# CH402 Chemical Engineering Process Design

## Class Notes L2

### Piping Design

# Piping Design

Piping can range from 15 to 70% of the total delivered equipment cost.

This does not include instrumentation (control valves, sensors, actuators, IT.)

# Piping Design Equations

## Mechanical Energy Balance – 1st Law

Determines energy for pumping fluid through pipe network.
BLUF - very important – energy has cost ($/kWh).

**incompressible:**

Eq. 12-12, page 492

1st Law, steady state, one entrance, one exit, constant T

$$W_o = \underbrace{g\Delta z}_{\text{potential energy change}} + \underbrace{\Delta\left(\frac{V^2}{2\alpha}\right)}_{\text{kinetic energy change}} + \underbrace{\Delta(pv)}_{\text{external pressure change}} + \underbrace{\sum F}_{\text{frictional losses inside piping}}$$

new term not used in CH365

$$g = 9.8\frac{m}{s^2}$$

Correction factor:
α = 1.0 (turbulent)
α = 0.5 (viscous)

specific volume, m³/kg

$$\Delta(pv) = \frac{p_2 - p_1}{\rho}$$

equivalent length (straight pipe + fittings)

$$F = \frac{2fV^2L_{eq}}{D}$$

$f = f(R_n)$
(slide 4)

$$R_n = \frac{DV\rho}{\mu}$$

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$$\Delta h = R \cdot \int_{T_1}^{T_2} \left(C_{P_{298}}^{ig} / R\right) dT$$

**compressible:**

Eq. 12-13, page 493
(example 12-2)

not shown in eq 12-13

$$W + Q = g\Delta Z + \Delta h + \Delta\left(\frac{V^2}{2\alpha}\right) + \sum F$$

