Article

The Elementary Attributes and Denotations of the Corrosion in Petroleum Refining Event

Kardan Journal of Engineering and Technology
2 (1) 20–39
©2020 Kardan University
Kardan Publications
Kabul, Afghanistan
DOI: 10.31841/KJET.2021.10
https://kardan.edu.af/Research/Kardan_journal_of_engineering_and_technology.aspx#

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Abstract

Crude oil is a natural resource for the generations of energy, occurred based on the phenomenon of the natural environment that also composed with most of hydrocarbons and some of trace compounds which are having various properties including the corrosiveness. Anticipations of this research were the investigations of the spirit of the corrosion of seven different types of ferrous metals with respect to the two different types of crude oils in both quality and quantity. The chemical compositions of selected metals, the strength of leading corrosive compounds of both crude oils, corrosion rates of each metal with respect to both crude oils and the aspects of corrosion were tested and determined by the standard methodologies and instruments. The concluded results interpret that some of the metals are having corrosion protection ability while especially stainless steels were having relatively lower corrosion rates, higher compositions of corrosive compounds in Das Blend accordingly with the concentrations of such compounds, salts play a dominant role in the metallic corrosion basically at the room temperatures that the experiments were performed, formation of FeS, Fe2O3, corrosion cracks and some irregular distributions of cavities on the corroded metal surfaces under these processes and also some property changes of the surfaces of metals due to the corrosion.

Keywords: *Crude oils, Corrosive compounds, Ferrous metals, Weight loss method, Destruction*

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Introduction

Crude oil is a resource which is found from the natural environment and can be used as a fuel for the energy generation. It gives most beneficial stuffs to fulfill the essential needs of humans. Also, crude oils are the resources that are impossible to be consumed in their raw form they are refined into some final products such as the petroleum gas, petrol and diesel. According to the preparation of the refining equipment of crude oil, ferrous metals play a dominant role because of the adequacy of metals for such purpose with some kind of failures foremost of the corrosion basically caused by the corrosive compounds of such crude oils especially elemental sulfur, active sulfur compounds, salts, organic acids and some bacterial activities rarely [4]. In the formation of the corrosion on some metal the compulsory requirements, the metal need to be exposed to either some sort of strong oxidizing agent rather than Fe^{2+} such as some strong acid or any corrosive environment that contained both water and oxygen or it can be modified with organic acids and salts presence in the relevant system also can be defined as either chemical or electrochemical process that usually gives metal oxides, sulfides or hydroxides as the corrosion compounds that formed the metallic surface itself although unstable compounds [12]. By referring the nature of the formed corrosion compounds and accessory features, the corrosion can be further defined into various categories such as the general corrosion, galvanic corrosion, pitting corrosion or stress corrosion which depend on the conditions of the surrounded environment and the chemical compositions of such metals as well [8].

The major motives of the current research were the speculations of the corrosion rates of seven different types of ferrous metals which are typically used in the industry of crude oil refining regarding vast applications with respect to two different types of crude oils separately, qualitative analysis of the corrosion compounds regarding each metal, decay of metallic elements into crude oils during the corrosion and eventually the deductions of the initial hardness of metals due to the formations of the corrosion on those metallic surfaces.

2. Materials and Methodology

2.1. Materials

Seven different types of ferrous metals, having various applications in the crude oil refining industry under different processes with various conditions namely below were selected for this research.

- Carbon Steel (High) – Transportation tubes, storage tanks

- Carbon Steel (Medium)- Storage tanks
- Carbon Steel (Mild Steel)- Storage tanks
- 410-MN: 1.8 420-MN: 2.8 (Stainless Steel)- Heat exchangers
- 410-MN: 1.7 420-MN: 1.7 (Stainless Steel)- Crude distillation columns
- 321-MN:1.4 304-MN:1.9 (Stainless Steel)- Crude distillation columns
- Monel 400- Pre heaters, desalting process

Two different types of crude oils were selected as the samples by considering the variations of the chemical compositions of such crude oils foremost of the corrosive properties of both crude oils. These two crude oils are Murban and Das Blend. Das Blend, also considered as a "sour" crude oil is because of the higher sulfur content. However, Murban crude oil contains a normative chemical composition. Also, both crude oils contained a diminutive amount of water since inside of the earth which is an essential component for the corrosion [9].

2.2. Methodology

2.2.1. Testing of Chemical Compositions of Selected Metals

The elemental compositions of the selected ferrous metals were tested by the digital XRF detector. This is an instrument which is working under the principle of the penetration of the X-ray through the relevant materials. According to the methodology, either the material needs to be exposed or touched to the detector of the instrument and the digital readings of experiment or it will be displayed on the digital screen of the instrument as shown in the Figure 1.

