

04

Fluid Mechanics

Objectives

When you have completed study of this chapter you should be able to:

- Understand the various types of fluids;
- Be familiar with the terms used in fluid mechanics;
- Know the devices used for pressure measurement;
- Decide the equipment to be used for flow monitoring;
- Describe the methods used for transportation of fluids;
- Understand the requirement of mixing and agitation in process systems.

4.1 An Overview to Fluid Mechanics

The branch of engineering that deals with the behavior of Fluids (liquids, gases and vapors) is called Fluid mechanics.

Fluid mechanics can be further classified into two areas of unit operations:

Fluid Statics

It explains the nature of fluids in equilibrium with no shear stress. In the case of liquids, this subject is known as hydrostatics. For gases it is termed pneumatics.

Fluid Dynamics

It describes the behavior of fluids in motion relative to other sections.

4.1.1 Nature of Fluids

A fluid is a substance that undergoes continuous deformation when exposed to a shear stress.

Classification of fluids

- Compressible fluid is one in which the density of a fluid is sensitive to changes in temperature and pressure, e.g. Gases
- Incompressible fluid is one in which moderate changes in temperature and pressure has very little impact on density, e.g. Liquids
- Ideal or Perfect Fluid is a hypothetical gas or liquid, which offers no resistance to shear, and therefore has zero viscosity
- Non-Newtonian Fluid is one in which the viscosity is a function of pressure, temperature and shear stress. It is further categorized into three classes
 - a) Fluids whose properties are independent of time and shear
 - Bingham-plastic Fluids are the simplest non-Newtonian fluids because they differ from Newtonian fluids only in that their linear relationship between shear stress and shear rate does not go through the origin or source. Examples are water suspension of rock and sewage sludge.
 - Pseudoplastic Materials include the majority of Newtonian fluids. Examples are suspensions of paper pulp or pigments

- Dilatant Materials exhibit rheological behavior opposite to that of pseudoplastics. Examples are quicksand and beach sand
- b) Fluids whose properties are time-dependent
- Thixotropic Fluids break down under continued shear and on mixing give lower shear stresses for a given shear rate, e.g. paints and inks
 - Rheopectic Materials are those in which an increase in viscosity occurs when rhythmically shaken or tapped e.g. Vanadium pentoxide solution and gypsum suspensions in water
- c) Viscoelastic Fluids
- They exhibit elastic recovery from deformations which occur during flow e.g. Polymeric liquids. A shear diagram for the various fluids is illustrated in Figure 4.1

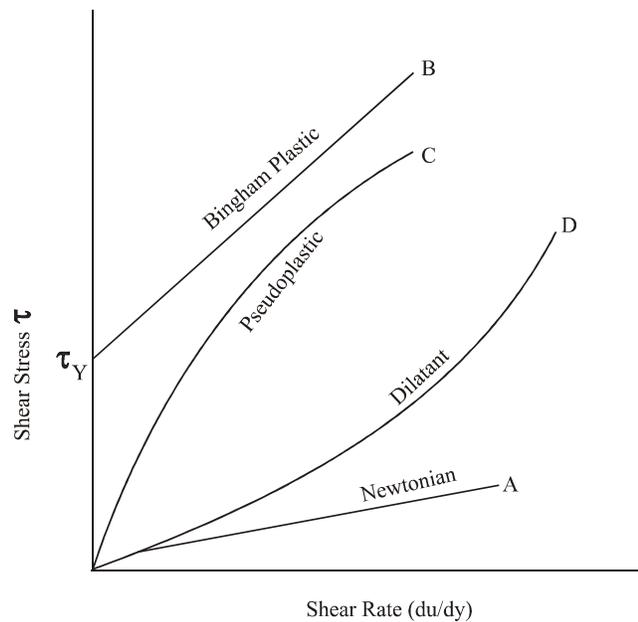


Figure 4.1
Shear Diagrams

4.1.2 Terminology in Fluid Mechanics

- A flow is said to be steady if the mass flow rate is constant and all other quantities (velocity, temperature, pressure) are independent of time
- A flow is said to be unsteady if the mass flow rate and all other quantities (velocity, temperature, pressure) vary with time. A flow is said to be accelerated if it is unsteady or if the velocity varies in the general direction of the flow
- A stream is said to be uniform if the shape and size of its cross section is the same throughout the channel
- The ratio of the velocity of flow to the velocity of sound is called the Mach number. Flows at Mach number less than unity are called **sub sonic**

- Reynolds number (N_{Re}) is any of several dimensionless quantities which are all proportional to the ratio of internal force to viscous force in a flow system

$$N_{Re} = D V \rho / \mu$$

Where D = Diameter of tube
 V = Average velocity of liquid
 μ = Viscosity of liquid
 ρ = Density of liquid

Reynolds number and transition from laminar to turbulent flow: Laminar flow is always encountered at Reynolds numbers below 2,100. Under ordinary conditions of flow, the flow is turbulent at Reynolds numbers above 4,000. Between 2,100 and 4,000 a transition region is found, where the type of flow may be either laminar or turbulent, depending upon conditions at the entrance of the tube and on the distance from the entrance.

- A streamline is defined as a line which lies in the direction of flow at every point at a given instant
- Laminar flow is defined as a flow in which the streamlines remain distinct from one another over their entire length
- Laminar flow at $N_{Re} < 1$ is called slow flow or creep flow
- Turbulent flow is when the flow rate increases, a critical velocity is reached

4.2 Fluid Statics and Pressure Measurement

4.2.1 Definitions

- Fluid statics are concerned with the static properties and behavior of fluids. In the case of liquids, this subject is known as Hydrostatics; in the case of gases, it is called Pneumatics
- A body of fluid in static equilibrium is being acted upon only by compressive forces. The intensity of this force, expressed in terms of force per unit area, is known as static pressure
- Gauge pressure is the difference between a given fluid pressure and that of the atmosphere. The readings of pressure gauges are commonly positive gauge pressures. A vacuum gauge may be used to show negative gauge pressures, i.e., fluid pressures less than atmospheric
- Absolute pressure is the true total pressure and is equal to gauge pressure plus atmospheric pressure
- The term static head generally denotes the pressure in a fluid due to the head of fluid above the point in reference. Its magnitude is given by the application of Newton's law (force = mass x acceleration). In the case of liquids (constant density), the static head p_h is given by

$$p_h = h r (g/g_c)$$

Where

h = head of liquid above the point

r = liquid density

g = local acceleration due to gravity

g_c = dimensional constant.

- Viscosity (μ) The resistance exhibited by a real fluid to deformations is termed as fluid viscosity.
- Kinematic viscosity (ν) The ratio of the absolute viscosity to the density of a fluid is kinematic viscosity

$$\mu / \rho = \nu$$

Where

μ = viscosity,

ρ = density

4.2.2 Liquid - Column Manometers

Principle

The height, or head, to which a fluid rises in an open vertical tube fixed to an apparatus containing a liquid, is a direct measure of the pressure at the point of attachment. This is frequently used to show the level of liquids in tanks and vessels. This principle is applied to liquid column manometers.

- For high vacuums or for high pressures and large pressure differences, the gauge liquid is a high-density liquid, generally mercury
- For low pressures and small pressure differences, a low-density liquid is used, e.g. Alcohol, water, or carbon tetrachloride

Types of Liquid-Column Manometers

- Open manometer
- Differential U tube
- Closed U tube
- Mercury barometer

4.2.3 Multiplying Gauges

These types of gauges are used to magnify and obtain accurate readings.

Types of Multiplying Gauges

- Inclined U tube
- Draft gauge
- Two-fluid U tube

4.2.4 Mechanical Pressure Gauges

The various types under this category are:

- Bourdon-tube Gauge
- Diaphragm Gauge

Bourdon and Diaphragm Gauges that show both pressure and vacuum indications on the same dial are called compound gauges.

4.2.5 Calibration of Gauges

Simple liquid-column manometers do not require calibration if they are so constructed as to minimize errors due to capillary. If the scales used to measure the readings have been checked against a standard, the accuracy of the gauges depends solely upon the precision of determining the position of the liquid surfaces. Hence, liquid-column manometers are primary standards used to calibrate other gauges.

4.3 Measurement of Fluid Flow

Different types of meters are used industrially, including:

- Meters based on direct weighing or measurement of volume
- Variable-head meters
- Area meters
- Current meters
- Positive-displacement meters
- Magnetic meters
- Ultrasonic meters

Most widely used for flow measurement are the several types of variable-head meter and area meters.

4.3.1 Variable Head Meters

Venturi meter

In the venturi meter along the upstream cone, the velocity is increased and the pressure decreased. The velocity is then decreased and the original pressure recovered in the downstream cone. Venturi meters are generally used for the measurement of liquids, especially water.

