Practical Study on the Corrosion Rates of Alloys (Aluminum, Medium Carbon Steel, Copper & Brass) Using Dissolved Ozone

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ABSTRACT

Ozone is a strong oxidizing a gen, with a standard electrode potential of 2.07V.Oxidize materials, equipment a, surfaces wanted to clean. Ozone unfortunately, reacts with those materials and others leading to corrosion in those materials moreover those materials could lose their effectiveness. Because of multiple uses of Ozone, its effect on corrosion of Aluminum, Medium Carbon Steel, Copper & Brass in three different flow rates by weight losses method with benefits from linear fitting process was studied. The experimental shows that corrosion rates of Aluminum & Brass in three flow rates, decreasing with increasing the exposure time to corrosion, meanwhile the corrosion rates for Medium Carbon Steel & Copper decreasing only for (0.25 ft^3/hr) and for another two flow rates (0.5 & 0.75 ft^3/hr) the corrosion rates increasing with increasing the exposure time to corrosion, because of ozone gas flow rate positive& negative effected by forming oxide and hydroxide film which damage or not by increasing the corrosion intervals and ozone flow rates increasing. The average of total corrosion rates for the materials used in previous work increasing with increase the flow rate of Ozone in distilled water and the maximum value was (8.71×10^{-17}MPY), meanwhile the minimum values was (4.08×10^{-17}MPY).

Keywords*:* Aluminum, Medium Carbon Steel, Copper, Brass, Ozone, Corrosion.

دراسة عملية لمعدل تاكل السبائك (الالمنيوم، الحديد المتوسط الكاربون، النحاس والبراص) بأستخدام الاوزون المذاب

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الملخص

الأوزون هو عامل مؤكسد قوي الذي جهد الاختزال له 2.07 فولت. يتفاعل الأوزون مع المعدات، المواد والأسطح المراد تنظيفها والمعقماتوبسبب امكانية حدوث التاكل والذي يسبب فقدانها لهذه الخاصية. بسبب الاستخدامات المتعددة للاوزون نم دراسة تاثيره على تاكل االالمنيوم، الفولاذ المتوسط الكاربون، النحاس وعلى البراص بثلاث معدلات تدفق للغاز بطريقة الفقدان بالوزن مع الاستفادة من عملية التقريب الخطي. اضهرت التجارب ان معدل التاكل لكل من الالمنيوم والبراص بثلاث معدلات تدفق للغاز يتناقص مع زيادة زمن التعرض للتاكل، بينما معدل التاكل لكل من الفولاذ المتوسط الكاربون والنحاس يتناقص فقط عند 0.25قدم مكعب /ساعة'، بينما لمعدلات التدفق (0.5و0.75 قدم مكعب/ساعة) معدل التاكل يتزايد مع زيادة زمن التعرض للتاكل. نتيجة للتاثير الايجابي والسلبي لمعدلات تدفق الاوزون بسبب تكوينها طبقات الاكاسيد والهيدروكسيدات التي ربما تتكسر او لا بزيادة فترة لتاكل وزيادة معدلات تدفق الغاز. ان معدل التاكل العام للمعادن المستخدمة في الدراسة الحالية يزداد مع زيادة تدفق غاز الاوزون في الماء المقطر والقيمة الاعلى كانت (8.71×10^{-17}مل /سنة)بينما الادنى كانت (4.08×10^{-17} مل / سنة).

الكلمات الدالة: االالمنيوم، الحديد المتوسط الكاربون، النحاس، اليراص، الاوزون، التاكل.

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1. Introduction

Ozone gas which exists even on the stratosphere layer contains three oxygen atoms, which is unstable and in a reactive state. Ozone is a gaseous material produced from oxygen in an electric discharge field (corona discharge) type ozone generator. Ozone gas which exists even on the stratosphere layer contains three oxygen atoms, which is unstable and in a reactive state. Ozone has no color but with an odor attributed to the smell of air following the thunderstorm in the spring season. Others refer it to the smell of the watermelons. And Ozone is not a steady gas. It must be produced by passing air or oxygen through two electrodes with high alternating potential difference [1]. Today, the output of the ozone generator typically contains 3-10 percent by weight (% wt.) of Ozone in unreacted oxygen gas stream. Early ozone generators operated at 1-2 %wt. ozone concentration. The product ozone gas stream is brought into contact with the water to be treated in a device called an ozone contactor. In the ozone contactor, the ozone is dissolved in the water for the treatment, and the un-dissolved ozone remaining in the off-gas stream is discharged through an ozone decomposer where it is reconverted to oxygen and then released to the atmosphere at rooftop levels [2]. In the present time, the output of Ozone generator typically contains (3-10) % of the weight of unreacted oxygen gas stream. Early generators of Ozone used to operate at (1-2) % Ozone concentration. The product ozone flux is brought it to contact with water to be handled in a device called an ozone contactor. With the ozone contactor, the ozone is melted in the water for the treatment, and the un dissolved ozone remaining in the off-gas flux is discharged through an ozone decomposer whereas converted again to oxygen and the set to the atmosphere at rooftop levels [3]. Ozone is a very strong disinfectant and oxidizer. Changed or removed by oxidation process will be impacted by ozone. It is powerful of all molecules exist for disinfection in water treatment and considered to be the second for fluorine in oxidizing power. By comparing it to Chlorine considered to be the highly common water chemical disinfection, ozone is more than 50% powerful oxidizer, which is 3000 times quicker, chlorine and fluorine considered to be and classified as strongly high [4]. The powerful of ozone oxidizing ability had been used as alternative to chlorination for sterilizing water drinking since seventy years. And because of the environmental worries grow about using chlorine for industrial oxidizing applications, Ozone of harmless by product of oxygen, is turn into more vastly utilized, concerns has been increased about using ozone as a disinfectant in the water treatment industry, in fields like

