

CH402 Chemical Engineering Process Design

Class Notes L2

Piping Design, Part 2

BONUS OP

Chemical Engineering Plebe Open House

18 JAN 2023 1245 to ~1400

Bartlett Hall Room 150¹

30 minutes = 5 points²

Max 1.5 hours (15 points)

Notes:

1. If we are moved to a different location, we will still be somewhere near 150.
2. Sign in and out on the provided roster with time in and time out. Interact with prospective cadets. Stay active. Try not to congregate in friend clusters.

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 of Thermodynamics

Determines energy for pumping fluid through pipe network.

BLUF - very important – energy has cost (\$/kWh).

(Derived in CH365 L7, Chapter 2 of Smith, van Ness, Abbott, & Swihart, page 50, at steady state, with $\Delta U=0$ and $Q=0$)

incompressible:

Eq. 12-12, page 492

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

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

$g = 9.8 \frac{m}{s^2}$ Correction factor: $\alpha = 1.0$ (turbulent) $\alpha = 0.5$ (viscous) $\Delta(pv) = \frac{p_2 - p_1}{\rho}$ ρ = specific volume, m³/kg

new term not used in CH365

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

f = friction factor

$f = f(R_n)$
(slide 12)

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

equivalent length
(straight pipe + fittings)

compressible:

