MAXIMUM PIPING OPERATING PRESSURE
AS RECOMMENDED BY THE ASME PROCESS PIPING CODE

Jacques Chaurette
www.pumpfundamentals.com
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Summary

Often one of the tasks of designing new pump systems or retro-fitting existing systems is to determine the allowable pressure in the pipes thereby ensuring a safe and reliable operation. The ASME process piping code provides this information. This article describes what the relevant sections of the ASME pressure code are and how they can be used to calculate the allowable pressure in a piping system.

ASME process piping code and pressure calculations

The ASME code recommends an allowable tensile stress level in the pipe material (see the terminology section at the end of this article). The pressure that can generate this tensile stress level can be calculated taking into account the type of material, temperature and other factors.

The formula (see B31.3-1999 code, page 20) which gives the relationship between the pressure (p) labeled p (see equation[1]), the outside diameter (D), the allowable tensile stress (S) and the thickness (t) of the pipe is:

$$t(in) = \frac{p(psig) \times D(in)}{2 \times (S(psi)\ E\ +\ p(psi)\ Y)} \qquad [1]$$

where E: material and pipe construction quality factor as defined in ASME Process Piping code B31.3-1999, Table A-1A

Y: wall thickness coefficient with values listed in ASME Process Piping code B31.3-1999, Table 304.1.1

Formula [1] is re-written in terms of the pressure (p) of the fluid within the pipe:

$$p\ \ (psig) = \frac{2 \times t(in)\ \times S(psi)\ \times E}{(D(in) - 2 \times t(in)\ \times Y)} \qquad [2]$$

Calculation example

The pipe is a typical spiral-weld construction assembled according to the specification ASTM A 139-96. The material is carbon steel ASTM A 139. The outside diameter of the pipe is 20.5 inches and the wall thickness is 0.25-inch.

For this material, the ASME code recommends that an allowable stress (S) of 16,000 psi be used for a temperature range of -20°F to +100°F. The quality factor E for steel A139 is 0.8; the wall thickness coefficient Y is 0.4.

Material	Minimum tensile strength (psi)	ASME code Allowable stress (S) (psi)
ASTM A139	48000	16000

The value of the internal fluid pressure that will produce the tensile stress level stipulated by the ASME code is 315 psig (see formula [3]).

$$p\,(psig) = \frac{2 \times t(in) \times S(psi) \times E}{(D(in) - 2 \times t(in) \times Y)} = \frac{2 \times 0.25 \times 16000 \times 0.8}{(20.5 - 2 \times 0.25 \times 0.4)} = 315 \qquad [3]$$

This pressure should be compared to the normal operating pressure. The pressure in a pump system can vary dramatically from place to place. The pressure level vs. location can only be determined on a case by case basis. However, typically the pressure is maximum near the pump discharge and decreases towards the outlet of the system.

It is possible that the system could be plugged. When the system plugs, the pump head increases and reaches (at zero flow) the shut-off head in the case of a centrifugal pump. The maximum pressure in the pump system will then be the pressure corresponding to the shut-off head plus the pressure corresponding to the pump inlet suction head. Since the system is plugged, this pressure will extend all the way from the pump discharge to the plug if the plug is at the same elevation as the pump discharge. The relationship between pressure head and pressure is given in equation [4].

$$H(ft\ \ fluid) = \frac{2.31 \times p\,(psi)}{SG} \qquad [4]$$

where (H) is the pressure head, (p) the pressure and (SG) the specific gravity of the fluid.

If the shut-off pressure exceeds the allowable operating pressure as calculated by the ASME code, then pressure relief devices may have to be installed. This is not likely to occur in single pump systems, but multiple series pump systems may produce excessive shut-off pressures since the pressure at the outlet of the last pump depends on the sum of the shut-off pressures of each pump. Exceptions are provided for in the code and are relative to the duration of the maximum pressures events, if they are of short duration these events may be allowed for short periods.

