# Determination of Corrosion rates and remaining life of piping using API and ASME standards in oil and gas industries

**Nibin V Baby[1], Mr. Bibhudatta Paricha[2], Dr. Shailendra J. Naik[3]**

*[1]ME 2nd year, Department of Petroleum Engineering, Maharashtra Institute of Technology, Pune, India*
*[2]Assistant Inspection Manager at BPCL, Mumbai*
*[3]Associate Professor, Department of Petroleum Engineering, Maharashtra Institute of Technology, Pune, India*

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**Abstract –** *Process piping play an extremely important role in Petroleum refineries throughout the world as a means for carrying Hydrocarbons from one location to other. These process piping are subjected to Corrosion over a period of operational time, which is the destructive attack of material by reaction with its service fluids containing corrodents such as Sulphur, $H_2S$, HCl, $CO_2$, organic and inorganic acids and external environments thus causing a natural potential hazard associated with oil and gas transportation facilities.*

*Various potential damage mechanisms are identified for pre-heated crude inlet piping to atmospheric distillation column using American Petroleum Institute standards such as API 581 and API 571. These damage mechanisms consist mainly of High Temperature Sulfidic and Naphthenic acid corrosion. Corrosion rates for this damage mechanism is identified for two crudes namely Kuwait crude and Arab Extra Light Crude using API 581. Retirement thickness for this piping is calculated using ASME B 31.3. Further remaining life of this piping is estimated using corrosion rate, present thickness and retirement thickness of the piping.*

***Key Words***: Process piping, Corrosion rate, Retirement thickness, remaining life estimation, API standards, ASME standards.

## 1. INTRODUCTION

The transportation of oil and gas from the reservoir to the processing facilities by pipelines and piping has played a vital part in the growth of petroleum industry. Over a period of operational time, it is quite natural that these pipelines and piping are subjected to Corrosion, which is the destructive attack of material by reaction with its service fluids containing corrodents such as Sulphur, $H_2S$, HCl, $CO_2$, organic and inorganic acids and external environments, causing a potential hazard associated with oil and gas transportation facilities. This is one of the primary factors affecting the longevity and reliability of the pipelines and piping that transport crudes. Several measures were taken to reduce the presence of these corrodents in order to reduce the corrosion effects on these piping, pipelines. It is not possible to completely remove the effects of corrosion as it is a continuous process, but by adopting proper control and mitigation measures, its impact could be reduced to a great extent thereby saving a lot of revenue. [1]

On 30th June, 2014 there was an explosion of the gas pipeline at Nagaram village in East Godavari district of Andra Pradesh, India. The Gas Authority of India (GAIL) alleged that the presence of sulphur, carbon dioxide and water in the pipeline indicates that the petroleum products supplied by the oil companies were not properly refined and has resulted in corrosion of the pipeline used by Oil and Natural Gas Corporation (ONGC), Reliance Industries Limited (RIL) and Cairn Energy. According to the Petroleum and Explosives Safety Organisation (PESO), there was "no evidence of any efforts" by the organisation to enforce the utilisation of a Gas Dehydration Unit to remove water and liquids that lead to the pipeline corrosion. This caused a huge loss in life and property. These incidents reflect the importance of corrosion prevention and the measures that should be taken to reduce the rate of corrosion. [2]

## 2. PROJECT WORK DESCRIPTION

The expected corrosion rate and remaining life of preheated crude inlet piping to the atmospheric distillation column of a refinery is estimated using the API 581 and API 571 standards. These examinations are carried out for two different crudes namely Kuwait crude (sour crude) and Arab Extra Light (sweet crude). The results, comparison and conclusion are given at the end of the case study.

### 2.1 Pathway of crude in a refinery

After the crude is received at the refinery, it is stored in large tanks in tank farm. This is then mixed with water inline upstream with desalter vessel to dissolve the salts contained in the crude oil, as these have to be removed from the crude oil to mitigate vessel and piping fouling and corrosion as well as poisoning of downstream catalysts.

The desalted crude is then preheated by several heat exchangers and by a fired heater. The preheating raises the crude temperature to 340-380°C. This preheated crude is then transferred via preheated crude inlet piping to the atmospheric distillation column. Here various components such as Heavy Naphtha, Light kero, Heavy kero etc are separated based on their boiling points and are distributed for further downstream processing and conversion.

