# EQUIPMENT DESIGN

## LECTURE 6

## PUMPS & PIPING SYSTEMS -1

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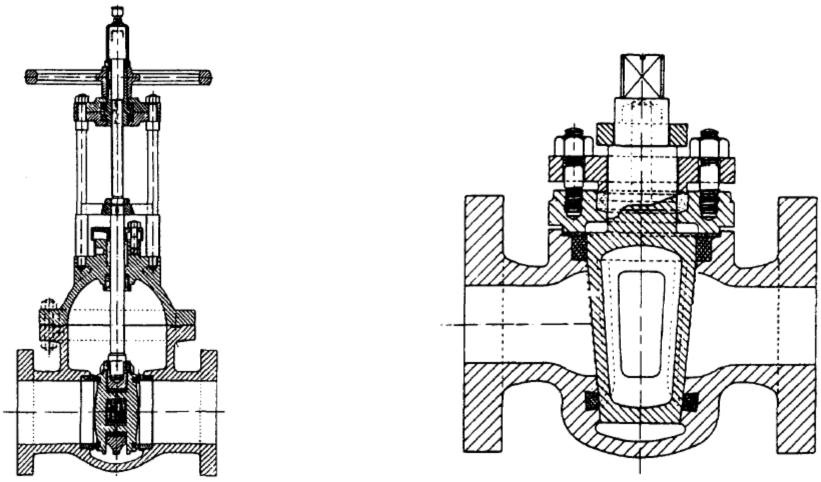
## VALVE SELECTION

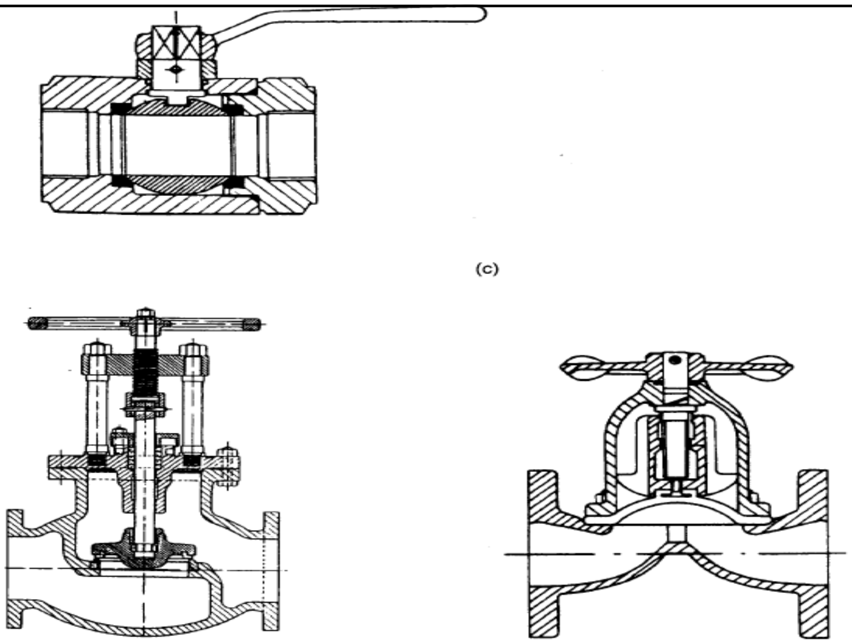
The valves used for chemical process plant can be divided into two broad classes, depending on their primary function:

1. Shut-off valves (block valves), whose purpose is to close off the flow.
2. Control valves, both manual and automatic, used to regulate flow.



(a) (b)

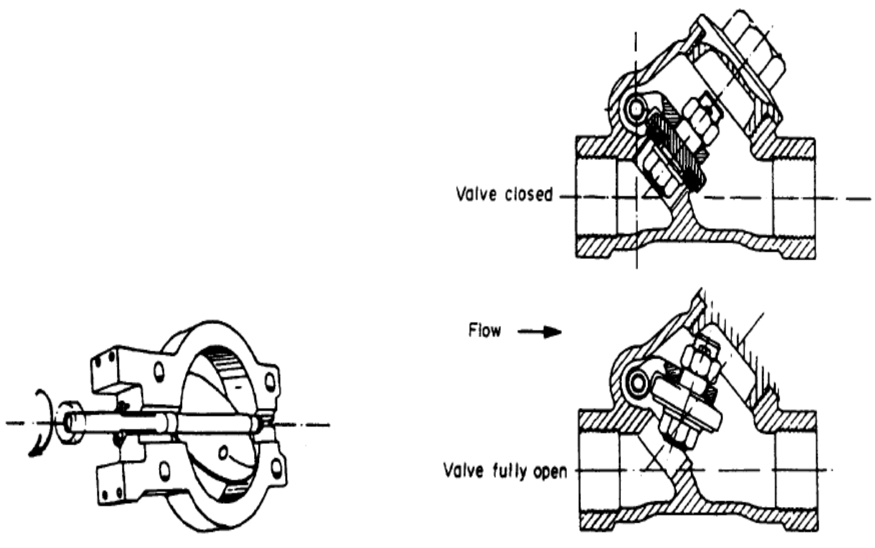
Figure 5.5. (*a*) Gate valve (slide valve) (*b*) Plug valve



