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Research paper

Vibration effect on the corrosion rate of crude oil pipeline

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Abstract

In this paper, evaluation the influence of vibration on the corrosion rate of API 5L X60 and API 5L X80 carbon steel pipelines used for delivering of crude oils. A grouped of equipment are constructed laboratory and then used in the vibration-immersion corrosion test. The experimental results demonstrated that the vibration effects on crude oil properties and contribute to the dissociation of components of crude oils essentially water, dissolved gases and asphalt which leads to increase the corrosion rates compared to static case. The vibration process effect on the material compositions, i.e., the vibration effect on bonds between atoms of metal which leads to reduces of resistances of material to corrosion process.

Keywords: *Chloride Salts; Trace Element; Vibration; Asphalt; CO_2 and H_2S Gases.*

1. Introduction

There are usually two types of pipeline vibration: steady state vibration and nonlinear transient vibration. Over a long period of time, steady state vibration occurs due to forced or cyclic vibration. For a relatively short period of time, a nonlinear transient vibration occurs and stops quickly [1, 2]. The crude oil pipeline vibrations can be initiated in a number of ways but can result in very significant effects if the resonances are involved. The crude oil pipeline vibration can be induced due to various factors such as high wind speeds, high flow rate, fluid petroleum pressure variations and pumps [3].

The corrosion in petroleum pipeline is one of the significant problems confronting the petroleum industry operators. This problem is closely associated with the presence of water, dissolved gases (CO_2 and H_2S), asphalt and sediments that accumulates in the pipeline and contains a variety complex component including chlorides, sulfates, and salts [4]. In addition, different parameters, including metallurgy and vibrations from different sources, affect the corrosion rate of the crude oil pipeline [5].

Different experimental methods are used for testing and estimation of corrosion rates. Among them only the immersion test method can be employed to study the vibration effect in metal corrosion rates. An immersion test is a method that is not electrochemical. In immersion test, the metal specimen of the well-known area is exposed for a period of time to the solution and then the loss of metal mass due to corrosion process has been measured [6-7].

Hart et al. [8] studied the oil pipeline wind-induced vibration phenomenon. They show that the oscillation can result from the effect of the horizontal wind flow across the oil pipelines and the amplitudes of these oscillations are normally quite small, but the accumulation of these oscillations can lead to induce damage in pipelines. Habib et al. [9] developed a simple numerical method based on the resonance frequencies asymptotic formulae and shapes mode for identifying and characterizing the small internal corrosion in a pipeline through structural vibration analysis. They show that the method developed gives accurate results to determine the location of the corrosion as well as from the measured information a suitable initial guess can be obtained for the reverse of the method developed. Fei [10] studied the fretting corrosion induced in the electrical connector by the vibration phenomenon. They examined the effect of normal force on fretting corrosion caused by vibration, and the results showed that the vibration had a greater effect on fretting corrosion. Safri et al. [11] investigated the Kuwait's crude oil pipeline corrosion problems that used for transporting crude oil from fields in Wafra south Kuwait to the Arab Gulf export port. It is found that half of the pipelines have severe corrosion through the pipeline length and need repairs. Kong et al. [12] used numerical methods and non-destructive methods to study vibration failure of the stainless steel piping system induced by the fluid flow. They determine the maximum operating pressure under vibration effects that a piping system can withstand. Eslami et al. [13] studied the free vibration of pitted corroded plates under condition that the plates were simply supported. They showed that the different patterns of corrosion have little influence on natural frequency reduction and the ratio of pit depth to plate thickness has no influence on natural frequency reduction. Wael et al. [14] proposed that a new sensor may be used under the action of vibration for quality inspection of newly manufactured pipes and study the flow accelerated corrosion. The technique is based on the analysis of the piping system's vibration response and provides both the wear's magnitude and location due to flow accelerated corrosion. Yang et al. [15] introduced a new vibration method for detecting pipeline corrosion damage by measuring the pipeline's first and second natural frequencies and then comparing it with the results obtained from the numerical method. They found that the result obtained from numerical method is agreement with the result acquired from the developed method. Lu et al. [16] analyzed by using both the numerical simulation method and experimental approaches the oil pipeline vibration phenomena resulting from the oil fluid reciprocal pump pressure pulsation. Their results showed that the influence of the pipeline vibration could result in pipe failure, distortion and damage. Also, they indicate that both thermal stresses and raise temperature affected on vibration amplitude of pipelines.