Orifice meter

For a specified meter and defined manometer system, the maximum measurable flow rate is fixed. If the flow range is altered, the throat diameter may be too large to give an accurate reading or too small to accommodate the next maximum flow rate. The orifice meter meets these requirements but with a higher power consumption.

A typical sketch of an orifice meter is shown in fig 4.2. A standard sharp-edged orifice comprises of an accurately machined and drilled plate. This is seated between two flanges with the hole concentric with the pipe in which it is mounted. The opening in the plate may be bevelled on the downstream side. Pressure taps, one above and one below the orifice plate, are installed and are connected to a manometer or equivalent pressure-measuring devices. The positions of the taps are arbitrary and the coefficient of the meter will depend upon the position of the taps.

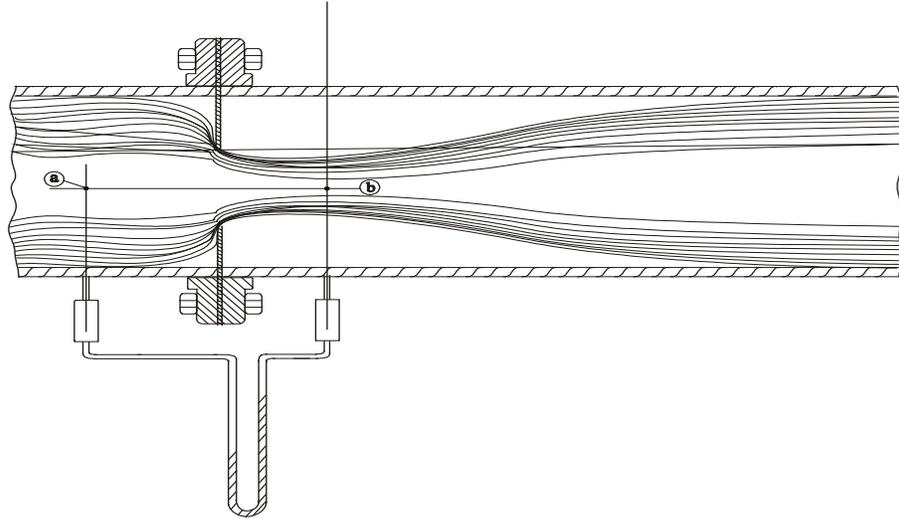


Figure 4.2
Orifice meter

4.3.2 Velocity Meters

Pitot tube

The pitot tube is an apparatus to measure the local velocity along a streamline. The principle of the device is shown in Fig. 4.3. The opening of the impact tube *a* is perpendicular to the flow direction. The opening of the static tube *b* is parallel to the direction of flow. The two tubes are connected to the legs of a manometer or equivalent device for measuring small pressure differences. It should be noted that whereas the orifice and venturi meters measure the average velocity of the entire stream of fluid, the pitot tube indicates the velocity at one point only.

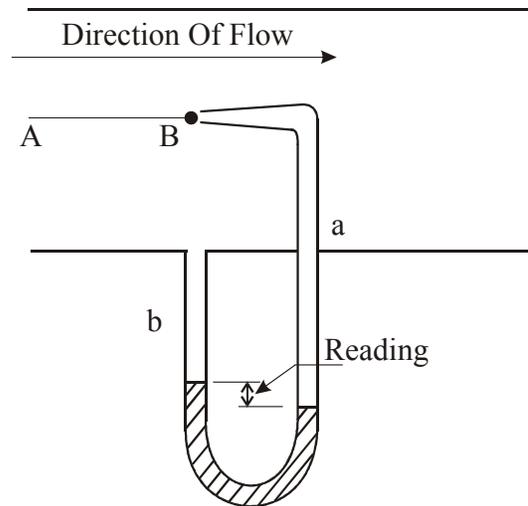


Figure 4.3
Pitot Tube

4.3.3 Area Meters

These meters consist of devices in which the pressure drop is nearly constant. The area through which the fluid flows varies with the flow rate. The area is related through proper calibration to the flow rate.

Rotameters

It basically consists of a gradually tapered glass tube mounted vertically in a frame with the large end up. The fluid flows upward through the tapered tube and freely suspends a float. The float is the indicating element. The entire fluid stream must flow through the annular space between the float and the tube wall. The tube is marked in divisions and the reading of the meter is obtained from the scale reading of the float. A calibration curve must be available to convert the observed scale reading to flow rate. Rotameters can be used for either liquid or gas flow measurements.

Target Meters

In a target meter a sharp-edged disk is set at right angles to the direction of flow and the drag force exerted by the fluid is measured. The flow rate is proportional to the square root of this force and to the fluid density. Target meters are rugged and inexpensive and can be used with a variety of fluids, even viscous liquids and slurries. The bar mechanism, however, tends to clog if the solids content of the slurry is high.

Vortex-shedding Meters

In a vortex-shedding meter the “target” is a bluff body, often trapezoidal in cross section. The body is designed to create, when flow is turbulent, a “vortex street” in its wake. Sensors close to the bluff body measure the pressure fluctuations and hence the frequency of the vortex shedding from which the volumetric flow rates may be inferred. These meters are suitable for many types of fluids, including high-temperature gas and steam. The minimum Reynolds number

required for a linear response is fairly high, so the flow rate of high viscous liquids cannot be measured by this type of instrument.

Turbine Meters

They are exceptionally accurate when used under proper conditions but tend to be fragile and their maintenance costs may be high

Positive -Displacement Meters

They are very accurate and suitable for clean gases and liquids, even viscous ones. They perform well under high viscosities and can handle dirty liquids or slurries. They are relatively expensive and may be costly to operate.

Magnetic Meters

These meters are non-intrusive. They create no pressure drop in the fluid. The rate of flow is measured from outside the tube. Commercial magnetic meters can measure the velocity of almost all liquids except hydrocarbons, whose electrical conductivity is too small.

Ultrasonic Meters

There are two types: Transit time and Doppler shift. Though not highly accurate, they find application in many services including measuring the flow rate of corrosive fluids.

Coirolis Meters

They are highly accurate and directly measure the mass flow rate. Used mostly with small pipes. They are costly to install and operate. Consequently their applications are generally limited to difficult fluids or to situations in which their high accuracy justifies their costs.

Insertion Meters

A few insertion meters measure the average flow velocity but the majority measure the local velocity at one point only.

4.4 Transportation of Fluids

Fluid pumping arises from the requirement to move fluids from one location to another through conduits or channels. A fluid is made to move by means of transfer of energy.

Fluids are normally transported in pipe or tubing, which is circular in cross-section and available in widely varying sizes, wall thickness and materials of construction.

4.4.1 Pipe and Tubing

The basic differences between the pipe walls and tubing are as follows:

- Pipe walls are slightly rough; tubing has very smooth walls
- Lengths of pipe are joined by screwed, flanged, or welded fittings; pieces of tubing are connected by compression fittings, flare fittings, or soldered fittings
- Finally, tubing is usually extruded or cold-drawn, while metallic pipe is made by welding, casting or piercing a billet in a piercing mill

Pipe and tubing are made from many materials, including metals and alloys, wood, ceramics, glass, and various plastics, Polyvinyl chloride, or PVC.

In process plants, the most common material is low-carbon steel, fabricated and termed as black-iron pipe. Wrought-iron and cast-iron pipes are also used for a number of special purposes.

Sizes

Pipe and tubing are specified in terms of their diameter and wall thickness:

- For steel pipe the standard nominal diameters, in American practice, range from 1/8 to 30 in.
- For large pipe (more than 12 in) in diameter, the nominal diameters are the actual outside diameters
- For small pipe the nominal diameter does not correspond to any actual dimension.

The standard sizes for steel pipe are normally referred to as follows:

- IPS - Iron Pipe Size
- NPS - Normal Pipe Size.

The wall thickness of pipe is indicated by the schedule number which increases with the thickness. The size of the tubing is indicated by the outside diameter. Wall thickness is generally given by the BWG (Birmingham Wire Gauge) number, which ranges from 24 (very light) to 7 (very heavy).

Selection of pipe size

The optimum size of pipe for a specific situation depends upon the relative cost of investment, power, maintenance and inventory for pipe and fittings.

In small installations, rules of thumb are sufficient. Low velocities should be considered for gravity flow from overhead tanks. For large complex systems, the cost of piping may be a substantial fraction of the total investment and elaborate computer methods of optimizing pipe size are justified.