(c)

(d) (e)

Figure 5.5. (*c*) Ball valve (*d*) Globe valve (*e*) Diaphragm valve



(f) (g)

Figure 5.5. (*f*) Butterfly valve (*g*) Non-return valve, check valve, hinged disc type

# PIPE SIZE SELECTION

Typical pipe velocities and allowable pressure drops, which can be used to estimate pipe sizes, are given below:

| | Velocity m/s | $\Delta P$ kPa/m |
|---|---|---|
| Liquids, pumped (not viscous) | 1–3 | 0.5 |
| Liquids, gravity flow | — | 0.05 |
| Gases and vapours | 15–30 | 0.02 per cent of line pressure |
| High-pressure steam, >8 bar | 30–60 | — |

Rase (1953) gives expressions for design velocities in terms of the pipe diameter. His expressions, converted to SI units, are:

| | |
|---|---|
| Pump discharge | $0.06d + 0.4$ m/s |
| Pump suction | $0.02d + 0.1$ m/s |
| Steam or vapour | $0.2d$ m/s |

## Economic pipe diameter
## Optimum pipe diameter

Carbon steel pipe:

$$d, \text{optimum} = 293\ G^{0.53} \rho^{-0.37} \qquad (5.14)$$

Stainless steel pipe:

$$d, \text{optimum} = 260\ G^{0.52} \rho^{-0.37} \qquad (5.15)$$

## Pipe Wall thickness: pipe schedule

The British Standard 5500 gives the following formula for pipe thickness:

$$t = \frac{Pd}{20\sigma_d + P} \qquad (5.8)$$

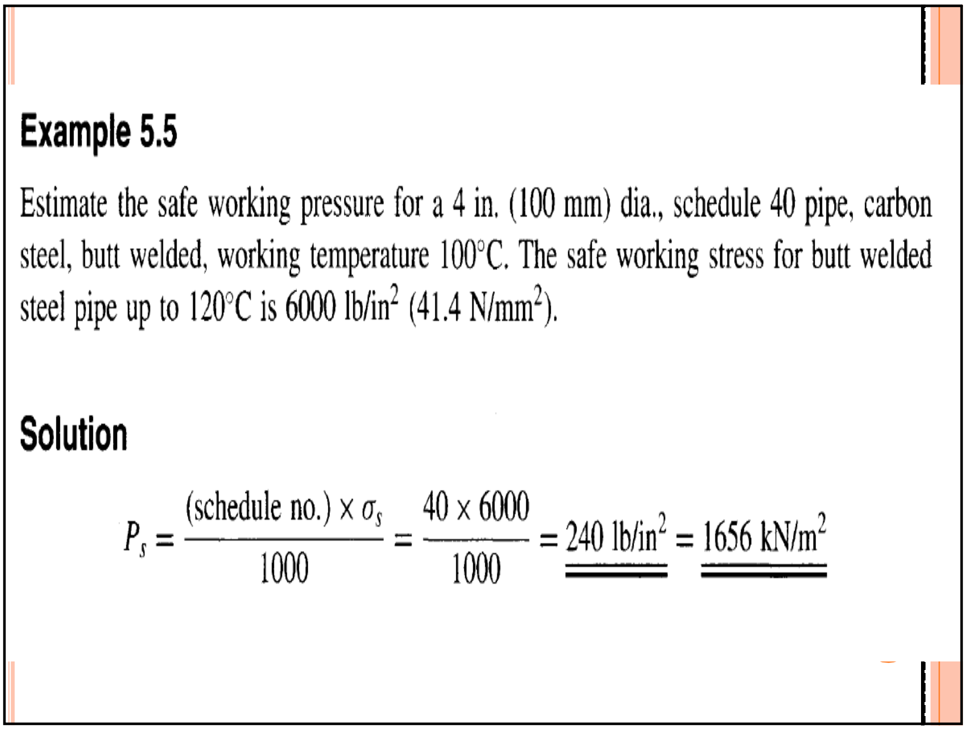
where $P$ = internal pressure, bar,
$d$ = pipe od, mm,
$\sigma_d$ = design stress at working temperature, N/mm$^2$.

