# EQUIPMENT DESIGN

## LECTURE 7
## PUMPS & PIPING SYSTEMS - 2

**5.4. PUMPS**
**5.4.1. Pump selection**

The pumping of liquids is covered by Volume 1, Chapter 8. Reference should be made to that chapter for a discussion of the principles of pump design and illustrations of the more commonly used pumps.

Pumps can be classified into two general types:

1. Dynamic pumps, such as centrifugal pumps.
2. Positive displacement pumps, such as reciprocating and diaphragm pumps.

The single-stage, horizontal, overhung, centrifugal pump is by far the most commonly used type in the chemical process industry. Other types are used where a high head or other special process considerations are specified.

Pump selection is made on the flow rate and head required, together with other process considerations, such as corrosion or the presence of solids in the fluid.

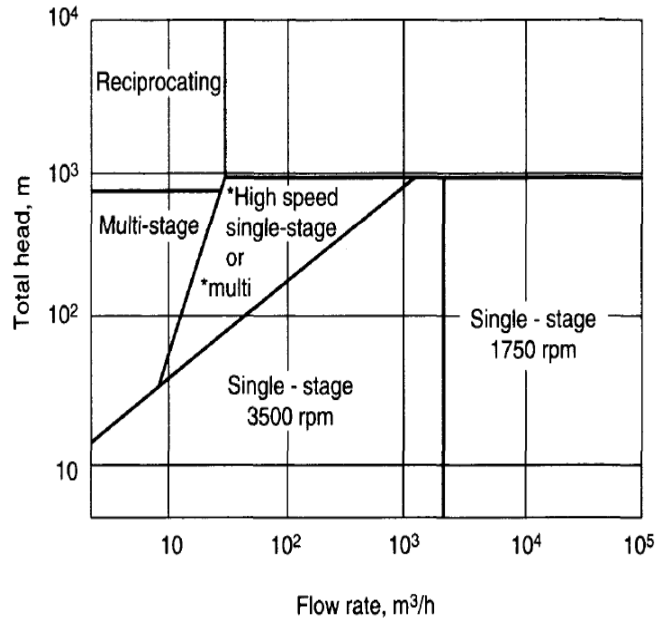


Figure 5.6. Centrifugal pump selection guide. *Single-stage >1750 rpm, multi-stage 1750 rpm

# Power requirements for pumping liquids

The total energy required can be calculated from the equation:

$$g\Delta z + \Delta P/\rho - \Delta P_f/\rho - W = 0 \quad (5.5)$$

where $W$ = work done, J/kg,
$\Delta z$ = difference in elevations $(z_1 - z_2)$, m,
$\Delta P$ = difference in system pressures $(P_1 - P_2)$, $N/m^2$,
$\Delta P_f$ = pressure drop due to friction, including miscellaneous losses, and equipment losses, (see section 5.4.2), $N/m^2$,
$\rho$ = liquid density, $kg/m^3$,
$g$ = acceleration due to gravity, $m/s^2$.

## Example 5.2

A tanker carrying toluene is unloaded, using the ship's pumps, to an on-shore storage tank. The pipeline is 225 mm internal diameter and 900 m long. Miscellaneous losses due to fittings, valves, etc., amount to 600 equivalent pipe diameters. The maximum liquid level in the storage tank is 30 m above the lowest level in the ship's tanks. The ship's tanks are nitrogen blanketed and maintained at a pressure of 1.05 bar. The storage tank has a floating roof, which exerts a pressure of 1.1 bar on the liquid.

The ship must unload 1000 tonne within 5 hours to avoid demurrage charges. Estimate the power required by the pump. Take the pump efficiency as 70 per cent.

Physical properties of toluene: density 874 kg/m$^3$, viscosity 0.62 mNm$^{-2}$ s.

## Solution

$$\text{Cross-sectional area of pipe} = \frac{\pi}{4}(225 \times 10^{-3})^2 = 0.0398 \text{ m}^2$$

$$\text{Minimum fluid velocity} = \frac{1000 \times 10^3}{5 \times 3600} \times \frac{1}{0.0398} \times \frac{1}{874} = 1.6 \text{ m/s}$$

$$\text{Reynolds number} = (874 \times 1.6 \times 225 \times 10^{-3})/0.62 \times 10^{-3}$$

$$= 507{,}484 = 5.1 \times 10^5 \quad (5.4)$$

Absolute roughness commercial steel pipe, Table 5.2 = 0.046 mm
Relative roughness = 0.046/225 = 0.0002
Friction factor from Figure 5.7, $f = 0.0019$
Total length of pipeline, including miscellaneous losses,

$$= 900 + 600 \times 225 \times 10^{-3} = 1035 \text{ m}$$

$$\text{Friction loss in pipeline, } \Delta P_f = 8 \times 0.0019 \times \left(\frac{1035}{225 \times 10^{-3}}\right) \times 874 \times \frac{1.6^2}{2}$$

$$= \underline{\underline{78{,}221}} \text{ N/m}^2 \quad (5.3)$$

Maximum difference in elevation, $(z_1 - z_2) = (0 - 30) = \underline{\underline{-30 \text{ m}}}$

Pressure difference, $(P_1 - P_2) = (1.05 - 1.1)10^5 = \underline{\underline{-5 \times 10^3}}$ N/m$^2$

Energy balance

$$9.8(-30) + (-5 \times 103)/874 - (78{,}221)/874 - W = 0 \quad (5.5)$$

$$W = \underline{\underline{-389.2}} \text{ J/kg,}$$

$$\text{Power} = (389.2 \times 55.56)/0.7 = 30{,}981 \text{ W}, \quad \text{say } \underline{\underline{31 \text{ kW}}}. \quad (5.6a)$$

