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Corrosion behavior of API – 5L – Grade – X52 Steel pipe line in Crude oil containing different environment.

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Abstract

Effective corrosion studies are carried out on API -5L-Grade-X52 Steel pipe line specimen in crude Oil with different environment containing various percentage of water including Free water, Emulsified water with/without corrosion induced gases like CO_2 and H_2Setc., In this deteriotion studies with different exposure time mainly focus on mass loss measurements. The observed result reveals that the crude oil itself acts as an inhibitor without water content. However, its inhibiting tendency gradually decreases when entering free water and emulsified water. When the exposure time increased beyond 72 hrs the corrosion rate significantly accounted due to the breakdown of protective film.

Keywords: API -5L-Grade-X52, Crude oil, Free water, Emulsified Water, Mass Loss, Spectral studies.

1. Introduction

Materials used for pipeline construction play an important role in the petroleum industry as they carrying liquids and gases over a long distance from their source to the ultimate consumers. Recent years the Corrosion is a major problem associated with the transportation process can exist at every stage of production, from the initial extraction to refining and storage prior to the usage [1 - 3].Corrosion of materials causes great loss in the industrial applications, especially under some extreme conditions i.e., the Corrosive Atmosphere and high Temperature [4–5].Thus Corrosion is a serious problem which are necessities to investigate especially in oilfield applications, because large portion of the total costs of oil and gas producing companies losing $ 2.5 trillion dollars ($40 billion dollars in India) every year in the worldwide. Moreover, appropriate corrosion control can help us to avoid many potential disasters that can cause serious issues including loss of life, negative social impacts and water resource and environmental pollution. Corrosion in oilfield occurs at all stages from downhole to surface equipment and processing facilities. It appears as leaks in tanks, casings, tubing, pipelines, and other equipments [6-8]. Corrosion problems are generally connected with the operation, equipment maintenance, leading to recurrent partial and even total process shutdown, resulting in severe economic losses [9]. In the petroleum industry, there is a great variation in the salt content of crude oils mainly depending upon the source and possibility of producing well and/or zones in the Oil field. The amount of mineral salts varies with the geological formation and can be as much as 2,00,000 ppm. In addition, at the refinery, salt water introduced during shipment by tanker may contribute to the total salt contents [10-11]. Almost in all cases, the salt content of the crude oil consists of salt dissolved in small droplets of water that are dispersed in the crude oil [12]. The chemical composition of these salts of the saline water varies, but the major portion is nearly always sodium chloride with lesser amounts of calcium and magnesium chlorides[13]. In fact, the presence of salt, corrosion induced gases like CO_2 and H_2S in the crude oil leads to create several problems during transporting and the refining process, including corrosion of lines, fouling, and also the deactivation of catalysts employed at the refinery.From previous studies,a few authors investigated and reportedthat the crude oil and the chemical content presence in crude oil may itself act as an inhibitor for the steel pipe lines. However,a detailed studies and to suggests a suitable corrosive mechanism for self-inhibiting effect of crude oil is not clearly known.Thus in our present investigation, we have carried out the corrosion of API -5L-Garde-X52 Steel pipe line in crude oil with various formational water content by using mass loss measurements.

2. Materials and Methods

2.1 Materials

3.1.1 Steel Specimen (API -5L-Grade-X 52 pipe lines)

Commercially available steel pipeline. API -5L-Grade-X52, specimen was mechanically pressed cut to form different coupons, each of dimension exactly 40.092 cm^2 (5.1 cm × 2.5 cm × 0.96 cm), polished with emery wheel of 80 and 120 mesh, and degreased with trichloroethylene then washed with distilled water, cleaned, dried and then stored in desiccator for the use of our present investigation.

2.1.2 Crude oil and Formation water (E_w, F_w&T_w)

The sample of crude oil collected from near storage tank according to API (American Petroleum Institute) sampling manual and subjected to various fundamental laboratory test according to the available API (American Petroleum Institute) specifications. From the available specification, emulsified water (E_w) and free water (F_w) as a part of formation water confirmed with and without adding OSD (Oil Soluble Demulsifiers) in respective crude oil. The water content (W_c) of Crude oil also confirmed by the available API standards involves Dean – Stark distillation -ASTM D-4006 [14], BS&W (Basic Sediment and water) - ASTM D 4007[15] and Karl Fischer titration ASTM D-4377 [16] . The amount of Total water (Tw) calculated from summation of Emulsified water (Ew), Free water (Fw) and Water content (Wc).