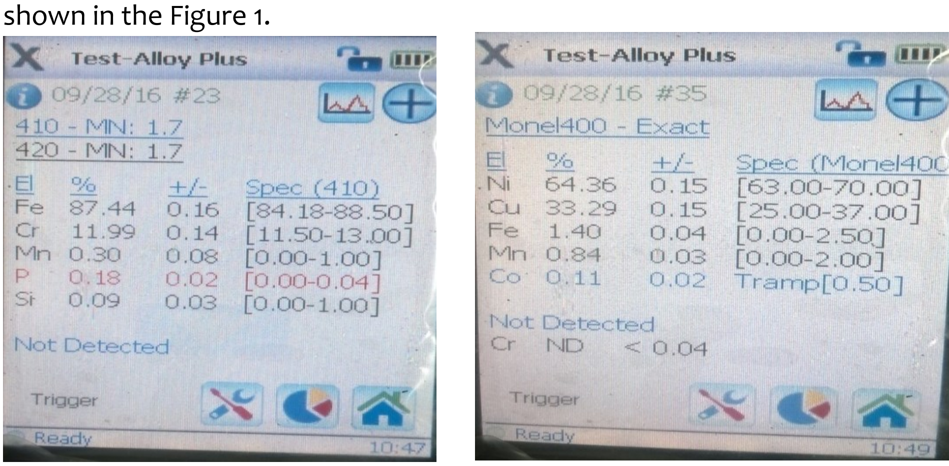


Figure 1: *The displaying of results by the XRF detector***.**

2.2.2. Testing of the Corrosive Compounds of both Crude Oils

The corrosive compounds of both crude oils were investigated by the standard methodologies and instruments as explained in the Table 1.

Property	Method	Readings
Sulfur content	Directly used the crude oil samples to the XRF analyzer.	Direct reading
Acidity	Each sample was dissolved in a mixture of toluene and isopropyl and titrated with potassium hydroxide.	End point
Mercaptans content	Each sample was dissolved in sodium acetate and titrated with silver nitrate.	End point
Salt content	Each sample was dissolved in organic solvent and exposed to the cell of analyzer.	Direct reading

Table 1: *Testing procedures of the corrosive properties of crude oils.*

2.2.3. Preparation of the Metal Coupons and Corrosion Test

A set of metal coupons were prepared from seven different types of ferrous metal in equal dimensions, their surfaces were cleaned so that the presence of any corroded or embrocated material is minimal on the metal surfaces while observing through the 400X lens of an optical microscope. The prepared metal coupons have been shown in the Figure 2.

Figure 2: *Prepared metal coupons.*

The dimensions and the initial weights of each metal coupon were measured. The prepared metal coupons were separately and completely immersed in both crude oil containers. The three homogeneous metal coupons in one crude oil container altogether makeup fourteen crude oil samples, including 7 Murban samples and 7 Das Blend Samples as shown in the Figure 3.

(a) (b)

Figure 3: *(a) Immersion of metal coupons and (b) apparatus.*

After 15 days from the immersion time period, each metal coupon was taken from each crude oil sample, thus fourteen metal coupons from fourteen crude oil samples. That batch of metal coupons represents each type of metal and both crude oils as well. The corroded surfaces of each metal coupon were observed under the 400X lens of the laboratory optical microscope and the surface was cleaned by sand papers and iso-octane until free of corrosion. The final weight of each metal coupon was measured by electronic balance. The corrosion rate of each metal coupon was determined by the relative weight loss method which is explained in the section of theory and calculations [15].

The same procedure was repeated twice again for another similar two batches of remaining metal coupons in crude oil containers after thirty and forty-five days from the immersion to determine the corrosion rate of each metal coupon and finally the average values of the corrosion rates were calculated for each type of metal with respect to crude oil and such values were interpreted as the summary of the results.

2.2.4. Microscopic Analysis of the Corroded Metal Surfaces

The metal surfaces were observed under 400X lens of the laboratory optical microscope based on objectives given below:

- Confirmation of the purity of the metallic surfaces before immersion in the crude oils.
- Identification of the formation of the corrosion compounds qualitatively.
- Confirmation of the cleaning of metal surfaces to determine the weight loss.

Based on above objectives, each metal coupon was observed by 400X lens of the laboratory optical microscope before the immersion in crude oils and after taking out from the crude oils often as necessary.

2.2.5. Decay of the Metals into Crude Oils

In virtue of the invisible weight loss of some metal coupons while determining of the corrosion rates of such metal coupons, this section was performed as a confirmation stage of the formation of the corrosion. The ferrous and copper concentrations of each crude oil sample after the interaction with the metal coupons by the atomic absorption spectroscopy (AAS). According to the methodology of sample preparation, 1 ml of each crude oil sample was diluted with 9 ml of 2-propanol and filtered. The initial ferrous and copper compositions of both crude oils were referred as zero by crude assays regarding both Murban and Das Blend crude oils. Therefore, the final readings easily conclude the decayed ferrous and copper amounts from the metals.

2.2.6. Deduction of the Initial Hardness of Metals

The variations of the initial hardness of metal coupons due to the corrosion were considered as the essential parameters regarding the corrosion. According to the procedure, the initial hardness of each metal coupon was measured and the hardness after formation of the corrosion on each metal coupon was measured by the Vicker's hardness tester. The working principles of the Vicker's hardness tester have been discussed in the section of theory and calculations.

