

PUMP BASICS III

Mr Tony Salisbury

PRINCIPLES OF POSTIVE DISPLACEMENT PUMPS

1. INTRODUCTION

The basic principles to be discussed apply to both type of machines, with the need to account for the effects of compressibility when dealing with a gas, as well as the effects of viscosity and density change involved with all machines. The notes therefore deal with the principles that apply to both pumps and compressors and then discuss effects that uniquely affect pumps and compressors.

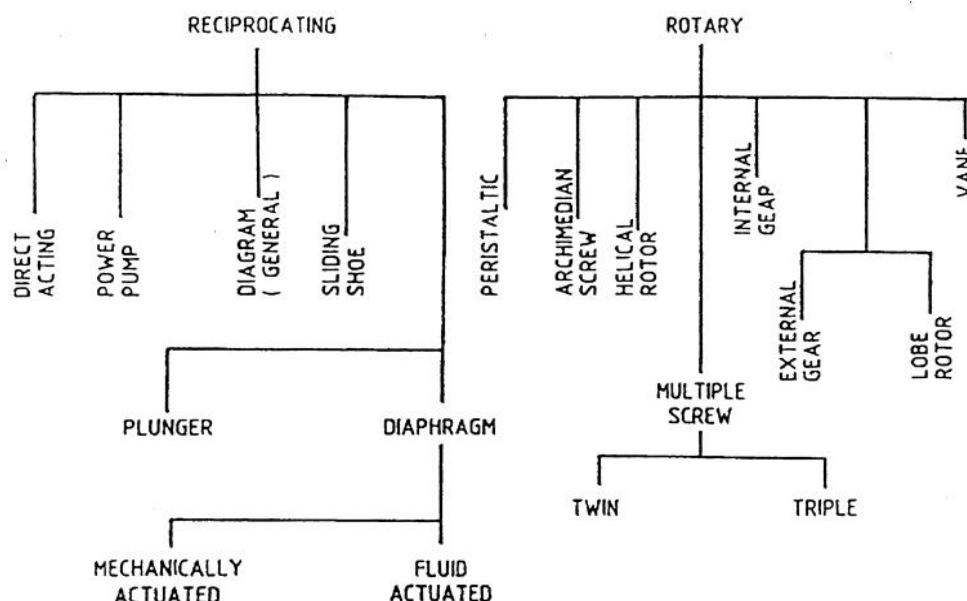


Figure 1 The positive displacement pump family tree

2. BASIC PRINCIPLES

Figure 1 covers the main types of machines in use, and figure 3 and 4 illustrate the layouts of the main types of pumps and compressors. The charts show in figures 5, 6 and 7 illustrate the typical duty ranges. Fluids delivered include hydrocarbons, both liquids and gases, food products, pharmaceutical compounds, difficult and corrosive liquids, solids in suspension, pharmaceutical compounds, difficult and corrosive liquids, solids in suspension, liquid concrete, pastes, two phase compounds, blood products, water sewage, pure and combined gases, and refrigerants.

All positive displacement machines operate on discrete 'parcels' of fluid, and the flow is therefore intermittent, with the fluctuation in pressure and/or flow dependent on the design of the machine.

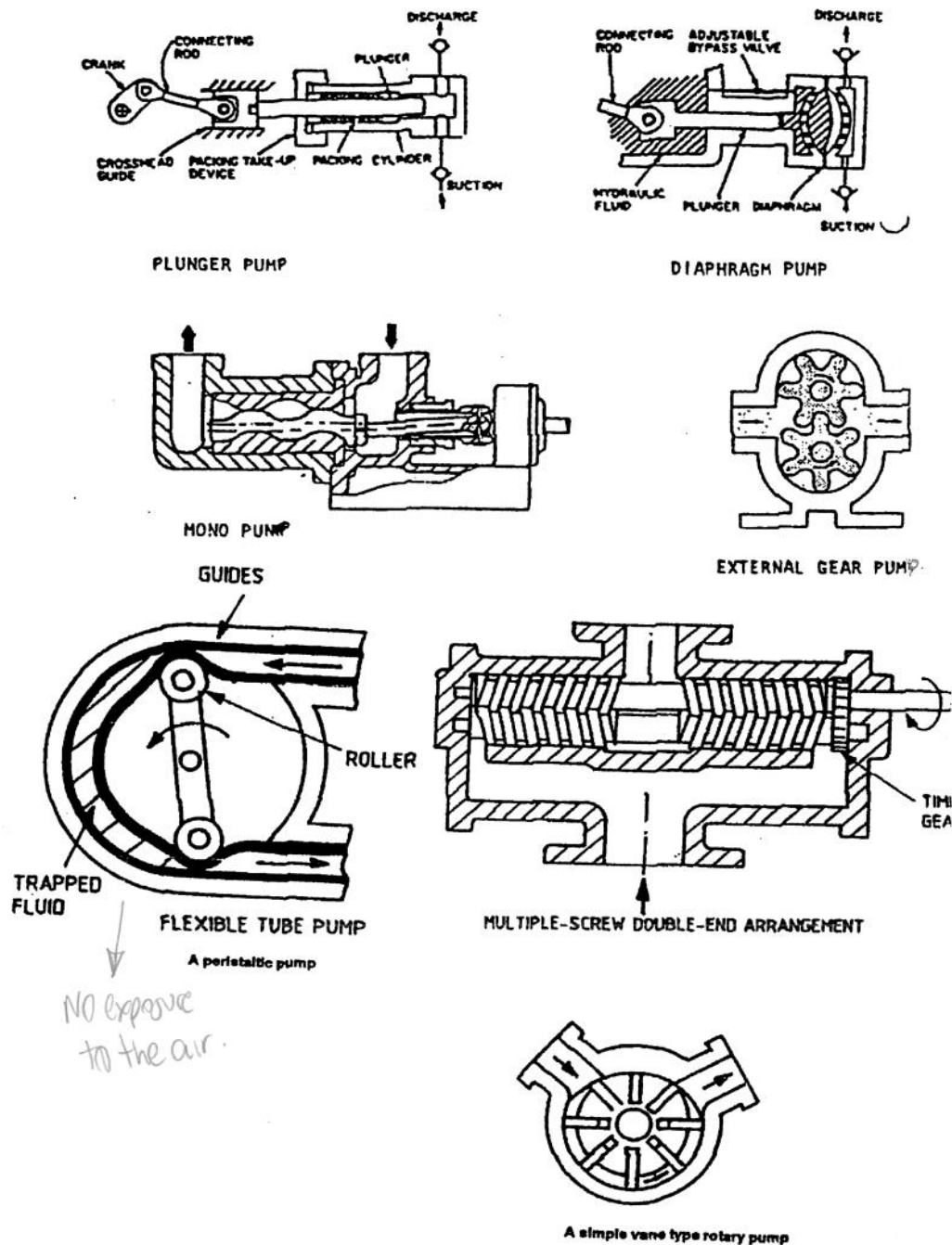


Figure 2 Positive
displacement pumps

2.1 PUMP PRINCIPLES

Consider a plunger pump as sketched in figure 3. This is single acting in operation, as the crank drive draws the piston back allowing fluid into the cylinder on the suction stroke, and then forcing the fluid out as the piston reverses its motion. The inlet pressure to the cylinder is a function of the suction system, and the delivery pressure is related to the downstream resistance. The outlet valve isolates the delivery system during the suction stroke and the inlet valve similarly isolates the suction system during the delivery stroke.

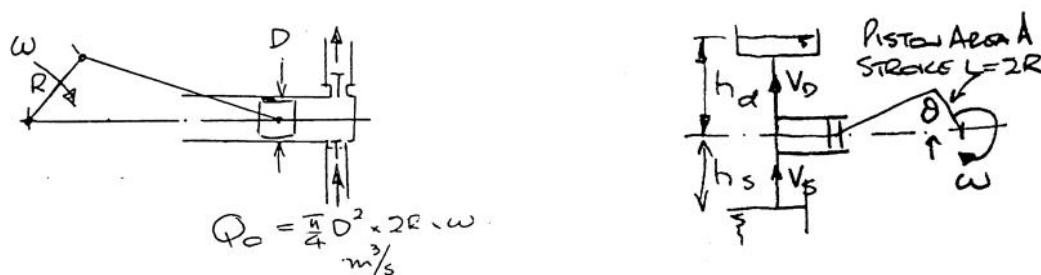


Figure 3

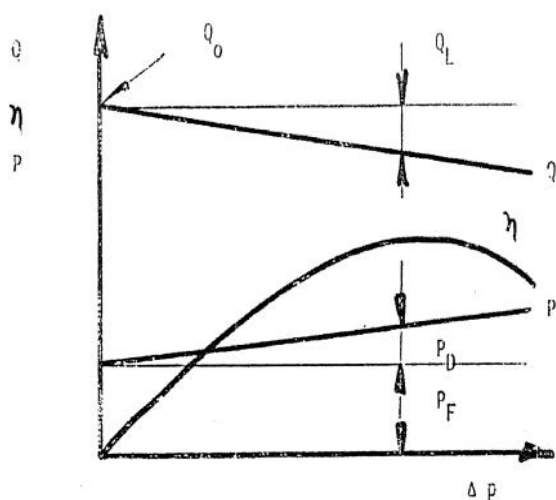


Figure 4

The volume delivered is given by the formula

$$Q_0 = \left(\frac{\pi D^2 L}{4} \right) \times \text{number of strokes per minute} \quad (1)$$

If leakage Q_L takes place the actual flow rate delivered is

$$Q = Q_0 - Q_L \quad (2)$$

The volumetric efficiency

$$\eta_v = 1 - \frac{Q_L}{Q_0} \quad (3)$$

Figure 3 shows a typical characteristic.

Table 1 Some typical values of efficiency

	η_v	η
Precision gear	98%	95%
External gear		20 – 60%
Screw		75 – 85%
Vane	95 – 90%	75 – 80%
Axial piston	98%	90%

For a piston pump, the phenomenon called separation occurs when the pressure at the piston on the suction stroke falls to about liquid vapour pressure and a vapour pocket forms (effectively cavitation). The conditions that lead to this will now be discussed.

The ideal indicator diagram is shown in figure 5.

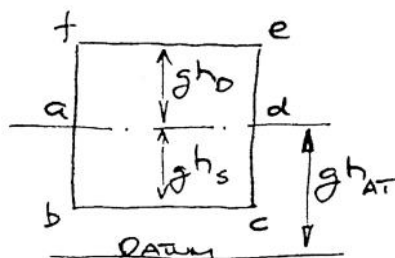


Figure 5 An ideal indicator diagram

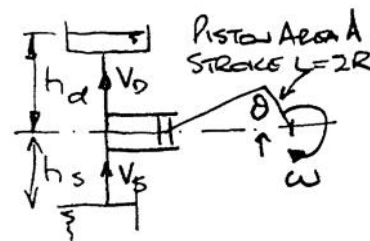


Figure 6 Simple Reciprocating Pump

The shape of the ideal diagram must be modified to describe real flow effects due to acceleration and deceleration in the suction and delivery lines and for flow losses. If the pump piston is being driven by a crank system it will follow SHM (simple harmonic motion) as in figure 6.

The energy required to accelerate the fluid in the delivery line is given by the expression based on figures 5 and 6

$$gH_{AD} = L_D \frac{A}{a_D} \omega^2 r \cos \theta \quad (4)$$

where L = pipe length
A = cylinder area
a = pipe area
r = crank radius

subscripts D and S denote delivery and suction respectively.