The objective of this study is to examine the effects of the vibration on the corrosion rate of two types of seamless carbon steels API 5L X60 and API 5L X80 used for crude oil pipelines at

Maysan oil fields southern Iraq. An experimental immersion-vibration test apparatus is collected and used for testing. Three types of crude oil assembled from Maysan oil fields Bazergan, Faqa and Halfaya south of Iraq were considered for testing. The effect of various parameters includes vibration, temperatures, crude oil compositions and pipeline materials were studied and discussed.

2. Crude oil samples analysis

The crude oil found in Iraq essentially vary as far as of quality with API gravities generally are ranged from 22° (heavy crude oil) to 35° (light to medium crude oil) [16]. The raw crude oil samples used for testing are gathered from three different oil fields in the Maysan proven southern Iraq (Buzerkan, Halfaya and Faqa) oil fields. The crude oil material compositions, physical properties and dissolved gases are analyzed in the Nahr Umer laboratory of South Oil Company of Iraq and it is outlined in Tables 1 and 2 respectively.

Table 1: Material Constitution of Buzerkan, Halfaya and Faqa Crude Oils.

Materials constitution (ppm wt)	Fields Bazerkan	Faqa	Halfaya
Iron	2.2	3.76	2.8
Copper	3.6	5.1	3.1
Vanadium	32	31	34
Nickel	10	11	7.1
Cadmium	0.41	0.52	0.23
Aluminum	0.13	0.31	0.16
Manganese	0.17	0.22	0.27

3. Pipelines materials and sample preparation for testing

By using two different types of pipeline materials, API 5L X60 and API 5L X80 seamless carbon steels, the crude oil was transported over a distance of 300 km from the Maysan oil fields to the Al-Basrah terminal at the Arab Gulf. The diameter of API 5L X60 pipeline is 71.12 cm and a wall thickness of 14 mm, while the diameter of API 5L X80 pipeline is 122 cm and a wall thickness of 16 mm. Tables 3 and 4 show their elemental chemical compositions and mechanical properties of the two pipelines materials.

Table 2: Physical Properties of Buzerkan, Halfaya and Faqa Crude Oils

Properties	Fields Bazergan	Faqa	Halfaya
API	24.7	22.5	27
Sulfur %	5.12	3.89	4.85
Water content %	2	1.96	1.75
Salt NaCl ppm	44	24.4	14
Asphaltenes %	13.2	12.5	10.1
Specific gravity at 20ºC	0.8901	0.9048	0.8835
Kinematics viscosity cst at 20ºC	45	33.5	44
Dielectric Constant	1.78	2.11	1.92
H_2S (g) ppm	0.49	0.44	0.37
CO_2 (g) ppm	0.57	0.67	0.41

Table 3: The Percent of Material Composition of X60 Carbon Steel [18]

Elements	%	Elements	%
C	0.007	Al	0.008
Si	0.22	Cu	0.013
Mn	1.63	Ti	0.010
P	0.01	V	0.072
S	0.005	Nb	0.052
Cr	0.011	N	0.008
Ni	0.011	Mo	0.228

Table 4: Mechanical Properties of X80 and X60 Carbon Steel [17-18]

Grade	Permissible yield point ratio	Yield strength MPa (Min.)	Tensile strength MPa.	Elongation % (Min.)
X80	$\leq$ 0.90	555 Min.	625- 700	20 Min.
X60	$\leq$ 0.42	541 Min.	627	27 Min.

The test specimens were cut and manufactured from the X60 and X80 carbon steel pipeline materials for the purpose of the immersion test with dimensions of (50 × 25 × 5) in mm. The specimens were polished with 160, 180, and 200 grade sandpapers, then the specimens are cleaned by wishing with distilled water. After that, at atmospheric pressure and temperature, the specimens are dried by hot air. A hole was drilled on the central of each specimen for suspension process. A total of 75 specimens were processed for testing. Figure 1 shows samples of carbon steels X60 and X80.

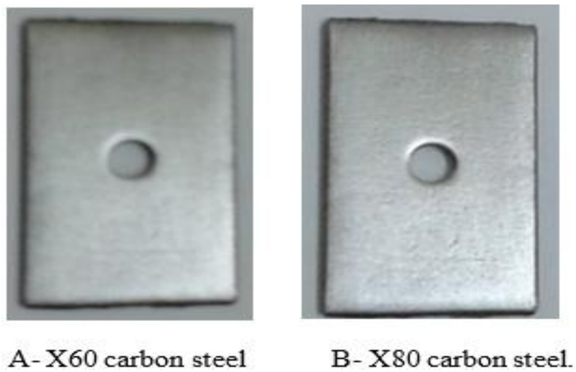

Fig. 1: Immersion Testing Specimens.