2.3. Theory and Calculation

2.3.1. Weight loss method

The mathematical expression of the weight loss method has been discussed with its terms and units in the Equation 1 [15].

$$CR = W * k/(D * A * t) \qquad (1)$$

Where;

W = weight loss due to the corrosion in gramsk = constant (22,300)D = metal density in g/cm^{3}A = area of metal piece (inch^2)t = time (days)CR= Corrosion rate of metal piece

2.3.2. Indenter of the Vicker's hardness tester

The working principle of the indenter of the Vicker's hardness tester is shown in the Figure 4.

Figure 4: *The indenter of Vicker's hardness tester.*

The mathematical expression of the calculation of the hardness of the metal with the applied load on it has been given in the Equation 2.

$$\mathrm{HV} = 1.854 * \mathrm{P}^2/\mathrm{L}^2 \qquad (2)$$

Where;

P= Applied Load on the surface of metal L= Diagonal length of squareHV= Hardness

This procedure was basically defined for the manual calculations of the hardness of some particular point on the metal surface when it is calculated manually according to the mechanical Vicker's hardness tester although using the digital Vicker's hardness tester in this research. Therefore, the readings were directly received.

3. Results and Discussion

The obtained results have been summarized under separate chapters and the discussion also continued with the relevant subtopics.

3.1. Elemental Compositions of Metals

According to the results, the elemental compositions of selected ferrous metals have been summarized as given in the Table 2.

Metal	Fe (%)	Mn (%)	Co (%)	Ni (%)	Cr (%)	Cu (%)	P (%)	Mo (%)	Si (%)	S (%)	Ti (%)	V (%)
(1)Carbon Steel (High)	98	0.	-	0.1	0.1	0.3	0.1	0.	0.	-	-	-
(2) Carbon Steel (Medium)	99.36	0.39	-	-	-	-	0.109	-	0.14	<0.02	<0.04	-
(3) Carbon Steel (Mild Steel)	99	0.5	<0.	-	<0.	-	-	-	-	-	<0.	<0.
(4) 410-MN: 1.8 420-MN: 2.8 (Stainless Steel)	88.25	0.28	-	0.18	10.92	0.10	0.16	-	0.11	-	-	-
(5) 410-MN: 1.7 420-MN: 1.7 (Stainless Steel)	87.44	0.30	-	-	11.99	-	0.18	-	0.09	-	-	-
(6) 321-MN:1.4 304-MN:1.9	72.	1.4	-	8.	17.	-	0.1	-	0.1	-	-	-

(Stainless Steel)														
(7) Monel 400	1.4	0.8	0.11	64.	<0.	[illegible]	33.	[illegible]	-	-	-	-	-	-

Table 2: *Chemical compositions of selected ferrous metals.*

Referring to the above results, it is visible that there is existence of higher ferrous amounts in carbon steels, intermediate ferrous amounts in stainless steels and trace amount of ferrous in Monel metal since the majority were obtained by both nickel and copper regarding the Monel metal. As a special observation the doping of trace metal with major elements were identified regarding stainless steels. According to the theoretical explanation, this incident can be emphasized mainly in a few expectations given below [17].

- Enhancement of the strength of mechanicals of such metals such as the hardness and tensile strength
- Enhance the corrosive protection strength of such metals

The corrosive protection ability of stainless steel is much important for this discussion because of the significant trend of the corrosion regarding this research. According to the theoretical explanations, stainless steels are some sort of solution against the corrosion. Because approximately at the chemical composition ~12% of chromium with substantial amount of nickel tend to form a self-corrosive protection film on the metal surface itself although the performances and the efficiency of the formation of such corrosive protection film and the progress of the corrosion protection of that film may be varied with both compositions of chromium and nickel [12]. These things have been descriptively discussed in the next chapters with the observed results and conclusions.

3.2. Corrosive compounds of crude oils

According to the results of the investigations of the corrosive properties of both Murban and Das Blend, crude oils such values have been interpreted with respect to the property and the relevant crude oil as given in the Table 3.

Property	Murban	Das Blend
Sulfur content (Wt. %)	0.758	1.135
Salt content (ptb)	4.4	3.6
Acidity (mg KOH/g)	0.01	0.02
Mercaptans content (ppm)	25	56

Table 3: *Corrosive properties of both crude oils.*

As the preliminary conclusion of above results, we can reach to a conclusion that only referring the corrosive compounds of both crude oils: the Das Blend might have affected strongly in the metallic corrosion rather than the effect of Murban in the metallic corrosion. The reason is that the Das Blend crude oil is composed of relatively higher amounts of elemental sulfur, Mercaptans, organic acids and only lower number of salts than the Murban crude oil. The progress of such compounds on the metallic corrosion with the required conditions and the obtained results are discussed in the next section in details.

Organic acids are the dominant corrosive properties found in crude oils, since the occurrences are also known as naphthenic acids having a chemical formula of "RCOOH" [1]. The effects of such organic acids on different types of metal have been discussed in some of previous studies as a corrosive compound even at room temperatures. These organic acids may be slightly varied with the chemical compositions although the total amount of these organic or naphthenic acids is known as the "acidity" or the "total acid number (TAN)" such crude oil. The general chemical reactions between such organic acids and ferrous metals are given in the Equation 3, Equation 4 and Equation 5 [6].

$$\mathrm{Fe + 2RCOOH \rightarrow Fe(RCOO)2 + H2} \quad (3)$$

$$\mathrm{FeS + 2\,RCOOH \rightarrow Fe(COOR)2 + H2S} \quad (4)$$

$$\mathrm{Fe(COOR)2 + H2S \rightarrow FeS + 2\,RCOOH} \quad (5)$$

As the main product of FeS can be emphasized with some of by products such as the hydrogen sulfide also highly corrosive form of sulfur. Although it may be affected in portion, it is possible to be neglected because hydrogen sulfide may have less retention time in the phase of liquid before the evaporation. The special feature that can be assumed with the above chemical process is, both Fe and FeS tend to be reacted with organic acids, as this is a mechanism of reproduction of the organic acids and the catalytic process [13].