This is a maximum when $\cos \theta = 1$. Similarly for the suction system

$$gH_{AS} = L_S \frac{A}{a_S} \omega^2 r \cos \theta \quad (5)$$

The ideal diagram now becomes that shown in figure 12. The quantity related to the distance bb' is the further energy loss due to inertia at the start of the stroke and cc' relates to the regain as the fluid accelerates at the end of the stroke. Friction loss is given by D'arcy equation

$$gH_F = f \frac{L}{D} \frac{V^2}{2} = f \frac{L}{2D} \left(\frac{A}{a} \omega r \sin \theta \right)^2 \quad (6)$$

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This is at maximum when $\theta = 90^\circ$ (i.e. at midstroke)

Thus the maximum values for the discharge and suction lines are

$$gH_{FD} = \left(f \frac{L}{D} \right)_D \left(\frac{A}{a_D} \omega r \right)^2 \quad (7)$$

and

$$gH_{FS} = \left(f \frac{L}{D} \right)_S \left(\frac{A}{a_S} \omega r \right)^2 \quad (8)$$

The diagram becomes further modified as in Figure 8. In this figure the maximum loss to friction in equation 7 is shown as $gh_{fs}(\max)$ and is given by equation 8.

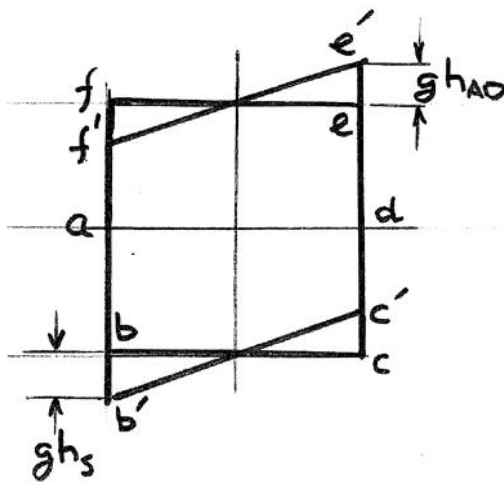


Figure 7

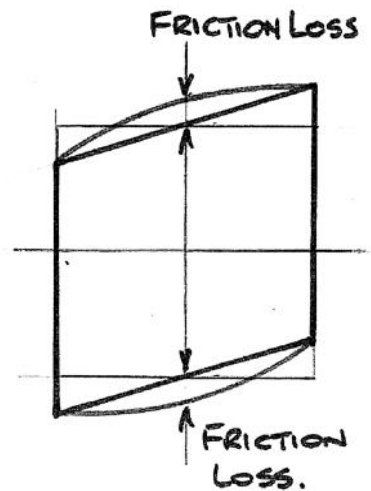


Figure 8

In addition to the friction loss the effects of losses due to bends, valves and other features need to be accounted for particularly with short lines where the feature losses become a large part of the loss.

If pumping liquid, for example water, there is a limit placed on flow and stroking rate that is related to the vapour pressure of the water, and the effects of the losses in the suction system. The specific energy in the cylinder due to the suction system is

$$gH = gH_{AT} - gH_S - gH_{AS} - gH_{FS} - \text{other losses} \quad (9)$$

The limiting specific energy gH is $2.4g$ for water (related to vapour pressure) so equation 9 allows flow rate or ω to be determined. Other limits on pump performance are those due to viscosity (see figure 9) and gas content in the liquid (corrections for this are shown in figure 10a and 10b).

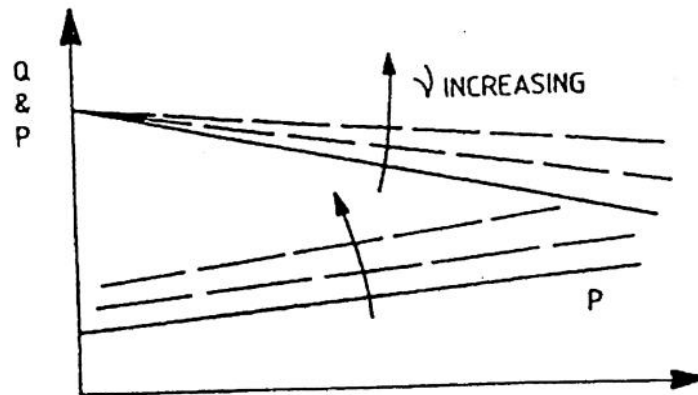


Figure 9 Effect of viscosity on pump performance

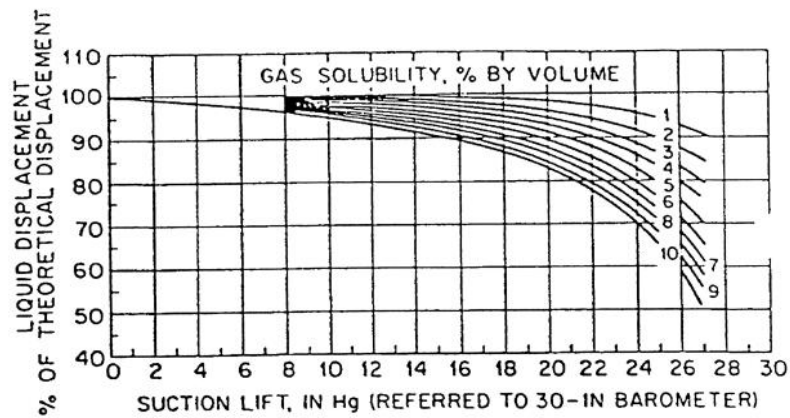


Figure 10a Effect of dissolved gas on liquid displacement

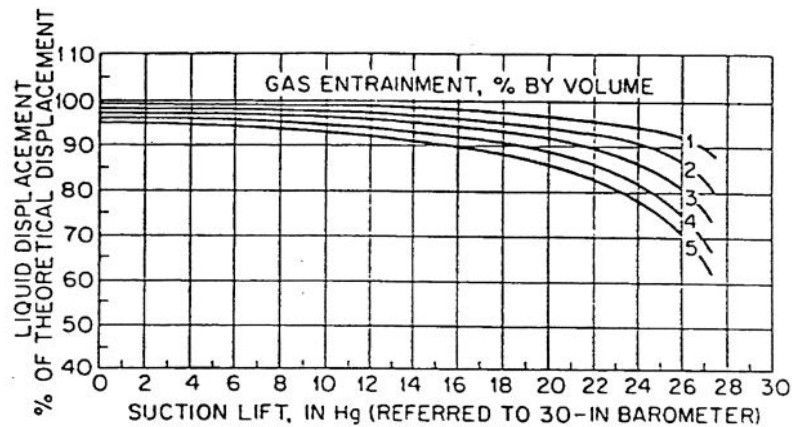


Figure 10b Effect of entrained gas on liquid displacement

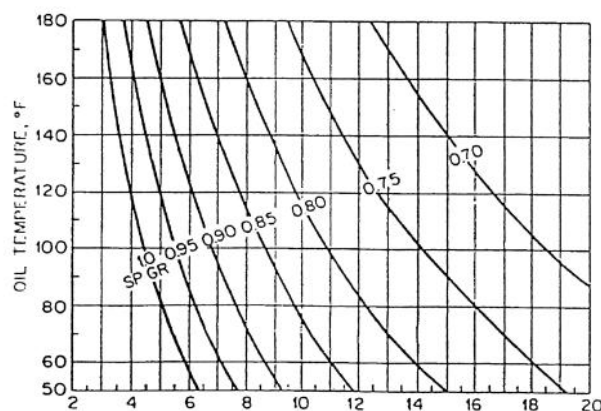


Figure 10c Solubility of air in oil

Pulsation in pump systems occurs due to the action of the machine. For example in a single acting reciprocating pump the piston moves with SHM of conventional design, this gives a pulsing of flow and pressure, as sketched in figure 16 showing the effects of multiple cylinder combinations. To smooth these pulses dampers close to the cylinder are usually fitted, and figure 11 compares the designs commonly used. All reciprocating pumps must have valves and must be fitted with a relief valve.

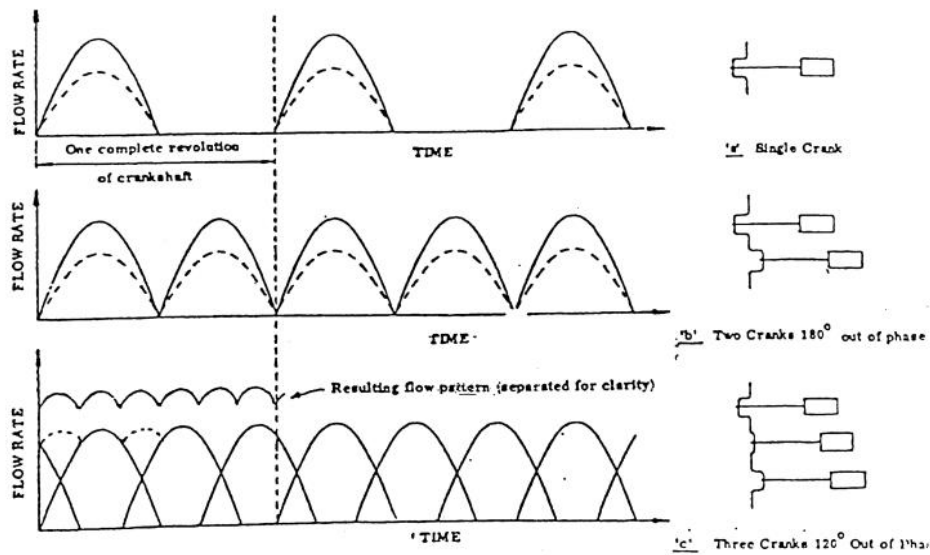


Figure 11 Variation of flow rate with number of pistons in a reciprocating pump

	DIVERTER	APPENDAGE	GAS-OVER LIQUID	ACOUSTIC
ATTENUATION:				
HIGH FREQUENCY	FAIR	POOR	POOR	EXCELLENT
LOW FREQUENCY	EXCELLENT	EXCELLENT	EXCELLENT	POOR
BACK PRESSURE ON PUMP	SLIGHT	NONE	NONE	HIGH
EFFECTIVENESS AT:				
VARIOUS PUMP rpm	EXCELLENT	EXCELLENT	EXCELLENT	POOR
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VARIOUS PUMP PRESSURES				FAIR
INITIAL COST	HIGH	LOW	MEDIUM	HIGH
REPAIR COST	MODERATE	MODERATE	NONE	NONE
MAINTENANCE COST	LOW	LOW	MEDIUM	NONE
SLURRY CAPACITY	POOR	EXCELLENT	GOOD	POOR

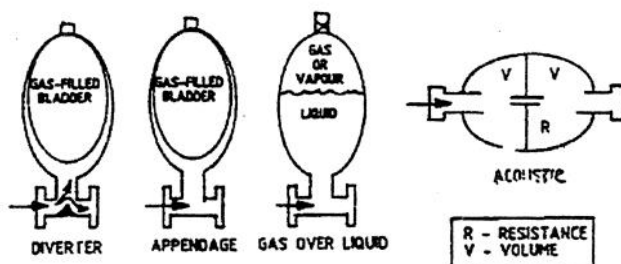
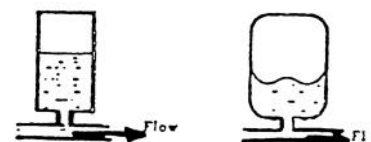


Figure 12 Relative performance of damper design

POSITIVE DISPLACEMENT & OTHER PUMP TYPES

1. POSITIVE DISPLACEMENT PUMP TYPES

Due to the very wide variety of positive displacement pump types and even working principles it is only possible to illustrate and discuss a very small selection of these.

