

Damaging of Steel-Oil Pipes by Erosion and Erosion -Corrosion Phenomena

Asst. Prof. Dr. Sami Abulnoun Ajeel*

Asst.lecturer MS.C.Mohammed Abdullateef Ahmed*

Abstract

Erosion and erosion-corrosion have important role in oil fields especially in steel oil pipelines. Therefore; in the present work erosion and erosion-corrosion tests are studied individually to investigate the relation between erosion and erosion-corrosion processes and to quantify the synergy (that is 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.

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 were 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 CO₂ gas as the corrosive medium in crude oil , but in erosion-corrosion 1 wt % silica sand was added as slurry to that medium, pure erosion using 1 wt % silica sand as the erodent in distilled water purged with N₂ gas as anti corrosive medium to get erosion just during pure erosion , all tests above were done in pumped media and pumped media had constant pressure of 1 bar, flow rate Q = 36 L/min, temperature ≈ 25 °C and pH = 4.4 for erosive-corrosive media but pH = 7.4 for erosive medium.

After traditional weight loss technique was achieved, it was found that erosion rate (E.R) was smaller than that of erosion-corrosion rate(E-C.R).

الخلاصة

للتعرية والتآكل-التعرية للفولاذ دور مهم في المجالات النفطية وخصوصاً خطوط أنابيب النفط الفولاذية . لذلك تركز الدراسة الحالية على اجراء تجارب عن التعرية والتآكل-التعرية بصورة منفصلة لكل منها لبحث العلاقات المتداخلة بين عمليات التعرية والتآكل-التعرية ولمعرفة المقدار الكمي للتخفيف (الناتج بسبب التعرية) في أوساط الجريان الفعلية.

اجريت التجارب المختبرية باستخدام جهاز خاص تم تصميمه وتصنيعه استناداً الى المعيار العالمي [(G 73) ASTM] ،

التجارب المختبرية أنجزت باستخدام تقنية فرق الوزن التقليدية لقياس معدلات فرق الوزن بوحدة .(gmd)

ومن الجدير بالذكر ان التجارب أنجزت بشكل كامل على أنبوب نفط نوع (X60) مصنوع من الفولاذ المنخفض الكربون (المشكل على شكل صفيحة) ، في التجارب المبينة على التآكل الصرف يتم استخدام محلول كلوريد الصوديوم بنسبة (3.5 wt %) . محلول كلوريد الصوديوم المشابه لماء البحر يكون مشبعاً أو مشرباً بغاز ثاني أوكسيد الكربون (CO₂) لتكوين وسط أكال مشابه للوسط الأكال الموجود في النفط الخام ولكن في حالة التآكل-التعرية أضيف رمل السيليكا بنسبة (1 wt %) كعالق في ذلك الوسط ، في التعرية الصرفية تم استخدام رمل السيليكا بنسبة (1 wt %) كمادة معرية في الماء المقطر المشبع أو المشرب بغاز النتروجين (N₂) لتكوين وسط غير أكال وللحصول على تعرية فقط خلال التعرية الصرفية .

* Production & Metallurgy Eng. Dept., UOT., Baghdad, IRAQ.

جميع التجارب أعلاه أنجزت باستخدام وسط قد تم ضخه علماً إن مقدار ضغط الضخ الثابت ومقداره (1 bar) ، ومعدل الجريان مقداره (Q = 36 L/min) ، ودرجة حرارة الوسط تقريباً (25 °C) ومقدار الحامضية (pH = 4.4) لوسط ألتآكل-التعرية ولكن مقدار الحامضية (pH = 7.4) بالنسبة لوسط التعرية. بعد أنجاز تقنية فقدان الوزن التقليدية ، وجد ان معدل التعرية الصرفة (E.R) أقل من معدل التآكل- التعرية (E-C.R)

.1. Introduction

Erosion is a mechanical wear process i.e. loss of materials from solid surfaces by the impingement or impacting of liquid , gases or solids, while corrosion is a material degradation process which occurs due to chemical or electrochemical action i.e. pure corrosion is a corrosion of metal in the static corrosive medium or with out any movement between metal and corrosive medium, 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^[1-3].

There are very few studies in which erosion and erosion-corrosion were 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 not possible to clearly separate the damage due to erosion and erosion-corrosion .

There has been extensive work done in understanding the pure erosion 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.

Erosion-corrosion is produced by the impingement of a 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 metal surface. The disturbance disrupts protective films, leading to a corroded surface with a characteristic rough and pitted appearance.

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

Chloride ions 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 pure 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 CO₂ 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 erosion-corrosion interactions in realistic flow conditions. Perform weight loss measurements is to be able to separate the material loss due to the individual erosion and erosion-corrosion processes. Study the effect of pure erosion mechanism and erosion-corrosion on the microstructure observations of the samples of the oil pipe are also applied.

