INTRODUCTION

In process operations, liquids and their movement and transfer from place to place, plays a large part in the process. Liquid can only flow under its own power from one elevation to a lower elevation or, from a high pressure system to a lower pressure system.

The flow of liquid is also affected by friction, pipe size, liquid viscosity and the bends and fittings in the piping.

To overcome flow problems, and to move liquids from place to place, against a higher pressure or to a higher elevation, energy must be added to the liquid. To add the required energy to liquids, we use 'PUMPS'. A pump therefore is defined as 'A machine used to add energy to a liquid'.

Pumps come in many types and sizes. The type depends on the function the pump is to perform and the size (and speed) depends on the amount (volume) of liquid to be moved in a given time.

TYPES OF PUMP

Most pumps fall into two main categories.

- I. CENTRIFUGAL PUMPS
- II. POSITIVE DISPLACEMENT PUMPS

I. CENTRIFUGAL PUMPS

Modern process plants use powerful centrifugal pumps, primarily because of the following factors:
1. The low initial cost.
2. Low maintenance costs.
3. Simple in operation.
4. Ability to operate under a wide variety of conditions.
5. Give a smooth, continuous flow, free from pulsation.

CENTRIFUGAL FORCE

The word, 'CENTRIFUGAL' is derived from the Latin language and is formed from two words - 'CENTRI' meaning 'CENTRE' and 'FUGAL' meaning 'TO FLY AWAY FROM'. CENTRIFUGAL - 'TO FLY AWAY FROM THE CENTRE'.

This is the force developed due to the rotation of a body - solid, liquid or gas. The force of rotation causes a body, or a fluid, to move away from the centre of rotation.

A centrifugal pump is built up of TWO MAIN PARTS:

1. THE ROTOR (or Rotating Element).
2. THE CASING (or Housing or Body).

PART 1. THE ROTOR

One of the greatest advantages of a centrifugal pump is that it has very few moving parts which minimises mechanical problems and energy losses due to friction. Other than the bearings, (and of course the driver), the only moving part in a centrifugal pump
is the Rotor.

The Rotor (Rotating Element), is made up of the following main components:

1. **THE IMPELLER(S)** - Often called the 'Wheel(s)'. (In the centre of an impeller, is the 'EYE' which receives the inlet flow of liquid into the 'Vaness' of the impeller).
2. **THE SHAFT** - The impeller(s) is/are mounted on the shaft and enclosed by a casing.

### 1. The Impellers

These consist of wheel shaped elements containing 'Curved Vanes' at the centre of which is the liquid inlet called the 'EYE' of the impeller.

The wheel(s) is/are mounted on the shaft, (together called 'the Rotating Element' which is rotated at high speed. The liquid is thrown off the outer edge of the vanes, and more liquid flows into the eye to take its place.

The speed of rotation of the wheel imparts kinetic energy to the liquid in the form of velocity which will be converted to pressure (potential) energy.

There are various types of impeller depending on the duty to be performed by the pump.

1. **The Open Impeller**: This type consists of vanes attached to a central hub with no side wall or 'shroud'. It is used for pumping highly contaminated slurry type liquids.
2. **Semi-Open Impeller**: This type has the vanes attached to a wall or shroud on one side. It is used mainly for lightly contaminated and abrasive liquids and slurries.
3. **Closed Impeller**: This impeller has the vanes enclosed on both sides by a shroud and is the most efficient impeller, used for clean or very slightly contaminated liquids. (See Figure: 18)

Impellers can also be classified according to the vane curvature - i.e. 'Backward' curve used for high flow rate. 'Forward' curve for high liquid head and 'Straight' for either service. TYPES OF IMPELLER

The diagram (Fig: 19) on the following page shows a single stage Centrifugal Pump in detail.
Figure: 19 – Centrifugal Pump in Detail

High power, high volume pumps are fitted with more than one impeller.

This type is called a 'Multi-stage' pump and is actually a series of pumps mounted on the shaft within a single casing. The liquid leaving each impeller rim, is fed into the eye of the next wheel. In this way, the pressure is built up in stages through the pump. The more stages, the higher the discharge pressure. As liquids cannot be compressed and therefore no change in volume takes place, the impellers of a multi-stage pump are all the same size – (unlike those of a compressor).