Pipes are often specified by a schedule number (based on the thin cylinder formula). The schedule number is defined by:

$$\text{Schedule number} = \frac{P_s \times 1000}{\sigma_s} \qquad (5.9)$$

$P_s$ = safe working pressure, lb/in$^2$ (or N/mm$^2$),
$\sigma_s$ = safe working stress, lb/in$^2$ (or N/mm$^2$).

Schedule 40 pipe is commonly used for general purposes.

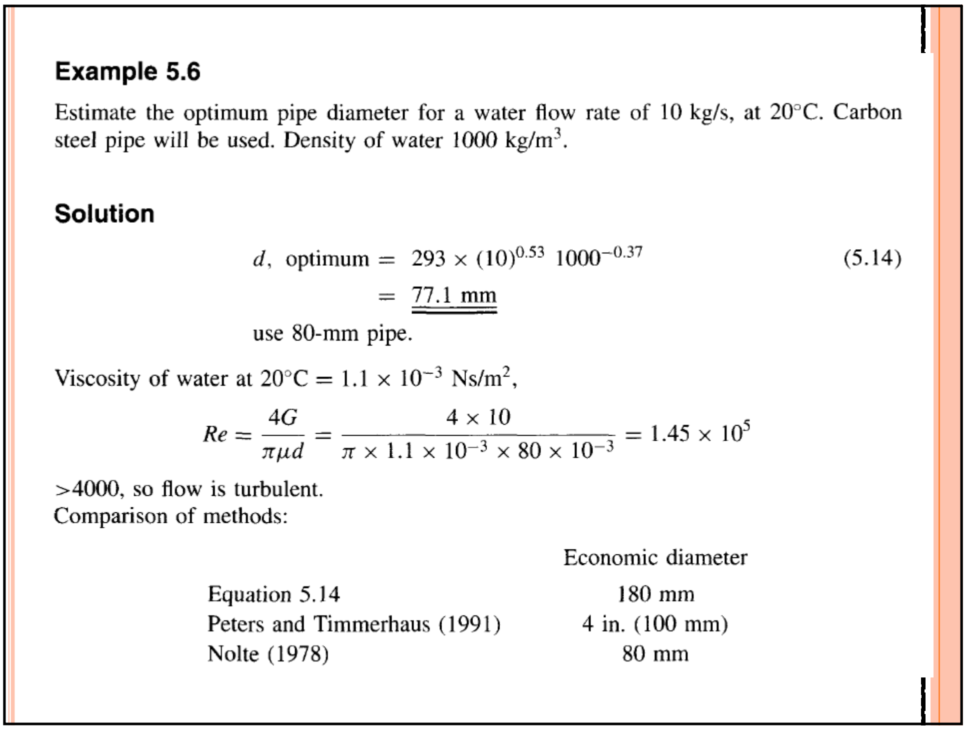


## Example 5.5

Estimate the safe working pressure for a 4 in. (100 mm) dia., schedule 40 pipe, carbon steel, butt welded, working temperature 100°C. The safe working stress for butt welded steel pipe up to 120°C is 6000 lb/in$^2$ (41.4 N/mm$^2$).

## Solution

$$P_s = \frac{(\text{schedule no.}) \times \sigma_s}{1000} = \frac{40 \times 6000}{1000} = \underline{\underline{240\ \text{lb/in}^2}} = \underline{\underline{1656\ \text{kN/m}^2}}$$



## Example 5.6

Estimate the optimum pipe diameter for a water flow rate of 10 kg/s, at 20°C. Carbon steel pipe will be used. Density of water 1000 kg/m$^3$.

## Solution

$$d,\ \text{optimum} = 293 \times (10)^{0.53}\ 1000^{-0.37} \qquad (5.14)$$

$$= \underline{\underline{77.1\ \text{mm}}}$$

use 80-mm pipe.