4. Immersion test and apparatus

The grouped devices used in the vibration-immersion corrosion test are constructed laboratory according to ASTM G32-03 [20, 21] and illustrated in Figure 2. Basically, the apparatus consists from vibrating test table (VIBCO's model US-900); this table is produced by VIBCO Co. Inc., USA and used as a source for generating vibrations. The grouped devices also included a tablet digital electrical heater model SD300; these types of heaters are produced by Bibby Scient. Ltd. UK that used to regulate the temperature during test. A 500 ml glass beaker was mounted on a plate of the electrical heater and full with crude oil solutions for testing.

The vibration -immersion corrosion test was conducted at sets of temperatures (25, 30, 35, 40, 45, 50, 55 and 60°C). The mass loss during test is record for a constant period of time 15 days and for a total period of testing of 180 days at the test temperature.

The standard clean solution used for removing the oxidation product on specimen surface after test consists from 50g of $SnCl_2$ + 20g of SbC_3 in 1000 ml of concentrated HCl [22], [23]. After each 15 days of testing the specimens are withdrawn from the test oil solution and washings by kerosene to remove the residual asphalt and other components of crude oil that deposits in specimen surfaces. Then, the test specimen is insertion in a beaker contains the cleaning solution for 3 mints according to procedure given by ASTM G1-90 [22] to remove the oxidation product. The specimen was finally weighted and the mass losses were recorded. Subtraction the mass weighted from the initial mass of specimen; the mass loses due corrosion process (W) is obtained. The corrosion rate (Cr) is computed from the mass loses (W) using the formula [24]:

$$C_r = \frac{W * K}{\rho \, A \, t} \quad (1)$$

Where,

$K = 8.76*10^4$ for C_r in mm/year.

ρ: Mass density of steel in kg/m^3.
A: Total surface area of specimen cm^2.
t: Time of immersion in hr.

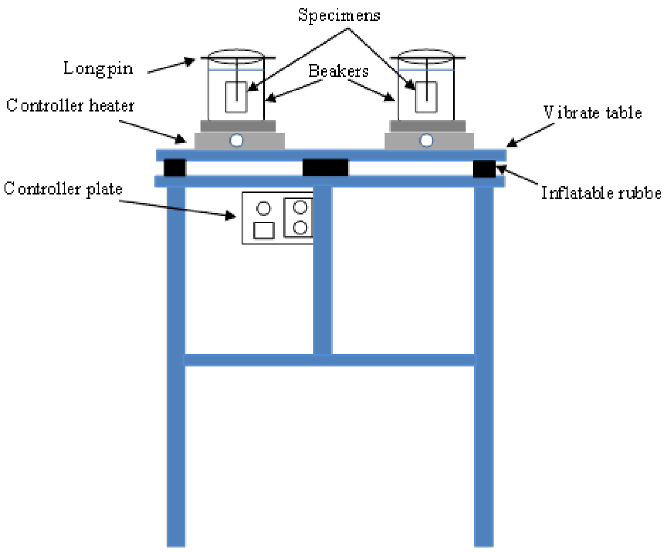

Fig. 2: Schematic Diagram for Immersion Test Apparatus.

5. Results and discussion

In order to demonstrate the effect of vibration on API 5L X60 and API 5L X80 carbon steel corrosion rate values and on crude oil properties, the corrosion vibration test is performed using 100 Hz vibration frequency with 0.5 mm amplitudes. Both static and vibration corrosion test of X60 and X80 carbon steels results are illustrated in Figures 3 and 4 respectively. It has been shown that the difference in corrosion rate between static and vibration for both types of steel alloys in the three crude oil types is small after 30 days of immersion test. However, the trend has been reversed for longer immersion times. This is because the increase in immersion time, increases the values of corrosion reactions on specimen surface, i.e., increased of the dissolution of the steel under the continuous attack of corrosive ions and agents in crude oil on the surface of the specimen, leading to increased weight loss over time. As shown in Figures 3 and 4, the corrosion rate obtained for vibration case is greater than that obtained from static case.

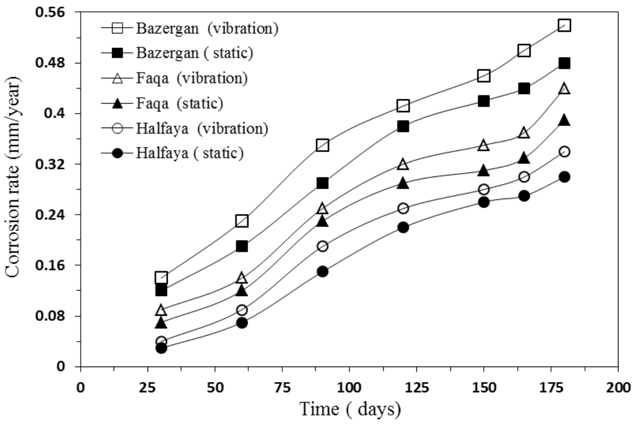

Fig. 3: Vibration and Static Corrosion Rates for X60 Steel Pipe at 25℃.