Salts are the trace compounds that can be found in most of the crude oils since the occurrences of such crude oils is also known as a corrosive compound. Mainly there were found NaCl, $MgCl_2$ and $CaCl_2$ as those salts and the summation of such compounds is known as the total salt content of that particular crude oil. When the system is arising up to higher temperatures, these salts tend to be reacted with water presence in crude oils and formed HCl molecules although behave as inactive compounds at that occasion as given in the Equation 6 [18].

$$\mathrm{CaCl2 + H2O \rightarrow CaO + 2HCl} \quad (6)$$

When the system is approaching to the lower temperature, HCl molecules are normally reacted with the moisture and water in the system and form highly corrosive hydrochloric acids. Such hydrochloric acids are able to oxidize the metal easily and suddenly even at the normal temperature [11]. The chemical reactions of the above process are given in the Equation 7 and Equation 8 and Equation 9.

$$HCl + Fe \rightarrow FeCl2 + H2 \quad (7)$$

$$H2 + S \rightarrow H2S \quad (8)$$

$$FeCl2 + H2S \rightarrow FeS + 2HCl \quad (9)$$

Also, regarding the above process of oxidizing there can be seen the formation of hydrogen sulfide as an intermediate product also highly corrosive form of active sulfur compounds. As a special incident that there can be emphasized the contribution of the elemental sulfur of active sulfur compounds on the formation of hydrogen sulfides during the above corrosion process also the oxidizing process of metals is happening with the effect of both hydrochloric acids and such hydrogen sulfide. The proper chemical reaction can be expected in a closed system because of the gas phase of the hydrogen sulfide and less retention time in the phase of liquid.

Sulfur also considered as a corrosive compound in various forms of it such as elemental sulfur, Mercaptans, hydrogen sulfide, thiophenes and sulfoxides. Even though such compounds need some advanced conditions to form the corrosion such as the high temperature conditions. Mercaptans have been identified as high corrosive compounds because of the significant reactance of the functional group of "RSH" [9]. The corrosion due to the effect of the Mercaptans is known as the "Sulfidation" usually required about 230°C for the proper progress of the chemical reaction and also the corrosion process due to the effect of elemental sulfur is known as the "localized corrosion" which is properly happened at about 80°C [6]. According to the nature of the sulfur and such sulfur compounds most of them are corrosive compounds because of the reactivity of the functional groups. The general chemical reactions for the above chemical processes are given in the Equation 10 and Equation 11.

$$S8(s) + 8\ H2O\ (l) \rightarrow 6\ H2S\ (aq) + 2\ H2SO4\ (aq) \quad (10)$$

$$8\ Fe + S8 \rightarrow 8\ FeS \quad (11)$$

According to the above chemical reactions the elemental sulfur tends to react with water when increasing of the temperature in the relevant system and formed the sulfuric acid also known as the highly corrosive compound. As the considerable incident that the elemental sulfur directly reacts with the metal and formed the metal sulfide at higher temperatures.

By referring such observations and the theoretical backgrounds of such observations finally it is possible to expect some proper progress from both organic acids and salts in the metallic corrosion in current conditions such as the room temperature since there may be impacted improperly by both elemental sulfur and Mercaptans on the metallic corrosion at lower temperatures.

3.3. Corrosion rates of metals

Metal	Corrosion Rate after 15 Days (cm^3 inch^{-1}day^{-1})	Corrosion Rate after 30 Days (cm^3 inch^{-1} day^{-1})	Corrosion Rate after 45 Days (cm^3 inch^{-1} day^{-1})	Average Corrosion Rate (cm^3 inch^{-1} day^{-1})
(1) Carbon Steel (High)	0.811	0.466	0.068	0.449
(2) Carbon Steel (Medium)	0.817	0.180	0.073	0.357
(3) Carbon Steel (Mild Steel)	0.109	0.048	0.038	0.065
(4) 410-MN: 1.8 420-MN: 2.8 (Stainless Steel)	0.041	0.016	0.011	0.023
(5) 410-MN:1.7 420-MN: 1.7 (Stainless Steel)	0.116	0.011	0.007	0.045
(6) 321-N:1.4 304-MN:1.9 (Stainless Steel)	0.016	0.007	0.005	0.009
(7) Monel 400	0.356	0.034	0.026	0.139