Best handled in CHEMCAD

# Friction Factors – Straight Pipe

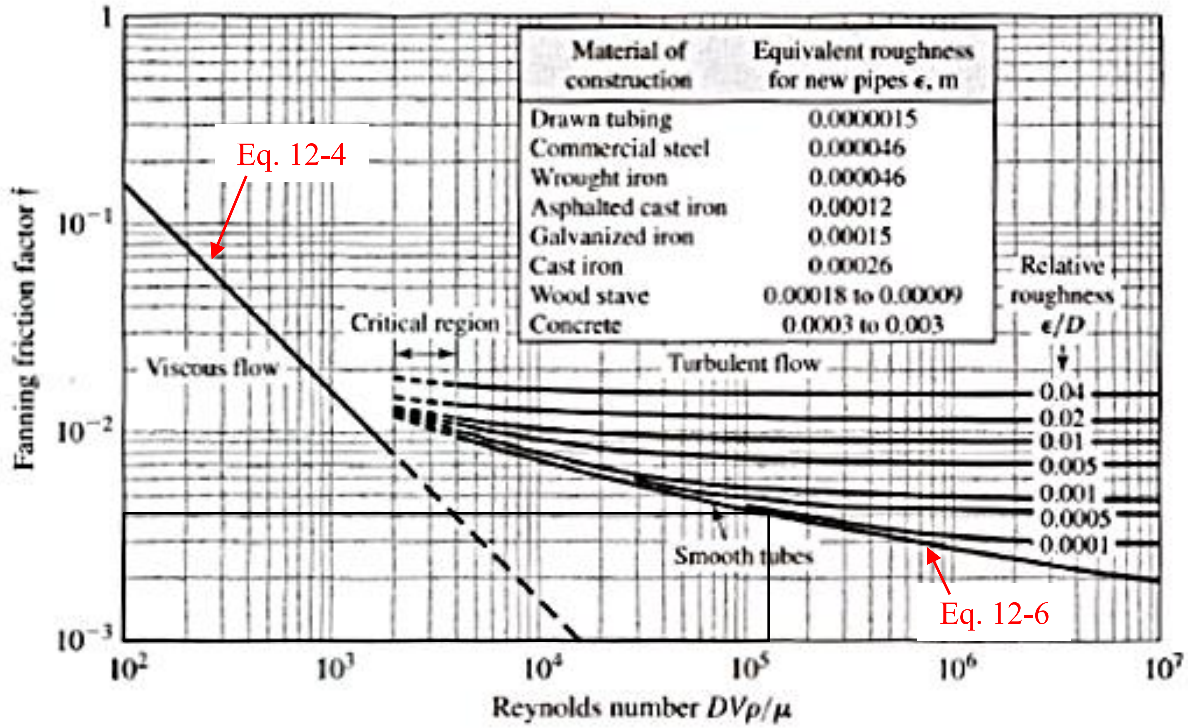



**Figure 12-1**
Fanning friction factors for long, straight pipes. [Based on L. F. Moody, *Trans. ASME.* 66: 671–684 (1944).]

$$R_n = \frac{DV\rho}{\mu}$$

Eq. 12-3b, page 486

Re ≤ 2100

$$f = \frac{16}{Re}$$

Eq. 12-4, page 487

4000 < Re < 100,000

$$f = \frac{.079}{Re^{0.25}}$$

Eq. 12-5, page 487

Re > 4,000

$$\frac{1}{f^{1/2}} = -4\log\left[\frac{\varepsilon}{3.7D} + \frac{1.256}{(Re)(f)^{1/2}}\right]$$

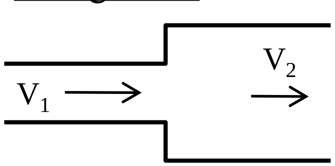
Eq. 12-6, page 487

# Frictional Losses in Fittings

Table 12-1 on page 490 is more comprehensive

| $F = \dfrac{2fV^2\left(L_{straight} + L_e\right)}{D}$ | $L_e/D$ per fitting (dimensionless) |
|---|---|
| 45-degree elbows | 15 |
| 90-degree elbows, std. radius | 32 |
| 90-degree elbows, med. Radius | 26 |
| 90-degree elbows, long radius | 20 |
| 90-degree elbows, square | 60 |
| 180-degree close-return bend | 75 |
| 180-degree medium-radius return bend | 50 |
| Tee, used as elbow, entering run | 60 |
| Tee, used as elbow, entering branch | 90 |
| couplings | 0 |
| unions | 0 |
| gate valves, open | 7 |
| globe valves, open | 300 |

