applies equally to all types as regards general principles.

Acid Transport and Handlign

TABLE IV

Cost of Pumping Acid

Duty of Pump	Average temperature of acid pumped	Life of pump in months	Life of pump in acid tons pumped	Cost per ton of Acid Pumped: Power	Maintenance: Material	Maintenance: Labour	Total
				d.	d.	d.	d.
TNT mixed acid from mixers to blenders	25	5½	17,000	0.04	0.50	0.07	0.61
TNT mixed acid from blenders to storage tanks	25	6½	20,000	0.06	0.43	0.07	0.56
TNT mixed acid from storage tanks to nitration houses	25	6½	20,000	0.04	0.43	0.07	0.54
90 per cent. sulphuric acid from concentration plant to mixers	48	2¾	5,500	0.13	1.16	0.16	1.45
93 per cent. sulphuric acid for retort feed from mixer to storage	30	3	12,000	0.11	0.53	0.04	0.68
90 per cent. sulphuric acid from storage to oleum plant	30	6	20,000	0.07	0.32	0.04	0.43

"In this table power is reckoned at 1d. per unit. The maintenance costs, the material cost for which includes cost of new pumps and parts , represent fair averages for the year 1918. It is evident that maintenance charges constitute the heaviest item in the working costs, particularly the cost of material.

As the efficiency of a Douglas pump decreases with continuous working, it is customary, when this figure has declined to below 50 per cent. of the maximum, to operate two pumps at the same time rather than to replace the pumps immediately. This course is taken in view of the low power cost in relation to the cost of renewal of the pump.

The least satisfactory case is shown by the pumps used to deliver 90 per cent, sulphuric acid from the concentration plant to the storage tanks at the mixers. As mentioned elsewhere, the most troublesome factor undoubtedly is the high temperature of the acid, which is mainly responsible for the excessive wear and tear. This is seen from the fact that, when the temperature is reduced to about 20°C., the cost of pumping the same variety of acid is reduced approximately 70 per cent. Centrifugal pumps have since been substituted to some extent for Douglas pumps for use with this variety of acid.

In conclusion, it may be stated that the duty for which the Douglas pump can be said undoubtedly to have justified its selection is that of pumping mixtures of nitric and sulphuric acids. Provided that the acid be kept cool, little trouble is experienced."

Efficiency of Centrifugal Pumps

The operation of the centrifugal pump depends upon imparting velocity to the liquid by means of an impeller. When the liquid leaves the impellor and is thrown out into the casing, this velocity head is converted to static head.

The performance of the pump, therefore, depends upon:-

1. The speed of the impeller;
2. the design of the impeller;
3. the efficiency of the conversion from velocity to static head which depends on the design of the casing in relation to the speed and design of the impeller.

Acid Transport and Handling

In practice the efficiency is also affected by the design of the pipe line whilst the life of the pump is very largely determined by the nature of the liquid pumped and the care with which the pump is treated.

As these pumps are usually coupled direct to the motor they are in effect constant speed machines.

The effect of the various factors upon the performance of the pump is indicated in the curves (Figs. 19 and 20).

It will be observed that the efficiency curve rises to a maximum and, therefore, for any pump there is a definite set of optimum conditions.

For example, the pump represented in Fig. 20 would work most efficiently (about 65%) when it delivers about 110 g.p.m. at 150 ft. head. The corresponding optimum condition for the pump represented in Fig. 19 are 45 g.p.m. at 32 ft. head and 65% efficiency, whereas at 45 g.p.m. the first pump would develop nearly 160 ft. head but the efficiency would be less than 50% whilst at 32 ft. head the efficiency would be about 45%.

It is the object of the maker to produce as flat an efficiency curve as possible, so as to give the greatest possible flexibility in operation and, on the other hand, the purchaser should endeavour to use the pump under conditions consistent with the maximum efficiency.

In this connection it should be noted that apart from the loss of efficiency due to running the pump under unsuitable conditions, e.g., leaving the pump running idle, there is an adverse reaction on the whole power circuit if multi-phase current is used. Under such conditions, current is thrown out of phase and this affects the efficiency of all the other machines in the circuit.

The Selection of Pumps

The selection of a pump of the required capacity depends, in the first place, upon:-

(1) the amount of liquid to be moved in a given time;
(2) the height to which it must be raised;
(3) nature of the liquid;

It has also to be decided:-

(a) At what speed at which the pump shall work (R.P.M.);
(b) the diameter of pipe to be used.

The cost of the line depends upon the weight of metal and this increases considerably more rapidly than the diameter as the larger diameter demands a greater wall thickness. This, however, may be more than compensated for by the lower power consumption in pumping and hence lower maintenance charges on the pump and less tendency to choking in the pipe system. The first step is therefore to estimate the total amount of work required of the pump and to express it in terms of equivalent head of liquid. The elementary mathematical treatment of the problem is discussed in the Appendix (p.).

The total dynamic head is the height of a column of water equivalent to the algebraic sum of all the pressures which the pump has to overcome in moving the liquid from one place to another. This includes:-

1. Raising the liquid to a given height;
2. overcoming resistance due to friction against the pipe surface and to the various obstructions (valves, bends, changes of dimensions and so forth in the system).

It will be noted that with viscous flow the frictional resistance is proportional to the viscosity of the liquid, whilst with turbulent flow viscosity is included in the Reynolds number. In the case of a centrifugal pump operating at constant speed the volume delivered is independent of the viscosity and gravity of the liquid but the power required is affected by both. The efficiency of operation is therefore affected. As viscosity varies greatly with temperatures, neither can be neglected in calculating the specification for the pump.

The loss of head due to bends and various fittings is given in terms of equivalent length of pipe in Appendix Table (p.).

It is thus possible to calculate with reasonable accuracy the length of uniform pipe equivalent to the system under investigation and hence the total equivalent head of liquid which the pump must overcome.

In practice, one has invariably to allow for a certain amount of deposit on the surface of the pipe with consequent increase in friction and reduction of effective diameter. This is particularly the case in dealing with acids, and therefore, the selection of pipe diameter should err on the generous side.

Two cases have to be considered:

1. Continuous pumping, e.g. the feed to a denitration tower.
2. Discontinuous pumping, e.g. the transport of stated quantities of acid from one plant to another at intervals.

The former appears the more exacting as regards efficiency and reliability of the pump over long periods but in practice, the second requires no less care - the pump must be relied upon to deliver the requisite quantity of acid in the stipulated time whenever desired and the continual stopping and starting of the pump involves wear and tear to an extent which, especially with unskilled labour such as must be accepted in war-time, not infrequently more than balances the effects of continuous operation.

ROTARY PUMPS

The rotary pump consists essentially of two rotating parts, the simplest form of which is illustrated in Figure 21. Liquid is carried round in the cavities from the suction side and forced out to the delivery side when the spurs engage.

In the simplest forms, the flow of liquid naturally tends to be pulsating - the liquid being forced out in gushes as the parts rotate. Very little wear is necessary to cause considerable loss due to leaking back to the suction side.

A more satisfactory type is the Douglas pump (Fig.22) which was used very extensively in the last war and found to be particularly successful with mixtures of sulphuric and nitric acid. This type of pump is still in use at some factories, [notably Royal Gunpowder Factory Waltham Abbey.]

Following is a summary of the experience with these pumps at one of the Royal Ordnance Factories.

TABLE VI

Part	Material	LIFE: Waste Acid (1) 60% H_2SO_4, 20% HNO_3, 20% Water	LIFE: Waste Acid (2) 68% H_2SO_4, 13% HNO_3, 19% Water
Casing		Indefinitely	Indefinitely
Crescent		"	"
Rotor Drum		4 - 6 months	3 months
Rotor Pin	Stainless Steel	3 - 4 months	4 - 6 months
Gasket	Klingerite 1000 - 1/54"	Indefinitely	Brown paper and mineral jelly Renewed on repair
Packing	Blue Asbestos and Mineral Jelly		
Carrier		3 - 4 months	Indefinitely
Shaft		3 - 4 months	Stainless steel shaft. Indefinitely

The impellor blocks travel in the channel between the casing and the crescent attached to the pump body, and push the liquid before them towards the delivery side. The drum makes $1\frac{1}{2}$ revolutions for each revolution of the impellor and is adjusted so that an impellor block enters the cavity on the delivery side and drives out the liquid at the same time as another impellor block leaves the cavity on the suction side and, in doing so, admits a corresponding amount of liquid. In this way, the flow of liquid is kept practically steady.

The capacity of the pump depends on the speed of rotation and the capacity of the main circulation chamber. The acid in the cavity of the drum merely acts as a valve, the amount expelled at one side balancing that taken in on the other and the volume of the cavities compensates for the volume of the impellor blocks.

Acid Transport and Handling

The circulation chamber extends for 2/3 of the circumference but as the drum makes $1\frac{1}{2}$ revolutions for one revolution of the impellor, the volume of the delivery for each revolution is equal to the volume of the circulation chamber if completed to full circle.

Example - a 3" pump:

Mean diameter of circulation chamber	$12\frac{1}{2}$"
Width " " "	$2\frac{1}{2}$"
Depth " " "	4"

Speed of impellor 75 r.p.m.

Effective volume of chamber $= 3.1416 \times 12\frac{1}{2} \times 2\frac{1}{2} \times 4$
$= 384.8$ cubic inches

Volume pumped per hour $= 384.8 \times 60 \times 75$
$= 1731600$ cu. ins.
$= 1002$ cu. ft.
$= 27.9$ tons water

In practice, this pump delivered 47 tons of acid, Sp.Gr. 1.835 which is equivalent in volume to 25.6 tons of water.

$$\text{Efficiency} = \frac{25.6}{27.9} = 91\%$$

Corresponding data for a new 2" pump gave an efficiency of 80%.

The speed of the Douglas pump is slow compared with that of the centrifugal (about 1/10) and this makes for durability.

There is a tendency to "seize up" if the pump stands idle for more than a day and therefore a stand-by pump should always be run for a few minutes at least once a day.

The following records from the last war illustrate the kind of service which may be expected from such pumps. An important feature is the greatly reduced life when dealing with acids at a high temperature.

1. T.N.T. mixed acid (79.5 H_2SO_4, 17.8 HNO_3) above 32°C. caused either the impellor or shaft to seize up.
2. <u>90% sulphuric acid</u>. The life of the pump with the acid at 45°C. was less than half that with the acid at 29°.

TABLE VII

Data from Operation Records of Douglas Pumps

Size of Pump	Duty of Pump	HP of electric motor used to drive pump	Length of pipe line in feet	Diameter of pipe line in inches	Static head in ft.	Average tonnage of acid pumped per hour	Life of pumps in months	Life of pump in tonnage of acid pumped
3 inch	T.N.T. mixed acid from mixers to blenders	5	150	4	11	31.0	5½	17,500
"	M.N.T. mixed acid from mixers to blenders	5	150	4	11	32.0	19	15,800
"	T.N.T. mixed acid from blenders to storage	5	200	4	27	32.5	6½	20,600
"	M.N.T. mixed acid from blenders to storage	5	200	4	27	32.0	19	15,800
"	T.N.T. mixed acid from storage to nitration houses	5	2,400	4	3	32.5	6	19,800
2 inch	M.N.T. mixed acid from storage to M.N.T. section	-	3,600	3	-	16.0	19	15,800
"	93 per cent. sulphuric acid for retort feed from mixer to storage	4	1,830	3	11	12.0	3	12,000
"	90 per cent. sulphuric acid from Gaillard concentrators to storage	2½	540	3	29	10.0	2¾	5,500
"	90 per cent. sulphuric acid from storage to Grillo oleum plant	2½	1,830	3	11	14.5	6	20,000

Friction due to pipe lines is an important item in the efficiency and length of service of this type of pump and the delivery line should always err on the generous side - a 2" pump should be fitted with a 3" delivery pipe and a 3" pump with a 4" delivery pipe. An increase of as much as 25% in the life of the pump may be obtained in this way.

EXPERIENCE IN ROYAL ORDNANCE FACTORIES

PUMPS

Generally speaking Centrifugal Pumps have superseded other pumps though rotary pumps of the Douglas type are still in use and also some acid eggs: - notably at Waltham Abbey.

The majority of pumps are either LaBour self priming pump or glandless acid type.

The LaBour pump in some cases gives an undue amount of trouble with regard to packing but this is largely accounted for by the dearth of skilled labour and in some cases the quality of the packing appears to be at fault. Only in one case is it suggested that trouble with the glandless acid pump in other directions (not specifically stated) more than balances the advantage due to absence of glands and therefore the troubles associated with packing. This certainly should not be the case with a properly constructed and carefully operated pump. Entrainment of air in the suction system and defects in the design of the casing or material used may account for unduly rapid break-down and some cases have arisen, especially in the early part of the war, where this has occurred.

Sulphuric Acid

For acid over about 75 per cent H_2SO_4 both glandless acid and LaBour pumps have been used.

Regulus metal, Alloy R.55, stainless steel and cast iron are all in use. Stainless steel is mentioned in one case as being good but is of course expensive. The use of R.55 alloy for impellors in the LaBour pump is generally recommended. For the glandless acid pump, cast iron is satisfactory. Regulus metal is apt to wear out rather quickly. The glandless acid pump appears preferable for low heads and intermittent working.

Packing for the LaBour pump

Some criticism has been raised concerning the packing recently supplied for the LaBour pump as not being equal to the old and some factories are buying their packing direct from Crane Company.

Weak Sulphuric Acid, 60 - 75%

Regulus metal is generally used for glandless acid pumps. A Hathernware stoneware pump has proved satisfactory at Ardeer but trouble due to breakages is reported. Carelessness and lack of competent workmen is blamed for this. LaBour pumps, preferably with an impellor of R.55 are proving satisfactory. At one factory an "acid bronze" containing 89.3% copper and 10.7% of 5% phospher tin is used.

Nitric Acid (Concentrated)

Stainless steel is mainly used, though R.55 has proved satisfactory. With glandless acid pumps an aluminium sump is provided.

With LaBour pumps, packing presents some difficulty and some factories prefer "Chlornite" to the standard LaBour packing. A pump of the Guthrie type is preferred to LaBour by one factory but another considers the LaBour better.

Weak Nitric

Stainless steel is generally used and in the case of LaBour pumps there is the same complaint of packing troubles and "Chlornite" packing is preferred in some factories.

Spent and Mixed Acid

Regulus metal is generally used and glandless acid pumps are more common than LaBour though one factory appears to think that LaBour pumps might be of advantage. The Douglas Rotary pump which was highly esteemed for this class of acid during the last war, is still proving satisfactory in this war at some factories.

SAFETY PRECAUTIONS*

The dangers in handling acid liquids in R.O.Fs are of two kinds:-

(1) Acid burns caused by actual contact with the acid;
(2) Inhaling nitrous vapours given off by nitric acid and mixtures of nitric and sulphuric.

The first concern of the management is to prevent accidents. There are two important methods:-

(1) Design of the plant so that the operators are not unnecessarily exposed to danger.
(2) Provision of protective clothing and appliances.

Should an accident occur, it is important that:-

(1) The injured person should receive skilled attention as quickly as possible;
(2) first aid materials should be immediately available;
(3) operatives should know where they are and how to use them.

The provision of first aid materials involves some difficult questions. There is a danger that:-

(a) first aid materials on the plant may become contaminated;
(b) be unskilfully applied;
(c) the usage of these in any case leads to breach of the rule that all injuries however slight must be dealt with at the surgery. The tendency is therefore to reduce first aid materials to the absolute minimum necessary for safety till the injured person reaches the Surgery.

*N.B. The whole subject of safety precautions and factory hygiene has recently been dealt with in "Factory Health and Hygiene" (Memorandum No.6 Ministry of Supply R.O.F. (Explosives) 51404) which should be consulted.

Acid Transport and Handling

Design of Plant

(a) When liquid is being transported by hand, the obvious danger is due to spills. Transport in this case covers carrying samples from plant to test bench or laboratory as well as larger quantities in carboys. In either case a clear passage-way free from obstruction is the first essential. If stair-cases are unavoidable, wide slip-proof steps at a reasonable angle (less than 45 to the horizontal is recommended) should be provided. This is somewhat a council of perfection as the necessities of the plant often exercise a determining influence but the object should be to approach the ideal as nearly as possible.

(b) Carboys should never be used if it can be avoided. When however they must be used, they should always be enclosed in cages packed with straw and the straw should be damp. Single carboys should always be transported in a wheeled carrier and when possible should be emptied by means of a carboy syphon.

When in special cases these mechanical appliances cannot be used:-

(1) Carboys should be carried by two men provided with acid-proof gloves, trousers and boots.
(2) The carboy should be securely sealed and not too full.
(3) There is considerable danger of cutting the hands on the metal basket particularly when lifting heavy carboys (e.g. filled with C.O.V.) The grip should therefore be protected by rags or some stout material in addition to the acid proof glove.

Carboy containers should be carefully inspected. It frequently happens that the iron-work becomes corroded with the result that the cage may collapse under strain with disastrous consequences.

2. Transport through pipe lines

The liquid in this case is invariably under pressure and danger arises through:-

(1) leaks from pipe line;
(2) leaks from valves;
(3) unexpected release of acid left in pipe lines during repairs;
(4) sudden break-down of valve packing or fracture of valve during attempts to adjust or repair it whilst in actual service.

Leaks in Pipe line

When there is considerable pressure, leaks may result in a fine stream of acid being projected to a considerable distance, which is a serious danger particularly during hours of darkness.

So far as possible:-

(1) pipe lines should be so placed that men do not have to walk under them. If this is unavoidable catch trays should be provided particularly in the cases of highly corrosive liquids such as hot nitric acid and especially at points such as the joints between sections where experience shows that leaks are most likely to develop.

(2) it should be unnecessary to point out that there should always be plenty of head-room though this is often forgotten particularly when the pipe line crosses a stairway or ladder.

(3) Acid pipe lines should not be laid near electric cables or where leaks from the pipe line may come into contact with the cable.

(4) when a pipe line has to be repaired, it is most important to ensure that it is completely empty before work is started upon it. In any case when breaking a pipe line, a man should never stand in the line of discharge. This of course involves proper design of the plant and pipe line. It must be possible for the operator to stand clear and do his work in security and reasonable comfort as regards physical conditions.

(5) where a branched line is served by more than one pump, both pumps must be blanked off and the line passed as safe for breaking by a responsible authority before work is started. This of course is most important when the pumps in question are widely separated or under the control of different operators. An alternative safeguard is to remove the fuses from the starting gear.

(6) pipe-lines should be frequently inspected. Breakdown is often revealed in the early stages by the appearance of salts produced by corrosion e.g. sulphate on lead or iron pipe.

3. Valves and Cocks

(1) Valves and cocks should always be in easily accessible positions with plenty of room round them for the operative to work upon them.

(2) They should be frequently inspected and packing (where used) replaced at the first signs of corrosion or breakdown.

(3) When a valve sticks and cannot be moved by normal application of force, the line should be emptied and the valve properly inspected and readjusted. Attempts to force a valve which has any pressure of liquid behind it is a frequent source of serious accidents. Sticking is often the result of corrosion due to the use of an unsuitable material for the valve or use of the wrong type of packing.

4. Acid Tanks and Vats

Acid storage tanks and vats should be placed on good sound foundations. Concrete is generally used but is open to the objection that it is rapidly destroyed by acid. The resulting uneveness of the foundations may throw excessive strain upon the tank. Acid proof brick is preferable where possible. Tanks should be so placed that complete inspection and if necessary minor repairs can be conveniently made on site.

The inspection and repair of these acid tanks comes within the scope of the Factory Act, Chemical Regulations 1922 Nos. 7, 8 and 9 which must be exposed in the factory in such a position that all workers can read them.

The tops of open tanks should be at least 3 ft. above floor level and if it is necessary to use a stool or ladder to look inside, it must not be so high that a man can get more than waist height above the top of the tank.

In the case of small feed tanks on the upper staging of a plant precautions must be taken to prevent overflows or leaks falling upon operatives on lower staging.

In the case of closed tanks, e.g. boiler tanks there should be free access of air to prevent development of pressure due to changes of temperature, chemical reaction etc.

5. Protective Clothing and Appliances

A complete suit of protective clothing is supplied to acid workers. The following points require special attention:-

(1) Jackets - These should be kept fastened up and sleeves should not be too long or wide - many accidents are caused by loose clothing catching in things.

(2) Trousers - the bottoms should be tucked inside the socks.

(3) Boots - Rubber boots should be carefully inspected for holes and conditions of the treads. Defective treads often cause slips with serious consequences.

(4) Gloves - Rubber gloves should be worn when handling acids. Long sleeved gauntlets are generally not desirable. When circumstances demand their use the sleeve should not be too wide. Jacket sleeves should of course always be tucked inside gloves or gauntlets, not rolled up. It is important to examine gloves carefully for slits especially between the fingers.

