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 150[1]

30 minutes = 5 points[2]

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.)

A mid-sized chemical manufacturing plant can contain more than 61 miles of insulated piping, and a mid-sized refinery contains 356 miles of piping.

https://insulation.org/io/articles/insulation-management-and-its-value-to-industry/

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 ΔU=0 and Q=0)

new term not used in CH365

equivalent length (straight pipe + fittings)

incompressible:

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

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

$f = friction\ factor$

Eq. 12-12, page 492

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

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

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

specific volume, m³/kg

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

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

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

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

not shown in eq 12-13

compressible:

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

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

Best handled in CHEMCAD

Friction Factors – Straight Pipe

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=.0409 m.

f=0.0055

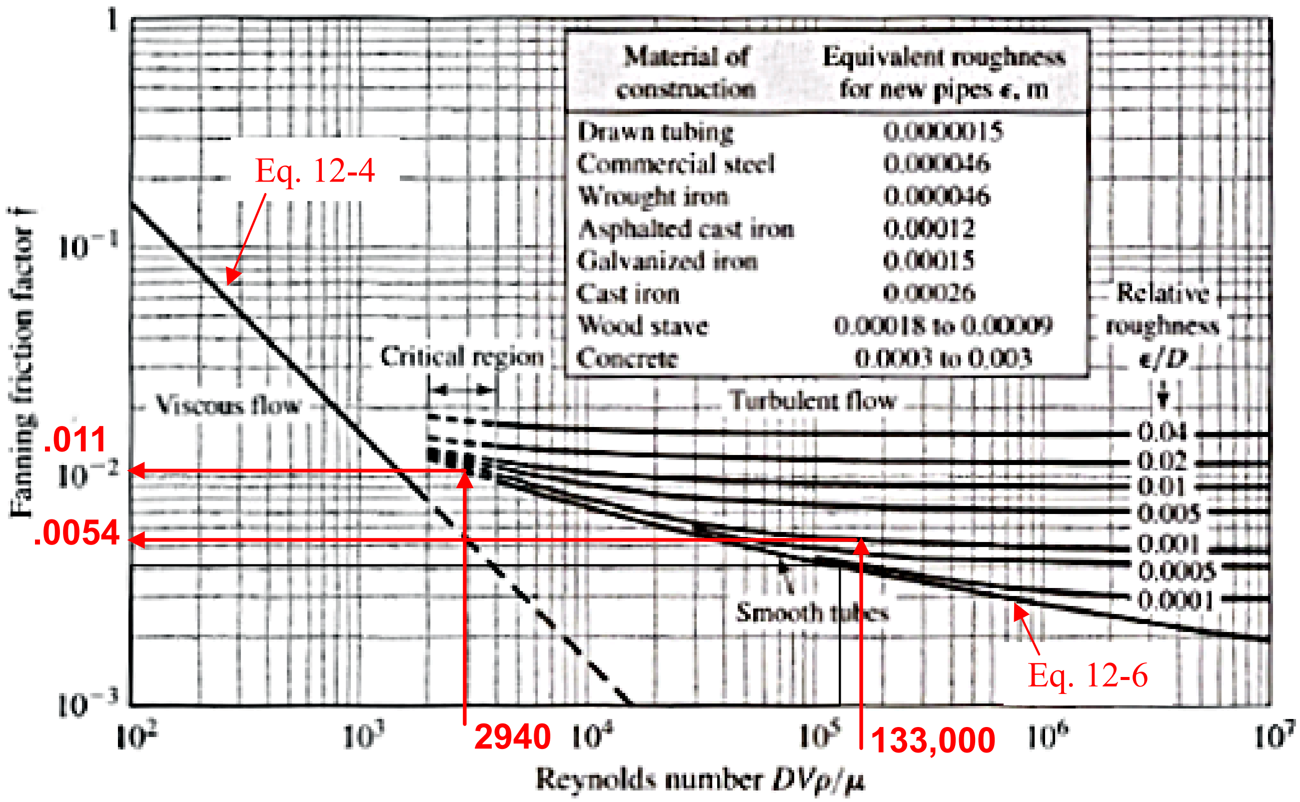


Figure 12-1

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

ε = .000046 m

d = 0.0409 m

ε/d = .0011

Re ≤ 2100

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

Eq. 12-4, page 487

4000 < Re < 100,000

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

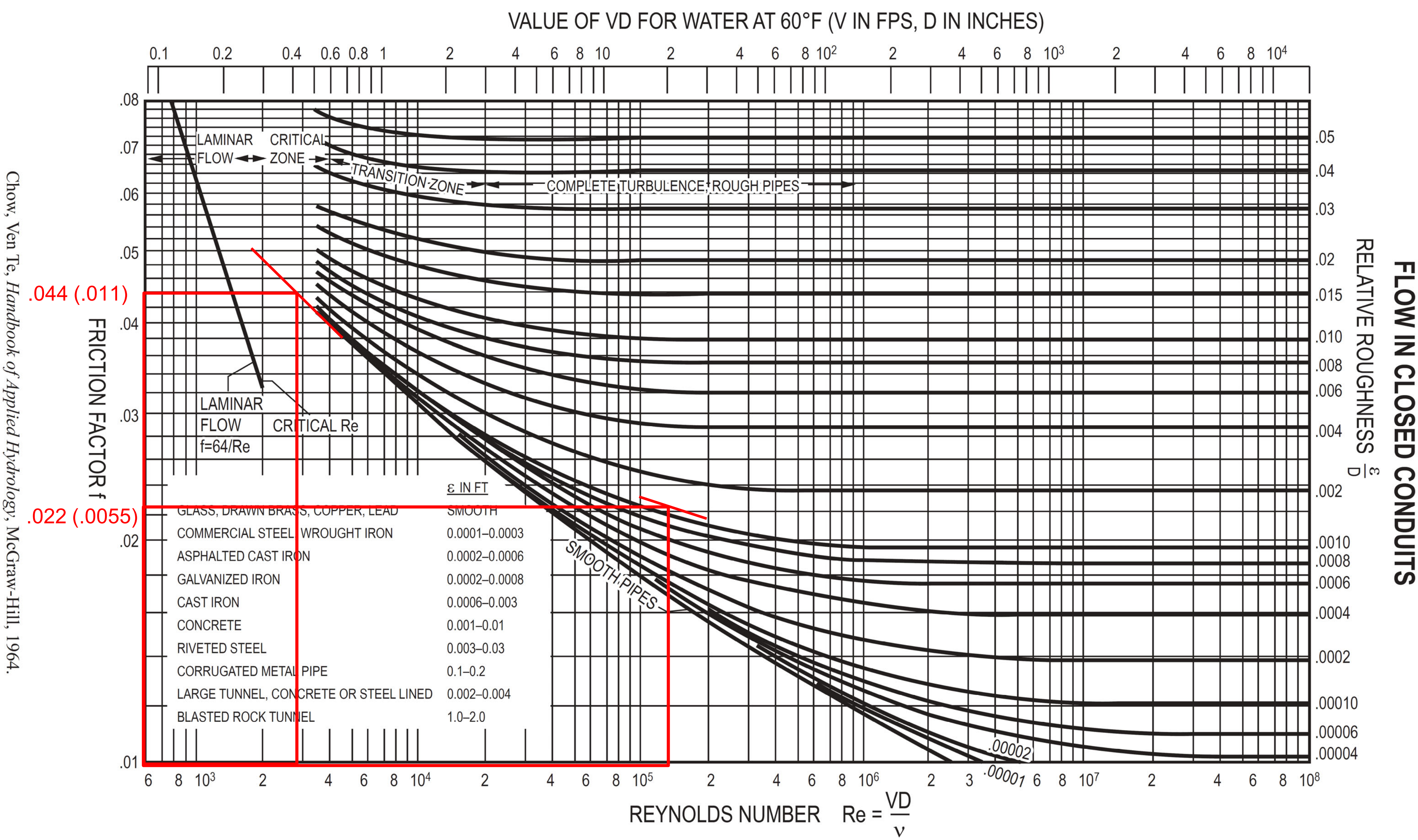
Eq. 12-5, page 487

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

Using Moody plot from FE reference manual, page 201



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

Frictional Losses in Fittings

Table 12-1 on page 490 is more comprehensive

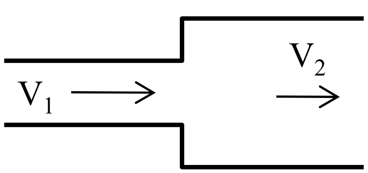
$F = \frac{2fV^2(L_{straight} + L_e)}{D}$	L_e/D per fitting (dimensionless)
45-degree elbows	15
90-degree elbows, std. radius	32
90-degree elbows, med. Radius	26