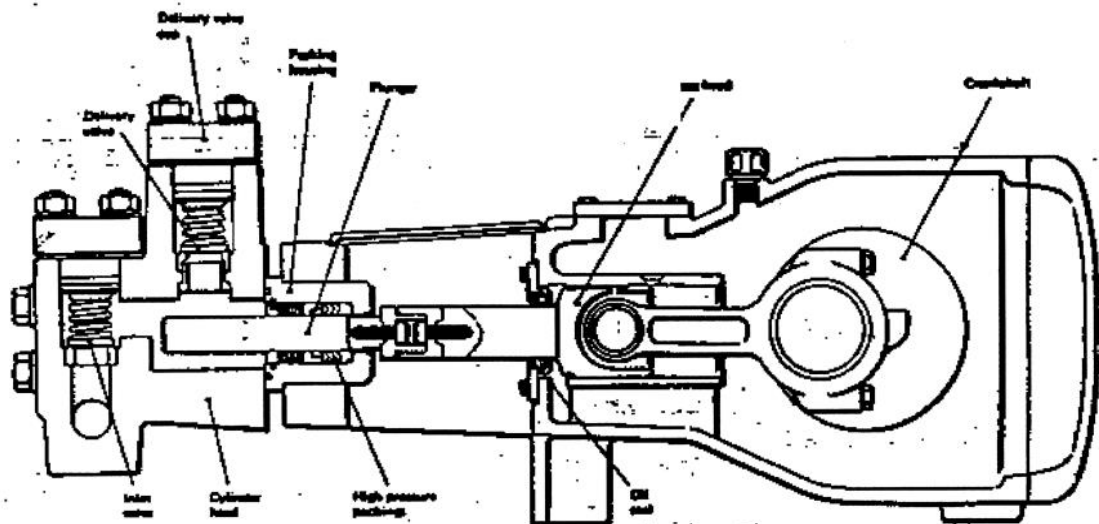


Figure 1 - High pressure jetting pump

Figure 1 above shows a high pressure jetting pump typically used for high pressures and clean liquids. This is most likely to be used on cleaning duties, but does illustrate the typical construction comprising a wet end with poppet valves, small diameter single acting pistons and a crankshaft / connecting rod / guide bore arrangement of drive. Variations on this theme can be used for sludge pumping.

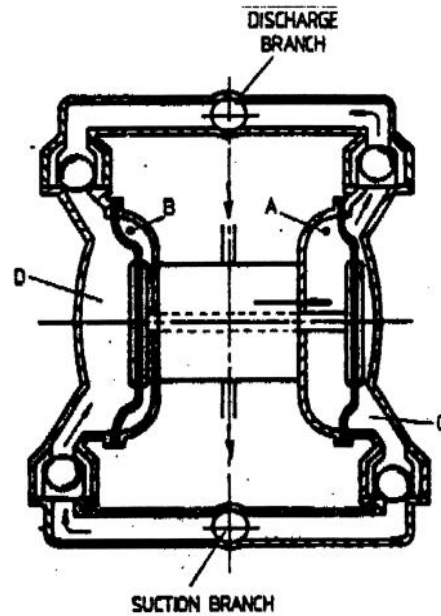


Figure 2 - Cross section through air operated diaphragm pump.

The figure above shows an air operated diaphragm pump. The pumped liquid is on the "outer" side of the diaphragm while the compressed air provides the driving force on the "inner" side. Fluid flow is controlled by ball valves and there are two pumping elements operating 180° out of phase. The whole arrangement is controlled by a shuttle valve assembly. The air operated version has the benefit of light weight making it attractive for portable applications, but compressed air is an inefficient driving medium. A similar wetted end can be applied to the crankshaft drive arrangement. Typical applications include sludge and scum in the smaller treatment works.

The energy required to accelerate the fluid in the delivery line is given by the expression based on figures 5 and 6

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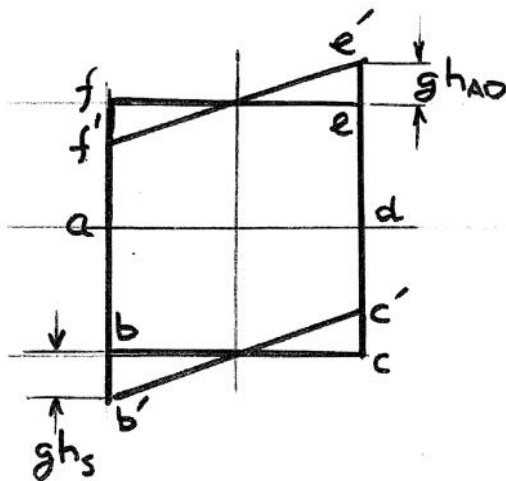


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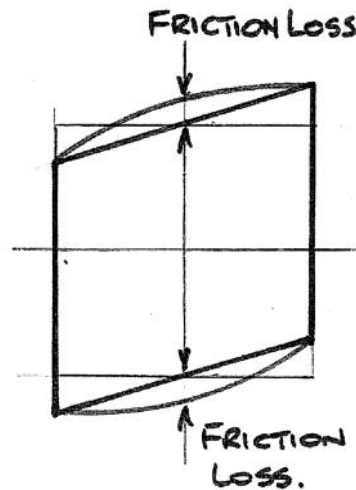


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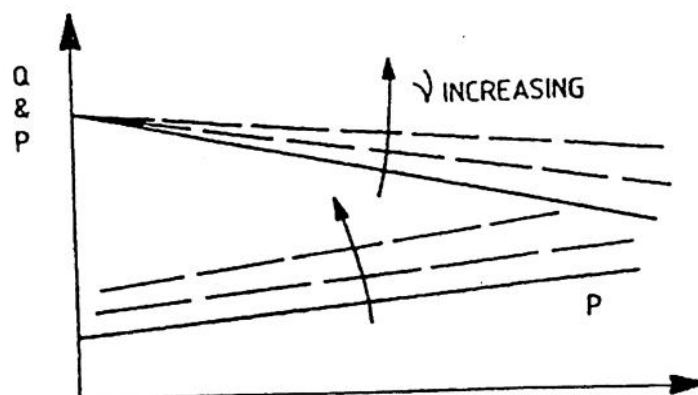


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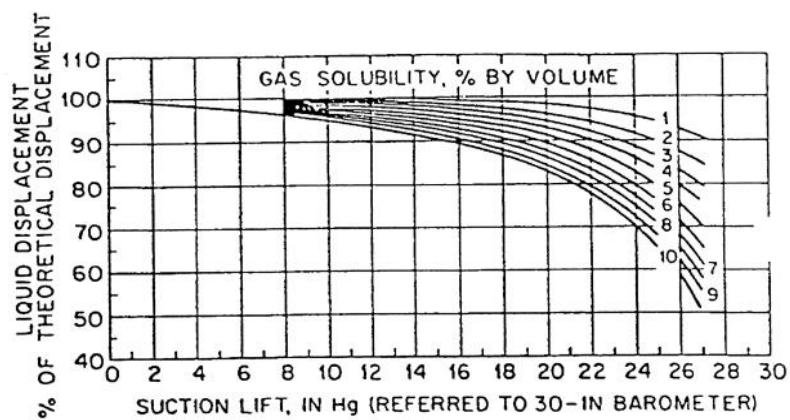


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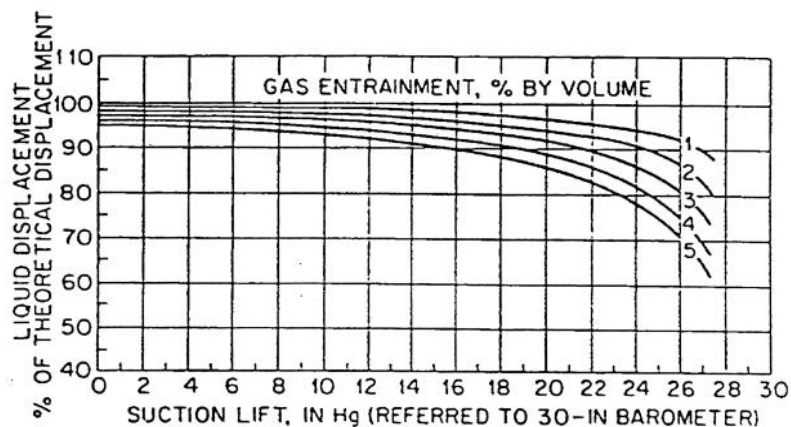


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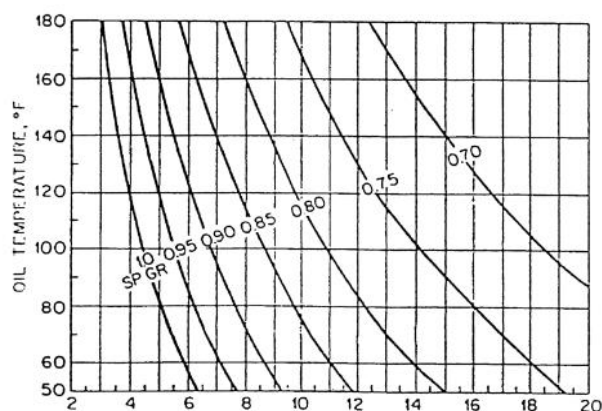


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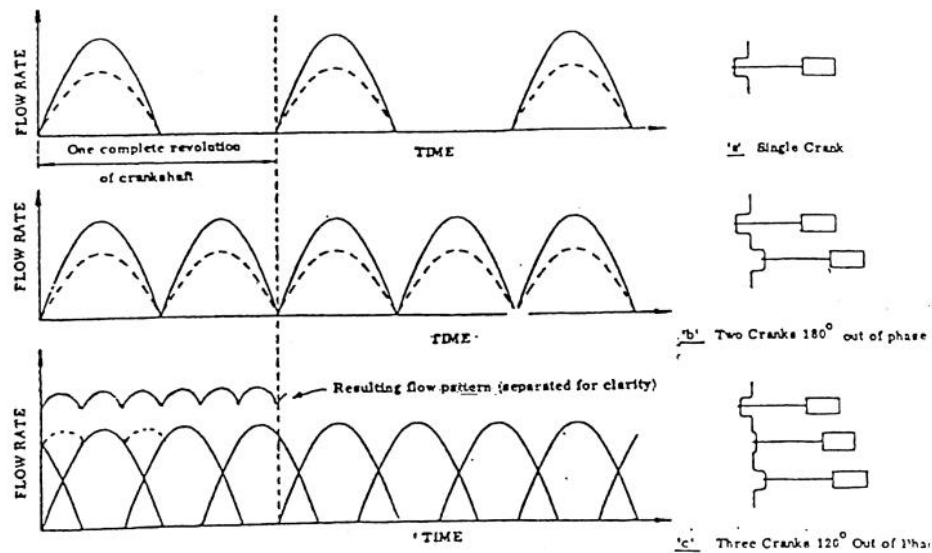


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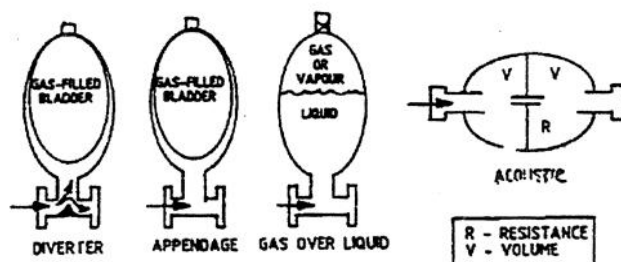