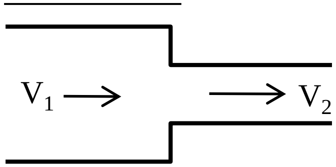
enlargement




$$F_{expansion} = \frac{(V_1 - V_2)^2}{2\alpha}$$

$\alpha$=1.0 for turbulent flow
$\alpha$=0.5 for laminar flow

constriction




$$F_{constriction} = \frac{K_C V_2^{\,2}}{2\alpha}$$

$$for \quad A_2 / A_1 < 0.715, \quad K_c = 0.4(1.25 - A_2 / A_1)$$

$$for \quad A_2 / A_1 > 0.715, \quad K_c = 0.75(1.00 - A_2 / A_1)$$

for conical and rounded shapes, $K_c$=0.05

# Cost of Piping

http://www.mhhe.com/engcs/chemical/peters/data/ce.html

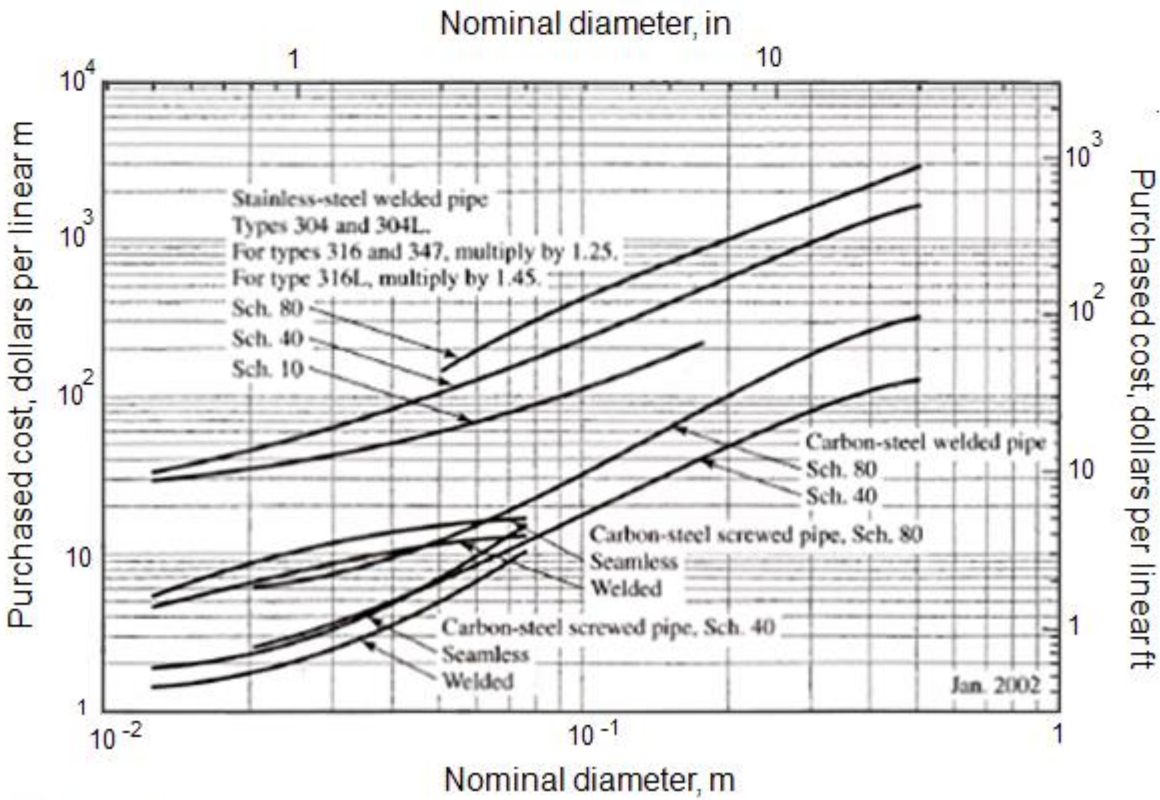



**Figure 12-4**
Purchased cost of pipe per unit length

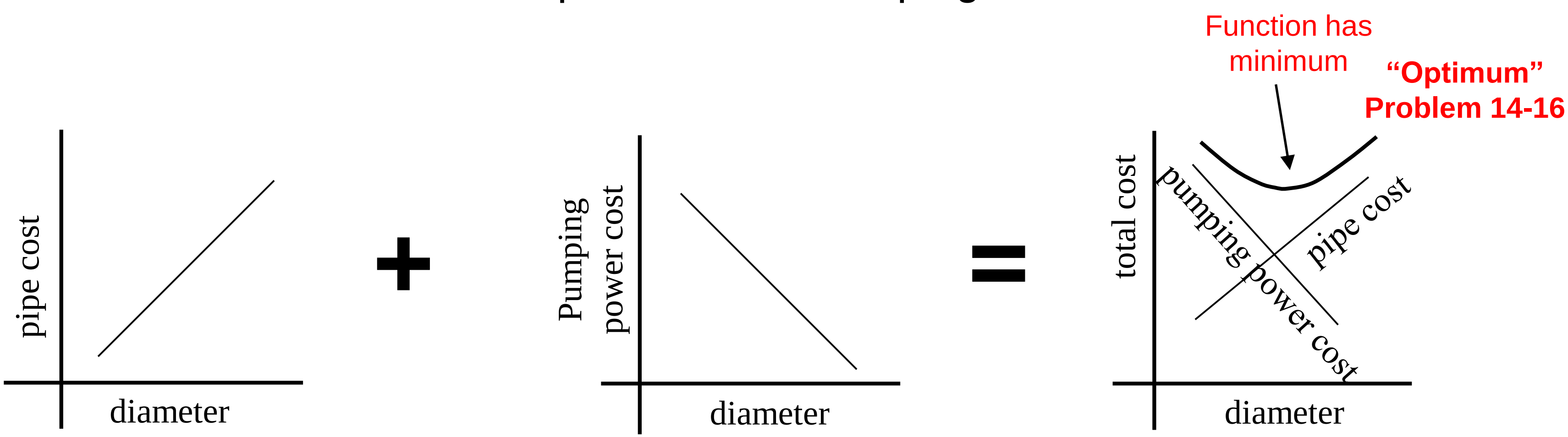
**Factors for Determining Cost:**
- Length
- Diameter and thickness
- Material of construction
- Mounting and support hardware
- Insulation and paint