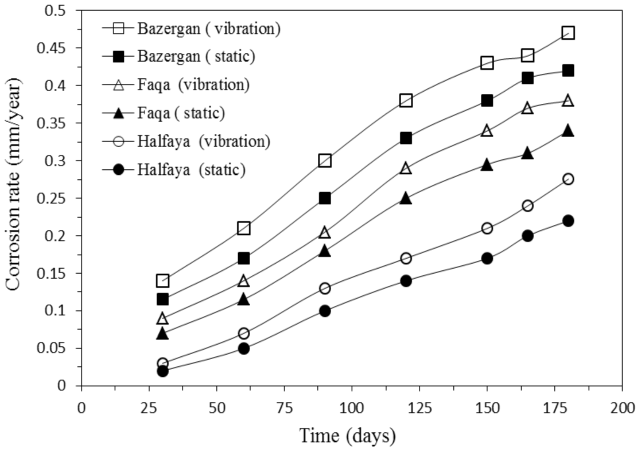

Fig. 4: Vibration and Static Corrosion Rates for X80 Steel Pipe at 25℃.

The corrosion rate values of X60 and X80 carbon steels tested in Bazergan, Faqa and Halfaya crude oil at 25°C under vibration and static immersion tests after 180 days are outlined in Table 5. If corrosion rate is compared between crude oil of the three fields, it can be seen that the Bazergan crude oil exhibits higher value of corrosion rate and Halfaya crude oil has smallest values, while Faqa crude oil has a moderate value. This may be due to the highest water percentage of Bazergan crude oil and high impurities, i.e. salts, dissolved gases and material compositions as shown in Tables 1 and 2 respectively. It was observed that both material pipes throughout the test period were found to have unstable increases in corrosion rate.

It can also be noted that the corrosion rate of the X80 carbon steel pipe material is lower, while the X60 carbon steel material has high corrosion rate. This attributed to the differences in chemical composition practically the elements of C, P and S as given in Tables 3 and 4. The C, P and S metals are more active compared to other types of elements especially (Mo and Nb) and causing the X60 carbon steel material more prone to corrosion. The corrosion rates of X60 steel for static and vibration tests are 0.4685 and 0.5432 mm/year respectively, whereas for X80 steel at static and vibration tests are 0.4196 and 0.4705 mm/year respectively.

Table 5: Corrosion Rate Values After 180 Days at 25ºc

Immersion test condtions	Corrosion rate (mm/year)		
	Bazergan oil	Faqa oil	Halfaya oil
X60 Carbon steel			
Static	0.4685	0.3927	0.3041
Vibration	0.5432	0.4461	0.3407
X80 Carbon steel			
Static	0.4196	0.3789	0.2236
Vibration	0.4705	0.3817	0.2711

The vibration process effects on metal surface and on crude oil components that contributed on corrosion process. This both reduction and oxidation process are directly influenced by vibration process. In general the vibration is increased the kinetic energy possessed by crude oil components and then accelerated the movement of these components. These increased the speed up arrival of corrosion components into the surface of metal. The collision between these components in a crude oil provides the kinetic energy needed to break the necessary bonds and new bonds can be formed, thereby increasing the rate of the corrosion reaction. Additionally, the vibration contributed to the braking of the slag film which is made up due to oxidation process on the metal surface. As a result, a small cavities and dig is made up on these slag films on metal surface which becomes as points of corrosion cell formed on surfaces. These events enhance corrosion rates.

To clarify the common influence of vibration and temperature on corrosion rate of X60 and X80 carbon steels in the various types of crude oil solution. The corrosion rates have been drawn as a function of temperature as described respectively in Figures 5 and 6. Each vibration and temperature affects the interaction rate between the crude oil components and the pipeline material surface.

Both vibration and temperature effects on various components of crude oil includes asphalt, water, salts, trace element and dissolved gases. Both vibration and temperature affected on movement and distribution of ions and charges in a solution of crude oil results increases of oxidation process.