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

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

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

not shown in eq 12-13

Best handled in CHEMCAD

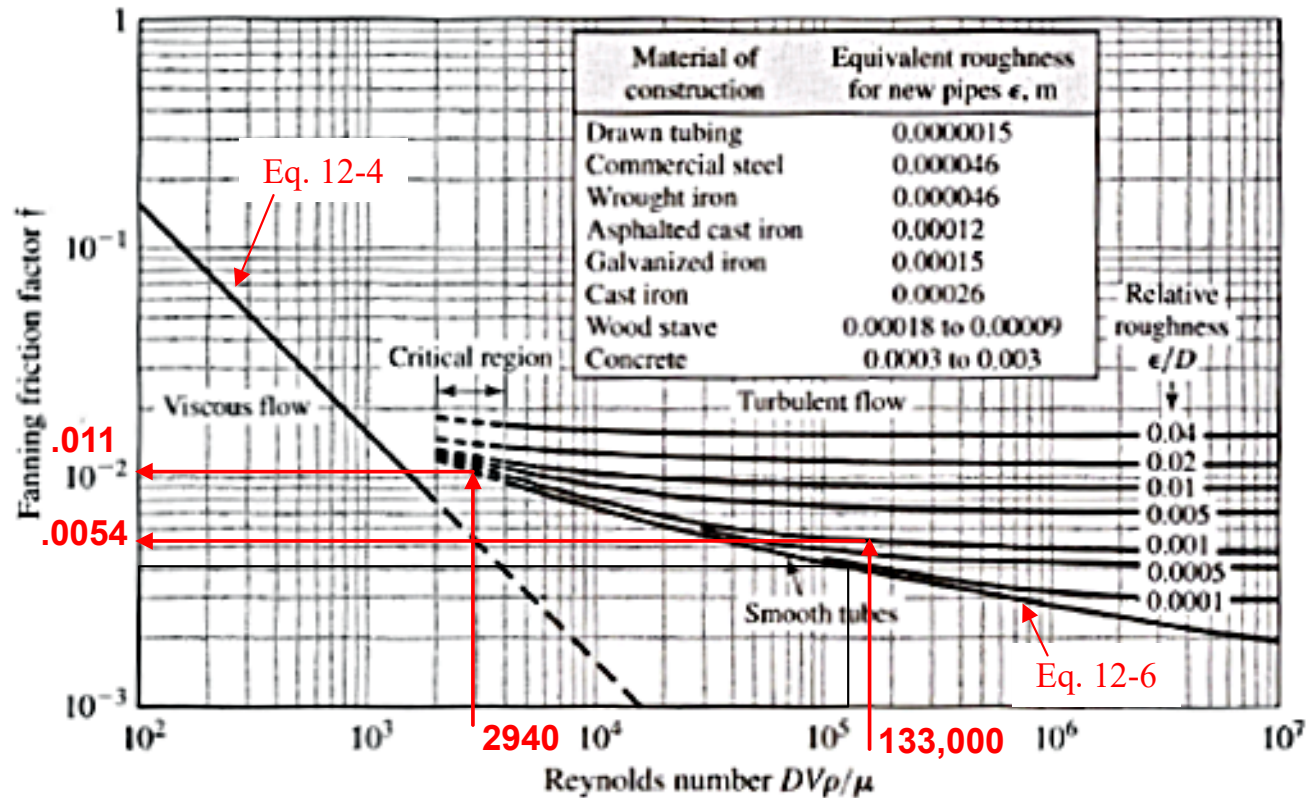
Friction Factors – Straight Pipe

Example 1:
Determine f for
commercial
“carbon” steel
when Reynolds
number is 2940.

$$f=0.011$$

Example 2:
Determine f for
commercial
“carbon” steel
when Reynolds
number is
133,000 and
 $d=0.0409$ m.

$$f=0.0055$$



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

Eq. 12-3b,
page 486

$$\begin{aligned}\epsilon &= .000046 \text{ m} \\ d &= 0.0409 \text{ m} \\ \epsilon/d &= .0011\end{aligned}$$