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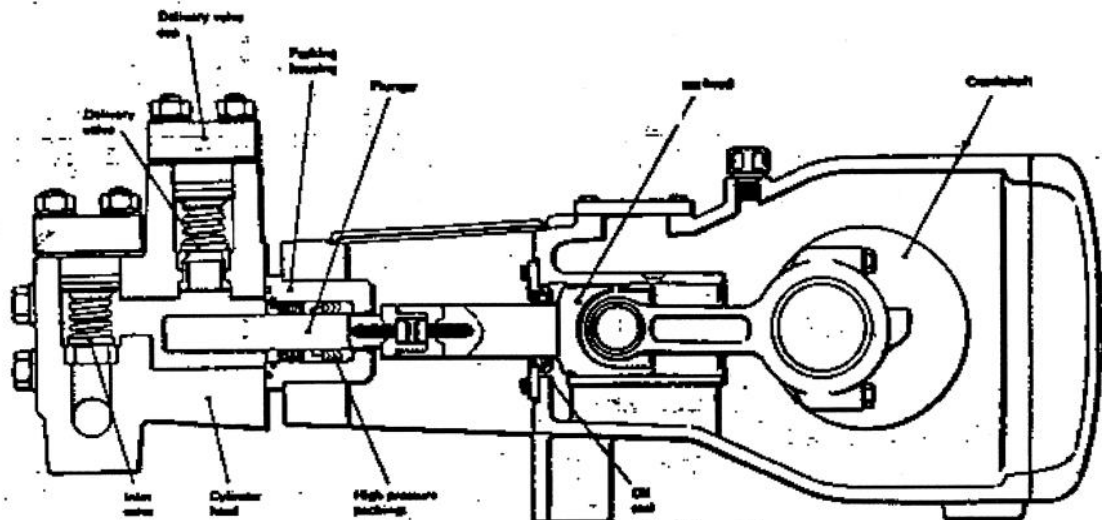


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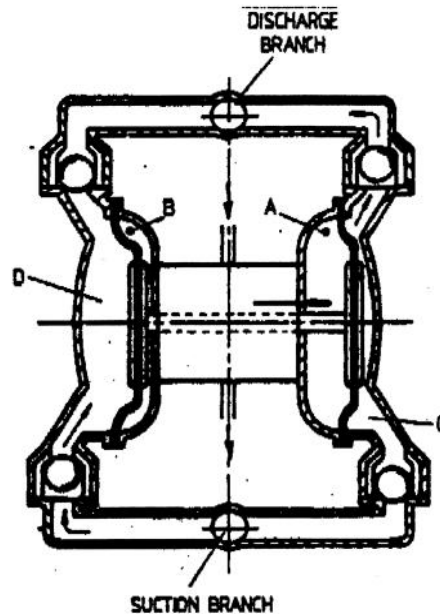


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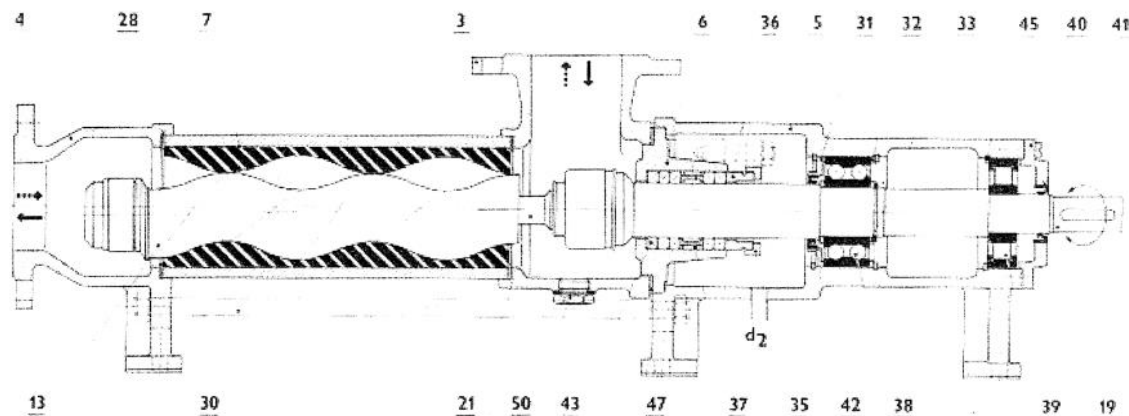


Figure 3 - Progressive cavity "Mono" pump

Figure 3 above shows a very common pump type which was invented by a Mr. Moineau and was patented, hence only "Mono" pumps made this type. The patent expired some 15 years ago and now several manufacturers offer this type. The rotor is of helix form and precesses inside a rubber stator having a helical bore of double the pitch. The combined action moves pockets of liquid from the inlet to the outlet. Various forms of connection are used between the drive shaft and the rotor to accommodate the precessing motion of the stator. These joints must be flexible, reliable and waterproof; a variety of joint types are offered by different manufacturers. The pump is available with various forms of seal and a range of drive options. Typical duties include sludges and scum. Smaller versions can also be used for clean applications. In some cases, the pump can be used as a crude metering pump. Borehole versions are also available for drive by hand, electric motor, diesel engine or windmill in remote or third world applications. The steel rotor / rubber stator combination is not very tolerant of abrasives. Dry running can cause extensive damage in less than a minute.

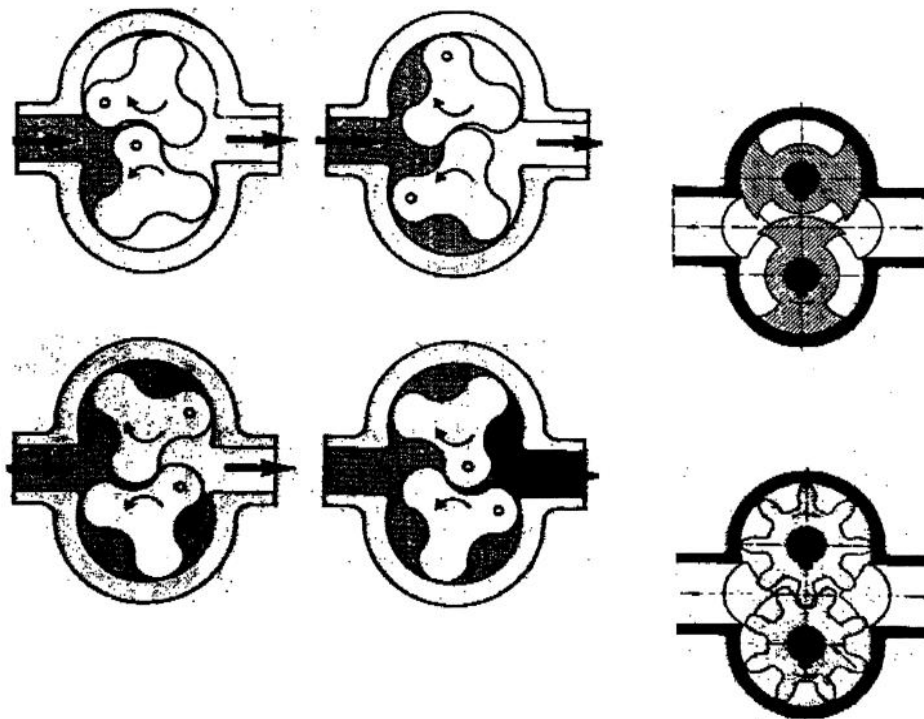


Figure 4 - Lobe rotor and gear pump principles.

The above figure illustrates the gear pump, lobe rotor and circumferential piston styles of pump. All are similar in operating principle and rely on meshing rotors in closely fitting housing for their pumping actions. The lobe styles will usually have external gears on both shafts to keep the lobes in phase. The gear geometry does not need this, but does require liquid with reasonable lubricating qualities. Pump types with external drive gears usually have carefully engineered clearances between rotor teeth, rotor tips / casing and rotor ends / casing which makes them less susceptible to abrasive damage. Pumps are available with elastomeric rotors, hardened metal rotors and all stainless construction. Applications include sludges of all types.

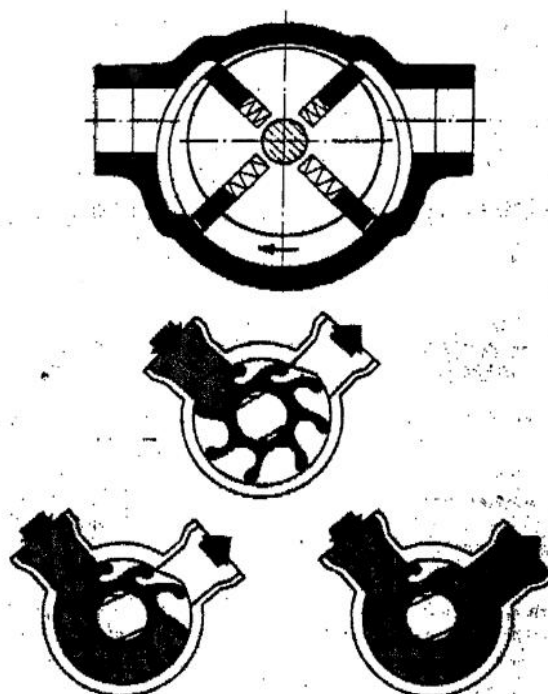


Figure 5 - Sliding vane and flexible vane pumps.

The above pump style also relies on rotor in a closely fitting housing. The sliding vane type is rarely used in water processing applications, but the flexible rotor type is sometimes used for small flows and light sludges.

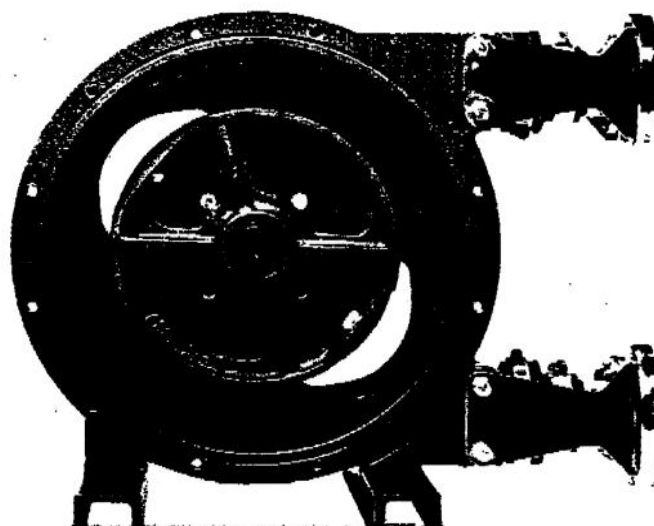


Figure 6 - Peristaltic pump

The above figure shows a large scale peristaltic pump. These are available in branch sizes up to 150 mm for pumping heavy and abrasive sludges. The peristaltic hose is of multi layer construction with a thick rubber lining. The shoes which provide the peristaltic action run on the hose in a bath of lubricating and cooling medium such as glycerine. The hose and casing are designed to allow easy replacement of the hose. The same pumping principle is used for

pumps as small as laboratory units and can be used for some less demanding metering applications.

2. POSITIVE DISPLACEMENT PUMP THEORY

This class of pumps operate by transferring an enclosed volume of liquid from the inlet port to the outlet port. Regardless of particular pump type, the outlet is isolated from the inlet by a seal or valve. This results in the performance parameters of a P.D. pump being very different to those of a rotodynamic pump.

2.1 Pump Characteristics and Losses

Since an enclosed volume of liquid is pumped with each operating cycle, the volumetric displacement is proportional to pump speed and the displaced volume, which of course depends on the particular pump geometry. Therefore, the theoretical PD pump performance would be a flowrate equal to theoretical displacement multiplied by the number of strokes or volumes displaced per unit time. The pressure generated would be anything from zero to infinity, dependant on the back pressure imposed by the system and the absorbed power would be the product of the displaced volume times the pressure generated.

