

Ballot ID:

Title: Changes to Sulfidation/Naphthenic Acid Corrosion

Purpose: Modifications to module to address variability of corrosion.

Impact: No changes to the corrosion tables are suggested.

Rationale: The current module is not as clear about variability of corrosion rates when sulfidation and naphthenic acid are active.

Technical Reference(s):

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Proposed Changes and/or Wording

Risk-Based Inspection Methodology
Part 2—Probability of Failure Methodology
Annex 2.B—Determination of Corrosion Rates

2.B.3 High Temperature Sulfidic and Naphthenic Acid Corrosion

2.B.3.1 Description of Damage

High temperature sulfidic corrosion is a form of normally uniform corrosion that can occur at temperatures typically above about ~~204232~~ °C (~~400450~~ °F). This form of corrosion most often occurs in many of the same areas as naphthenic acid corrosion. Sulfur species occur naturally in most crude oils but their concentrations vary from crude-to-crude. These naturally occurring compounds may be corrosive themselves as well as when they are converted to hydrogen sulfide through thermal decomposition. Catalytic conversion of sulfur compounds to 2S occurs in the presence of hydrogen and a catalyst bed in hydroprocessing units. Corrosion in vapor streams containing both H₂S and hydrogen is covered in [Section 2.B.4](#).

As with sulfur compounds, naphthenic acids occur naturally in some crude oils. During distillation, these acids tend to concentrate in higher boiling point fractions such as heavy atmospheric gas oil, atmospheric resid, and vacuum gas oils. The acids may also be present in vacuum resid, but often many of the more corrosive ones will have distilled into the vacuum side streams. Lower boiling point streams are usually low in naphthenic acids. Corrosion may appear either as pitting, more common at lower acid levels, or grooving and gouging at higher acid levels and, particularly, at higher velocities. Naphthenic acids may modify or destabilize protective films (sulfides or oxides) on the material and thus allow a high sulfidation corrosion rate to continue or it may itself directly attack the base material.

The corrosion rate in high temperature sulfidic and naphthenic acid environments is primarily a function of the material, temperature, and the concentration of the sulfur compound(s) present. The presence of naphthenic acid in sufficient amounts, however, can dramatically decrease a material's corrosion resistance where it might otherwise have suitable corrosion resistance. The following summarize the key variables in corrosion.

- a) In high temperature sulfidic environments, materials such as carbon and low alloy steels form sulfide corrosion products that adhere to the metal and therefore slow corrosion reactions. The rate at which these scales form and how well they adhere to the metal surface depends on the environmental factors mentioned.
- b) Moderate additions of chromium to carbon steel increase the material's corrosion resistance. ~~Alloys containing 5Cr-0.5Mo, 7Cr-1Mo, and 9Cr-1Mo are often sufficient to provide acceptable material performance in these environments.~~ Lower alloys such as 1.25Cr-0.5Mo ~~and~~ 2.25Cr-1Mo ~~and~~ 5Cr-0.5Mo generally do not offer sufficient benefits over carbon steel to justify their use. Stainless steels such as 12Cr (Type 405, 410, 410S) and Type 304 may be required at higher sulfur levels and temperatures.
- c) Sulfidation corrosion is related to the amount of sulfur present in the stream and is usually reported simply as wt% sulfur. Corrosion generally increases with increasing sulfur content.
- d) High temperature sulfidic corrosion occurs at temperatures greater than about 204 °C (400 °F). Naphthenic acid corrosion typically has been observed in the ~~204232~~ °C to ~~399427~~ °C (~~400450~~ °F to ~~750800~~ °F) temperature range although corrosion which exhibits naphthenic acid characteristics has been reported outside this temperature range. Above 399 °C (750 °F), the naphthenic acids either break down or distill into the vapor phase. While sulfidation will occur in both liquid and vapor phases, naphthenic acid corrosion occurs only where liquid phase is present.
- e) The materials most vulnerable to naphthenic acid corrosion are carbon steel and the iron-chrome (5 to 12 % Cr) alloys commonly used in corrosive refining services. 12Cr may experience corrosion rates greater than that of carbon steel. Type 304 stainless steel offers some resistance to naphthenic acid corrosion at lower acid levels, but normally the molybdenum containing austenitic stainless steels (Type 316 or Type 317 SS) are required for resistance to greater acid concentrations. It has been found that a minimum Mo content of 2.5 % is required in Type 316 SS to provide the best resistance to naphthenic acids.
- f) The amount of naphthenic acid present is most commonly indicated by a neutralization number or total acid number (TAN). The various acids which comprise the naphthenic acid family can have distinctly different corrosivities. The TAN is determined by an ASTM standard titration and is reported in mg KOH/g,

which is the amount of potassium hydroxide (KOH) required to neutralize the acidity of one gram of oil sample. While both colorimetric and potentiometric titration methods are available, the potentiometric method covered by ASTM D664 is the more commonly used method. It should be noted that the titration neutralizes all of the acids present and not just the naphthenic acids. For example, dissolved hydrogen sulfide will be represented in the TAN of a sample. From a corrosion standpoint, the TAN of the liquid hydrocarbon stream being evaluated rather than the TAN of the whole crude is the important parameter in determining susceptibility to naphthenic acid corrosion.

- g) Another important factor in corrosion is the stream velocity, particularly where naphthenic acid is a factor in corrosion. Increased velocity increases the corrosivity by enhancing removal of protective sulfides. This effect is most pronounced in mixed liquid-vapor phase systems where velocities may be high.
- h) At particularly low sulfur levels, naphthenic acid corrosion may be more severe, even at low TAN since protective sulfides may not readily form.

2.B.3.2 Corrosion Rate Variability

There are several factors that influence the variability in the corrosion rates for sulfidation, when values obtained from the modified McConomy Curves and measured corrosion rates are compared. Factors including sulfur content, silicon content of the carbon steel, and flow regime/velocity, should be considered when determining the estimated corrosion rates, specifically when little or no information is available for the specific unit components.