for example pulp and paper industry, which is focusing on utilizing Ozone as substitute bleaching material. Moreover there is increasing concerns in utilizing Ozone in biocide in heat exchanges, and cooling towers, whereas the static water can lead to the proliferation of microbiological corrosion. The erosion conduct of engineering alloys in ozonated solutions is of specific interest since ozone is a powerful oxidizer and quick erosion may be resulted. In the meantime, there are a very little literature on erosion subject for the materials exposed to ozonated solutions, and the obtainable information are confusing ozone infection. [5] .The effect of different concentration of ozone on corrosion of 304 stainless steel, Monel 400 and Naval brass were studied at room temperature by Brown B. E. and Duquette D. J. after 17 hour exposure time to erosion, the results were the increasing of ozone concentration caused the passivation of potential of 304 stainless steel and the Monel 400 specimens meanwhile to the other types of specimens showed no susceptibility to crevice corrosion the effect on the specimens color [6]. The Pehkonen & Anterowere studied the corrosion behavior of four different materials of stainless steels and pure metals in solutions with dissolved ozone. The pH of the test solution was (1- 3) and neutral (adjusted by H_2SO_4) also some g/l Na2SO$_4$ was added to increase anodic and cathodic polarization measurements conductivity. The temperature of the test solution was 20, 50 and 75 °C. The Higher concentration of ozone shows has no effect on the erosion behavior of stainless steels. The corrosion of stainless steels is general but peeling of oxide layers was also observed. Dissolved ozone increases the thickness of the oxide layers greatly. In oxygen bubbled solution at pH 3the difference was very clear in the thickness of the layers which was a few nanometers however in ozonated solution was $(60 - 260)$ nm[7]. And Yang, D. B. & Etal were studied the effect of dissolved Ozone on Mild Steel, Copper , Copper –Nike alloy and finally with Copper-Zinc alloy admiralty in typical cooling tower waters with different solute contents was studied using electrochemical techniques. They obtained that the low concentration of dissolved Ozone has no effect on Mild steels specimens, in general the effect of ozone was on the yellow metals and the maximum effect was on Copper and the on Copper-Nickel and then on Cooper-Zinc alloys even in high concentration or low concentration of dissolved Ozone [8]. The aim of this search is to study the erosion behavior of different metals in distilled water base solutions, where ozone is dissolved, due to limited uses of Ozone as corrode medium. The utilization and possible limitations of corrosion by weight losses method was applied to know the average of corrosion rates and the corrosion rates.

Kirkuk University Journal /Scientific Studies (KUJSS)

Volume 13, Issue 1, March 2018, pp. (187-211)

ISSN 1992 – 0849

2. Experimental Work

2.1. Experimental Procedure

Four different alloys were used in the work and they were: pure aluminum (99%putity), pure copper (free oxygen copper (98% purity), Brass (%70 Cu+30%Zn) and low carbon steel [9].

2.2. Devices and Equipment Used in this Work

The following machines and equipment were used:

1- Air compressor.

2- Ozone generator.

3- Digital balance (4digit).

4- Volumetric flasks with different volume.

5- Grinding and polishing machine.

6- Electrical saw to cut specimens.

7- Glass container to store the specimens in ozone medium.

8- Thermometer and humidity tester.

9- Fish tank air stones (diffuser) for bubble making.

10- Tubes for ozone transferring to the specimens.

11- Valve for controlling ozone generate.

12- Hot air gun for drying the specimens

2.3. Prepare Samples:

The following steps were done to prepare the specimens:

1- Cutting the specimens by using a mechanical saw and a coolant solution used during the cutting operation to prevent over heating the specimens.

2- Facing each specimen by using turning machine, the final dimension of the specimens is shown in Table (1)

Table (1): The final dimension of the specimens.