Figure 12-1

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

$$Re \leq 2100$$

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

Eq. 12-4,
page 487

$$4000 < Re < 100,000$$

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

Eq. 12-5,
page 487

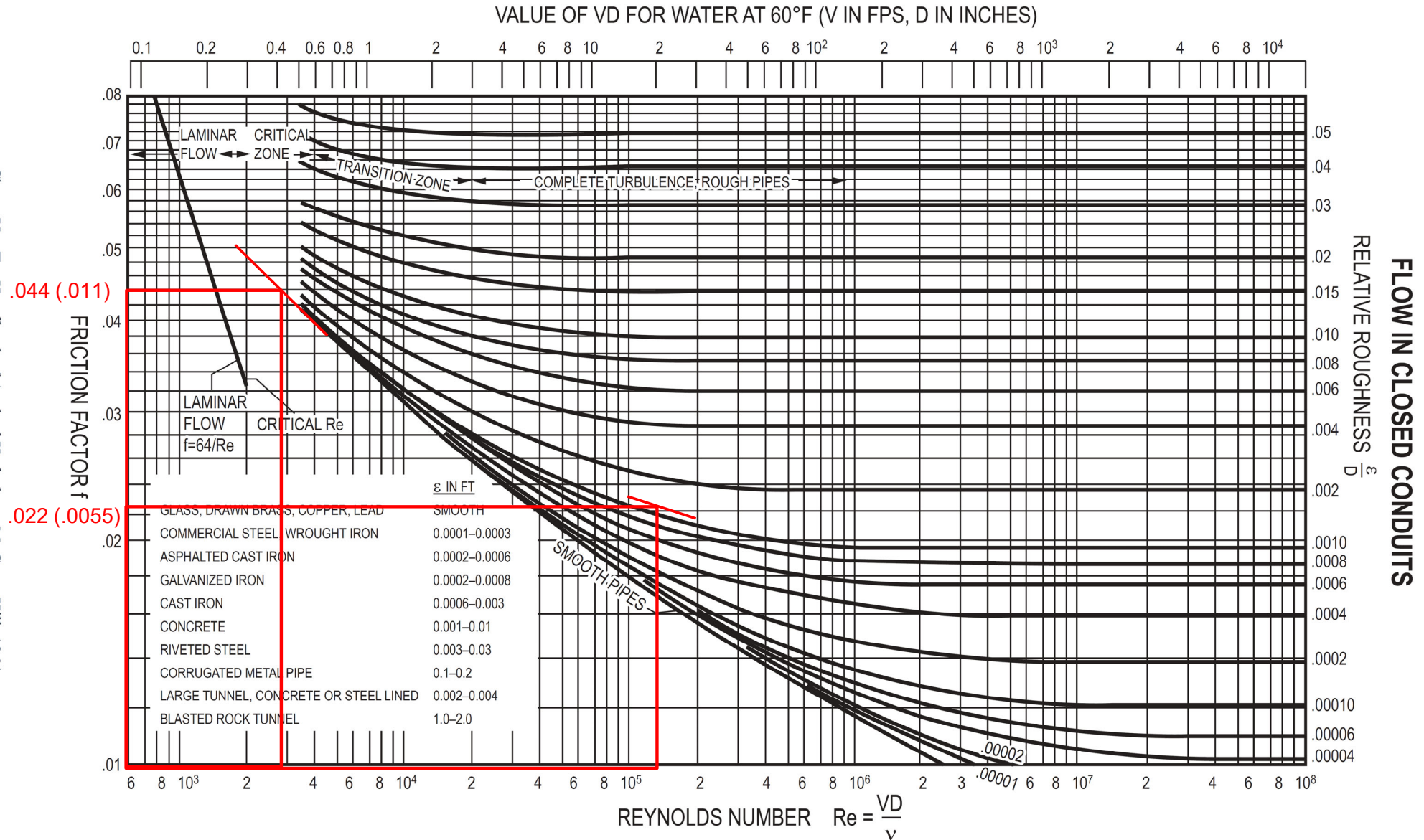
$$Re > 4,000$$

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

Eq. 12-6,
page 487

Using Moody plot from FE reference manual, page 201

Chow, Ven Te, Handbook of Applied Hydrology, McGraw-Hill, 1964.



Head Loss Due to Flow

The Darcy-Weisbach equation is

$$h_f = f \frac{L}{D} \frac{v^2}{2g}$$

page 183
(pdf page 189/502)

PTW equation 12-7: $F = \frac{2fV^2L_{eq}}{D}$

Frictional Losses in Fittings

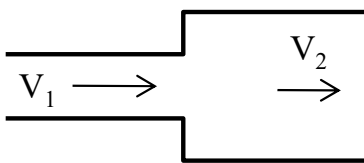
Table 12-1 on page 490 is more comprehensive

$F = \frac{2fV^2(L_{\text{straight}} + L_e)}{D}$	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

Example:
Determine the
equivalent length of
5 90-degree elbows
when the diameter
is 0.078 m

$5 \times 32 \times 0.078 \text{ m} =$
12.48 m of pipe

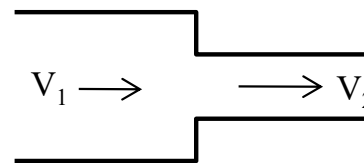
enlargement



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

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

constriction



$$F_{\text{constriction}} = \frac{K_c V_2^2}{2\alpha}$$

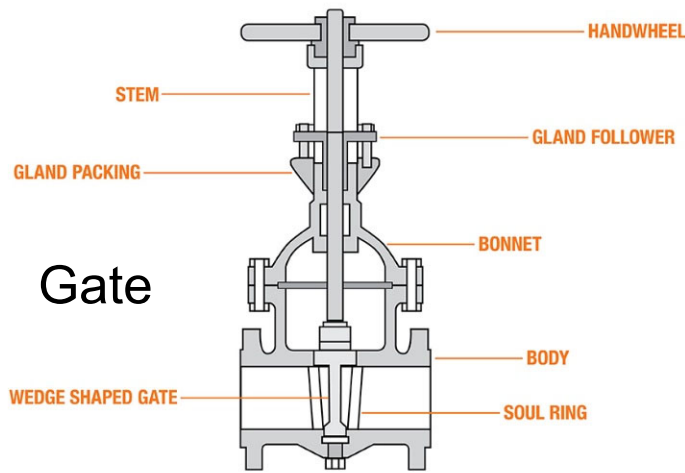
for $A_2 / A_1 < 0.715$, $K_c = 0.4(1.25 - A_2 / A_1)$