Piping: Preheated crude inlet piping to ADU

Material of construction: A335 GradeP5, 5% Cr-0.5Mo Alloy Steel

Max. Operating Temperature: 327°C

Fig -2.1a: Atmospheric distillation Unit (ADU)

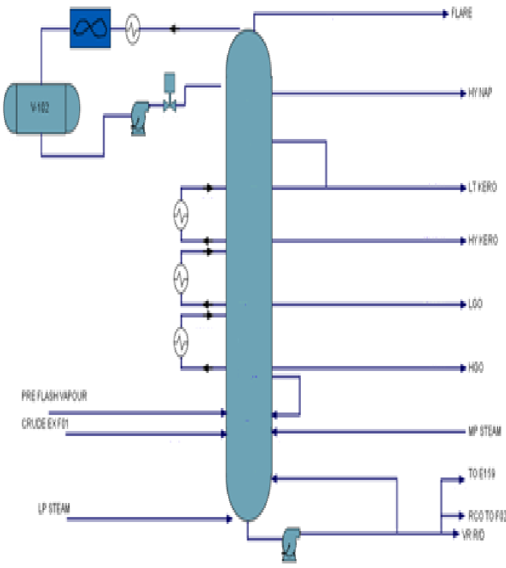



Fig -2.1b: ADU connected piping

(Picture courtesy: BPCL)

## 2.2 Determination of probable damage mechanism and estimation of the corrosion rate [4, 5]

The probable damage mechanism for the preheated crude inlet piping is determined using the risk-based resource document API 581. Screening questions for High temperature Sulfidic/Naphthenic acid corrosion matches with given piping conditions. The presence of sulphur compounds in the crude, the operating condition of 327° C for the preheated crude inlet piping and further discussions with the operational personnel lead to the confirmation of the type of corrosion being the same.

High temperature Sulfidic corrosion is a type of uniform corrosion which occurs when the given operating conditions are above 204°C followed by the presence of sulphur in the crude. This corrosion often occurs with naphthenic acid corrosion and is localized.

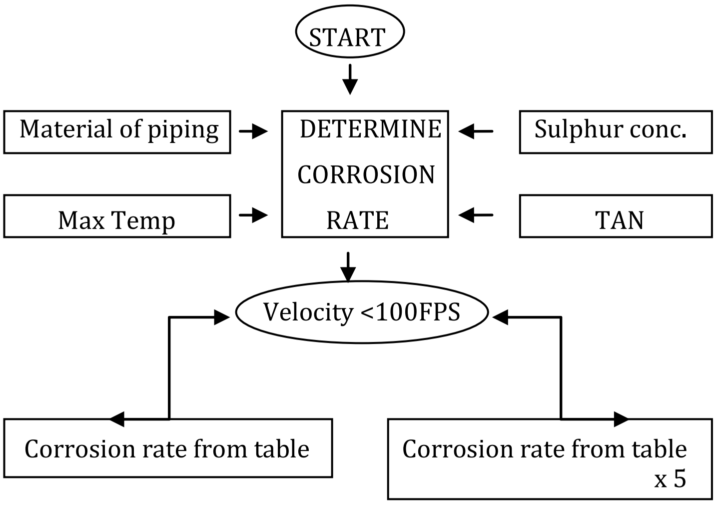
Total Acid Number (TAN) is a measurement of acidity that is determined by the amount of potassium hydroxide in milligrams that is needed to neutralize the acids in one gram of oil

**Table -1:** Requirements to determine High temperature Sulfidic/naphthenic acid corrosion

| Basic Data | Comments |
|---|---|
| Material of construction | Identify the piping material |
| Maximum Temperature (°C) | Determine the maximum temperature of process stream |
| Sulphur content of the stream | Determine the sulphur content of the stream. If not known consult process engineer for an estimate |
| Total Acid Number (TAN)= mg KOH/g oil sample | Determine the TAN of the stream. If not known consult process engineer for an estimate |

Above data are obtained from test run reports and by consulting a knowledgeable process engineer. These data varies from crude to crude, operational plant conditions etc.