Viscosity of water at 20°C $= 1.1 \times 10^{-3}$ Ns/m$^2$,

$$Re = \frac{4G}{\pi \mu d} = \frac{4 \times 10}{\pi \times 1.1 \times 10^{-3} \times 80 \times 10^{-3}} = 1.45 \times 10^5$$

$>4000$, so flow is turbulent.
Comparison of methods:

| | Economic diameter |
|---|---|
| Equation 5.14 | 180 mm |
| Peters and Timmerhaus (1991) | 4 in. (100 mm) |
| Nolte (1978) | 80 mm |

## Example 5.7

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

### Solution

Molecular weight HCl = 36.5.

$$\text{Density at operating conditions} = \frac{36.5}{22.4} \times \frac{5}{1} \times \frac{273}{288} = \underline{\underline{7.72\ \text{kg/m}^3}}$$

$$\text{Optimum diameter} = 260\left(\frac{7000}{3600}\right)^{0.52} 7.72^{-0.37} \qquad (5.15)$$

$$= \underline{\underline{172.4\ \text{mm}}}$$

use 180-mm pipe.
Viscosity of HCl 0.013 m $Ns/m^2$

$$Re = \frac{4}{\pi} \times \frac{7000}{3600} \times \frac{1}{0.013 \times 10^{-3} \times 180 \times 10^{-3}} = \underline{\underline{1.06 \times 10^6}}, \text{ turbulent}$$

Comparison of methods:

| | Economic diameter |
|---|---|
| Equation 5.15 | 180 mm |
| Peters and Timmerhaus (1991) | 9 in. (220 mm) carbon steel |
| Nolte (1978) | 7 in. (180 mm) carbon steel |

## Pressure drop in pipelines

$$\Delta P_f = 8f(L/d_i)\frac{\rho u^2}{2} \qquad (5.3)$$

where $\Delta P_f$ = pressure drop, $N/m^2$,
$f$ = friction factor,
$L$ = pipe length, m,
$d_i$ = pipe inside diameter, m,
$\rho$ = fluid density, $kg/m^3$,
$u$ = fluid velocity, m/s.

## Table 5.2. Pipe roughness

| Material | Absolute roughness, mm |
|---|---|
| Drawn tubing | 0.0015 |
| Commercial steel pipe | 0.046 |
| Cast iron pipe | 0.26 |
| Concrete pipe | 0.3 to 3.0 |

Table 5.3. Pressure loss in pipe fittings and valves (for turbulent flow)

| Fitting or valve | $K$, number of velocity heads | number of equivalent pipe diameters |
|---|---|---|
| 45° standard elbow | 0.35 | 15 |
| 45° long radius elbow | 0.2 | 10 |
| 90° standard radius elbow | 0.6–0.8 | 30–40 |
| 90° standard long elbow | 0.45 | 23 |
| 90° square elbow | 1.5 | 75 |
| Tee-entry from leg | 1.2 | 60 |
| Tee-entry into leg | 1.8 | 90 |
| Union and coupling | 0.04 | 2 |
| Sharp reduction (tank outlet) | 0.5 | 25 |
| Sudden expansion (tank inlet) | 1.0 | 50 |
| Gate valve | | |
| fully open | 0.15 | 7.5 |
| 1/4 open | 16 | 800 |
| 1/2 open | 4 | 200 |
| 3/4 open | 1 | 40 |
| Globe valve, bevel seat- | | |
| fully open | 6 | 300 |
| 1/2 open | 8.5 | 450 |
| Plug valve - open | 0.4 | 18 |

**Example 5.1**

A pipeline connecting two tanks contains four standard elbows, a plug valve that is fully open and a gate valve that is half open. The line is commercial steel pipe, 25 mm internal diameter, length 120 m.

The properties of the fluid are: viscosity 0.99 $\text{mNM}^{-2}$ s, density 998 $\text{kg/m}^3$.

Calculate the total pressure drop due to friction when the flow rate is 3500 kg/h.