In general, the stream corrosivity will increase as the sulfur content of the stream increases. Many different sulfur species exist in crude oil and can affect corrosion differently. Sulfur in the crude can be in the form of H₂S, mercaptans, elemental sulfur, polysulfides, thiophenes, aliphatic sulfides and aliphatic disulfides. Each one of these species has a different reactivity or effect on corrosion rates. As a result, different crudes with same total sulfur content can have very different corrosivity due to the sulfur species combination. Crude analysis of crude oils and its fractions is performed to identify the various sulfur species present. Predictive models can be developed based on a combination of laboratory testing and field experience.

Corrosion rates are accelerated when components are put in service due to the exposed steel surface in the sulfur containing environment. Corrosion rates slow down as a protective sulfide scale forms and reduces diffusion. The protective sulfide scale is a relative weak crystal lattice that may be removed in high velocity conditions that induces shear stress and/or by naphthenic acid. Exposing the unprotected material surface to the sulfur compounds causes accelerated corrosion. The repeated process of stripping the protective sulfide scale to expose the material and reforming the sulfide scale results in high corrosion rates. A flow velocity \geq 180 ft/s (60 m/s) is known to strip the sulfide protective scale and prevent formation of the sulfide scale and result in severe corrosion.

No flow or very low flow can cause stratification of corrosive species and result in preferential corrosion attack. Silicon content of $< 0.10\%$ in carbon steel components can also result in accelerated sulfidation corrosion rates. In some applications, carbon steel may appear to be performing well with low measured corrosion rates until an unexpected failure occurs at an unidentified, low-silicon component in the circuit.

The process units where sulfidic and naphthenic acid corrosion is most commonly observed are atmospheric and vacuum crude distillation as well as the feed systems of downstream units such as hydrotreaters, catalytic crackers, and cokers. In hydrotreaters, naphthenic acid corrosion has not been reported downstream of the hydrogen addition point, even upstream of the reactor. Catalytic crackers and cokers thermally decompose naphthenic acids so this form of corrosion is also not normally reported in the fractionation sections of these units unless uncracked feed is carried in. Naphthenic acids can appear in high concentrations in lube extract oil streams when naphthenic acid containing feeds are processed. It should be noted that, where naphthenic acids may thermally decompose, lighter organic acids or carbon dioxide may form that can affect the corrosivity of condensed waters.

2.B.3.3 Basic Data

The data listed in [Table 2.B.3.1](#) are required to determine the estimated rate of corrosion in high temperature sulfidic and naphthenic acid service. If precise data have not been measured, a knowledgeable process specialist should be consulted.

2.B.3.4 Determination of Corrosion Rate

~~The steps required to determine the corrosion rate are shown in Figure 2.B.3.1.~~ The corrosion rate may be determined using the basic data in [Table 2.B.3.1](#) in conjunction with [Tables 2.B.3.2](#) through [2.B.3.10](#).

The corrosion rate in high temperature sulfidic environments in the absence of a naphthenic acid influence is based upon the modified McCconomy curves. For components in service with no naphthenic acid, the corrosion rate follows the McCconomy curves represented by the lowest ~~naphthenic acid~~TAN content in each of [Tables 2.B.3.2](#) through [2.B.2.10](#). While various papers have been presented on naphthenic acid corrosion, no widely accepted correlations have yet been developed between corrosion rate and the various factors influencing it. Due to the lack of accurate industry tools for estimating naphthenic acid corrosion, the estimate rates provided in [Table 2.B.3.2](#) through [Table 2.B.3.10](#) should be adjusted to improve accuracy as high quality plant corrosion rate data becomes available through UT scans, RT surveys, well placed corrosion and/or ultrasonic probes, and other monitoring methods. Consequently, the corrosion ~~rate to be used when~~rates provided in the tables for naphthenic acid is a factor is only an order of magnituderough estimate of the actual corrosion rate in the specific service. Once a corrosion rate is selected from the appropriate table, it should be multiplied by a factor of 5 if the velocity is > 30.48 m/s (100 ft/s).

2.B.3.5 References

See References [94], [95] ([Appendix 3](#)), [96], and [97] in [Section 2.2](#).

2.B.3.6 Tables

Table 2.B.3.1—High Temperature Sulfidic and Naphthenic Acid Corrosion—Basic Data Required for Analysis

Basic Data	Comments
Material of construction	Determine the material of construction of the equipment/piping. For 316 SS, if the Mo content is not known, assume it is < 2.5 wt%.
Maximum temperature, (°C:°F)	Determine the maximum temperature of the process stream.
Sulfur content of the stream	Determine the sulfur content of the stream that is in this piece of equipment. If sulfur content is not known, contact a knowledgeable process engineer for an estimate.
Total acid number (TAN) (TAN = mg KOH/g oil sample)	The TAN of importance is that of the liquid hydrocarbon phase present in the equipment/piping being evaluated. If not known, consult a knowledgeable process engineer for an estimate.
Velocity	Determine the maximum velocity in this equipment/piping. Although conditions in a vessel may be essentially stagnant, the velocity in flowing nozzles should be considered.

Table 2.B.3.2—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for Carbon Steel (mpy)

Sulfur (wt%)	TAN (mg/g)	Temperature (°F)							
		≤450	500	550	600	650	700	750	>750
0.2	0.3	1	3	7	15	20	35	50	60
	0.65	5	15	25	35	45	55	65	75
	1.5	20	25	35	65	120	150	180	200
	3.0	30	60	60	120	150	160	240	240
	4.0	40	80	100	160	180	200	280	300
0.4	0.3	1	4	10	20	30	50	70	80
	0.65	5	10	15	25	40	60	80	90
	1.5	8	15	25	35	50	75	90	110
	3.0	10	20	35	50	70	100	120	130
	4.0	20	30	50	70	90	120	140	160
0.6	0.3	1	5	10	25	40	60	90	100
	0.65	5	10	15	30	50	80	110	130
	1.5	10	15	30	50	80	100	130	150
	3.0	15	30	50	80	100	120	140	170
	4.0	25	40	60	100	120	150	180	200
1.5	0.3	2	5	15	30	50	80	110	130
	0.65	7	10	20	35	55	100	130	150
	1.5	15	20	35	55	100	120	140	170
	3.0	20	30	55	85	110	150	170	200
	4.0	30	45	75	120	140	180	200	260
2.5	0.3	2	7	20	35	55	95	130	150
	0.65	7	10	30	45	60	120	140	170
	1.5	15	20	40	60	75	140	170	200
	3.0	20	35	60	90	120	170	200	260
	4.0	35	50	80	120	150	200	260	280
3.0	0.3	2	8	20	40	60	100	140	160
	0.65	8	15	25	45	65	120	150	170
	1.5	20	25	35	65	120	150	180	200
	3.0	30	60	60	120	150	160	240	240
	4.0	40	80	100	160	180	200	280	300