(5) Goggles - It is difficult to get men to wear goggles particularly on plants where there is condensation or the temperature is high. Their use should be insisted upon wherever a man is engaged upon work where acid splashes are likely and especially when handling pipe lines and valves where acid is under pressure.

(6) Gas masks - these should be worn wherever nitrous fumes are present or when entering a closed space which has not been tested.

6. PHYSIOLOGICAL ACTION

It should always be remembered that the conditions in a chemical works are favourable to the development of septic conditions in even trivial wounds. Prompt attention to all injuries is therefore essential.

(1) Sulphuric Acid

The immediate effect of sulphuric acid is dehydration of the tissues. If the acid is removed quickly no very serious effect beyond a rather painful blister, which heals fairly quickly, results. More prolonged contact causes actual charring and distruction of the tissue which may become septic and in any case is slow to heal and usually leaves a permanent scar.

(2) Nitric Acid

The action is more rapid and drastic than that of sulphuric. The tissues are almost immediately destroyed and unless the acid is quickly removed, deep seated and very painful wounds result which are slow to heal and readily become septic.

(3) Nitrous Acid

Susceptibility to nitrous fumes varies greatly. Those who suffer from chest and lung troubles are very much more susceptible than healthy young persons.

The great danger lies in the fact that the effects are frequently not apparent until several hours after exposure. When the immediate irritation has disappeared, the subject is tempted to think that no further trouble will arise.
Often, however, the serious effects develop many hours later.
If the effect appears after the subject has left the factory the cause of his collapse and the best method of treatment are not likely to be known nor the proper treatment to be available which greatly increases the danger of serious complications. It is therefore important that any operative who has been subjected to nitrous fumes should be examined as soon as possible by a competent authority. Until that is possible the patient should lie down in the fresh air.
On no account should a person subject to even slight gassing be allowed to proceed unaccompanied to the surgery.
Neglect, particularly in the case of older men and those with "weak chests" may prove fatal. When exposed unprotected to nitrous fumes it is important not to breathe deeply.
Rapid short breaths should be taken thus restricting the attack of the fumes to the upper part of the lungs.

(4) Other gases and vapours

The danger of "gassing" is not confined to nitric and nitrous fumes.

Acid tanks, especially iron tanks used for sulphuric acid are liable to contain appreciable quantities of arsine and/or sulphuretted hydrogen both of which are extremely poisonous. The production of these gases, and of hydrogen is accelerated by the presence of water which may be absorbed from the atmosphere when a tank is left practically empty for any length of time.

Gas masks should be regularly inspected and recharged according to a definite schedule. They should be disinfected after use and passed by the recognised authority (usually the works Safety Officer) before being again put into service.

7. First Aid on the Plant

(1) Acid Burns

The most effective treatment is the immediate application of large quantities of water - with sulphuric acid a little water is worse than useless - it merely raises the temperature.

Baths full of clean tepid water should be placed in convenient position. Immediate total immersion of the injured part should be the objective.

(2) Injury to the eye

A suitable eye wash is ½% Sodium Bicarbonate. This should be kept in a special and distinctive bottle on every plant together with an eye bath. All operatives should be instructed in its proper use.

It is important that the bottle of eye wash be distinctive. If an ordinary sample bottle be used there is a danger or a mistake which may have very serious consequences.

(3) Gassing Cases

For reasons already explained this is a matter for skilled treatment at the first aid centre. Those who have been subjected to fumes should be sent to the surgery even if the immediate apparent effects are only slight. They must be accompanied by another person.

Acid Transport and Handling

Operatives whose work compels them to enter a fume laden atmosphere should be compelled to wear gas masks and if the spaces are enclosed e.g. a tank entered through a manhole should have a life line, and a companion in constant attendance outside the tank.

This contingency, however, should be avoided if at all possible. The space should be purged and passed by a competant authority after tests according to regulations, before any one is allowed to enter it.

APPENDIX I - MATHEMATICAL DATA

Flow of Liquid through Pipes

In addition to raising the liquid to a given height, the pump has to provide sufficient energy to overcome the frictional resistance of the walls of the pipe and the resistances of obstacles such as valves and of changes of direction and velocity caused by bends in the line and alterations of diameter.

For purposes of calculation, the total resistance of all these items is calculated as equivalent head of liquid.

In the case of chemical plant handling such materials as sulphuric and nitric acid the problem is not capable of accurate solution as, apart from irregularities in the pipes themselves, the action of the acid rapidly alters the nature of the surface and hence the frictional resistance. In some cases, it may even alter the effective diameter of the pipe to an appreciable extent. In practice, therefore, the choice of plant is largely determined by the results of experience and practical tests.

It is desirable, however, to consider briefly the main factors involved in determining the amount of work which will be demanded of the pump and the extent to which this may be modified by the dimensions and design of the pipe line and attachments.

Rate of flow - Below a certain critical velocity, the flow of liquid is streamline or viscous, that is, it obeys the well known laws of viscous flow

$$H_f = \frac{32\eta Lv}{gD^2P} \qquad (1)$$

H_f = head of liquid required to overcome resistance

η = Viscosity (lbs. per ft. per sec.)

P = density (lbs. per cu. ft.)

L = length of pipe (ft.)

v = velocity (ft. per sec.)

D = diameter (ft.)

g = gravity (32.2 ft. per sec.^{2}).

Above the critical velocity, flow is turbulent, and does not obey the simple law.

To meet this case, various formulae have been evolved, the usually accepted being:-

(a) For clean new iron pipes

$$H_f = \left[0.0001906 + \frac{0.01171}{Re^{0.38}} \right] \frac{Lv^2}{D} \quad \cdots (2)$$

(b) For smooth circular pipe, e.g. brass, copper, etc.

$$Hf = \left[0.0000870 + \frac{0.00777}{Re^{0.38}} \right] \frac{Lv^2}{D} \quad \cdots (3)$$

where Re is the Reynolds number.

It has been shown that when Re is less than 2000 flow is viscous and that about 4000 it is turbulent. Between these two values, it is of an indefinite character.

The Reynolds number is therefore a criterion of the type of flow occurring in a specific case. It is a dimensionless number.

$$Re = \frac{Du\rho}{\eta}$$

The relation between the loss of head due to friction and the Reynolds number is given in the form of a graph which is reproduced in most of the standard handbooks.

It will be noted that equations (2) and (3) can be written in the form:

$$H_f = x \frac{Lv^2}{D}$$

Values of x for various values of Re are given in Table 4 and graphically in Fig. 25.

The accuracy of these formulae is between ± 5 for (2) and ± 10% for (3).

In addition to the friction of the pipe, the other factors to be taken into account are:-

1. Valves and bends

The resistances for the more common types of valves and bends have been experimentally determined and are given in terms of equivalent length of straight pipe. A list of these is given in table 5. For bends other than right angles the formulae:-

$$H_f = \sin^2 \theta \frac{v^2}{2g}$$

when θ = angle of the bend.

2. Sudden changes of diameter

(a) increase:

$$H_f = \frac{(V_1^2 - V_2^2)}{2g}$$

(b) contraction:

$$H_f = K \frac{V_2^2}{2g}$$

where V_1 and V_2 = the velocities before and after the change respectively.

For general purposes K may be taken as:

Ration of cross section	K
0.90	0.1
0.75	0.2
0.50	0.3
0.25	0.4
0.00	0.5

3. Entrance loss, e.g. from tank may be taken as special case, i.e. ratio of areas = 0.00 and K = 0.5.

4. Exit loss from tanks may usually be ignored, i.e. ratio of areas = infinity, K = 0.0.

5. Velocity head = $P\frac{V^2}{2g}$

6. Coils

The resistance due to coils is complicated by the fact that the velocity at which flow becomes turbulent depends upon the curvature of the coil.

The problem was investigated by C. M. White (Proc. Roy. Soc. A. 1929. 123, 645) and a summary of the subject is given by H. M. Spiers (Technical Data on Fuel, London 1937 p.76).

The tables below are based on C. M. White's work and are quoted by Spiers.

The resistance due to an equivalent length of straight pipe is calculated and then multiplied by the appropriate factor.

For streamline flow the resistance is a function of the expression

$$f = \frac{vD\rho}{\eta} \times \left(\frac{D}{2R}\right) 0.5$$

where D is the diameter of the pipe and R the radius of the coil.

$\left(\frac{vD\rho}{\eta}\right) \times \left(\frac{D}{2R}\right)^{0.5}$	Factor f	$\left(\frac{vD\rho}{\eta}\right) \times \left(\frac{D}{2R}\right)^{0.5}$	Factor f	$\left(\frac{vD\rho}{\eta}\right) \times \left(\frac{D}{2R}\right)^{0.5}$	Factor f
10 or less	1.00	150	1.71	1100	3.76
20	1.05	200	1.90	1200	3.90
30	1.12	300	2.22	1300	4.04
40	1.19	400	2.48	1400	4.17
50 (A)	1.25	500	2.71	1500	4.30
60	1.31	600	2.90	1600	4.43
70	1.36	700	3.09	1700	4.55
80	1.41	800	3.27	1800	4.66
90	1.46	900 (B)	3.44	1900	4.75
100	1.50	1000	3.61	2000 (C)	4.93

(A) At values exceeding this, turbulent flow exists in coils having $\frac{2R}{D} = 2050$

(B) At values exceeding this, turbulent flow exists in coils having $\frac{2R}{D} = 50$

(C) At values exceeding this, turbulent flow exists in coils having $\frac{2R}{D} = 15.15$

For turbulent flow

$$f = e^{\frac{\pi D}{R}}$$

where D = diameter of the pipe

R = Radius of the coil

e = 2.718

$\frac{D}{R}$	.01	.02	.03	.04	.05	.06	.07	.08	.09	.10
f	1.03	1.06	1.10	1.13	1.17	1.21	1.25	1.29	1.33	1.37

$\frac{D}{R}$	.12	.14	.16	.18	.20	.22	.24	.26	.28	.30
f	1.46	1.55	1.65	1.76	1.87	2.00	2.13	2.26	2.41	2.57

Acid Transport and Handling

Practical Application

Data concerning the pipe lines in a typical R.O.F. T.N.T. factory are given in Table.

The normal limits for acid flow appears to be from 1000 gallons per hour through a 2" pipe to 6000 gallons (an extreme case) through a 3" pipe and the average may be taken as about 3000 gallons per hour through a 2" pipe.

Taking the case of C.O.V. (96% H_2SO_4)

Viscosity	=	19.57 c.p.	=	0.0131 British units
Density	=	1.834	=	115 lbs./cu. ft.

the Reynolds numbers are

(i)	6000 g.p.h. 3" pipe	Re	=	11950
(ii)	1000 g.p.h. 2" pipe			2986
(iii)	3000 g.p.h. 2" pipe			8962

Flow is definitely turbulent in two cases and indefinite in the third. For general purposes therefore the flow in factory pipes may be taken as turbulent.

Using the formulae (2) and taking the Reynolds criteria as 12000, 4000 and 9000 respectively the resistance of a pipe line may be calculated assuming turbulent flow.

(i)	6000 g.p.h. 3" pipe	=	5.448 cu. ft. sec.
	Re	=	11950
	L	=	100 ft.
	Friction head (formulae 2)	=	28.09 ft.
(ii)	1000 g.p.h. 2" pipe	=	2.042 ft. sec.
	Re	=	4000
	L	=	100
	Friction head H_f (formulae 2)	=	0.673

Re = 4000 is the lowest value at which turbulent flow is definite.

If stream line flow be assumed then

$$Hf = \frac{32 \eta Lv}{gD^2 \rho}$$

$$= \frac{32 \times 0.0131 \times 100 \times 2.042}{115 \times 32 \times 0.1667 \times 0.116}$$

$$= 0.8371$$

It would, in practice, be safer to assume the higher figure in view of the irregularities in chemical pipe lines and the changes in resistance due to deposits etc. formed in operational processes.

(iii)	3000 g.p.h. 2" pipe	=	6.124 ft. per sec.
	Re	=	9000
	Friction head		3.636

It will be observed that the friction head rises very rapidly with increasing rates of flow. Thus using the same methods of calculation for a flow of 200 gallons per minute through pipes of 2, 3 and 4 inches diameter the friction head per 100 feet is

2" pipe	133 ft.
3" "	40 "
4" "	10 "

Coils

A typical case is that of the preheater in a denitration plant the dimensions of which are usually $1\frac{1}{2}$" diameter pipe length 100 ft. radius of coil 2'6".

The rate of flow of spent acid is about 10000 lbs. per hour say 600 gallons.

Velocity is therefore 2.18 ft. per second (say 2.2).

The temperature varies from about 15°C. at the inlet and 70° at the exist.

Acid Transport and Handling

Taking 40° as an average

Density = 1.6 = 99.68 lbs. per cu. ft. (say 100)

Little data is available as to the viscosity of spent acid but is of the order of 6 to 7 c.p. (say) 0.004 British units.

$$\text{Reynolds Criteria} = \frac{\frac{1}{8} \times 100 \times 2.2}{.004} = 6870$$

flow is turbulent and using the formulae for a straight pipe

Friction head = 0.987

$$\text{Factor for the coil } \frac{D}{R} = \frac{1\frac{1}{2}''}{15''} = \frac{1}{10} = 1.37$$

Friction head for coil is therefore 1.37 x 0.987
= 1.36 ft.

Centrifugal Pump

The general principles of the centrifugal pump may be summarised as follows.

Liquid entering the eye of the impellor is forced along the blade and finally is thrown off the tip. The velocity and direction at this point is determined by the angle of the blade and its peripheral velocity as shewn in fig. 23.

V_B - Velocity parallel to the surface of the blade.

V_T - Peripheral velocity (tangential to the circle of rotation).

V_R - The resultant velocity.

β - Angle of the blade.

then $V_R = \sqrt{V_B^2 + V_T^2 + 2 V_B V_T \cos.\beta}$

The direction of V_R is given by the formula

$$\sin. \alpha = \frac{V_B}{V_R} \sin \beta$$

Neglecting the viscosity of the liquid, the pressure increase due to the pump will vary as the square of the fluid velocity.

The power input is proportional to the cube of the speed of rotation.

The following relations obtain if:

Q = capacity (galls. per min.)
H = head developed
N = revs. per min.
P = power consumption (shaft H.P.)

Q is proportional to N
H " " " Q^2
P " " " Q^3

Assuming two pumps to be of exactly similar design and neglecting disturbing factors such as viscosity of liquid, surface roughness and irregularities, etc.

$$\frac{Q1}{Q2} = \frac{N1}{N2} = \frac{H1}{H2} = \frac{Q1^2}{Q2^2} = \frac{N1^2}{N2^2}$$

$$\frac{P1}{P2} = \frac{Q1^3}{Q2^3} = \frac{N1^3}{N2^3}$$

These similar relations do not apply in practice over extended variations or for small pumps dealing with viscous liquids. The efficiency of centrifugal pumps increases with size and speed of rotation.

The above relations may be further summarised in the equations:

(1) $\frac{QD^2}{\sqrt{H}}$ = constant and (2) $\frac{ND}{\sqrt{H}}$ = constant, hence

(3) $\frac{N\sqrt{Q}}{H^{0.75}}$ = constant

The expression $\frac{NQ^{\frac{1}{2}}}{H^{0.75}}$ is termed the specific speed of the pump and any one value for this includes all the conditions necessary for similar flow of liquid in pumps of similar geometric design so that, knowing the values for any one pump of the series, those for any other can be calculated by substituting the new values in the equations.

It follows from this expression that low specific speeds require high head with low capacity and speed of rotation. A high head demands a high peripheral velocity so that a large impeller with comparatively small passages is necessary. These small passages naturally increase the friction losses and therefore there is a limit to which design can be pursued in this direction. Generally the lowest practical limit for the specific speed is about 1,500 when Q is measured in gallons per minute. The upper limit is determined by the erosion due to fast moving liquids and the ability of the pump to withstand the vibration and stresses set up. It is, of course, desirable to fix the specific speed as high as possible so as to reduce the dimension of the pump to a minimum.

In practice, it is not possible to use speeds above those of the electric motor, i.e. 3,600 maximum and usually for chemical works about 2,000.

The theoretical H.P. required to raise a liquid is:

$$H.P. = \frac{QPH}{550}$$

where:

P = density (lbs. per cu. ft.)
H = total head (ft.)
Q = cubic ft. per sec. delivered

In practice, the efficiency of pumps used in acid factories, when in good condition, is between 60 and 70%.

It will be noted that, at any given speed, the volume of liquid raised by the pump is independent of the specific gravity as the process is essentially one of converting energy (velocity head) to potential energy (pressure head). On the other hand, the power required is proportional to the density of the liquid and both viscosity and density are factors in determining the friction head.

This is an important consideration when changes of temperature are involved as both viscosity and density are reduced. Thus with C.O.V. (95% H_2SO_4):

	25°C.	75°C.
Viscosity	19.57 cps.	5.32 cps.
Density	1.838	1.781

The friction head at 75°C. is therefore:

$$\frac{5.32 \times 1.781 \times 100}{19.57 \times 1.838} = 26\%$$

of that at 25°C. At 25°C. the friction head is 35 times that of water under the same condition but at 75° it is only eight times. It is therefore necessary to take into account the physical properties and the temperature of the liquid when selecting a pump and to bear in mind that, unless otherwise stated, manufacturer's data concerning pump performance always relate to water at ordinary atmospheric temperature.

It some cases, it is also necessary to consider the vapour pressure of the liquid. Liquid on the suction side of the pump is under reduced pressure and, if the vapour pressure of the liquid is high compared with the pressure in the pump, bubbles of vapour are formed which, on passing to the pressure side, collapse thus producing the phenomenon of cavitation already discussed (p. 29).

When it is necessary to reduce the delivery of the pump, this may be done either by reducing the speed or throttling the exit. The former is to be preferred as throttling reduces efficiency and increases erosion of the throttle. There are, however, limits to this as shown in Fig. 24.

Reducing speed lowers the general level of the head capacity. If the effective head of the system increases in such a way that the system head curve cuts the head capacity curve in two places, an unstable condition may arise. Small momentary changes in the head capacity cause a rapid oscillation between the two points giving rise to heavy vibration throughout the system.

Table 1

4. Specific Gravity - lbs. per cu. ft.

Sp. G.	lbs. per cu. ft.
1.0	62.3
1.1	68.53
1.2	74.76
1.3	80.99
1.4	87.22
1.5	93.45
1.6	99.68
1.7	105.91
1.8	112.14
1.9	118.37
2.0	124.60

Table 2

5. Viscosity - cps. - lbs. ft. sec.

cps.	lbs. ft. sec.
1	0.000672
2	0.001244
3	0.001916
4	0.002488
5	0.003360
6	0.003832
7	0.004704
8	0.005376
9	0.006048
10	0.006720

TABLE 3.

Rate of flow through pipes

feet per sec.

Diameter inches Area of cross section sq. ft.		1 0.005455	1½ 0.01227	2 0.02181	2½ 0.03409	3 0.04909	3½ 0.06668	4 0.08728
Delivery								
Galls. per hr.	cu. ft. per sec.							
500	0.022275	4.083	1.817	1.021	0.6535	0.454	.3342	0.25525
1000	0.04455	8.1166	3.634	2.042	1.307	0.908	0.6685	0.5105
1500	0.066825	12.249	5.451	3.064	1.960	1.362	1.0026	0.76575
2000	0.089100	16.332	7.268	4.083	2.614	1.816	1.3368	1.0210
2500	0.111375	20.415	9.085	5.104	3.267	2.270	1.6710	1.2762
3000	0.13365	24.498	10.902	6.124	3.921	2.724	2.0052	1.5315
3500	0.15592	28.581	12.719	7.145	4.574	3.178	2.3394	1.7868
4000	0.17820	32.664	14.536	8.168	5.228	3.632	2.6736	2.0420
4500	0.20047	36.747	16.353	9.189	5.881	4.086	3.0078	2.2972
5000	0.22275	40.833	18.17	10.214	6.535	4.540	3.3420	2.5525
5500	0.24502	44.9163	19.987	11.235	7.188	4.994	3.6762	2.8077
6000	0.26730	48.996	21.804	12.252	7.842	5.448	4.0110	3.0630

Table 4

Reynolds Number (Re) and Friction Head H

$$H = \left(0.0001906 + \frac{0.001771}{Re^{0.38}}\right)\frac{LV^2}{2} = \frac{xLV^2}{D}$$

Re	x
4000	0.0002664
5000	0.0002602
6000	0.0002556
8000	0.0002488
10000	0.0002441
20000	0.0002316
30000	0.0002258
40000	0.0002222
60000	0.0002176
100000	0.0002129
500000	0.0002027
1000000	0.0001999

Table 5

Resistance of Screw Fittings Expressed in Equivalent Lengths in feet of Straight Standard Pipe

Forster (A.S.M.E., 1920, 42, 647) calculated the resistance of various screw fittings using the formula:

$L_e = 4.37r\ D^{1.2}$ where L_e = equivalent length of straight pipe in feet

D = diameter of the pipe in feet.

r = a factor depending on the form of the resistance

The following table is quoted from Perry's "Chemical Engineers Handbook" 1st Ed. p. 741.