**Flowchart -1:** Step by step procedure for determining corrosion rate



### 2.3 Determination of retiring thickness

Retiring thickness is defined as the minimum thickness up to which the piping can be operated. The retiring thickness for pipelines is calculated as the higher of Pressure design thickness and minimum structural thickness plus the future corrosion allowance.

### 2.3.1 Pressure design thickness

Pressure design thickness is calculated using the formula,

$t = PD/2(SEW + PY)$

Where,
t is the pressure design thickness for internal pressure, in millimeters.
P is the internal design pressure of the pipe, in kilopascals
D is the outside diameter of the pipe in millimeters
S is the allowable unit stress at the design temperature, in kilopascals
E is the longitudinal quality factor (1)
W is the weld joint strength reduction factor (1)
Y is the coefficient whose value if 0.4 for temp < 492$^{o}$ C

### 2.3.2 Minimum structural thickness

Based on API 574, Minimum structural thickness for all the lines are summarized as follows

**Table -2:** Minimum structural thickness

| NPS(inch) | Default Minimum structural thickness for temp < 205$^{o}$ C in mm |
|---|---|
| ½ to 1 | 1.8 |
| 1 ½ | 1.8 |
| 2 | 1.8 |
| 3 | 2.0 |
| 4 | 2.3 |
| 6 to 18 | 2.8 |
| 21 to 24 | 3.1 |

### 2.3.3 Retiring thickness

Retiring thickness $T_{required}$ is the thickness maximum of computed by the Design formulas (Pressure, Structural) before corrosion allowance and manufactures tolerances are added.

### 2.4 Remaining life calculation of piping

Remaining Life of the pipeline is estimated using the data's such as Corrosion Rate, Present thickness and retirement thickness. Actual thickness of the pipeline is directly obtained using Ultra Sonic Technique.
We have the formula to calculate the remaining life as

$$L_r = (T_{actual} - T_{required}) / C_r$$

Where,
$L_r$ is the remaining life of the pipeline in years
$T_{actual}$ is the actual thickness measured at the time of inspection for a given location
$T_{required}$ is the required thickness of the pipeline at the same location which is the maximum of thickness computed by the design formulas (i.e. pressure and structural) and including manufacturing tolerance (12.5%)

$C_r$ is the corrosion rate of pipeline in mm/y

## 3. Calculations

### 3.1 Corrosion rate calculation

Corrosion in crude inlet feed line is mainly due to the high temperature Sulfidic and naphthenic acid corrosion.
Various data required to determine the corrosion rate due to high temperature Sulfidic and naphthenic acid are,

Material of Construction = Alloy steel
Crude type considered =
(i) 100% Kuwait Crude
(ii) 100% Arab Extra Light Crude
Max Operating temp ($^{o}$C) = 372 $^{o}$C
Sulphur Content of the Stream =
(i) 2.487 wt%
(ii) 1.33 wt%
Total Acid Number (TAN) = < 0.2 mg/g
(TAN = mg KOH/g oil sample)
Velocity = <100FPS

**a) High Temperature Sulfidic and Naphthenic corrosion**

**(i) For 100% Kuwait Crude with 2.487 wt% Sulphur**

**Table -3:** High Temperature Sulfidic and Naphthenic Acid Corrosion – Estimated Corrosion Rates for 5Cr-0.5Mo (mm/y) for Kuwait Crude in Pre heated Crude Inlet piping

| **Sulphur (wt %)** | **TAN (mg/g)** | **Corrosion Rate ($C_r$) mm/y at various Temp ($^{o}$C)** | | |
|---|---|---|---|---|
| | | 357 $^{o}$C | **372 $^{o}$C** | 385 $^{o}$C |
| 1.5 ($X_1$) | >0.2 | 0.51 ($Y_1$) | | 0.76 ($Z_1$) |
| **2.487 (X)** | >0.2 | **Y** | **--** | **Z** |
| 2.5 ($X_2$) | >0.2 | 0.51 ($Y_2$) | | 0.89 ($Z_2$) |

We have the general interpolation formula as
$Y = Y_1 + (X-X_1)*(Y_2-Y_1)/(X_2-X_1)$,
Applying these to get the values of Y and Z

