Study Synergy Effect on Erosion-Corrosion in Oil Pipes

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Abstract

Steel corrosion and erosion-corrosion have an important role in oil fields utilizing steel pipelines. Therefore; in the present work corrosion, erosion and erosion-corrosion tests are studied individually to investigate the interaction between corrosion and erosion processes and to quantify the synergy (that caused by erosion) in realistic flow environments.

The experimental work tests were done using special device which was designed and manufactured according to (G 73) ASTM with certain modifications.

The experimental work tests were achieved using traditional weight loss technique to measure weight loss rates in (gmd) unit. Also the microstructure observations of the test specimens are studied.

It was observed that whole tests were conducted on oil pipe (X 60) made of low carbon steel in plate form, tests were made on corrosion using 3.5 wt % sodium chloride. (NaCl) solution as sea water purged with CO_2 gas as the corrosive medium in crude oil, erosion using 1 wt % silica sand as the erodent in distilled water purged with N_2 gas as anti corrosive medium to get erosion just during erosion and erosion-corrosion using the same mentioned medium in the corrosion but in erosion-corrosion 1 wt % silica sand was added as slurry to that medium, all tests above were done under pumped media except in case of corrosion and pumped media had constant pressure of 1 bar, flow rate Q = 36 L/min, temperature ≈ 25 ºC and pH = 4.4 for corrosive and erosive-corrosive media but pH = 7.4 for erosive medium.

After traditional weight loss technique was achieved, it was found that corrosion rate C.R (0.18144 gmd) was the smallest, erosion rate E.R (0.80214gmd) was greater than corrosion rate (C.R), but erosion-corrosion rate EC.R (3.99161gmd) was the biggest ie. (EC.R was greatest), in addition synergy (0.0315g) was calculated by using special equation related to weight loss which was measured in (g) unit.

الخلاصة

للتآكل والتآكل بالتعرية للفولاذ دور مهم في المجالات النفطية المستخدمة خطوط الأنابيب الفولاذية . لذلك تركز الدراسة الحالية على اجراء تجارب عن التآكل والتعرية والتآكل بالتعرية بصورة منفصلة لكل منها لبحث العلاقات المتداخلة بين عمليات التآكل والتعرية ولمعرفة المقدار الكمي للتحفيز (الناتج بسبب التعرية) في أوساط الجريان الفعلية.

اجريت التجارب المختبرية بأستخدام جهاز خاص تم تصميمه وتصنيعه استناداً الى المعيار العالمي [ASTM (G 73)] , وقد اجريت تعديلات وتحويرات عليه.

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التجارب المختبرية أُنجزت باستخدام تقنية فرق الوزن التقليدية لقياس معدلات فرق الوزن بوحدة (gmd). علاوة على ان معاينة البنية المجهرية لعينات الاختبار قد درست أيضاً.
ومن ألجدير بالذكر ان التجارب أُنجزت بشكل كامل على أنبوب نفط نوع (X60) مصنوع مـن الفولاذ المنخفض الكاربون (المشكل على شكل صفيحة) , في التجارب المبنية على التآكـل يـتم استخدام محلول كلوريد الصوديوم بنسبة (3.5 wt %) . محلول كلوريد الصوديوم المشابه لمـاء البحر يكون مشبعاً أو مشّرباً بغاز ثاني أوكسيد الكاربون (CO_2) لتكوين وسط أكال مشابه للوسط الأكال الموجود في النفط الخام , في التعرية تم استخدام رمل السيليكا بنسـبة (1 wt %) كمـادة معرية في الماء المقطر المشبع أو المشرب بغاز النتروجين (N_2) لتكـوين وسـط غيـر أكـال وللحصول على تعرية فقط خلال التعرية.
اما في حالة التآكل بالتعرية فان الوسط المستخدم هو نفس الوسط المذكور سابقاً في حالة التآكـل ولكن في حالة التآكل بالتعرية أُضيف رمل السيليكا بنسبة (1 wt %) كعالق في ذلك الوسـط ، جميع التجارب أعلاه أنجزت باستخدام وسط قد تم ضخه ما عدا حالة التآكـل علمـاً إن مقـدار ضغط الضخ الثابت ومقداره (1 bar) , ومعدل الجريان مقداره (Q = 36 L/min) , ودرجـة حرارة الوسط تقريباً (25 ºC) ومقدار الحامضية (pH = 4.4) للوسط الأكال والوسـط ألأكـال بالتعرية ولكن مقدار الحامضية (pH = 7.4) بالنسبة لوسط التعرية.
بعد انجاز تقنية فقدان الوزن التقليدية , وجد ان معـدل التآكـل C.R (0.18144 gmd) أقـل المعدلات , معدل التعرية E.R (0.80214 gmd) أكبر من معدل التآكل (C.R) , ولكن معـدل التآكل بالتعرية EC.R (3.99161 gmd) كان أكبر المعدلات ,أي إن معدل التآكـل بالتعريـة (EC.R) يعتبر أكبر من جميـع المعـدلات الأخـرى , فضـلاً عـن إن التحفيـز Synergy (0.0315g) قد تم حسابه باستخدام معادلة رياضية ذات صلة بفقدان الوزن ويكون التحفيز مقاساً بوحدة الغرام (g) .