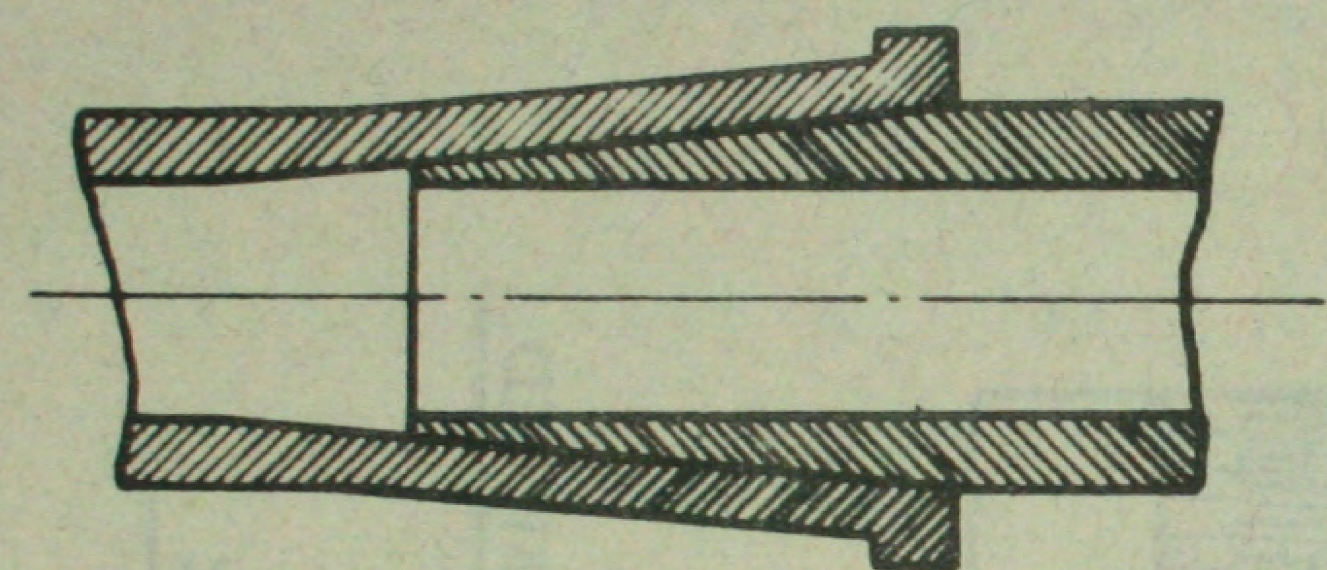
Nominal pipe size, inches	Gate Valve	Long sweep elbow or on run of standard tee	Medium sweep elbow or on run of tee reduced in size ¼	Standard elbow or on run of tee reduced in size ½	Angle Valve	Close return bend	Tee through side outlet	Globe valve
	r = 0.25	r = 0.33	r = 0.42	r = 0.67	r = 0.90	r = 1.00	r = 1.33	r = 200
½	0.31	0.41	0.52	0.84	1.12	1.25	1.66	2.50
¾	0.44	0.57	0.73	1.17	1.57	1.75	2.33	3.50
1	0.57	0.77	0.98	1.57	2.11	2.34	3.11	4.68
1¼	0.82	1.07	1.37	2.19	2.94	3.27	4.35	6.54
1½	0.98	1.29	1.64	2.63	3.52	3.92	5.21	7.84
2	1.32	1.74	2.23	3.55	4.77	5.30	7.05	10.60
2½	1.64	2.16	2.75	4.39	5.91	6.56	8.71	13.12
3	2.13	2.81	3.59	5.72	7.69	8.54	11.40	17.08
3½	2.53	3.34	4.26	6.80	9.10	10.13	13.50	20.26
4	2.96	3.90	4.97	7.94	10.65	11.84	15.75	23.68
4½	3.27	4.45	5.66	9.05	12.14	13.50	17.95	27.00
5	3.88	5.11	6.52	10.40	13.95	15.51	20.60	31.02
6	4.81	6.35	8.09	12.90	19.35	19.27	25.60	38.54
7	5.75	7.59	9.66	15.40	20.70	23.02	30.60	46.08
8	6.70	8.85	11.20	17.90	24.10	26.80	35.60	53.60
10	8.75	11.54	14.70	23.40	31.50	35.00	46.60	70.00
12	10.90	14.40	18.35	29.30	39.30	43.70	58.10	87.40

TABLE 6

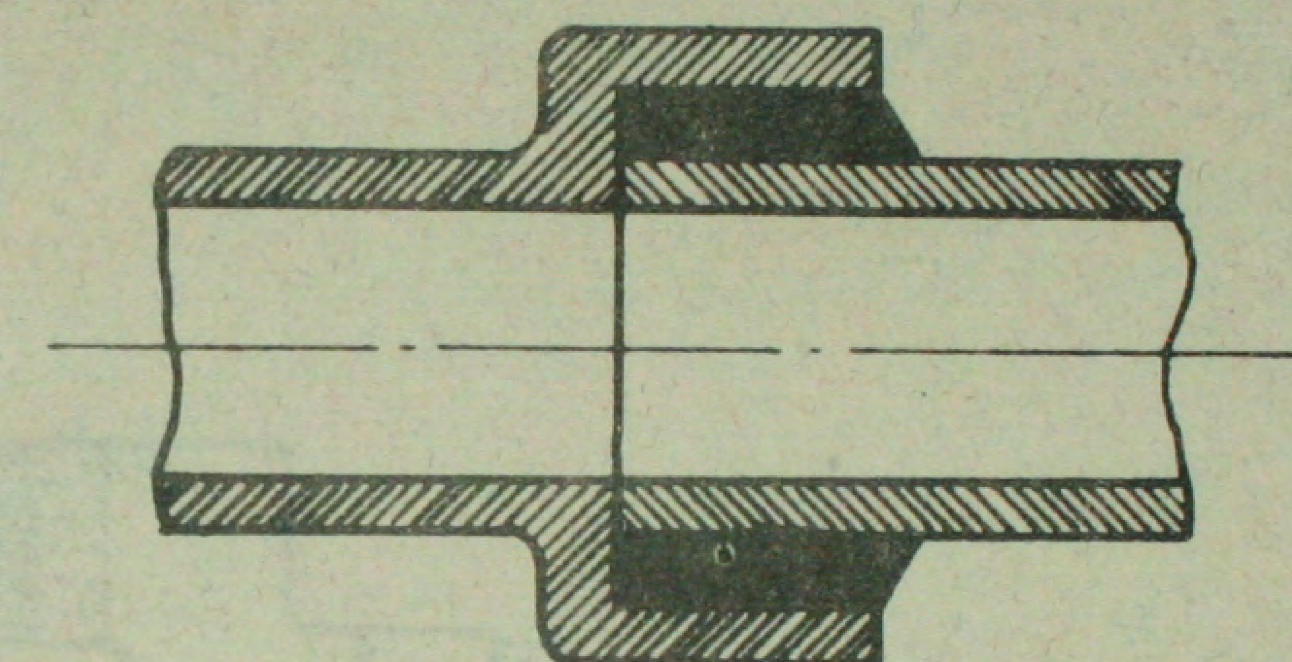
THIS TABLE BELOW GIVES DETAILS OF THE PUMP AND PIPE LINE SYSTEM OF THE T.N.T. SECTION AT A TYPICAL ROYAL ORDNANCE FACTORY

Acid	Pump		Delivery Pipe diameter ins.	Pipe Line			Height ft.	Delivery Rate galls. per hr.
	Type	H.P.		Length ft.	Diameter ins.	No. of Rt. Angled Bends		
C.N.A.	Glandless, Stainless Steel	1½	2	26	2	4	20	1000
W.N.A.	-do-	1½	2	26	2	4	20	1000
C.O.V.	Glandless, Mild Steel	4	2	26	2	4	20	4000 max.
D.N.A.	Glandless, Regulus	7	2	15	2	5	8	2000
M.A.	-do-	7 (	2	450	2	7	12	2000
M.A.	-do-	(	2	26	2	4	15	4000
M.A.	Kestner	12 (		255	3	6	15	3500
		(		26	3	4	20	5000
M.N.T.	Glandless, Regulus	4	2	270	2	7	20	3000
S/A.	-do-	4	2	40	2	5	12	2000
M.N.T.	Pulsometer	7½	3	50	3	5	25	6000
Toluene	Centrifugal	5	3	1500	2	6	12	5000
M.N.T.	Centrifugal, Mild Steel	¾	2	50	2	3	12	3000
M.N.T.	-do-	2	2	300	2	6	12	3000

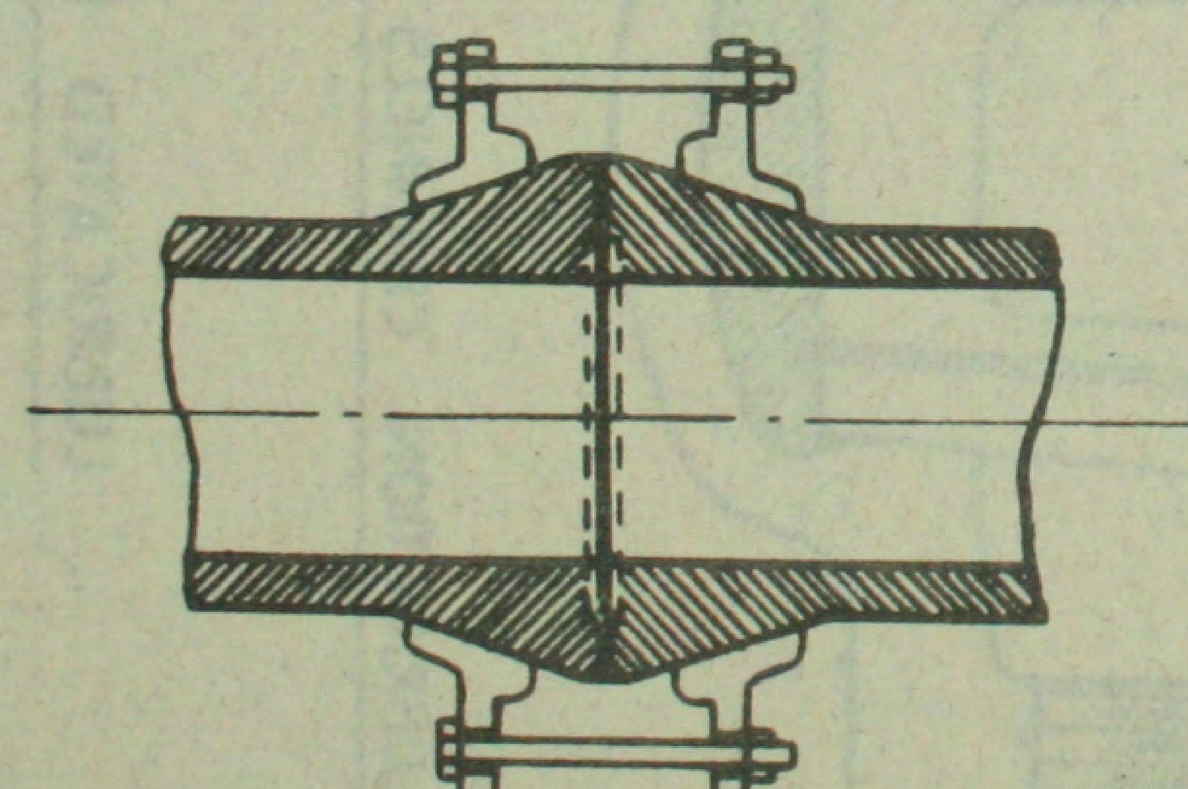
54711-1



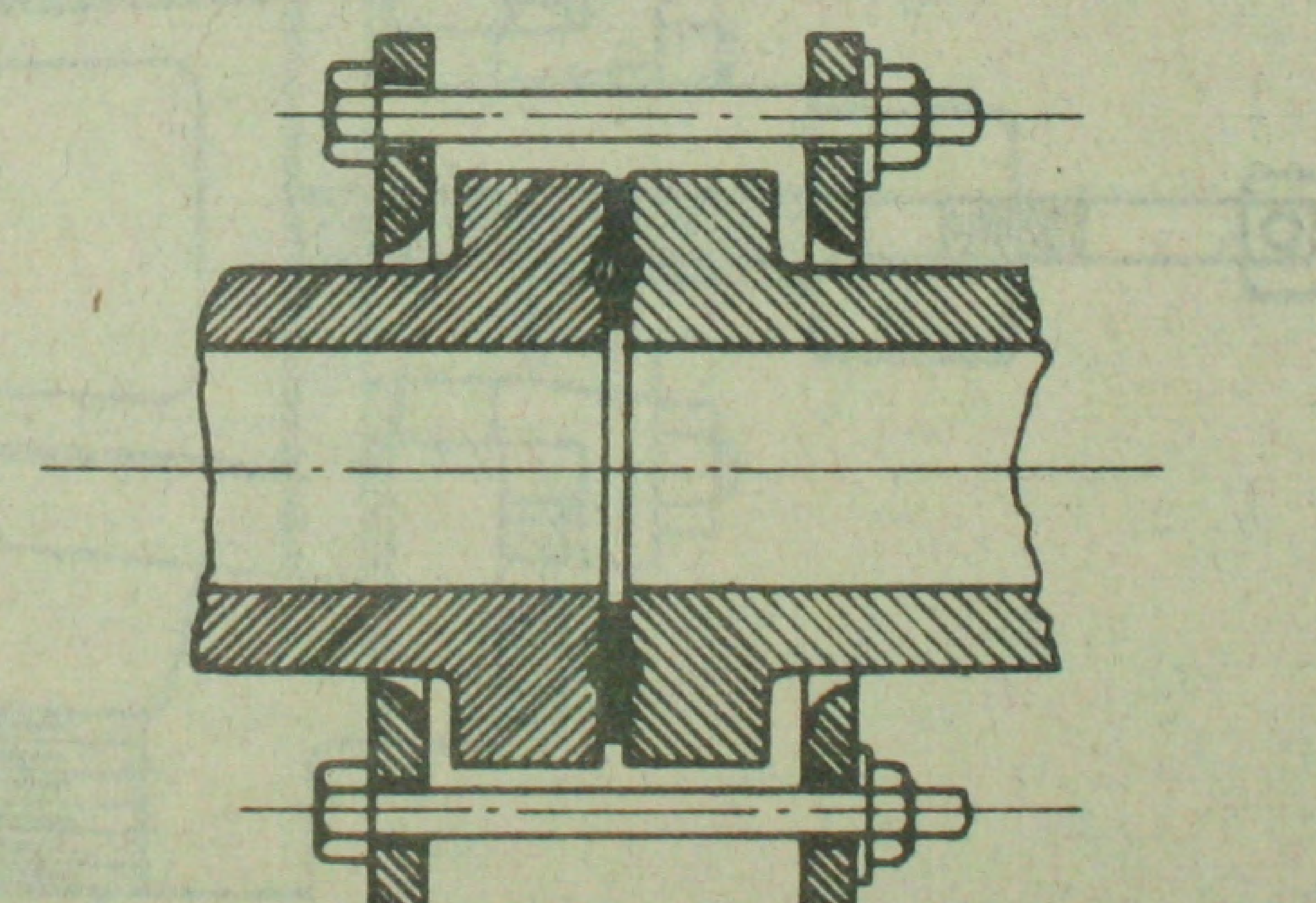
TAPER JOINT.



SPIGOT & SOCKET.



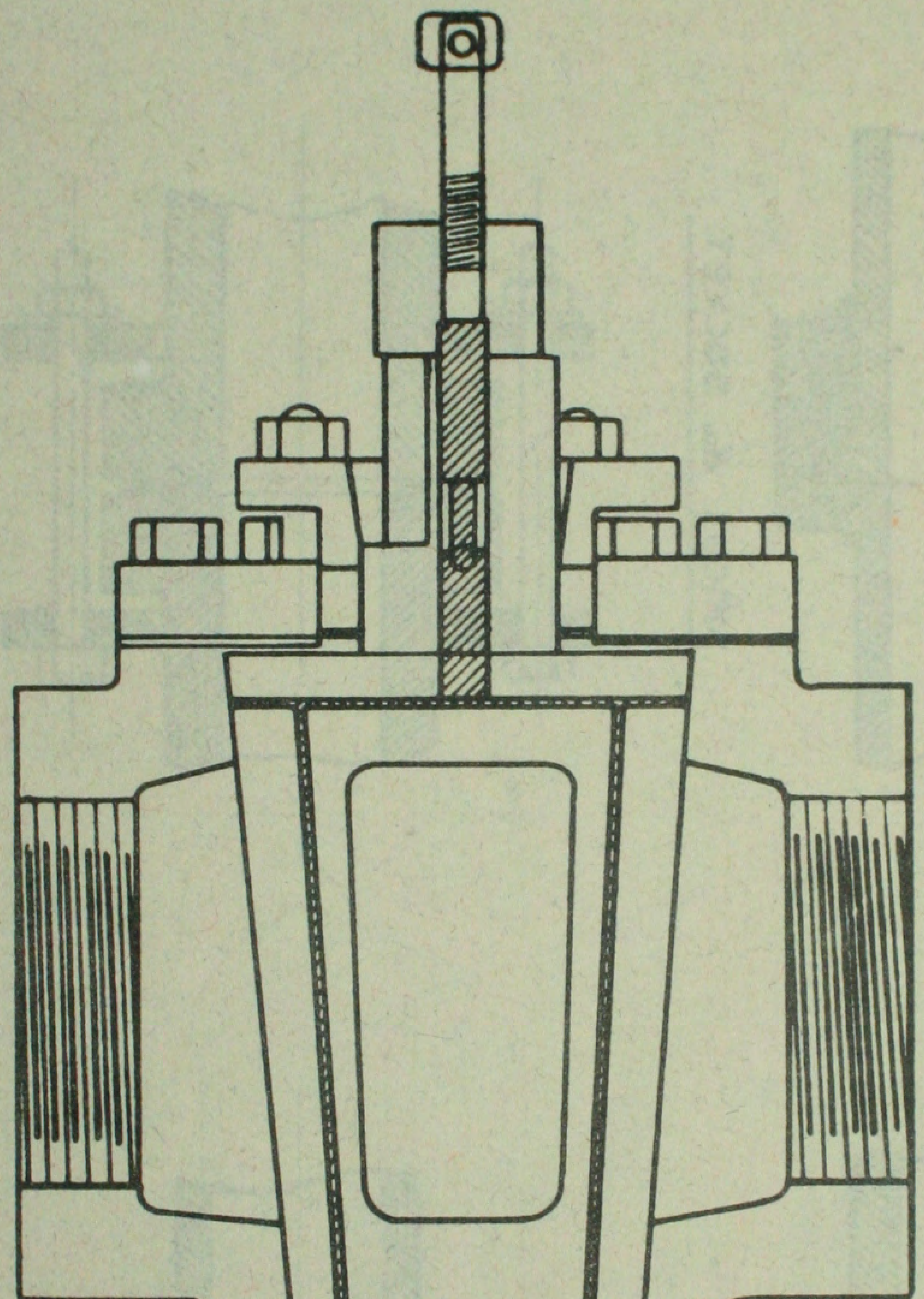
CONICAL FLANGE.



PLAIN FLANGE.

VARIOUS TYPES OF STONEWARE PIPE FLANGES.

