$$H_2/H_1 = (n_2 D_2/n_1 D_1)^2 \tag{3.17}$$

$$\dot{P}_2/\dot{P}_1 = (\rho_2/\rho_1)(n_2/n_1)^3(D_2/D_1)^5 \tag{3.18}$$

Centrifugal pumps are characterized by their specific speed. In the dimensionless form, specific speed is given by Equation 3.19:

$$N_s = NQ^{0.5}/(gh)^{0.75} \tag{3.19}$$

Pump manufacturers do not generally use the dimensionless specific speed, but define the impeller specific speed by the equation:

$$\dot{N}_s = NQ^{0.5}/(gh)^{0.75} \tag{3.20}$$

where $\dot{N}_s$ is rotational speed per minute, Q is the flow, US gal/min, h is the head, in ft.

Example

(H.W) A Tanker carrying toluene is unloaded, using the ships pump, to an onshore storage tank, The pipeline is 225 mm internal diameter and 900 m long. Miscellaneous loss 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 tank. The ships tanks are nitrogen blanketed and maintained at pressure 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 metric tons within 5 hours to avoid demurrage charges. Estimate the power required by the pump. Take the pump efficiency 70%.

Physical properties of toluene: density 874 kg/m^3, viscosity 0.62 mN·m^2

Extra information: Absolute roughness commercial steel pipes=0.046mm, friction factor f=0.0019

Solution:

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

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

Absolute roughness commercial steal pipes = 0.046 mm

Relative roughness= 0.046/225=0.0002

Friction factor f =0.0019

Total length of pipeline, including miscellaneous losses =900+600 $\times$ 225$\times 10^{-3}$

Friction loss in pipeline:

$$\Delta P_f = 8f(L/d_i)\frac{\rho u^2}{2}) = 78221\, N/m^2$$

Maximum difference in elevation = z_1-z_2

=0-30 =-30m

Pressure difference =1.05-1.1

=-5$\times$ $10^{-3}\, N/m^2$

Energy balance:

9.8$\times$ -30+(-5$\times$103)/874-78221/874-W=0

W=-389.2 J/kg

Power=389.2$\times$55.56/0.7=30981

W=31kW

3.3 Mechanical design of piping systems

3.3.1 Piping system design codes

Most of the codes that are used for pressure piping are those set by the ASME B31 committee. Different standards are used for different purposes. Oil refinery and most chemical plant are designed according to the ASME B31.3.

The ASME code can be apply to piping for raw, refrigerants, and cryogenic fluids. Table 3.2 shows different codes for different services.

Table 3.2: ASME pipe codes

Code No.	Scope	Latest revision
B31.1	Power piping	2007
B31.2	Fuel gas piping	1968
B31.3	Process piping	2008
B31.4	Pipeline transportation systems for liquid hydrocarbons and other liquids	2006
B31.5	Refrigeration piping and heat transfer components	2006
B31.8	Gas transmission and distribution piping system	2007
B31.9	Building services piping	2008
B31.11	Slurry transportation piping system	2002
B31.12	Hydrogen piping and pipelines	2008

3.3.2 Wall thickness: Pipe Schedule

Pipe wall thickness is selected to resist the internal pressure, with allowances for corrosion, and other mechanical allowances for pipe threads.

Process pipes can be considered as thin cylinders. The ASME B31.3 code gives the following formula for pipe thickness:

$$t_m = t_P + c \tag{3.21}$$

$$t_P = \frac{Pd}{2(SE + P\gamma_T)} \tag{3.22}$$

where t_m minimum required thickness, t_P is the pressure design thickness, c is the sum of mechanical allowances (thread depth) plus corrosion and erosion allowances, P is the internal design gauge pressure (N/mm^2), d is the pipe outside diameter, S is the basic allowable stress for pipe material given in the Appendix A of the code B31.1 (N/mm^2), E is the casting quality factor, and γ_T is the temperature coefficient.

The pipe are specified by Schedule number (Based on thin cylinder formula), which is estimated as follows:

$$\text{Schedule number} = \frac{P_s \times 1000}{\sigma_s} \tag{3.23}$$

where P_s is the safe working pressure (N/mm^2), and σ_s is the safe working stress (N/mm^2)

Schedule 40 is commonly used for general purpose application at low pressure (below 50 bar).

(Note: High pressure pipes such as High pressure steam lines are likely considered as thick cylinders and must be special consideration)

Example

(H.W) Estimate the safe working pressure for a 4 in(100 mm)dia, Schedule 40 pipe, SA53 carbon steel welded, working temperature 100 ^{o}C. The maximum allowable stress for butt welded steel pipe up to 120 ^{o}C is 11700 lb/in^2 (79.6 N/mm^2) ?

Solution:

$$P_s = \frac{schduleno. \times \sigma_s}{1000} = \frac{40 \times 11700}{1000} = 468\,\mathrm{lb}\cdot\mathrm{in}^{-2} = 3180\,\mathrm{kN}\cdot\mathrm{m}^{-2} \tag{3.24}$$

3.3.3 Economic pipe diameter

The capital cost of a pipe run increases with the diameter. The rule used for economic pipe diameter in metric units is given by:

$$d_{optimum} = 3.2(m/\rho)^{0.5} \tag{3.25}$$

where m is the mass flow rate (kg/s), ρ is the density (kg/m^3), d_i is the inside pipe diameter (m).

The cost equations can be developed by considering a 1 meter length of pipe. The purchase cost will be roughly proportional to the diameter raised to some power:

$$\text{Purchase cost} = Bd^n\$/m \tag{3.26}$$

where the value of the constant B and index n depend on the pipe material and schedule.

The optimum diameter for turbulent flow after complex derivation can be estimated according to the following equations:

For carbon steel pipe:

a- Diameter 25 to 200 mm:

$$d_{i,optimum} = 0.664\, m^{0.51}\rho^{-0.36} \tag{3.27}$$

b- Diameter 250 to 600 mm:

$$d_{i,optimum} = 0.534\, m^{0.43} \rho^{-0.30} \tag{3.28}$$

For stainless steel pipe:

a- Diameter 25 to 200 mm:

$$d_{i,optimum} = 0.550\, m^{0.49} \rho^{-0.35} \tag{3.29}$$

b- Diameter 250 to 600 mm:

$$d_{i,optimum} = 0.465\, m^{0.43} \rho^{-0.31} \tag{3.30}$$

Example

Estimate the pipe diameter for a water flow rate of 10 kg·s^{-1}, at 20 ^oC. Carbon steel pipe will be used. Density of water is 1000 kg·m^3.

Solution

Example

Estimate the optimum pipe diameter for a flow of HCl of 7000 kg/h at 5bar, 15 ^oC, stainless steel. Molar volume is 22.4 m^3·kmol, at 1 bar, 0 ^oC.

Solution