Investigating Failure in A Pipe Connectors

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Abstract: **The aim of this project was to investigate and evaluate corrosion using sample analysis and computer modelling for the causes of failure on specimens which had similar behavior and nature of failures, used in petroleum industry. A nipple-connecter reducer made from malleable cast iron and 90 degrees elbow made from carbon steel A25 grade B used to carry liquid and gas in a petro chemical company located in Bahrain was used as sample.**

The corrosion was evaluated considering the environmental degradation which states the water in Bahrain is not corrosive but does have high amount of alkalinity, which will cause the formation of time scales on the high stress areas. The other analysis was done using non-destructive test rig, in which the reduction of wall thickness was measured and compared. The microstructure test indicates that ferrites have a lower resistance to erosion and corrosion than pearlitic malleable iron. And it is recommended to apply a ferritec heat treatment to increase the corrosion resistant in the zone.

Key-words: Non-Distractive test NDT, Mechanical erosion, Microstructure, Environmental degradation

1 INTRODUCTION

Different industries around the world are facing breakdowns problem due to corrosion including the petrochemical industries in Kingdom of Bahrain. Corrosion is a major industrial problem that causes component failure that leads to economical and human loss. Usually, corrosion is the degradation of metal that is caused by the reaction of the material and the surrounding environment. It occurs in different forms. According to Penn West which is one of the largest conventional oil and gas producers in Canada (Penn West, n.d), in 2013 - 60% of the total failures in the pipelines was caused by corrosion, where 33% was due internal corrosion and 27% due external corrosion (Penn West, n.d). This research targets xxxxxxxxxx located in Kingdom of Bahrain consist of two plants to produce Ammonia and methanol, which plants contain a huge number of pipelines made from different materials and used for different applications.

A connector-nipple reducer assembly made from mellable white cast iron was used for this analysis with a diameter of 484 mm, length of 75mm and a wall thickness of 4.4mm. The component made of cast iron and coated at the outside wall, the fluid passing inside is water with a velocity of 0.0018117 m/s

The other specimen used for analysis was a two phase carbon steel pipeline, often gets effected by internal corrosion which is caused due to thinning of pipe wall of 90 degrees elbow, and that can lead to a pipe leakage.

This research paper mainly addresses corrosion identification in the nipple reducer assembly and 90 degree elbow, taken from industry in Bahrain. Different methods can be used to evaluate the degradation including, the non-destructive test to determine the effect of corrosion on the inner wall by analyzing the properties of water; evaluate the surrounding environment, study the microstructure and flow behavior in the occurrence of corrosion.

CORROSION FORMS

1. **Uniform corrosion:** Uniform corrosion is defined as the process when the entire metal surface corrodes, where the attack in the metal is more or less uniform that covers the surface. It basically causes a general thinning on the pipe or tube wall, it either on one side or on both sides. The process of the uniform corrosion begins from the interaction of metals with the environment and then it follows by the hydroxides formation. Furthermore, this type of corrosion has greater penetration of metal and the effect of environment has the same entrance in all metal surface (Chaturvedi, 2008). There are four specific types of uniform corrosion as the following:

a) **Atmospheric corrosion:** It occupies the territory between immersed corrosion and dry oxidation, since metals maybe exposed to damp atmosphere or maybe subjected to the full force of the weather. In the atmospheric corrosion the attack in the exposed metal is due to the atmosphere, unlike when the attacked caused by liquids. The weathering factors such as temperature, wind velocity or solar radiation and air pollutant such as hydrogen sulphide or oxides nitrogen are the considered as usual parameters of this corrosion(Syed , 2006). Atmospheric corrosion occurs in different forms, in the case of dry corrosion, caused by high temperature it occurs in metal that have a negative free energy to oxide, the other form is the damp which occurs due to the atmospheric moisture, and the third form is the wet which caused by sea spry or rain or drops of dew (Garverick , 1994).