In reality, the performance is modified by the following losses:

- The liquid is enclosed by a seal or valve, both of which have a tendency to leak. Therefore, there is a continuous flow of liquid through this leakage path and the rate of leakage is a function of type of sealing element and degree of wear of same, pressure differential across the sealing element or valve, viscosity of the liquid being pumped.
- Valves need a finite time to operate, hence the speed of operation of the sealing element can result in some back leakage during the closing time of the valve. This effect becomes more marked as the rotational speed of reciprocating pumps is increased. Increased liquid viscosity can also slow the closure rate of the valves, making this effect more important.
- At very low generated pressures, the flow through a reciprocating PD pump can exceed the theoretical displacement as liquid flows forward through the pump valves due to the inertia of the liquid column at both inlet and outlet.
- If the pumped liquid is compressible, a certain volume is "lost" at each pumping cycle as the liquid is compressed. This can happen with gaseous media such as sewage sludge where the finely dispersed bio-gas or dissolved gas will give the liquid an appreciable compressibility.
- There will be some hydraulic friction within the inlet, outlet, valves and pump body. This will reduce the generated differential pressure, but will require power input to overcome.
- There will be significant mechanical friction to overcome both within the pump and within speed reducing drives often associated with PD pumps. Units incorporating a diaphragm sealing and pumping element or other elastomeric elements can have hysteresis losses within the elastomer.
- There may be some flow through the pressure relief system at pressures below the nominal protection point, leading to extra internal flow losses.

The presentation of positive displacement pump curves does not follow a uniform convention as the rotodynamic industry does. However, a typical presentation would be as follows:

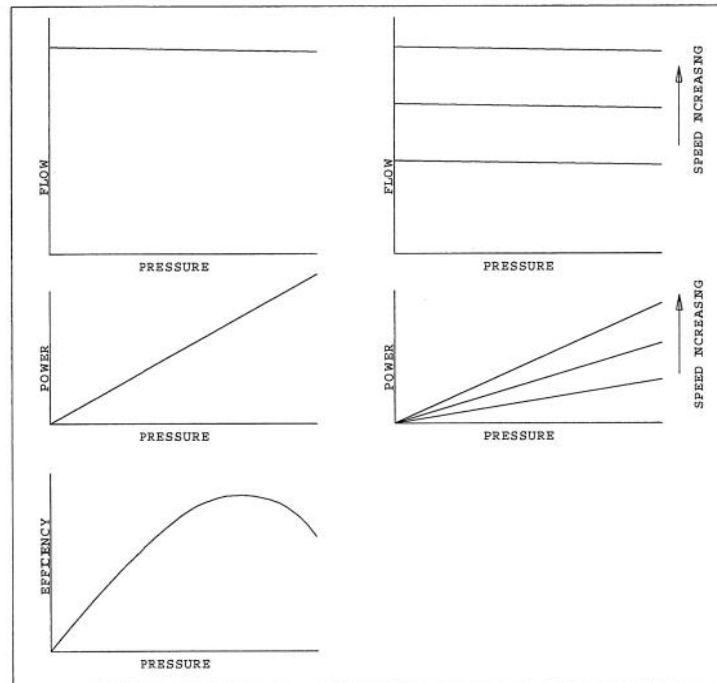


Figure 7 - Typical presentation of positive displacement pump characteristic

In addition to the data shown above, a manufacturer may also publish families of curves to show the variation with changing liquid viscosity, changing pump internal clearances and application areas depending on lubrication properties of the pumped liquid.

2.2 Pressure Relief Arrangements

A positive displacement pump is capable of generating very high pressures and if the outlet is blocked or discharge flow stopped, the pressure will rise sufficiently to cause mechanical damage to the pump. Therefore, most PD pumps are fitted with a pressure relief system, either a bypass valve or a pressure switch or slipping clutch and sometimes a combination of these measures. The design, selection and specification of these protection systems can be quite complex because:

- Relief valves do not operate at a single pressure. The relieving pressure will depend on the liquid viscosity, the associated relief pipework and the flow through the relief system.
- A relief valve will generally only close once the pressure has dropped significantly (Say 10 % approximately) below the opening pressure.
- Within the limits of operation dictated by the above considerations, a relief valve should protect the pump, drive and pipe system under all conditions but should not operate at pressures below the nominal set point.
- Slipping clutches have a stick / slip characteristic that is not fully predictable to close limits.
- Pressure switches can become clogged or "sticky".
- All of the above items are safety related and are subject to dirt, blocking, misuse and unauthorised tampering.

2.3 Pump Priming

Positive displacement pumps are often capable of priming; that is "sucking" a column of liquid up an empty inlet pipe. Manufacturers may provide details of the priming abilities in terms of a maximum suction lift height. In some cases, figures will be presented for a "wet prime" and a "dry prime". The former relates to a pump containing some residual pumped product from the last cycle which helps to lubricate and seal the working surfaces and/or valves. The latter relates to a completely dry pump and generally gives a lower priming performance than a wet pump. For some types of construction, any dry running would be completely unacceptable.

The priming ability is likely to deteriorate with wear. Therefore, do not rely on the stated priming ability for successful system operation.

Important Note: Priming ability is completely separate from the cavitation performance of a pump. It may be possible that a pump can prime at levels which will induce cavitation. Alternatively, a pump may continue to work (once primed) at inlet levels which would not allow priming.

2.4 Pump Cavitation and NPSH

In a P.D. pump, cavitation usually commences in or around the inlet valves. As with rotodynamic pumps, the vapour cavities reduce the pump performance and will ultimately lead to damage of the pump internals. Some workers have shown that the NPSH required by a positive displacement pump is a function of liquid viscosity, the viscosity increasing the losses between pump inlet flange and pumping element

2.5 Mechanical Design Aspects

Much of the science of practical PD pump technology is concerned with sealing and tribology since the pumping effect relies on internal seals and wetted rubbing surfaces are inevitable.

Detailed consideration of the mechanical design constraints depends on the particular pump type. However, in general terms all loadings are proportional to pressure generated. The following points will be the limiting mechanical factors to any pump application:

- Shaft loads increase in proportion to pressure. In the case of a rotary lobe pump this would be a radial loading, while a progressive cavity design would produce an axial load, for example.
- Shaft deflections are usually proportional to load. Remember that some pumps are designed with internal clearances to prevent rotors (for example) rubbing. High pressures can cause sufficient deflections to make internal parts rub, leading to rapid wear and failure. Seals may also give problems due to shaft deflections.
- Bearing loads similarly increase and bearing lives decrease
- The pump casing, cylinders or outer parts are a pressure vessel with a consequent pressure limitation.

2.6 Starting and Stopping

For most positive displacement pumps, the liquid column commences moving as soon as the pump starts. Hence the driver may be accelerating not only the inertia of the pump parts, but perhaps several tonnes of liquid stored in the pipe. For this reason, P.D. pumps usually need careful design of the starting and drive system. Practical possibilities include:

- Slip ring motor with resistance starter
- "Direct on Line" starter – this starts suddenly and the short term pressure rise may cause the pressure relief system to operate for a short time.
- Actuated valve to relieve all pressure until the pump is started and up to speed.
- Mechanical clutch system to start motor before engaging pump drive.

Reduced voltage starters such as "Star Delta" or soft start controls are not usually suitable for positive displacement pumps.

3. METERING PUMPS

The correct metering and dosing of chemicals is important to the water processing industries and therefore the correct selection and application of pumps to accurately meter chemicals should be considered.

3.1 Pump Types

The majority of metering pumps are of the single acting, single pumping element positive displacement type. Multiple pistons or other pump elements are sometimes used, but these are not as common as the single head machine. The pumps are generally small and carefully engineered to deliver a repeatable dose with each stroke and to have the ability to vary the dose in proportion to some external setting. In addition, some applications will also require the provision of variable speed drives to further vary the dose rate delivered to the process.

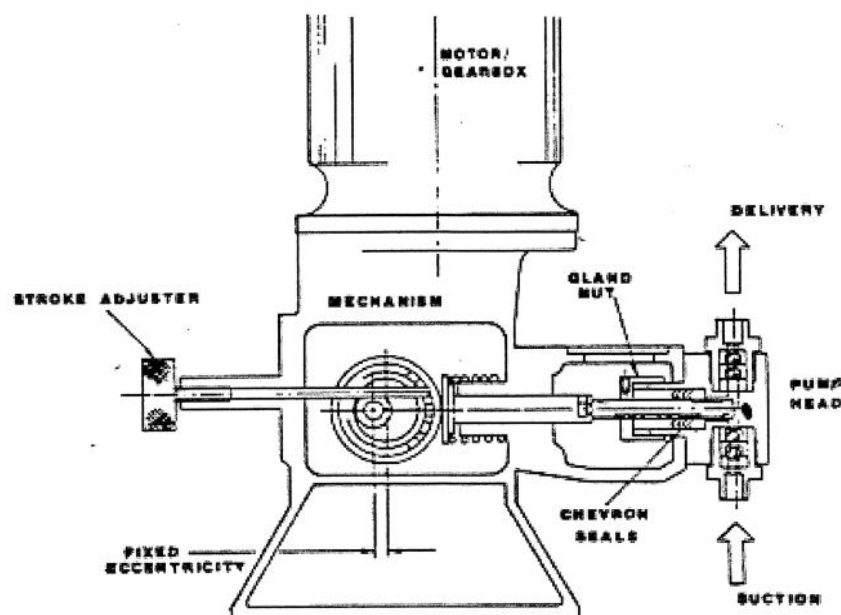


Figure 8 - Simple metering pump with lost motion system for changing dose rate.

The figure above shows a simple plunger type pump, which incorporates a spring return in the plunger assembly. This mechanism allows some "lost motion" to be introduced into the connection between connecting rod and plunger, which allows the displaced volume per stroke to be varied. While simple and potentially quite accurate, the delivered flow changes "instantaneously" as the lost motion between crank and plunger is taken up at each stroke; this introduces potential problems of pressure pulses as the liquid is accelerated. The crankshaft drive is typical for a metering pump, being a worm wheel drive direct from a small electric motor.

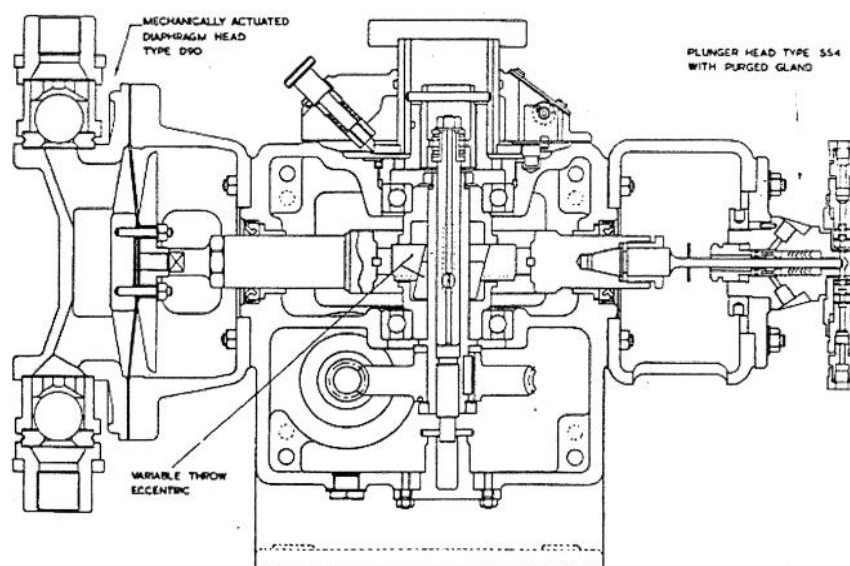


Figure 9 - Metering pump with Z crank drive and showing two styles of pump head.

The illustration on previous page shows a more complex drive mechanism known as the "Z Crank". By moving the central Z shaped member axially, the crank throw can be varied thus changing the pump displacement. This is a more complex mechanism but has the advantage of providing a sinusoidal motion to the plungers throughout the stroke range.