Percentage of volume of water Content (W_c) in the crude oil can be calculated as follows:

$$\text{Volume \% water} = \frac{A - B}{C} \times 100 \quad \text{-------------- (1)}$$

Where
A= ml of water in crude and xylene
B= ml of water in solvent blank
C= ml of test crude sample
Percentage of volume of Emulsified water (E_W) and Free water (F_w) in the crude oil can be calculated as follows:

Volume of water in percentage

$$(E_w \& F_w) = \frac{A}{1000} \times 100 \quad \text{-------------- (2)}$$

Where
A= ml of water in 1000 ml crude oil

The detailed physical and chemical properties of Crude oil and the Formation water were listed out in Table from 01 to Table 02

2.1.3 Different Conditions

2.1.3.1 Crude oil without both Corrosion Inducing Gases (CIG) and Formation water (E_w, F_w and T_w)

The pure sample of crude oil withoutthe formation water in which the dissolved gases like CO_2 and H_2S was removed by purging with the inert gasHelium. The absence of Emulsified water (E_w) and free water (F_w) was confirmed by application of both Non-emulsifier(NE) and OSD (Oil Soluble Demulsifiers) with and without adding to respective Crude oil samples. The water content (W_c) also confirmed by the same procedureas above (ASTM D4928 – 12).

2.1.3.2 Crude oil with Corrosion Inducing Gases (CIG) and without Formation water (E_w, F_w and T_w)

Inthis condition the crude oil taken with CIG (Corrosion Inducing Gases) andwithout formationof water. The absence of different categories (F_w, E_w and T_w) of water confirmed by the ASTM standard.

2.1.3.3 Crude Oil with CIG (Corrosion Inducing Gases) and with Different portion of water.

In this condition the crude oil with increasing order of water percentage in the range of 5 - 100 % were taken with CIG (Corrosion Inducing Gases) as per the ASTM Standard.

2.2 Methods

2.2.1 Mass loss measurement

In mass loss measurements the API -5L-Grade-X52 coupons in triplicate and completely immersed in 100ml of the test solution in the absenceof inhibitor for the different conditions of crude oil from 3.1.3.1 to 3.1.3.3. During the exposure time the evaporation of the crude oil periodically maintained. The metal specimens were withdrawn from the test solutions in intervals of 24 -720 hrs (1- 60 days) at room temperature. The significant change in mass was taken as the difference in weight of the specimens before and after immersion using PRECISA XR 205SM – DR (Made in Switzerland) digital balance with sensitivity of ±0.0001 mg. The measurements were performed in triplicate to guarantee the reliability of the results and the mean value of the mass loss is taken.

From the mass loss measurements, the corrosion rate was calculated using the following relationship.

$$\text{Corrosion Rate}(\text{mmpy}) = \frac{87.6 \times W}{DAT} \quad \text{--------------------- (1)}$$

Where, mmpy = Millimeter per year, W = Mass loss (mg), D = Density (gm/cm^3),

A = Area of specimen (cm^2), T = Time in hours.

From the observation we inferred that the Crude oil itself behaves as an inhibitor in absence of the formational water. The specimens were uniformly covered by thin layer of crude oil in the condition of crude oil alone. The crude oil forms additional layer on the surface of Steel material to prevent the attacks of Corrosions Inducing Agent (CIA) when it dissolved in crude oil. By increasing the concentration of water in crude oil it may be Water Content (Wc), Emulsified water (Ew) and Free water (Fw), the corrosion of API - 5L-Grade-X52 steel specimen accelerated due to heavy salinity (including in the Properties table of formation water). Due to the presence of the water, stealing not taking uniformly in the whole surface of the steel specimens. The density of two different phases (Formation water and crude oil) taken very important role in the variation observed in stealing because of higher density of water, it settled bottom to the Crude oil. Ahugeof Corrosion rate observed in the bottom of steel specimen due to the immersion caused by formation water in the form of free water (Fw) is settled below to the crude oil. The additional corrosion also observed in the region between the free water and crude oil in which the emulsion were formed. The emulsion formed may range from millimeter to centimeter on the basis of formational water percentage. A careful observation, the Stealing on emulsion area was taken but its effects were only minor compare to the area of free water. The stealing not clearly known, but few spot appeared on the specimen in immersed area due to a little more water dispersed in the same crude oil, here the crude oil itself behaves as an inhibitor up to some extent.