b) **Galvanic corrosion:** It classified under uniform corrosion and it occurs due to an electrical contact between two metals in which, the metal with higher conductivity will have a higher corrosion potential and more noble and it will acts as cathode redaction between oxygen and hydrogen. Furthermore, the metal with lower conductivity will provide the anodic reaction where oxidation takes place. Activating galvanic corrosion requires some conditions including, two or more metals with different conductivity to allow the ionic current to flow between them, the metals. (Hihara, Adler & Latanision, 2013).

c) **Localized corrosion:** Localized corrosion is defined as the processes when a specific area of the metal surface is corroded. In the localized corrosion even if the metal is protected from corrosion, the protection of the corroded area would stop working (Nimmo & Hinds, 2003). The

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process of the localized corrosion stats if the separated corrosion cells appear which occur due to the difference in the electrode potential over the metal. However, the corrosion increases when the ratio of cathodic and anodic area increases (FIP & CEB, 1994). The presence of the protective oxide film is a related factor of the localized attack and the presence of aggressive ions is the factor of another form of localized corrosion.

d) **Crevice corrosion:** The mechanism of crevice is initiated when the dissolution of the passive film and the acidification of the electrolyte is caused by oxygen. Increasing the amount of the oxygen will allow the catholic to move to the unprotected surface and proceeds its reaction causing the crevice to continue, and the corrosion current will increase to the limit near the crevice mouth, then the anodic reaction will achieve and the cathodic reaction will be the limiting factor of the corrosion. During the processes the resistance in the PH solution between the oxidation of metal in the gap and the cathode reaction in the disclose surface will increase, causing corrosion (Wika, 2013).

2) **Pitting corrosion:** Pitting corrosion has two stages, in the first the pits will initiate due to different factors may, when the anode defect in the material acts as the anode the pits will form. For example, when the particles of second phase (metallic particles) precipitating along the grain boundaries can function as a local anode causing localized pits. Furthermore, when a local stress take a form of dislocations emerging on the metal and become anodes this also can initiate pits (Kopeliovich, n.d). When the pit initiate it will start to grow and this will be the second stage going deep in the metal due to the electrochemical reaction. In the bottom of the initiated pit, it will tend to be deprived of oxygen, thus causing a wider growth of the pits (Yuan Ma,2012).

3) **Mechanical erosion:** It is type of localized corrosion and it consider as a metal degradation that combines the sum of electrochemical corrosion, mechanical abrasion and cavitation erosion.

a) **Erosion-corrosion:** The main parameters that influence the occurrence of erosion-corrosion are the component geometry and the velocity of the fluid, as this type of corrosion is normally characterized on components that usually have directional pattern such as grooves, gullies, waves and valleys or pipe bends. The reason of that is, those components are coupled with nominal stress created during fabrication or significant local stresses generated by the flow which result in accelerated electrochemical corrosion and at that point the velocity of the flow will not be uniform (Chawla&Gupta, 1993).

b) **Flow acceleration corrosion:** It is a metal degradation process that is caused due to mechanical and continually wall thinning by flowing water or wet steam in the oxide layer that forms inside the pipe wall. It basically occurs in two main processes one of them is the soluble iron production (Fe^{2+}) at the oxide and water interface. The second process is the transfer of the corrosion products to the bulk flow across the diffusion boundary layer, the rate of wall thinning is measured due to material composition, water chemistry and hydrodynamics. This type of corrosion usually occurs in low carbon steel pipes (Ahmed , 2012).

2 METHODOLOGIES

The research probe suggests that the corrosion occurs in both components is a mechanical corrosion. In both the elbow and the connector nipple reducer assembly are attacked by mechanical corrosion, since velocity and fluoride take place in this degradation.

Environmental degradation

In this section a study was done for the flowing fluid inside the nipple connecter and reducer assembly. The following is obtained by XXX readings compared to different studies and experiment done by Las Vegas Valley in Water District.