The illustration also shows two alternative pumping heads. On the left is a direct drive diaphragm unit with ball valves for suction and delivery. This would be used for a relatively high flow and low pressure application and the diaphragm seal would prevent external leakage. The right hand side shows a small bore plunger with chevron seals and a flushing arrangement for leakage. Valves are either ball or disk style and this head would be used for a low flow, high pressure application on a dangerous or aggressive liquid.

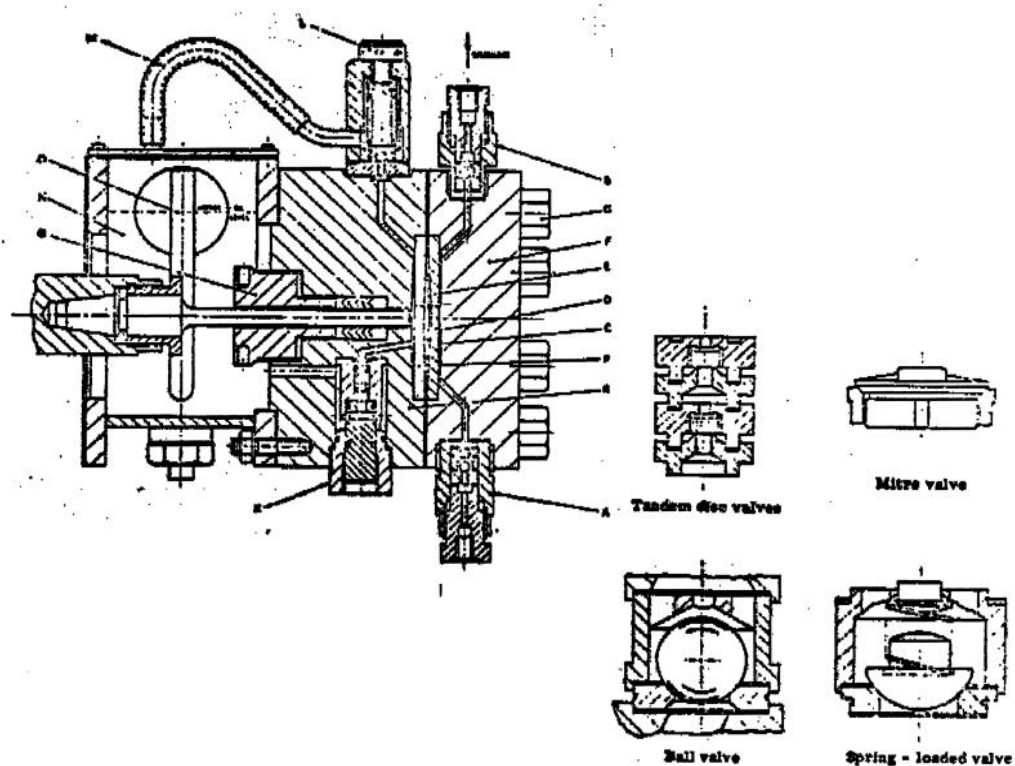


Fig.11 Typical pump valves

Figure 10 - Hydraulically actuated diaphragm pump. Also showing a range of valve types.

The above figure shows a third type of pumping head, the hydraulically actuated diaphragm. In this case, the plunger acts on a buffer liquid (usually oil) in a closed chamber causing the diaphragm to oscillate. Ancillary valves ensure that the oil chamber is always full and prevent over-pressure in this area. The pumped liquid is to the right of the diaphragm. The advantage of this construction is that the diaphragm only transfers pressure and so can be of light construction.

It will be appreciated that to handle the wide range of chemicals, flows, and applications the manufacturers offer a similarly wide range of material options, seal options and valve options.

3.2 Application of Metering Pumps

Design of the full metering pump system can be quite complex and the detail is beyond the scope of this lecture. For further interest students are recommended to refer to "Pulsations, Vibrations and Noise – The Flowguard Book" published by Flowguard Ltd. of Stockport, Cheshire.

The problems to be addressed are:

1. The maximum instantaneous flow for a single piston unit is $\pi/2$ times the mean flow. Calculate system resistance and pipe sizes on the basis of the maximum flow.
2. Flow in both the suction and discharge systems is accelerated from zero to the maximum and decelerated to zero again at every stroke. For a single acting pump the acceleration head is:

$$h_{acc} = \frac{\Omega \pi V_m}{g}$$

where:

Ω = Pump rotational speed [radians per second]

V_m = Mean flow velocity in main [m/s]

g = Acceleration due to gravity [9.81 m/s/s]

This acceleration head is required 90 degrees out of phase to the maximum friction head. The liquid columns in both suction and discharge systems require an acceleration head.

3. The combination of flow resistance at peak flow, acceleration head to overcome liquid column inertia and significant resistance in valves to ensure rapid valve closure can result in cavitation at the pump inlet which will prevent accurate metering.
4. The same effect as above can give cavitation on the outlet and prevent accurate metering.
5. The inertia of both suction and discharge liquid columns can lead to excess flow passing through the pump which prevents accurate metering.
6. Metering pumps do not like solids – always specify a suction strainer.

Points 1, 2, 3 and 4 can be overcome by adequately sizing inlet and outlet pipes and / or providing pulsation dampers on inlet and outlet. Point 5 can be overcome by providing a loading valve on the discharge to create extra discharge resistance.

4. OTHER PUMP TYPES

4.1 Archimedean Screw Pump

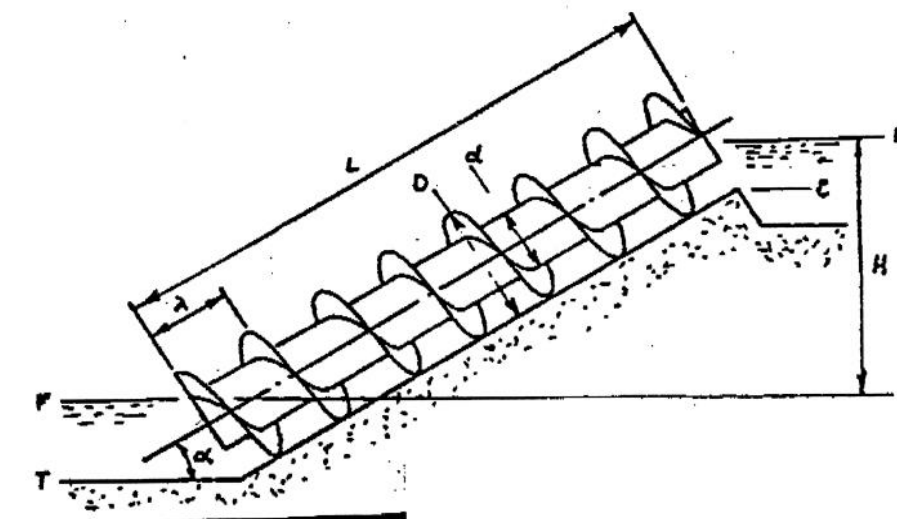


Figure 11 - Archimedean screw pump

The above type is widely used in the water industry for applications such as Return Activated Sludge or for raw sewage. The inclined screw rotates within a closely fitting trough of concrete or steel. In some smaller pumps, the helix may be completely enclosed in a tube. The helical action of the screw lifts pockets of fluid up the inclined slope. The inclined slope will typically be at around 30° to the horizontal.

Because the amount of liquid pumped with each revolution depends on the inlet liquid level, the pump is self regulating, a lower inlet level causing it to pump less. The pump is also very tolerant of large scale solids, hence its popularity for use at the inlet to a sewage treatment works.

The pump draws from and discharges to open channels. It is important that the discharge channel level is not allowed to rise too far (around 20% of screw diameter as a maximum) above the "chute point" shown as "I" in the above diagram. If this happens it will prevent the screw discharging freely. In addition, the downstream water must be prevented from running back down a stationary screw pump; either by a flap valve or by preventing the level rising above the chute point.

The above type of pump can be applied to total lifts of up to 10 metres and for flows from a few hundred litres per second up to several thousand litres per second.

Possible problems to watch out for in applying such pumps:

Static pumps can jam due to solar heating on one side, causing the screw to expand and bend in the trough. Provide a roof or shading structure to prevent this or slowly motor the screw round at all times.

The lower bearing is submerged and usually grease lubricated. Check that the downstream process can accept the waste grease.

The exposed liquid surface is large and agitated. This can cause odour problems. Provide a cover and odour extraction to counter this.

The screw can run backwards when power is lost due to the weight of water held up in the pump. Provide or specify anti run back clutches to counter this.

4.2 The Jet Pump

This is a momentum exchange device in which the momentum of an incoming jet of fluid (usually water but sometimes air), Q_m is used to entrain a second liquid stream, Q_s . A diffusing cone then converts the velocity energy of the mixture back to pressure energy and delivers the mixture Q_d .

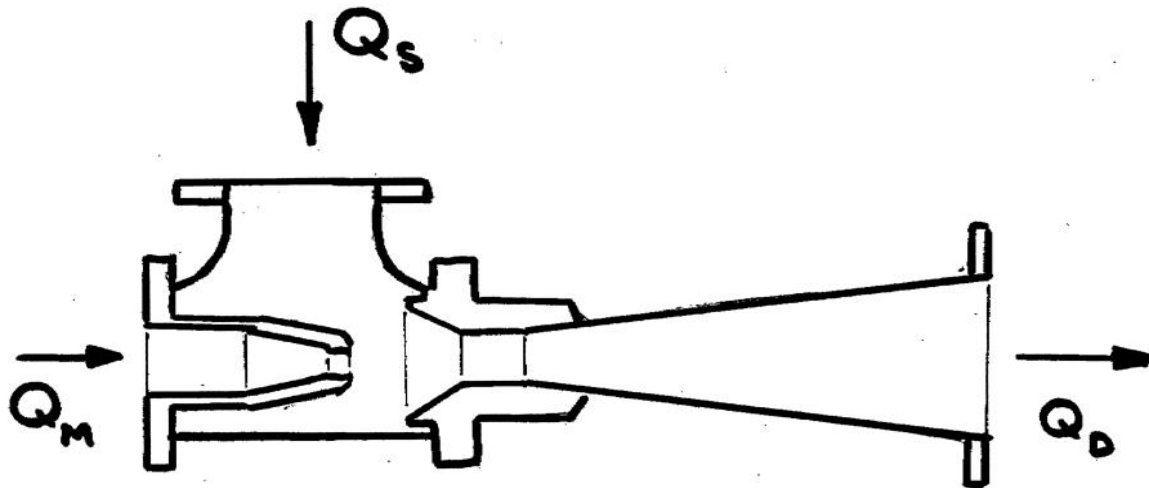


Figure 12 - Jet pump in cross section.

Applications of this device include:

- Chlorine injector to maintain a negative pressure on the chlorine system and inject the chlorinated water mixture into a pressurised area.
- Deep well jet pump keeping a motive water pump on the surface and using a jet pump down a borehole, for example.
- Tank stirrer and / or air diffuser; usually powered by a submersible pump directly fitted to the jet pump.
- Vacuum pump to prime other pumps.
- Pump for moving slurries such as granular activated carbon.

4.3 The Pitot Pump

A very low specific speed device in which a stationary "Pitot" nozzle is located within a spinning body of liquid. The delivered flow is taken from the pitot nozzle and out of the pump. This pump should fall into the rotodynamic class, since the head gain is due to an increase of velocity energy which is converted back into pressure energy.

4.4 The Side Channel Regenerative Pump

Another low specific speed device. The rotor comprises a disc with multiple small teeth around the periphery. The rotor fits closely within the casing and flow enters the impeller at the periphery and also leaves at the periphery. Relatively large head rises can be achieved in a single stage, but the device is relatively inefficient. They usually have a steep head – flow curve and falling power curve.

Used in branch sizes up to around 40 mm for clean liquid duties such as providing pressurised service water.