Introduction

Corrosion is a material degradation process which occurs due to chemical or electrochemical action i.e. corrosion is a corrosion of metal in the static corrosive medium or with out any movement between metal and corrosive medium, while erosion is a mechanical wear process i.e. loss of materials from solid surfaces by the impingement or impacting of liquid, gases or solids. When these two processes act together, the conjoint action of erosion and corrosion in aqueous environments is known as erosion-corrosion. In oil and gas production system, erosion-corrosion due to sand is an increasingly significant problem. The combined effects of erosion and corrosion can be significantly higher than the sum of the effects of the processes acting separately. This net effect is called synergism. As proposed by many researchers, this net effect is due to the enhancement of corrosion by erosion and / or enhancement of erosion by corrosion [1, 2, 3].

There are very few studies in which synergism was quantified ; however , most of the work was carried out using jet impingement apparatus or rotating cylinder electrode systems in which the flow patterns or hydrodynamics are very different from reality making it difficult to transfer the results to large scale pipeline systems. Very little work was done using more realistic systems such as flow loops. Therefore, it was

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not possible to clearly separate the damage due to erosion and corrosion in a combined erosion-corrosion process, and hence it is still unclear whether corrosion enhancement due to erosion or erosion enhancement due to corrosion, if either, is dominant.

There has been extensive work done in understanding the corrosion and erosion mechanisms, and erosion-corrosion mechanisms. It is accepted that impinging particles and / or liquid remove deposits or the protective layer (oxide film) on the metal surface resulting in continuous exposure of fresh metal surface to the corrosive environment resulting in higher corrosion rates [1, 2, 4, 5].

Erosion-corrosion effect is induced by rapid relative movement between a flowing electrolyte. e.g., slurry, and metal parts, pipes or containers. All metals can be affected to a greater or lesser degree.

Erosion — corrosion accelerates corrosion by dispersing the mechanisms that protect metals in static or slow-moving contact with an aqueous environment. As the name implies, one aspect of the effect is to scour the metal surface, interfering with the formation of films that would otherwise offer protection. This applies not only to passivating metals but also to other metals that, although not normally protected by passivity, derive at least some protection from surface films. If the moving liquid carries solid particles in suspension, the scouring effect is so much the greater.

The relative movement also tends to sweep away the boundary layer of static liquid present at the metal/liquid interface. This further stimulates corrosion by dispersing concentration polarization, especially for the oxygen reduction reaction, and for anodic reactions yielding soluble products.

Erosion-corrosion is produced by the impingement of slurry on a metal at high velocity and is particularly associated with rapidly moving metal parts in water, such as propellers and pump impellers. The relative movement induces a hydrodynamic condition that creates streams of small cavities in the liquid which collapse, delivering multiple sharp blows at the etal surface. The disturbance disrupts protective films, leading to a corroded surface with a characteristic rough and pitted appearance.

Material properties which militate against erosion-corrosion are good general corrosion resistance, strong passivating characteristics and hardness of the metal.

Chloride iones cause the pitting corrosion to the metal surface of steel pipe if exposed to corrosive medium such as sea water especially in low pH medium and that found in corrosion and erosion-corrosion [6, 7].

Carbon steel is widely used in chemical process plants for several important reasons. For one it is low in cost and easy to fabricate. Strong and performance specifications are well defined [7,8]. However; the general corrosion resistance of carbon steel is low in certain environment [7, 9]. Most iron occurs naturally as stable oxide and iron that had been processed into steel tend to return to that form [7, 8, 10, 11].

The aim of this work was to study erosion-corrosion due to sand and CO_2 in a recirculating flow loop. In order to achieve the research objectives, a unique test flow loop was designed and developed with the aim to investigate the erosion and the corrosion interactions in realistic flow conditions. Perform electrochemical measurements as well as weight loss measurements to be able to separate the material loss due to the individual erosion and corrosion processes and to determine the major mechanism influencing the synergism. Study the effect of corrosion mechanism, erosion mechanism and erosion-corrosion on the microstructure observations of the samples of the oil pipe.

Experimental Work

Material

The material used in this work is low carbon steel pipe (ASTM A179-84a) type as X 60, it is machined and formed to discs of (40) mm in diameter and (3) mm thick.