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.2M—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for Carbon Steel (mm/y)

Sulfur (wt%)	TAN (mg/g)	Temperature (°C)							
		≤232	260	288	315	343	371	399	>399
0.2	0.3	0.03	0.08	0.18	0.38	0.51	0.89	1.27	1.52
	0.65	0.13	0.38	0.64	0.89	1.14	1.40	1.65	1.91
	1.5	0.51	0.64	0.89	1.65	3.05	3.81	4.57	5.08
	3.0	0.76	1.52	1.52	3.05	3.81	4.06	6.10	6.10
	4.0	1.02	2.03	2.54	4.06	4.57	5.08	7.11	7.62
0.4	0.3	0.03	0.10	0.25	0.51	0.76	1.27	1.78	2.03
	0.65	0.13	0.25	0.38	0.64	1.02	1.52	2.03	2.29
	1.5	0.20	0.38	0.64	0.89	1.27	1.91	2.29	2.79
	3.0	0.25	0.51	0.89	1.27	1.78	2.54	3.05	3.30
	4.0	0.51	0.76	1.27	1.78	2.29	3.05	3.56	4.06
0.6	0.3	0.03	0.13	0.25	0.64	1.02	1.52	2.29	2.54
	0.65	0.13	0.25	0.38	0.76	1.27	2.03	2.79	3.30
	1.5	0.25	0.38	0.76	1.27	2.03	2.54	3.30	3.81
	3.0	0.38	0.76	1.27	2.03	2.54	3.05	3.56	4.32
	4.0	0.64	1.02	1.52	2.54	3.05	3.81	4.57	5.08
1.5	0.3	0.05	0.13	0.38	0.76	1.27	2.03	2.79	3.30
	0.65	0.18	0.25	0.51	0.89	1.40	2.54	3.30	3.81
	1.5	0.38	0.51	0.89	1.40	2.54	3.05	3.56	4.32
	3.0	0.51	0.76	1.40	2.16	2.79	3.81	4.32	5.08
	4.0	0.76	1.14	1.91	3.05	3.56	4.57	5.08	6.60
2.5	0.3	0.05	0.18	0.51	0.89	1.40	2.41	3.30	3.81
	0.65	0.18	0.25	0.76	1.14	1.52	3.05	3.56	4.32
	1.5	0.38	0.51	1.02	1.52	1.91	3.56	4.32	5.08
	3.0	0.51	0.89	1.52	2.29	3.05	4.32	5.08	6.60
	4.0	0.89	1.27	2.03	3.05	3.81	5.08	6.60	7.11
3.0	0.3	0.05	0.20	0.51	1.02	1.52	2.54	3.56	4.06
	0.65	0.20	0.38	0.64	1.14	1.65	3.05	3.81	4.32
	1.5	0.51	0.64	0.89	1.65	3.05	3.81	4.57	5.08
	3.0	0.76	1.52	1.52	3.05	3.81	4.06	6.10	6.10
	4.0	1.02	2.03	2.54	4.06	4.57	5.08	7.11	7.62

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.3—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 1 Cr-0.2 Mo, 1 Cr-0.5 Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, and 3Cr-1Mo (mpy)

Sulfur (wt%)	TAN (mg/g)	Temperature (°F)							
		≤450	500	550	600	650	700	750	>750
0.2	0.3	1	1	4	7	13	21	25	30
	0.65	3	8	15	20	25	30	35	40
	1.5	10	15	20	30	60	75	90	100
	3.0	15	30	30	60	75	85	120	120
	4.0	20	40	50	80	100	120	140	160
0.4	0.3	1	2	5	10	20	30	35	40
	0.65	3	5	8	15	20	30	40	45
	1.5	4	8	15	20	25	40	45	55
	3.0	5	10	20	25	35	50	60	65
	4.0	10	15	25	35	45	60	70	80
0.8	0.3	1	3	6	15	25	40	45	50
	0.65	3	5	8	20	30	45	55	60
	1.5	5	8	15	25	40	50	65	75
	3.0	7	15	25	40	50	60	70	85
	4.0	12	20	30	50	60	75	90	100
1.5	0.3	2	3	8	15	30	50	55	65
	0.65	4	5	10	20	40	55	65	75
	1.5	6	10	20	30	50	65	70	80
	3.0	10	15	30	45	60	75	85	100
	4.0	15	20	35	60	75	90	100	130
2.5	0.3	2	4	9	20	35	55	65	75
	0.65	4	5	15	25	40	60	70	80
	1.5	7	10	20	30	45	70	80	100
	3.0	10	15	30	45	60	80	100	120
	4.0	15	25	40	60	80	100	120	140
3.0	0.3	2	4	10	20	35	60	70	80
	0.65	5	8	15	25	40	70	75	85
	1.5	10	15	20	30	60	75	90	100
	3.0	15	30	30	60	75	85	120	120
	4.0	20	40	50	80	100	120	140	160

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.3M—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 1 Cr-0.2 Mo, 1 Cr-0.5 Mo, 1.25Cr-0.5Mo, 2.25Cr-1Mo, and 3Cr-1Mo (mm/y)