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

for conical and rounded shapes, $K_c=0.05$

units are
 m^2/s^2

Gate Valves and Globe Valves



Gate

<https://www.homedepot.com>

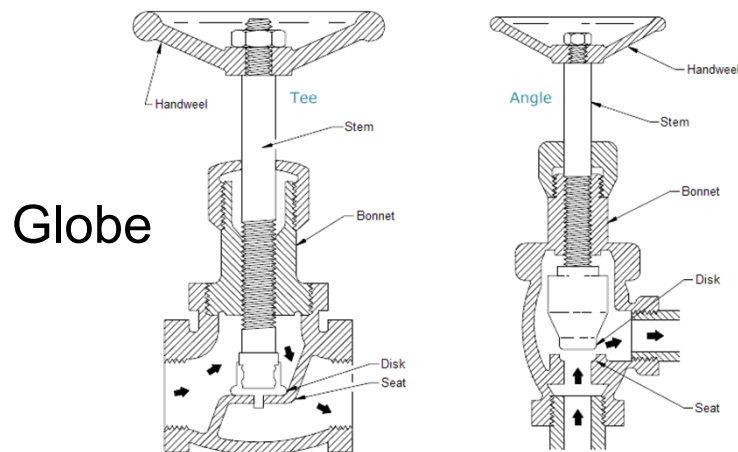


<https://www.homedepot.com>



<https://www.irrigationking.com>

Gate valves can be used for starting and stopping flow, but they cannot regulate flow because a partial flow can damage the gate and introduce vibrations.



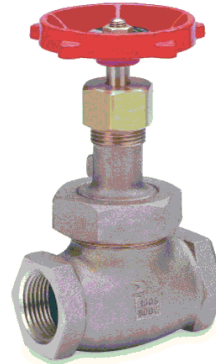
Globe

<https://www.wermac.org>

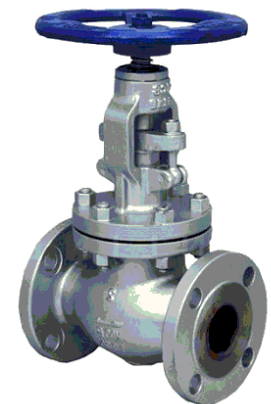
Fig. 12-7 (1/2-inch, 2070 kPa):

$$\$31 \cdot \frac{1278.7}{555.8} = \$71.32$$

Grainger: \$81.50
(10 Jan 2024)