Fig 1 (see p22)

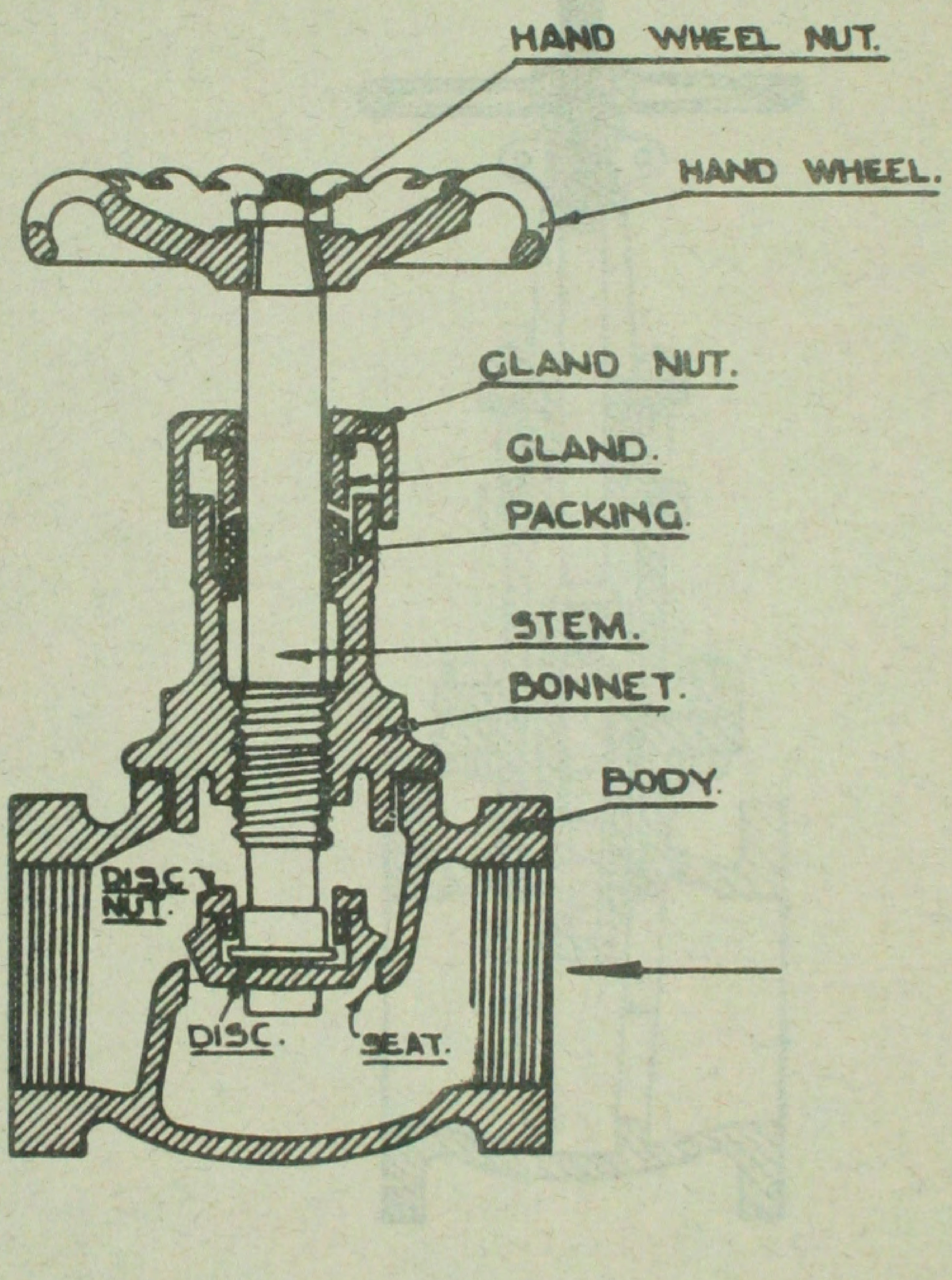


LUBRICATION CHANNELS SHOWN HATCHED.

LUBRICATED PLUG COCK.

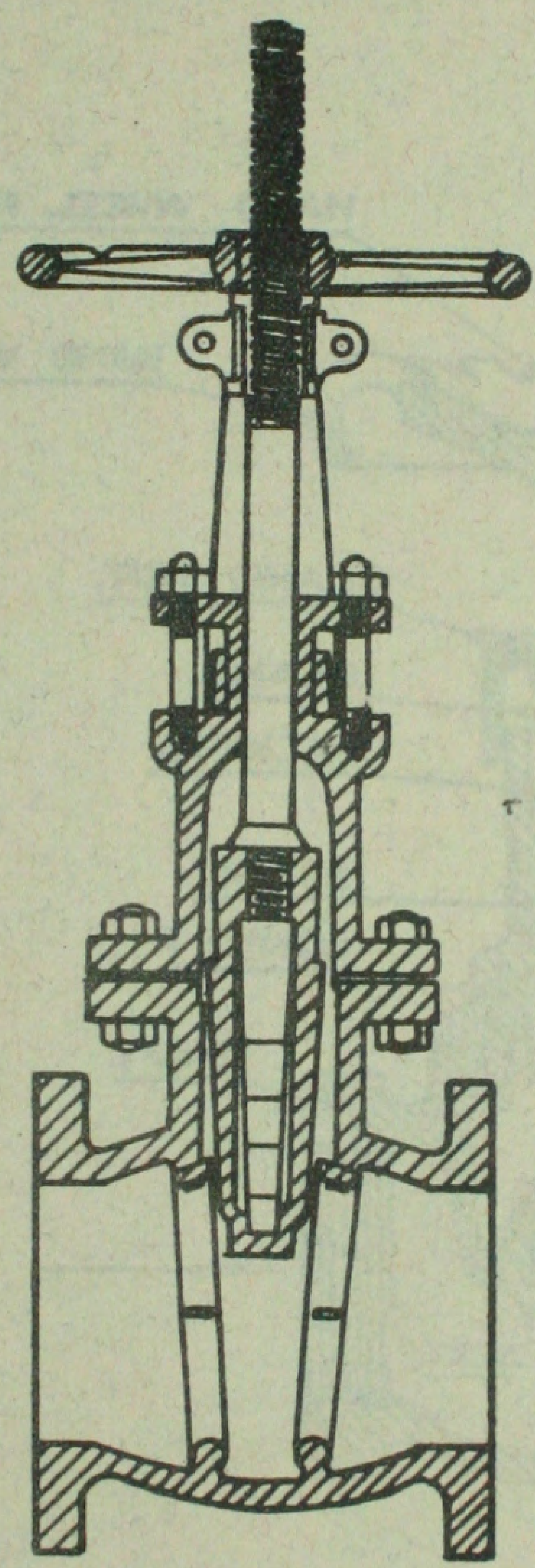
54711-1

Fig. 2. (see p25)



GLOBE VALVE.

Fig. 3 (see p. 27)

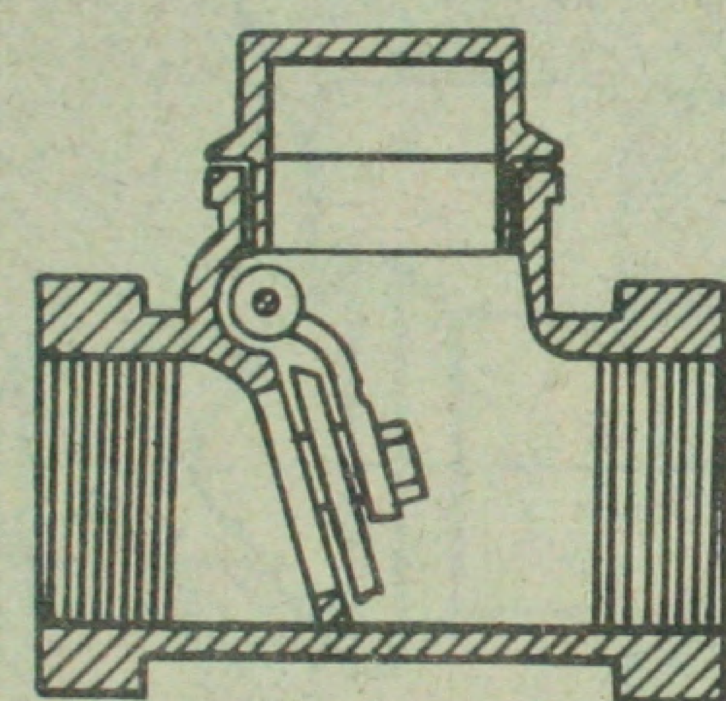


OUTSIZE SCREW AND YOKE GATE VALVE.

54711-1

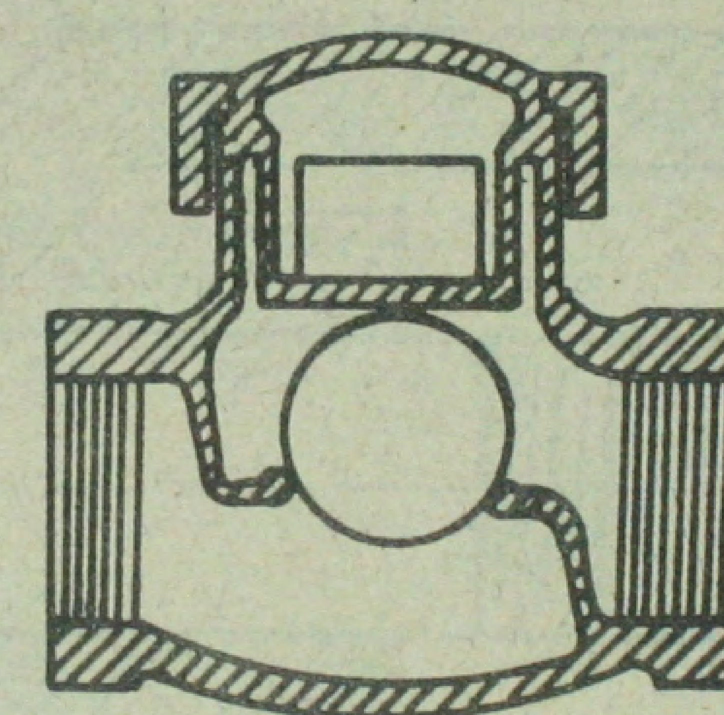
Fig. 4. (see P27)

54711-1



a.

SWING CHECK.

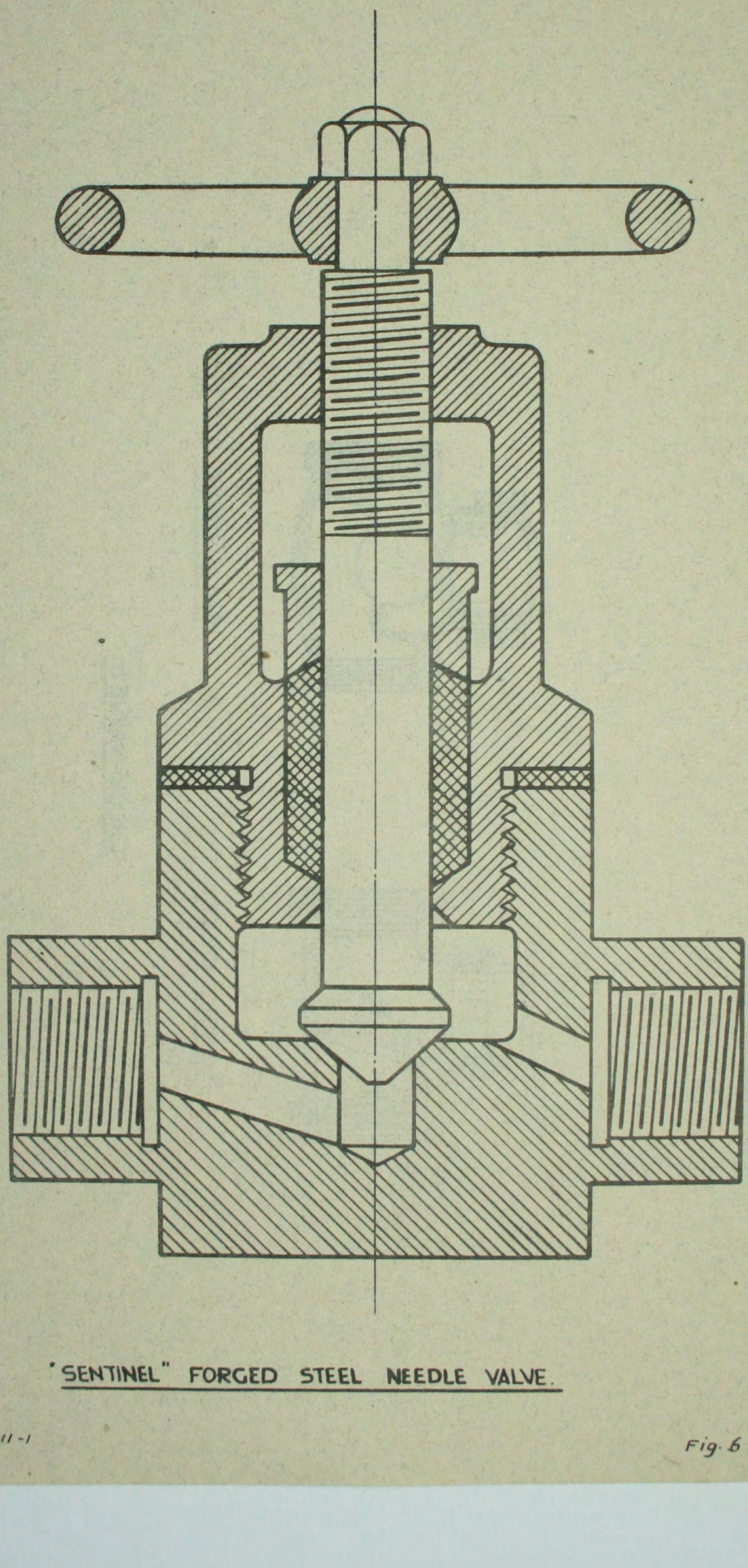


b.

BALL CHECK.

CHECK VALVES.

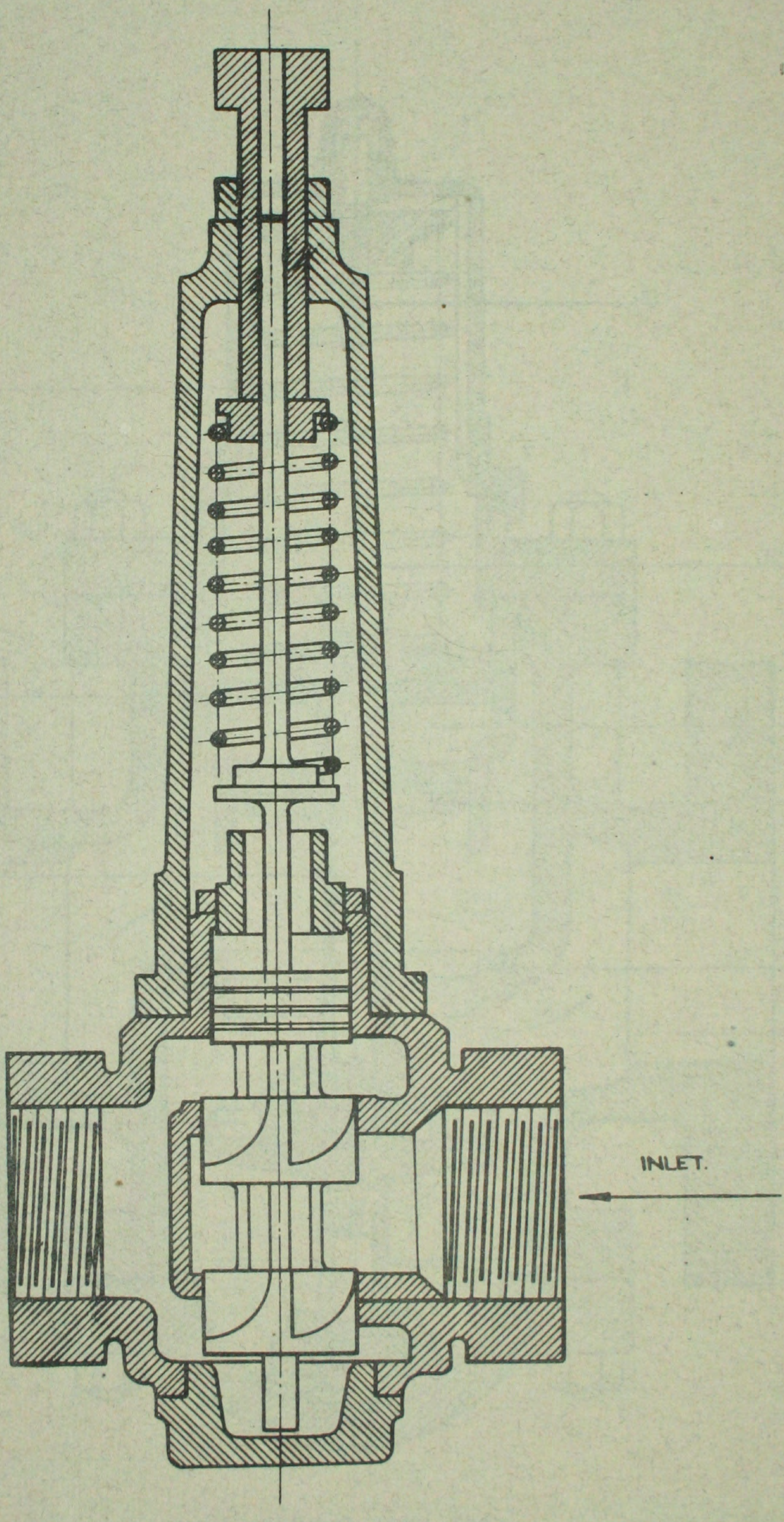
Fig 5 (see p28)



"SENTINEL" FORGED STEEL NEEDLE VALVE.

54711-1

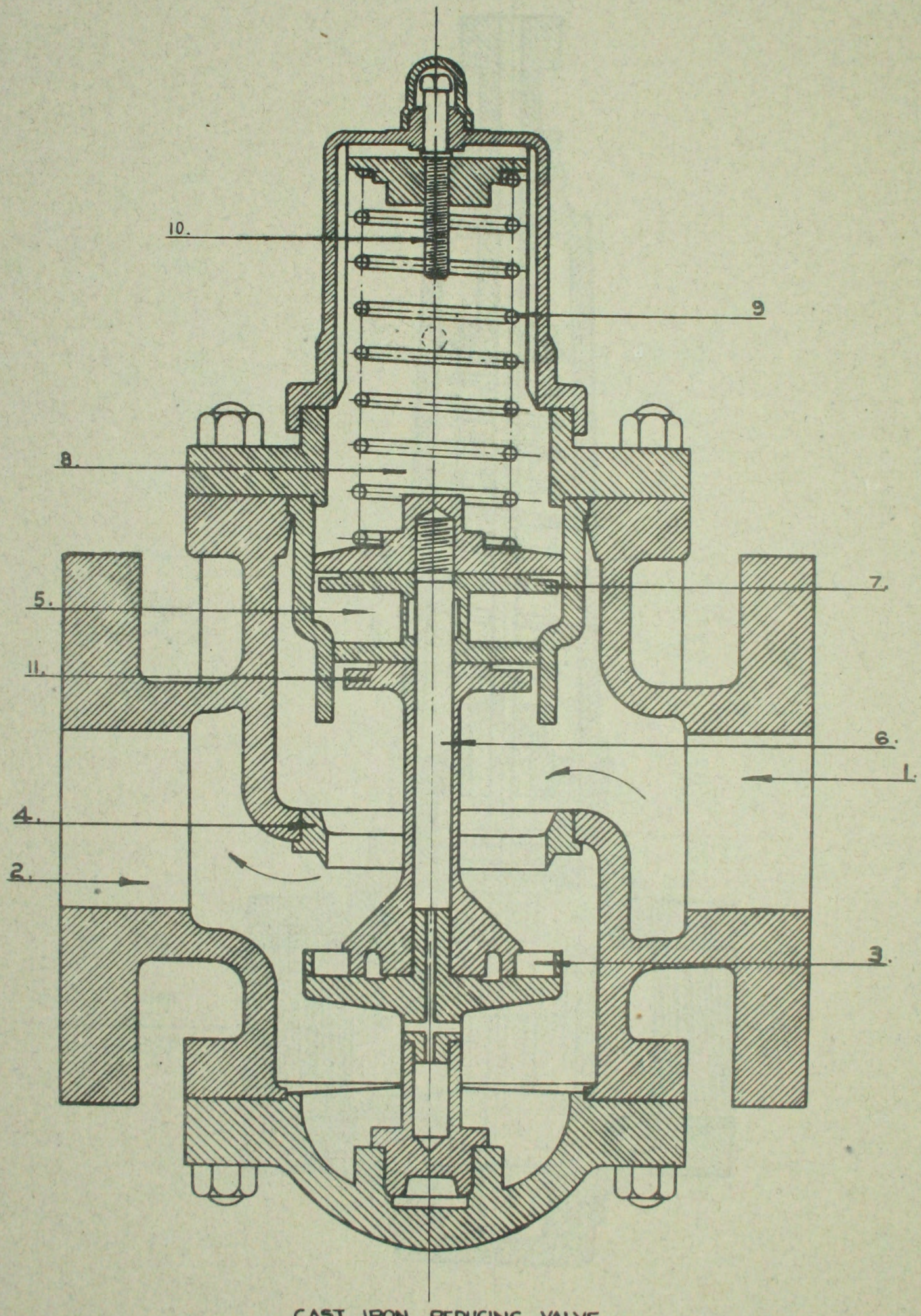
Fig. 6 (see p.28)



GUN METAL STEAM REDUCING VALVE.