Sulfur (wt%)	TAN (mg/g)	Temperature (°C)							
		≤232	260	288	315	343	371	399	>399
0.2	0.3	0.03	0.03	0.10	0.18	0.33	0.53	0.64	0.76
	0.65	0.08	0.20	0.38	0.51	0.64	0.76	0.89	1.02
	1.5	0.25	0.38	0.51	0.76	1.52	1.91	2.29	2.54
	3.0	0.38	0.76	0.76	1.52	1.91	2.16	3.05	3.05
	4.0	0.51	1.02	1.27	2.03	2.54	3.05	3.56	4.06
0.4	0.3	0.03	0.05	0.13	0.25	0.51	0.76	0.89	1.02
	0.65	0.08	0.13	0.20	0.38	0.51	0.76	1.02	1.14
	1.5	0.10	0.20	0.38	0.51	0.64	1.02	1.14	1.40
	3.0	0.13	0.25	0.51	0.64	0.89	1.27	1.52	1.65
	4.0	0.25	0.38	0.64	0.89	1.14	1.52	1.78	2.03
0.8	0.3	0.03	0.08	0.15	0.38	0.64	1.02	1.14	1.27
	0.65	0.08	0.13	0.20	0.51	0.76	1.14	1.40	1.52
	1.5	0.13	0.20	0.38	0.64	1.02	1.27	1.65	1.91
	3.0	0.18	0.38	0.64	1.02	1.27	1.52	1.78	2.16
	4.0	0.30	0.51	0.76	1.27	1.52	1.91	2.29	2.54
1.5	0.3	0.05	0.08	0.20	0.38	0.76	1.27	1.40	1.65
	0.65	0.10	0.13	0.25	0.51	1.02	1.40	1.65	1.91
	1.5	0.15	0.25	0.51	0.76	1.27	1.65	1.78	2.03
	3.0	0.25	0.38	0.76	1.14	1.52	1.91	2.16	2.54
	4.0	0.38	0.51	0.89	1.52	1.91	2.29	2.54	3.30
2.5	0.3	0.05	0.10	0.23	0.51	0.89	1.40	1.65	1.91
	0.65	0.10	0.13	0.38	0.64	1.02	1.52	1.78	2.03
	1.5	0.18	0.25	0.51	0.76	1.14	1.78	2.03	2.54
	3.0	0.25	0.38	0.76	1.14	1.52	2.03	2.54	3.05
	4.0	0.38	0.64	1.02	1.52	2.03	2.54	3.05	3.56
3.0	0.3	0.05	0.10	0.25	0.51	0.89	1.52	1.78	2.03
	0.65	0.13	0.20	0.38	0.64	1.02	1.78	1.91	2.16
	1.5	0.25	0.38	0.51	0.76	1.52	1.91	2.29	2.54
	3.0	0.38	0.76	0.76	1.52	1.91	2.16	3.05	3.05
	4.0	0.51	1.02	1.27	2.03	2.54	3.05	3.56	4.06

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.4—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 5Cr-0.5Mo (mpy)

Sulfur (wt%)	TAN (mg/g)	Temperature (°F)							
		≤450	500	550	600	650	700	750	>750
0.2	0.7	1	1	2	4	6	8	10	15
	1.1	2	3	4	6	10	10	15	20
	1.75	7	10	15	20	25	35	45	50
	3.0	10	15	20	30	40	45	50	60
	4.0	15	20	30	40	50	60	70	80
0.4	0.7	1	2	3	5	8	10	15	20
	1.1	2	3	4	6	10	15	20	25
	1.75	2	4	6	8	15	20	25	30
	3.0	4	6	8	10	15	20	30	35
	4.0	6	8	10	10	20	25	35	40
0.75	0.7	1	2	4	6	10	15	23	25
	1.1	2	4	6	8	15	20	25	30
	1.75	4	6	8	10	15	20	30	35
	3.0	6	8	10	10	20	25	35	40
	4.0	8	10	10	15	20	30	40	50
1.5	0.7	1	2	5	8	15	20	30	35
	1.1	3	5	10	15	20	30	35	40
	1.75	5	10	15	20	30	35	40	45
	3.0	10	15	20	30	35	40	45	50
	4.0	15	20	30	35	40	50	60	70
2.5	0.7	1	3	6	9	15	20	35	40
	1.1	5	7	10	15	20	25	40	45
	1.75	7	10	15	20	25	35	45	50
	3.0	10	15	20	30	40	45	50	60
	4.0	15	20	30	40	50	60	70	80
3.0	0.7	2	3	6	10	15	25	35	40
	1.1	5	7	10	15	20	30	40	45
	1.75	7	10	15	20	25	35	45	50
	3.0	10	15	20	30	40	45	50	60
	4.0	15	20	30	40	50	60	70	80

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.4M—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 5Cr-0.5Mo (mm/y)

Sulfur (wt%)	TAN (mg/g)	Temperature (°C)							
		≤232	260	288	315	343	371	399	>399
0.2	0.7	0.03	0.03	0.05	0.10	0.15	0.20	0.25	0.38
	1.1	0.05	0.08	0.10	0.15	0.25	0.25	0.38	0.51
	1.75	0.18	0.25	0.38	0.51	0.64	0.89	1.14	1.27
	3.0	0.25	0.38	0.51	0.76	1.02	1.14	1.27	1.52
	4.0	0.38	0.51	0.76	1.02	1.27	1.52	1.78	2.03
0.4	0.7	0.03	0.05	0.08	0.13	0.20	0.25	0.38	0.51
	1.1	0.05	0.08	0.10	0.15	0.25	0.38	0.51	0.64
	1.75	0.05	0.10	0.15	0.20	0.38	0.51	0.64	0.76
	3.0	0.10	0.15	0.20	0.25	0.38	0.51	0.76	0.89
	4.0	0.15	0.20	0.25	0.25	0.51	0.64	0.89	1.02
0.75	0.7	0.03	0.05	0.10	0.15	0.25	0.38	0.58	0.64
	1.1	0.05	0.10	0.15	0.20	0.38	0.51	0.64	0.76
	1.75	0.10	0.15	0.20	0.25	0.38	0.51	0.76	0.89
	3.0	0.15	0.20	0.25	0.25	0.51	0.64	0.89	1.02
	4.0	0.20	0.25	0.25	0.38	0.51	0.76	1.02	1.27
1.5	0.7	0.03	0.05	0.13	0.20	0.38	0.51	0.76	0.89
	1.1	0.08	0.13	0.25	0.38	0.51	0.76	0.89	1.02
	1.75	0.13	0.25	0.38	0.51	0.76	0.89	1.02	1.14
	3.0	0.25	0.38	0.51	0.76	0.89	1.02	1.14	1.27
	4.0	0.38	0.51	0.76	0.89	1.02	1.27	1.52	1.78
2.5	0.7	0.03	0.08	0.15	0.23	0.38	0.51	0.89	1.02
	1.1	0.13	0.18	0.25	0.38	0.51	0.64	1.02	1.14
	1.75	0.18	0.25	0.38	0.51	0.64	0.89	1.14	1.27
	3.0	0.25	0.38	0.51	0.76	1.02	1.14	1.27	1.52
	4.0	0.38	0.51	0.76	1.02	1.27	1.52	1.78	2.03
3.0	0.7	0.05	0.08	0.15	0.25	0.38	0.64	0.89	1.02
	1.1	0.13	0.18	0.25	0.38	0.51	0.76	1.02	1.14
	1.75	0.18	0.25	0.38	0.51	0.64	0.89	1.14	1.27
	3.0	0.25	0.38	0.51	0.76	1.02	1.14	1.27	1.52
	4.0	0.38	0.51	0.76	1.02	1.27	1.52	1.78	2.03