4.4.2 Joints and Fittings

The methods used to join pieces of pipe or tubing depend in part on the properties of the material but primarily on the thickness of the wall. Thick-walled tubular products are usually connected by screwed fittings, or by welding. Pieces of thin-walled tubing are joined by soldering or by

compression or flare fittings. Pipe made of brittle materials like glass or carbon or cast iron is joined by flanges or bell-and spigot joints.

| Fluid | Type of flow | Velocity | |
|----------------|----------------|----------|-----------|
| | | ft/s | m/s |
| Thin liquid | Gravity flow | 0.5-1 | 0.15-0.30 |
| | Pump inlet | 1-3 | 0.3-0.9 |
| | Pump discharge | 4-10 | 1.2-3 |
| | Process line | 4-8 | 1.2-2.4 |
| Viscous liquid | Pump inlet | 0.2-0.5 | 0.06-0.15 |
| | Pump discharge | 0.5-2 | 0.15-0.6 |
| Steam | | 30-50 | 9-15 |
| Air or gas | | 30-100 | 9-30 |

Table 4.1
Fluid Velocities in Pipe

When screwed fittings are used, the ends of the pipe are threaded externally with a threading tool. The thread is tapered and the few threads farthest from the end of the pipe are imperfect, so that a tight joint is formed when the pipe is screwed into a fitting. Tape of polytetrafluoroethylene is wrapped around the threaded end to ensure a good seal.

Threading weakens the pipe wall and the fittings are generally weaker than the pipe itself. When screwed fittings are used, a higher schedule number is needed than with other types of joints. Screwed fittings are standardized for pipe sizes up to 12 in., but because of the difficulty of threading and handling large pipe, they are rarely used in the field with pipe larger than 3 in.

Lengths of pipe larger than about 2 in., are usually connected by flanges or by welding. Flanges are matching disks or rings of metal bolted together and compressing a gasket between their faces. The flanges themselves are attached to the pipe by screwing them on or by welding or brazing. A flange with no opening, used to close a pipe, is called a blind flange or a blank flange. For joining pieces of large steel pipe in process piping, especially for high-pressure service, welding has become the standard method.

Allowances for expansion

If the pipe is rigidly fixed to its supports, it may tear loose, bend, or even break. In large lines, therefore, fixed supports are not used; instead, the pipe rests loosely on rollers or is hung from above by chains or rods. Provision is also made in all high-temperature lines for taking up expansion, so that the fittings and valves are not put under strain. This is done by bends or loops in the pipe, by packed expansion joints, by bellows or packless joints; and sometimes by flexible metal hose.

Prevention of leakage around moving parts

In many kinds of processing equipment, it is necessary to have one part move in relation to another part without excessive leakage of a fluid around the moving member. Common devices for minimizing leakage while permitting relative motion, are stuffing boxes and mechanical seals. The motion of the moving part

may be reciprocating or rotational, or both together; it may be small and occasional, as in a packed expansion joint, or virtually continuous.

- ***Stuffing boxes***

A stuffing box can provide a seal around a rotating shaft and also around a shaft which moves axially. In this it differs from mechanical seals, which are good only with rotating members.

The box is a chamber cut into the stationary member surrounding the shaft or pipe, as shown in Fig.4.4. Often a boss is provided on the casing or vessel wall to give a deeper chamber. The annular space between the shaft and the wall of the chamber is filled with packing, consisting of a rope or rings of inert material, containing a lubricant such as graphite.

The packing, when compressed tightly around the shaft, keeps the fluid from passing out through the stuffing box and yet permits the shaft to turn or move back and forth. The packing is compressed by a follower ring, or gland, pressed into the box by a flanged cap or packing nut. The shaft must have a smooth surface so that it does not wear away the packing; even so, the pressure of the packing considerably increases the force required to move the shaft. A stuffing box, even under ideal condition, does not completely stop fluid from leaking out. When the box is operating properly, there should be small leakage. Otherwise the wear on the packing and the power loss in the lubricated stuffing box are excessive. When the fluid is toxic or corrosive, means must be provided to prevent it from escaping from the equipment. This can be done by using a lantern gland, which can be considered as two stuffing boxes on the same shaft with two sets of packing separated by a lantern ring.

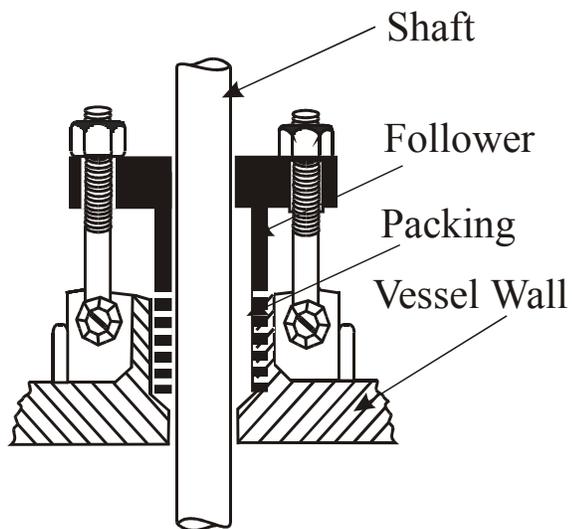
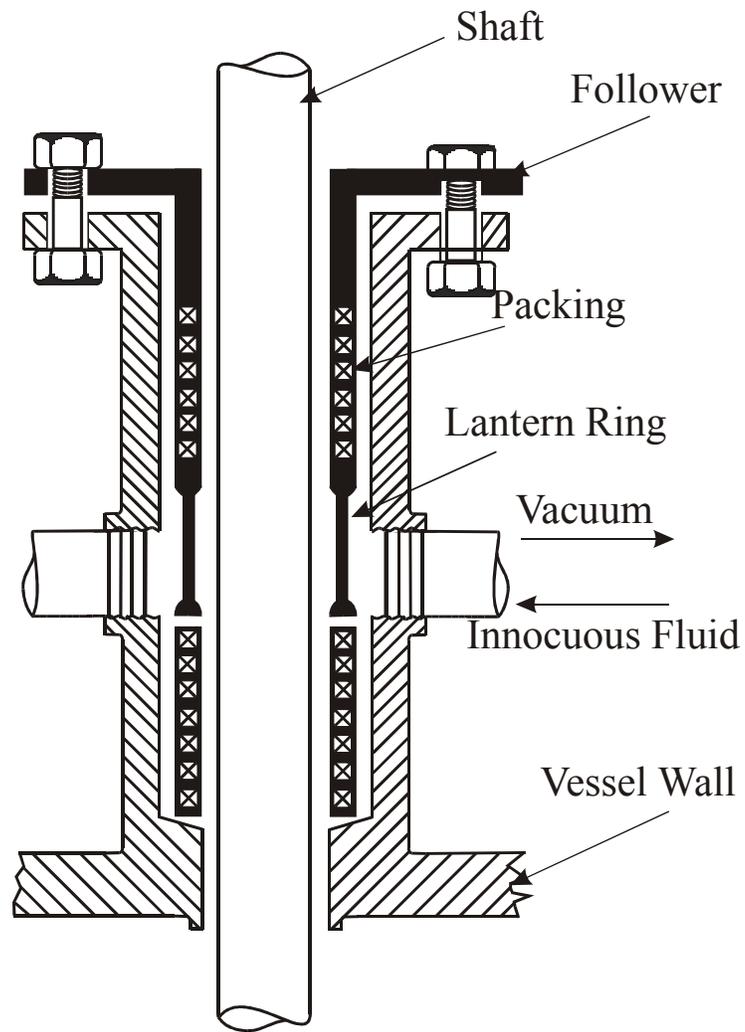


Figure 4.4
Stuffing Box

- **Mechanical seals**

In a rotary or mechanical seal, the sliding contact is between a ring of graphite and a polished metal face, usually of carbon steel.

Fluid in the high-pressure zone is kept from leaking out around the shaft by the stationary graphite ring held by springs against the face of the rotating metal collar. Stationary U-cup packing of rubber or plastic is set in the space between the body of the seal and the chamber holding it around the shaft; this keeps fluid from leaking past the non-rotating part of the seal and yet leaves the graphite ring free to move axially so that it can be pressed tightly against the collar. Rotary seals require less maintenance than stuffing boxes and have come into wide use in equipment handling of highly corrosive fluids.

