Saudi Aramco

Metal Loss

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Section Contents:

A design engineer takes many factors into consideration when designing plant piping. One important consideration is the thickness of the metal. The pipe wall must be thick neough to withstand operating pressures. The design engineer must determine what minimum thickness of metal (TM) is required to withstand the normal operating pressure. However, the design engineer must also consider other factors, such as structural integrity.

Structural Integrity

Structural Integrity is an important factor in piping design. A pipe wall can exceed the TM required by pressure calculations, yet be incapable ofsupporting its own weight across a given open span. Table 1 shows absolute minimum allowable thicknesses for piping of various sizes. The calculated TM for any given piping must be compared to the figures in this table. The retirement thickness must be the greater of the two.

Corrosion Allowance

In addition to the calculated thickness for pressure and the thickness required for structural integrity, the design engineer must allow for general corrosion during normal operation. Due to the nature of the products flowing through it, piping will suffer a certain amount of general corrosion during operation. The design engineer must allow for this

Table 1.

Plain-end Pipe Sizes (in.)			Minimum Thickness
>0	TO	1/2	.08
>1/2	TO	1	.09
>1	TO	2	.10
>2	TO	3	.11
>3	TO	4	.13
>4	TO	6	.15
>6	TO	8	.18
>8	TO	24	.20
>24			.25

loss of metal so the piping will have a reasonable operating life. The additional thickness allowed for corrosion is called the corrosion allowance. The amount of corrosion allowance is based on data collected throughout the industry. The full thickness of the metal when new, also called thickness original (TO), is the TM plus the corrosion allowance.

Thickness Minimum

For pressure vessels and critical piping, the TM calculated by the design engineers is specified on Safety Instruction Sheets (SISs), in the Operating Limits section. However, the TM for regular process piping must be calculated according to API Chapter XI, paragraph 11.10.1. In some cases, the thickness data has been computerized and TMs are available from computer printouts. These printouts can be obtained from the On Stream Inspection Coordinator or the unit supervisor. If the TM is not available on the computer, the formula shown below can be used to calculate the TM for piping:

$$t = \frac{PD}{2SE}$$

where

- t = required thickness of the pipe walls, measured in millimeters
- P = pressure contained by the pipe, measured in kilopascals per square inch (ksi)
- D = outside diameter of the pipe, measured in millimeters
- S = allowable unit stress at the operating temperature, measured in ksi
- E = longitudinal joint efficiency (joint efficiency is a rating for the strength of any longitudinal seam in a pipe)

Notice that all measurements used in this formula are metric. You may not always find the measurements in the metric system. Measurements in inches or pounds per square inch (psi) must be converted to metric measures before they can be used in the formula. Multiply inches by 25.4 to convert to millimeters. Divide psi by 1,000 to convert to kilopascals.

In the following example, values have been substituted for the variables to demonstrate how the formula works:

$$t = \frac{.66*355.6}{2*13.6}$$

$$t = \frac{234.696}{27.2}$$

$$t = 8.629$$

In the example, pressure P is .66 kilopascals, outside diameter D is 355.6 mm, and the combined value of stress S and joint efficiency E is 13.6 ksi. Thus TM for this pipe must be 8.629 mm.

The values for the formula's variables come from several sources. The relief valve setting that protects a piping system determines the maximum pressure that can occur in the pipe during operation. The relief valve is usually located on a column or other type of pressure vessel in the system. Follow these steps to verify the maximum operating pressure:

- locate the pipe on the Piping and Instrument Drawing (P&ID)
- determine which relief valve protects the pipe
- look up the maximum operating pressure on the SIS for the vessel where the relief valve is located

Substitute the value you located for the variable *P* in the formula.

The outside diameter of the pipe is not the same thing as the nominal pipe size. Look at the table entitled Dimensions and Minimum Nozzle Thicknesses of Seamless and Welded Pipe; a copy appears below. The value for the variable *D* comes from the Outside Diameter column. For example, a pipe with a nominal size of 4″ has an outside diameter of 4.5″.