Table 4: *Corrosion rates of metal coupons in Murban crude oil.*

Metal	Corrosion Rate after 15 Days (cm^3 inch^{-1} day^{-1})	Corrosion Rate after 30 Days (cm^3 inch^{-1} day^{-1})	Corrosion Rate after 45 Days (cm^3 inch^{-1} day^{-1})	Average Corrosion Rate (cm^3 inch^{-1} day^{-1})
(1) Carbon Steel (High)	0.350	0.224	0.024	0.199
(2) Carbon Steel (Medium)	0.481	0.140	0.059	0.226
(3) Carbon Steel (Mild Steel)	0.162	0.141	0.100	0.134
(4) 410-MN: 1.8 420-MN: 2.8 (Stainless Steel)	0.044	0.034	0.006	0.028
(5) 410-MN: 1.7 420-MN: 1.7 (Stainless Steel)	0.053	0.034	0.016	0.034
(6) 321-MN:1.4 304-MN:1.9 (Stainless Steel)	0.022	0.006	0.002	0.010
(7) Monel 400	0.061	0.037	0.016	0.038

Table 5: *Corrosion rates of metal coupons in Das Blend crude oil.*

The concluded graphical representation of the above numerical results has been shown in the Figure 5.

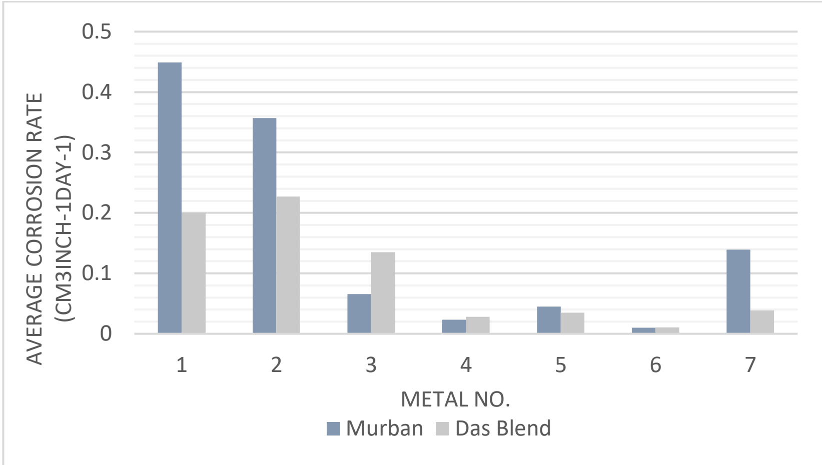
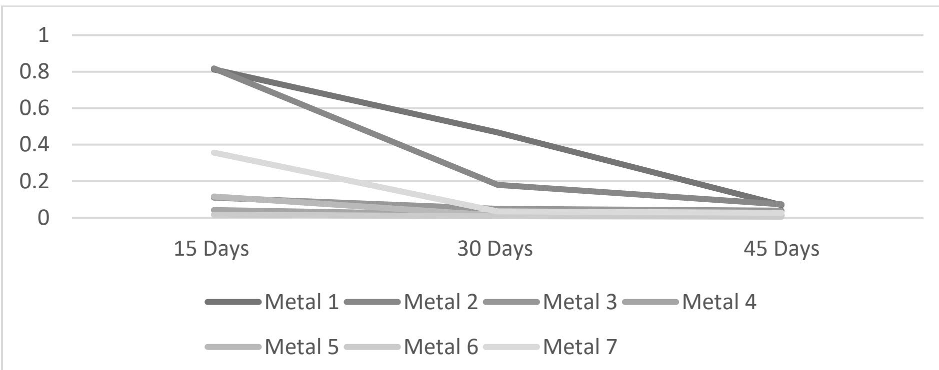


Figure 5: *Average corrosion rates of ferrous metals in both Murban and Das Blend crude oils.*

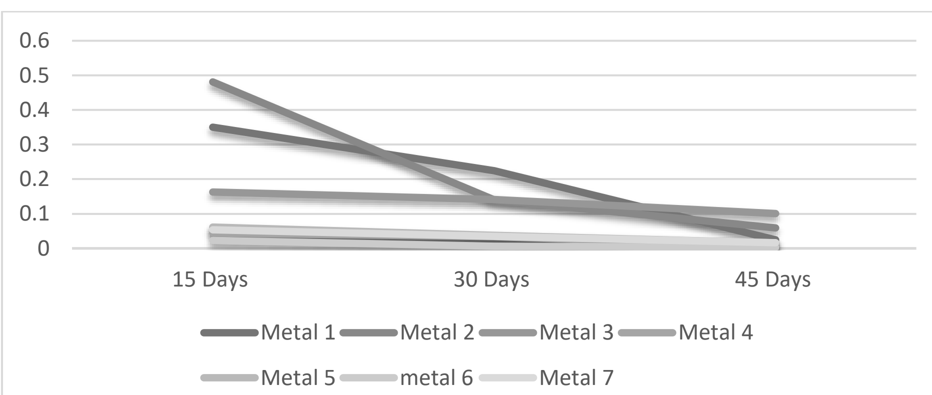
Above concluded results show that the relatively higher corrosion rates from carbon steels and significantly lower corrosion rates from stainless steels as expected before. Also, some intermediate corrosion rates were found from Monel metal. The least corrosion rates were found from 321-MN:1.4 304-MN:1.9(Stainless Steel) in both Murban and Das Blend crude oils. When considering the chemical composition of 321-MN:1.4 304-MN:1.9(Stainless Steel) it was composed ~18% of chromium and ~8.7% of nickel. In the explanations of the self-corrosive protection film of the stainless steels it required ~12% of chromium with sufficient amount of nickel to combine with that. Regarding the corrosion rates of other stainless steels 410-MN: 1.7 420-MN: 1.7(Stainless Steel) took a possession of highest corrosion rates among stainless steels which was composed ~12% of chromium with lack of nickel and 410-MN: 1.8 420-MN: 2.8 (Stainless Steel) showed an intermediate corrosion rates among stainless steels since it was having ~11% of chromium and ~0.2% of nickel [12]. Altogether with these results and the explanations that there can be suggested the requirements of both nickel and chromium at least in the recommended percentage to have optimal corrosive protection performances from that self-corrosive protection film in stainless steels.

