CH402 Chemical Engineering Process Design

Class Notes L1

Course Admin and Piping Design

BONUS OP

Chemical Engineering Plebe Open House

23 JAN 2025 ~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 “friends” clusters.

USMA Chemical Engineering Mission

To prepare commissioned leaders of character who are proficient in applying chemical and engineering principles to solve problems in a complex operational environment.

Published in the USMA Redbook (Part 2 – Disciplinary Offerings)

Chemical Engineering Program Educational Objectives

During a career as commissioned officers in the United States Army and beyond, program graduates:

- Demonstrate effective leadership by leveraging chemical engineering expertise and precise technical communication
- Contribute to the solution of complex problems in a dynamic environment
- Apply disciplined technical expertise to succeed in advanced study programs

Published in the USMA Redbook (Part 2 – Disciplinary Offerings)

Developed by Firsties, Faculty, and Advisory Board
Firsties provide input PEOs during the program briefing in January.

Chemical Engineering Student Outcomes

Student Outcome 8

The chemical engineering curriculum closely tracks the topics in the Fundamentals of Engineering Exam

On completion of the chemical engineering program, our graduates demonstrate an ability to understand …

- Chemistry
- Material and energy balances
- Safety and environmental factors.
- Thermodynamics of physical and chemical equilibria
- Heat, mass, and momentum transfer
- Chemical reaction engineering
- Continuous and staged separation processes
- Process dynamics and control
- Modern experimental and computing techniques
- Process design.

Published in the USMA Redbook (Part 2 – Disciplinary Offerings)

Red designates course emphasis; Gray designates minor emphasis

Student Outcomes, cont.

Student Outcomes 1-7

The Chemical Engineering Major contains the student outcomes recommended by ABET.

On completion of the chemical engineering program, our graduates demonstrate an ability to …

- Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
- Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
- Communicate effectively with a range of audiences.
- Recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
- Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
- Design and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
- Acquire and apply new knowledge as needed, using appropriate learning strategies.

Published in the USMA Redbook
(Part 2 – Disciplinary Offerings)

Red designates course emphasis; Gray designates minor emphasis

Redbook

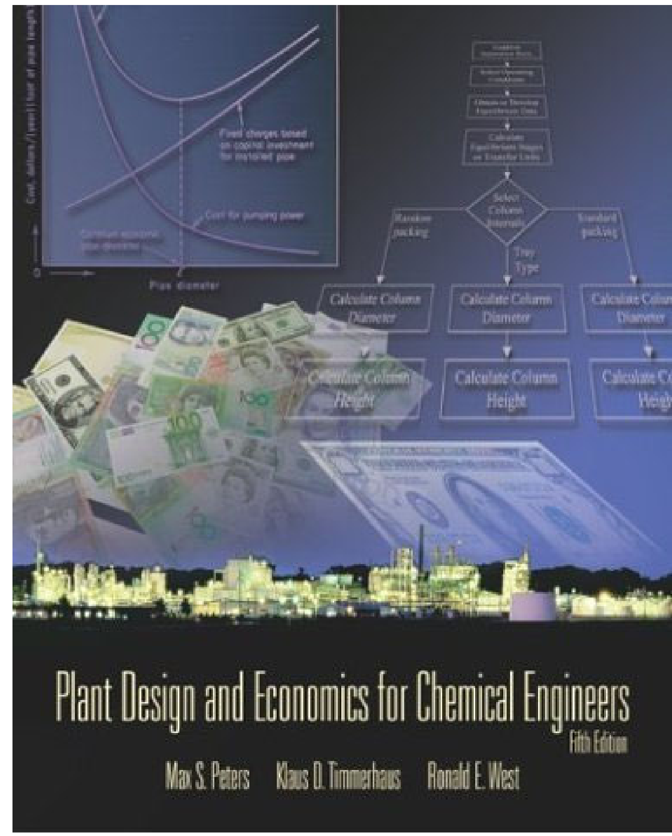
Credit Hours: 3.5 (BS=0, ET=3.5, MA=0)

