

## Chapter 3

### Pumps Design

#### 5.1 Introduction

*Pumps* are devices for supplying energy or head to a flowing liquid in order to overcome head losses due to friction and also if necessary, to raise liquid to a higher level.

For the pumping of liquids or gases from one vessel to another or through long pipes, some form of mechanical pump is usually employed. **The energy required by the pump** will depend on the height through which the fluid is raised, the pressure required at delivery point, the length and diameter of the pipe, the rate of flow, together with the physical properties of the fluid, particularly its *viscosity and density*.

The pumping of liquids such as sulphuric acid or petroleum products from bulk store to process buildings, or the pumping of fluids round reaction units and through heat exchangers, are typical illustrations of the use of pumps in the process industries. On the one hand, it may be necessary to inject reactants or catalyst into a reactor at a low, but accurately controlled rate, and on the other to pump cooling water to a power station or refinery at a very high rate. The fluid may be a gas or liquid of low viscosity, or it may be a highly viscous liquid, possibly with non-Newtonian characteristics. It may be clean, or it may contain suspended particles and be very corrosive. All these factors influence the choice of pump.

Because of the wide variety of requirements, many different types are in use including centrifugal, piston, gear, screw, and peristaltic pumps, though in the chemical and petroleum industries the centrifugal type is by far the most important.

## 5.2 The Total Head ( $\Delta h$ )

The head imparted to a flowing liquid by a pump is known as the total head ( $\Delta h$ ). If a pump is placed between points ① and ② in a pipeline, the head for steady flow are related by: -

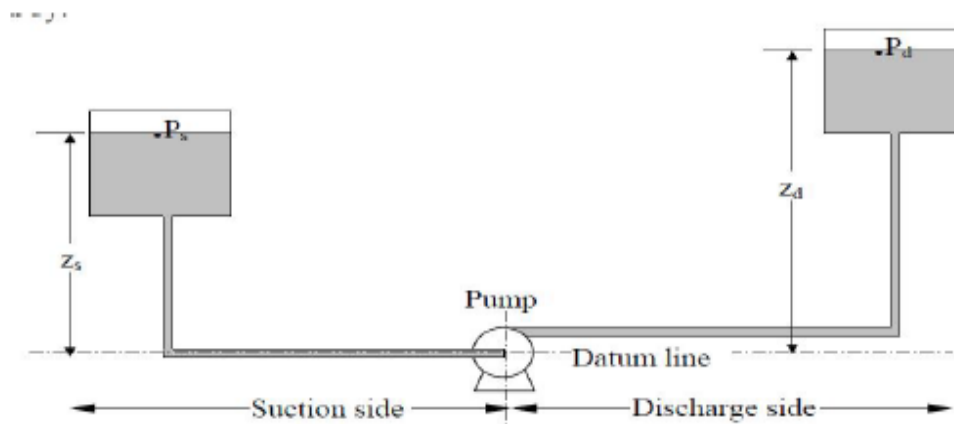


Figure (1) Typical pumping system.

$$\Delta h = \frac{\eta W_s}{g} = \left( \frac{P_2}{\rho g} + \frac{u_2^2}{2\alpha_2 g} + z_2 \right) - \left( \frac{P_1}{\rho g} + \frac{u_1^2}{2\alpha_1 g} + z_1 \right) - h_f$$

$$\rightarrow \Delta h = \frac{\Delta P}{\rho g} + \frac{\Delta u^2}{2\alpha g} + \Delta Z + h_f$$

## 5.3 System Heads

The important heads to consider in a pumping system are: -

- 1- Suction head
- 2- Discharge head
- 3- Total head
- 4- Net positive suction head (NPSH)

The following definitions are given in reference to typical pumping system shown in preceding Figure, where the datum line is the centerline of the pump

$$\mathbf{1- Suction\ head\ (h_s)} \quad h_s = z_s + \frac{P_s}{\rho g} - (h_F)_s$$

$$\mathbf{2- Discharge\ head\ (h_d)} \quad h_d = z_d + \frac{P_d}{\rho g} - (h_F)_d$$

### **3- Total head ( $\Delta h$ )**

The total head ( $\Delta h$ ), which is required to impart to the flowing liquid is the difference between the discharge and suction heads.