2. Experimental Parts

2.1 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. Analysis of these specimens was carried out using (spectrometer DV.4) in *AL-Nasser Company*. Table (1) shows the nominal and the analytical chemical compositions of the carbon steel pipe.

2.2 Experimental Media

With the aim of quantifying the synergism accurately, the test matrices shown in Table (2) and Table (3) 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 25C⁰ and 1 bar respectively.

2.3 Sand Preparation and Its Chemical Composition

The sand preparation was performed by sieving with special device after making sure of chemical composition to the selected sand.

That sieving was done by using: - Ridsdale – Dietert Design Ridsdale & Co. Ltd, Middlesbrough. Eng. England, TS8 9Ea.

The chemical composition of the sand type Al-Ardhemah (Iraqi Sand) is shown in Table (4). The analysis was done in *Geology Survey and Mining* in Ministry of Industry and Minerals in Baghdad, using *atomic absorption spectrophotometer, Pye Unicom*, England, 1978.

The weight percentage and particle size are illustrated in Table (5).

2.4 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 (1). A plastic (Perspex) tank is used as a chamber. The Perspex tank has a special 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 the 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.

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, that in case weight loss technique.

This apparatus designed and manufactured in accord with the test apparatus explained in American standard (ASTM G73), and has many modifications to pumping gases such as CO₂ and N₂ in tests media.

Figures (1) and (2) illustrate erosion and erosion-corrosion devise and its sketch respectively.

2.5 Weight Loss Method

Weight loss method is one of the classical methods to find out pure 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 the primary weight often cleaning and drying.

Fixing the specimen in the fixer tool in such a way that it faces the jet nozzle.

Filling the chamber of the testing apparatus mentioned in section (2.4) and illustrated in Figure (1) with test medium for each type of test. These media are listed in Tables 2 and 3. Nitrogen gas is pumped to dismiss O₂ and produce natural medium (pH \cong 7) when pure erosion test is carried out. On the other hand, when erosion-corrosion test is done, CO₂ is pumped to produce weak acidic medium (pH \cong 4).

Test medium is injected toward the specimen surface for (10) minutes. This is carried out for two hours. In pure erosion test and erosion – corrosion test, the flow rate is 36 L/min and medium injection pressure is (1) bar.

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 laws are applied to find out pure erosion rate and erosion – corrosion rate and to get results in gmd unit. Microstructure examinations are made on every specimen before and after the given tests.

Table (1) Nominal^[13] and analytical chemical compositions of carbon steel pipe.

Chemical composition	C %	Mn %	P %	S %	Cr %	Ni %	Mo %	V %	Cu %	Fe %
Nominal	0.199	1.95	0.016	0.018	0.015	0.007	0.008	0.004	0.024	Rem.
Analytical	0.191	1.95	0.014	0.015	0.015	0.003	0.008	0.003	0.028	Rem.

Table (2) Pure erosion test matrix.

Medium Type	Two-Phase: Erosive Material (Sand) with distilled Water .
Temperature (C °)	25 (Room Temperature).
Medium Pressure (bar)	1
Flow Rate (Q) (l/min)	36
pH	(7.3) By pumping N ₂ gas in distilled water with sand.

Table (3) Erosion – corrosion test matrix.

Medium Type	Two-Phase :Sea water purged with CO ₂ gas (Corrosive Medium)and 1wt% silica sand as slurry(Erosive Medium)
Temperature (C °)	25 (Room Temperature).
Medium Pressure (bar)	1
Flow Rate (Q) (l/min)	36
pH	(4.4) By pumping CO ₂ gas in sea water and with sand.

Table (4) Illustrates chemical composition of the used sand.

SiO ₂ %	CaO %	MgO %	Al ₂ O ₃ %	Fe ₂ O ₃ %	SO ₃ %	CL %	Na ₂ O %	K ₂ O %
98.37	0.56	0.06	1.06	0.16	Very low	0.04	0.12	0.15

Table (5) Illustrates percentage of weight and size of the used sand.