54711-1

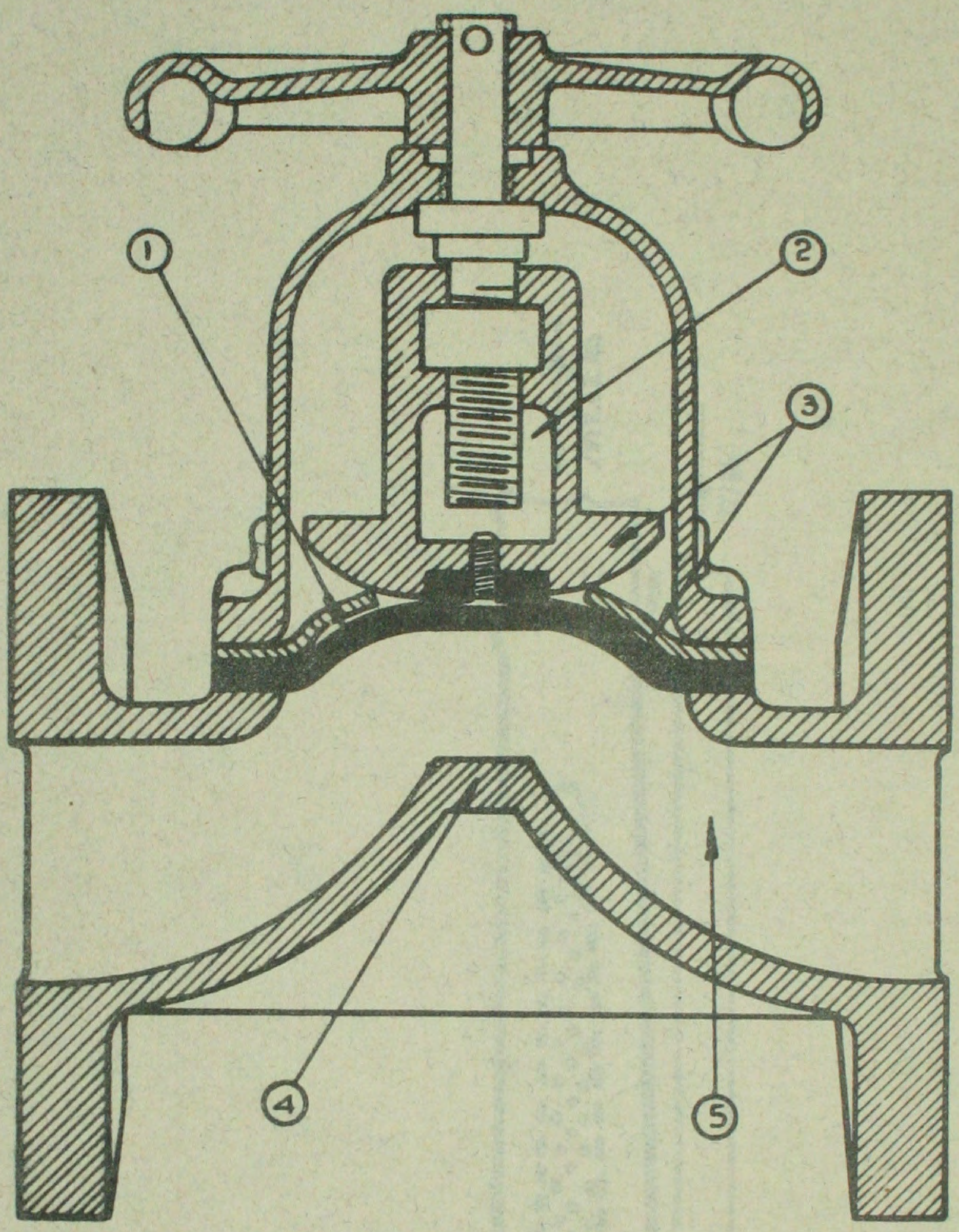
Fig. 7 (see p 28)



CAST IRON REDUCING VALVE.

SL3M !

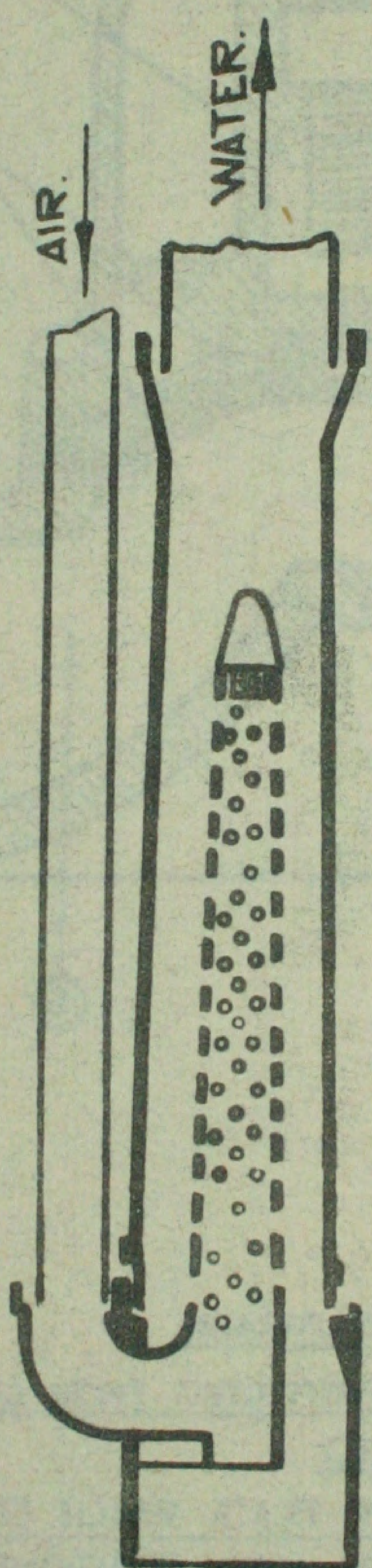
Fig. 8 (see p 28)



1. FLEXIBLE REINFORCED DIAPHRAGM.
2. OPERATING MECHANISM PROTECTED FROM CORROSION & PERMANENTLY LIBRICATED.
3. COMPRESSOR AND FINGER PLATE WHICH COMBINE TO SUPPORT THE DIAPHRAGM IN ALL POSITIONS.
4. WEIR OR SEAT ON WHICH THE DIAPHRAGM BEDS DOWN.
5. CLEAN STREAMLINE PASSAGE WITHOUT POCKETS.

SAUNDERS VALVE.

Fig. 9 (see p 29)



AIR-JET LIFT FOOTPIECES.

54711-1

Fig 10 (see p31.)

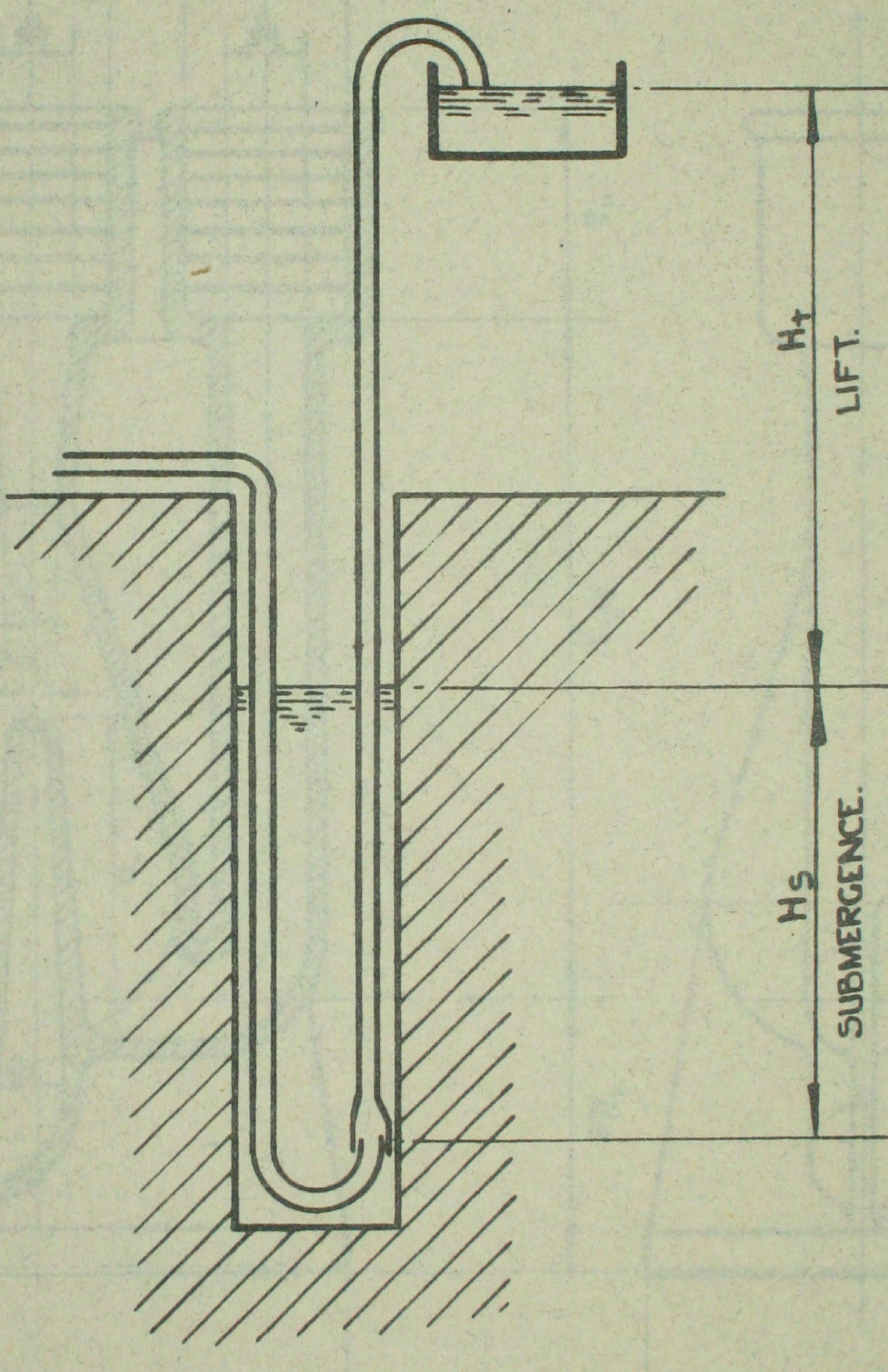
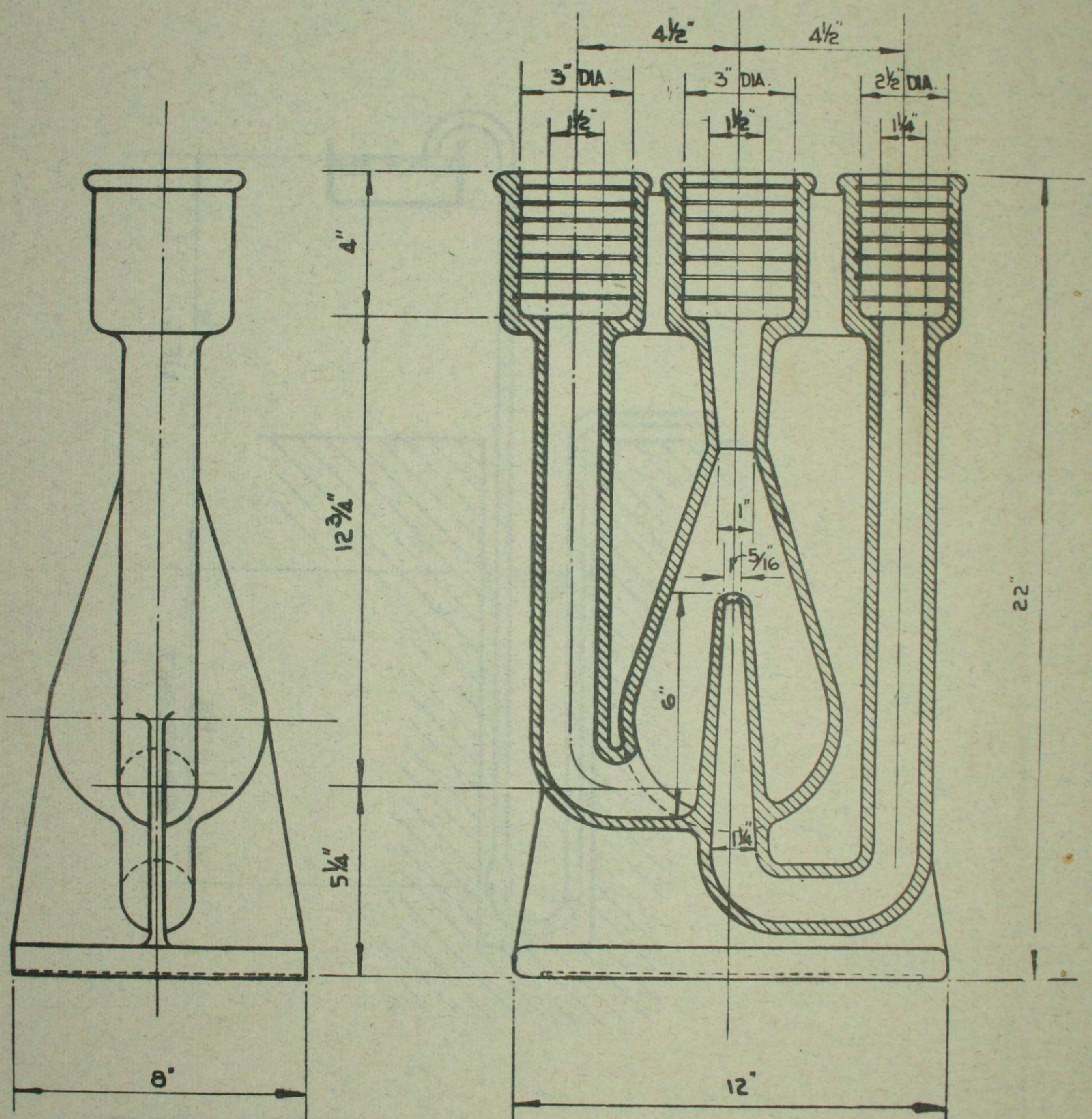


DIAGRAM OF AIR-JET LIFT.

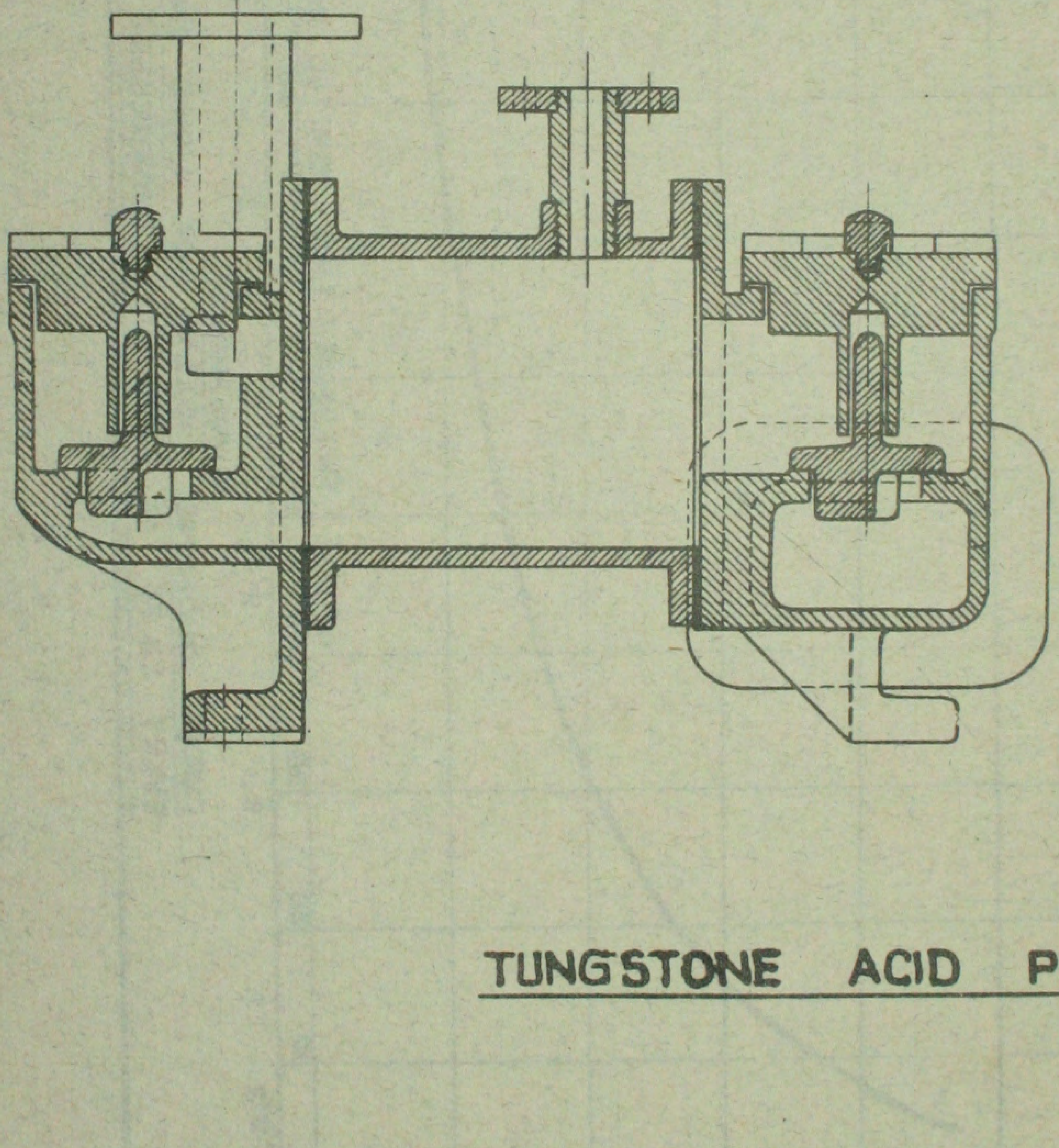
Fig 11. (see p 35)



INJECTOR TYPE LIFT.

54711-1

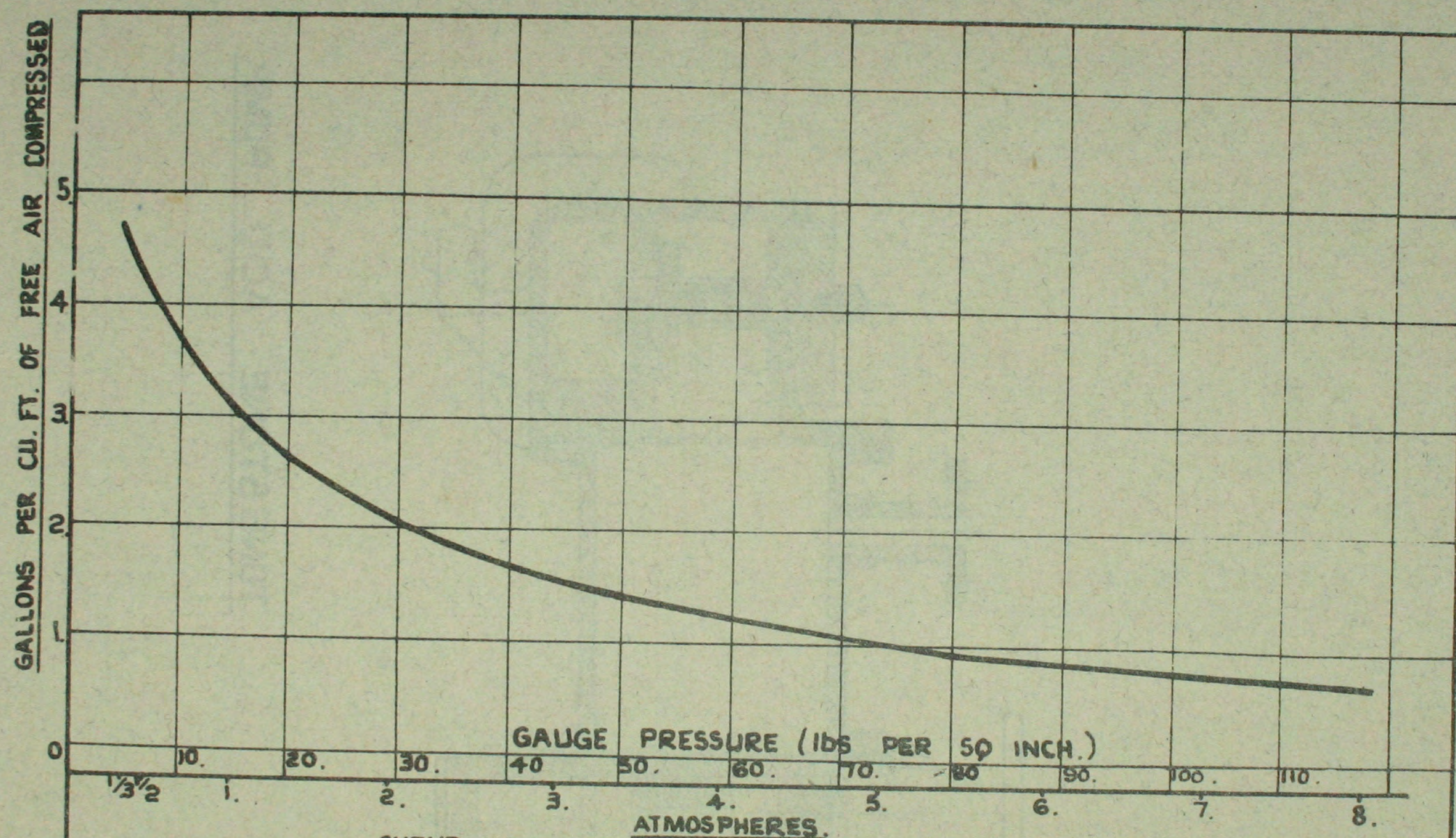
Fig 12. (see p 36)



TUNGSTONE ACID PUMP.