Thus, 
$$\Delta h = h_d - h_s$$

$$\Delta h = (z_d - z_s) + \left( \frac{P_d - P_s}{\rho g} \right) + [(h_F)_d + (h_F)_s]$$

Where

$$(h_F)_d = 4 f_d \left( \frac{L}{d} + \sum \frac{L_e}{d} \right)_d \frac{u_d^2}{2g}$$

$$(h_F)_s = 4 f_s \left( \frac{L}{d} + \sum \frac{L_e}{d} \right)_s \frac{u_s^2}{2g}$$

The suction head ( $h_s$ ) decreases and the discharge head ( $h_d$ ) increases with increasing liquid flow rate because of the increasing value of the friction head loss terms  $(h_F)_s$  and  $(h_F)_d$ . Thus the total; head ( $\Delta h$ ) which the pump is required to impart to the flowing liquid increases with increasing the liquid pumping rate.

### **Note:**

If the liquid level on the suction side is below the centerline of the pump,  $z_s$  is negative.

### **4- Net positive suction head (NPSH)**

Available net positive suction head

$$\mathbf{NPSH = } z_s + \left( \frac{P_s - P_v}{\rho g} \right) - (h_F)_s$$

This equation gives the head available to get the liquid through the suction piping.  $P_v$  is the vapor pressure of the liquid being pumped at the particular temperature in question.

The available net positive suction head (NPSH) can also be written as:

$$\mathbf{NPSH = } h_s - \frac{P_v}{\rho g}$$

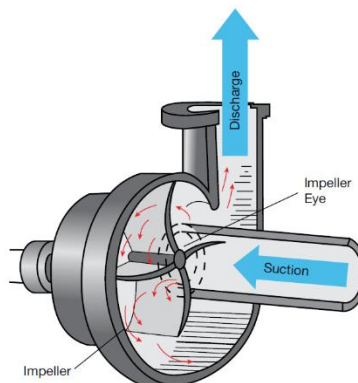
## 5.5 Types of Pumps

Pumps can be classified into: -

1- Centrifugal pumps. 2- Positive displacement pumps.

### 1- Centrifugal pumps

This type depends on giving the liquid a high kinetic energy, which is then converted as efficiently as possible into pressure energy. It used for liquid with very wide ranging properties and suspensions with high solid content including, for example, cement slurries, and may be constructed from a very wide range of corrosion resistant materials. Process industries commonly use centrifugal pumps. The whole pump casing may be constructed from plastics such as polypropylene or it may be fitted with a corrosion resistant lining. Because it operates at high speed, it may be directly coupled to an electric motor and it will give a high flow rate for its size. They are available in sizes about 0.004 to 380 m<sup>3</sup>/min [1-100,000 gal/min] and for discharge pressures from a few m H<sub>2</sub>O head to 5,000 kPa. In this type of pump (Figure 2), the fluid is fed to the center of a rotating impeller and is thrown outward by centrifugal action. As a result of the high speed of rotation the liquid acquires a high kinetic energy and the pressure difference between the suction and delivery sides arises from the interconversion of kinetic and pressure energy.



▲ **Figure 1.** In a centrifugal pump, a rotating impeller imparts energy to the liquid moving through the pump.