When comparing the corrosion rates of different types of metals in both crude oils four types of metals showed their higher corrosion rates in Murban crude oil since other three types of metals were showing their higher corrosion rates in Das Blend crude oils. In the explanations of the corrosive strength of both Murban and Das Blend crude oils first of all it is possible to neglect the proper effects of elemental sulfur and Mercaptans on the metallic corrosion at the room temperature because both "localized corrosion" and "Sulfidation" processes are usually occurred properly at the higher temperatures [6]. Therefore, it is possible to emphasize that the impact of salts on the metallic corrosion is much stronger than the impact of organic acids on the metallic corrosion because Murban crude oil was composed higher number of salts since Das Blend was having higher number of organic acids.

The variations of the corrosion rates of metal coupons with the exposure time period against the crude oils have been shown in the Figure 6.



(a)



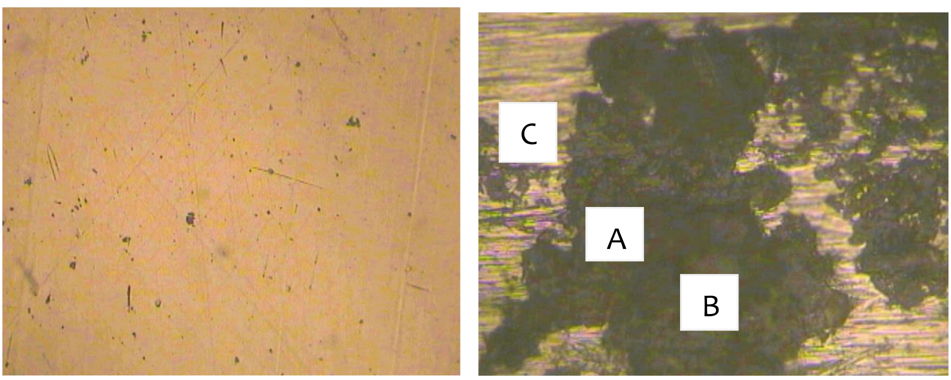
(b)

Figure 6: *Variations of the corrosion rates of metal types in (a) Murban and (b) Das Blend.*

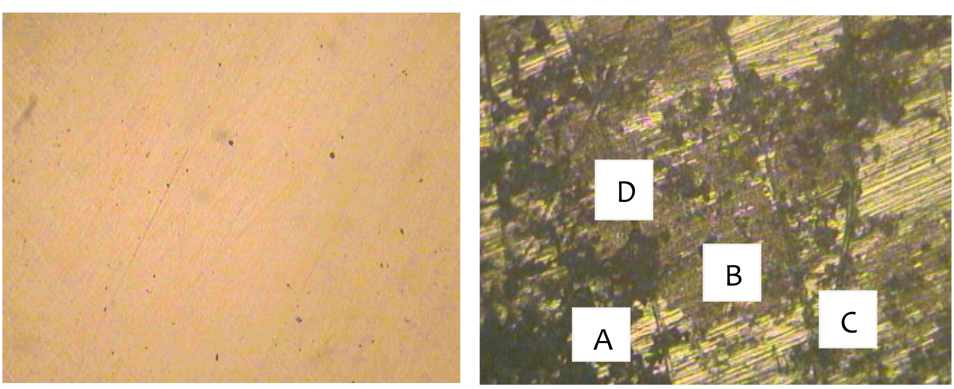
The above distributions of the corrosion rates of metals showed some similar curves regarding each type of metal. Further it is revealed that there was negligible effect even from the crude oil. In briefly observing such variations of the corrosion rates with the immersion time period it's possible to confirm the accuracy and validity of the inversely proportional relationship between corrosion rate and the immersion time period in the corrosive medium in the weight loss method. Also, it can be corroborated the reduction of the corrosion causing rate with the exposure time because of the self-corrosive barrier from the remaining previously formed corrosion compound on the continuously formation of the corrosion in a constant rate [16].

3.4. Microscopic Observations of Corroded Metal Surfaces

According to the observations through the 400X lens of the laboratory optical microscope there were observed some common observations and the distinguished features as well. Some of highlighted observations have been shown in the Figure 7.



(a)



(b)

Figure 7: *Corroded metal surface of (a) 410-MN: 1.7 420 - MN: 1.7 (stainless steel) in Murban and (b) Carbon Steel (Mild Steel) in Murban.*

The observations were based on their visible features foremost of the color and surface changes such corrosion cracks and cavities [14]. Some of such observations have been shortlisted in the below and compared with their properties in the Table 6.