Table 1: Water quality standard at Bahrain and Las Vegas

Parameters water quality	Bahrain	Las Vegas Vally Water District
Temperature, °C	28	23.5
PH	8.04	7.61
Total Alkalinity (mg/L as CaCO3)	128.2	162
Hardness (mg/L as CaCO3)	8157	255
Calcium (mg/L as CaCO3)	1451	141
Sodium	1400	6
Total Dissolved Solids, mg/L	46960	293
Chloride, mg/L	25240	8
Sulphates, mg/L	3357	44

The environmental factors that influence the existence of erosion-corrosion is concluded by numerical values shown in the below table 1.

Non-Destructive test (NDT)

In this section a study was conducted using ultrasonic method to indicate measurement of thickness in the sample. The material used for this experiment was cast iron, available as a connecter with diameter of 48.4mm. The thickness was 4.4 mm with length of 75mm, the material was galvanized from the outer surface and was corroded from the inner surface.

Micro-structural analysis

This section is aimed to study the microstructure of the corroded pipe nipple made of cast iron modelled in an actual industrial loading conditions provided by Bahrain polytechnic.

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3 RESULTS AND DISCUSSION

The environmental degradation shown in table-1, contains a comparison between water quality at Bahrain according to XXX authority and general water used in Las Vegas; the results conclude that water combination has physical, chemical and biological factors that influence the alkalinity, hardness, the presence of sulphates and chloride leads to corrosion occurrence and loading behaviour. The physical factor infers high velocity and temperature that factors basic cause of erosion-corrosion.

According to the geometry of pipe nipple-connecter reducer assembly shown in figure 4, the inlet velocity at the reducer of the nipple measured by flow probe is equal to 0.0018117 m/s and the temperature assumed is higher than 28 °C at the same point.

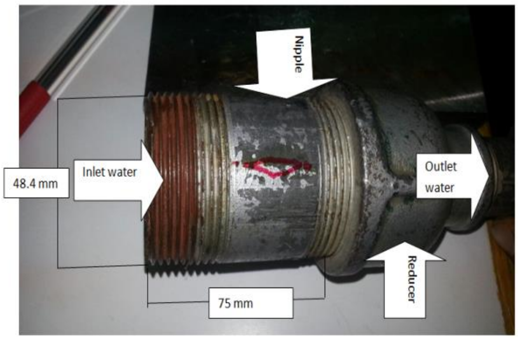

Figure 4: Sample nipple connecter assembly

The alkalinity at Bahrain is too high compared to US water standards. This increases alkalinity that causes increase in the formation of the calcium carbonate that results in resistance to the changes in PH. The Baylis curve shows the relationship between the pH and alkalinity under water stability. The water found in the blue zone is scale forming, water in the white zone is stable and water in the gray zone is corrosive.

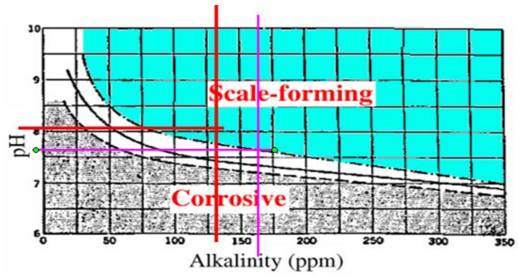

Figure 5: Baylis graph

Baylis graph (Figure 5) was used to evaluate the stability of water in both standards, the red lines in the graph shows the result of Bahrain water quality and pink lines for US standards. It shows that the water in Bahrain have a lower alkalinity and higher pH value, thus the measure of stability is visible in blue zone which means, the water is not corrosive but does have excessive amounts of alkalinity present, which will cause the formation of time scale in the lines of flow. Thus forming a coating of calcium or magnesium carbonate on the inside wall of the pipe leading to pipe clog. Thus combining results from table 1 and figure 5, Bahraini water with high level of sodium chloride, hardness and scales increase the conductivity of water and causes corrosion.