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.5—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 7Cr-1Mo (mpy)

Sulfur (wt%)	TAN (mg/g)	Temperature (°F)							
		≤450	500	550	600	650	700	750	>750
0.2	0.7	1	1	1	2	4	6	7	8
	1.1	1	2	3	5	7	8	10	15
	1.75	4	7	10	15	20	25	30	35
	3.0	7	10	15	20	25	30	35	45
	4.0	10	15	20	25	30	35	45	60
0.4	0.7	1	1	2	4	5	8	10	15
	1.1	1	2	4	5	8	10	15	15
	1.75	2	4	5	6	10	15	15	20
	3.0	3	5	6	9	12	15	20	20
	4.0	4	6	9	10	15	20	20	25
0.8	0.7	1	1	3	4	6	10	15	15
	1.1	2	3	4	6	10	15	15	20
	1.75	3	4	6	10	12	15	20	25
	3.0	4	6	10	12	15	20	25	30
	4.0	5	10	12	15	20	25	30	35
1.5	0.7	1	2	3	6	8	15	15	20
	1.1	2	3	6	10	15	15	20	25
	1.75	3	6	10	15	20	20	25	30
	3.0	6	10	15	20	20	25	30	35
	4.0	10	15	20	20	25	30	35	45
2.5	0.7	1	2	4	6	9	15	20	25
	1.1	6	7	9	10	15	20	25	30
	1.75	7	9	10	15	20	25	30	35
	3.0	9	10	15	20	30	35	35	40
	4.0	10	15	20	30	35	40	50	55
3.0	0.7	1	2	4	7	10	15	20	25
	1.1	2	4	7	10	15	20	25	30
	1.75	4	7	10	15	20	25	30	35
	3.0	7	10	15	20	25	30	35	45
	4.0	10	15	20	25	30	35	45	60

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.5M—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 7Cr-1Mo (mm/y)

Sulfur (wt%)	TAN (mg/g)	Temperature (°C)							
		≤232	260	288	315	343	371	399	>399
0.2	0.7	0.03	0.03	0.03	0.05	0.10	0.15	0.18	0.20
	1.1	0.03	0.05	0.08	0.13	0.18	0.20	0.25	0.38
	1.75	0.10	0.18	0.25	0.38	0.51	0.64	0.76	0.89
	3.0	0.18	0.25	0.38	0.51	0.64	0.76	0.89	1.14
	4.0	0.25	0.38	0.51	0.64	0.76	0.89	1.14	1.52
0.4	0.7	0.03	0.03	0.05	0.10	0.13	0.20	0.25	0.38
	1.1	0.03	0.05	0.10	0.13	0.20	0.25	0.38	0.38
	1.75	0.05	0.10	0.13	0.15	0.25	0.38	0.38	0.51
	3.0	0.08	0.13	0.15	0.23	0.30	0.38	0.51	0.51
	4.0	0.10	0.15	0.23	0.25	0.38	0.51	0.51	0.64
0.8	0.7	0.03	0.03	0.08	0.10	0.15	0.25	0.38	0.38
	1.1	0.05	0.08	0.10	0.15	0.25	0.38	0.38	0.51
	1.75	0.08	0.10	0.15	0.25	0.30	0.38	0.51	0.64
	3.0	0.10	0.15	0.25	0.30	0.38	0.51	0.64	0.76
	4.0	0.13	0.25	0.30	0.38	0.51	0.64	0.76	0.89
1.5	0.7	0.03	0.05	0.08	0.15	0.20	0.38	0.38	0.51
	1.1	0.05	0.08	0.15	0.25	0.38	0.38	0.51	0.64
	1.75	0.08	0.15	0.25	0.38	0.51	0.51	0.64	0.76
	3.0	0.15	0.25	0.38	0.51	0.51	0.64	0.76	0.89
	4.0	0.25	0.38	0.51	0.51	0.64	0.76	0.89	1.14
2.5	0.7	0.03	0.05	0.10	0.15	0.23	0.38	0.51	0.64
	1.1	0.15	0.18	0.23	0.25	0.38	0.51	0.64	0.76
	1.75	0.18	0.23	0.25	0.38	0.51	0.64	0.76	0.89
	3.0	0.23	0.25	0.38	0.51	0.76	0.89	0.89	1.02
	4.0	0.25	0.38	0.51	0.76	0.89	1.02	1.27	1.40
3.0	0.7	0.03	0.05	0.10	0.18	0.25	0.38	0.51	0.64
	1.1	0.05	0.10	0.18	0.25	0.38	0.51	0.64	0.76
	1.75	0.10	0.18	0.25	0.38	0.51	0.64	0.76	0.89
	3.0	0.18	0.25	0.38	0.51	0.64	0.76	0.89	1.14
	4.0	0.25	0.38	0.51	0.64	0.76	0.89	1.14	1.52

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.6—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 9Cr-1Mo (mpy)