Additional Charts and Data:

| | | |
|---|---|---|
| Pipes | pp 503-504 | (figs. 12-4 to 12-6) |
| Valves | pp 505-507 | (figs. 12-7 to 12-11) |
| Insulation, paint | p 507 | (fig 12-12) |
| Additional Fittings | See Link to Pipe Fitting Prices – 1979 Edition | |

# How to Find the Pipe Diameter

Combination of Pipe Cost and Pumping Power Cost




## Chapter 12: Eqns. 12-15,16 page 501

(abbreviated)

$$D_{i,opt} = 0.363\dot{m}_v^{0.45}\rho^{0.13}$$

Re > 2100 and $D_i \geq 0.0254$m

$$D_{i,opt} = 1.33\dot{m}_v^{0.40}\mu^{0.20}$$

Re < 2100 and $D_i \leq 0.0254$m

book has .133 (typo)

$\dot{m}_v$ = volumetric flowrate, $\frac{m^3}{s}$

$\mu$ = viscosity, $Pa \cdot s$

## Chapter 9: Eqns. 9-76 to 9-79 page 404

(complete set of equations)

$$D_{i,opt} = 0.363\dot{m}_v^{0.45}\rho^{0.13}\mu^{0.025}$$

Re > 2100 and $D_i \geq 0.0254$m

$$D_{i,opt} = 0.49\dot{m}_v^{0.49}\rho^{0.14}\mu^{0.027}$$

Re > 2100 and $D_i < 0.0254$m

$$D_{i,opt} = 0.863\dot{m}_v^{0.36}\mu^{0.18}$$

Re < 2100 and $D_i \geq 0.0254$m

$$D_{i,opt} = 1.33\dot{m}_v^{0.40}\mu^{0.20}$$

Re < 2100 and $D_i < 0.0254$m

(To learn more, there is an excellent tutorial hyperlinked to figure, or copy and paste this link into your browser: https://hardhatengineer.com/pipe-class-piping-specifications-pipeend/pipe-schedule-chart-nominal-pipe-sizes/ )