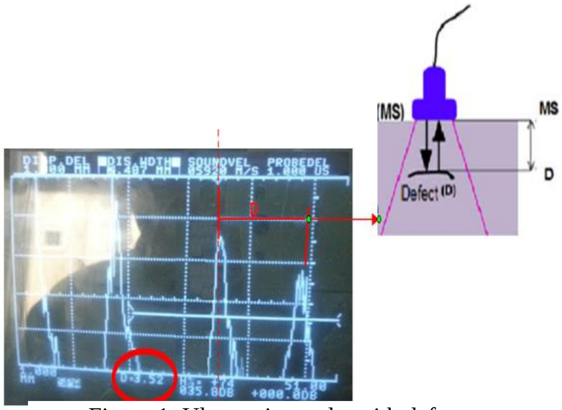

Figure 1: Ultrasonic results with defect

For the non-destructive testing using the scanning process, the pipe nipple was divided into four sections in order to scan all the area around the pipe. The results as shown in figure 6 shows time – distance relationship that will obtain the sound speed. When the wave of the sound reduces it means there is a reduction within the pipe thickness and the distance from peak to peak measures the depth of the thickness reduction.

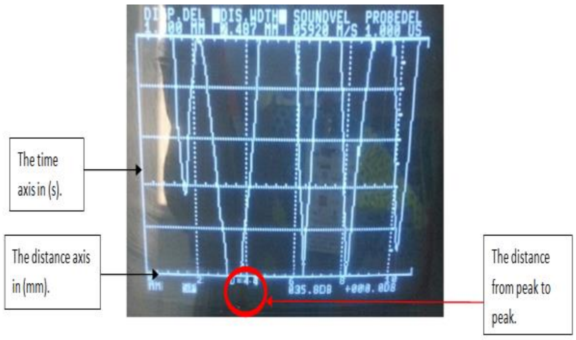

Figure 2: Ultrasonic results with no defect

In the beginning of the test the waves show the thickness of the pipe nipple that is in a good condition with no reduction. The graph in figure 7, shows the speed of the sound waves is stable in the first, second and third section, which means at this case the probe works as a sender only, it sends the waves then this waves travels through the pipe wall thickness 4.4 mm and then reflected back to the probe this indicated that the corrosion in the pipe nipple did cause some defects in the inner pipe wall to this time.

For the microstructure, the outer surface of the pipe nipple was grinded to remove the galvanized layer to test the microstructure of corroded material. A 45 x 10 mm piece was cut from the pipe nipple, and cut again to three smaller pieces to be tested.

A cold mold, was prepared, by mixing a fasttech powder with solution liquid that was poured into a plastic mold. The samples were kept in the molds and cured at room temperature for an hour until the molding mixture gets solidified, the plastic molds were removed. The samples were grinded using a roll grinder at different grit papers starting from the softest at grit 240 then a bit harder grit 320, followed by harder grit 400 and finally the hardest grit 600. The samples then polished using micro polish alumina solution, this procedure extended until the metal piece gets shine. The samples were attached with 5% HN 035 cc methanol 95 cc, by applying a drop in each sample and left for 3 minutes.

The samples were subjected to the microscope and the images are shown in magnification of X50, X100, X500. Figure 8: a) shows a sample taken from the inside wall of the eroded metal, the light area has grinded, polished and attached and the dark area shows the nature of erosion. The dark area shows the natural form of corrosion and the cracks states the breaking of the passive layer. This specimen (figure 8:b) was taken from the area where the thickness reduction was indicated, the micrographic showed that an irregular attack had occurred (figure 8:b).

The ferrite zone had been almost eroded and corroded and exposing the pearlitic zone. Comparing the corroded spacemen with the non-corroded, in the first figure showed no signs of attack it had a typical a fine malleable microstructure. Some cracks were captured and they were starting to grow as the, as well as some pitting were found going deeply in the surface within the eroded surface as the dissolve of the passive layer has prepare a suitable environment for this attacks.