(See Figure: 20)

How the liquid is passed from stage to stage is discussed later in the notes on the casing.

Figure: 20

2. The Shaft

The Impeller(s) are mounted on this part of the pump which is then referred to as the ‘Rotor’ or rotating element which is coupled (connected) to the pump driver. The driver imparts the rotation to the rotor that is housed in the casing, supported by the bearings.

The shaft, due to the high speed of rotation, will tend to move:

- Radially -movement across the shaft (Vibration) and,
- Axially -movement along the shaft (Thrust).

In order to minimise and control these movements, bearings are fitted (as discussed earlier).

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PART 2. THE CASING

This is the stationary part of the pump and includes the:
1. Suction Nozzle(s) (or Port(s)).
2. Discharge Nozzle (or Port).
4. Seals.

(The casing of a multi-stage centrifugal pump is very similar to that of a multi-stage compressor having diaphragms with diffusers & return passages. However, as liquids are non-compressible, the stages do not become progressively narrower).

The 'Volute' casing. This is named from the spiral shape of the casing which is so constructed to act as a collector for the liquid as it leaves the outer edge of the impeller vanes.

The liquid at this point is at high velocity. As the liquid enters the volute, the velocity is decreased. This causes an increase in pressure which is the objective of the pump. (Increased pressure is increased energy).

(See Figure: 21)

Figure: 21 - Volute Type Casing

Earlier, the types of bearings and their purpose was discussed as was the types of seals and their purpose.

Briefly, the purpose of bearings is to support the weight of the rotor and to minimise radial and axial movement and therefore, vibration.

Seals are used to prevent leakage of fluid to atmosphere and/or between the stages of a multi-stage machine.

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**PRIME MOVERS**

The prime movers for pumps are the devices used to drive them - whether they are rotating machines or otherwise.

The types of prime mover used for modern pumps are:

1. Electric Motor.
2. Diesel (or petrol) engine.
4. Steam Turbine.

CHARACTERISTICS OF CENTRIFUGAL PUMPS

Centrifugal pumps are specified by four characteristics.

1. Capacity:
   This is defined as the quantity of liquid which is discharged from the pump in a given time. Capacity is expressed in 'm³/hr', 'gal/min', etc. The capacity of a pump is governed by the 'Head', the 'Speed' and the 'Size' of the pump.

2. Total Head:
   The total head of a pump is the difference between the pump suction and discharge pressures - expressed in terms of metres or feet head:

   **Suction Head:**
   This is the vertical distance, in feet or metres, from the centreline of the pump to the level of liquid in the vessel from which the liquid is being pumped.

   **Discharge Head:**
   Is the discharge pressure of the pump, expressed in feet or metres of liquid.

   **Total Head:** = Discharge head - Suction head
   (See Figure: 22)

3. Power:
   This is the energy used by the pump in a given time. Its unit is 'Horsepower' (HP). 1 HP is equivalent to 0.746 kilowatt (kW).

4. Efficiency:
   This is a percentage measure of the pump's effectiveness in transferring the power used into energy added to the pumped liquid.

   The formula for calculation of efficiency is:

   Efficiency = (Output power)/(Input power)X 100%
Pumps in industry, usually operate at 70% to 80% efficiency.

In Figure 22, the pump is taking suction from Tank ‘A’ and discharging to Tank ‘B’. The Head (or height) of water in ‘A’ to the centre-line of the pump is 23 feet. This is called the ‘SUCTION HEAD’.

The discharge line inlet to ‘B’ is 50 feet above the pump centre-line. This is the ‘DISCHARGE HEAD’. The ‘TOTAL HEAD’ is the difference between the two figures.

This is 50 - 23 = 27 feet.

(Note: If the suction vessel is BELOW the pump centre line, the suction head will be a NEGATIVE figure).

Using the formula for Static Head Pressure, we can find the suction and discharge pressures of the pump. (Both tanks are at atmospheric pressure).

Suction pressure = 23 x 0.433 = 10 Psig. Discharge pressure = 50 x 0.433 = 21.7 Psig

If a liquid other than water is used, the Specific Gravity of the liquid must be included in the above formula to obtain the pressures.