54711-1

Fig 13 (see p 36)



CURVE SHOWING VOLUME OF LIQUID IN GALLONS FOR EVERY CU. FT. OF FREE AIR COMPRESSED TO VARIOUS PRESSURES.

Fig. 14 (see p 36)

54711-1

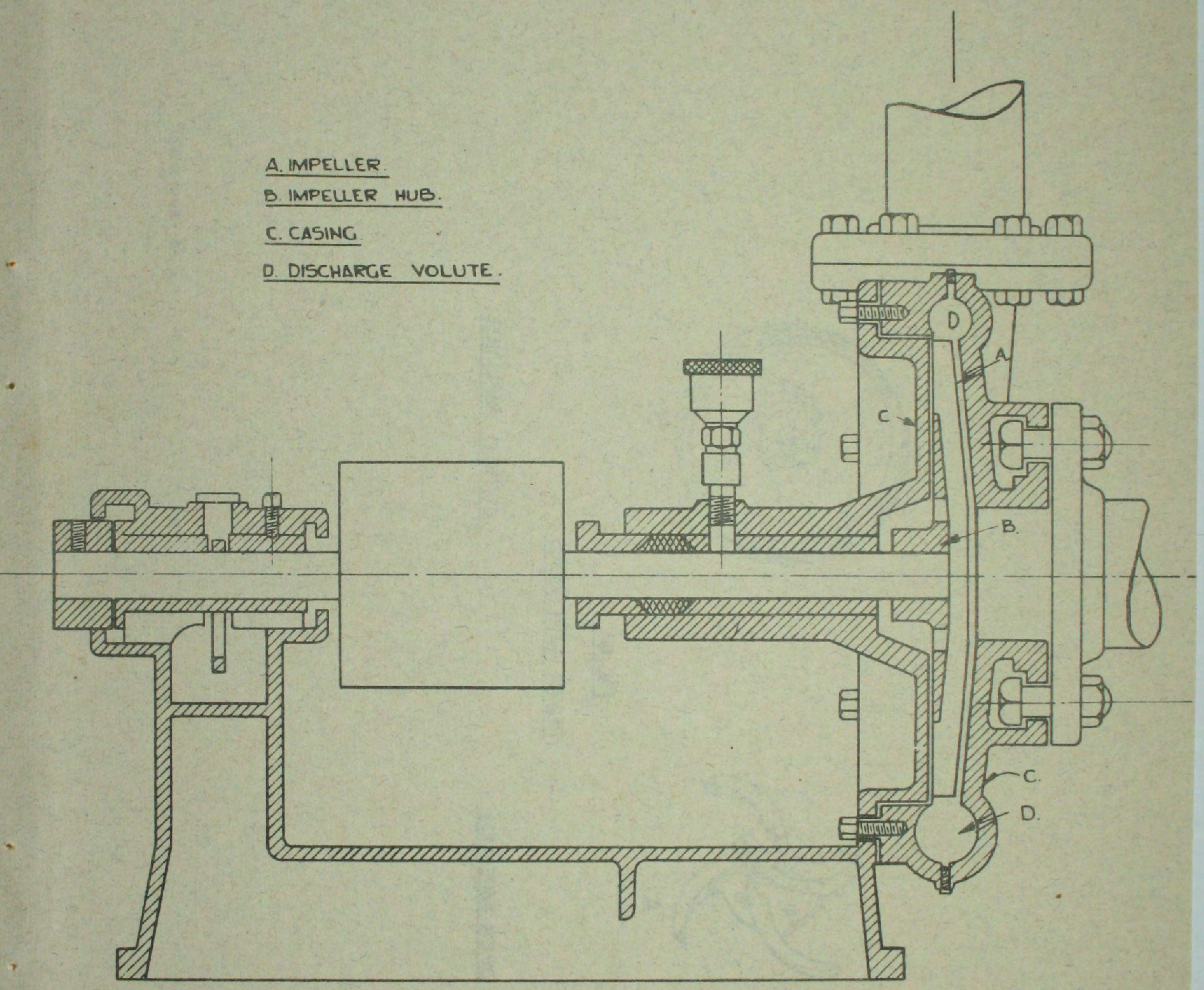
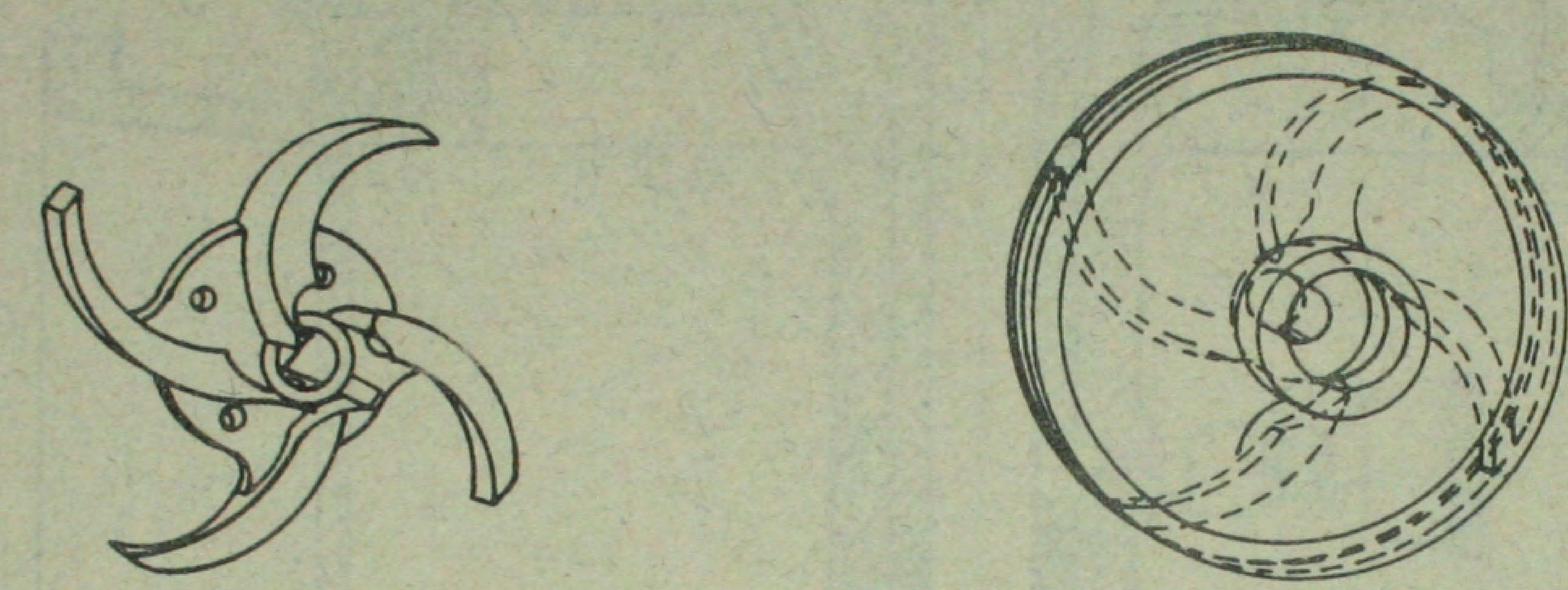


FIG. 60.

SINGLE - STAGE, SINGLE - SUCTION, OPEN - IMPELLER, VOLUTE PUMP.

54711-1

Fig 15. (see p37)



A. B.

FIG. 61.

PUMP IMPELLERS.

OPEN IMPELLER. CLOSED IMPELLER

Fig. 16 (see p37)

54711-1

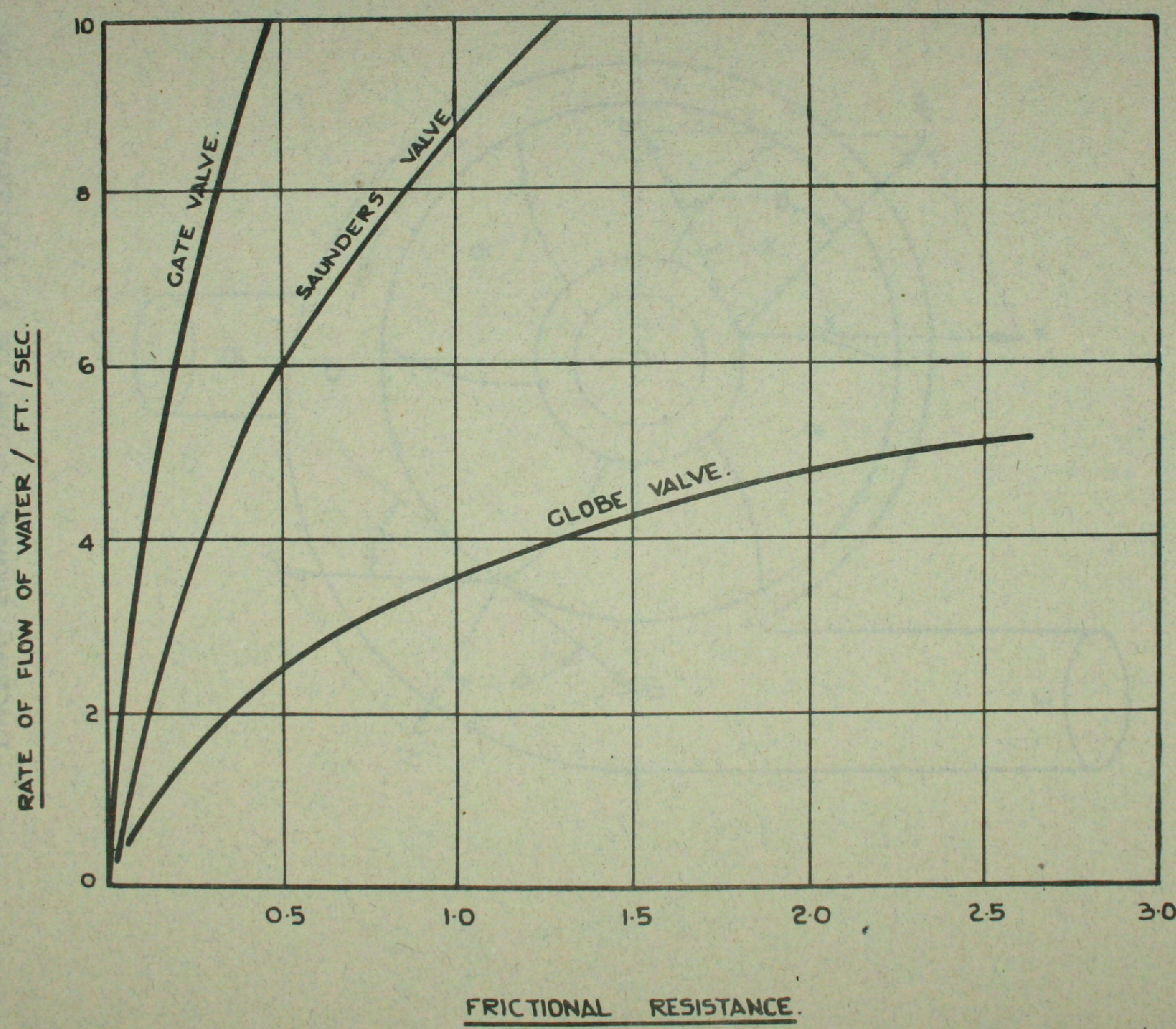


Fig 16a (see p 37)

54711-1

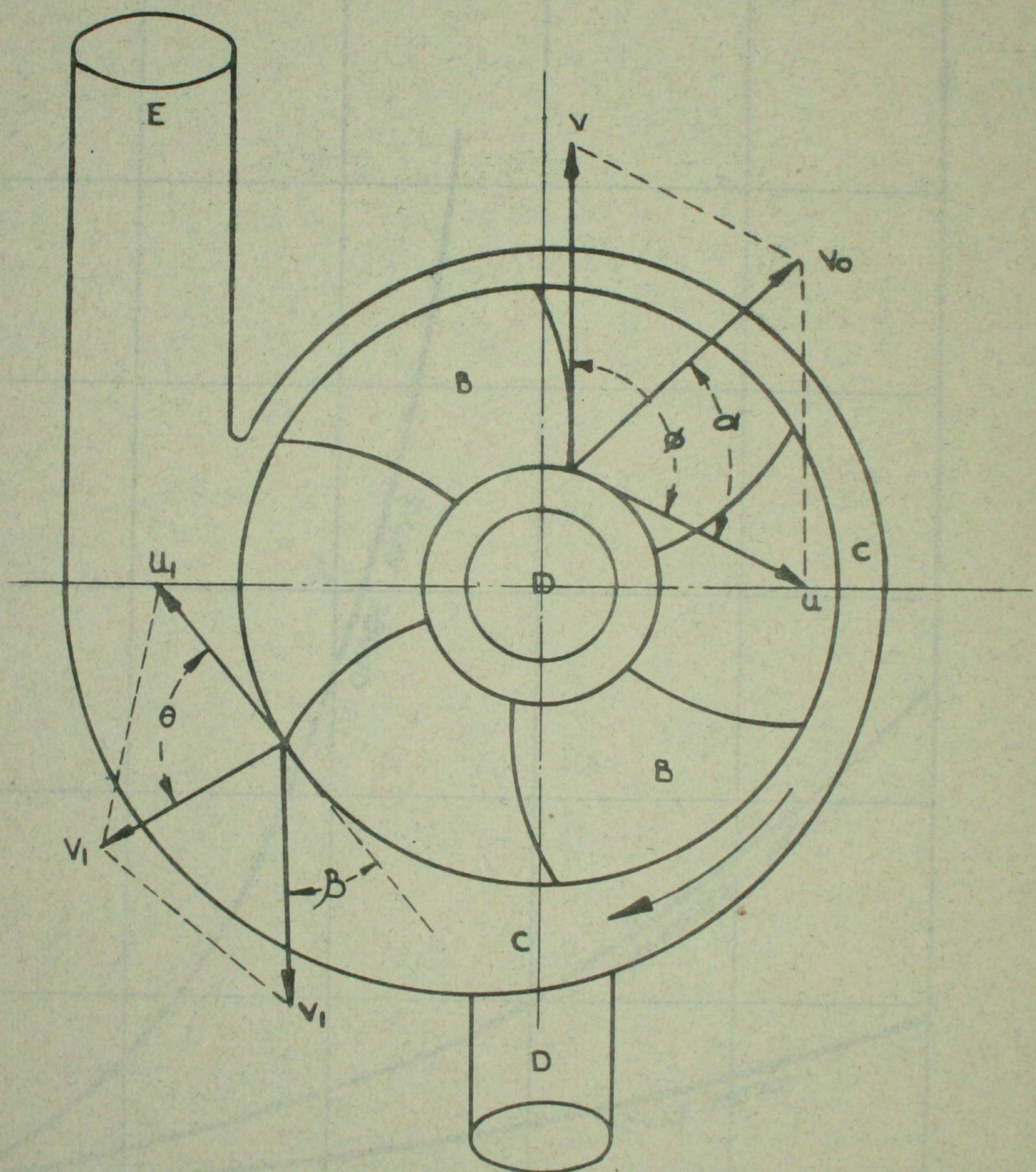
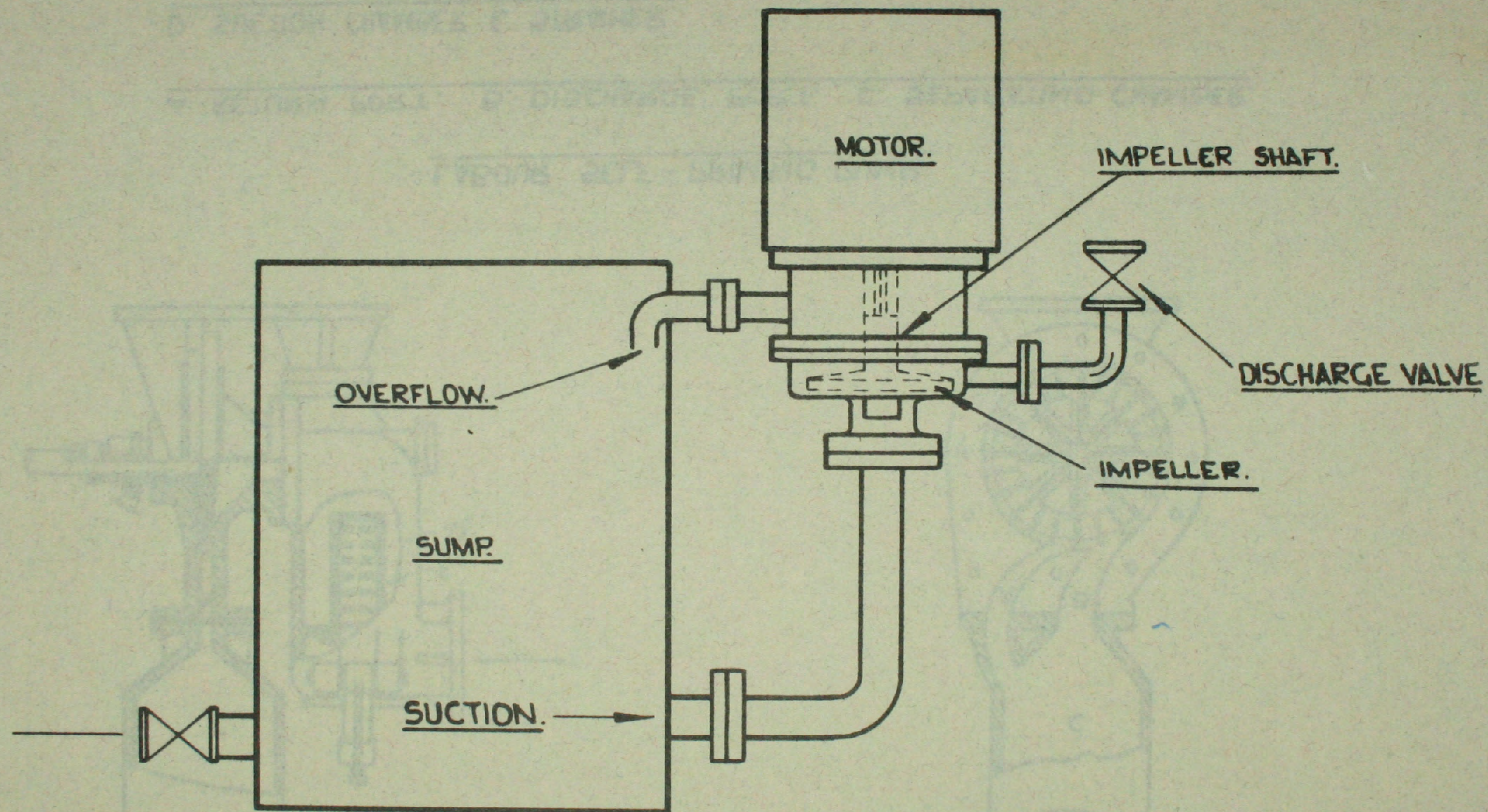


DIAGRAM SHOWING ACTION OF A CENTRIFUGAL PUMP.