Asphalt is one of the most important components of crude oil that affects the process of corrosion. Its polar composite and it is agglutinated on the metal surface and the membrane layer construction, this layer works to isolate the surface of the metal from the crude oil component that causes corrosion. This helps to reduce the corrosion reactions and then the rates of corrosion. Both raises the temperature or vibration process contributes to dismantle the asphalt and increases the percentage of ions in crude oil solution and this lead to increase corrosion rates. As given in Table 2, the Bazergan crude oil has larger asphalt contents 13.2 %, while the crude oil from Faqa field has 12.5 % and that value for crude oil from Halfaya is 10.1%.

The water accumulated as a thin layer at the bottom of the pipeline due to the difference in density between crude oil and water. Increase the sliding of crude oil layers over a water liquid thin

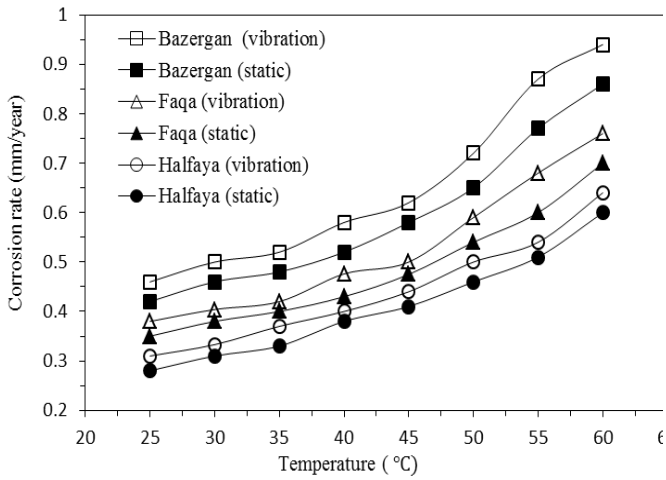

Fig. 5: Vibration and Static Corrosion Rate of X60 Steel Pipe at Different Temperature.

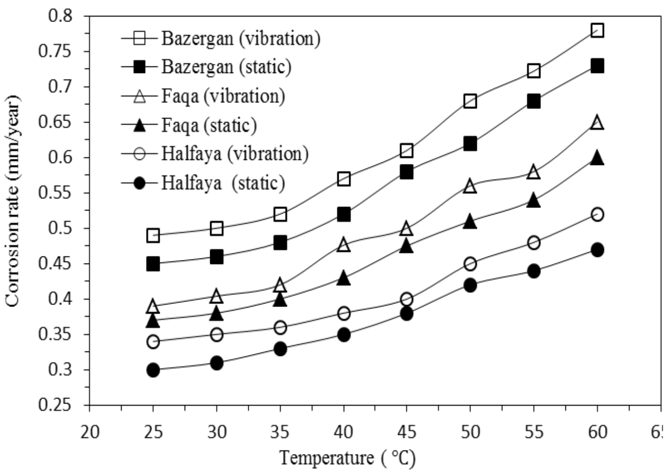

Fig. 6: Vibration and Static Corrosion Rate of X80 Steel Pipe at Different Temperature.

layer at the bottom of the pipe as a result of the vibration process. This increased water erosion process and reactivity of the water with metal surface. Also, vibration effects of the bonded between water components and accelerates it is dissociated into ions H+ and OH-. The ion H+ raises the acidity, i.e. the pH of crude oil and accelerates the oxidation processes.

The dissolved water in the crude oil containing various chlorides salts in particular NaCl, MgCl and $CaCl_2$. The concentrations of NaCl salt are presented in Table 2. The vibration as well as temperature effects on these salts and causing ionization, deliquescence and mixing with different components contains in the crude oils. The ionized process involves breaking up the bonds between these salts and constricting new acids and releasing chloride ions that enhance the the occurrence of corrosion pitting. The rising temperatures during the immersion vibration corrosion test are caused a salt hydrolysis in the water of crude oil and formation of HCl and this enhance the corrosion processes. Chlorides salts hydrolysis is listed by the following reactions:

$$NaCl + H_2O \longrightarrow NaOH + HCl \quad (2)$$

$$MgCl_2 + 2H_2O \longrightarrow Mg(OH)_2 + 2HCl \quad (3)$$

$$CaCl_2 + H_2O \longrightarrow CaO + 2HCl \quad (4)$$

Crude oil contains various trace elements (vanadium, nickel, copper, aluminum, cadmium, manganese and iron) both temperatures and vibration effects on the reactivity of these elements with other ions in crude oils solution. The concentration of some of these elements are high especially vanadium and nickel. Table 1 shows their difference in trace element between the three crude oils tested. Some of these elements are corrosive only at very high temperature, i.e., vanadium and nickel. From these elements, because of its reactivity the iron and copper is more effect by vibration and temperature. Iron has more tendencies to interact with water and sulfur and this reaction enhance by the vibration process. The copper ions react with sulfur and this produces a wide range of copper-sulfur salts and the reaction can be given as:

$$2Cu + S \longrightarrow Cu_2S \quad (5)$$

The dissolved gases H2S and CO_2 are present in the crude oil; these dissolved gases are affected by vibrations. The reaction between CO_2 and H_2S gases with iron generated various oxide films such as iron sulfide FeS, iron carbide Fe_3C and iron carbonate $FeCO_3$. The vibration contribute to destroy these oxides films and make up the chloride ion easily access through these films and reach to the metal surface. This process contributes to increase oxidation rates. The vibrations enhanced dissociations of H_2S gas and release the H_2 gas. The H_2 generation increases the acidity, i.e., pH values of crude oil and results increase corrosion problems.

The vibration has a large effect on molecular structures of X60 and X80 carbon steels. It is helped to break up or crashes the atomic bond between compositions elements of these material and it is increased the deformations that take place within and on the material surfaces. Also, it is reduced the bonds between the atoms on the surfaces of metal and other substances of materials. So, these processes reduce the material resistance to oxidation process and it is lead to increase the corrosion rates.

The microscopic view of the test specimens under static and vibration immersion test after 180 days at 25°C was illustrated in Figures 7, 8 and 9. The surface of the specimens shows damage, defects, cavities and pits spread throughout the entire surface. It is also notes that the oxide slag layer spreads on certain points of the surfaces. Comparisons between X60 and X80 carbon steels show that the X60 carbon steel specimen surfaces have more pits and large cavities under the same testing condition compared to X80 carbon steel. These pits and large cavities are also distributed arbitrarily across the surfaces. The vibrations create deformations that are concentrated in the crude oil wall pipeline's defect area. Pits and cavities were created on the specimen surfaces as a result of the corrosion process; these pits and cavities created increases as a result of increased deformation resulting from the vibration effects. Also, it is noted increased in the oxide films layer cover specimen's surfaces after vibration test compared to static test.

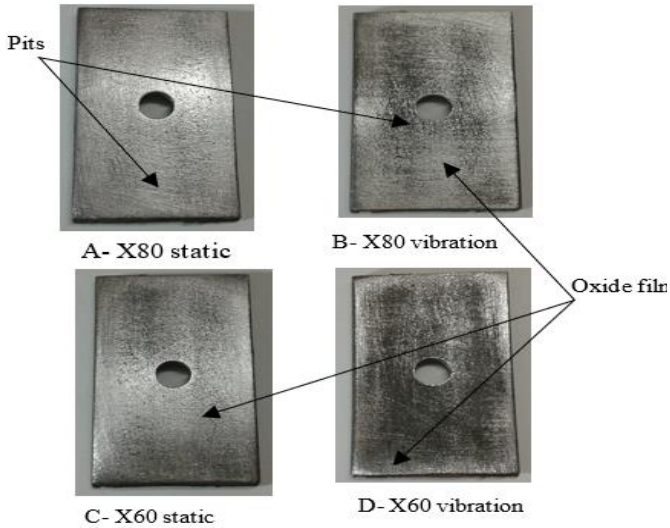

Fig. 7: Surface Morphology of Specimens after Test in Halfaya Crude Oil.

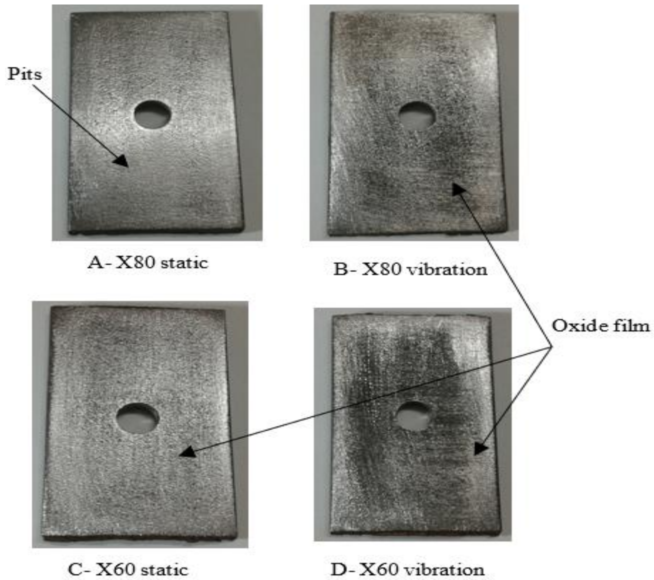

Fig. 8: Surface Morphology of Specimens after Test in Faqa Crude Oil.