Rupture disks are often used in these situations. They are accurate, reliable pressure relief devices. However, these devices are not mandatory in many systems and their installation are then a matter of engineering judgment.

Existing systems

In an existing system, one should not rely on the original thickness of the pipe to do the pressure calculations. The pipe may suffer from corrosion, erosion or other chemical attacks which may reduce the wall thickness in certain areas. The pipe wall thickness can easily be measured by devices such as the Doppler ultra sound portable flow meter. The smallest wall thickness should be used as the basis for the allowable pressure calculations or the damaged areas should be replaced.

New systems

In new systems, consider if a corrosion allowance (depending on the material) should be used. The corrosion allowance will reduce the wall thickness that is used in the allowable pressure calculations.

Also the piping code allows pipe manufacturers a fabrication tolerance which can be as high as 12.5% on the wall thickness, this allowance should be considered when determining the design pipe wall thickness.

Terminology

Figure 1 shows the location of the various stress levels in a typical stress vs. strain graph.

TS: Tensile strength
YP: Yield point
BS: Breaking strength

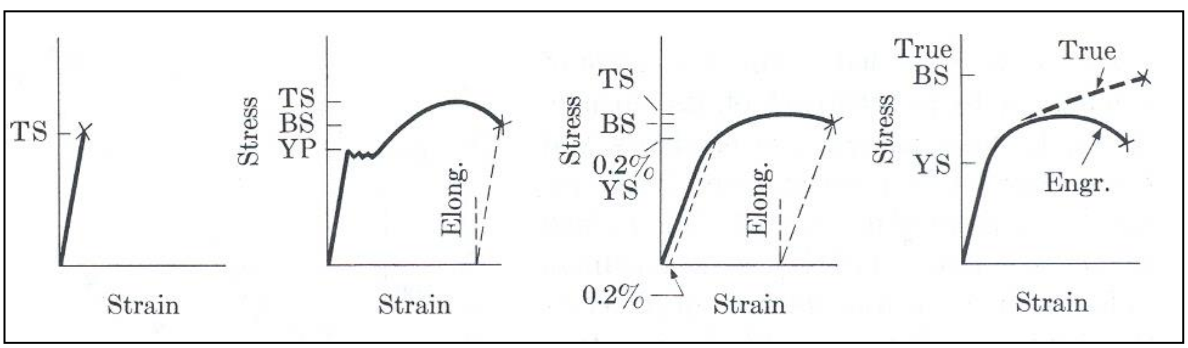

Figure 1. Definition of stress terms in a deformation test (reference Elements of Material Science by Van Vlack, Addison-Wesley Publishing Company, 2nd edition).