The micrographic test clearly shows that the ferrite zone was almost attacked leaving some pearlite at the same position. Examination of the micrographs indicated that the nipple connecter reducer assembly had been given the usual annealing and normalization treatment for the fertilizing malleable iron. As a result of that, the resistance to erosion and corrosion was lower than pearlitic malleable iron. Pitting attack was distributed around the corroded zone, some of them were in their early stage but in another area it was going deeply in the material and it assumed it was the cause of the reduction in the thickness that was founded earlier during the NDT.

This attack can be cause due to different factors but in the case of the effected component it is caused when the protected layer in the internal wall of the pipe is almost attacked by erosion-corrosion which results in allowing some percent of chlorides present; thus unprotecting material and that provides a favorable condition to form pitting (figure 8:b).

CONCLUSION

The environmental degeneration proves that the water at Bahrain has scale formation, that leads to corrosion with time; as it has high level of sodium, chloride or hardness that increase the conductivity which results in more ability to transmit anodic and cathodic path that leads to further reaction. Since it is less corrosive; it can be controlled or reduced by using a connecter with a bigger diameter to increase flow rate and eliminate tuberculation problems.

The non-destructive test results shows, the position of the defect and depth but it is not able to show the width. The points are shown within figure 8 A and B, as the area that is

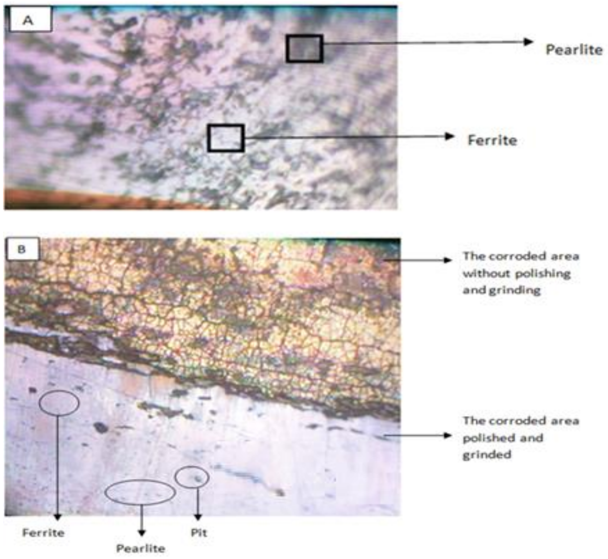

Figure 8: a - Cast iron microstructure with no corrosion
b. Microstructure of eroded cat iron

covered by the probe has a diameter of 24 mm. To obtain more defined results different non-destructive tests can be applied such as radiography which can provide an image with more definitions to the defects.

The NDT indicates that the reduction in the thickness occurs in the dead area of the connecter because of the velocity change and the turbulence factor.

The microstructural results indicate heat treatment of the replaced component that will use the same condition to produce a pearlitic malleable iron that suits the loading conditions or increasing the pipe diameter to reduce velocity and turbulence.

For modeling, the effect of the flow proves inside the nipple-connecter reducer assembly that has a boundary layer disruption due to formation of boundary burst and sweep as the movement of the fluid was toward the wall that rupture's the protected film of the material. The bulk flow velocity inside the connecter results in high shear stress which helps the movement of the corrosion in the form of boundary layer.

The investigation for the elbow yet not completed but it will consider as a further work for this research paper. For my further work, the problem is going to be modeled using CFD to analysis the effect of flow rate in causing this corrosion (Flow acceleration corrosion).