Table (2.1) shows the nominal and the analytical chemical compositions of the carbon steel pipe.

Experimental Media

With the aim of quantifying the synergism accurately ,the test matrices shown in Tables (2.2) through (2.4) were followed .As this was only an initial study intended to investigate the basic erosion and corrosion interactions ,the effect of such parameters as flow type , flow rate ,and pH; but temperature and media pressure were remained constant ,in 25C^{O} and 1 bar respectively.

General Description of the Tests Apparatus Used

The test apparatus used in this study was similar to that proposed by Mksim Antonov and Margaret Stack[12].

The principal scheme is shown in Figure (2.1). A plastic (Perspex) tank is used as a chamber of dimensions such as (30) cm in length, (20) cm in height, and (20) cm in width.

The different media are delivered directly with high pressure and with vertical direction to the specimen face through jet nozzle by sucking the different media from plastic tank (chamber) with 1 horse power, single phase electric motor made from Teflon (chemical pump).The chemical pump is resistant to the slurry and chemical solution .The pump with adjustable capacity by a system of valves was used to adjust the required flow rate (Q) and pressure of different media.

The pipe joints and valves connected to the chamber with chemical pump are made from PVC plastic to resist chemical media and slurry as well as jet nozzle. The chemical composition of the sand type Al-Ardhemah (Iraqi sand) as a slurry is shown in table (2.5).

A close flow loop for the jet impingement apparatus was designed with test specimen mounted or fixed by special tool (fixer) directly front the orifice of the jet nozzle. This apparatus designed and manufactured in accord with the test apparatus explained in American standard (ASTM G73), and has many modifications to accommodate typical three electrodes and connected them to the potentiostat, and pumping gases such as CO2 and N2 in tests media.

Figure (1) illustrates corrosion, erosion and erosion-corrosion devise and its sketch respectively.

Weight Loss Method

Weight loss method is one of the classical methods to find out corrosion rate, erosion rate and erosion – corrosion rate in different units, but in this section, gmd (gram/meter square∗day) unit is used to measure the above mentioned rates.

The weight loss method is used as follows:-

Cleaning the previously prepared specimens with acetone and drying them carefully with drying paper. They are then put in a dissector or (container) containing a silicon gel bed.

Weight the specimens to find out

Filling the chamber of the testing apparatus mentioned in section (2.3) and illustrated in Figure (1) with test medium for each type of test. These media are listed in Tables 2.2, 2.3 and 2.4 respectively. Nitrogen gas is pumped to dismiss O_2 and produce natural medium (pH ≅ 7) when erosion test is carried out. On the other hand, when corrosion or erosion-corrosion test is done, CO_2 is pumped to produce weak acidic medium (pH ≅ 4).

Test medium is injected toward the specimen surface each 10 minutes up to two hours exposure time. Tables 2.2 through 2.4 illustrate corrosion, erosion and erosion-corrosion conditions.

The specimen is weighted again after the specified (10) minutes of exposure to the medium. The weighting is carried out after the specimens are cleaned with distilled water and a brush, and then with acetone or alcohol. Drying of the specimens is carried out using drying paper and specimens driers.

This process is repeated several times to get several readings. Thus a diagram can be made to show weight loss with time and with medium.

The related law is $\left(\dfrac{\Delta w}{A.t}\right)$

applied to find out corrosion rate, erosion rate and erosion – corrosion rate and to get results in gmd unit.

Synergy law $\left[S = T - (E + C)\right]$ is applied to find out stimulation results and compare them with corrosion results.

Microstructure examinations are made on every specimen before and after the given tests.

Results and Discussion

Weight Loss Rates

Weight loss plays an important role in assessing the effects of corrosion, erosion and erosion-corrosion. Weight loss, in fact, indicates loss of parts of metal or specimen mass and its break-down. Therefore finding weight loss due to effects of corrosion, erosion or erosion-corrosion is necessary. It is worth mentioning that the same unit must be used in all measurement so that these effects can be compared and the most effective process is identified. The traditional weight loss rate equation $\left(\dfrac{\Delta w}{A.t}\right)$ is applied. (gmd) is used as a standard unit.

After weight loss rates for the previously mentioned three cases are found, weight loss rates curves are drawn for corrosion, erosion, and erosion-corrosion, taking exposure time into consideration.

Microstructure plays an important role in assessing metal behavior in different media such as corrosive medium, erosive medium or erosive-corrosive medium.

Corrosion Rate (C.R)

It can be seen from Figure (2), the rate of weight loss in corrosion increases with time. The increase in weight loss rate by corrosion is caused by metal softness, therefore;

the corrosion increases continuously with simple way.

Figure (3) shows a metal surface exposed to corrosion. Pits are seen on the surface resulting from pitting corrosion which accompanies corrosive media with chloride ions (Cl^-).