90-degree elbows, long radius	20
90-degree elbows, square	60
180-degree close-return bend	75
180-degree medium-radius return bend	50
Tee, used 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 x 32 x 0.078 m = 12.48 m of pipe

units are m^2/s^2

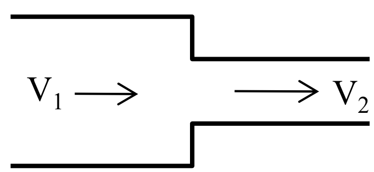
enlargement



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

α=1.0 for turbulent flow
α=0.5 for laminar flow

constriction



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

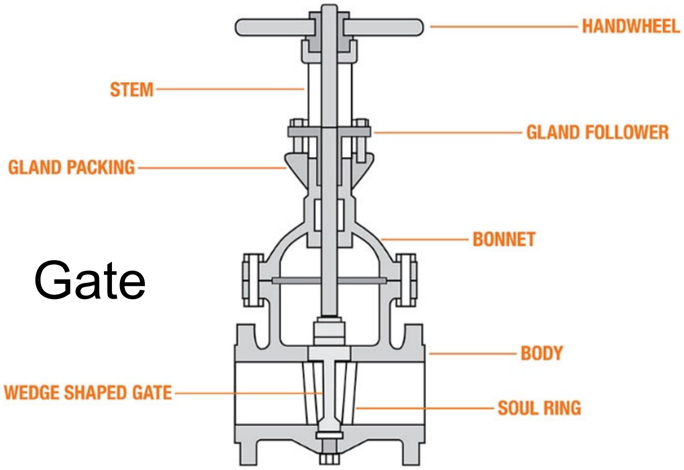
$$for \quad A_2 / A_1 < 0.715, \quad K_c = 0.4(1.25 - A_2 / A_1)$$

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

for conical and rounded shapes, K_c=0.05

Gate Valves and Globe Valves

Gate



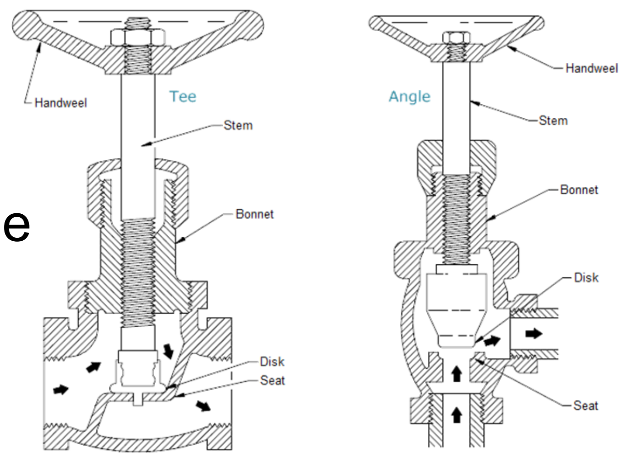
https://www.homedepot.com

https://www.homedepot.com

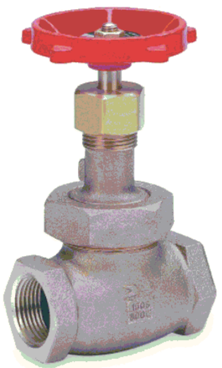
https://www.irrigationking.com

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

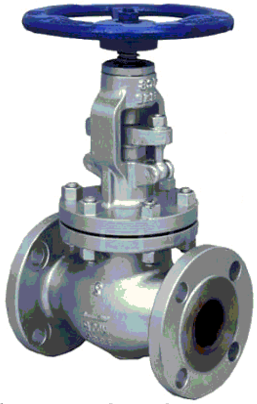


https://www.grainger.com

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.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