Results and Discussion

3.3.1 Mass loss measurements

Various physical parameters of formation of water which is removed from the crude oil are reported in Table-01. The observed chemical oxygen demand (250ppm)and the biological oxygen demand (5750ppm)values are clearly indicates that it is one of factor may induce to damage inside the oil pipe line to cause the primary source of corrosion.

Table-01 Various Physical parameters of Formation water, removed from the crude oil.

S.No	Parameters	Unit	Values
1	pH	-	6.9
2	Turbidity	NTU	81
3	Total Suspended Solids	mg/L	68
4	Oil and Grease	mg/L	9.8
5	COD(Chemical Oxygen Demand)	ppm	250
6	BOD(Biological Oxygen Demand)	ppm	5750
7	Dissolved Oxygen	ppm	3

Different chemical parameters of formation of water which removed from the crude oil also placed in Table -02. It shows that the rich contents of NaCl (67,780 mg/l), Chloride ion Cl^- (41,131 mg/l), bicarbonate (HCo^{-3}976 mg/l) and sulphate ions (SO_4^{2-}188 mg/l) are existing in the formation of water which is separated from the crude oil. In general chloride ion (Cl^-) and sulphate ion (SO_4^{2-})are worst pollutants active to corrosive media. Thus the presence of this content of pollutants is main criteria to damage the oil pipe lines. The natural sea water containing maximum of 36,000 ppm (3.5%) of Cl^- ion content. However, in the crude oil the presence of major chloride content is nearly 67.78 g/l is almost double the content of chloride ions (Cl^-) is major source to cause the dissolution of the metal surface of inner side of the oil pipe line.

Table-02.Various chemical parameters of formation water, removed from the crude oil.

S.No	Parameters	Values in ppm
1	Salinity as NaCl	67780
2	Sodium as Na^{+}	26462
3	Chloride as Cl^{-}	41131
4	Hardness as $CaCO_3$	19000
5	Calcium as Ca^{2+}	7040
6	Magnesium as Mg^{2+}	342
7	Carbonate as CO_3^{2-}	0
8	Bicarbonate as HCO_3^{-}	976
9	Sulphate as SO_4^{2-}	188
10	Total Dissolved Solids	76139
11	Iron as Fe^{3+}	41

The various physical and chemical parameters of crude oil also measured and the observed values are represented in Table-03.It shows that the average viscosity 80 Cps and average pumping velocity 60 KL/hr at room temperature may also one of the important factor to activate the dissolution process inside the surface of the pipe line can cause impeachment of the metal due to its speed of velocity.

Table-03. Various Physical and Chemical parameters of crude oil.

S.No	Parameters	Unit	Values
1	Appearance		Dark Brown Liquid
2	Density at 15°C	g/cc	0.9195
3	Specific Gravity @60^{0}F		0.9201
4	API Gravity	deg.	22.30
5	Water Content	% (v/v)	0.6
6	Pour Point	° C	<-6
7	Average Viscosity@ 30^{0}C	Cps	80
8	Plastic Viscosity @ 30^{0}C	Cps	77.5
9	Yield point	dynes/cm^2	20.4
10	Wax content	%w/w	1.58
11	Asphaltine content	%w/w	3.37
12	Resin	% w/w	14.08
13	Average pumping velocity/hrs	KL/hr	60

Different physical parameters of crude oil were observed when on distillation process are presented in Table – 04. This table shows the fraction wise composition of gasoline (6%), kerosene (15%) and diesel (15%) along with the crude oil, it also the another important factors to affect the metal surface leads to activate the corrosion rate reaction.

Table-04.Various Physical parameters of crude oil on Distillation

S.No	Temp (° C) From	Temp (° C) To	Yield (%)	Cum. Yield	Sp. Gr. @ 60°/60°F	Correlation Index	Fraction wise Compositi on (%)	Classification
1	IBP	50	-	-	-	-		Paraffinic –Naphthenic-Aromatic
2	50	75	-	-	-	-		
3	75	100	1	1	-	-	Gasoline (6.0)	
4	100	125	2	3	-	-		
5	125	150	3	6	0.7543	19.00		
6	150	175	3	9	0.7725	20.82		
7	175	200	3	12	0.7898	22.95		
8	200	225	4	16	0.8096	26.89	Kerosene (15.0)	
9	225	250	5	21	0.8341	33.59		
10	250	275	8	29	0.8581	38.14	Diesel (15.0)	
11	275	300	7	36	0.8778	45.79		
Distilled up to 300°C (Under atm. Pressure)			36					
Residue after 300^0 C:			63.5					
Loss			0.5					
Initial Boiling Point (IBP) 98^0C								