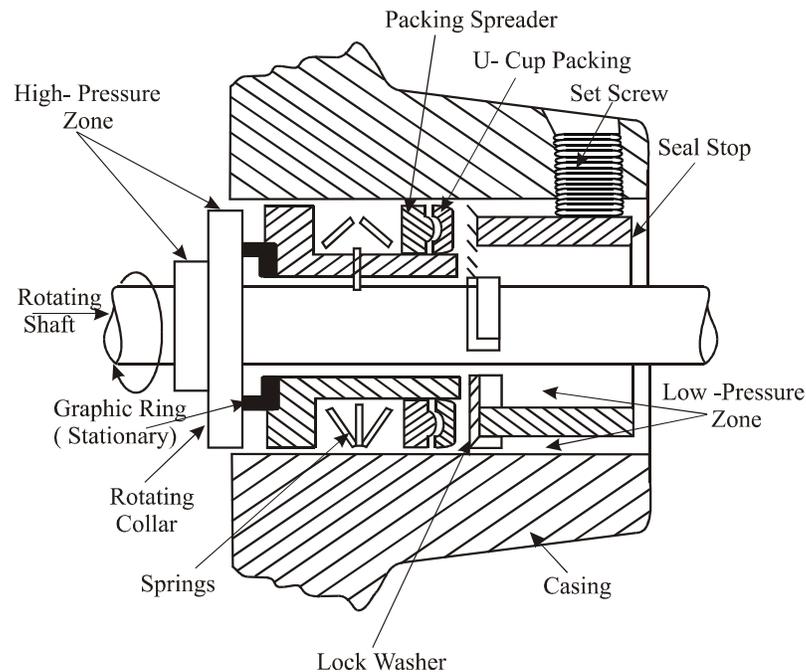


Figure 4.5
Mechanical Seal

4.4.3 Valves

A typical processing plant contains numerous types of valves, of many different sizes and shapes. Despite the variety in their design, most of them have a common primary purpose; to slow down or stop the flow of a fluid. Some valves work best in on-or-off service, ie fully open or fully closed. Others are designed to throttle, to reduce the pressure and flow rate of a fluid. Still others permit flow in one direction. Finally, with the addition of accessory devices, valves can be made to regulate the temperature, pressure, liquid level, or other properties of a fluid at points remote from the valve itself.

All valves initially stop or control flow. This is done by placing an obstruction in the path of the fluid. This obstruction can be moved around as desired inside the pipe, with little or no leakage of the fluid from the pipe to the outside. Where the resistance to flow introduced by an open valve must be small, the obstruction and the opening which can be closed by it, are large. For precise control of flow

rate, usually obtained at the price of a large pressure drop, the cross-sectional area of the flow channel is greatly reduced and a small obstruction is set into the small opening .

- Gate Valves

In a gate valve, the diameter of the opening through which the fluid passes is nearly the same as that of the pipe and the direction of flow does not change. As a result, when a wide-open gate valve is opened, the disk rises into the bonnet, completely out of the path of the fluid. Gate valves are not recommended for controlling flow and are usually left fully opened or fully closed.

- Plug Cocks and Ball Valves

For temperatures below 250°C, metallic plug cocks are useful in chemical process lines. A quarter turn of the stem takes the valve from fully opened to fully closed. When fully opened, the channel through the plug may be as large as the inside of the pipe itself and the pressure drop is minimal. In a ball valve the sealing element is spherical and the problem of alignment and “freezing” of the element are less than with a plug cock. In both plug cocks and ball valves, the area of contact between moving element and seat is large and both can therefore be used in throttling service. Ball valves find occasional applications in flow control.

- Check valves

A check valve permits flow in one direction only. It is opened by the pressure of the fluid in the desired direction; when the flow stops or tends to reverse, the valve automatically closes by gravity or by a spring pressing against the disk.

4.5 Fluid- Moving Machinery

Fluids are transported by means of pumps, compressors, fans etc. The methods used to move fluid can be based on two principles:

- Machinery applying direct pressure to the fluid
- Machinery utilizing torque to generate rotation

4.5.1 Pump Selection Criteria

When selecting the pumps for any service, it is necessary to be aware of the following feature:

System requirements

- Liquid to be handled
- The total dynamic head
- The suction and discharge heads
- Temperature
- Pressure
- Viscosity
- Vapor pressure
- Specific gravity

Selection Guidelines

- Range of Operation

A wide variety of pumps are available from which the requirement for a specific installation must be considered.

- Pumps Material of Construction

In the chemical process industry, the selection of pump material of construction is dictated by considerations of corrosion, erosion, personnel safety and liquid contaminants.

- Presence of solids

When a pump is required to transfer a liquid containing suspended solids, there are unique specifications which are to be considered. Dimensions of all internal passages are critical. Pockets and dead spots, areas where solids can accumulate, must be avoided. Close internal clearances are undesirable because of abrasion. Flushing connections for continuous or intermittent use should be provided.

- Pump costs

Economic factors also play a vital role in the selection of various models for a specific service.

4.5.2 Centrifugal Pumps

Basic Concepts of Operation, Maintenance, and Troubleshooting

The operating manual of any centrifugal pump often starts with a general statement, “Your centrifugal pump will give you completely trouble free and satisfactory service only on the condition that it is installed and operated with due care and is properly maintained.”

Despite all the care in operation and maintenance, engineers often face the statement “the pump has failed i.e. it can no longer be kept in service”. Inability to deliver the desired flow and head is just one of the most common conditions for taking a pump out of service. There are other many conditions in which a pump, despite suffering no loss in flow or head, is considered to have failed and has to be pulled out of service as soon as possible. These include seal related problems (leakages, loss of flushing, cooling, quenching systems, etc), pump and motor bearings related problems (loss of lubrication, cooling, contamination of oil, abnormal noise, etc), leakages from pump casing, very high noise and vibration levels, or driver (motor or turbine) related problems.

The list of pump failure conditions mentioned above is neither exhaustive nor are the conditions mutually exclusive. Often the root causes of failure are the same but the symptoms are different. A little care when first symptoms of a problem appear can save the pumps from permanent failures. Thus the most important task in such situations is to find out whether the pump has failed mechanically or if there is some process deficiency, or both. Many times when the pumps are sent to the workshop, the maintenance people do not find anything wrong on disassembling it. Thus the decision to pull a pump out of service for maintenance / repair should be made after a detailed analysis of the symptoms and root causes of the pump failure. Also, in case of any mechanical failure or physical damage of pump internals, the operating engineer should be able to relate the failure to the process unit’s operating problems.

Any operating engineer, who typically has a chemical engineering background and who desires to protect his pumps from frequent failures must develop not only a good understanding of the process but also thorough knowledge of the mechanics of the pump. Effective troubleshooting requires an ability to observe changes in performance over time, and in the event of a failure, the capacity to thoroughly investigate the cause of the failure and take measures to prevent the problem from re-occurring.

The fact of the matter is that there are three types of problems mostly encountered with centrifugal pumps:

- design errors
- poor operation
- poor maintenance practices

The present article is being presented in three parts, covering all aspects of operation, maintenance, and troubleshooting of centrifugal pumps. The article has been written keeping in mind the level and interests of students and the beginners in operation. Any comments or queries are most welcome.

Working Mechanism of a Centrifugal Pump

A centrifugal pump is one of the simplest pieces of equipment in any process plant. Its purpose is to convert energy of a prime mover (a electric motor or turbine) first into velocity or kinetic energy and then into pressure energy of a fluid that is being pumped. The energy changes occur by virtue of two main parts of the pump, the impeller and the volute or diffuser. The impeller is the rotating part that converts driver energy into the kinetic energy. The volute or diffuser is the stationary part that converts the kinetic energy into pressure energy.

Note: All of the forms of energy involved in a liquid flow system are expressed in terms of feet of liquid i.e. head.

Generation of Centrifugal Force

The process liquid enters the suction nozzle and then into eye (center) of a revolving device known as an impeller. When the impeller rotates, it spins the liquid sitting in the cavities between the vanes outward and provides centrifugal acceleration. As liquid leaves the eye of the impeller a low-pressure area is created causing more liquid to flow toward the inlet. Because the impeller blades are curved, the fluid is pushed in a tangential and radial direction by the centrifugal force. This force acting inside the pump is the same one that keeps water inside a bucket that is rotating at the end of a string. Figure A.01 below depicts a side cross-section of a centrifugal pump indicating the movement of the liquid.

Conversion of Kinetic Energy to Pressure Energy

The key idea is that the energy created by the centrifugal force is *kinetic energy*. The amount of energy given to the liquid is proportional to the *velocity* at the edge or vane tip of the impeller. The faster the impeller revolves or the bigger the impeller is, then the higher will be the velocity of the liquid at the vane tip and the greater the energy imparted to the liquid.

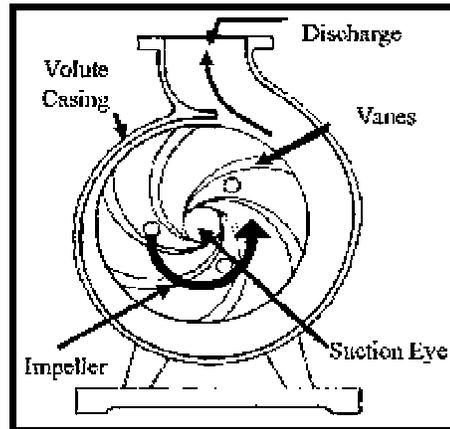


Figure 4.6
Liquid Flow Direction Inside a Centrifugal Pump

This kinetic energy of a liquid coming out of an impeller is harnessed by creating a *resistance* to the flow. The first resistance is created by the pump volute (casing) that catches the liquid and slows it down. In the discharge nozzle, the liquid further decelerates and its velocity is converted to pressure according to Bernoulli's principle.