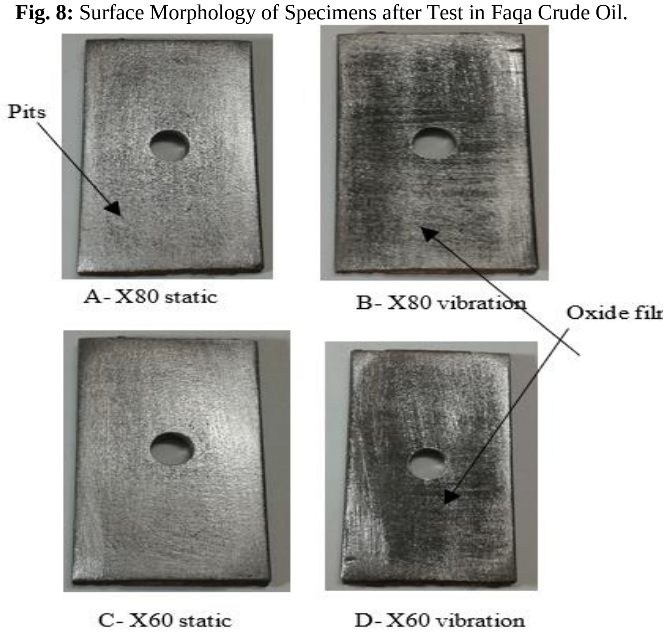

Fig. 9: Surface Morphology of Specimens after Test in Bazergan Crude Oil.

6. Conclusions

Based on the vibration and static corrosion tests results, the conclusions of the paper can be summarized as follows:

1) The crude oil properties are effects by the vibration process and the vibration enhance the separation of different crude oil components from each other particularly the water, organic salts and asphalt.
2) The corrosion rate values effects by vibration process and the corrosion rate under vibration is larger than that under static cases for the same conditions.
3) Bazergan, Faqa and Halfaya crude oils show high, moderate, and low values of the corrosion rates respectively.
4) The temperature effect directly on the vibration process, i.e., high temperature leads to increase vibration of metal and crude oil which increases of the oxidation reactions of corrosion process.
5) The vibration process reduces the link between the atoms or molecules within the steel materials and on the surface of materials and other substances of materials and reduces the material resistance to oxidation process. This contributed to increase the corrosion rates and spread of corrosion along the internal surface of crude oil pipeline.
6) The vibration accelerates the oxidation reactions of dissolved gases H_2S and CO_2 and accelerates the dissociation of the slag film and increases the initiation of pits at the metal surface.

Acknowledgement

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References

[1] Atila E., ‘Engineering mechanics and design applications: Trans. disciplinary engineering application’, Chapter 6, CRC Press Taylor and Francis Group, USA, 2012.

[2] Peter V. and Leonid F., ‘Analytical study of piping flow-induced vibration, example of implementation’, *Transactions of the 17th Int. Conference on Structural Mechanics in Reactor Technology (SMiRT 17) Prague*, Czech Republic, August 17–22, 2003. https://www.cvs.spb.su/PAPERS/Flow-inducedVibration.pdf.

[3] Shigehiko K., Tomomichi N., Fumio I., Minoru K., Kunihiko I., Takashi N., Njuki W. M., and Mikael A. L., ‘Flow-induced vibrations: classifications and lessons from practical experiences’, Chapter 4, Second Edition, Publishers by Elsevier B. V., Amsterdam, 2014.

[4] Cao H. Z., ‘Crude oil storage tank floor corrosion mechanism and protective measures’, M.Sc. Thesis, Zhejiang University of Technology, China, 2002.

[5] Subrata K. C., ‘The theory and practice of hydrodynamics and vibration’, *Advance Serous in Ocean Engineering*, Vol.20, Publisher World Scientific Publishing Company (1773), USA, 2002.

[6] Rongguang W., ‘Influence of ultrasound on pitting corrosion and crevice corrosion of SUS304 stainless steel in chloride sodium aqueous solution’, *Corrosion Science*, 50, 2, (2008) 325-328. https://doi.org/10.1016/j.corsci.2007.11.001.

[7] Yakupov N. M. and Yakupov S. N., ‘Corrosion wear under vibrations’, *Doklady Physics*, 63, 4, (2017) 147-149. https://link.springer.com/article/10.1134/S1028335818040109. https://doi.org/10.1134/S1028335818040109.