DIMENSIONS AND MINIMUM NOZZLE THICKNESS OF SEAMLESS AND WELDED STEEL PIPE

NOMINAL PIPE SIZE	OUTSIDE DIAMETER	STD. SCH.	SCH. 30	SCH. 40	SCH. 60	SCH. 80	SCH. 160	* T M PIPE	T M NOZZLE	NOMINAL PIPE SIZE
1/2"	0.840	.109		.109		.147	0.187	.08	.096	1/2"
3/4"	1.050	.113		.113		.154	0.218	.09	.099	3/4"
1"	1.315	.133		.135		.179	0.250	.09	.117	1"
1-1/2"	1.900	.145		.145		.200	0.281	.10	.128	1-1/2"
2"	2.375	.154		.154		.218	0.343	.10	.135	2"
3"	3.5	.216		.216		.300	0.438	.11	.190	3"
4"	4.5	.237		.237		.337	0.531	.13	.209	4"
6"	6.625	.280		.280		.432	0.718	.15	.246	6"
8"	8.625	.322	.277	.322	.406	.500	0.906	.18	.283	8"
10"	10.75	.365	.307	.365	.500	.593	1.125	.20	.320	10"
12"	12.75	.375	.330	.406	.562	.687	1.312	.20	.330	12"
14"	14.0	.375	.375	.438	.594	.750	1.406	.20	.330	14"
16"	16.0	.375	.375	.500	.656	.843	1.593	.20	.330	16"
18"	18.0	.375	.438	.562	.750	.937	1.781	.20	.330	18"
20"	20.0	.375	.500	.593	.812	1.031	1.968	.20	.330	20"
24"	24.0	.375	.562	.687	.969	1.218	2.343	.20	.330	24"
30"	30.0	.375	.625					.25		30"

*FROM PIPE+ COMPUTER PROGRAM

The value for the variable *S* can be read from the table in ANSI B31.3. The joint efficiency, indicated by the variable *E* in the formula, is included in the stress values in the ANSI tables. If the ANSI table specifies **SE** values (rather than simply **S** values) then, **SE**, as taken from the ANSI table, is used as one value to calculate the TM in the formula given above. In this case, you do not need a separate value for the variable *E*.

Joint efficiency is a rating for the strength of any longitudinal seam in a pipe. Most of the pressure piping used at Saudi Aramco is seamless piping; however, the amount of new seamed piping is increasing because it is less expensive. The joint efficiency **E** for seamless pipe is **1.0**.

Table 302.3.4 of ASME B31.3. shows the various kinds of longitudinal seams used for pipe manufacture. The column for the value **E** indicates the joint efficiency. Pipe with the type of joint shown in category one, Furnace Butt Weld, is never used by Saudi Aramco. However, the other categories are in use and you should be able to identify them.

Look at category 3, Single Butt Weld, in the table. Notice that the joint efficiency varies based on the extent of the radiographs performed on longitudinal welds. The minimum value for **E** is 0.80, but if the quality of the welds were spot checked by radiographs during fabrication, then the value for **E** can be increased to 0.90. The joint efficiency can be increased to the maximum value of 1.0 if 100% of the pipe welds were radiographed during fabrication.

The safety factor for process plant piping is 3 to 1. Power piping is specified in a separate standard, B31.1, because its safety factor is 4 to 1.

Joint efficiency is not included with the stress values in Table A-1 of ASME B31.3, 1990 Edition. Table A-1B of ASME B31.3 gives the joint efficiency for various kinds of pipe with longitudinal seams. The Inspector looks up **S** and **E** values as follows:

- Process plant piping: **S** from Table A-1 and **E** from Table A-1B of ASME B31.3, 1990 Edition.
- Power piping: **S** and **E** from separate columns of Table A-1 of ASME B31.1, 1990 Edition.

Every year or two the societies that produce the industry standards issue new editions. The new editions contain some changes, however, most of the information is the same. The inspector can use older editions if they are cited by Saudi Aramco standards. However, he must be careful to use the data in the standards in the way that it was intended.

Most of the standards currently cited in Saudi Aramco standards related to TM and pipe thicknesses are found in ANSI B31.3 for process plant piping and in ANSI B31.1 for power piping. However, the 1990 edition of the these standards is found in the ASME standards with the same identification numbers, ASME B31.3 and ASME B31.1 respectively.