E.g.
If we use an oil with S.G. of 0.88, the pressures would be: -
Suction pressure = 23 x 0.433 x 0.88 = 8.8 Psig.
Discharge pressure = 50 x 0.433 x 0.88 = 19.1 Psig

**NET POSITIVE SUCTION HEAD REQUIRED**

The pump manufacturer’s specified margin of suction pressure above the boiling point of the liquid being pumped, is required to prevent cavitation. This pressure is called the ‘Net Positive Suction Head’ pressure (NPSH).

In order to ensure that a NPSH pressure is maintained, the Available NPSH should be higher than that required. The NPSH depends on the height and density of the liquid and the pressure above it.

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The Valves of a Centrifugal Pump
The suction and discharge piping of a centrifugal pump, will generally have the following valve arrangements:

1. **Suction Valve**: Allows liquid to enter the pump.
2. **Discharge Valve**: Allows liquid to flow from the pump to other parts of the system.
3. **Check or Non-Return Valve**: In the discharge line - Prevents back-flow from discharge to suction through the pump.
4. **Vent (priming) Valve**: This is used to vent off air/gases from the pump before start-up.
5. **Gauge Isolation Valves**: Allows the replacement of pressure gauges on suction and discharge lines, the most important being the discharge pressure.
6. **Gland Seal Valve**: (where fitted). Controls the flow of cooling media to the pump gland cooling fluid.
7. **Recycle Valve**: This is a flowline valve which is used to recycle pumped liquid back to the suction side or to the suction vessel, in order to maintain a flow through the pump when the discharge valve, (and/or FCV), is closed. (Prevents heat build-up).
8. **Drain Valve**: Fitted on the bottom of the pump casing and used to drain the pump prior to maintenance work being done. (See Figure: 23)

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**CENTRIFUGAL PUMP OPERATION**

1. **Pump Start-up Procedure**
   1. Line up the pump valves.
   2. Ensure that the drain valve is closed.
   3. Open the suction valve.
   4. Open the vent valve to bleed off gases - when liquid comes from the vent valve - close it again. (This is called 'Priming the pump').
   5. Open the gland-seal valve (if fitted).
   6. Commission the bearing and oil cooling systems (if fitted).
   7. If an oil bottle or 'slinger-ring' reservoir is used for the bearings, ensure it is full and functioning properly.
   8. Check by hand that the pump shaft is freely rotating - (power is OFF at this point).
   9. Energise or, if the rule applies, have the electrician energise, the power supply.
   10. The discharge valve, at this point, should still be closed.
11. Start the pump motor. Check that the pump is rotating in the correct direction.
12. Check that the discharge pressure is steady - if not check at the vent and release any further trapped gas.
13. Check for vibration, overheating and/or any undue noise from the pump, bearings or coupling.
14. Re-check the lube and cooling systems and check for leaks at the pump glands. (With the 'packed' type gland seal, a slight leakage is desirable for lubrication and cooling of the gland). Open the discharge valve
15. Report to control room that the pump is in operation and all is O.K. (If not O.K. - shut down the pump and have the control room operator call a maintenance mechanic).

16. **Pump Shut-down Procedure**
   1. Close the discharge valve.
   2. Press the stop button.

Leave the suction open unless the shut-down is for maintenance. This will prevent pressure build up due to temperature increase on hot days.

**If the shut-down is for maintenance:**
   3. Close the suction valve and stop other ancillary systems where fitted.
   4. Open the drain and vent valves and ensure that the pump is fully drained and de-pressured.
   5. Report to the control room that the pump is ready for maintenance.

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**CENTRIFUGAL PUMPS - FLOW & PRESSURE**

**A. In Parallel:**
Where extra flow is required, two or more pumps can be operated in 'parallel'. This means that the pumps all take suction from a common header and discharge into another common header. The number of pumps in the parallel line-up, depends on the system flow requirements.

**B. In Series:**
Where extra pressure is required, pumps may be operated in 'series'. Here, a pump takes suction from a vessel and discharges into the suction of another pump which then discharges into the system. The number of pumps lined up in series depends on the system pressure requirements.