Therefore, the head (pressure in terms of height of liquid) developed is approximately equal to the velocity energy at the periphery of the impeller expressed by the following well-known formula:

$$H = \frac{v^2}{2g}$$

where

- H = Total head developed in feet.
- v = Velocity at periphery of impeller in ft/sec.
- g = Acceleration due to gravity - 32.2 feet/Sec²

A handy formula for peripheral velocity is:

$$v = \frac{N \times D}{229}$$

where

- v = Velocity at periphery of impeller in ft/sec.
- N = The impeller RPM (revolutions per minute)
- D = Impeller diameter in inches

This head can also be calculated from the readings on the pressure gauges attached to the suction and discharge lines.

Pump curves relate flow rate and pressure (head) developed by the pump at different impeller sizes and rotational speeds. The centrifugal pump operation should conform to the pump curves supplied by the manufacturer. In order to read and understand the pump curves, it is very important to develop a clear understanding of the terms used in the curves. This topic will be covered later.

General Components of Centrifugal Pumps

A centrifugal pump has two main components:

- A rotating component comprised of an impeller and a shaft
- A stationary component comprised of a casing, casing cover, and bearings.

The general components, both stationary and rotary, are depicted in Figure 4.7. The main components are discussed in brief below. Figure 4.8 shows these parts on a photograph of a pump in the field.

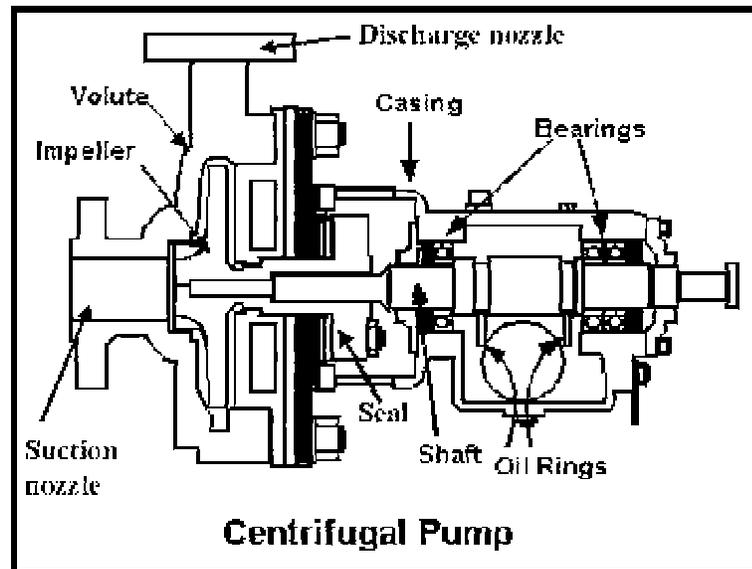


Figure 4.7
General Components of Centrifugal Pump

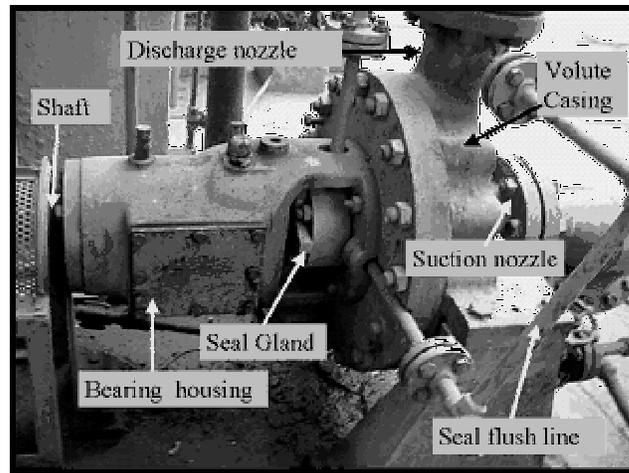


Figure 4.8
Field Photograph of Centrifugal Pump

Stationary Components

- **Casing**

Casings are generally of two types: volute and circular. The impellers are fitted inside the casings.

1. **Volute casings** build a higher head; **circular casings** are used for low head and high capacity.

- A **volute** is a curved funnel increasing in area to the discharge port as shown in Figure B.03. As the area of the cross-section increases, the volute reduces the speed of the liquid and increases the pressure of the liquid.
- One of the *main purposes of a volute casing* is to help balance the hydraulic pressure on the shaft of the pump. However, this occurs best at the manufacturer's recommended capacity. Running volute-style pumps at a lower capacity than the manufacturer recommends can put lateral stress on the shaft of the pump, increasing wear-and-tear on the seals and bearings, and on the shaft itself. Double-volute casings are used when the radial thrusts become significant at reduced capacities.

2. **Circular casing** have stationary diffusion vanes surrounding the impeller periphery that convert velocity energy to pressure energy. Conventionally, the diffusers are applied to multi-stage pumps.

- The casings can be designed either as solid casings or split casings. **Solid casing** implies a design in which the entire casing including the discharge nozzle is all contained in one casting or fabricated piece. A **split casing** implies two or more parts are fastened together. When the casing parts are divided by horizontal plane, the casing is described as horizontally split or axially split casing. When the split

is in a vertical plane perpendicular to the rotation axis, the casing is described as vertically split or radially split casing. Casing Wear rings act as the seal between the casing and the impeller.

- **Suction and Discharge Nozzle**

The suction and discharge nozzles are part of the casings itself. They commonly have the following configurations.

- **End suction/Top discharge**

The suction nozzle is located at the end of, and concentric to, the shaft while the discharge nozzle is located at the top of the case perpendicular to the shaft. This pump is always of an overhung type and typically has lower NPSHr because the liquid feeds directly into the impeller eye.

- **Top suction Top discharge nozzle**

The suction and discharge nozzles are located at the top of the case perpendicular to the shaft. This pump can either be an overhung type or between-bearing type but is always a radially split case pump.

- **Side suction / Side discharge nozzles**

The suction and discharge nozzles are located at the sides of the case perpendicular to the shaft. This pump can have either an axially or radially split case type.

- **Seal Chamber and Stuffing Box**

Seal chamber and Stuffing box both refer to a chamber, either integral with or separate from the pump case housing that forms the region between the shaft and casing where sealing media are installed. When the sealing is achieved by means of a mechanical seal, the chamber is commonly referred to as a Seal Chamber. When the sealing is achieved by means of packing, the chamber is referred to as a Stuffing Box. Both the seal chamber and the stuffing box have the primary function of protecting the pump against leakage at the point where the shaft passes out through the pump pressure casing. When the pressure at the bottom of the chamber is below atmospheric, it prevents air leakage into the pump. When the pressure is above atmospheric, the chambers prevent liquid leakage out of the pump. The seal chambers and stuffing boxes are also provided with cooling or heating arrangement for proper temperature control. Figure B.06 below depicts an externally mounted seal chamber and its parts.

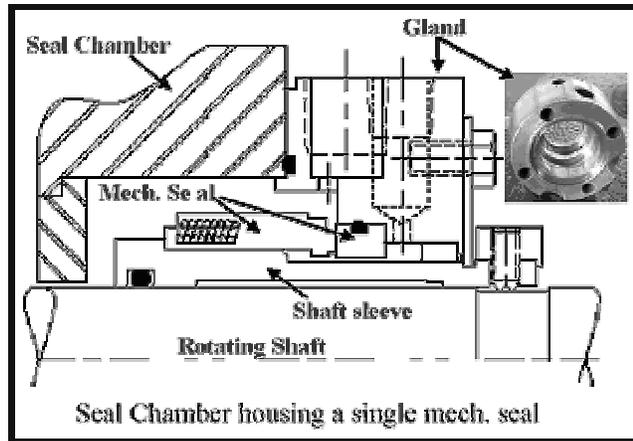


Figure 4.9

Simple Seal Chamber Components

- **Gland:** The gland is a very important part of the seal chamber or the stuffing box. It gives the packings or the mechanical seal the desired fit on the shaft sleeve. It can be easily adjusted in axial direction. The gland comprises of the seal flush, quench, cooling, drain, and vent connection ports as per the standard codes like API 682.
- **Throat Bushing:** The bottom or inside end of the chamber is provided with a stationary device called throat bushing that forms a restrictive close clearance around the sleeve (or shaft) between the seal and the impeller.
- **Throttle bushing** refers to a device that forms a restrictive close clearance around the sleeve (or shaft) at the outboard end of a mechanical seal gland.
- **Internal circulating device** refers to device located in the seal chamber to circulate seal chamber fluid through a cooler or barrier/buffer fluid reservoir. Usually it is referred to as a pumping ring.
- **Mechanical Seal:** The features have been discussed earlier.
- **Bearing housing**

The bearing housing encloses the bearings mounted on the shaft. The bearings keep the shaft or rotor in correct alignment with the stationary parts under the action of radial and transverse loads. The bearing house also includes an oil reservoir for lubrication, constant level oiler, jacket for cooling by circulating cooling water.