Sulfur (wt%)	TAN (mg/g)	Temperature (°F)							
		≤450	500	550	600	650	700	750	>750
0.2	0.7	1	1	1	2	3	4	5	6
	1.1	1	2	2	4	4	5	6	8
	1.75	2	4	5	8	10	15	15	20
	3.0	3	6	10	12	15	20	20	25
	4.0	5	8	12	15	20	25	30	30
0.4	0.7	1	1	2	3	4	6	7	8
	1.1	1	1	2	4	5	7	8	10
	1.75	2	2	3	5	8	8	10	10
	3.0	3	3	5	8	10	10	12	15
	4.0	4	5	8	10	10	12	15	15
0.8	0.7	1	1	2	3	5	8	9	10
	1.1	1	2	3	5	8	10	10	10
	1.75	2	3	5	8	10	10	10	15
	3.0	3	5	8	10	10	15	15	15
	4.0	5	8	10	10	15	15	20	20
1.5	0.7	1	1	2	4	6	10	10	15
	1.1	1	2	3	5	7	10	15	15
	1.75	2	4	4	6	8	12	15	20
	3.0	3	6	5	8	10	15	20	20
	4.0	5	8	10	12	15	20	20	25
2.5	0.7	1	1	3	5	7	10	15	15
	1.1	1	2	4	6	8	10	15	15
	1.75	2	4	5	8	10	15	15	20
	3.0	3	6	10	12	15	20	20	25
	4.0	5	8	12	15	20	25	30	30
3.0	0.7	1	1	3	5	8	10	15	15
	1.1	2	3	5	8	10	15	15	20
	1.75	3	5	10	12	15	20	20	25
	3.0	5	8	12	15	20	25	30	30
	4.0	7	9	15	20	25	30	35	40

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.6M—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 9Cr-1Mo (mm/y)

Sulfur (wt%)	TAN (mg/g)	Temperature (°C)							
		≤232	260	288	315	343	371	399	>399
0.2	0.7	0.03	0.03	0.03	0.05	0.08	0.10	0.13	0.15
	1.1	0.03	0.05	0.05	0.10	0.10	0.13	0.15	0.20
	1.75	0.05	0.10	0.13	0.20	0.25	0.38	0.38	0.51
	3.0	0.08	0.15	0.25	0.30	0.38	0.51	0.51	0.64
	4.0	0.13	0.20	0.30	0.38	0.51	0.64	0.76	0.76
0.4	0.7	0.03	0.03	0.05	0.08	0.10	0.15	0.18	0.20
	1.1	0.03	0.03	0.05	0.10	0.13	0.18	0.20	0.25
	1.75	0.05	0.05	0.08	0.13	0.20	0.20	0.25	0.25
	3.0	0.08	0.08	0.13	0.20	0.25	0.25	0.30	0.38
	4.0	0.10	0.13	0.20	0.25	0.25	0.30	0.38	0.38
0.8	0.7	0.03	0.03	0.05	0.08	0.13	0.20	0.23	0.25
	1.1	0.03	0.05	0.08	0.13	0.20	0.25	0.25	0.25
	1.75	0.05	0.08	0.13	0.20	0.25	0.25	0.25	0.38
	3.0	0.08	0.13	0.20	0.25	0.25	0.38	0.38	0.38
	4.0	0.13	0.20	0.25	0.25	0.38	0.38	0.51	0.51
1.5	0.7	0.03	0.03	0.05	0.10	0.15	0.25	0.25	0.38
	1.1	0.03	0.05	0.08	0.13	0.18	0.25	0.38	0.38
	1.75	0.05	0.10	0.10	0.15	0.20	0.30	0.38	0.51
	3.0	0.08	0.15	0.13	0.20	0.25	0.38	0.51	0.51
	4.0	0.13	0.20	0.25	0.30	0.38	0.51	0.51	0.64
2.5	0.7	0.03	0.03	0.08	0.13	0.18	0.25	0.38	0.38
	1.1	0.03	0.05	0.10	0.15	0.20	0.25	0.38	0.38
	1.75	0.05	0.10	0.13	0.20	0.25	0.38	0.38	0.51
	3.0	0.08	0.15	0.25	0.30	0.38	0.51	0.51	0.64
	4.0	0.13	0.20	0.30	0.38	0.51	0.64	0.76	0.76
3.0	0.7	0.03	0.03	0.08	0.13	0.20	0.25	0.38	0.38
	1.1	0.05	0.08	0.13	0.20	0.25	0.38	0.38	0.51
	1.75	0.08	0.13	0.25	0.30	0.38	0.51	0.51	0.64
	3.0	0.13	0.20	0.30	0.38	0.51	0.64	0.76	0.76
	4.0	0.18	0.23	0.38	0.51	0.64	0.76	0.89	1.02

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.7—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 12 % Cr Steel (mpy)

Sulfur (wt%)	TAN (mg/g)	Temperature (°F)							
		≤450	500	550	600	650	700	750	>750
0.2	0.7	1	1	1	1	1	1	2	2
	1.1	1	1	1	1	1	2	4	5
	1.75	2	2	2	4	4	5	8	10
	3.0	5	10	15	20	25	30	25	40
	4.0	10	15	20	25	30	25	40	45
0.4	0.7	1	1	1	1	1	2	3	3
	1.1	1	1	1	1	1	2	3	3
	1.75	1	2	2	2	2	4	5	5
	3.0	2	3	3	3	3	5	10	15
	4.0	3	4	5	8	10	12	15	20
0.8	0.7	1	1	1	1	1	2	3	4
	1.1	1	1	1	1	1	2	3	4
	1.75	2	2	4	5	6	6	7	8
	3.0	3	3	5	8	10	12	15	20
	4.0	4	5	5	8	10	15	20	25
1.5	0.7	1	1	1	1	2	3	4	5
	1.1	1	1	1	1	2	3	4	5
	1.75	2	2	3	5	7	8	10	10
	3.0	3	3	5	8	10	12	15	20
	4.0	5	8	10	12	15	20	25	30
2.5	0.7	1	1	1	1	2	3	5	6
	1.1	1	1	1	1	2	3	5	6
	1.75	2	5	7	9	10	12	15	15
	3.0	3	8	10	15	20	20	25	30
	4.0	5	10	15	20	25	30	35	40
3.0	0.7	1	1	1	1	2	4	5	6
	1.1	1	1	1	1	2	4	5	6
	1.75	3	5	7	9	10	12	15	15
	3.0	4	8	10	15	20	20	25	30
	4.0	5	10	15	20	25	30	35	40