(See Figure: 24)
CAVITATION

Cavitation is a problem condition which may develop while a centrifugal pump is operating. This occurs when a liquid boils inside the pump due to insufficient suction head pressure. Low suction head causes a pressure below that of vaporisation of the liquid, at the eye of the impeller.

The resultant gas which forms causes the formation and collapse of 'bubbles' within the liquid. This, because gases cannot be pumped together with the liquid, causes violent fluctuations of pressure within the pump casing and is seen on the discharge gauge. These sudden changes in pressure cause vibrations which can result in serious damage to the pump and, of course, cause pumping inefficiency.

To overcome cavitation:

1. Increase suction pressure if possible.
2. Decrease liquid temperature if possible.
3. Throttle back on the discharge valve to decrease flow-rate.
4. Vent gases off the pump casing.

AIR BINDING IN A CENTRIFUGAL PUMP

Air binding occurs when air is left in a pump casing due to improper venting, or, air collects when the pump is operating. The air, as it collects, forms a pocket around the impeller which forces liquid away from it. The impeller then spins in the air and heat begins to build up.

Symptoms of air binding:

1. Fluctuating pressure for a short time. The pressure may then stop jumping and fall quickly.
2. Overheating of the pump may take place shortly after air binding occurs.
3. An air-bound pump sounds quieter than normal.
To correct air binding:

1. Vent the pump during operation.
2. In some cases, the pump must be shut down and allowed to cool. The air must then be vented off.

**POSITIVE DISPLACEMENT PUMPS**

Positive displacement means that, when the pump piston or rotor moves, fluid moves and displaces the fluid ahead of it. Because of its operation, a positive displacement pump can build up a very high discharge pressure and, should a valve in the discharge system be closed for any reason, serious damage may result - the cylinder head, the casing or other downstream equipment may rupture or the driver may stall and burn out.

A Positive Displacement pump must therefore be fitted with a safety relief system on the discharge side.

**TYPES OF POSITIVE DISPLACEMENT PUMP**

- **A. ROTARY PUMPS**
- **B. RECIPROCATING (PISTON) PUMPS**

**A. ROTARY PUMPS**

In Rotary pumps, movement of liquid is achieved by mechanical displacement of liquid produced by rotation of a sealed arrangement of intermeshing rotating parts within the pump casing.

**A. 1. THE GEAR PUMP** (See Figure : 25)

Construction and Operation:

In this pump, intermeshing gears or rotors, rotate in opposite directions, just like the gears in a vehicle or a watch mechanism. The pump rotors are housed in the casing or stator with a very small clearance between them and the casing. (The fluid being pumped will lubricate this small clearance and help prevent friction and therefore wear of the rotors and casing).

1. In this type of pump, only one of the rotors is driven. The intermeshing gears rotate the
other rotor. As the rotors rotate, the liquid or gas, (this type of machine can also be used as a compressor), enters from the suction line and fills the spaces between the teeth of the gears and becomes trapped forming small 'Slugs' of fluid between the teeth.

2. The slugs are then carried round by the rotation of the teeth to the discharge side of the pump.

3. At this point, the gears mesh together and, as they do so, the fluid is displaced from each cavity by the intermeshing teeth.

4. Since the fluid cannot pass the points of near contact of the intermeshed teeth nor between the teeth and casing, it can only pass into the discharge line.

5. As the rotation continues, the teeth at the suction end are opened up again and the same amount of fluid will fill the spaces and the process repeated. The liquid at the discharge end is constantly being displaced (moved forward).

Thus gear pumps compel or force a fixed volume of fluid to be displaced for each revolution of the rotors giving the 'Positive Displacement' action of the pump.

Gear pumps are generally operated at high speed and thus give a fairly pulse-free discharge flow and pressure. Where these pumps are operated at slower speeds, as in pumping viscous liquids, the output tends to pulsate due to the meshing of the teeth.

Any gas or air drawn into the pump with the liquid, will be carried through with the liquid and will not cause cavitation. This action of the pump means that it's a 'Self Priming' pump. The discharge pressure may however, fluctuate.

The output from this type of pump is directly proportional to the speed of operation. If the speed is doubled, the output will be doubled and the pressure will have very little effect. (At higher pressures, due to the fine clearances between the teeth and between the casing and the rotors, a small leakage back to the suction side will occur resulting in a very small drop in actual flow rate. The higher the discharge pressure, the more likely that internal leakage will occur).