Attachments

- Excerpts from the ASME Power Piping code B31.3

ASTM A 139 Standard Specification for Electric-Fusion (Arc)-welded Steel Pipe

(14) **Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)**

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Material	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Min. Temp. to 100	200	300
Carbon Steel													
Pipes and Tubes (2)													
A285 Gr. A	A134	...	...	...	...	1	(8b)(57)	B	45	24	15.0	14.7	14.2
A285 Gr. A	A672	A45	K01700	...	...	1	(57)(59)(67)	B	45	24	15.0	14.7	14.2
Butt weld	API 5L	A25	...	...	...	1	(8a)(77)	−20	45	25	15.0	15.0	14.7
Smls & ERW	API 5L	A25	...	...	...	1	(57)(59)(77)	B	45	25	15.0	15.0	14.7
...	A179	...	K01200	...	...	1	(57)(59)	−20	47	26	15.7	15.7	15.3
Type F	A53	A	K02504	...	...	1	(8a)	20	48	30	16.0	16.0	16.0
...	A139	A	...	...	...	1	(8b)	A	48	30	16.0	16.0	16.0
...	A587	...	K11500	...	...	1	(57)(59)	−20	48	30	16.0	16.0	16.0
...	A53	A	K02504	...	...	1	(57)(59)	B	48	30	16.0	16.0	16.0
...	A106	A	K02501	...	...	1	(57)	B	48	30	16.0	16.0	16.0
...	A135	A	...	...	...	1	(57)(59)	B	48	30	16.0	16.0	16.0
...	A369	FPA	K02501	...	...	1	(57)	B	48	30	16.0	16.0	16.0
...	API 5L	A	...	...	...	1	(57)(59)(77)	B	48	30	16.0	16.0	16.0
A285 Gr. B	A134	...	...	...	...	1	(8b)(57)	B	50	27	16.7	16.5	15.9
A285 Gr. B	A672	A50	K02200	...	...	1	(57)(59)(67)	B	50	27	16.7	16.5	15.9
A285 Gr. C	A134	...	...	...	...	1	(8b)(57)	A	55	30	18.3	18.3	17.7
...	A524	II	K02104	...	...	1	(57)	−20	55	30	18.3	18.3	17.7
...	A333	1	K03008	...	...	1	(57)(59)	−50	55	30	18.3	18.3	17.7
...	A334	1	K03008	...	...	1	(57)(59)	−50	55	30	18.3	18.3	17.7
A285 Gr. C	A671	CA55	K02801	...	...	1	(59)(67)	A	55	30	18.3	18.3	17.7
A285 Gr. C	A672	A55	K02801	...	...	1	(57)(59)(67)	A	55	30	18.3	18.3	17.7
A516 Gr. 55	A672	C55	K01800	...	...	1	(57)(67)	C	55	30	18.3	18.3	17.7
A516 Gr. 60	A671	CC60	K02100	...	...	1	(57)(67)	C	60	32	20.0	19.5	18.9
A515 Gr. 60	A671	CB60	K02401	...	...	1	(57)(67)	B	60	32	20.0	19.5	18.9
A515 Gr. 60	A672	B60	K02401	...	...	1	(57)(67)	B	60	32	20.0	19.5	18.9
A516 Gr. 60	A672	C60	K02100	...	...	1	(57)(67)	C	60	32	20.0	19.5	18.9
...	A139	B	K03003	...	...	1	(8b)	A	60	35	20.0	20.0	20.0
...	A135	B	K03018	...	...	1	(57)(59)	B	60	35	20.0	20.0	20.0
...	A524	I	K02104	...	...	1	(57)	−20	60	35	20.0	20.0	20.0
...	A53	B	K03005	...	...	1	(57)(59)	B	60	35	20.0	20.0	20.0
...	A106	B	K03006	...	...	1	(57)	B	60	35	20.0	20.0	20.0
...	A333	6	K03006	...	...	1	(57)	−50	60	35	20.0	20.0	20.0
...	A334	6	K03006	...	...	1	(57)	−50	60	35	20.0	20.0	20.0
...	A369	FPB	K03006	...	...	1	(57)	−20	60	35	20.0	20.0	20.0
...	A381	Y35	...	...	...	1	...	A	60	35	20.0	20.0	20.0
...	API 5L	B	...	...	...	1	(57)(59)(77)	B	60	35	20.0	20.0	20.0

Figure 2 Excerpts from the ASME Power Piping code B31.3, values for allowable stress according to temperature.

Y may be interpolated for intermediate temperatures.

For $t \geq D/6$,

$$Y = \frac{d + 2c}{D + d + 2c}$$

304.1.2 Straight Pipe Under Internal Pressure

(a) For $t < D/6$, the internal pressure design thickness for straight pipe shall be not less than that calculated in accordance with Eq. (3a):

$$t = \frac{PD}{2(SE + PY)} \qquad (3a)$$

Equation (3b), (3c), or (3d) may be used instead of Eq. (3a):

$$t = \frac{PD}{2SE} \qquad (3b)$$

$$t = \frac{D}{2}\left(1 - \sqrt{\frac{SE - P}{SE + P}}\right) \qquad \text{(Lamé Equation)} \qquad (3c)$$

$$t = \frac{P(d + 2c)}{2[SE - P(1 - Y)]} \qquad (3d)$$

(b) For $t \geq D/6$ or for $P/SE > 0.385$, calculation of pressure design thickness for straight pipe requires special consideration of factors such as theory of failure, effects of fatigue, and thermal stress.