$Y = 0.51 + (2.487-1.5)*(0.51-0.51)/(2.5-1.5)$
$= 0.51$ mm/y

Z = 0.76+ (2.487-1.5)*(0.89-0.76)/(2.5-1.5)
= 0.88 mm/y

**Table -4:** General interpolation results for Kuwait crude in Pre heated Crude Inlet piping

| Sulphur (wt %) | Corrosion rates ($C_r$) mm/y at various Temperature °C | | |
|---|---|---|---|
| | 357 °C ($M_1$) | **372 °C (M)** | 385 °C ($M_2$) |
| 1.5 | 0.51 | | 0.76 |
| **2.487** | **0.51 ($N_1$)** | **N** | **0.88 ($N_2$)** |
| 2.5 | 0.51 | | 0.89 |

Once again using the general interpolation formula,
$N = N_1 + (M-M_1)*(N_2-N_1)/ (M_2-M_1)$
N = 0.51 + (372-357)(0.88-0.51)/(385-357)
= 0.7082 mm/y

Corrosion rate is estimated to be 0.7082 mm/y from interpolating the values in the table.

**(ii) For 100% Arab Extra Light with 1.33 wt% Sulphur**

**Table -5**: High Temperature Sulfidic and Naphthenic Acid Corrosion – Estimated Corrosion Rates for 5Cr-0.5Mo (mm/y) for Arab Extra Light Crude in Pre heated Crude Inlet piping

| Sulphur (wt %) | TAN (mg/g) | Corrosion Rate ($C_r$) mm/y at various Temperature (°C) | | |
|---|---|---|---|---|
| | | 357 °C | 372 °C | 385 °C |
| 0.75 ($X_1$) | >0.2 | 0.38 ($Y_1$) | | 0.58 ($Z_1$) |
| 1.33 (X) | >0.2 | Y | -- | Z |
| 1.5 ($X_2$) | >0.2 | 0.51 ($Y_1$) | | 0.76 ($Z_1$) |

We have the general interpolation formula as
$Y= Y_1+ (X-X_1)*(Y_2-Y_1)/(X_2-X_1)$,
Applying these to get the values of Y and Z

Y = 0.38+ (1.33-0.75)*(0.51-0.38)/(1.5-0.75)
= 0.48 mm/y
Z = 0.58+ (1.33-0.75)*(0.76-0.58)/(1.5-0.75)
= 0.719 mm/y

**Table -6**: General interpolation results for Arab Extra Light Crude in Preheated Crude Inlet piping

| Sulphur (wt %) | Corrosion rates ($C_r$) mm/y at various Temperature °C | | |
|---|---|---|---|
| | **357 °C (M)** | **372 °C (M)** | **385 °C (M)** |
| 0.75 | 0.38 | | 0.58 |
| 1.33 | 0.48 (N) | N | 0.719 (N) |
| 1.5 | 0.51 | | 0.76 |

Once again using the general interpolation formula,
$N = N_1 + (M-M_1)*(N_2-N_1)/ (M_2-M_1)$
N = 0.48 + (372-357)(0.719-0.48)/(385-357)
= 0.608 mm/y

Corrosion rate is estimated to be 0.608 mm/y from interpolating the values in the table.

### 3.2 RETIREMENT THICKNESS CALCULATION

#### 3.2.1 Pressure design thickness

To determine the required thickness of straight pipe subjected to internal pressure. We have the formula,
$t$ = PD/2(SEW + PY)
Where,
$t$ = Pressure design thickness for internal pressure, in millimeters
P = Internal design gauge pressure of the pipe, in kilopascals
D = Outside diameter of the pipe, in millimeters
S = Allowable unit stress at the design temperature, in kilopascals
E = Longitudinal quality factor (1)
W = Weld Joint strength reduction factor (1)
Y = Coefficient whose value is 0.4 for Temp< 492 C

The Allowable unit stress at the design temperature is obtained by referring the ASME B 31.3-2012 Edition. The readings are as follows

**Table -7**: Summary of Line Internal Design Gauge Pressure P (KPa), Out Diameter D (mm) and Allowable Unit Stress S at Design Temperature*1000 (KPa)* (*ref 5.2.1)

| Line | Internal Design Gauge Pressure P (KPa) | Outer Dia D (mm) | Design Temp°C | Allowable Unit Stress S*1000 (KPa) |
|---|---|---|---|---|
| Preheated Crude inlet piping | 588.399 | 864 | 390 | 110 |