**Solution**

$$\text{Cross-sectional area of pipe} = \frac{\pi}{4}(25 \times 10^{-3})^2 = 0.491 \times 10^{-3}\text{m}^2$$

$$\text{Fluid velocity, } u = \frac{3500}{3600} \times \frac{1}{0.491 \times 10^{-3}} \times \frac{1}{998} = 1.98 \text{ m/s}$$

$$\text{Reynolds number, } Re = (998 \times 1.98 \times 25 \times 10^{-3})/0.99 \times 10^{-3}$$

$$= 49{,}900 = 5 \times 10^4 \qquad (5.4)$$

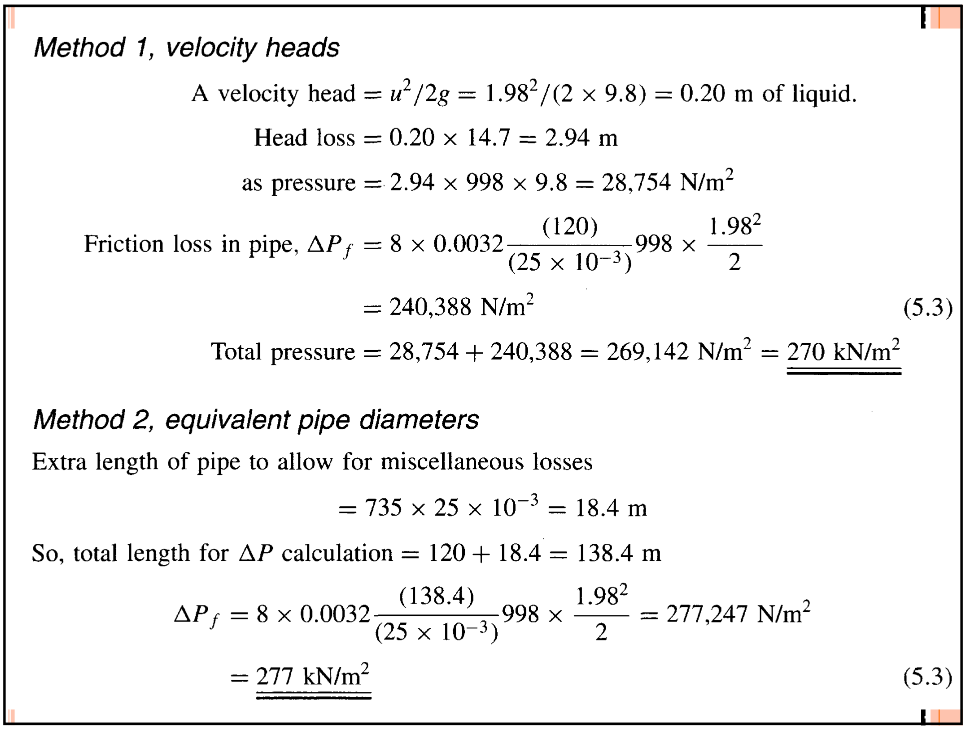
Absolute roughness commercial steel pipe, Table 5.2 = 0.046 mm

Relative roughness = $0.046/(25 \times 10^{-3}) = 0.0018$, round to 0.002

From friction factor chart, Figure 5.7, $f = 0.0032$

*Miscellaneous losses*

| fitting/valve | number of velocity heads, $K$ | equivalent pipe diameters |
|---|---|---|
| entry | 0.5 | 25 |
| elbows | (0.8 x 4) | (40 x 4) |
| globe valve, open | 6.0 | 300 |
| gate valve, 1/2 open | 4.0 | 200 |
| exit | 1.0 | 50 |
| Total | 14.7 | 735 |



*Method 1, velocity heads*

$$\text{A velocity head} = u^2/2g = 1.98^2/(2 \times 9.8) = 0.20 \text{ m of liquid.}$$

$$\text{Head loss} = 0.20 \times 14.7 = 2.94 \text{ m}$$

$$\text{as pressure} = 2.94 \times 998 \times 9.8 = 28{,}754 \text{ N/m}^2$$

$$\text{Friction loss in pipe, } \Delta P_f = 8 \times 0.0032 \frac{(120)}{(25 \times 10^{-3})} 998 \times \frac{1.98^2}{2}$$

$$= 240{,}388 \text{ N/m}^2 \qquad (5.3)$$

$$\text{Total pressure} = 28{,}754 + 240{,}388 = 269{,}142 \text{ N/m}^2 = \underline{\underline{270 \text{ kN/m}^2}}$$

*Method 2, equivalent pipe diameters*

Extra length of pipe to allow for miscellaneous losses

$$= 735 \times 25 \times 10^{-3} = 18.4 \text{ m}$$

So, total length for $\Delta P$ calculation $= 120 + 18.4 = 138.4$ m

$$\Delta P_f = 8 \times 0.0032 \frac{(138.4)}{(25 \times 10^{-3})} 998 \times \frac{1.98^2}{2} = 277{,}247 \text{ N/m}^2$$

$$= \underline{\underline{277 \text{ kN/m}^2}} \qquad (5.3)$$