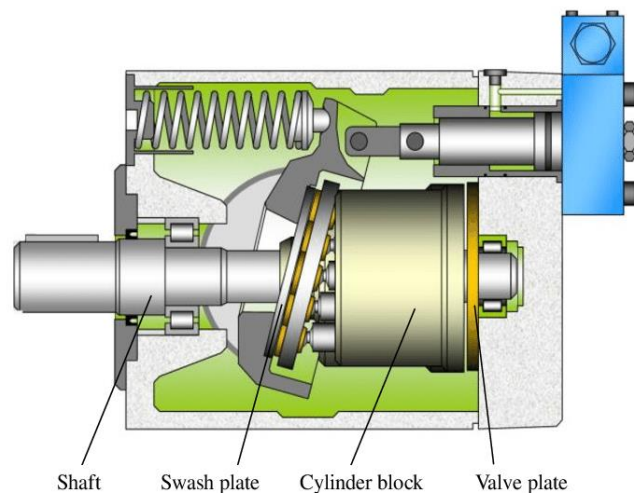
## 2- Positive Displacement Pumps

In this type, the volume of liquid delivered is directly related to the displacement of the piston and therefore, increases directly with speed and is not appreciably influenced by the pressure. It used for *high pressure and constant rates this type can be classified into: -*

### 2.1-Reciprocating Pumps, such as

#### a- The Piston Pump

This pump may be single-acting, with the liquid admitted only to the portion of the cylinder in front of the piston or double-acting, in which case the feed is admitted to both sides of the piston. The majority of pumps are of the single-acting type typically giving a low flow rate of say 0.02 m<sup>3</sup>/s at a high pressure of up to 100 Mpa.

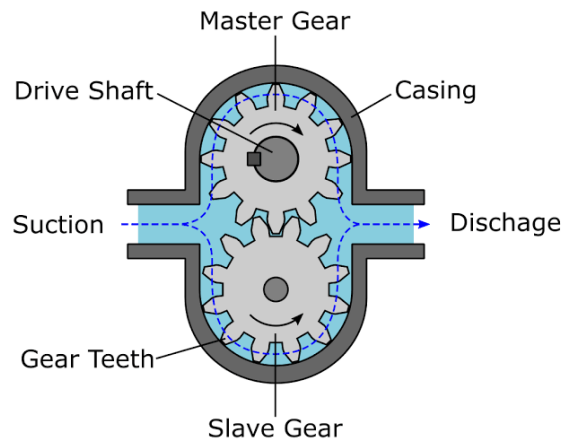


### 2.2-Rotary Pumps, such as

#### a- The Gear Pump

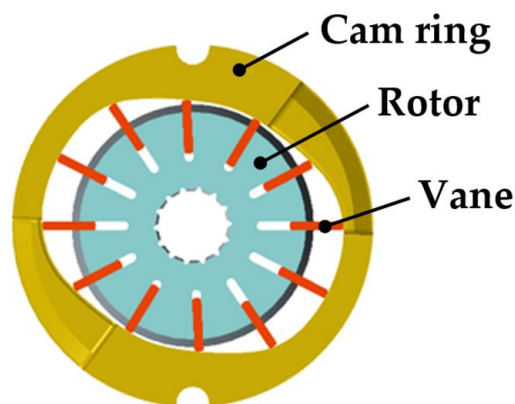
Gear and lobe pumps operate on the principle of using mechanical means to transfer small elements or "packages" of fluid from the low pressure (inlet) side to the high pressure (delivery) side. There is a wide range of designs available for achieving this end. The general characteristics of the pumps are

similar to those of reciprocating piston pumps, but the delivery is more even because the fluid stream is broken down into so much smaller elements. The pumps are capable of delivering to a high pressure, and the pumping rate is approximately proportional to the speed of the pump and is not greatly influenced by the pressure against which it is delivering. Again, it is necessary to provide a pressure relief system to ensure that the safe operating pressure is not exceeded.



### b- The Cam Pump

A rotating cam is mounted eccentrically in a cylindrical casing and a very small clearance is maintained between the outer edge of the cam and the casing. As the cam rotates it expels liquid from the space ahead of it and sucks in liquid behind it. The delivery and suction sides of the pump are separated by a sliding valve, which rides on the cam. The characteristics again are similar to those of the gear pump.