The percentage of various chemical composition of natural gas in the different period of time (week wise) also measured and presented the Table – 05. The observed resultsclearly indicate that there is a significant changes leads to some chemical process involved depends upon the time factor. This process also can induce dissolution process inside of the pipe line leads to create the vacant d-orbitals on the surface of the metal. If once vacant creation occurs may accumulate and damage the entire structure of the pipe line.

Table .05 Percentages of various Chemical compositions of natural gases in the different period of time intervals (Every Week)

Time Intervel	I	II	III	IV	V	VI
Pr Kg/cm^2	1.6	1.9	1.7	1.7	2.0	1.8
Temp °C	49	45	44	46	38	48
Gas Composition (% Vol)						
C_1	85.14	80.93	83.60	84.14	83.52	82.85
C_2	6.09	7.14	6.48	6.15	5.96	6.59
C_3	3.92	5.24	4.46	4.34	4.39	4.65
i-C_4	0.70	1.01	0.84	0.85	0.9	0.92
n-C_4	1.36	1.92	1.62	1.60	1.72	1.8
i-C_5	0.36	0.57	0.44	0.44	0.54	0.51
n-C_5	0.33	0.58	0.44	0.43	0.53	0.49
C_6+	0.70	1.30	0.84	0.82	1.15	0.94
CO_2	0.48	0.43	0.35	0.21	0.23	0.29
N_2	0.92	0.88	0.93	1.02	1.06	0.96
H_2S	0.00	0.00	0.00	0.00	0	0
C_3+C_4	5.98	8.17	6.92	6.79	7.01	7.37
Gas Parameters						
Z	0.9968	0.9961	0.9965	0.9966	0.9964	0.9964
SP.GR.	0.6922	0.7459	0.7110	0.7065	0.7206	0.7215
CV(Net)	9680.858	10389.587	9949.106	9906.563	10079.55	10094.307
CV(Gross)	10687.733	11447.867	10975.719	10930.249	11115.587	11131.495
AV. Mwt	20.0	21.5	20.5	20.4	20.8	20.8

The corrosion parameters of API -5L-Grade in crude oil at different condition after 24 hrs exposure time are placed in Table 06. The observed result indicates that the corrosion rate gradually increased from 28.10 x 10^{-3} mmpy to 93.29 x 10^{-3} mmpy suggests that due to the increase of water from 5% to 100%.

Table-06. Corrosion parameter of **API -5L-Grade-X52** in after **24 hours'** exposure time.

S.No	Electrolyte (Different Conditions)	Mass Loss (mg)	Corrosion rate (mmpy x10^{-3})
1.	Crude oil without Corrosion Inducing Gases ,Water content, Free water and Emulsified Water.	0.0011	1.27
2.	Crude oil without Water content, Free water and Emulsified Water.	7.4670	86.36
3.	Crude oil with 5 %, Free water	2.4300	28.10
4.	Crude oil with 10 %, Free water.	4.6670	53.98
5.	Crude oil with 25 %, Free water.	1.1330	13.10
6.	Crude oil with 50 %, Free water.	1.4430	16.57
7.	Crude oil with 75 %, Free water.	1.3330	15.42
8.	100 %, free water	8.0660	93.29

Corrosion parameters of API – 5L –Grade – X52 in different conditions after 72hrs exposure period are reflected in Table 07. The observed data clearly indicates with different conditions of crude oil i.e, increased with percentage of water from 0 to 100%, the corrosion rate increased from 0.46 x 10^{-3} mmpy to 44.59 x 10^{-3} mmpy. However, when compared to 24 hrs exposure time the corrosion rate slow down due to the primary layer formed on the oil pipe surface may itself prevent further dissolution.

Table-07.Corrosion parameter of **API -5L-Grade-X52** in after **72 hours** exposure time.