4.5 Air Lift Pump

Compressed air is bubbled into a riser tube and the upward flow of bubbles carries liquid with it. Additionally, the lower density of the rising mixture tends to "float" while higher density clear liquid is drawn into the base of the riser pipe. Relatively low efficiency due to the inefficiency of compressing air.

Applied in the water industry for de-sludging of settlement tanks. Also used at the base of deep shaft aeration processes for circulating sewage down and back up the deep shaft.

Pump Basics III

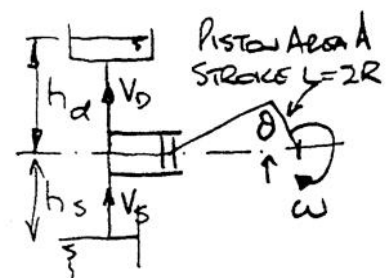
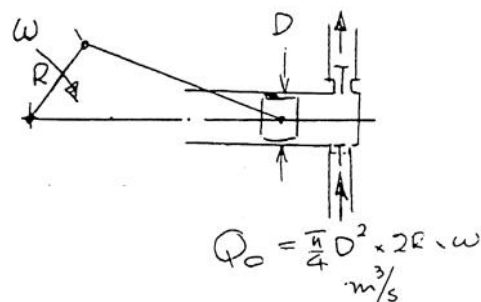
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A Piston Pump – Reciprocating PD Pump

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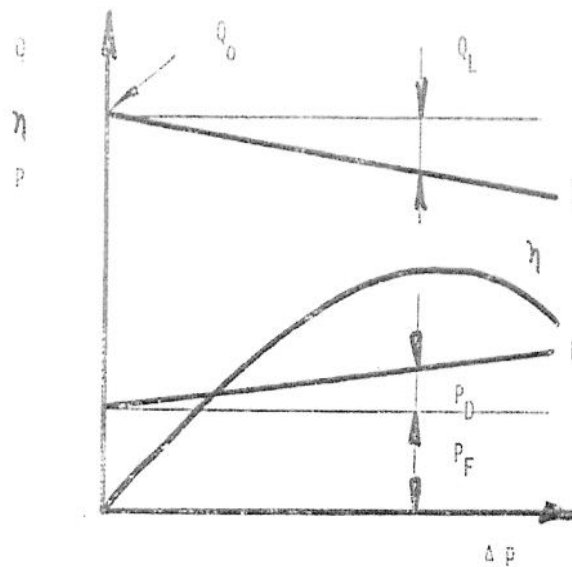
Process Systems Engineering



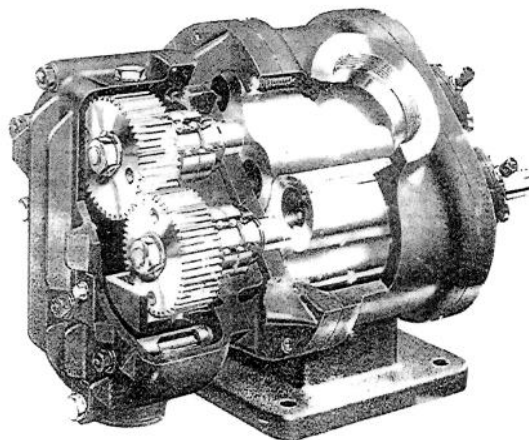
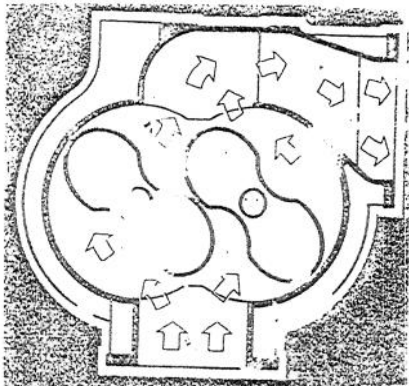
$$Q_O = \left(\frac{\pi D^2 L}{4} \right) \times \text{number of strokes per minute}$$

$$Q = Q_O - Q_L \qquad \eta_V = 1 - \frac{Q_L}{Q_O}$$

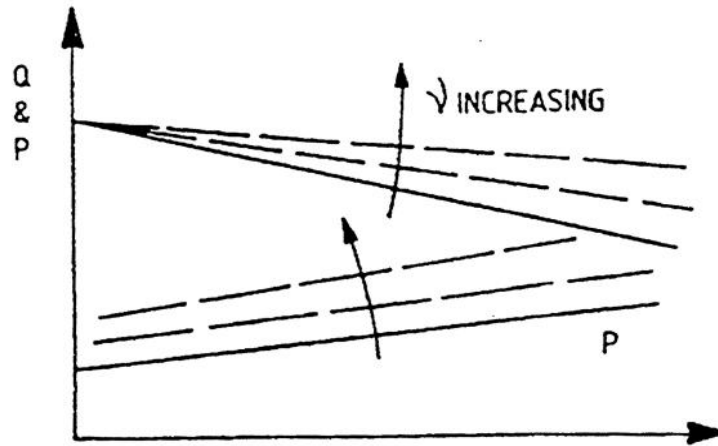
Positive Displacement Pump Characteristics



Rotary PD Pump

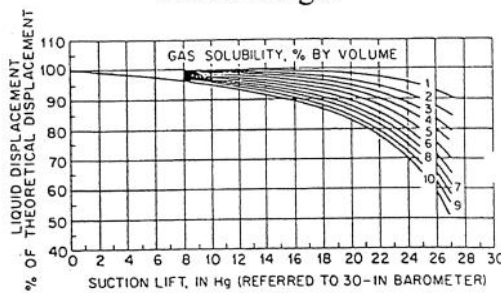


Effect of viscosity on performance

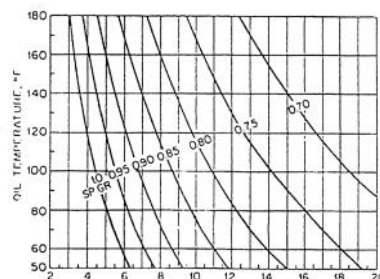
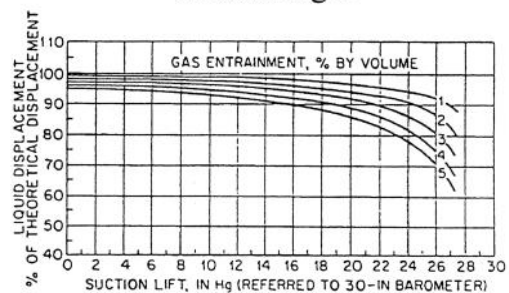


Effect of gas in liquid for a rotary pump

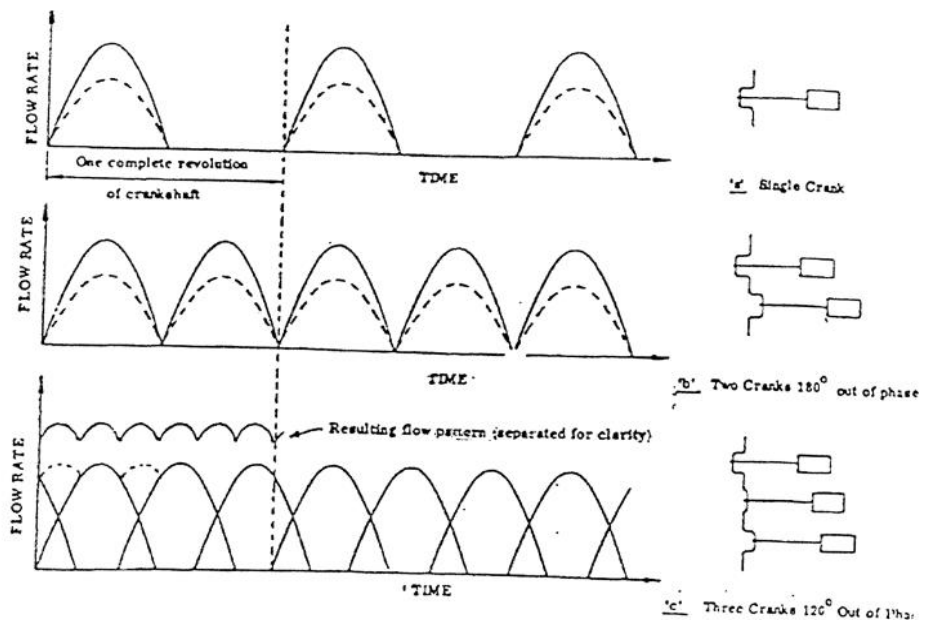
Dissolved gas



Entrained gas

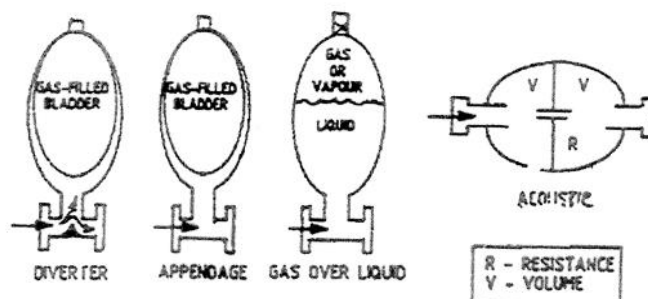


Pulsation in a reciprocating pump



Damping solutions

	DIVERTER	APPENDAGE	GAS-OVER LIQUID	ACOUSTIC
ATTENUATION:				
HIGH FREQUENCY	FAIR	POOR	POOR	EXCELLENT
LOW FREQUENCY	EXCELLENT	EXCELLENT	EXCELLENT	POOR
BACK PRESSURE ON PUMP	SLIGHT	NONE	NONE	HIGH
EFFECTIVENESS AT:				
VARIOUS PUMP rpm	EXCELLENT	EXCELLENT	EXCELLENT	POOR
VARIOUS PUMP gpm	EXCELLENT	EXCELLENT	EXCELLENT	POOR
VARIOUS PUMP PRESSURES				FAIR
INITIAL COST	HIGH	LOW	MEDIUM	HIGH
REPAIR COST	MODERATE	MODERATE	NONE	NONE
MAINTAINANCE COST	LOW	LOW	MEDIUM	NONE
SLURRY CAPACITY	POOR	EXCELLENT	GOOD	POOR



- Unlimited Pressure?
- Fixed Volume/Stroke – metering/dosing
- Not so sensitive to Viscosity
- Self Priming?
- Valves
- Unlimited Pressure – Pressure Relief Valve
- Hard solids?
- Pulsations

Pump Basics III

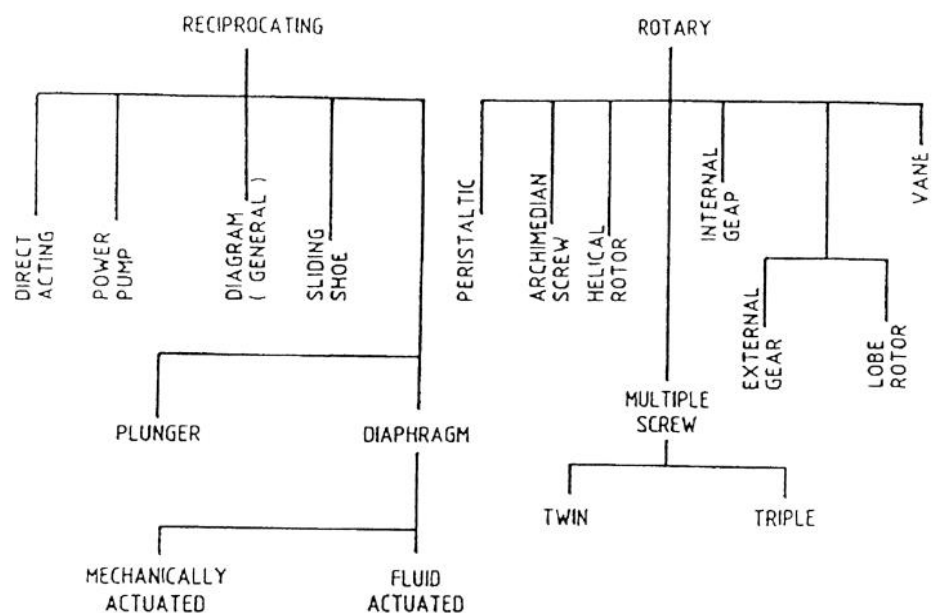
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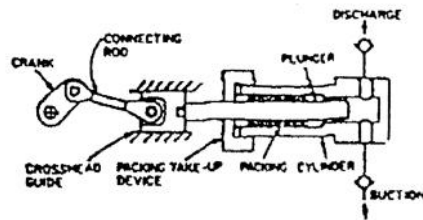
PD Classification