The values found in the tables are the same, but the data is presented in a slightly different way. Table A-1 of ASME B31.1, 1990 Edition gives the data for carbon steel pipe. Notice that the stress **(S)** values and the joint efficiency **(E)** values are in separate columns in this table. As you recall in the ANSI tables S and E were given as one value called **SE**.

> The Inspector must carefully determine the values he uses in the formula for calculating TM. If he uses incorrect values for S and E, then he may calculate a TM that is substantially higher than it should be.

Remaining Life

The Remaining Life (RL) is an estimate of how much longer a pipe can remain in service without going beyond the TM. In order to estimate RL, we must determine the Corrosion Rate (C) and the Remaining Corrosion Allowance (RCA).

Corrosion Rate

The corrosion rate is the amount of corrosion that occurs during a specified period of time. In most cases, we express it as millimeters of metal loss per year. The formula shown below can be used to calculate the rate of corrosion:

$$C = \frac{TO - TA}{Time}$$

where

- C = the corrosion rate, represented in millimeters per year
- TO = thickness original, measured in millimeters
- TA = thickness actual, measured in millimeters
- Time = operating period, measured in years

As with the TM formula, the measurement increments are metric. Convert any measurements recorded in inches to metric before using the formula.

In the following example, values have been substituted for the variables to demonstrate how the formula works.

$$C = \frac{30 - 28.829}{2.5}$$

$$C = \frac{1.171}{2.5}$$

$C = .4684$

In this example, TO is 30 mm. TA was measured at 28.829 mm. The pipe has been in operation for 30 months, or 2.5 years. Thus, C equals .4684 mm per year.

For critical piping and pressure vessels, an SIS lists the TO. For non-critical process piping, we can determine the TO from the table Dimensions and Minimum Nozzle Thickness of Seamless and Welded Steel Pipe. For example, assume we are working with six-inch, Schedule 80 piping. The first column on the left lists nominal pipe sizes. Find 6". Now move right to the seventh column, titles SCH. 80. The nominal TO is .432". Remember that this measurement must be converted to millimeters before using it in the formula.

TA is obtained by measuring the piping. There are several tools used to measure thickness, including the D-meter, the Steeltest™ magnetic flux leak detector, and X-rays.

Time is obtained from the plant history, UT Gauging Sheet, or other inspection records.

Remember that C is not constant. There are fluctuations in the chemical components of the various products that cause corrosion. These fluctuations can cause corrosion to increase or increase during a given run. A variation of the general corrosion rate formula can be used to calculate C for a specific run:

$$C_1 = \frac{TA_1 - TA}{\text{Time}}$$

where

C_1 = the previous run's corrosion rate, represented in millimeters per year

TA_1 = TA from the previous inspection, measured in millimeters

TA = the current TA, measured in millimeters

Time = the length of the previous run, measured in years

We can then compare C to C_1 in order to determine whether the corrosion rate has increased during the previous run. If it has, Operations must be notified so that they can determine what is causing the increase and take the necessary steps.

Remaining Corrosion Allowance

The Remaining Corrosion Allowance (RCA) is the amount of metal left in the pipe wall beyond the TM after the piping has been in service for some period of time. Piping is kept in service as long as there is sufficient RCA. RCA is calculated with a simple formula:

$$RCA = TA - TM$$

Calculating RL and the Inspection Interval

To calculate RL, we divide the remaining corrosion allowance by C or C_1, whichever is greater:

$$RL = \frac{RCA}{C} \quad \text{or} \quad RL = \frac{RCA}{C_1}$$

Due to the possibility of an increase in the corrosion rate, the piping is inspected again when half the RL has passed by. For example, if RL is 3 years, the piping must be inspected again in 1.5 years:

$$NI = \frac{RL}{2}$$

where

NI = next inspection interval, expressed in years.

NI lets us determine whether the piping will limit the next run. For example, if RL for a given section of piping is 4 years and the run is 3 years, NI—one half of RL—limits the run.