**Table D-13 Steel pipe dimensions†**

| Nominal pipe size, in. | OD, in. | Schedule no. | ID, in. | Flow area per pipe, in.$^2$ | Surface per linear ft, ft$^2$ Outside | Surface per linear ft, ft$^2$ Inside | Weight per lin ft, lb steel |
|---|---|---|---|---|---|---|---|
| 1/8 | 0.405 | 40§ | 0.269 | 0.058 | 0.106 | 0.070 | 0.25 |
| | | 80‡ | 0.215 | 0.036 | 0.106 | 0.056 | 0.32 |
| 1/4 | 0.540 | 40 | 0.364 | 0.104 | 0.141 | 0.095 | 0.43 |
| | | 80 | 0.302 | 0.072 | 0.141 | 0.079 | 0.54 |
| 3/8 | 0.675 | 40 | 0.493 | 0.192 | 0.177 | 0.129 | 0.57 |
| | | 80 | 0.423 | 0.141 | 0.177 | 0.111 | 0.74 |
| 1/2 | 0.840 | 40 | 0.622 | 0.304 | 0.220 | 0.163 | 0.85 |
| | | 80 | 0.546 | 0.235 | 0.220 | 0.143 | 1.09 |
| 3/4 | 1.05 | 40 | 0.824 | 0.534 | 0.275 | 0.216 | 1.13 |
| | | 80 | 0.742 | 0.432 | 0.275 | 0.194 | 1.48 |
| 1 | 1.32 | 40 | 1.049 | 0.864 | 0.344 | 0.274 | 1.68 |
| | | 80 | 0.957 | 0.718 | 0.344 | 0.250 | 2.17 |
| 1 1/4 | 1.66 | 40 | 1.380 | 1.50 | 0.435 | 0.362 | 2.28 |
| | | 80 | 1.278 | 1.28 | 0.435 | 0.335 | 3.00 |
| 1 1/2 | 1.90 | 40 | 1.610 | 2.04 | 0.498 | 0.422 | 2.72 |
| | | 80 | 1.500 | 1.76 | 0.498 | 0.393 | 3.64 |
| 2 | 2.38 | 40 | 2.067 | 3.35 | 0.622 | 0.542 | 3.66 |
| | | 80 | 1.939 | 2.95 | 0.622 | 0.508 | 5.03 |
| 2 1/2 | 2.88 | 40 | 2.469 | 4.79 | 0.753 | 0.627 | 5.80 |
| | | 80 | 2.323 | 4.23 | 0.753 | 0.609 | 7.67 |
| 3 | 3.50 | 40 | 3.068 | 7.38 | 0.917 | 0.804 | 7.58 |
| | | 80 | 2.900 | 6.61 | 0.917 | 0.760 | 10.3 |
| 4 | 4.50 | 40 | 4.026 | 12.7 | 1.178 | 1.055 | 10.8 |
| | | 80 | 3.826 | 11.5 | 1.178 | 1.002 | 15.0 |
| 6 | 6.625 | 40 | 6.065 | 28.9 | 1.734 | 1.590 | 19.0 |
| | | 80 | 5.761 | 26.1 | 1.734 | 1.510 | 28.6 |
| 8 | 8.625 | 40 | 7.981 | 50.0 | 2.258 | 2.090 | 28.6 |
| | | 80 | 7.625 | 45.7 | 2.258 | 2.000 | 43.4 |
| 10 | 10.75 | 40 | 10.02 | 78.8 | 2.814 | 2.62 | 40.5 |
| | | 60 | 9.75 | 74.6 | 2.814 | 2.55 | 54.8 |
| 12 | 12.75 | 30 | 12.09 | 115 | 3.338 | 3.17 | 43.8 |
| 16 | 16.0 | 30 | 15.25 | 183 | 4.189 | 4.00 | 62.6 |
| 20 | 20.0 | 20 | 19.25 | 291 | 5.236 | 5.05 | 78.6 |
| 24 | 24.0 | 20 | 23.25 | 425 | 6.283 | 6.09 | 94.7 |

†The data provided in this table are in the USCS units used by the pipe manufacturers in the United States.
§Schedule 40 designates former "standard" pipe.
‡Schedule 80 designates former "extra-strong" pipe.