[8] James D. Hart, Richard S., G. W. Ford and Dennls G. Row, ‘Mitigation of wind induced vibration of arctic pipelines systems’, *Proceedings of the 11th International Conference on Offshore Mechanics and Arctic Engineering (OMAE92)*, Vol.2, ASME, New York, (1992) 169-180. http://ssdinc.com/documents/WIV_OMAE92.pdf

[9] Habib A., Hyeonbae K., Eunjoo K., Hyundae L. and Kaouthar L., ‘Vibration testing for detecting internal corrosion’, *Studies In Applied Mathematics*, 122, 1, (2006) 85-104.

http://www.cmap.polytechnique.fr/~ammari/papers/vibration-final.pdf. https://doi.org/10.1111/j.1467-9590.2008.00424.x.

[10] Fei X., 'A study of vibration induced fretting corrosion for electrical connector', Ph.D. Thesis, Auburn University, Alabama, USA, 2007.

[11] Safri S., Abdul Wahab A. and Andreas P., UT-ILI and fitness for purpose analysis for severely internally corroded crude oil pipeline, *8th Pipeline Technology Conference 2013*, Hannover Congress Centrum, Hannover, Germany, 2013. http://www.pipeline-journal.ru/pdf/eng/ptj-2013/PTJ_2-2013.pdf.

[12] Kong K. K., Khoo S.Y., Ong Z.C., Eng C., Ismail Z., Chong T., Noroozi S. and Rahman A., Failure analysis of flow-induced vibration problem of in-serviced duplex stainless steel piping system in oil and gas industry, *Materials Research Innovations*, 18 (2014) 417-422 https://www.tandfonline.com/doi/abs/10.1179/1432891714Z.000000000990. https://doi.org/10.1179/1432891714Z.000000000990.

[13] Eslami M. A. and Ahmad R. R., 'Free vibration analysis of corroded steel plates', *Journal of Mechanical Science and Technology*, 28, 6, (2014) 2081-2088. https://link.springer.com/article/10.1007/s12206-013-1114-7. https://doi.org/10.1007/s12206-013-1114-7.

[14] Wael H. A., Atef M. M. and Yehia A. K., 'An Innovative vibration sensor for flow accelerated corrosion measurement', *Innovations in Corrosion and Materials Science*, 2, 1, (2015) 61-65. http://www.eurekaselect.com/97694/article. https://doi.org/10.2174/1877610811202010061.

[15] [15] Yang Z. and Erkan O., 'Corrosion detection in pipelines based on measurement of natural frequencies', *Annals of Limnology and Oceanography*, 2, 1, (2017) 1-6. https://www.peertechz.com/articles/ALO-2-104.php.

[16] Lu H., Xiaonan W. and Kun H., Study on the effect of reciprocating pump pipeline system vibration on oil transportation stations, *Energies*, 11, 132, (2018) 1-23. https://www.mdpi.com/1996-1073/11/1/132. https://doi.org/10.3390/en11010132.

[17] Saad Z. Jassim and Jeremy C. G., 'Geology of Iraq', Polisher Geological Society of London, UK, 2006.

[18] Igor R. V. P. and Renato S. D. C., 'Study of phase transformations in API 5l X80 steel in order to increase its fracture toughness', *Materials Research*, 16, 2, (2013) 489-496. http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-14392013000200026. https://doi.org/10.1590/S1516-14392013005000024.

[19] John E. B., 'Handbook of comparative world steel standard', Third Edition, ASTM Data Series DS67A, USA, 2002.

[20] ASTM G32-03, 'Standard test method for cavitation erosion using vibratory apparatus', *Report of ASTM International*, USA, 2003.

[21] Mayer V. A., 'Material test methods and analytical procedures', *Annual Book of ASTM Standards*, Section 3, (2010) 94 -109.

[22] Singh D. D. N., Kumar A. and Fresh A., 'Look at ASTM G 1-90 solution recommended for cleaning of corrosion products formed on iron and steels', *Corrosion 2003*, 59, 11, (2003) 1029-1036. https://corrosionjournal.org/doi/10.5006/1.3277521. https://doi.org/10.5006/1.3277521.

[23] ASTM G1-90, 'Standard practice for preparing, cleaning, and evaluating corrosion test specimens', *ASTM Handbook 3.02 Corrosion of Metals*, Wear and Erosion, West, PA, USA, (1999) 20-28.

[24] Roland T. Loto, 'Study of the corrosion behaviour of S32101 duplex and 410 martensitic stainless steel for application in oil refinery distillation systems', *Journal of Materials Research and Technology*, 6, 3, (2017) 203-212. https://www.sciencedirect.com/science/article/pii/S2238785416301028. https://doi.org/10.1016/j.jmrt.2016.11.001.