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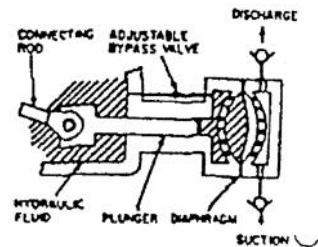
Process Systems Engineering



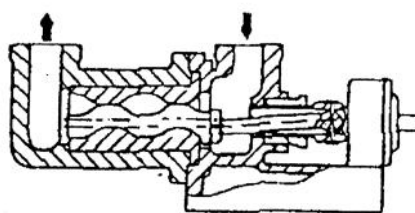
PD Pumps



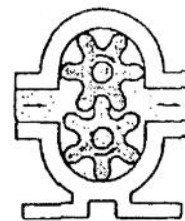
PLUNGER PUMP



DIAPHRAGM PUMP



MONO PUMP

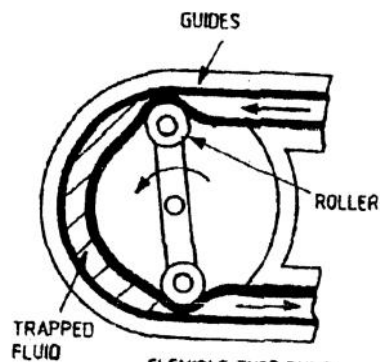


EXTERNAL GEAR PUMP

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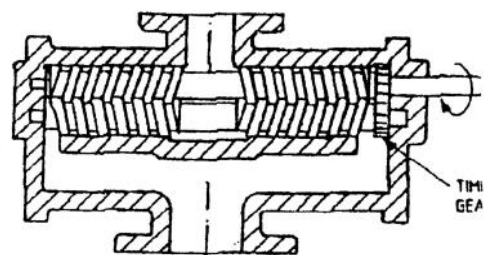
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PD Pumps



FLEXIBLE TUBE PUMP

A peristaltic pump



MULTIPLE-SCREW DOUBLE-END ARRANGEMENT

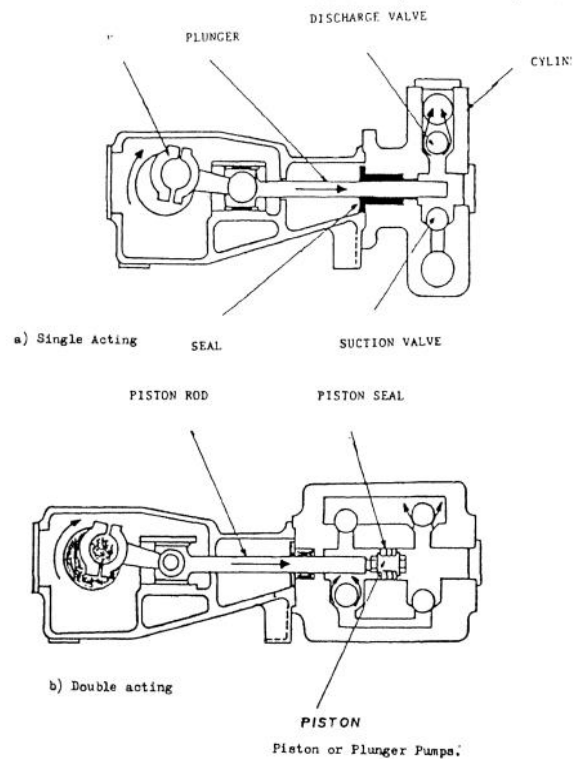
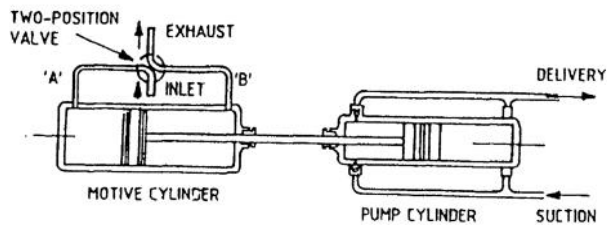


A simple vane type rotary pump

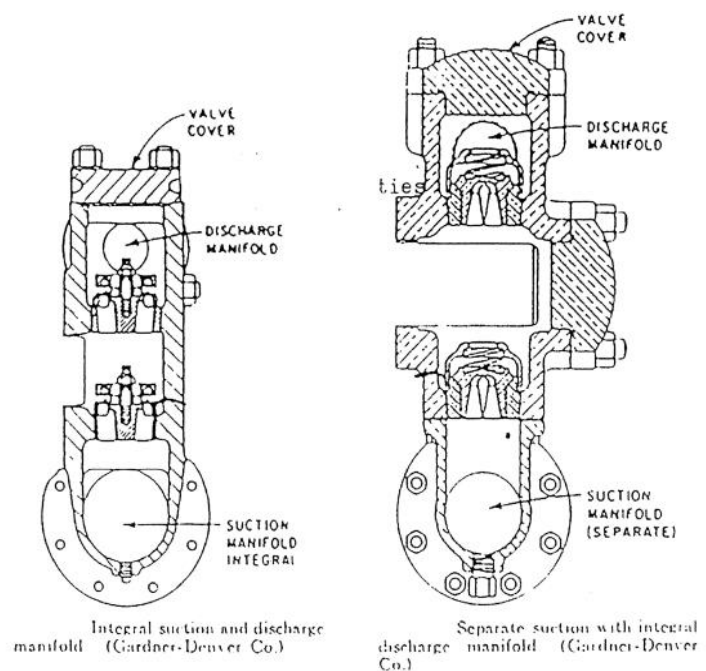
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Various Configurations of Piston or Plunger Pumps

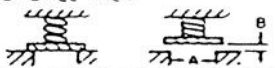
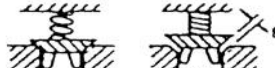
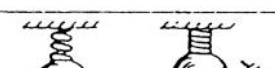
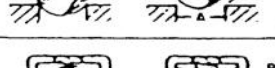
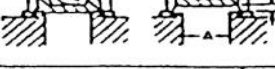


PD Pump Heads



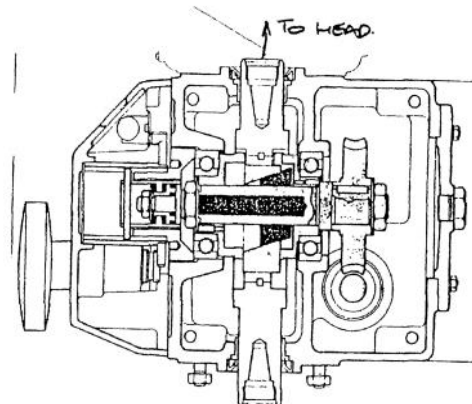
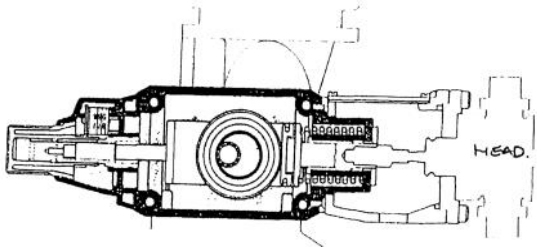
PD Pump Valves

Types of Valves and Their Applications

TYPE	SKETCH	PRESSURE	APPLICATION
PLATE		5,000	CLEAN FLUID. PLATE IS METAL OR PLASTIC
WING		10,000	CLEAN FLUIDS CHEMICALS
BALL		30,000	FLUIDS WITH PARTICLES CLEAR. CLEAN FLUID AT HIGH PRESSURE. BALL IS CHROME PLATED
PLUG		6,000	CHEMICALS : very difficult in exotic matls
SLURRY		2,500	MUD, SLURRY, POT DIMENSIONS TO API-12. POLYURETHANE OR BUNA-N INSERT

Typical velocities 1.8 – 3.6m/s

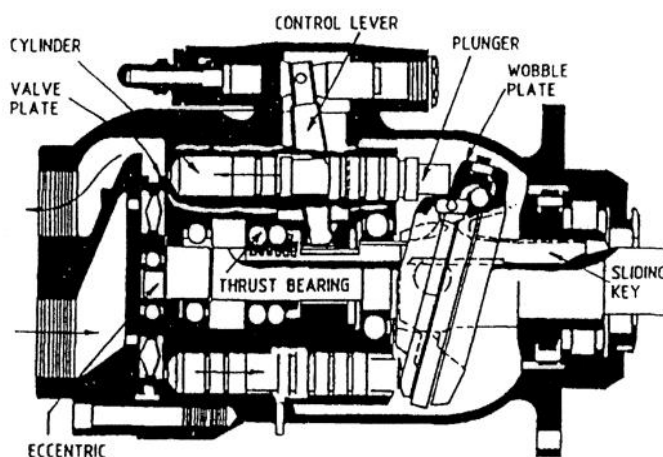
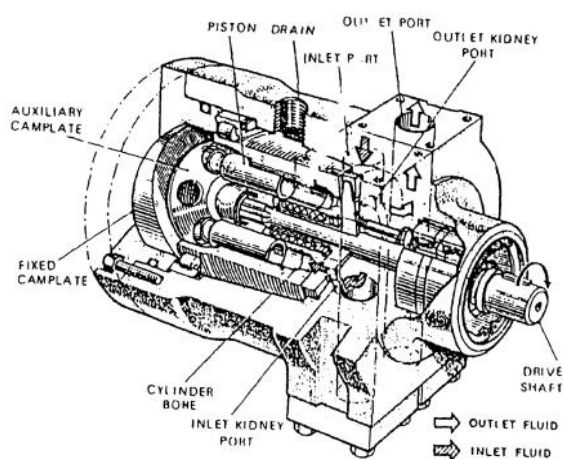
Variable Displacement PD Pumps



Adjustable Eccentric Drives

Variable Displacement PD Pumps

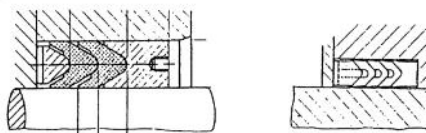
Adjustable Swashplate



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PD Pump Seals



APPLICATION	MATERIAL	SEAL CONFIGURATION
Limited space or general purpose	Rubber	O ring
Limited space high integrity	Rubber	Rectangular section
Low or consistent friction at breakout and low speed (leakage secondary consideration)	PTFE	Rubber or metal energised
Good sealing with wide tolerance	Rubber	U-seal
Very low leakage	Rubber	1. Sharp edged solid seal 2. V-ring set or combination of the two
Good wearing performance under arduous conditions, space limited	Rubber	1. above or 2. above 3. V ring set
High speed, low leakage	Rubber	V rings
High speed, leakage secondary	Rubber, PTFE	Solid rubber/rubber fabric
Chemically aggressive	PTFE	With suitable reinforcement
Temperature 200-300°C	PTFE	With metal reinforcement

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