# Pipe Schedule No.

Eqs. 12-14 and 12-14a page 499

$$schedule = \frac{1000 P_s}{S_s}$$

$$P_s = \frac{2 S_s t_m}{D_m}$$

$P_s$ = safe working pressure, kPa

$S_s$ = safe working stress, kPa

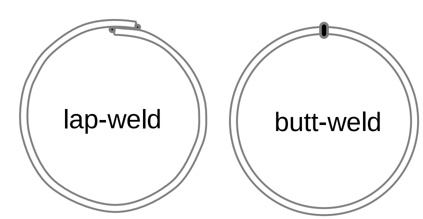
$S_s$ = 49,000 kPa for butt-welded steel

$S_s$ = 62,000 kPa for lap-welded steel

Stresses are in Table 12-10 page 555

$t_m$ = wall thickness

$D_m$ = mean diameter, m



# Homework

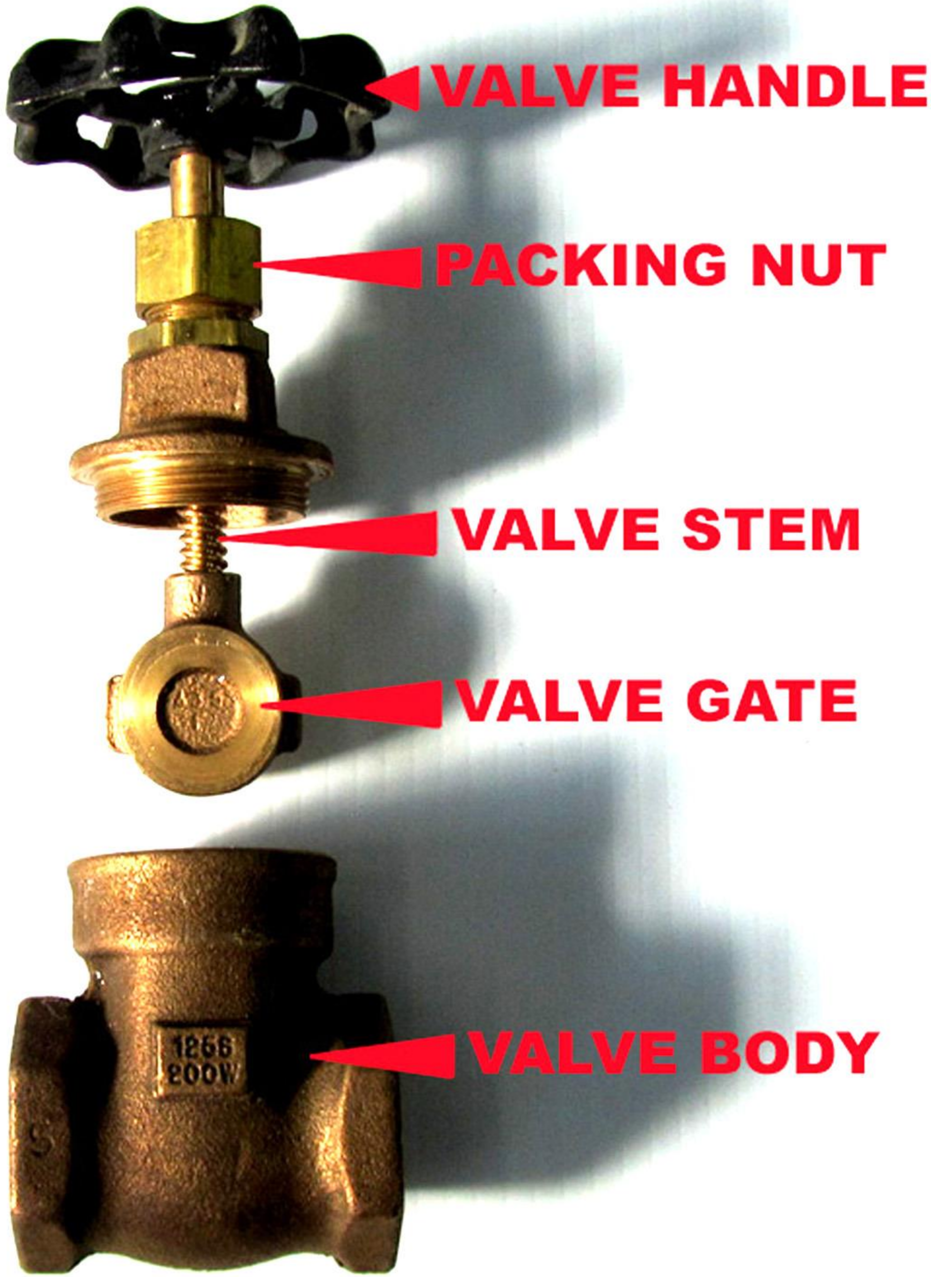
# Problem 12-1

Estimate the size of the motor necessary to pump a lean oil to the top of an absorption tower operating at a pressure of 445 kPa. The oil is to be pumped from an open tank with a liquid level 3 m above the floor through 46 m of pipe with an inside diameter of 0.078 m. There are five 90° elbows in the