304.1.3 Straight Pipe Under External Pressure. To determine wall thickness and stiffening requirements for straight pipe under external pressure, the procedure outlined in the BPV Code, Section VIII, Division 1, UG-28 through UG-30 shall be followed, using as the design length L the running center line length between any two sections stiffened in accordance with UG-29. As an exception, for pipe with $D_o/t < 10$, the value of S to be used in determining P_{a2} shall be the lesser of the following values for pipe material at design temperature:

(a) 1.5 times the stress value from Table A-1 of this Code; or

(b) 0.9 times the yield strength tabulated in Section II, Part D, Table Y-1 for materials listed therein.

(The symbol D_o in Section VIII is equivalent to D in this Code.)

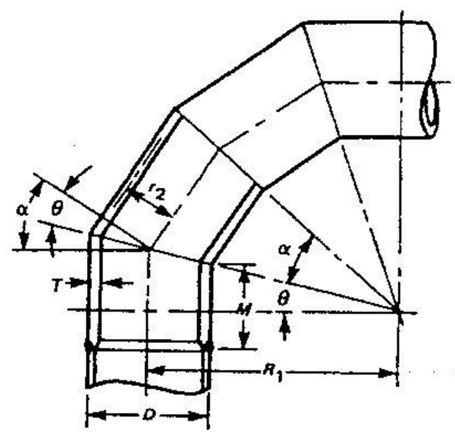

FIG. 304.2.3 NOMENCLATURE FOR MITER BENDS

304.2 Curved and Mitered Segments of Pipe

304.2.1 Pipe Bends. The minimum required thickness t_m of a bend, after bending, shall be determined as for straight pipe in accordance with para. 304.1.

304.2.2 Elbows. Manufactured elbows not in accordance with para. 303 shall be qualified as required by para. 304.7.2.

304.2.3 Miter Bends. An angular offset of 3 deg or less (angle α in Fig. 304.2.3) does not require design consideration as a miter bend. Acceptable methods for pressure design of multiple and single miter bends are given in (a) and (b) below.

(a) Multiple Miter Bends. The maximum allowable internal pressure shall be the lesser value calculated from Eqs. (4a) and (4b). These equations are not applicable when θ exceeds 22.5 deg.

$$P_m = \frac{SE(T - c)}{r_2}\left(\frac{T - c}{(T - c) + 0.643\tan\theta\sqrt{r_2(T - c)}}\right) \qquad (4a)$$

$$P_m = \frac{SE(T - c)}{r_2}\left(\frac{R_1 - r_2}{R_1 - 0.5r_2}\right) \qquad (4b)$$

(b) Single Miter Bends

(1) The maximum allowable internal pressure for a single miter bend with angle θ not greater than 22.5 deg shall be calculated by Eq. (4a).

(2) The maximum allowable internal pressure for

Figure 3 Excerpts from the ASME Power Piping code B31.3, formula for calculating the wall thickness according to the allowable stress.

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wind and earthquake, as occurring concurrently with test loads.

302.4 Allowances

In determining the minimum required thickness of a piping component, allowances shall be included for corrosion, erosion, and thread depth or groove depth. See definition for c in para. 304.1.1(b).

302.4.1 Mechanical Strength. When necessary, the wall thickness shall be increased to prevent overstress, damage, collapse, or buckling due to superimposed loads from supports, ice formation, backfill, or other causes. Where increasing the thickness would excessively increase local stresses or the risk of brittle fracture, or is otherwise impracticable, the required strength may be obtained through additional supports, braces, or other means without an increased wall thickness. Particular consideration should be given to the mechanical strength of small pipe connections to piping or equipment.