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.7M—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 12 % Cr Steel (mm/y)

Sulfur (wt%)	TAN (mg/g)	Temperature (°C)							
		≤232	260	288	315	343	371	399	>399
0.2	0.7	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.05
	1.1	0.03	0.03	0.03	0.03	0.03	0.05	0.10	0.13
	1.75	0.05	0.05	0.05	0.10	0.10	0.13	0.20	0.25
	3.0	0.13	0.25	0.38	0.51	0.64	0.76	0.64	1.02
	4.0	0.25	0.38	0.51	0.64	0.76	0.64	1.02	1.14
0.4	0.7	0.03	0.03	0.03	0.03	0.03	0.05	0.08	0.08
	1.1	0.03	0.03	0.03	0.03	0.03	0.05	0.08	0.08
	1.75	0.03	0.05	0.05	0.05	0.05	0.10	0.13	0.13
	3.0	0.05	0.08	0.08	0.08	0.08	0.13	0.25	0.38
	4.0	0.08	0.10	0.13	0.20	0.25	0.30	0.38	0.51
0.8	0.7	0.03	0.03	0.03	0.03	0.03	0.05	0.08	0.10
	1.1	0.03	0.03	0.03	0.03	0.03	0.05	0.08	0.10
	1.75	0.05	0.05	0.10	0.13	0.15	0.15	0.18	0.20
	3.0	0.08	0.08	0.13	0.20	0.25	0.30	0.38	0.51
	4.0	0.10	0.13	0.13	0.20	0.25	0.38	0.51	0.64
1.5	0.7	0.03	0.03	0.03	0.03	0.05	0.08	0.10	0.13
	1.1	0.03	0.03	0.03	0.03	0.05	0.08	0.10	0.13
	1.75	0.05	0.05	0.08	0.13	0.18	0.20	0.25	0.25
	3.0	0.08	0.08	0.13	0.20	0.25	0.30	0.38	0.51
	4.0	0.13	0.20	0.25	0.30	0.38	0.51	0.64	0.76
2.5	0.7	0.03	0.03	0.03	0.03	0.05	0.08	0.13	0.15
	1.1	0.03	0.03	0.03	0.03	0.05	0.08	0.13	0.15
	1.75	0.05	0.13	0.18	0.23	0.25	0.30	0.38	0.38
	3.0	0.08	0.20	0.25	0.38	0.51	0.51	0.64	0.76
	4.0	0.13	0.25	0.38	0.51	0.64	0.76	0.89	1.02
3.0	0.7	0.03	0.03	0.03	0.03	0.05	0.10	0.13	0.15
	1.1	0.03	0.03	0.03	0.03	0.05	0.10	0.13	0.15
	1.75	0.08	0.13	0.18	0.23	0.25	0.30	0.38	0.38
	3.0	0.10	0.20	0.25	0.38	0.51	0.51	0.64	0.76
	4.0	0.13	0.25	0.38	0.51	0.64	0.76	0.89	1.02

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.8—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for Austenitic SS Without Mo (mpy)

Sulfur (wt%)	TAN (mg/g)	Temperature (°F)							
		≤450	500	550	600	650	700	750	>750
0.2	1.0	1	1	1	1	1	1	1	1
	1.5	1	1	1	1	1	1	1	1
	3.0	1	1	1	1	2	3	4	4
	4.0	1	1	1	2	3	4	5	6
0.4	1.0	1	1	1	1	1	1	1	1
	1.5	1	1	1	1	1	1	1	1
	3.0	1	1	1	1	2	3	4	4
	4.0	1	1	1	2	3	4	5	6
0.8	1.0	1	1	1	1	1	1	1	1
	1.5	1	1	1	1	1	1	1	1
	3.0	1	1	1	2	3	4	5	6
	4.0	1	2	2	4	6	8	10	12
1.5	1.0	1	1	1	1	1	1	1	1
	1.5	1	1	1	1	1	1	1	1
	3.0	1	1	1	2	3	4	5	6
	4.0	1	2	2	4	6	8	10	12
2.5	1.0	1	1	1	1	1	1	1	1
	1.5	1	1	1	1	1	1	1	1
	3.0	1	2	2	4	6	8	10	12
	4.0	1	2	4	7	10	14	17	20
3.0	1.0	1	1	1	1	1	1	1	2
	1.5	1	1	1	1	1	2	2	2
	3.0	1	2	2	4	6	8	10	12
	4.0	1	2	4	7	10	14	17	20

—NOTE -1 Austenitic stainless steels without Mo include 304, 304L, 321, 347, etc.

NOTE 2 The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.8M—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for Austenitic SS Without Mo (mm/y)

Sulfur (wt%)	TAN (mg/g)	Temperature (°C)							
		≤232	260	288	315	343	371	399	>399
0.2	1.0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	1.5	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	3.0	0.03	0.03	0.03	0.03	0.05	0.08	0.10	0.10
	4.0	0.03	0.03	0.03	0.05	0.08	0.10	0.13	0.15
0.4	1.0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	1.5	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	3.0	0.03	0.03	0.03	0.03	0.05	0.08	0.10	0.10
	4.0	0.03	0.03	0.03	0.05	0.08	0.10	0.13	0.15
0.8	1.0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	1.5	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	3.0	0.03	0.03	0.03	0.05	0.08	0.10	0.13	0.15
	4.0	0.03	0.05	0.05	0.10	0.15	0.20	0.25	0.30
1.5	1.0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	1.5	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	3.0	0.03	0.03	0.03	0.05	0.08	0.10	0.13	0.15
	4.0	0.03	0.05	0.05	0.10	0.15	0.20	0.25	0.30
2.5	1.0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	1.5	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	3.0	0.03	0.05	0.05	0.10	0.15	0.20	0.25	0.30
	4.0	0.03	0.05	0.10	0.18	0.25	0.36	0.43	0.51
3.0	1.0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05
	1.5	0.03	0.03	0.03	0.03	0.03	0.05	0.05	0.05
	3.0	0.03	0.05	0.05	0.10	0.15	0.20	0.25	0.30
	4.0	0.03	0.05	0.10	0.18	0.25	0.36	0.43	0.51

NOTE 1 Austenitic stainless steels without Mo include 304, 304L, 321, 347, etc.