Rotary pumps are widely used for viscous liquids and are self-lubricating by the fluid being pumped.

This means that an external source of lubrication cannot be used as it would contaminate the fluid being pumped. However, if a rotary pump is used for dirty liquids or slurries, solid particles can get between the small clearances and cause wear of the teeth and casing. This will result in loss of efficiency and expensive repair or replacement of the pump.

Figure : 25 -The Gear Pump
OTHER TYPES OF ROTARY PUMPS

The following types of pump have similar characteristics to the gear pump and require no further explanation other than the diagrams.

A. 2. THE 'LOBE' PUMP
A. 3. THE 'SLIDING VANE' PUMP
A. 4. THE 'SCREW' PUMP

(See Figures: 26, 27 & 28)

Advantages of Rotary Pumps

- They can deliver liquid to high pressures.
- Self-priming.
- Give a relatively smooth output, (especially at high speed).
- Positive Acting.
- Can pump viscous liquids.

Disadvantages of Rotary Pumps

- More expensive than centrifugal pumps.
- Should not be used for fluids containing suspended solids.
- Excessive wear if not pumping viscous material.
- Must NEVER be used with the discharge closed.

B. RECIPROCATING (PISTON) PUMPS
To 'Reciprocate' means 'To Move Backwards and Forwards'.

A 'RECIROCATING' pump therefore, is one with a forward and backward operating action.

The most simple reciprocating pump is the 'Bicycle Pump', which everyone at some time or other will have used to re-inflate their bike tyres. The name 'Bicycle PUMP' is not really the correct term because it causes compression.

It is essentially a hand operated compressor and consists of a metal or plastic tube called a 'Cylinder' inside of which a hand-operated rod or 'Piston' is pushed back and forth. On the piston end, a special leather or rubber cup-shaped attachment is fixed.

When the piston is pushed forward, (this is called a 'Stroke'), the cup flexes against the cylinder walls giving a seal to prevent air passing to the other side. As the pump handle is pushed, air pressure builds up ahead of the cup and is forced (discharged) into the tyre through the tyre valve which also prevents air escaping when the pump is disconnected or when the piston is pulled back.

When the pump handle is pulled back, (called the 'Suction' stroke), the cup relaxes and the backward motion causes air to pass between it and the cylinder wall to replace the air pushed into the tyre. This reciprocating action is repeated until the tyre is at the required pressure.

Because the air is expelled from the pump during the forward stroke only, the pump is known as a 'Single Acting Reciprocating Pump'. (See Figure: 29)

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SINGLE ACTING RECIPROCATING PUMPS

In industry, reciprocating pumps are of many sizes and designs. Their operation is similar to the bicycle pump described above.

An industrial reciprocating pump is constructed of metal and has the following main parts:

1. **THE CYLINDER** This is a metal tube-shaped casing (or body), which is generally fitted with a metal lining called a 'cylinder liner'. The liner is replaceable when it becomes worn and inefficient. The cylinder is also fitted with suction and discharge ports which contain special spring loaded valves to allow liquid to flow in one direction only - similar to check valves.
2. THE PISTON The piston consists of a metal drive rod connected to the piston head which is located inside the cylinder. The piston head is fitted with piston rings to give a seal against the cylinder lining and minimise internal leakage. The other end of the drive rod extends to the outside of the cylinder and is connected to the driver. (In the old days of piston pumps, the driver used to be (and still is in some cases), high pressure steam which was fed to a drive cylinder by a system of valves in a steam chest).

Modern industries generally use high power electric motors, linkages and gearing to convert rotating motion into a reciprocating action.

In a single acting pump, the backward stroke of the piston causes a suction which pulls in liquid through the inlet valve. (The same suction action keeps the discharge valve closed).

On the forward stroke, the increase in pressure generated by the piston, closes the inlet valve and opens the discharge valve. The liquid is displaced into the discharge system.

The flow from a reciprocating pump is uneven or pulsating. This can be undesirable in some applications. Flow can be smoothed out, but we will discuss this a little later.

