Pipe Wall Thickness Calculation: An Alternative Approach in the Petroleum Industry

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Calculations on pipe wall thickness are performed to verify the pipe wall thickness of a selected pipe material specification in offshore/onshore oil and gas projects and are usually part of any oil and gas related piping engineering deliverables.

In most parts of the world, such calculations are generally performed based on ASME B31.3. However, in recent years, some shortfalls in this method of calculation have been highlighted. The most common solution proposed was to use a more fit purpose equation against the conservative equation.

DESIGN

Pipe wall thickness is a function of allowable hoop stress. It is derived from cylindrical stress under mechanics of material. A cylindrical stress has these patterns: Circumferential stress, hoop stress, axial/longitudinal stress and radial stress. In relation to internal pressure, we will use the hoop stress to calculate the pipe wall thickness for thin-walled cylinders (wall thickness less than 1/10th of the radius).

HOOP STRESS FOR THIN WALL PIPE

The hoop stress can be expressed as:

$\sigma_h = p\,d / 2\,t$

Where

σ_h = *hoop stress (MPa, psi)*

p = *internal pressure in the tube or cylinder (MPa, psi)*

d = *internal diameter of tube or cylinder (mm, in)*

t = *tube or cylinder wall thickness (mm, in)*

For thick walled cylinders, the Lame's equation will be used to determine pipe wall thickness. This equation is best suited for thicker walled high pressure piping, with wall thickness outside the schedule range (r/t ratio of less than 10).

HOOP STRESS FOR THICK WALL PIPE

The hoop stress can be expressed as:

$\sigma_c = ((p_i r_i^2 - p_o r_o^2) / (r_o^2 - r_i^2)) - (r_i^2 r_o^2 (p_o - p_i) / (r^2 (r_o^2 - r_i^2)))$

Where

σ_c = *stress in circumferential direction (MPa, psi)*

p_i = *internal pressure in the tube or cylinder (MPa, psi)*

p_o = *external pressure in the tube or cylinder (MPa, psi)*

r_i = *internal radius of tube or cylinder (mm, in)*

r_o = *external radius of tube or cylinder (mm, in)*

r = *radius to point in tube or cylinder wall (mm, in)* $(r_i < r < r_o)$

Maximum stress when $r = r_i$ *(inside pipe or cylinder)*

Generally, pipe wall thickness is calculated by:

- Determining the applicable ASME/ANSI B31 Code.
- Calculating the required thickness for internal pressure.
- Checking the calculated thickness to determine its acceptability for external pressure and other applied loads, if applicable.
- Increasing the calculated thickness, as needed, to account for corrosion allowance and mill tolerance.
- Selecting a thickness from an ANSI/API table of standard pipe thickness requirements.

All piping component wall thicknesses specified for the individual piping classes are calculated according to the formulae specified in Para 304.1.2 (3a) of ASME B31.3, and are based on continuous long-term internal design pressure and design temperature, specified corrosion/erosion allowance (under-tolerance), the manufacturing minus/under tolerance and the threading allowance as applicable.

Piping subject to any additional loading such as short-term upset conditions, occasional loads, external pressure, thermal loading, live loads, marine motions or bending allowances shall be individually assessed to ensure full compliance with ASME B31.3.

A typical pipe class sheet (diagram)

Sl. No.	Material Group	Rating
1.	Carbon Steel	CL150
2.	Duplex Stainless Steel 22Cr	CL150
3.	Duplex Stainless Steel 25Cr	CL150
4.	Austenitic Stainless Steel 316	CL150
5.	Austenitic Stainless Steel 316	CL150
6.	Austenitic Stainless Steel 6Mo	CL150
7.	Austenitic Stainless Steel 6Mo	CL150
8.	Titanium	CL150
9.	Titanium	CL150

Sl. No.	Material Group	Rating
10.	Duplex Stainless Steel 22Cr	CL300
11.	Austenitic Stainless Steel 316	CL300
12.	Austenitic Stainless Steel 6Mo	CL300
13.	Duplex Stainless Steel 22Cr	CL600
14.	Duplex Stainless Steel 22Cr	CL600
15.	Duplex Stainless Steel 25Cr	CL600
16.	Austenitic Stainless Steel 316	CL600
17.	Austenitic Stainless Steel 6Mo	CL600
18.	Duplex Stainless Steel 22Cr	CL900
19.	Duplex Stainless Steel 22Cr	CL900
20.	Duplex Stainless Steel 22Cr	CL900
21.	Austenitic Stainless Steel 6Mo	CL900
22.	Duplex Stainless Steel 22Cr	CL1500
23.	Duplex Stainless Steel 22Cr	CL1500
24.	Duplex Stainless Steel 22Cr	CL1500
25.	Duplex Stainless Steel 22Cr	CL1500
26.	Austenitic Stainless Steel 6Mo	CL1500
27.	Duplex Stainless Steel 22Cr	CL2500
28.	Duplex Stainless Steel 25Cr	CL2500
29.	Austenitic Stainless Steel 6Mo	CL2500
30.	Carbon Steel AISI 4130	API10000
31.	Duplex Stainless Steel 22Cr	CL4500
32.	Duplex Stainless Steel 22Cr	CL4500
33.	Duplex Stainless Steel 25Cr	CL4500
34.	Duplex Stainless Steel 22Cr	CL4500
35.	Austenitic Stainless Steel 6Mo	CL4500