PART 2
PRESSURE DESIGN OF PIPING COMPONENTS

303 GENERAL

Components manufactured in accordance with standards listed in Table 326.1 shall be considered suitable for use at pressure-temperature ratings in accordance with para. 302.2.1. The rules in para. 304 are intended for pressure design of components not covered in Table 326.1, but may be used for a special or more rigorous design of such components. Designs shall be checked for adequacy of mechanical strength under applicable loadings enumerated in para. 301.

304 PRESSURE DESIGN OF COMPONENTS

304.1 Straight Pipe

304.1.1 General

(a) The required thickness of straight sections of pipe shall be determined in accordance with Eq. (2):

$$t_m = t + c \qquad (2)$$

The minimum thickness T for the pipe selected, considering manufacturer's minus tolerance, shall be not less than t_m.

(b) The following nomenclature is used in the equations for pressure design of straight pipe.

- t_m = minimum required thickness, including mechanical, corrosion, and erosion allowances
- t = pressure design thickness, as calculated in accordance with para. 304.1.2 for internal pressure or as determined in accordance with para. 304.1.3 for external pressure
- c = the sum of the mechanical allowances (thread or groove depth) plus corrosion and erosion allowances. For threaded components, the nominal thread depth (dimension h of ASME B1.20.1, or equivalent) shall apply. For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of the cut.
- T = pipe wall thickness (measured or minimum per purchase specification)
- d = inside diameter of pipe. For pressure design calculation, the inside diameter of the pipe is the maximum value allowable under the purchase specification.
- P = internal design gage pressure
- D = outside diameter of pipe as listed in tables of standards or specifications or as measured
- E = quality factor from Table A-1A or A-1B
- S = stress value for material from Table A-1
- Y = coefficient from Table 304.1.1, valid for $t < D/6$ and for materials shown. The value of

TABLE 304.1.1
VALUES OF COEFFICIENT Y
FOR $t < D/6$

	Temperature, °C (°F)					
Materials	≤ 482 (900 & Lower)	510 (950)	538 (1000)	566 (1050)	593 (1100)	≥ 621 (1150 & Up)
Ferritic steels	0.4	0.5	0.7	0.7	0.7	0.7
Austenitic steels	0.4	0.4	0.4	0.4	0.5	0.7
Other ductile metals	0.4	0.4	0.4	0.4	0.4	0.4
Cast iron	0.0	...	...	...	...	...

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Figure 4 Excerpts from the ASME Power Piping code B31.3, values for the Y coefficient in formula [1].

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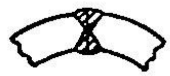
Table 302.3.4

(99)

TABLE 302.3.4
LONGITUDINAL WELD JOINT QUALITY FACTOR, E_j

No.	Type of Joint		Type of Seam	Examination	Factor, E_j
1	Furnace butt weld, continuous weld		Straight	As required by listed specification	0.60 [Note (1)]
2	Electric resistance weld		Straight or spiral	As required by listed specification	0.85 [Note (1)]
3	Electric fusion weld				
	(a) Single butt weld		Straight or spiral	As required by listed specification or this Code	0.80
	(with or without filler metal)			Additionally spot radiographed per para. 341.5.1	0.90
				Additionally 100% radiographed per para. 344.5.1 and Table 341.3.2	1.00
	(b) Double butt weld		Straight or spiral [except as provided in 4(a) below]	As required by listed specification or this Code	0.85
	(with or without filler metal)			Additionally spot radiographed per para. 341.5.1	0.90
				Additionally 100% radiographed per para. 344.5.1 and Table 341.3.2	1.00
4	Per specific specification				
	(a) API 5L	Submerged arc weld (SAW) Gas metal arc weld (GMAW) Combined GMAW, SAW 	Straight with one or two seams Spiral	As required by specification	0.95

NOTE:
(1) It is not permitted to increase the joint quality factor by additional examination for joint 1 or 2.

Figure 5 Excerpts from the ASME Power Piping code B31.3, values for the E coefficient in formula [1].