- ✓ A- Black color patches
- ✓ B- Black or rusty color patches
- ✓ C- Black or pale color cracks

✓ D- Cavities among black patches and cracks

Compound	Appearances	Observations
FeS	Black, brownish black, property of powder, pitting, cracks	Observed most of features in each metal piece.
Fe_2O_3	Rusty color	Observed rarely.
CuS	Dark indigo/ dark blue, property of powder	Unable to specify.

Table 6: *The distinguish appearances of the corrosion compounds.*

By referring the observations and the typical properties of regarding the corrosion compounds it can be concluded the formations of FeS regarding most of observations as explained under each corrosion mechanism with some accessory features such as the corrosion cracks and pitting corrosion. Especially such corrosion cracks and pitting corrosion were found from stainless steels. In addition, these were obtained from the general or rusty corrosion compounds Fe_2O_3 rarely in some of carbon steels and stainless steels also it can be assumed that it might have formed due to the oxidizing affect together both water presence in crude oils and dissolved oxygen in such crude oils [16]. According to the observations related to the Monel metal there were observed some black color patches which were similar to FeS also can be concluded as CuS although it's inaccurate if only considering the visible appearances also need a compositional analysis to approach an accurate decision to distinguish CuS from FeS [10].

3.5. Decay of metals into crude oils

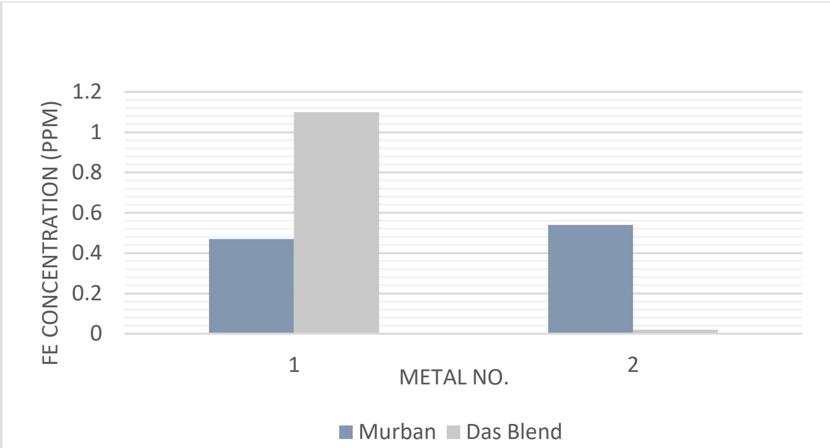
The decayed ferrous concentrations and decayed copper concentrations from the metals into crude oils have been given in the Table 7.

Metal	Crude Oil	Fe Conc./ppm	Cu Conc./ppm
Carbon Steel (High)	Murban	0.47	-
	Das Blend	1.10	-
Carbon Steel (Medium)	Murban	0.54	-
	Das Blend	0.02	-
Carbon Steel (Mild Steel)	Murban	-0.08	-
	Das Blend	-0.48	-
410-MN: 1.8	Murban	-0.65	-
420- MN: 2.8 (Stainless Steel)	Das Blend	-0.78	-
410-MN: 1.7	Murban	-0.71	-
420-MN: 1.7 (Stainless Steel)	Das Blend	-0.79	-
321-MN:1.4	Murban	-0.44	-
304-MN:1.9 (Stainless Steel)	Das Blend	-0.17	-
Monel 400	Murban	-	10.47
	Das Blend	-	9.49

Note: Conc. denotes Concentration

The above results have been graphically represented in the concluded way in the Figure 8.

(a)



(b)

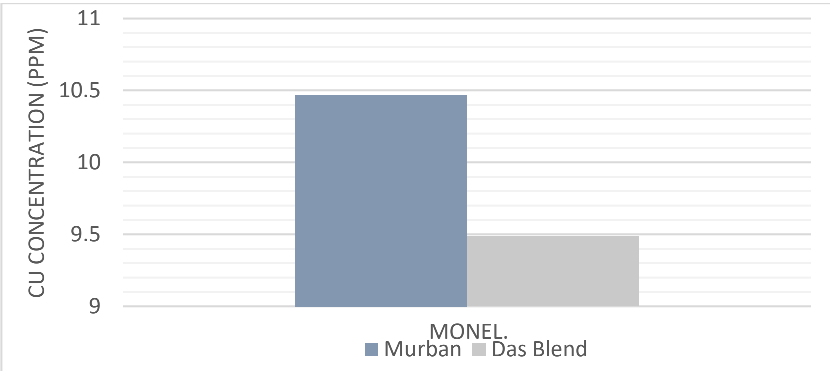
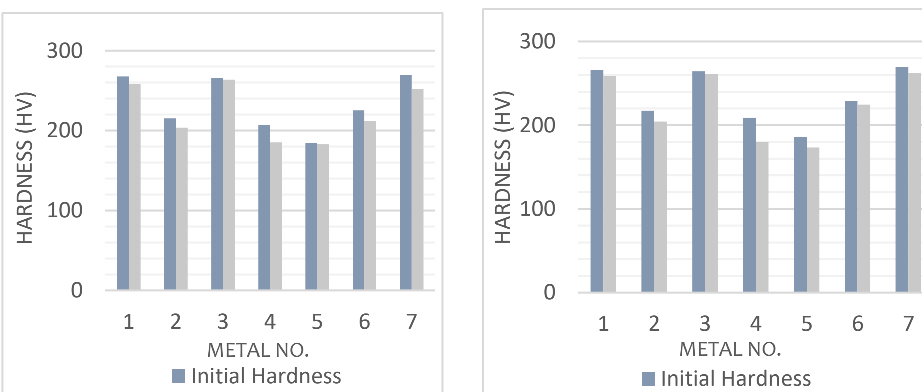