Like the rotary pumps, because the action is positive displacement, a piston pump can generate very high pressure and therefore MUST NEVER be operated against a closed discharge system valve unless it is fitted with a safety relief system in order to prevent damage to the pump and/or the driver and/or other downstream equipment.

(See Figure: 30)

DOUBLE ACTING RECIPROCATING PUMPS

This type of pump operates in exactly the same way as the single acting with respect to its action. The difference is, that the cylinder has inlet and outlet ports at EACH END OF THE CYLINDER. As the piston moves forward, liquid is being drawn into the cylinder at the back end while, at the front end, liquid is being discharged. When the piston direction is reversed, the sequence is reversed.

With a double acting pump, the output pulsation is much less than the single acting.

( See Figure : 31 )

In theory, a reciprocating pump will always deliver the same volume for each stroke regardless
of discharge pressure. But, as discharge pressure is increased, there is more likelihood of internal leakage between the piston rings and the cylinder liner, or leaking internal valves, causing a decrease in output. A measure of this is known as the 'Volumetric Efficiency' of the pump.

The amount of liquid which leaks internally is known as the 'Slip' and, if the pump is in good condition, the slip should be below 1.0%. If slip is above 5.0%, the pump needs to be overhauled. However, at operating pressures, the amount of slip is relatively constant as long as wear is not rapid. The output therefore can still be classed as constant. This type of pump is useful for delivery of fixed quantities of liquid as used in metering or dosing operations.

The speed of a reciprocating pump is generally measured as 'Strokes per Minute'. This is the number of times the piston moves back and forth in one minute. Speed can also be measured as 'R.P.M.' of the drive motor.

As the cylinder(s) are of constant dimensions, the volume of liquid moved for each stroke, (discounting leakage described above), is the same and therefore the output per minute, hour or day ..etc can be calculated.

Some Advantages of Piston Pumps

- Reciprocating pumps will deliver fluid at high pressure (High Delivery Head).
- They are 'Self-priming' - No need to fill the cylinders before starting.

Some Disadvantages of Piston Pumps

- Reciprocating pumps give a pulsating flow.
- The suction stroke is difficult when pumping viscous liquids.
- The cost of producing piston pumps is high. This is due to the very accurate sizes of the cylinders and pistons. Also, the gearing needed to convert the rotation of the drive motor into a reciprocating action involves extra equipment and cost.
- The close fitting moving parts cause maintenance problems, especially when the pump is handling fluids containing suspended solids, as the particles can get into the small clearances and cause severe wear. The piston pump therefore, should not be used for slurries.
- They give low volume rates of flow compared to other types of pump.

A single acting pump with One cylinder is called a 'Single-acting Simplex' pump.
A double acting pump with One cylinder is called a ' Double-acting Simplex '.

**MULTI-CYLINDER PUMPS**

Where more than one cylinder is being driven by one driver, the arrangement is named according to the type and number of cylinders.

1. A Single-acting Duplex pump has TWO single acting cylinders.
2. A Double-acting Duplex pump has TWO double acting cylinders.
3. A Single-acting Triplex pump has THREE single acting cylinders.
4. A ' Double-acting Triplex ' pump has THREE double acting cylinders.

The more double-acting cylinders in a pump arrangement, driven by a single motor, the smoother and pulsation-free, is the output.

**CONVERTING ROTATION INTO RECIPROCATION**

The electric motor drives a fly-wheel or cam-shaft which is connected eccentrically to a connecting rod. The other end of the connecting rod is coupled to a 'Cross-head Gear' and 'Slide Assembly’. (This arrangement is the basis of the operation of the old Steam Engine drive cylinders and pistons).

As the motor rotates the fly-wheel or cam, the eccentrically mounted connecting rod rotates with it. This causes the rod to move up and down and backwards and forwards. The up and down motion cannot be transmitted to the pump shaft - it would not work. We do however, need the back and forth movement.

The connecting rod goes to the cross-head gear which consists of a pivot inserted into the slide assembly. The pivot removes the up and down movement of the rod but allows the pump shaft to move back and forth.

The diagrams will explain the principle much more easily than words.

( See following Figures : 32, 33)
CONVERSION FROM ROTATION TO RECIPROcation

Figure: 33