Rotating Components

1. Impeller

The impeller is the main rotating part that provides the centrifugal acceleration to the fluid. They are often classified in many ways.

- Based on major direction of flow in reference to the axis of rotation
 - Radial flow
 - Axial flow
 - Mixed flow
- Based on suction type
 - Single-suction: Liquid inlet on one side.
 - Double-suction: Liquid inlet to the impeller symmetrically from both sides.
- Based on mechanical construction
 - Closed: Shrouds or sidewall enclosing the vanes.
 - Open: No shrouds or wall to enclose the vanes.
 - Semi-open or vortex type.

Closed impellers require wear rings and these wear rings present another maintenance problem. Open and semi-open impellers are less likely to clog, but need manual adjustment to the volute or back-plate to get the proper impeller setting and prevent internal re-circulation. Vortex pump impellers are great for solids and "stringy" materials but they are up to 50% less efficient than conventional designs. The number of impellers determines the number of stages of the pump. A single stage pump has one impeller only and is best for low head service. A two-stage pump has two impellers in series for medium head service. A multi-stage pump has three or more impellers in series for high head service.

- Wear rings

Wear ring provides an easily and economically renewable leakage joint between the impeller and the casing. clearance becomes too large the pump efficiency will be lowered causing heat and vibration problems. Most manufacturers require that you disassemble the pump to check the wear ring clearance and replace the rings when this clearance doubles.

2. Shaft

The basic purpose of a centrifugal pump shaft is to transmit the torques encountered when starting and during operation while supporting the impeller and other rotating parts. It must do this job with a deflection less than the minimum clearance between the rotating and stationary parts.

- Shaft Sleeve

Pump shafts are usually protected from erosion, corrosion, and wear at the seal chambers, leakage joints, internal bearings, and in the waterways by renewable sleeves. Unless otherwise specified, a shaft sleeve of wear,

corrosion, and erosion-resistant material shall be provided to protect the shaft. The sleeve shall be sealed at one end. The shaft sleeve assembly shall extend beyond the outer face of the seal gland plate. (Leakage between the shaft and the sleeve should not be confused with leakage through the mechanical seal).

- Coupling

Couplings can compensate for axial growth of the shaft and transmit torque to the impeller. Shaft couplings can be broadly classified into two groups: rigid and flexible. Rigid couplings are used in applications where there is absolutely no possibility or room for any misalignment. Flexible shaft couplings are more prone to selection, installation and maintenance errors. Flexible shaft couplings can be divided into two basic groups: elastomeric and non-elastomeric

- Elastomeric couplings use either rubber or polymer elements to achieve flexibility. These elements can either be in shear or in compression. Tire and rubber sleeve designs are elastomer in shear couplings; jaw and pin and bushing designs are elastomer in compression couplings.

- Non-elastomeric couplings use metallic elements to obtain flexibility. These can be one of two types: lubricated or non-lubricated. Lubricated designs accommodate misalignment by the sliding action of their components, hence the need for lubrication. The non-lubricated designs accommodate misalignment through flexing. Gear, grid and chain couplings are examples of non-elastomeric, lubricated couplings. Disc and diaphragm couplings are non-elastomeric and non-lubricated.

Auxiliary Components

Auxiliary components generally include the following piping systems for the following services:

- Seal flushing , cooling , quenching systems
- Seal drains and vents
- Bearing lubrication , cooling systems
- Seal chamber or stuffing box cooling, heating systems
- Pump pedestal cooling systems

Auxiliary piping systems include tubing, piping, isolating valves, control valves, relief valves, temperature gauges and thermocouples, pressure gauges, sight flow indicators, orifices, seal flush coolers, dual seal barrier/buffer fluid reservoirs, and all related vents and drains.

All auxiliary components shall comply with the requirements as per standard codes like API 610 (refinery services), API 682 (shaft sealing systems) etc.

Definition of Important Terms

The key performance parameters of centrifugal pumps are capacity, head, BHP (Brake horse power), BEP (Best efficiency point) and specific speed. The pump curves provide the operating window within which these parameters can be varied for satisfactory pump operation. The following parameters or terms are discussed in detail in this section.

- **Capacity**

Capacity means the flow rate with which liquid is moved or pushed by the pump to the desired point in the process. It is commonly measured in either gallons per minute (gpm) or cubic meters per hour (m³/hr). The capacity usually changes with the changes in operation of the process. For example, a boiler feed pump is an application that needs a constant pressure with varying capacities to meet a changing steam demand.

The capacity depends on a number of factors like:

- Process liquid characteristics i.e. density, viscosity
- Size of the pump and its inlet and outlet sections
- Impeller size
- Impeller rotational speed RPM
- Size and shape of cavities between the vanes
- Pump suction and discharge temperature and pressure conditions

For a pump with a particular impeller running at a certain speed in a liquid, the only items on the list above that can change the amount flowing through the pump are the pressures at the pump inlet and outlet. The effect on the flow through a pump by changing the outlet pressures is graphed on a pump curve.

As liquids are essentially incompressible, the capacity is directly related with the velocity of flow in the suction pipe. This relationship is as follows:

$$Q = 449 \times V \times A$$

where

- **Q = Capacity in gallons per minute (GPM).**
- **V = Velocity of flow in ft/sec.**
- **A = Area of pipe in ft²**

- **Head**

The pressure at any point in a liquid can be thought of as being caused by a vertical column of the liquid due to its weight. The height of this column is called the static head and is expressed in terms of feet of liquid.

The same *head* term is used to measure the kinetic energy created by the pump. In other words, head is a measurement of the height of a liquid column that the pump could create from the kinetic energy imparted to the

liquid. Imagine a pipe shooting a jet of water straight up into the air, the height the water goes up would be the head.

The head is not equivalent to pressure. Head is a term that has units of a length or feet and pressure has units of force per unit area or pound per square inch. The main reason for using head instead of pressure to measure a centrifugal pump's energy is that the pressure from a pump will change if the specific gravity (weight) of the liquid changes, but the head will not change. Since any given centrifugal pump can move a lot of different fluids, with different specific gravities, it is simpler to discuss the pump's head and forget about the pressure.

So a centrifugal pump's performance on any Newtonian fluid, whether it's heavy (sulfuric acid) or light (gasoline) is described by using the term 'head'. The pump performance curves are mostly described in terms of head.

- NPSH

When discussing centrifugal pumps, the two most important head terms are NPSHr and NPSHa.

- Net Positive Suction Head Required, NPSHr

NPSH is one of the most widely used and least understood terms associated with pumps. Understanding the significance of NPSH is very much essential during installation as well as operation of the pumps.

- Pumps can pump only liquids, not vapors

The satisfactory operation of a pump requires that vaporization of the liquid being pumped does not occur at any condition of operation. This is so desired because when a liquid vaporizes its volume increases very much. For example, 1 ft³ of water at room temperature becomes 1700 ft³ of vapor at the same temperature. This makes it clear that if we are to pump a fluid effectively, it must be kept always in the liquid form.

- Rise in temperature and fall in pressure induces vaporization

The vaporization begins when the vapor pressure of the liquid at the operating temperature equals the external system pressure, which, in an open system is always equal to atmospheric pressure. Any decrease in external pressure or rise in operating temperature can induce vaporization and the pump stops pumping. Thus, the pump always needs to have a sufficient amount of suction head present to prevent this vaporization at the lowest pressure point in the pump.

- NPSH as a measure to prevent liquid vaporization

The manufacturer usually tests the pump with water at different capacities, created by throttling the suction side. When the first signs of vaporization induced cavitation occur, the suction pressure is noted (the term cavitation is discussed in detail later). This pressure is converted into the head. This head number is published on the pump curve and is referred as the "net positive suction head required (NPSHr) or sometimes in short as the NPSH. Thus the Net Positive Suction Head (NPSH) is the total head at the suction flange of the pump less the vapor pressure converted to fluid column height of the liquid.

- NPSHr is a function of pump design

NPSH required is a function of the pump design and is determined based on actual pump test by the vendor. As the liquid passes from the pump suction to the eye of the impeller, the velocity increases and the pressure decreases. There are also pressure losses due to shock and turbulence as the liquid strikes the impeller. The centrifugal force of the impeller vanes further increases the velocity and decreases the pressure of the liquid. The NPSH required is the positive head in feet absolute required at the pump suction to overcome these pressure drops in the pump and maintain the majority of the liquid above its vapor pressure.