No.	Wt % of each sieve No.	Sieve No. (particle size)
1	15.724	Over 0.355
2	28.259	Over 0.250
3	40.114	Over 0.150
4	12.324	Over 0.106
5	3.072	Over 0.075
6	0.373	Over 0.053
7	0.324	Over Bottom

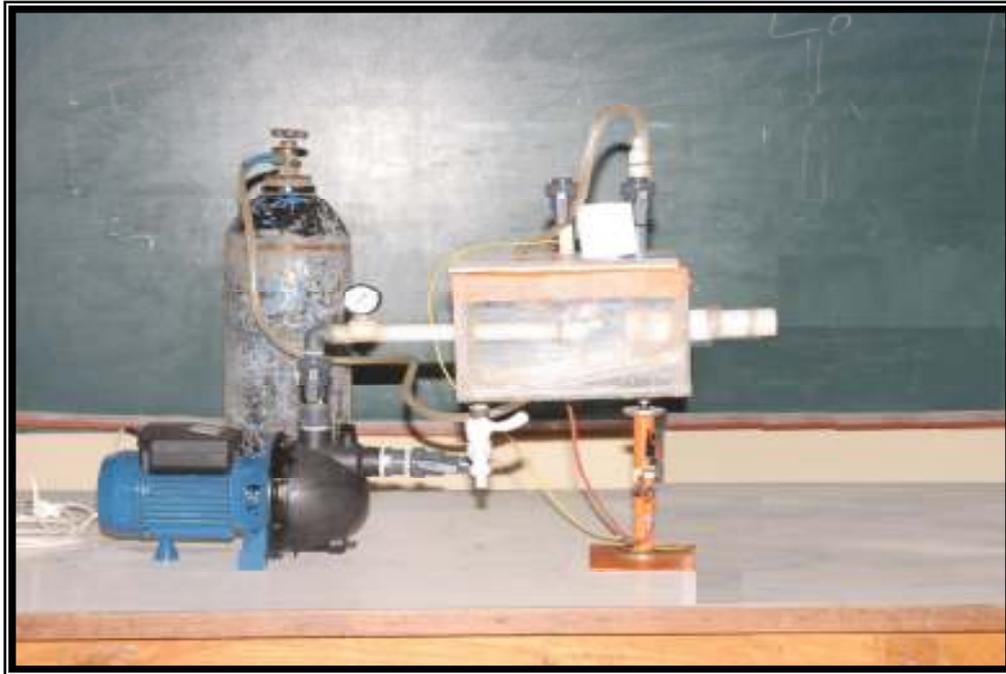


Figure (1) Illustrates corrosion & erosion-corrosion devise.

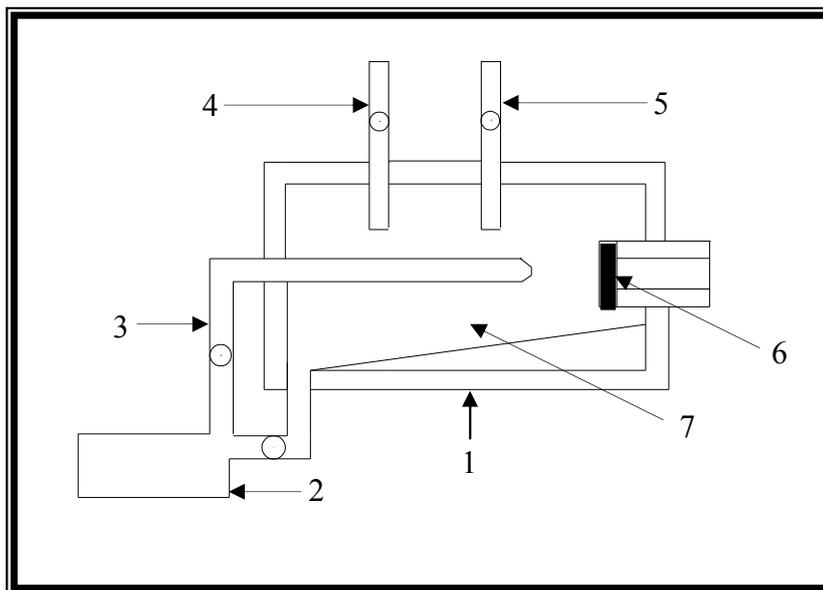


Figure (2) Illustrates corrosion, erosion & erosion-corrosion devise sketch.

1	Tank Perspex (plastic) Tank
2	1 H.P Motor
3	P.V.C PIPE
4	Outlet gas pipe
5	Inlet gas pipe
6	Metal specimen
7	Effective Media

3. Results

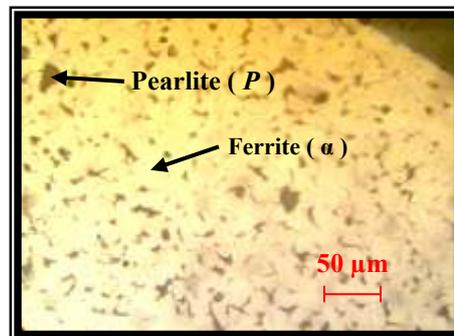
Weight Lt

Weight loss plays an important role in assessing the effects of pure 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 pure 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 is applied. (gmd) is used as a standard unit.