<https://www.grainger.com>



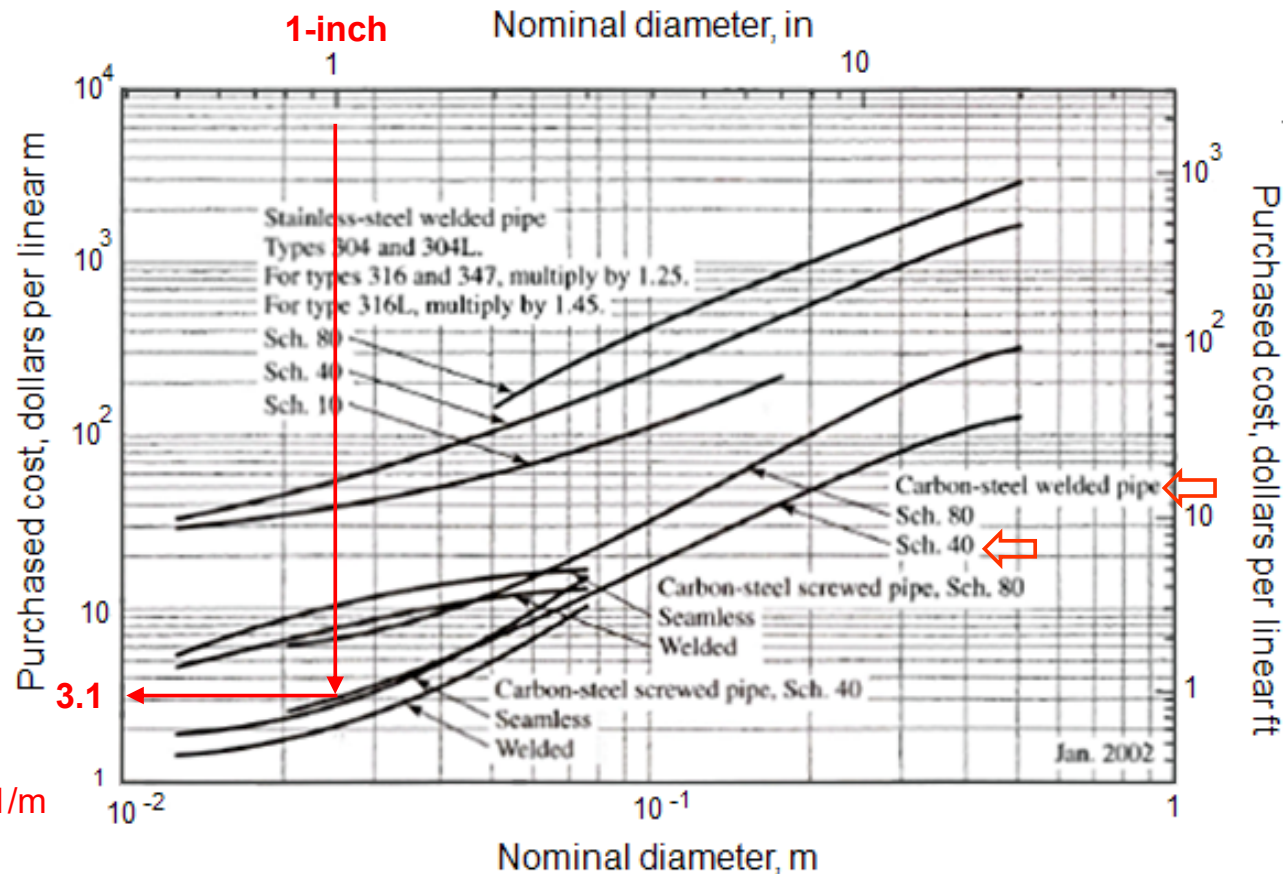
<https://www.plumbersstock.com>

Globe valves can be used to start, stop, and regulate flow. Their name comes from the shape of the valve body. A cone-shaped plug moves in and out of the flow of fluid. The flow is controlled by how far away the plug is from its seat. They offer more resistance to fluid flow, and the pressure drop is greater.

Cost of Piping

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

Nominal diameter defined,
Slide 16



Example:
1-inch Sch 40
carbon-steel
welded pipe

Cost is \$3.1/m in
January of 2002

$\frac{1278.7}{555.8} (\$3.1/\text{m}) = \$7.1/\text{m}$
January of 2024

Figure 12-4
Purchased cost of pipe per unit length

Factors for Determining Cost:

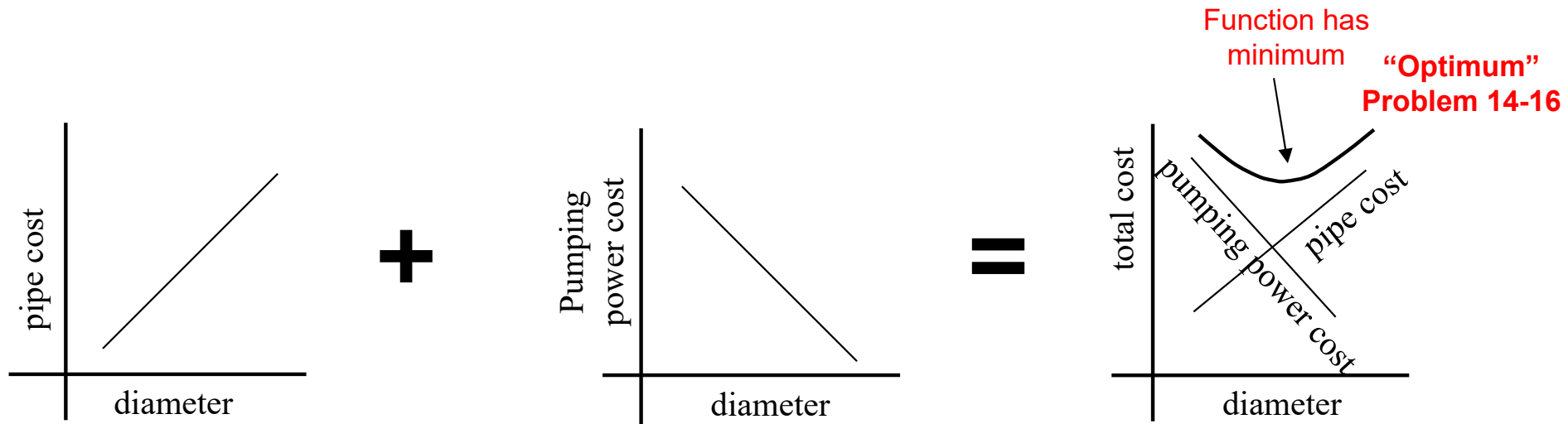
- Length
- Diameter and thickness
- Material of construction
- Mounting and support hardware
- Insulation and paint