The NPSH is always positive since it is expressed in terms of absolute fluid column height. The term "Net" refers to the actual pressure head at the pump suction flange and not the static suction head.

- NPSHr increases as capacity increases

The NPSH required varies with speed and capacity within any particular pump. The NPSH required increase as the capacity is increasing because the velocity of the liquid is increasing, and as anytime the velocity of a liquid goes up, the pressure or head comes down. Pump manufacturer's curves normally provide this information. The NPSH is independent of the fluid density as are all head terms. Note: It is to be noted that the net positive suction head required (NPSHr) number shown on the pump curves is for fresh water at 20°C and not for the fluid or combinations of fluids being pumped.

- Net Positive Suction Head available, NPSHa

- *NPSHa is a function of system design*

Net Positive Suction Head Available is a function of the system in which the pump operates. It is the excess pressure of the liquid in feet absolute over its vapor pressure as it arrives at the pump

suction, to be sure that the pump selected does not cavitate. It is calculated based on system or process conditions.

- **NPSHa calculation**

The formula for calculating the NPSHa is stated below:

$$NPSHa_s = h_{p_s} + h_s - h_{vp_s} - h_{f_s}$$

- h_{p_s} - Pressure Head i.e Barometric Pressure of the suction vessel converted to Head
- h_s - Static suction Head i.e.the vertical distance between the eye of the first stage impeller centerline and the suction liquid level.
- h_{vp_s} - Vapor pressure Head i.e. vapor pressure of liquid at its max. pumping temperature converted to Head
- h_{f_s} - Friction Head i.e. friction and entrance pressure losses on the suction side converted to Head

Note:

1. It is important to correct for the specific gravity of the liquid and to convert all terms to units of "feet absolute" in using the formula.
2. Any discussion of NPSH or cavitation is only concerned about the suction side of the pump. There is almost always plenty of pressure on the discharge side of the pump to prevent the fluid from vaporizing.

Significance of NPSHr and NPSHa

The NPSH available must always be greater than the NPSH required for the pump to operate properly. It is normal practice to have at least 2 to 3 feet of extra NPSH available at the suction flange to avoid any problems at the duty point.

- **Power and Efficiency**

Brake Horse Power (BHP)

The work performed by a pump is a function of the total head and the weight of the liquid pumped in a given time period.

Pump input or brake horsepower (BHP) is the actual horsepower delivered to the pump shaft.

Requirements for Consistent Operation

Centrifugal pumps are the ultimate in simplicity. In general there are two basic requirements that have to be met at all the times for a trouble free operation and longer service life of centrifugal pumps.

The first requirement is that no cavitation of the pump occurs throughout the broad operating range and the second requirement is that a certain minimum continuous flow is always maintained during operation.

A clear understanding of the concept of cavitation, its symptoms, its causes, and its consequences is very much essential in effective analyses and troubleshooting of the cavitation problem.

Just like there are many forms of cavitation, each demanding a unique solution, there are a number of unfavorable conditions which may occur separately or simultaneously when the pump is operated at reduced flows. Some include:

- Cases of heavy leakages from the casing, seal, and stuffing box
- Deflection and shearing of shafts
- Seizure of pump internals
- Close tolerances erosion
- Separation cavitation
- Product quality degradation
- Excessive hydraulic thrust
- Premature bearing failures

Each condition may dictate a different minimum flow low requirement. The final decision on recommended minimum flow is taken after careful “techno-economical” analysis by both the pump user and the manufacturer.

The consequences of prolonged conditions of cavitation and low flow operation can be disastrous for both the pump and the process. Such failures in hydrocarbon services have often caused damaging fires resulting in loss of machine, production, and worst of all, human life.

Thus, such situations must be avoided at all cost whether involving modifications in the pump and its piping or altering the operating conditions. Proper selection and sizing of pump and its associated piping can not only eliminate the chances of cavitation and low flow operation but also significantly decrease their harmful effects.

4.5.3 Positive-Displacement Pumps

These pumps, when they reach positive displacement, will ideally produce whatever head is impressed upon them by the system restrictions to flow. In general the overall efficiencies are higher than that of centrifugal equipment because internal losses are minimized. In all positive displacement pumps, a cavity or cavities are alternately filled and emptied of the pumped fluid by the action of the pump. There are two subclasses of positive-displacement pumps.

Reciprocating pumps

They may be single-cylinder or multi-cylinder design and of the following three types:

- Piston pumps
- Plunger pumps
- Diaphragm pumps

(A) Start-up Procedure

- Check for mechanical completion.
- Check level and quality of lube oil
- Check the movement of the shaft
- Energise the motor
- Line-up suction and discharge system and open suction and discharge valve .
Open steam tracers if any
- Line-up the minimum flow circuit and discharge relief valve
- Adjust the stroke length in case of dosing pumps
- Start the motor by push button
- Watch the discharge pressure
- If pressure continues to increase beyond normal pressure, stop the pump immediately and check the line-up
- Check for unusual noise, vibrations and rise in bearing temperature of motor and pump
- Discharge valve of reciprocating pumps should never be closed or throttled while the motor is running

(B) Shut-down Procedure

- Stop the motor
- Do not close suction/discharge valve unless it is to be handed over to maintenance

(C) Change Over of Pumps

- Start the standby pump as per standard procedure
- Immediately switch-off originally running pump as soon as the pressure starts increasing

Rotary pumps

Rotary pumps are available in two general classes . The interior-bearing type is used for handling liquids of a lubricating nature and the exterior-bearing type is used with non lubricating liquids.

A wide variety of rotary positive-displacement pumps are available. They are termed as gear pumps, lobe pumps, screw pumps, cam pumps and vane pumps. Rotary pumps operate best on clear, moderately viscous fluids. Discharge pressure up to 200 atm. or more can be attained.

Routine Checks :

- Quality and level of lube oil
- Pump and motor bearing temperatures
- Abnormal sound and vibrations
- Leakages
- Pressure gauges
- Motor amperage
- Cooling water, quench steam and sealing liquid flows
- Warm-up condition of standby pump
- Functioning of safety valves of reciprocating pumps

Trouble Shooting

| Symptom | Sequence of actions to be taken |
|----------------------------|---|
| Not developing pressure | Remove vapor locking, check suction side line up and level in suction vessel. Check coupling and direction of rotation. Clean strainer, consult maintenance. Also check the function of safety valve. |
| Abnormal sound/Vibration | Check for loose coupling guards, fan cover, foundation bolts, etc. Consult electrical/mech technicians. Change over the pump if the sound/ vibration is excessive. |
| High Bearing Temperature | Check lube oil level and quality. Adjust cooling water, change over if required. |
| Frequent tripping of motor | If the motor trips twice, don't restart unless cleared by electrical maintenance. |
| Hot gland | Check gland cooling water, arrange external cooling till mechanical help is available, get the gland nut loosened. Change over/stop the pump if temperature is very high. |
| Motor not Stopping with | Throttle discharge and trip the stop switch motor from the substation |

| | |
|-------------------------|---|
| Excessive leakage | Change over the pump. Isolate and depressurize. |
| High Discharge Pressure | Check the line up of discharge circuit. In case of reciprocating pumps, stop the pump immediately and then check the line-up before restarting. |

4.5.4 Compressors

Compressors are used for compressing gases or air. There are two types which are normally used in chemical process industries.

- Centrifugal compressor
- Reciprocating compressor

Compressor selection

The important factors to be considered are :

- Flow rate
- Head
- Temperature
- Power consumption
- Lubrication methods
- Serviceability
- Cost

1. Centrifugal Compressor

It is a high speed rotating machine used for compressing gases. Main parts of the centrifugal compressor are

- Drive
- Compressor casing
- Impellers
- Shafts
- Bladder accumulator
- Governor system
- Lube oil pumps
- Lube oils
- Coolers
- Filters
- Seal oil pumps
- Surface condenser
- Ejector
- Condensate pumps

Centrifugal compressors are widely used for many services - compressing process gas, supplying plant air, conveying solid materials in suspension, exhausters, ventilation, and aeration, etc. They are employed to handle large volume of gases. Centrifugal compressors may be single or multistage within a single casing. Intercoolers may be used between stages or casings to cool the partially compressed gas to the initial or other desired temperature in order to minimize the power required for compression.

Centrifugal compressor drives are usually steam turbines, gas turbines or electric motors. Most of these machines operate at speeds above 60 Hz, two pole motor speed of 3600 r/min and rotative speeds of nearly 50,000 r/min.