line, and the top of the tower is 9.1 m above the floor level. A flow of 2.7 kg/s of lean oil is required. The viscosity of the oil is 15 cP, and its density is 857 $kg/m^3$. Assume that the efficiency of the pumping system including the motor is 40%.

# Problem 12-2

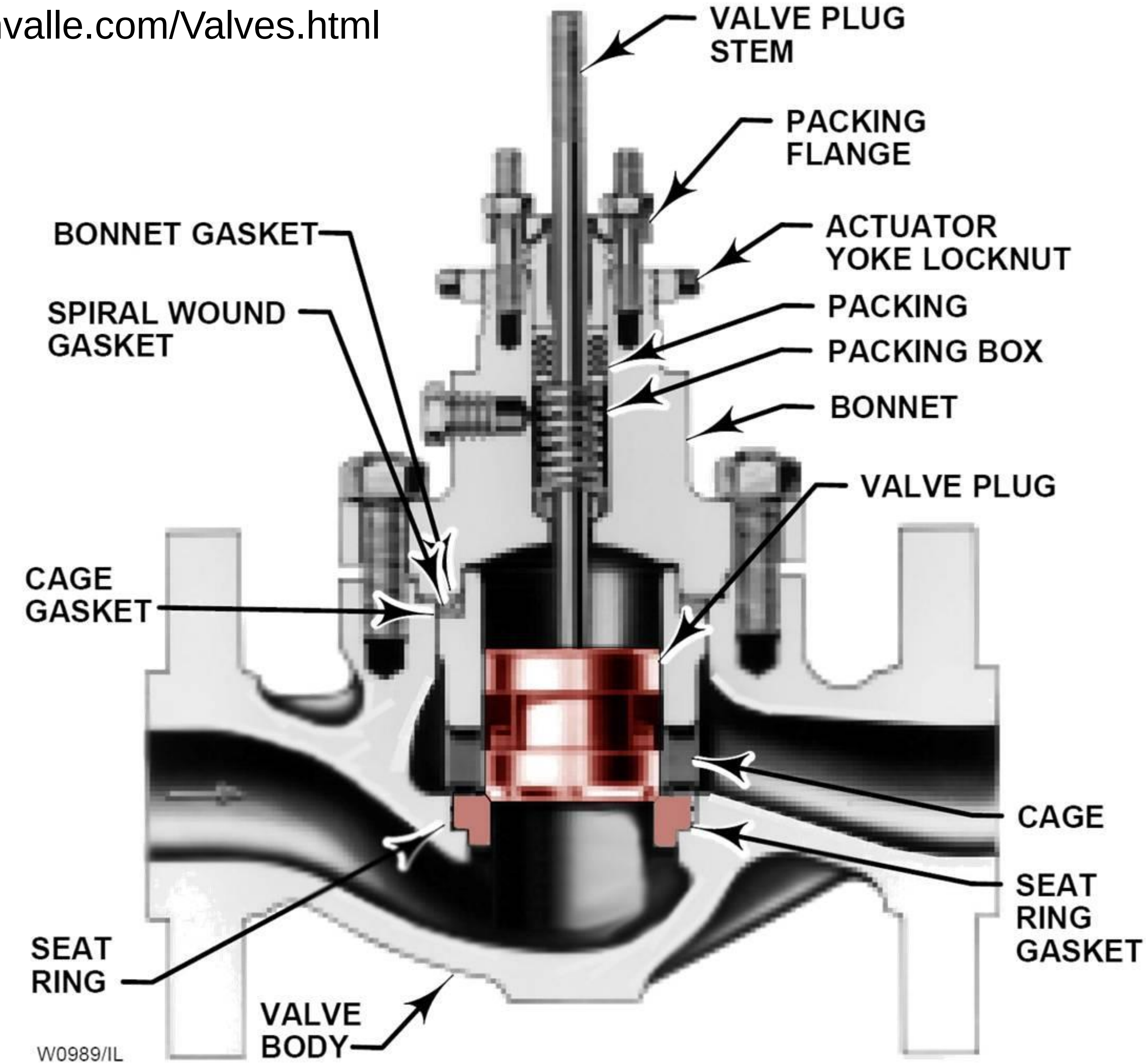
What is the pressure loss when 2.14 kg/s of pure benzene at 40°C flows through a 21-m length of straight pipe with an inside diameter of .0409 m? The pipeline contains six 90° elbows, one tee used as an elbow (equivalent resistance equal to 60 pipe diameters), one globe valve, and one gate valve. The density of the benzene is 849 $kg/m^3$., and the viscosity at 40°C is $5x10^{-4}$ Pa·s Assume that the efficiency of the pumping system including the motor is 40%.