NOTE 2 The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.9—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 316 SS with < 2.5 % Mo (mpy)

Sulfur (wt%)	TAN (mg/g)	Temperature (°F)							
		≤450	500	550	600	650	700	750	>750
0.2	0.2	1	1	1	1	1	1	1	1
	3.0	1	1	1	1	1	2	2	2
	4.0	1	1	1	2	4	5	7	10
0.4	0.2	1	1	1	1	1	1	1	1
	3.0	1	1	1	1	2	2	2	2
	4.0	1	1	2	3	4	5	7	10
0.8	0.2	1	1	1	1	1	1	1	1
	3.0	1	1	1	1	2	2	2	3
	4.0	1	1	2	3	5	5	7	10
1.5	0.2	1	1	1	1	1	1	1	1
	3.0	1	1	1	1	3	3	3	4
	4.0	1	1	3	5	5	5	7	10
2.5	0.2	1	1	1	1	1	1	1	1
	3.0	1	1	1	2	3	3	4	5
	4.0	1	1	3	5	5	6	8	10
3.0	0.2	1	1	1	1	1	1	1	2
	3.0	1	1	1	2	4	5	5	6
	4.0	1	2	3	5	5	6	8	10

—NOTE — 1 Includes stainless steels with < 2.5 % Mo, e.g. 316, 316L, 316H, etc.

NOTE 2 The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.9M—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 316 SS with < 2.5 % Mo (mm/y)

Sulfur (wt%)	TAN (mg/g)	Temperature (°C)							
		≤232	260	288	315	343	371	399	>399
0.2	0.2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	3.0	0.03	0.03	0.03	0.03	0.03	0.05	0.05	0.05
	4.0	0.03	0.03	0.03	0.05	0.10	0.13	0.18	0.25
0.4	0.2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	3.0	0.03	0.03	0.03	0.03	0.05	0.05	0.05	0.05
	4.0	0.03	0.03	0.05	0.08	0.10	0.13	0.18	0.25
0.8	0.2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	3.0	0.03	0.03	0.03	0.03	0.05	0.05	0.05	0.08
	4.0	0.03	0.03	0.05	0.08	0.13	0.13	0.18	0.25
1.5	0.2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	3.0	0.03	0.03	0.03	0.03	0.08	0.08	0.08	0.10
	4.0	0.03	0.03	0.08	0.13	0.13	0.13	0.18	0.25
2.5	0.2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	3.0	0.03	0.03	0.03	0.05	0.08	0.08	0.10	0.13
	4.0	0.03	0.03	0.08	0.13	0.13	0.15	0.20	0.25
3.0	0.2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05
	3.0	0.03	0.03	0.03	0.05	0.10	0.13	0.13	0.15
	4.0	0.03	0.05	0.08	0.13	0.13	0.15	0.20	0.25

—NOTE —1 Includes stainless steels with < 2.5 % Mo, e.g. 316, 316L, 316H, etc.

NOTE 2 The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.10—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 316 SS with ≥ 2.5 % Mo and 317 SS (mpy)

Sulfur (wt%)	TAN (mg/g)	Temperature (°F)							
		≤ 450	500	550	600	650	700	750	>750
0.2	4.0	1	1	1	1	1	1	1	1
	5.0	1	1	1	1	1	2	4	5
	6.0	1	1	1	2	4	5	7	10
0.4	4.0	1	1	1	1	1	1	1	1
	5.0	1	1	1	1	2	4	4	5
	6.0	1	1	2	3	4	5	7	10
0.8	4.0	1	1	1	1	1	1	1	1
	5.0	1	1	1	1	2	4	4	5
	6.0	1	1	2	3	4	5	7	10
1.5	4.0	1	1	1	1	1	1	1	1
	5.0	1	1	1	1	2	3	5	7
	6.0	1	1	3	5	5	5	7	10
2.5	4.0	1	1	1	1	1	1	1	1
	5.0	1	1	1	2	3	4	5	7
	6.0	1	1	3	5	5	6	8	10
3.0	4.0	1	1	1	1	1	1	1	2
	5.0	1	1	1	2	3	4	5	7
	6.0	1	2	3	5	5	6	8	10

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.

Table 2.B.3.10M—High Temperature Sulfidic and Naphthenic Acid Corrosion—Estimated Corrosion Rates for 316 SS with $\geq 2.5\%$ Mo and 317 SS (mm/y)

Sulfur (wt%)	TAN (mg/g)	Temperature (°C)							
		≤ 232	260	288	315	343	371	399	>399
0.2	4.0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	5.0	0.03	0.03	0.03	0.03	0.03	0.05	0.10	0.13
	6.0	0.03	0.03	0.03	0.05	0.10	0.13	0.18	0.25
0.4	4.0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	5.0	0.03	0.03	0.03	0.03	0.05	0.10	0.10	0.13
	6.0	0.03	0.03	0.05	0.08	0.10	0.13	0.18	0.25
0.8	4.0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	5.0	0.03	0.03	0.03	0.03	0.05	0.10	0.10	0.13
	6.0	0.03	0.03	0.05	0.08	0.10	0.13	0.18	0.25
1.5	4.0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	5.0	0.03	0.03	0.03	0.03	0.05	0.08	0.13	0.18
	6.0	0.03	0.03	0.08	0.13	0.13	0.13	0.18	0.25
2.5	4.0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	5.0	0.03	0.03	0.03	0.05	0.08	0.10	0.13	0.18
	6.0	0.03	0.03	0.08	0.13	0.13	0.15	0.20	0.25
3.0	4.0	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05
	5.0	0.03	0.03	0.03	0.05	0.08	0.10	0.13	0.18
	6.0	0.03	0.05	0.08	0.13	0.13	0.15	0.20	0.25

Note: The corrosion rates in this table are only order of magnitude estimates and can be nonconservative. Monitoring method and a field measurement data should be used when available for corrosion rate assignment in the RBI assessment.