S.No	Electrolyte (Different Conditions)	Mass Loss (mg)	Corrosion rate (mmpy x10^{-3})
1.	Crude oil without Corrosion Inducing Gases, Water content, Free water and Emulsified Water.	0.0012	0.46
2.	Crude oil without Water content, Free water and Emulsified Water.	4.3500	16.77
3.	Crude oil with 5 %, Free water	3.9330	15.16
4.	Crude oil with 10 %, Free water.	4.6000	17.73
5.	Crude oil with 25 %, Free water.	2.7667	10.67
6.	Crude oil with 50 %, Free water.	2.6000	10.02
7.	Crude oil with 75 %, Free water.	6.2000	23.90
8.	100 %, free water	11.5667	44.59

Corrosion parameter of API – 5L – Grade – x 52 in various conditions after 120hrs exposure time are listed out in Table-08. It shows that the corrosion rate is gradually increased from 0.02 x 10^{-3} mmpy to 69.01 x 10^{-3} mmpy at different conditions of crude oil but increased with percentage of water from 0 to 100%. However, when compared to 72 hrs exposure time, the corrosion rate significantly increased from 44.59 x 10^{-3} mmpy to 69.01 x 10^{-3} mmpy increase of exposure time from 72hrs to 120hrs. It is suggesting that the initial formation primary layer may continuously break down and leads to further dissolution.

Table-08. Corrosion parameter of **API -5L-Grade-X52** in after **120 hours** exposure time.

S.No	Electrolyte (Different Condition)	Mass Loss (mg)	Corrosion rate (mmpy x10 $^{-3}$)
1.	Crude oil without Corrosion Inducing Gases ,Water content, Free water and Emulsified Water.	0.0001	0.02
2.	Crude oil without Water content, Free water and Emulsified Water.	2.0660	4.77
3.	Crude oil with 5 %, Free water	0.7333	1.70
4.	Crude oil with 10 %, Free water.	3.6670	8.48
5.	Crude oil with 25 %, Free water.	4.1670	9.64
6.	Crude oil with 50 %, Free water.	3.8667	8.94
7.	Crude oil with 75 %, Free water.	7.7000	17.81
8.	100 %, free water	29.8330	69.01

Table-09 shows that the corrosion parameter of API -5L-Garde-X52 at different condition after 168hrs exposure time. It reflected that the corrosion rate is gradually increased from 0.52 x 10^{-3} mmpy to 49,29 x 10^{-3} mmpy at various conditions of crude oil with increased in percentage of water[from 0 to 100]. The above datas indicates that after 120hrs exposure, a thin film layer once again formed the surface of the oil pipe line leads to prevent further dissolution. Thus the corrosion rate slowely decreased.

Table-09.Corrosion parameter of **API -5L-Grade-X52** in after **168 hours** exposure time.

S.No	Electrolyte (Different Condition)	Mass Loss (mg)	Corrosion rate (mmpy x10 $^{-3}$)
1.	Crude oil without Corrosion Inducing Gases ,Water content, Free water and Emulsified Water.	0.0032	0.52
2.	Crude oil without Water content, Free water and Emulsified Water.	1.7330	2.86
3.	Crude oil with 5 %, Free water	4.0000	6.61
4.	Crude oil with 10 %, Free water.	5.3000	8.76
5.	Crude oil with 25 %, Free water.	4.1330	6.83
6.	Crude oil with 50 %, Free water.	6.3330	10.46
7.	Crude oil with 75 %, Free water.	9.6600	15.96
8.	100 %, free water	29.8330	49.29

Corrosion parameters of API-5L-Grade-X-52 in different conditions after 240hrs exposure period are presented in Table-10. The observed results indicates that the corrosion rate gradually increased from 1.07 x 10^{-3} mmpy to 80.42 x 10^{-3} mmpy with different conditions of crude oil and percentage of water content (0 to 100%). This datas clearly suggest that when we increase the exposure time after 168 hrs to 240 hrs, the film formation may protect the further damage of the oil pipe line.

Table-10.Corrosion parameter of **API -5L-Grade-X52** in after **240 hours** exposure time.

S.No	Electrolyte (Different Condition)	Mass Loss (mg)	Corrosion rate (mmpy x10 $^{-3}$)
1.	Crude oil without Corrosion Inducing Gases, Water content, Free water and Emulsified Water.	0.0093	1.07
2.	Crude oil without Water content, Free water and Emulsified Water.	3.6000	4.16
3.	Crude oil with 5 %, Free water	2.1000	2.43
4.	Crude oil with 10 %, Free water.	4.5000	5.21
5.	Crude oil with 25 %, Free water.	4.7000	5.44
6.	Crude oil with 50 %, Free water.	8.5667	9.91
7.	Crude oil with 75 %, Free water.	11.3000	13.07
8.	100 %, free water	69.5330	80.42

Table-11. Corrosion parameter of **API -5L-Garde-X52** in after **360 hours** exposure time.