Prerequisites: CH459, CH485, CH365

Co-requisite: None

Lessons: 40 @ 55 min, 7 @ 120 min

Special Requirements: None



Chapter Coverage

Introduction
Chapter 1

Heat Exchangers
Chapters 14

Fluid Handling
Chapter 12

Design Reports
Chapter 11

Flowsheet Synthesis
Chapter 4

Cost Estimation
Chapter 6

Interest
Chapter 7

Profitability
Chapter 8

Design Project
Independent Study

Assessment

29 Problem @ 6 pts each:	174	9.97%
5 Small Design Probs. @ 50 pts each:	250	14.33%
2 WPRs @ 200 pts each:	400	22.92%
1 Design Report @ 400 pts:	400	22.92%
2 IPRs @ 50 pts each:	100	5.73%
5 Quizzes @ 24 or 25 pts:	121	6.93%
1 Term End Exam @ 300 pts:	300	17.19%
Total:	1745	

All assignments are required.

Grade	Attributes
6	Cadets present complete solution and answers are correct.
2	Cadets present solution but answer is incorrect.
1	Cadet presents minimal work and answer is incorrect.
0	Answers shown with no work.

Procedure:

1. Detailed grading comments will not be provided by the instructor.
2. The instructor will notify the class when the assignment has been graded and the approved solution posted.
3. Cadets are responsible for reviewing the approved solutions and finding mistakes.
4. Cadets may then resubmit problem sets after grades have been posted.
5. Resubmissions must be submitted in Canvas within the suspense, generally 48 hours after notification of posting (weekends and holidays included). Beyond that time, resubmissions will not be graded.
6. Corrections must include a single pdf document with a cover page and a new title (e.g., PS10 Corrections). The instructor will find your resubmissions in Canvas. You are not required to email the instructor. Other documents such as Mathematica or Excel files may also be submitted to support your work, but the pdf is required.
7. Your resubmission must identify what your error was in the initial submission. You must also repair the error and verify the correction.
8. You may use the posted solutions to identify mistakes in your work. However, simply copying the instructor solution for the resubmission without correcting the initial submission will not change your grade.
9. Initial grade must be greater than 1/6 to be eligible for a resubmission.
10. The maximum score for a resubmission is 5/6.

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 – why do this? – energy has cost ($/kWh).

(Equation partially derived in CH365 L7, Chapter 2 of Smith, van Ness, Abbott, & Swihart, page 50, assuming steady state, ΔU=0, and Q=0)

incompressible:

Eq. 12-12, page 492
reduced form of 12-2

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

“mechanical” work

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

new term not used in eq 12-1 or 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)

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

$f = friction\ factor$

$f = f(R_n)$
(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)