# Characteristic curves for centrifugal pumps

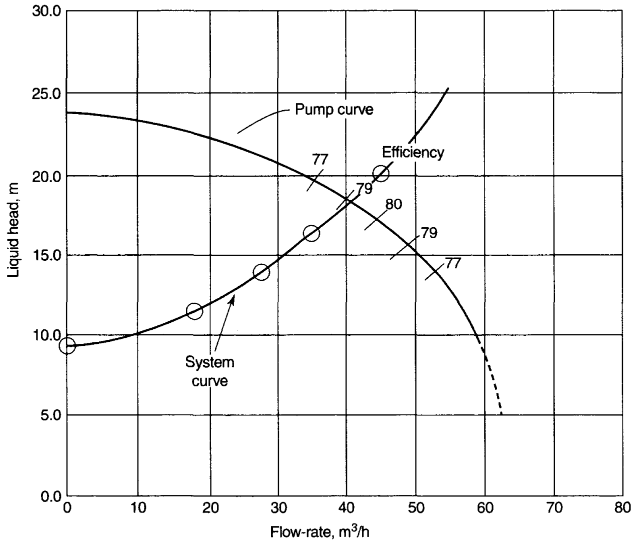


Figure A. Example 5.3

## Example 5.3

A process liquid is pumped from a storage tank to a distillation column, using a centrifugal pump. The pipeline is 80 mm internal diameter commercial steel pipe, 100 m long. Miscellaneous losses are equivalent to 600 pipe diameters. The storage tank operates at atmospheric pressure and the column at 1.7 bara. The lowest liquid level in the tank will be 1.5 m above the pump inlet, and the feed point to the column is 3 m above the pump inlet.

Plot the system curve on the pump characteristic given in Figure A and determine the operating point and pump efficiency.

Properties of the fluid: density 900 kg/m$^3$, viscosity 1.36 mN m$^{-2}$s.

## Solution

*Static head*

Difference in elevation, $\Delta z = 3.0 - 1.5 = 1.5$ m

Difference in pressure, $\Delta P = (1.7 - 1.013)10^5 = 0.7 \times 10^5$ N/m$^2$

as head of liquid $= (0.7 \times 10^5)/(900 \times 9.8) = 7.9$ m

Total static ead $= 1.5 + 7.9 = \underline{\underline{9.4 \text{ m}}}$

*Dynamic head*

As an initial value, take the fluid velocity as 1 m/s, a reasonable value.

$$\text{Cross-sectional area of pipe} = \frac{\pi}{4}(80 \times 10^{-3})^2 = 5.03 \times 10^{-3}\ \text{m}^2$$

$$\text{Volumetric flow-rate} = 1 \times 5.03 \times 10^{-3} \times 3600 = 18.1\ \text{m}^3/\text{h}$$

$$\text{Reynolds number} = \frac{900 \times 1 \times 80 \times 10^{-3}}{1.36 \times 10^{-3}} = 5.3 \times 10^4 \qquad (5.4)$$

$$\text{Relative roughness} = 0.46/80 = 0.0006$$

Friction factor from Figure 5.7, $f = 0.0027$

Length including miscellaneous loses $= 100 + (600 \times 80 \times 10^3) = 148$ m

$$\text{Pressure drop, } \Delta P_f = 8 \times 0.0027 \frac{(148)}{(80 \times 10^{-3})} \times 900 \times \frac{1^2}{2} = \underline{\underline{17{,}982\ \text{N/m}^2}}$$

$$= 17{,}982/(900 \times 9.8) = \underline{\underline{2.03}}\ \text{m liquid} \qquad (5.3)$$

Total head $= 9.4 + 2.03 = \underline{\underline{11.4\ \text{m}}}$

To find the system curve the calculations were repeated for the velocities shown in the table below:

| velocity m/s | flow-rate $m^3/h$ | static head m | dynamic head m | total head m |
|---|---|---|---|---|
| 1 | 18.1 | 9.4 | 2.0 | 11.4 |
| 1.5 | 27.2 | 9.4 | 4.3 | 14.0 |
| 2.0 | 36.2 | 9.4 | 6.8 | 16.2 |
| 2.5 | 45.3 | 9.4 | 10.7 | 20.1 |
| 3.0 | 54.3 | 9.4 | 15.2 | 24.6 |

Plotting these values on the pump characteristic gives the operating point as 18.5 m at 40.0 $m^3/h$ and the pump efficiency as 79 per cent.

# Characteristic curves for centrifugal pumps

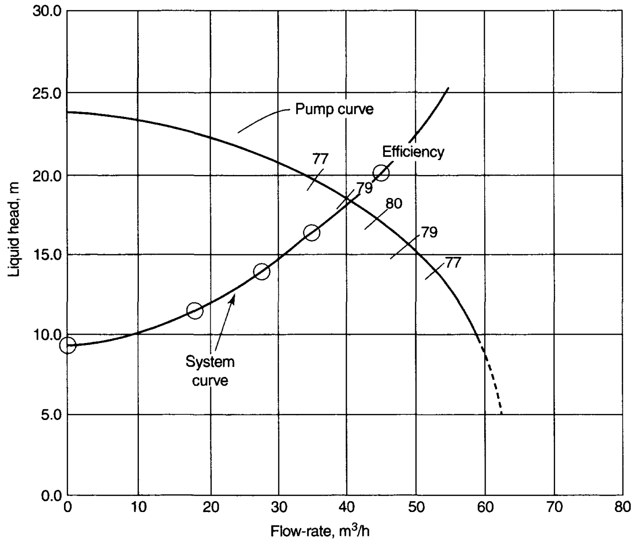


Figure A. Example 5.3