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

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

Figure (3) shows typical microstructure of low carbon steel which consists of ferrite (α) and pearlite (P) phases. Ferrite phases are more predominant than pearlite ones, resulting in reduction in hardness and softness of the metal. Thus this metal is easily affected by harsh external media such as erosion, and erosion-corrosion.



Figure(3) Shows typical microstructure of low carbon steel of ferrite and pearlite phases.

3.1 Pure Erosion Rate (E.R)

Figure (4) shows weight loss rate in pure erosion acting on the specimen surface. Pure 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 pure 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 scales until they break off.

It should be mentioned that this Figure represents weight loss rate as a result of pure erosion (pure mechanical effect) and electro-chemical effect is not considered.

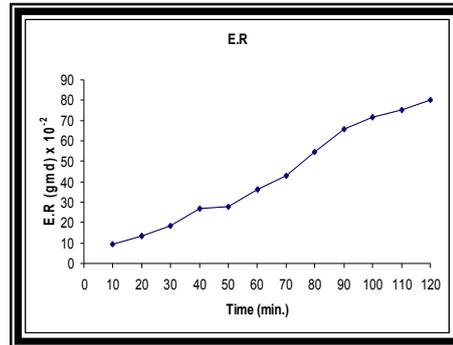


Figure (4) Erosion rate in pure erosive medium.

Pure erosion has clear-cut and distinctive form on the metal surface as shown in Figure (5) which shows the effect of pure 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.

The microstructure examination shows spalling of parts of the surface resulting in weight loss which generally accompanies pure erosion. Pure erosion traces on metal surface are called plough traces. This explanation is pointed out by Barik R.C. and others^[5].

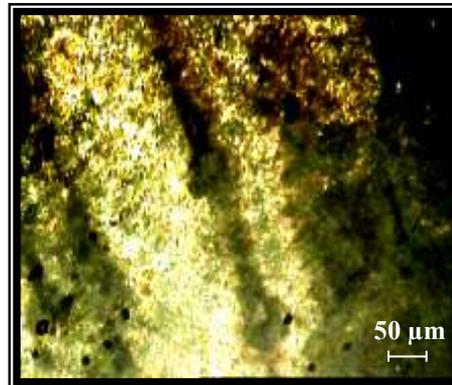


Figure (5) Microstructure of metal specimen exposed to the only erosive condition.

3.2 Erosion-Corrosion Rate (E-C.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 reasons in pure 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 erosive medium with slurry which produces cavitation 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.

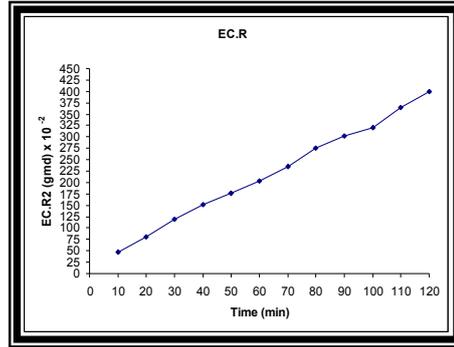


Figure (6) Erosion-corrosion rate in erosive-corrosive medium.

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 [14], who studied common features typically observed with erosion-corrosion of horseshoe-shaped and comet tail pitting damage.

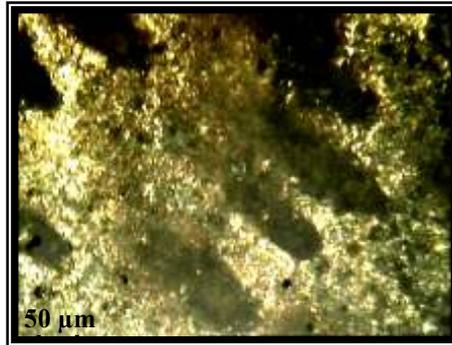


Figure (7) Microstructure of metal specimen exposed to the erosive-corrosive condition.

From the above results, one can conclude that erosion-corrosion produces the maximum weight loss rate, and pure erosion produces the least weight loss rate. This is shown in Table 6 which gives the weight loss rates for the two cases in (gmd) unit.

Table (6) Illustrates comparison between two types of weight loss rates.

E.R gmd	EC.R gmd
0.80214	3.99161

4. Conclusions

The conclusions resulted from the present work are:

Erosion-corrosion produces the maximum weight loss rate, and then pure erosion produces the least weight loss rate.

A metal surface exposed to pure 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.

Weight loss amount by erosion-corrosion is greater than weight loss amount by erosion effect, because of the effect of synergy caused by erosion that resulted from striking the metal surface by erosive suspended matter in the corrosive medium therefore the weight loss rate by this type of corrosion (erosion-corrosion) is accelerated.

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