Routine Operation /Checks :

- Ensure that all parameters are within their normal operating limits
- Get centrifugal bowl cleaned every fortnight
- Rotate the filter on governor oil system in every shift
- Ensure proper sealing and drain of safety valve on surface condensers
- Drain condensate from compressor casing
- Check the performance of trap on ejector condensers
- Check the draining rate of seal oil and quantity of gas vented
- Ensure that the local control room is always pressurized
- Check the annunciation panel with every shift
- Check the pressure and flow of inert gas
- Any abnormality should be brought to the notice of shift supervisor immediately

2. Reciprocating Compressor

They are fabricated in either single-stage or multistage types. The number of stages is determined by the compressor ratio. These machines are seldom used for gas compression because of the difficulty of preventing gas leakage and contamination of the lubricating oils.

The main components are:

- Drive
- Cylinder
- Valves
- Piston
- Intercooler
- Lube oil system
- Loading and unloading devices, etc.

Routine checks

- Check suction, discharge and inter stage pressure and temperatures
- Check the lube oil pressure and level
- Ensure proper lubrication of all the points
- Periodically drain the lube oil and condensate, if necessary
- Check cooling water pump and pressure
- Watch for any abnormality
- Check the operation of unloaders

4.6 Agitation and Mixing of Fluids

4.6.1 Purpose of Agitation

Liquids are agitated for a number of purposes, depending on the objectives of the process. These include:

- Suspending solid particles.
- Blending miscible liquids.
- Dispersing a gas through the liquid in the form of small bubbles.
- Dispersing a second liquid, immiscible with the first, to form an emulsion or suspension of fine drops.
- Promoting heat transfer between the liquid and a coil or jacket.

4.6.2 Agitation Equipments

Impellers

Impeller agitators are divided into two classes.

- Axial-flow impellers: These generate currents parallel with the axis of the impeller shaft.
- Radial-flow impellers: These generate currents in a tangential or radial direction.

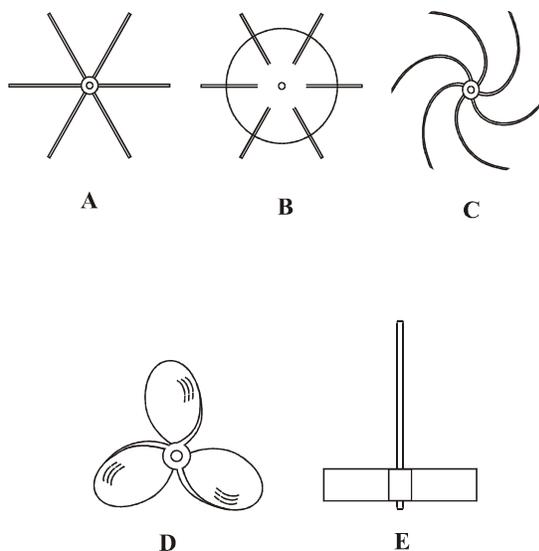
The three main types of impellers are mentioned below:

- Propellers
- Paddles
- Turbines.

Each type includes many variations and subtypes, which constitute the main forms of agitating devices.

Propellers

A propeller is an axial-flow, high-speed impeller for liquids of low viscosity. Small propellers turn at full motor speed, either 1,150 or 1,750 r/min and larger ones turn at 400 to 800 r/min.



- (A) Pitched - Blade Turbine
- (B) Disk Turbine
- (C) Concave - Blade Cd - 6 Impeller
- (D) Three Blade Marine Propeller
- (E) Simple Straight Blade Turbine

Figure 4. 10
Propellers

Paddles

For the simpler problems, an effective agitator consists of a flat paddle turning on a vertical shaft. Two-bladed and four-bladed paddles are common. Sometimes the blades are pitched; more often they are vertical. Industrial paddle agitators turn at speeds between 20 and 150 r/min. The total length of a paddle impeller is 50 to 80 percent of the inside diameter of the vessel.

Turbines

Most of them are multi bladed paddle agitators with short blades, turning at high speeds on a shaft mounted centrally in the vessel. The blades may be straight or curved, pitched or vertical. The impeller is smaller than with paddles, ranging from 30 to 50 percent of the diameter of the vessel.

4.6.3 Flow Patterns in Agitated Vessels

Prevention of swirling

Circulatory flow and swirling can be prevented by any of three methods. In small tanks, the impeller can be mounted off center. The shaft is moved away from the centerline of the tank, then tilted in a plane perpendicular to the direction of the move. In larger tanks, the agitator may be mounted in the side of the tank with the shaft in a horizontal plane but at an angle with a radius. In large tanks with vertical agitators, the preferable method of reducing swirling is to install baffles, which impede rotational flow without interfering with radial or longitudinal flow.

Draft tubes

The return flow to an impeller of any type approaches the impeller from all directions, because it is not under the control of solid surface. Draft tubes add to the fluid friction in the system and, for a given power input, they reduce the rate of flow; so they are not used unless they are required.

4.6.4 Blending and Mixing

Mixing is a much more difficult operation to study and describe than agitation. The patterns of flow of fluid velocity in an agitated vessel are complex but reasonably definite and reproducible.

Mixing of miscible liquids

The blending of miscible liquids in a tank is a fairly rapid process if the flow is turbulent. The impeller produces a high-velocity stream and the fluid is probably quite well mixed in the region close to the impeller because of the intense turbulence.

Jet mixing

Fluid flows into the jet and is absorbed, accelerated, and blended into the augmented jet. This process is called entrainment.

Motionless mixers

Gases or non-viscous liquids can often be satisfactorily blended by passing them together through a length of open pipe. Under appropriate conditions, the recommended pipe length may be as short as 5 or up to 100 pipe diameters.

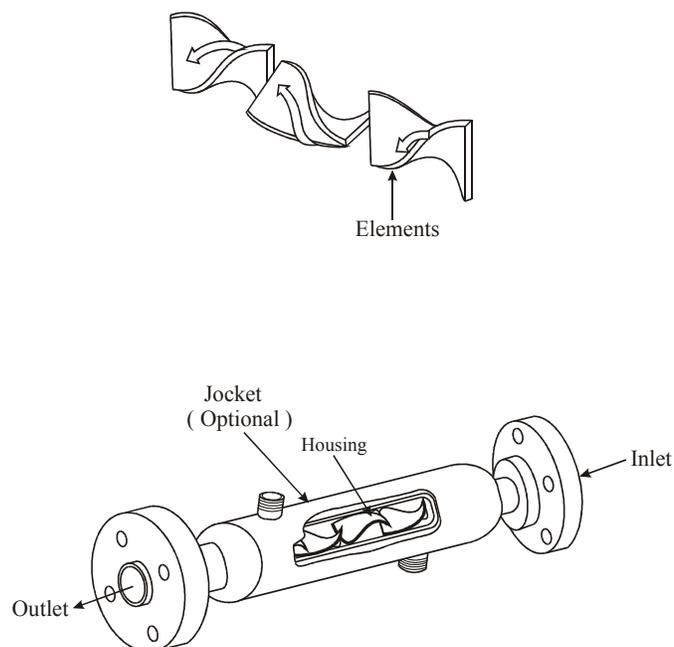


Figure 4.11
Motionless Mixers

Suspension of solid particles

Particles of solids are suspended in liquids for many purposes, perhaps to produce a homogeneous mixture for feeding to a processing unit, to dissolve the solids, to catalyze a chemical reaction, or to promote growth of a crystalline product from a supersaturated solution.

The degrees of suspension are given below in the order of increasing uniformity of suspension and increasing power input.

- Nearly complete suspension with filleting

Most of the solid is suspended in the liquid, with a few percent in stationary fillets of solid at the outside periphery of the bottom or at other places in the tank. Having a small amount of solids not in motion may be permissible in a feed tank. For crystallization or a chemical reaction, the presence of fillets would be undesirable.

- Complete particle motion

All the particles are either suspended or are moving along the tank bottom. Particles moving on the bottom have a much lower mass-transfer coefficient than suspended particles, which might affect the performance of the unit.

- Complete suspension or complete off-bottom suspension

All the particles are suspended off the tank bottom or do not stay on the bottom more than 1 or 2 Seconds. When this condition is just reached, there will generally be concentration gradients in the suspension and there may be a region of clear liquid near the top of the tank. The gradient in solid concentration will have little effect on the performance of the unit as a dissolver or a chemical reactor and the mass-transfer coefficient will not increase very much with further increases in stirrer speed.

- Uniform suspension

At stirrer speeds considerably above those needed for complete suspension, there is no longer any clear liquid near the top of the tank and the suspension appears uniform. However, there may still be vertical concentration gradients, particularly if the solid have a wide size distribution and care is needed in getting a representative sample from the tank.