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 $D_i \geq 0.0254\text{m}$

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

$Re < 2100$ and $D_i < 0.0254\text{m}$

book has .133
(typo)

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

μ = viscosity, $\text{Pa} \cdot \text{s}$

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 $D_i \geq 0.0254\text{m}$

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

$Re > 2100$ and $D_i < 0.0254\text{m}$

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

$Re < 2100$ and $D_i \geq 0.0254\text{m}$

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

$Re < 2100$ and $D_i < 0.0254\text{m}$

(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		Weight per lin ft, lb steel
					Outside	Inside	
¼	0.405	40 [§]	0.269	0.058	0.106	0.070	0.25
		80 [‡]	0.215	0.036	0.106	0.056	0.32
½	0.540	40	0.364	0.104	0.141	0.095	0.43
		80	0.302	0.072	0.141	0.079	0.54
¾	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	0.840	40	0.622	0.304	0.220	0.163	0.85
		80	0.546	0.235	0.220	0.143	1.09
1½	1.05	40	0.824	0.534	0.275	0.216	1.13
		80	0.742	0.432	0.275	0.194	1.48
2	1.32	40	1.049	0.864	0.344	0.274	1.68
		80	0.957	0.718	0.344	0.250	2.17
2½	1.66	40	1.380	1.50	0.435	0.362	2.28
		80	1.278	1.28	0.435	0.335	3.00
3	1.90	40	1.610	2.04	0.498	0.422	2.72
		80	1.500	1.76	0.498	0.393	3.64
4	2.38	40	2.067	3.35	0.622	0.542	3.66
		80	1.939	2.95	0.622	0.508	5.03
5	2.88	40	2.469	4.79	0.753	0.627	5.80
		80	2.323	4.23	0.753	0.609	7.67
6	3.50	40	3.068	7.38	0.917	0.804	7.58
		80	2.900	6.61	0.917	0.760	10.3
8	4.50	40	4.026	12.7	1.178	1.055	10.8
		80	3.826	11.5	1.178	1.002	15.0
10	6.625	40	6.065	28.9	1.734	1.590	19.0
		80	5.761	26.1	1.734	1.510	28.6
12	8.625	40	7.981	50.0	2.258	2.090	28.6
		80	7.625	45.7	2.258	2.000	43.4
16	10.75	40	10.02	78.8	2.814	2.62	40.5
		60	9.75	74.6	2.814	2.55	54.8
20	12.75	30	12.09	115	3.338	3.17	43.8
24	16.0	30	15.25	183	4.189	4.00	62.6
30	20.0	20	19.25	291	5.236	5.05	78.6
36	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.

5, 5S, 10, 10S, 20, 30, 40, 40S, 60, 80, 80S, 100, 120, 140, 160, STD, XS, and XXS

Pipe Schedule No.

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

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

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

Thickness,
Lesson 5

P_s = safe working pressure, kPa

S_s = safe working stress, kPa

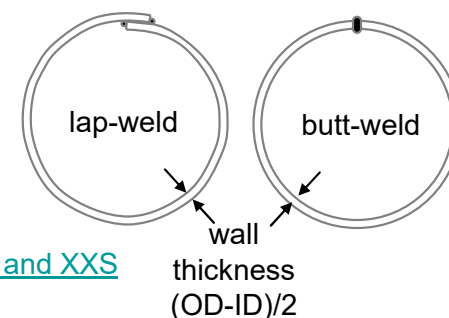
S_s = 49,000 kPa for butt-welded steel

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/m³. 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/m³, and the viscosity at 40°C is 5x10⁻⁴ Pa·s.

“pressure loss” is internal frictional pressure losses ΣF .