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

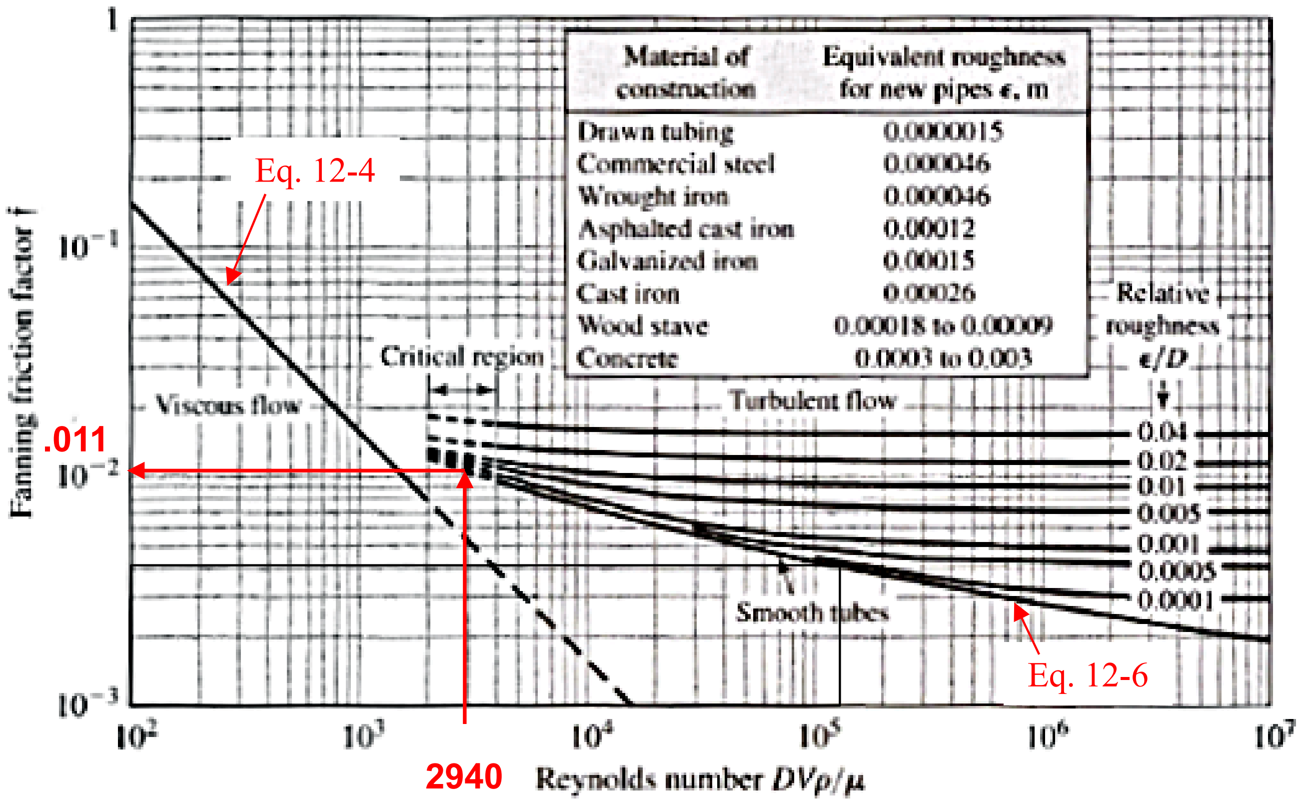
“shaft” work

Best handled in CHEMCAD

Friction Factors – Straight Pipe

Example:
Determine f for commercial "carbon" steel when Reynolds number is 2940.

f=0.011



Material of construction	Equivalent roughness for new pipes ε, m
Drawn tubing	0.0000015
Commercial steel	0.000046
Wrought iron	0.000046
Asphalted cast iron	0.00012
Galvanized iron	0.00015
Cast iron	0.00026
Wood stave	0.00018 to 0.00009
Concrete	0.0003 to 0.003

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

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

Eq. 12-4, page 487

4000 < Re < 100,000

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

Eq. 12-5, page 487

Re > 4,000

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

Eq. 12-6, page 487

Frictional Losses in Fittings

Table 12-1 on page 490 is more comprehensive

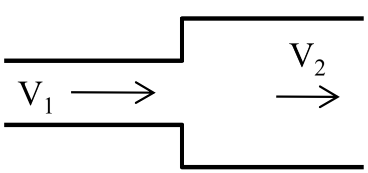
Example:
Determine the equivalent length of 5 90-degree elbows when the diameter is 0.078 m