Figure 8: *(a) The decayed ferrous concentrations and (b) the decayed copper concentrations in crude oil samples.*

By referring above results it can be concluded that the higher amount of ferrous decay from carbon steels (high) and carbon steel (medium) into both Murban and Das Blend crude oils also found higher corrosion rates from carbon steels (high) and carbon steel (medium) with respect to both crude oils. In addition, these were obtained by zero decay concentrations of ferrous in from carbon steels (mild steels) or any type of stainless steels into any crude oil sample were also found having least corrosion rates with respect to both Murban and Das Blend crude oils. Since these were found with some significant decay of copper from Monel metal into both crude oil samples also found some intermediate corrosion rates. In the explanation of such incident simultaneously formation of the corrosion is linked with the acting of some repulsive and attractive forces from between the successive electrons and protons on the metallic surfaces and the newly formed corrosion compounds such as the metal sulfides and oxides [12]. Therefore, such compounds tend to be removed from the metal surfaces into the surrounding environments partially or properly. Through the obtained results it can be concluded that this might have happened because of the metal decay under the explained mechanism and it can be emphasized some approximate linkage in between the corrosion rates and the decay of metals while the formation of the corrosion.

3.6. Variations of the hardness of metals

According to the obtained results for the initial and final hardness of metal coupons the graphical representations have been shown in the Figure 9.



(a) **(b)**

Figure 9: *Variations of the hardness of metals in (a) Murban and (b) Das Blend crude oils.*

The graphical distribution of the variations of the initial hardness of metal coupons showed a slight reduction with respect to each metal coupon after exposed to each crude oil while forming the corrosion on the surface itself. When comparing these observations with the theoretical concepts regarding the incident of the corrosion that it is possible to explain that after the formation of the corrosion compounds such corrosion compounds tend to be removed from the initial metal surface either in properly of partially due to the attractive and repulsive forces between successive electrons and protons of the participant atoms and molecules [12]. Therefore, it's impossible to expect the initial hardness on the metal surface because of the generated instability of the metal surface due to the heterogeneous conditions on the metal surfaces. Finally, it can be concluded the reduction of the initial hardness occurred due to the formation of the corrosion on the metal surfaces.

4. Conclusion

From the results of the research, it was observed that the least corrosion rates vary from 321-MN: 14 304-MN: 1.9 (Stainless Steel) in both crude oils since three types of stainless steels were showing lower corrosion rates among other metals because of the impact of the self-corrosion protection film of stainless steels due to the compositions of chromium and nickel in certain amounts approximately more than 12% chromium with sufficient amount of nickel. The Das Blend crude oil was composed in higher amounts of organic acids, elemental sulfur, Mercaptans and lower number of salts than the Murban crude oil although found higher effect from the salts and organic acids at the room temperature while affecting both Mercaptans and elemental sulfur improperly on the metallic corrosion at the room temperatures. The microscopic analysis showed the formations of FeS with corrosion cracks and pitting corrosion, Fe_2O_3 rarely and also it is possible to assume the formation of CuS. In addition to the basics there were found the decay of ferrous from carbon steels and stainless steels also decay of copper from Monel metal into crude oils and the slight reductions of the initial hardness of metal due to the formation of the corrosion. Some recommendations for the futures research works have been concluded in the below.

- Analysis of the corrosion rates of such metals or another types of metals at different temperatures because some corrosive processes are dependable on the temperature and emphasize the temperature which gives the optimal corrosion rates with respect to each metal.
- Determination of the corrosion rates of metal coupons by some electronic analysis method instead of the weight loss method or determination of the corrosion rates by both electrical and mechanical method and compare the obtained results to enhance the accuracy forever.
- Compositional analysis of the corrosion compounds which were formed on the metallic surfaces by the X-ray diffraction (XRD) or any advanced analytical method.
- Analysis of the dissolved hydrogen sulfide concentration by a standard method and discuss about the effect of hydrogen sulfide on the metallic corrosion with a possible mechanism as well in addition to these corrosive compounds.
- The analysis of decayed elemental concentrations from metals into crude oils can be extended up to another few of elements such as nickel, chromium by the same methodology of the atomic

absorption spectroscopy (AAS) to have a descriptive discussion with the observed results.

Acknowledgment

The author wishes to appreciate the supervisor, technical staff and the laboratory staff regarding this work.

Declaration

Authors declare that there is no any conflict regarding the publication of this research paper.

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