Appling these values to the formula,
1) Preheated Crude Inlet Line
$t$ = PD/ 2 (SEW + PY)
= 588.399*864/2*(110.2*1000+ 588.399*0.4)
= 2.30 mm

#### 3.2.2 Minimum structural thickness

Based on API 574, Minimum structural thickness for all the inlets and outlets piping having NPS in the range 6-18 and 20-24 are taken as 2.8 and 3.1 respectively

### 3.2.3 Retiring thickness of the piping

Maximum thickness on comparison with Design Pressure thickness and Minimum Structural Thickness along with added manufactures tolerance is taken into consideration while estimating the Remaining Life Calculation.

**Table -8**: Summary of Retiring Thickness ($T_{required}$)

| Line | Retiring Thickness ($T_{required}$) |
|---|---|
| Preheated Crude Inlet piping | 3.487 |

## 3.3 REMAINING LIFE CALCULATION

Retiring Life of the pipeline is estimated using the data's such as Corrosion Rate, Present thickness and retirement thickness. Actual thickness of the pipeline is directly obtained using Ultra Sonic Technique.
We have the formula to calculate the remaining life as
$L_r = ( T_{actual} - T_{required} ) / C_r$

**(i) For Kuwait Crude Oil**

**Table -9**: Review of Corrosion rate $C_r$ (mm), Actual thickness $T_a$ (mm) And Retiring thickness $T_r$(mm)

| Line | $C_r$ (mm) | $T_{actual}$ (mm) | $T_{required}$ (mm) |
|---|---|---|---|
| Preheated Crude inlet piping | 0.7082 | 12 | 3.487 |

Applying the formula, we get the estimated life in years as

1) Preheated Crude Inlet piping

$$L_r = T_{actual} - T_{required} ) / C_r$$
$$= (12-3.487)/0.7082$$
$$= 12.02 \text{ years}$$

**(ii) For Arab Extra Light**

**Table -10**: Review of Corrosion rate $C_r$ (mm), Actual thickness $T_a$ (mm) And Retiring thickness $T_r$(mm)

| Line | $C_r$ (mm) | $T_a$ (mm) | $T_r$ (mm) |
|---|---|---|---|
| Preheated Crude inlet piping | 0.608 | 12 | 3.487 |

Applying the formula, we get the estimated life in years as
1) Preheated Crude Inlet piping

$$L_r = (T_{actual} - T_{require} ) / C_r$$
$$= (12-3.487)/0.608$$
$$= 14.49 \text{ years}$$

## 4. RESULTS AND CONCLUSION

**Table- 11: Results and conclusion**

| Line | Material Of const | Probable damage mech. | $C_r$ (mm/y) | | $L_r$ (years) | |
|---|---|---|---|---|---|---|
| | | | $C_1$ | $C_2$ | $C_1$ | $C_2$ |
| Preheated Crude inlet piping | A335 GradeP 5, 5% Cr-0.5Mo Alloy Steel | High temp sulphidic and naphthenic acid corrosion | 0.7 | 0.6 | 12 | 14.4 |

This project clearly identifies the variation of corrosion with the difference in sulphur in the two types of crude namely Kuwait and Arab extra light crude. From the table above it can be identified that corrosion would be more for piping of the crude used is 100% Kuwait crude in comparison with Arab Extra Light crude. However in refineries in order to tackle this issue, blend crudes are used. Corrosion and its effects cannot be completely taken care of but proper adoption of design, selection of material, Mitigation and control measures, corrosion allowances can reduce the adverse impacts to a great extent.

Coating the words of Trevor Place-
"A simplifed analogy for pipe corrosion is tooth decay…If you brush regularly; you probably won't have many problems with your teeth. Similarly, if you sweep your pipeline clean of potential corrodents, you
won't have many problems with corrosion."

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Nibin V Baby is a second year master of engineering (ME) student in Department of Petroleum Engineering at Maharashtra Institute of Technology, Pune, Maharashtra

2nd Author

Mr. Bibhudatta Paricha is Assistant Inspection Manager at BPCL, Mumbai

3rd Author

Prof. Dr. Shailendra J. Naik is Associate Professor in Department of Petroleum Engineering at Maharashtra Institute of Technology, Pune, Maharashtra