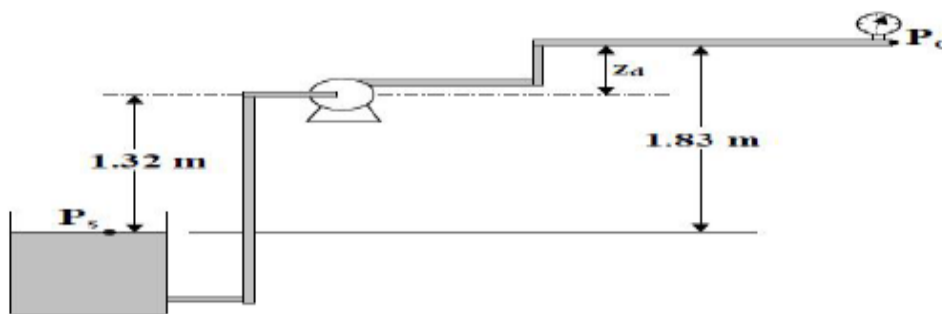


**Example -5.1-**

A petroleum product is pumped at a rate of  $2.525 \times 10^{-3} \text{ m}^3/\text{s}$  from a reservoir under atmospheric pressure to 1.83 m height. If the pump 1.32 m height from the reservoir, the discharge line diameter is 4 cm and the pressure drop along its length 3.45 kPa. The gauge pressure reading at the end of the discharge line 345 kPa. The pressure drop along suction line is 3.45 kPa and pump efficiency  $\eta=0.6$  calculate:-

- (i) The total head of the system  $\Delta h$ . (ii) The power required for pump. (iii) The NPSH

Take that: the density of this petroleum product  $\rho=879 \text{ kg/m}^3$ , the dynamic viscosity  $\mu=6.47 \times 10^{-4} \text{ Pa.s}$ , and the vapor pressure  $P_v=24.15 \text{ kPa}$ .



**Solution:**

(i)

$$\Delta h = (z_d - z_s) + \left( \frac{P_d - P_s}{\rho g} \right) + [(h_F)_d + (h_F)_s] + \frac{\Delta u^2}{2g \alpha}$$

$$u_s = 0$$

$$u_d = (2.525 \times 10^{-3} \text{ m}^3/\text{s}) / (\pi/4 \cdot 0.04^2) \\ = 2 \text{ m/s}$$

$$Re_d = (879 \times 2 \times 0.04) / 6.47 \times 10^{-4} \\ = 1.087 \times 10^5$$

The pressure drop in suction line 3.45kPa

$$\Rightarrow (h_F)_s = 3.45 \times 10^3 / (879 \times 9.81) \\ = 0.4 \text{ m}$$

And in discharge line is also 3.45 kPa  $\Rightarrow (hF)d = 0.4 \text{ m}$

The kinetic energy term =  $22/(2 \times 9.81) = 0.2 \text{ m}$

The pressure at discharge point = gauge + atmospheric pressure = 345 + 101.325

= 446.325 kPa

The difference in pressure head between discharge and suction points is  $(446.325 - 101.325) \times 10^3 / (879 \times 9.81) = 40 \text{ m}$

$\Delta z = 1.83 \text{ m}$

$\Rightarrow \Delta h = 40 \text{ m} + 1.83 \text{ m} + 0.2 \text{ m} + 0.4 \text{ m} + 0.4 \text{ m} = 42.83 \text{ m}$

**(ii)**

$$P = \frac{Q\Delta P}{\eta} = \frac{Q\Delta h \rho g}{\eta} = [(2.525 \times 10^3 \text{ m}^3/\text{s})(42.83 \text{ m})(879 \text{ kg/m}^3)(9.81 \text{ m/s}^2)]/0.6$$

$\Rightarrow P = 1.555 \text{ kW}$

**(iii)**

$$\begin{aligned} NPSH &= z_s + \left( \frac{P_s - P_v}{\rho g} \right) - (h_f)_s \\ &= (-1.32) + (1.01325 \times 10^5 - 24150) / (879 \times 9.81) - 0.4 \text{ m} \\ &= 7.23 \text{ m} \end{aligned}$$