The following pipe class sheet has higher pressure rating than tabulated in ASME B16.5/ASME B16.34 (diagram)

Sl. No.	Material Group	Rating	Temp. °C	Pressure, Barg	
				Pipe Class Sheet	ASME B16.5
1.	Duplex Stainless Steel 22Cr	CL300	100	51.5	50.7
			150	50.2	45.9
			200	48.6	42.7
2.	Austenitic Stainless Steel 6Mo	CL300	100	51.5	50.7
			150	50.2	50.2
3.	Duplex Stainless Steel 22Cr	CL600	100	103.0	101.3
			150	100.3	91.9
			200	97.2	85.3
			250	92.7	80.9
4.	Duplex Stainless Steel 22Cr	CL600	100	103.0	101.3
5.	Duplex Stainless Steel 25Cr	CL600	100	103.0	101.3
6.	Austenitic Stainless Steel 6Mo	CL600	100	103.0	101.3
			150	100.3	91.9
7.	Duplex Stainless Steel 22Cr	CL900	150	140.0	137.8

Sl. No.	Material Group	Rating	Temp. °C	Pressure, Barg	
				Pipe Class Sheet	ASME B16.5
8.	Duplex Stainless Steel 22Cr	CL900	100	154.6	152.0
9.	Austenitic Stainless Steel 6Mo	CL900	100	154.6	152.0
			150	150.5	137.8
			200	131.4	128.0
10.	Duplex Stainless Steel 22Cr	CL1500	100	257.6	253.3
			150	250.8	229.6
11.	Austenitic Stainless Steel 6Mo	CL1500	100	257.6	253.3
			150	250.8	229.6
			200	219.0	213.3
			250	209.7	202.3
			300	199.1	194.3
12.	Duplex Stainless Steel 22Cr	CL2500	150	395.0	382.7
13.	Duplex Stainless Steel 25Cr	CL2500	150	394.1	382.7
14.	Austenitic Stainless Steel 6Mo	CL2500	100	429.4	422.2
			150	418.1	382.7
15.	Duplex Stainless Steel 22Cr	CL4500	140	715.3	703.1

As individually noted in the following pipe class sheet, for certain sizes the selected pipe wall thickness is lower than the calculated value. This is because the Lame's equation used gives a lower wall thickness where the difference is small.

Sl. No.	Size, NPS	Material Group	Rating	Calculated thickness, mm based on hoop stress	Calculated thickness, mm based on Lame's equation	Difference, mm
1.	12	Austenitic Stainless Steel 6Mo	CL900	14.35	14.27	(-) 0.08
2.	16	Duplex Stainless Steel 22Cr	CL1500	16.76	16.66	(-) 0.10
3.	4	Duplex Stainless Steel 22Cr	CL1500	6.06	6.02	(-) 0.04
4.	24	Austenitic Stainless Steel 6Mo	CL1500	38.93	38.89	(-) 0.04
5.	1.5	Duplex Stainless Steel 22Cr	CL2500	5.10	5.08	(-) 0.02
	10			28.85	28.58	(-) 0.27
6.	8	Duplex Stainless Steel 25Cr	CL2500	18.37	18.26	(-) 0.11
	12			25.54	25.40	(-) 0.14
	14			28.01	27.79	(-) 0.22
7.	6	Duplex Stainless Steel 22Cr	CL4500	25.23	25.00	(-) 0.23
	10			40.08	40.00	(-) 0.08
	12			40.47	40.00	(-) 0.47
8.	8	Duplex Stainless Steel 22Cr	CL4500	36.11	36.00	(-) 0.11
9.	0.5	Austenitic Stainless Steel 6Mo	CL4500	2.79	2.77	(-) 0.02
	6			22.08	21.95	(-) 0.13

THE CHALLENGE

The main challenge identified in pipe wall thickness calculation is the alternative formula against the conservative formulae. The reason for the difference in pipe wall thickness calculations is based on a different formula used in the calculation. ASME B31.3 gives a more conservative calculation which, in general, is more accurate for thinner walled scheduled piping with thickness below ($t<D/6$).

The alternative formula is based on the Lame's equation where variables such as external pressure are given more consideration in the calculation. Lame's equation is better used for thicker walled high pressure piping, with wall thicknesses outside the schedule range ($t>D/6$ or $P/SE > 0.385$).

Section 304.1.2 (a), ASME B31.3 formula with $t<D/6$ and $P/SE<0.385$ is used for validation. The conditions/criteria and application of the formula, as given in section 304.1.2 (a), meet the design requirement. Hence, the design is accordance with section 304.1.2 (a), ASME B31.3 and the provisions of section 304.1.2 (b) should not be used.

However, under certain circumstances (refer to reasons mentioned below), the most common solution proposed will be the acceptance of using a fit purpose equation against the conservative equation.

1. Pipe wall thickness calculations aren't part of the discipline engineering deliverables.
2. Difference of the calculated wall thickness is negligible and most of the sizes are not used in a particular project.
3. Most of the line which uses the affected pipe classes are not designed as per maximum design, where the pipe wall thickness is calculated based on the maximum design pressure and temperature.

CONCLUSION

Pipe wall thickness calculation shall be performed based on ASME B31.3. However, issues such as acceptance of using a more fit equation can be accepted as the option for an alternative method. ■

Author's Bio data