The pitting corrosion takes the form of highly dense but minute pits covering most of the metal surface. The specimen was inactive at the start of the reaction. Then the oxide film breaksdown because the metal is soft and oxide film is porous, dense and non-adherent as indicated by Shrier L.L [7].

Erosion Rate (E.R)

Figure (4) shows weight loss rate in erosion acting on the specimen surface. Erosion results from impact of the erosive material which is sand in this case, suspended in the non-corrosive or natural medium.

The figure shows that erosion rate increases with time. The increase is slow in the early stages. Erosion fluctuation is due to stress hardening and hardness of metal surface resulting from bombardment of the surface with sand grains. This bombardment increases hardness of metal surface due to stress hardening resulting from the mechanical deformation on the metal surface. This is caused by the plasticity of the metal surface.

With the continuous bombardment by sand grains, the stress hardened surface layers will collapse. Scales are formed which are easily removed by the continuous bombardment, resulting in decrease in and later break-down of metal mass. In other words, specimen weight loss rate increases continuously because erosion. This supports the platelet mechanism proposed by Ramakrishna Malka[1] which assumes that in erosion, plastic deformation occurs by repeated impacts resulting in deformation hardening of the surface flakes until they break off.

osion has clear-cut and distinctive form on the metal surface as shown in Figure (5) which shows the effect of erosion on the metal surface. The erosion has the form of meteor-like pits, that is, the pits have tail indicating that the surface is affected by erosion due to impingement of erosive matter (sand in this case)in the slurry. The impingement has produced the mechanical deformation in the surface of a ductile and soft metal. The tail direction is opposite to that of slurry (sand) impingement.

This explanation is pointed out by Barik R.C. and others [5].

Erosion-Corrosion Rate (EC.R)

Figure (6) shows that the increase in weight loss rate is more than that of the previous case because of the sand slurry which erodes the soft metal surface layer and also because of the effects already mentioned reasons in corrosion. It can be stated that erosion by sand grains is merely synergy to the corrosion process. In other words, erosion-corrosion produces the maximum weight loss rate which comes from two effects – one mechanical resulting from the high velocity of the corrosive medium with slurry which produces cavitaion and impingement. The other is electro-chemical resulting from the reaction between the medium and the specimen.

Figure (7) shows the effect of erosion-corrosion. It produces horse-shoe-like traces which are a distinctive characteristic of erosion-corrosion.

This type of corrosion produces great weight loss as a result of removing large and clear-cut metal portions due to impingement, cavitation, erosion and corrosion.

The horse-shoe-like areas are dark, distinctive and oriented toward flow direction of the erosive-corrosive medium. The horse-shoe-like areas are distinctively deep because the metal is soft and easily eroded and spalled by sand grains which are considered erosive matter in the corrosive medium. This is in good agreement with that shown by Stephen M. McIntyre and others [15], who studied common features typically observed with erosion-corrosion of horseshoe-shaped and comet tail pitting damage.

From the above results, one can conclude that erosion-corrosion produces the maximum weight loss rate, erosion comes next, and corrosion produces the least weight loss rate. This is shown in Table 3.1 which gives the weight loss rates for the three cases in (gmd) unit.

Synergy

Weight loss amount by erosion-corrosion is greater than weight loss amount by other effects, because of the effect of synergy caused by erosion that resulted from striking the metal surface by erosive suspended matter. The synergy value was found using equation[5] $S = T - (E + C)$, which is (0.315) g. Where E is the material loss by mechanical erosion processes, C is the material loss by corrosion processes and S, the synergy, is the combined interaction between erosion and corrosion processes.

This comes in good agreement with Barik R.C. and others [5] as they have studied that under erosion-corrosion conditions the majority of material loss usually result from mechanical damage as a result of erosion. This is well in agreement with Ramakrishna Malka[1] findings.

It can be conclude that synergy is a quantitative or weight amount and it represents the increase in the amount of weight loss resulting from corrosion as well as side effects.

It is generally to say that synergy plays an important role in erosion –corrosion .

Conclusions

The conclusions resulted from the present work are:

1. Erosion-corrosion produces the maximum weight loss rate (3.99161 gmd), erosion rate (0.80214 gmd) comes next, then corrosion rate (0.18144 gmd) produces the least weight loss rate.
2. A metal surface exposed to corrosion has pits. The pits take the form of highly dense but minute pits covering most of the metal surface, the erosion has the form of meteor-like pits, the pits have tail, but the erosion-corrosion produces horse-shoe-like traces on the metal surface.
3. Synergy (0.0315 g) causes grater weight loss amount in the erosion-corrosion effect than weight loss amount by other effects. Therefore synergy plays an important role in erosion-corrosion.

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