# Supplemental Slides

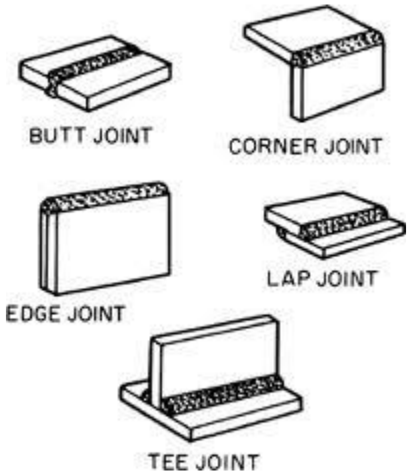



http://www.balkanplumbing.com/water-valve-replacement-repair-guide/

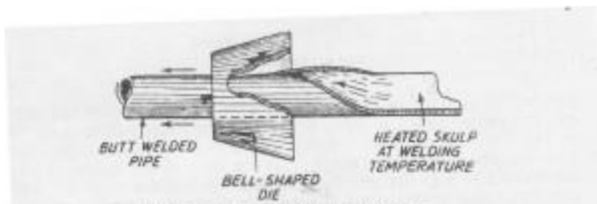
http://benvalle.com/Valves.html



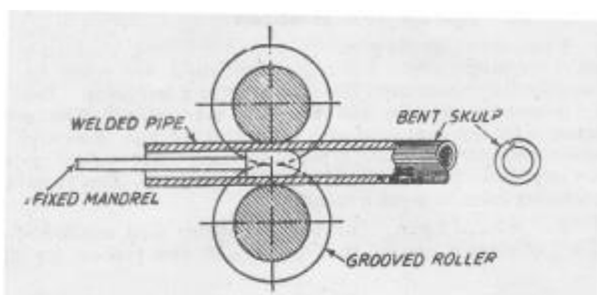

PUSH-DOWN-TO-CLOSE VALVE BODY ASSEMBLY




http://encyclopedia2.thefreedictionary.com/Welded+Joint




Production of pipe using bell shaped die.
Fig. 5·6.




Lap welding of pipes
Fig. 5·8.

http://www.mechlook.com/pipe-production/

U.S. Department of Transportation | Pipeline & Hazardous Materials Safety Administration