S.No	Electrolyte (Different Condition)	Mass Loss (mg)	Corrosion rate (mmpy x10 $^{-3}$)
1.	Crude oil without Corrosion Inducing Gases ,Water content, Free water and Emulsified Water.	0.0098	0.76
2.	Crude oil without Water content, Free water and Emulsified Water.	4.1660	3.21
3.	Crude oil with 5 %, Free water	4.8661	3.75
4.	Crude oil with 10 %, Free water.	3.7000	2.85
5.	Crude oil with 25 %, Free water.	4.5000	3.47
6.	Crude oil with 50 %, Free water.	8.6660	6.69
7.	Crude oil with 75 %, Free water.	10.7670	8.30
8.	100 %, free water	63.1330	48.68

Table 11 refletcs that the corrosion parameters of API – 5L – Grade after 360 hours exposure time at different conditions.It shows that the corrosion rate is gradually increased from 0.76 x 10 -3 mmpy to 48.68 x 10 -3 mmpy , with crude oil various percentage of water content.Using different condition of electrolyte , the same trends as in the case of 168 hrs exposure time .ie., once again the primary layer attached on the oil pipe line of the surface.Thus the rate moderately reduced from 80.42 x 10 -3 mmpy to 348.68 x 10 -3.

Table-12. Corrosion parameter of **API -5L-Garde-X52** in after **720 hours** exposure time.

S.No	Electrolyte (Different Condition)	Mass Loss (mg)	Corrosion rate (mmpy x10^{-3})
1.	Crude oil without Corrosion Inducing Gases, Water content, Free water and Emulsified Water.	0.0103	0.40
2.	Crude oil without Water content, Free water and Emulsified Water.	9.9660	3.84
3.	Crude oil with 5 %, Free water	1.7330	0.67
4.	Crude oil with 10 %, Free water.	4.6670	1.80
5.	Crude oil with 25 %, Free water.	4.0330	1.56
6.	Crude oil with 50 %, Free water.	4.3000	1.66
7.	Crude oil with 75 %, Free water.	25.6500	9.89
8.	100 %, free water	15.7000	6.05

The corrosion parameters of API – 5L- Grade X 52 in after 720 hrs exposure time at different conditions. The observed result indicates that the corrosion rate is gradually increased from 0.40 x 10^{-3} to 6.05 x 10^{-3} mmpy with crude oil and different percentage of water content. After 720 hrs exposure time, the corrosion rate shows that the formation of multilayer (physical reaction) followed by chemical reaction almost reduced to 6.05 x 10^{-3} mmpy.

Conclusion

From the above observations the following conclusions were drawn;

* Based on the observation of physical and chemical parameters in crude oil, among these various contents, the chloride (Cl^-) ions and sulphate (SO_4^{2-}) ions are the worst pollutants, mainly cause of the corrosion activities inside the oil pipe lines.

*Average pumping velocity 60 KL / hr can also be the cause of impeachment on the metal ion from the inner surface of the pipe line.

* Crude oil without corrosion inducing gases, water content, free water and emulsified water the corrosion rate gradually reduced from 1.27 x 10 -3 mmpy to 0.40 x 10 -3 mmpy when the exposure time increased from 24 hrs to 720 hrs.

*However the crude oil with corrosion inducing gases, the corrosion initially high ie.,83.36 x 10^{-3} after 24 hrs exposure time due to the increase of water content from 0 to cent percentage, but the period of exposure time increases, thecorrosion ratesignificantly reduced from 83.36 x 10^{-3}mmpy to 44 x 10^{-3} mmpy upto 72 hrs exposure time due to formation of protective film on the inner surface of the oil pipe lines.

* When the exposure time increased beyond 72 to 240 hrs, the dissolution rate increased from 44.59 x 10^{-3} mmpy to 80.42 x 10^{-3}mmpy clearly suggest that, theprotected film may breakdown leads to further deteriotion occurs inside the surface of the pipe line. Thus the protective filmformation ----- dissolution ----- formation mechanism continuously follows to damage the inner surface of the oil pipe lines.

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