REFERENCES

[1] **Ahmed , W. (2012).** Flow accelerated corrosion in nuclear power plants . Retrieved from http://cdn.intechopen.com/pdfs-wm/39784.pdf

[2] **Aluminium Federation. (n.d). UK.** Aluminium industry fact sheet 2: Aluminium and corrosion. Retrieved from http://www.alfed.org.uk/files/Fact sheets/2-aluminium-and-corrosion.pdf

[3] **Busch, M. (2005, June 8).** The savvy aviator. Retrieved from http://www.avweb.com/news/savvyaviator/189857-1.html

[4] **Chaturvedi, T. P. (2008, Jan).** Corrosion Behavior of Orthodontic Alloys. Retrieved from http://orthocj.com/journal/uploads/2008/01/0054_en.pdf

[5] **Davis , J. R. (2000).** Corrosion: Understanding the Bacis. (1st ed., p. 4,10,14, 34,35). Materials Park, Ohio, United States of America: ASM International.

[6] **Davis, J. (1999).** Corrosion of aluminum and aluminum alloys. (2nd ed., p. 86). Materials Park, Ohio, United States of America: ASM International.

[7] **Féron, D. (2012).** Nuclear corrosion science and engineering. (p. 187). HighStreet, Sawston, Cambridge, United Kingdom: Woodhead Publishing Limited

[8] **FIP ,& CEB, (1994).** Corrosion and corrosion protection of pre-stressed ground anchorages.(Vol. 2, p. 2). Old Street, London, England: Thomas Telford.

[9] **Garverick, L. (1994).** Corrosion in the petrochemical industry. (1st ed., Vol. 13, p. 3). Materials Park, Ohio, United States of America: ASM International.

[10] **Hihara, L., Adler, R., & Latanision, R. (2013).** Environmental degradation of advanced and traditional engineering materials. (1st ed., Vol. 49, p. 11). Boca Raton, Florida: CRC Press.

[11] **Kane, R. (n.d).** A new approach to corrosion monitoring. Retrieved from https://www.honeywellprocess.com/library/support/Public/Documents/ChemEngJune07.pdf

[12] **Kopeliovich , D. (n.d).** Crevice corrosion. Retrieved from http://www.substech.com/dokuwiki/doku.php?id=crevice_corrosion

[13] **Kopeliovich , D. (n.d).** Pitting corrosion. Retrieved from http://www.substech.com/dokuwiki/doku.php?id=pitting_corrosion

[14] **Kopeliovich , D. (n.d).** Pitting corrosion. Retrieved from http://www.substech.com/dokuwiki/doku.php?id=pitting_corrosion

[15] **Lieser, Mq., & Xu, J. (2010, Sept.)** Composites and the future of society: Preventing a legacy of costly corrosion with modern materials. Retrieved from http://www.ocvreinforcements.com/pdf/library/CSB_Corrosion_White_Paper_Sept_10_10_English.pdf

[16] **McCafferty, E. (2010).** Introduction to corrosion science. (1st ed., p. 25). Verlag New York: Springer Science & Business

[17] **Nimmo B., & Hinds G.,(2003,Feb).** Beginners guide to corrosion. Retrieved from http://www.npl.co.uk/upload/pdf/beginners_guide_to_corrosion.pdf

[18] **Penn West. (n.d).** The cost of a pipeline failure. Retrieved from https://www.aer.ca/PennWest-CostPipelineFailure.pdf

[19] **Penn West.(n.d).** Company overview. Retrieved from http://www.pennwest.com/about/penn-west-at-a-glance.html

[20] **Syed, S. (2006, May).** Atmospheric Corrosion of Materials. Retrieved from http://www.eng.uaeu.ac.ae/en/research/journal/issues/v11/pdf_iss1_11/p1.pdf

[21] **Wika , S. (2013, July 13).** Pitting and crevice corrosion of stainless steel under offshore conditions. Retrieved from http://www.diva-portal.org /smash/get/diva2:566900/FULLTEXT01.pdf

[22] **Yuan Ma, F. (2012, March 23).** Corrosive effects of chlorides on metals. Retrieved from http://cdn.intechopen.com/pdfs-wm/33625.pdf