average pipe size in a typical refinery is 6” (356 miles)

Nominal diameter defined, Slide 16

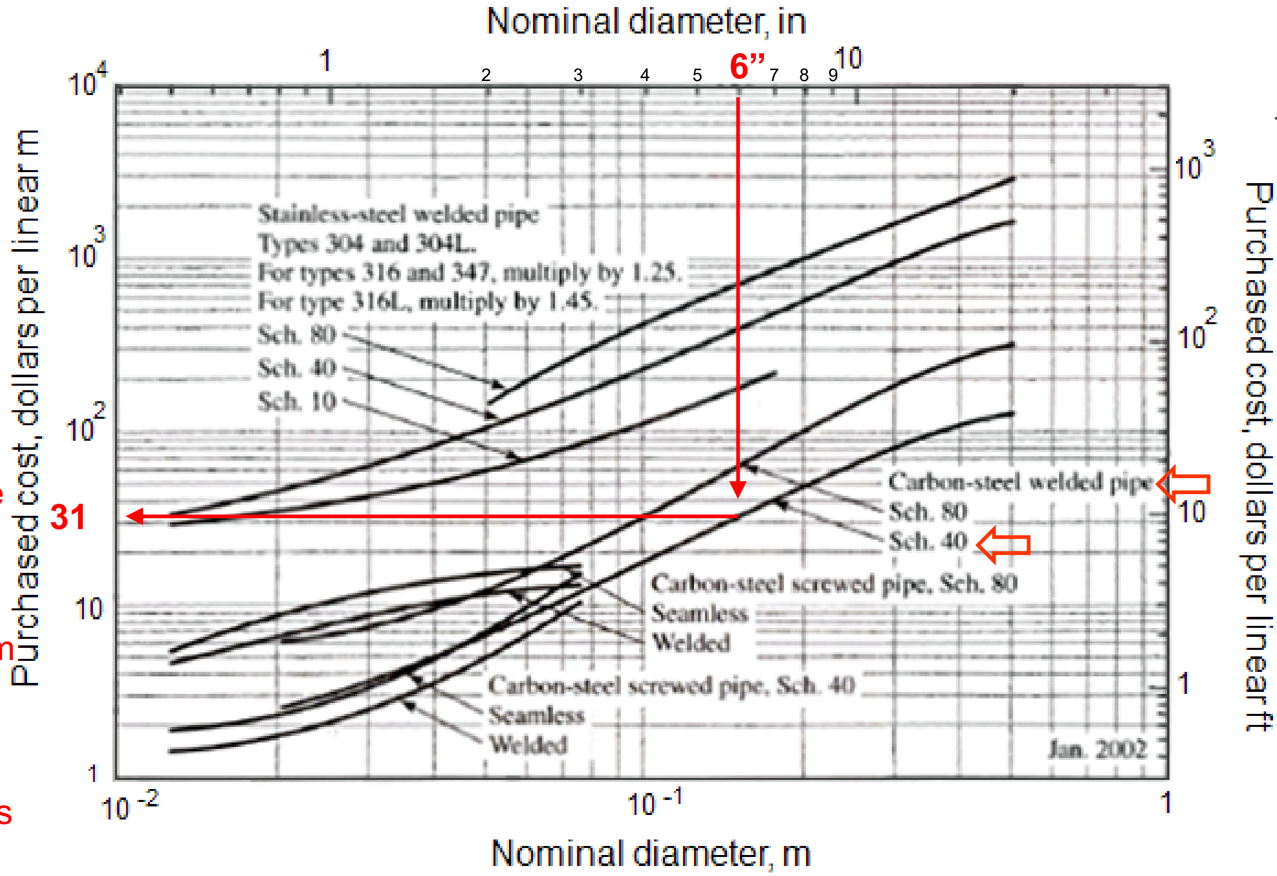


Figure 12-4
Purchased cost of pipe per unit length

Example: 6-inch Sch 40 carbon-steel welded pipe

Cost of 6-in Sch 40 pipe is \$31/m in Jan 2002

$\frac{1278.7}{555.8}$ (\$31/m) = \$71/m

Jan 2024

\$41 million, for 356 miles of pipe, not counting insulation or paint.

Factors for Determining Cost:

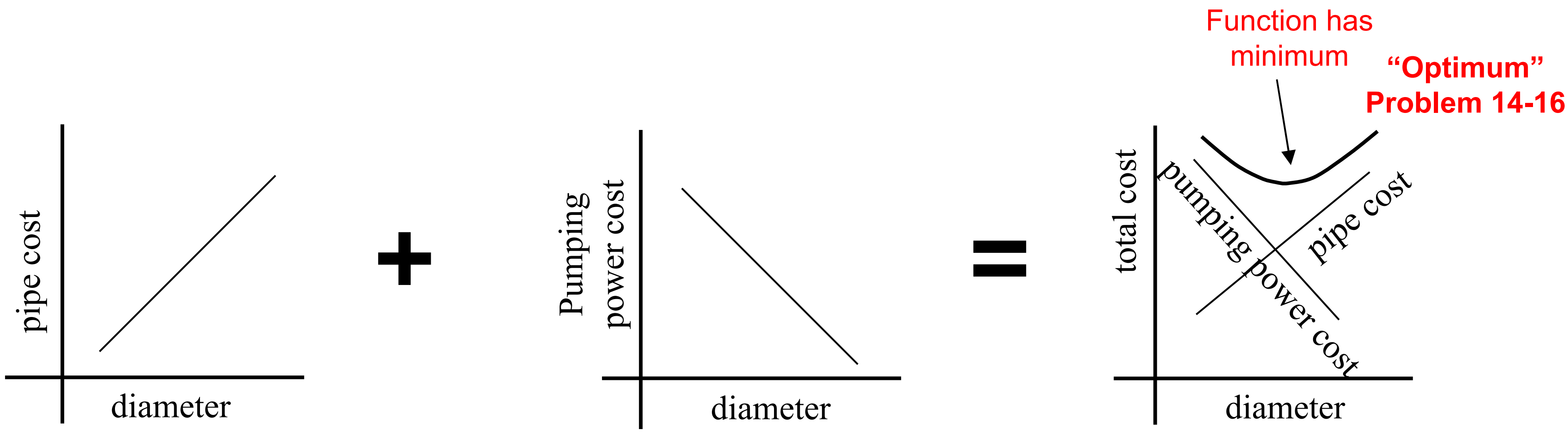
- Length
- Diameter and thickness
- Material of construction
- Mounting and support hardware
- Insulation and paint

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 $D_i < 0.0254$m

book has .133 (typo)

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

μ = 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, ft² Outside	Surface per linear ft, ft² 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.

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

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

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

Thickness, Lesson 5

P_s = safe working pressure, kPa

S_s = safe working stress, kPa

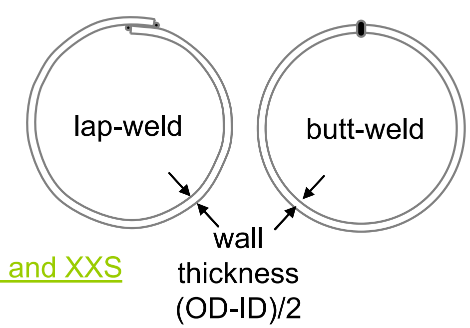
S_s = 49,000 kPa for butt-welded steel

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



Questions?