Fig 16b (see p 38)

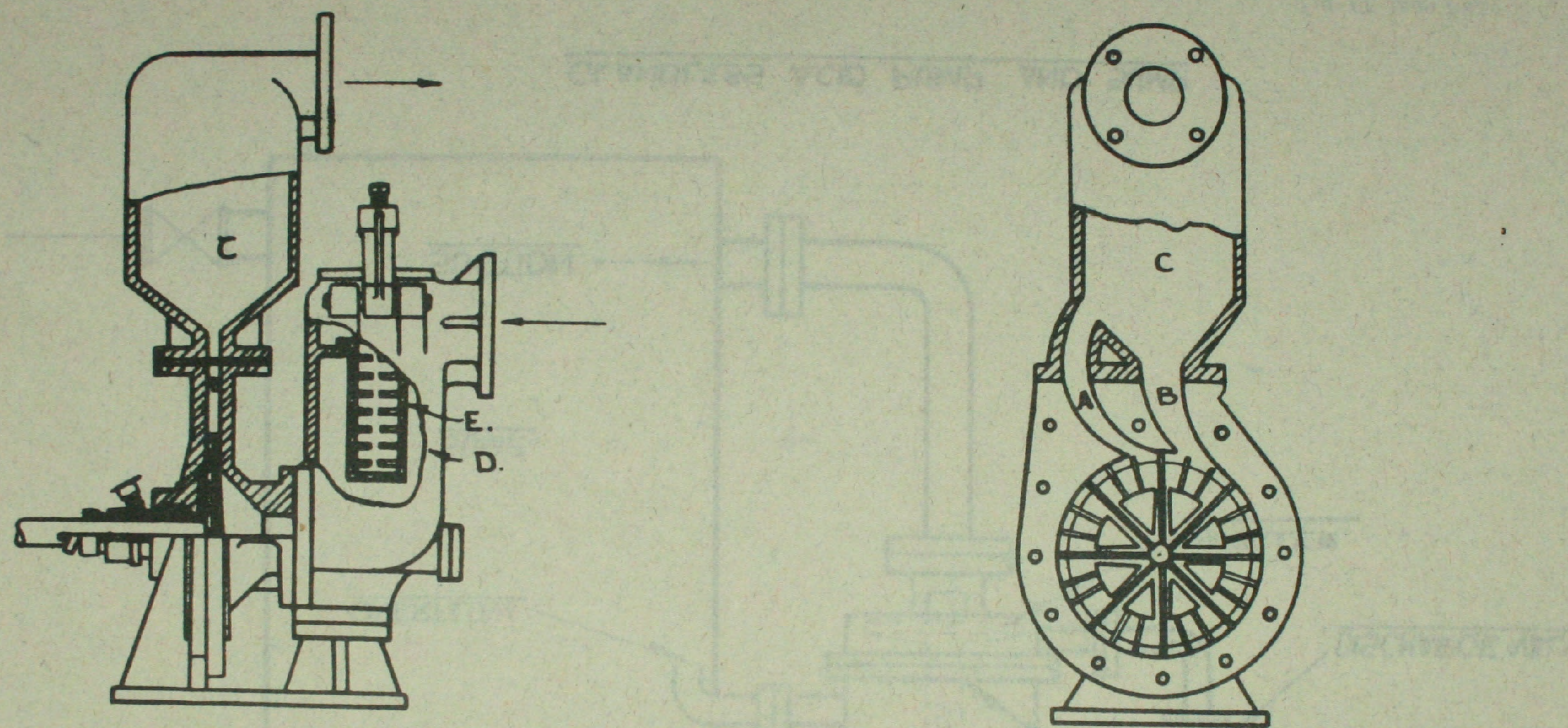
54-711-1



GLANDLESS ACID PUMP AND SUMP.

Fig 17 (see p38)

54711-1

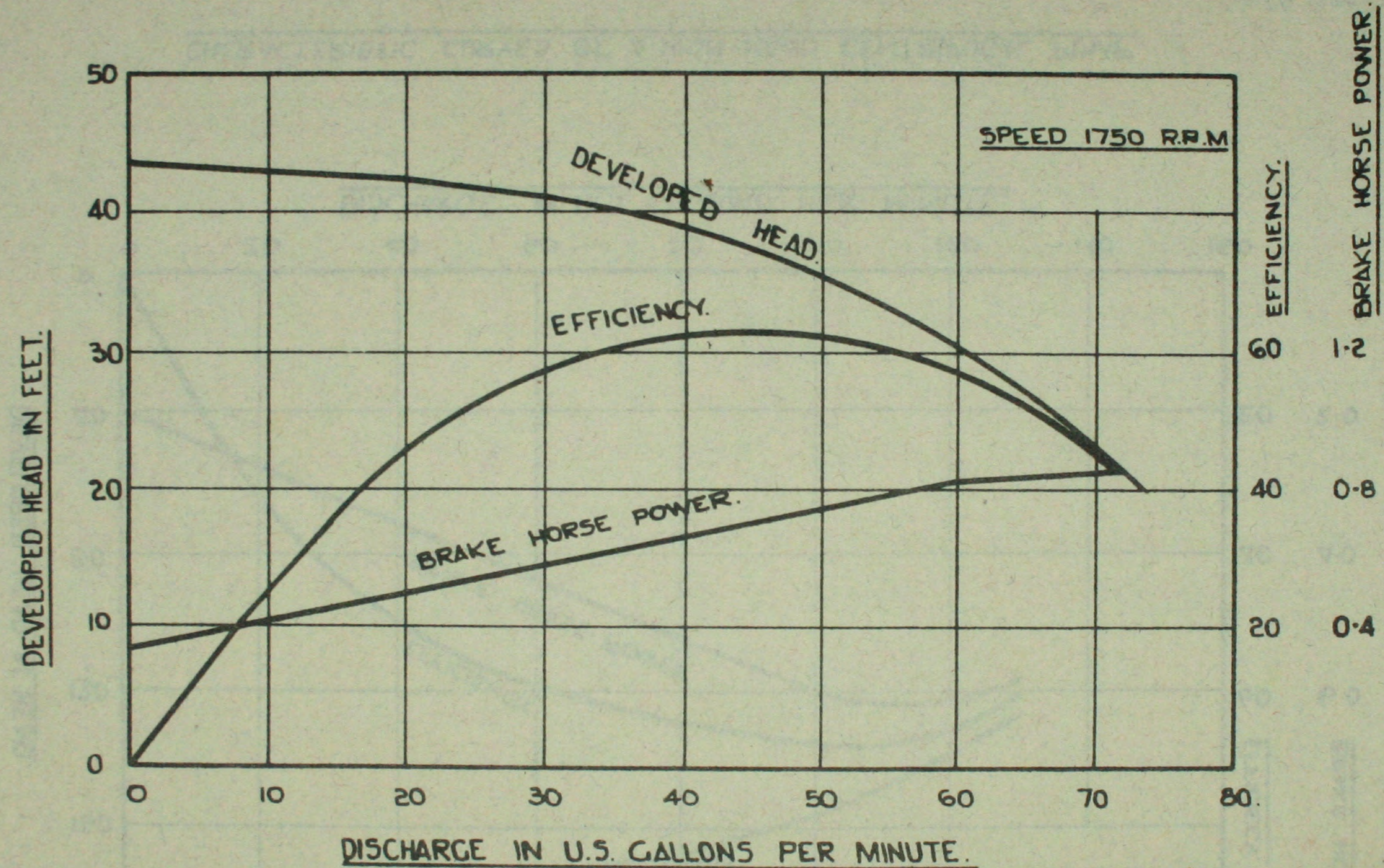


LABOUR SELF - PRIMING PUMP.

A. RETURN PORT. B. DISCHARGE PORT. C. SEPARATING CHAMBER.

D. SUCTION CHAMBER. E. STRAINER.

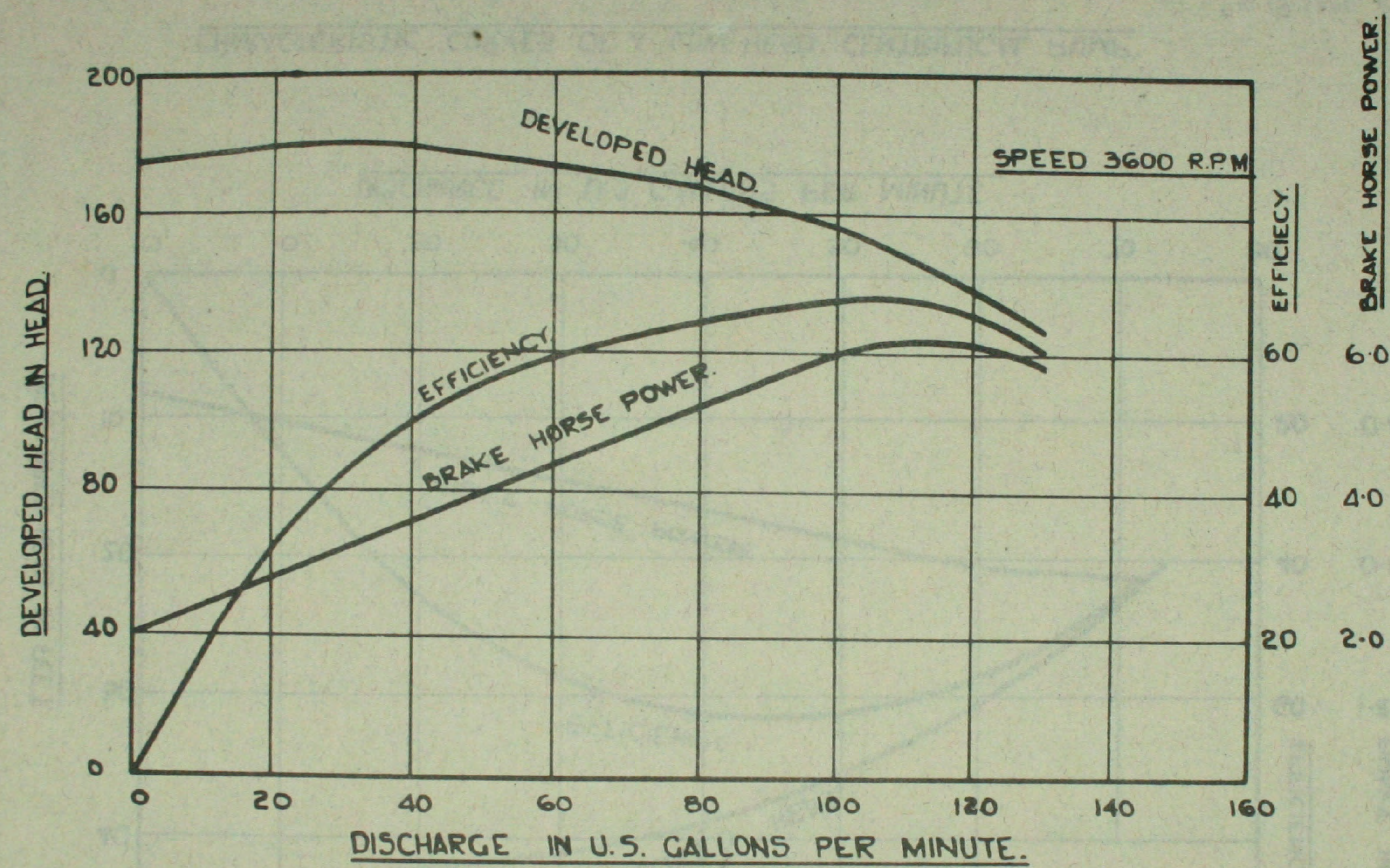
Fig 18 (see p 39)



CHARACTERISTIC CURVES OF A LOW-HEAD CENTRIFUGAL PUMP.

Fig 19 (see p 46)

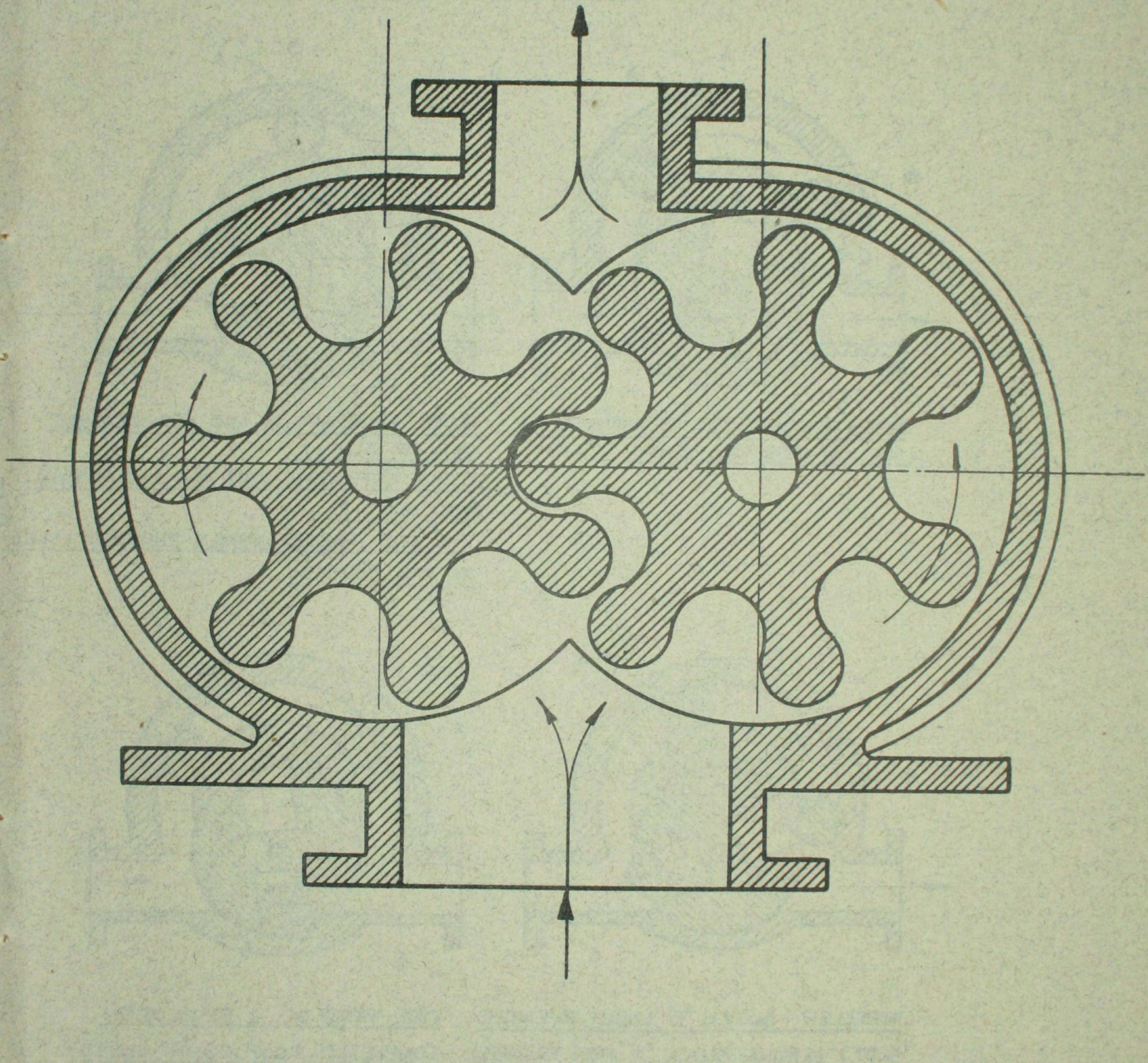
54711-1



CHARACTERISTIC CURVES OF A HIGH-HEAD CENTRIFUGAL PUMP.

Fig 20 (see p46)

1-11245



GEAR PUMP.

54711-1

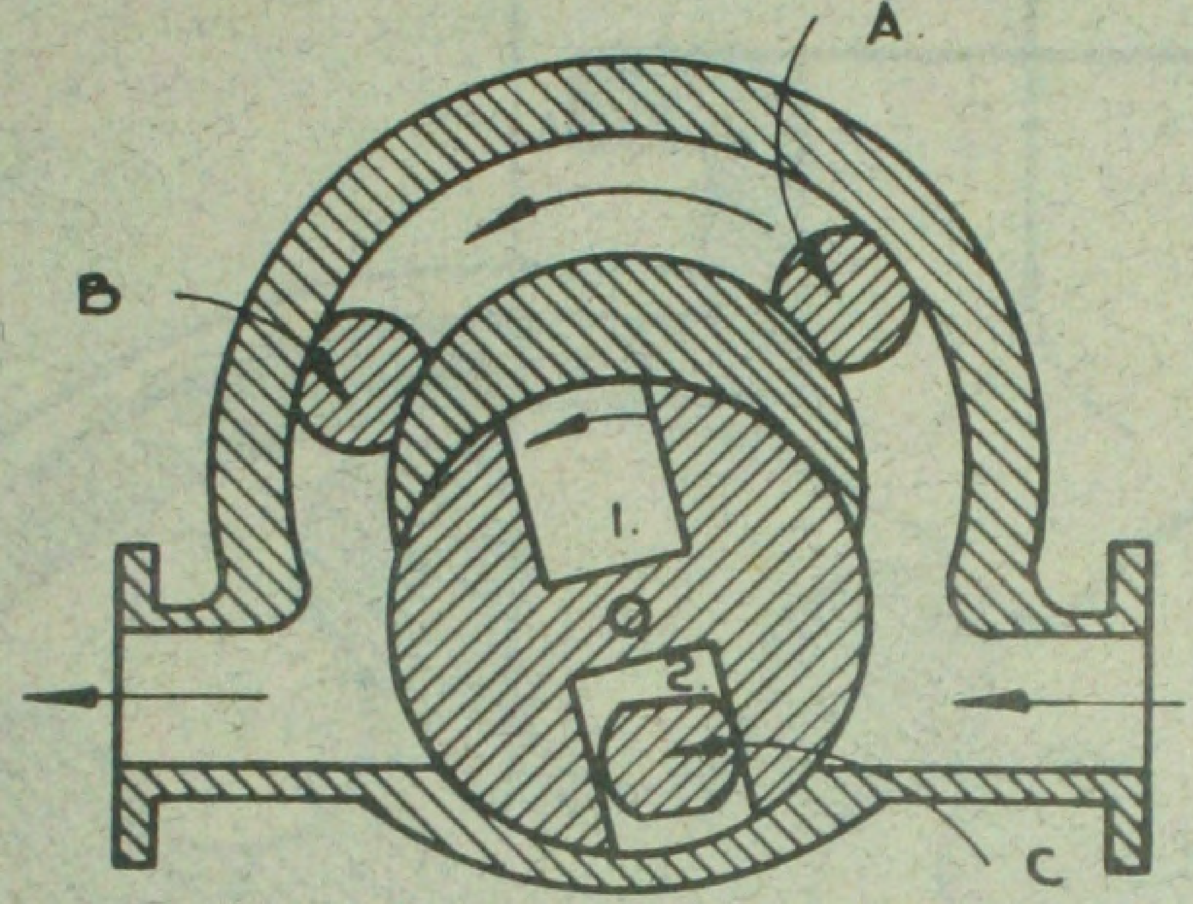
Fig 21. (see p 48)

DIAGRAM SHOWING SUCCESSIVE POSITIONS OF THE PARTS OF A DOUGLAS PUMP DURING ONE THIRD OF A REVOLUTION.

MOVING PARTS SHADED THUS.

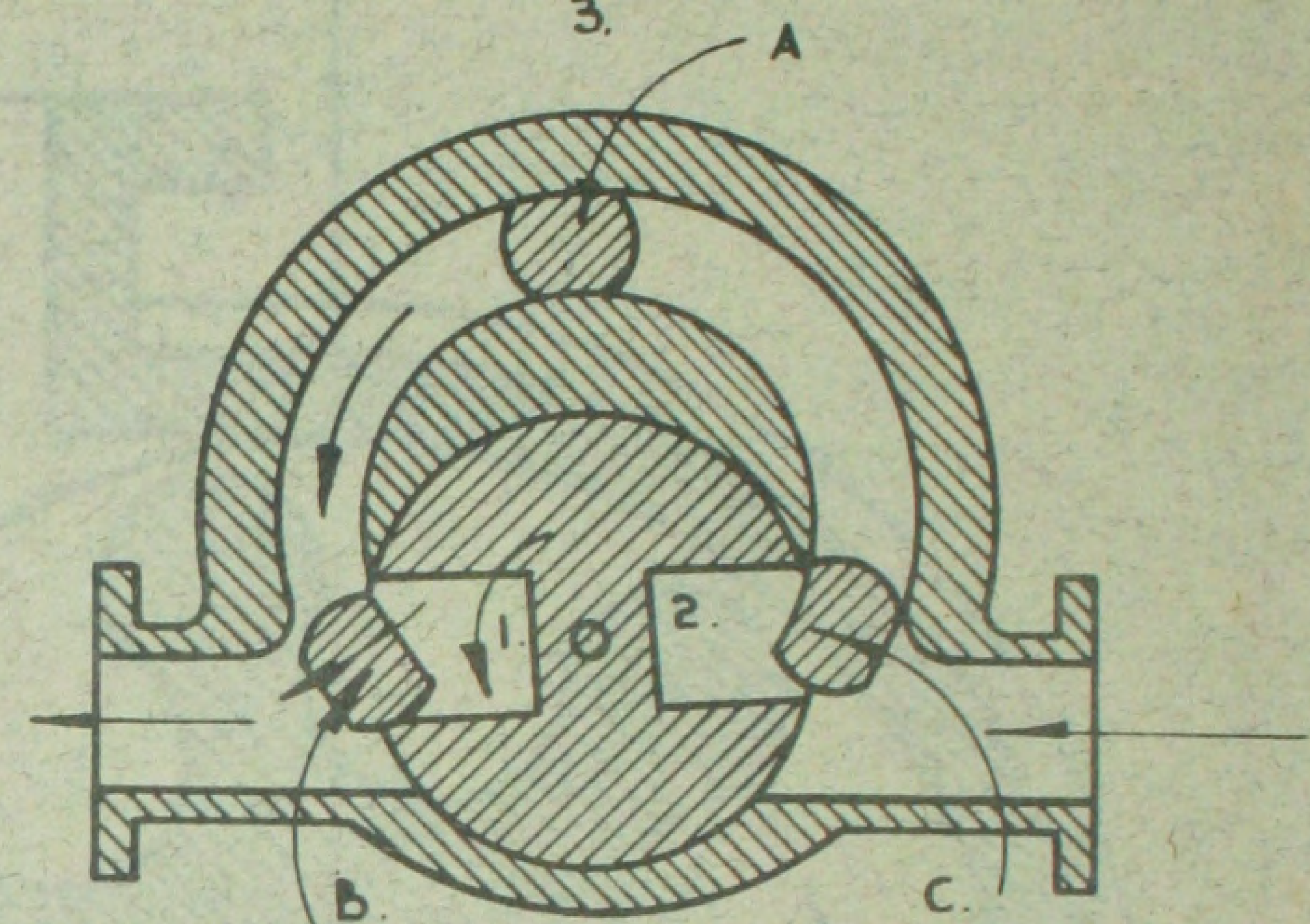
FIXED PARTS SHADED THUS.