5 x 32 x 0.078 m = 12.48 m of pipe

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

units are m^2/s^2

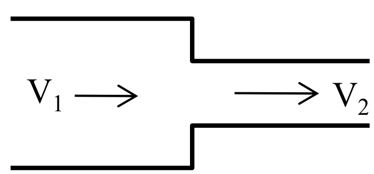
enlargement



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

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

constriction



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

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

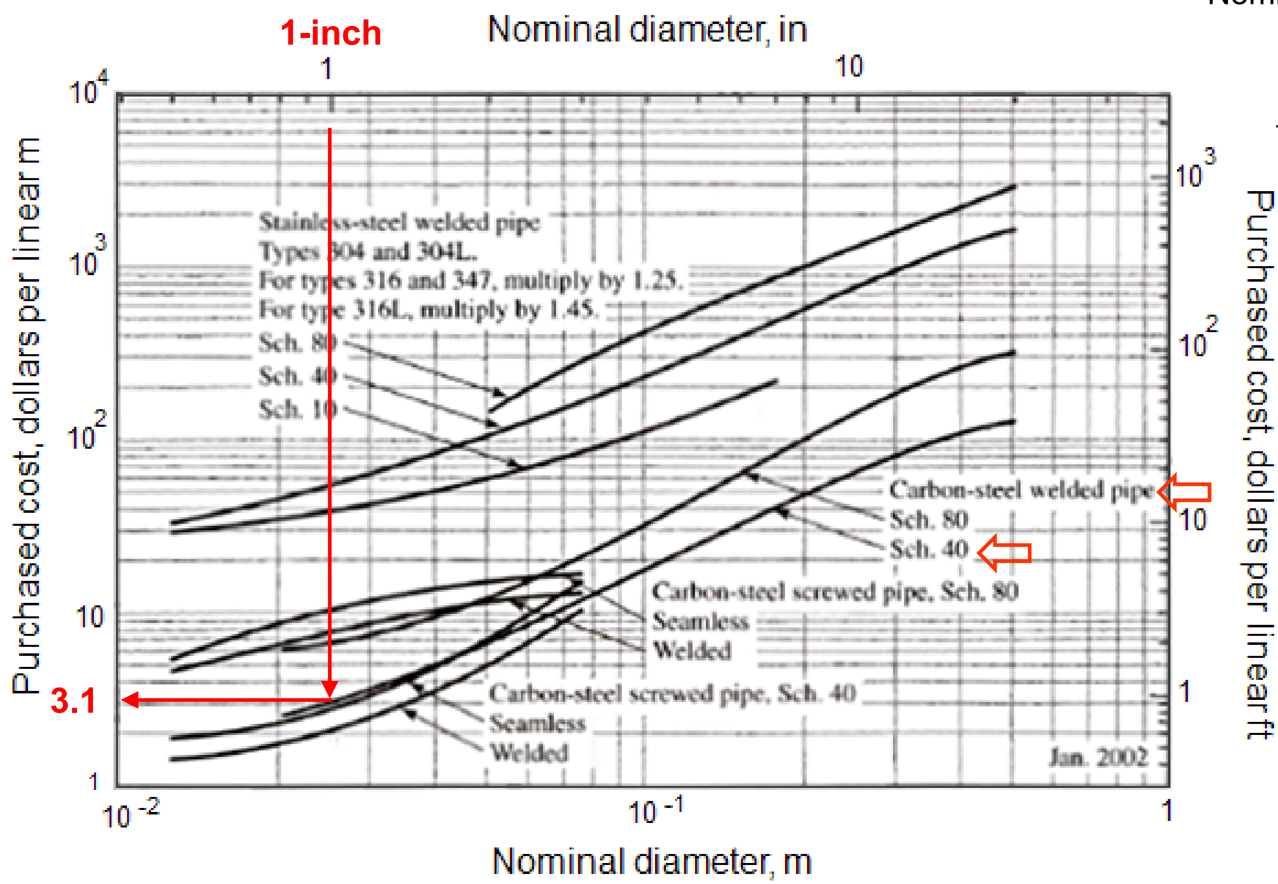
$$for\ \ A_2 / A_1 > 0.715,\ \ K_c = 0.75(1.00 - A_2 / A_1)$$

for conical and rounded shapes, K_c=0.05

Cost of Piping

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

Nominal diameter defined, Slide 16



Cost is \$3.1/m in January of 2002

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

Figure 12-4
Purchased cost of pipe per unit length

Factors for Determining Cost:

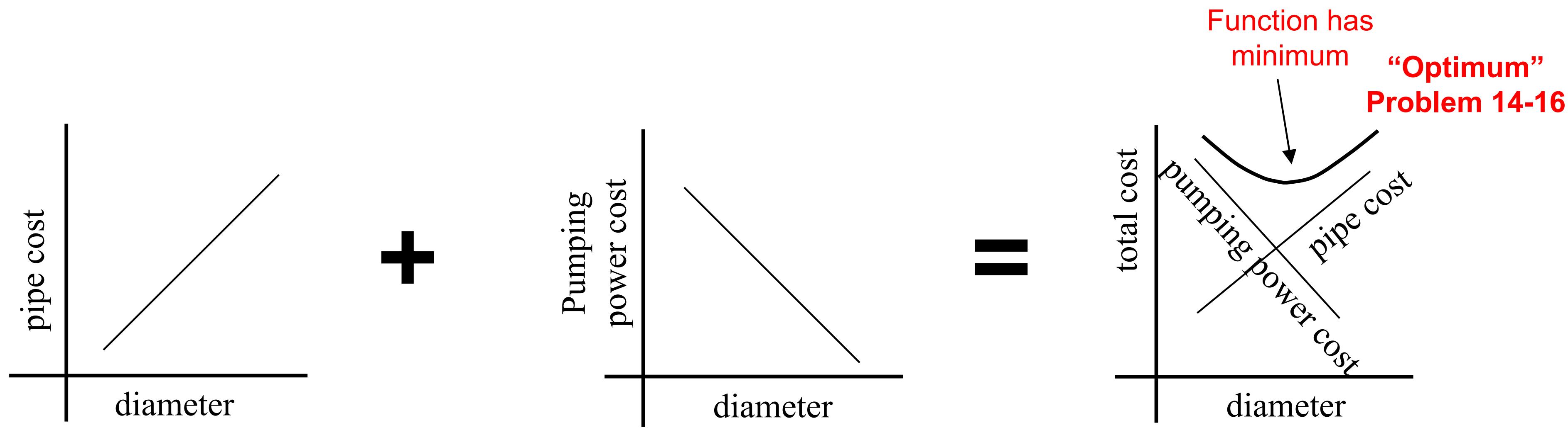
- Length
- Diameter and thickness
- Material of construction
- Mounting and support hardware
- Insulation and paint

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

Optimization of Combined 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 $D_i \geq 0.0254m$

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

$Re < 2100$ and $D_i < 0.0254m$

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 $D_i \geq 0.0254m$

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

$Re > 2100$ and $D_i < 0.0254m$

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

$Re < 2100$ and $D_i \geq 0.0254m$

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

$Re < 2100$ and $D_i < 0.0254m$

(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
⅛	0.405	40[‡]	0.269	0.058	0.106	0.070	0.25
		80[§]	0.215	0.036	0.106	0.056	0.32
¼	0.540	40	0.364	0.104	0.141	0.095	0.43
		80	0.302	0.072	0.141	0.079	0.54
⅜	0.675	40	0.493	0.192	0.177	0.129	0.57
		80	0.423	0.141	0.177	0.111	0.74
½	0.840	40	0.622	0.304	0.220	0.163	0.85
		80	0.546	0.235	0.220	0.143	1.09
¾	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
1¼	1.66	40	1.380	1.50	0.435	0.362	2.28
		80	1.278	1.28	0.435	0.335	3.00
1½	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
2½	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

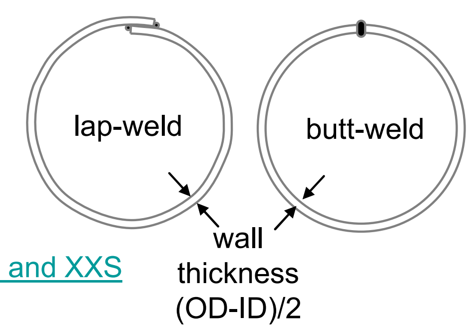
S_s = 49,000 kPa for butt-welded steel

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?