1.



IMPELLER - BLOCK "C" RETURNING TO SUCTION SIDE OF PUMP.

3.

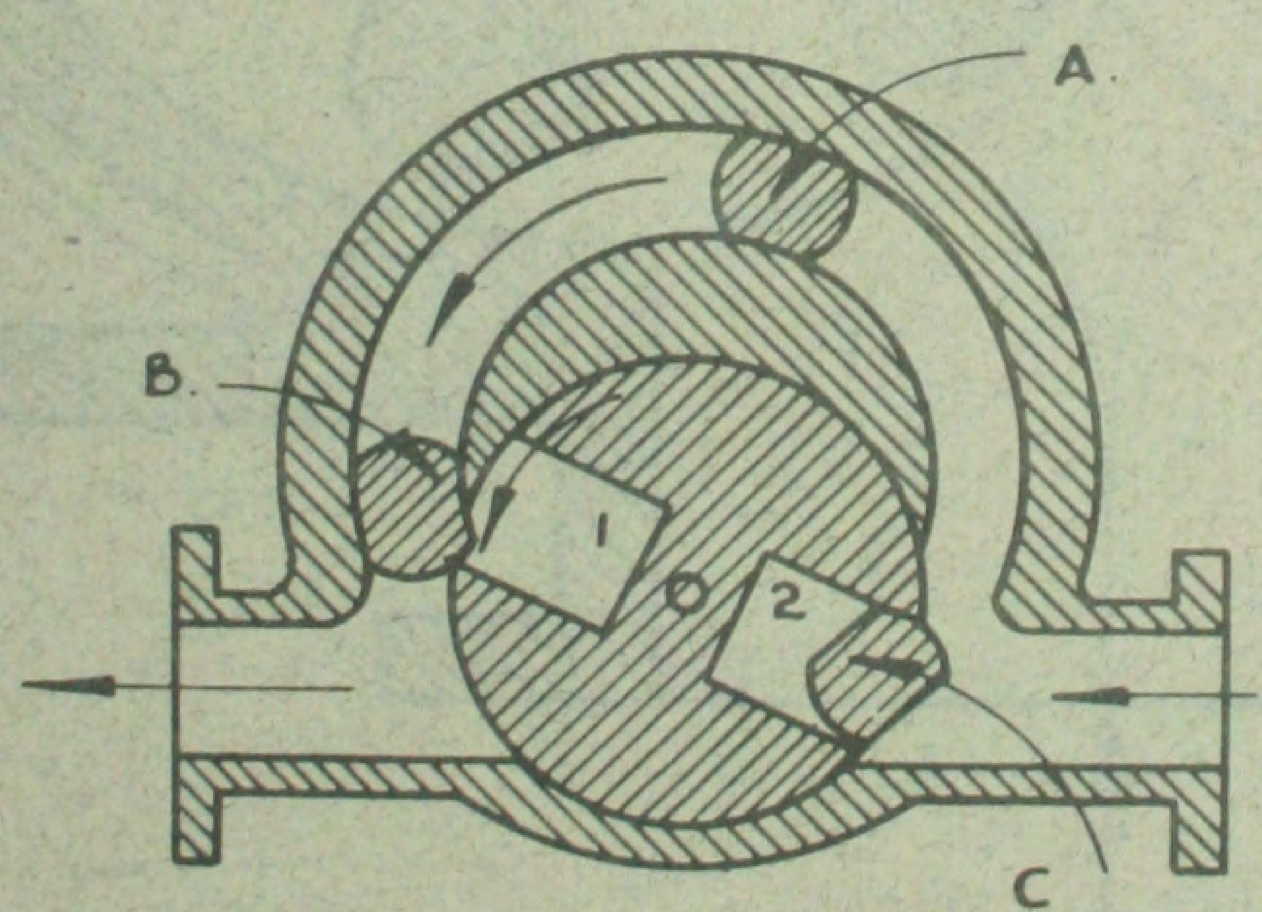


BLOCK "B" PASSING IN AND ACID PASSING OUT OF SLOT 1.

BLOCK "C" PASSING OUT AND ACID PASSING INTO SLOT 2.

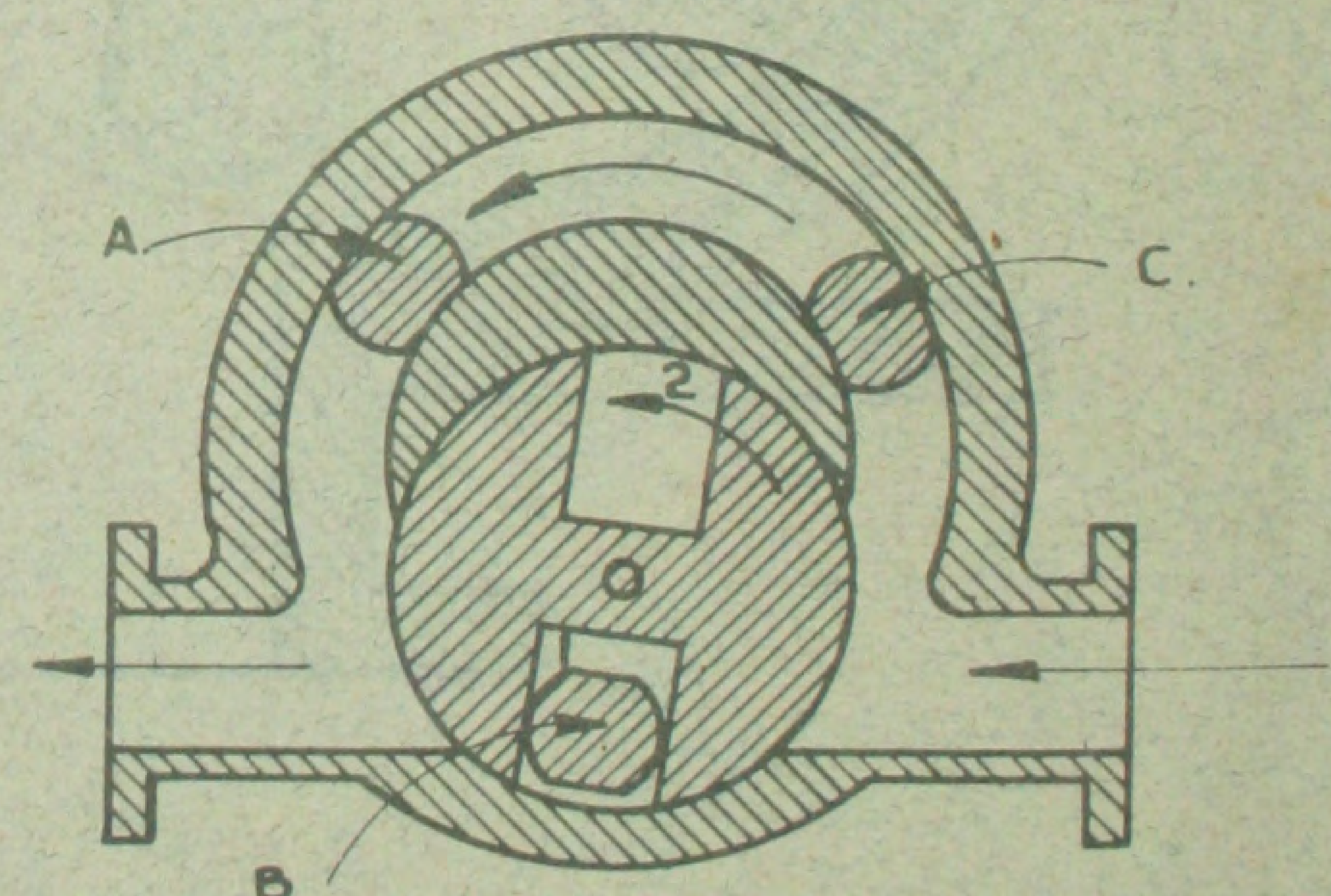
THE ACID PASSES MAINLY THROUGH HOLES IN THE BLOCKS.

2.



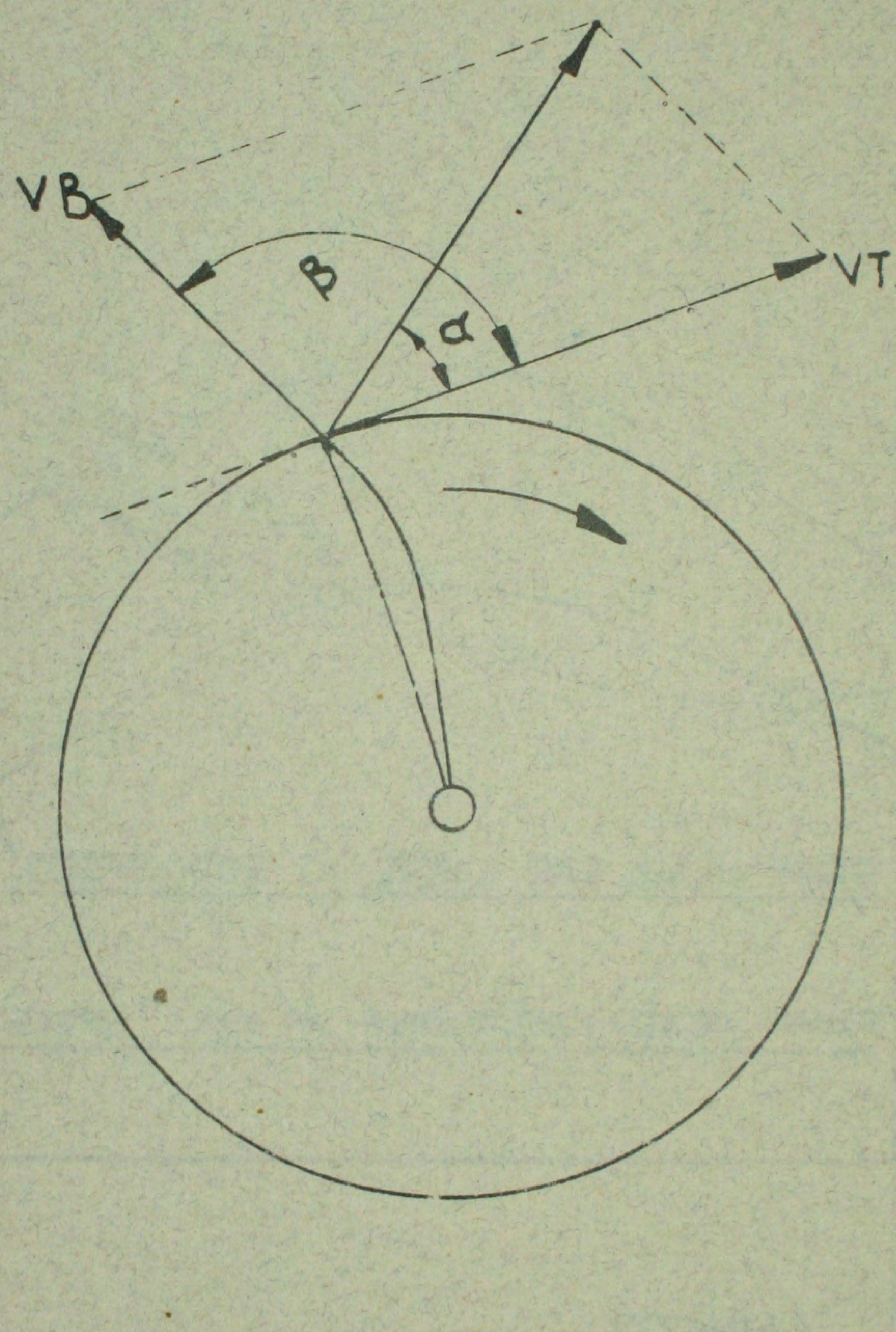
IMPELLER - BLOCK "B" ABOUT TO ENTER SLOT I LEAVING BLOCK "A" FREE TO EXPELL ACID FROM CIRCULATING CHANNEL TO OUTLET.

4.



ONE-THIRD OF A REVOLUTION COMPLETED, POSITION OF SLOTS IN DRUM REVERSED.

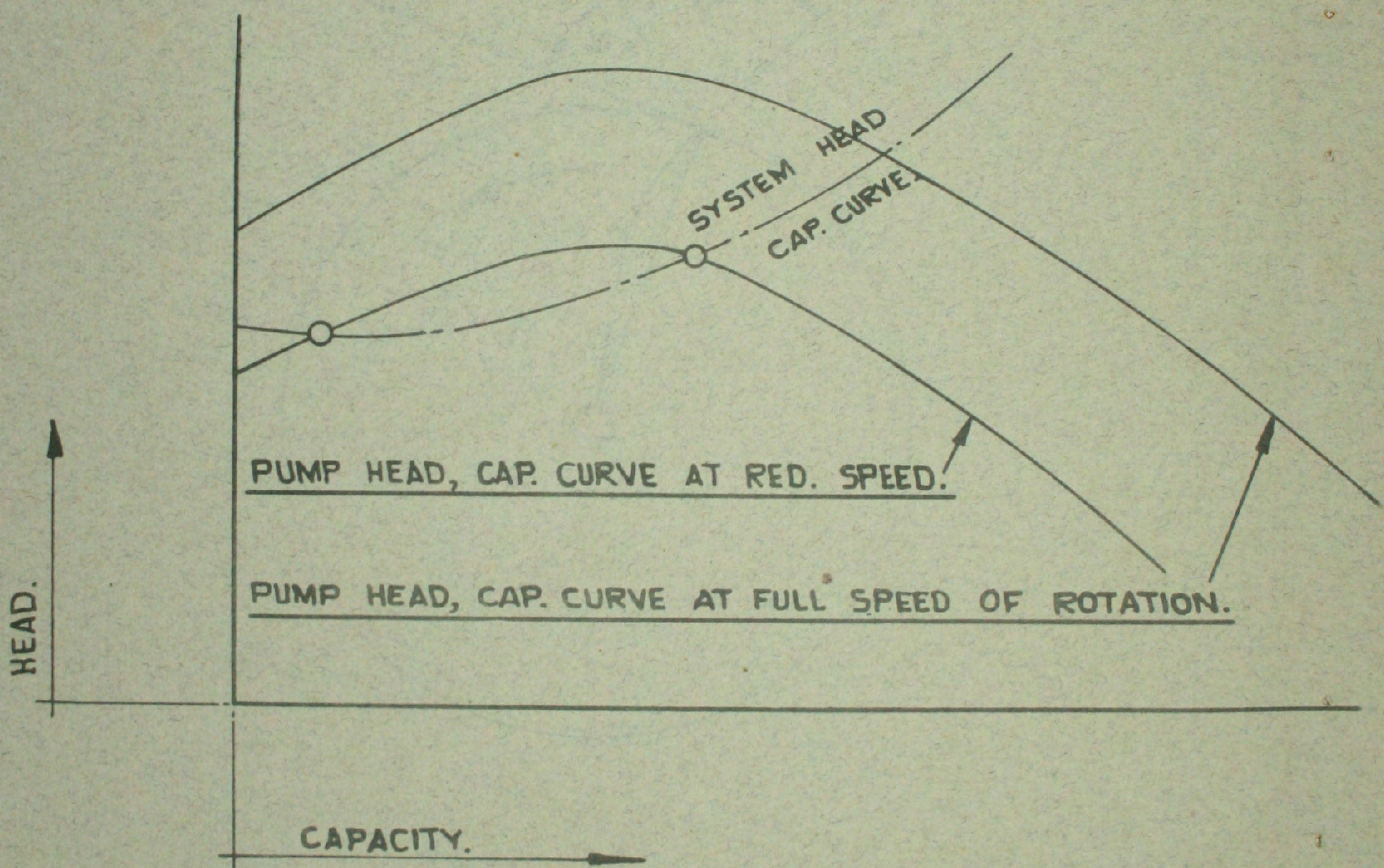
Fig. 22. (see p 48)



VECTOR DIAGRAM FOR CENTRIFUGAL PUMP

54711-1

Fig 23 (see p 70)



PUMP OPERATION WITH UNSTABLE HEAD CAPACITY CURVE.

54711-1

Fig 24 (see p 73)

ACID HANDLING AND TRANSPORT.

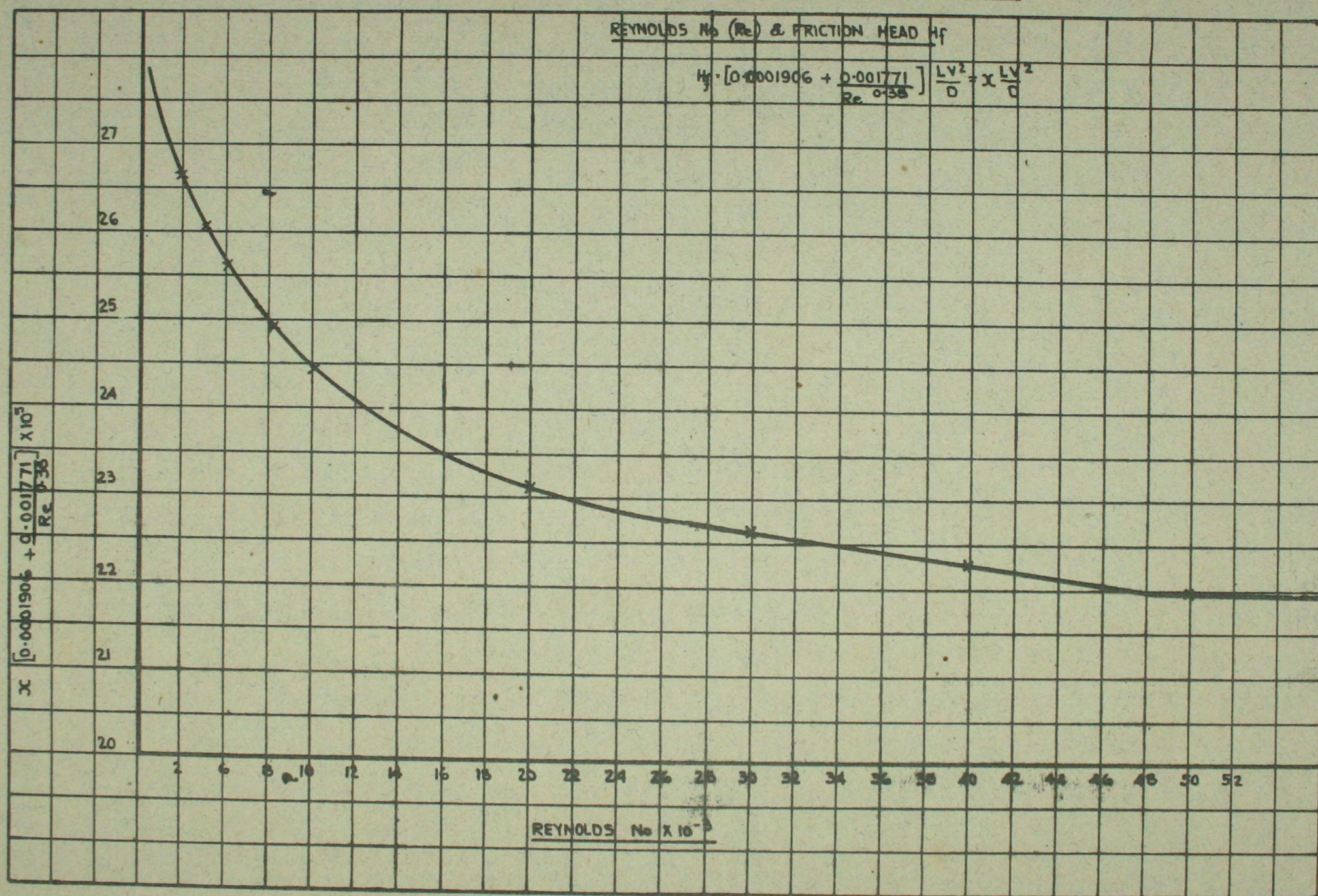


Fig 25 (see p64)

54771-1