Material type	Diameter/mm	Length/mm	Surface area/in^2
Copper	16	30	$2.90452*10^{18}$
Aluminum	16	30	$2.8827*10^{18}$
Brass	16	30	$2.845517*10^{18}$
Medium carbon steel	16	30	$2.804197*10^{18}$

3- Grinding and polishing the specimens by using a grinder and polishing machine.

4- Every specimen was polished at the faces by using a polishing machine.

5- Weighing every specimen by using a digital balance (4 digits).

6- The process of the operation design can be viewed in terms of the labels used in Fig. (1) as listed below:
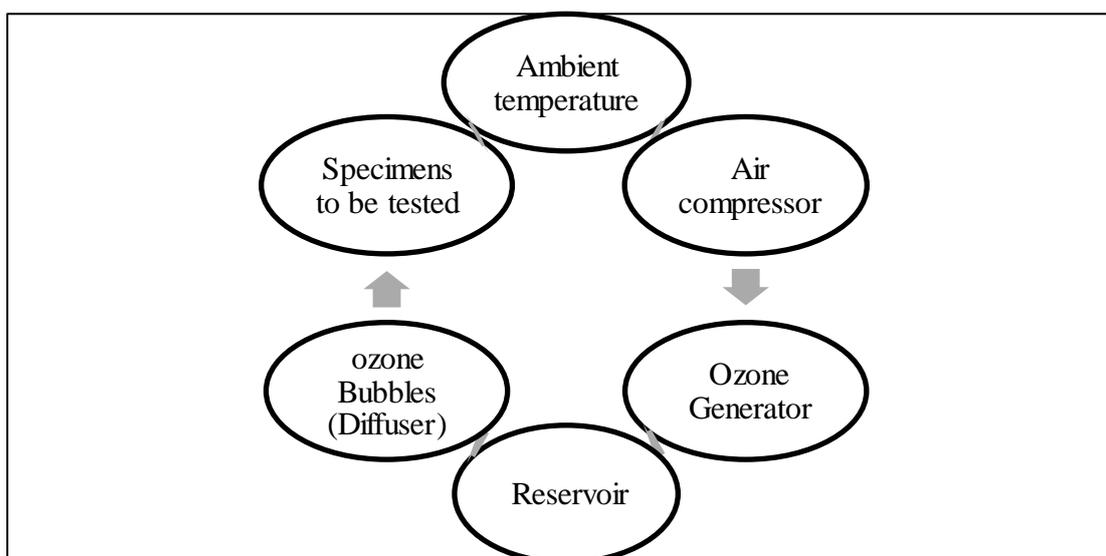
Fig. (1): Shows the flow chart of the operation procedure of the system.

7- The system was operated by using distilled water as a medium for every specimen by using variable flows of ozonated air as shown in the Tables (2-13).

Table (2): The flow meters (0.25 ft^3/hr) for Medium Carbon Steel specimen

Test no.	Specimen material type	Corrosion Time(Hours)	W_1	W_2	ΔW
1	Medium	5	26.2704	26.2567	0.0127
2	Carbon	10	26.2526	26.2306	0.0219
3	Steel	15	26.2591	26.2365	0.0226
4		20	26.2568	26.2374	0.0194
5		25	26.2693	26.2448	0.0245
6		30	26.2535	26.1878	0.0657

Table (3): The flow meters (0.25 ft^3/hr) for Aluminum specimen.

Test no.	Specimen material type	Corrosion Time(Hours)	W_1	W_2	ΔW
1	Aluminum	5	15.7317	15.7308	0.0009
2		10	15.7312	15.7303	0.0009
3		15	15.7309	17.7302	0.0007
4		20	15.7306	15.7303	0.0003
5		25	15.7498	15.7490	0.0008
6		30	15.7491	15.7488	0.0003

Table (4): The flow meters (0.25 ft^3/hr) for Copper specimen.

	Specimen material type	Corrosion Time(Hours)	W_1	W_2	ΔW
1	Copper	5	54.5331	54.5312	0.0019
2		10	54.5321	54.5305	0.0016
3		15	54.5319	54.5299	0.0020
4		20	54.5319	54.5303	0.0016
5		25	54.5327	54.5304	0.0023
6		30	54.5374	54.5366	0.0008

Table (5): The flow meters (0.25 ft^3/hr) for Brass specimen.

Test no.	Specimen material type	Corrosion Time(Hours)	W_1	W_2	ΔW
1	Brass	5	27.2995	27.2981	0.0014
2		10	27.2989	27.2955	0.0034
3		15	27.2981	27.2975	0.0006
4		20	27.2972	27.2941	0.0031
5		25	27.2955	27.2924	0.0026
6		30	27.2904	27.2882	0.0022

Table (6): The flow meters (0.5 ft^3/hr) for Medium Carbon Steel specimen.

Test no.	Specimen material type	Corrosion Time(Hours)	W_1	W_2	ΔW
1	Medium Carbon Steel	5	26.2434	26.2404	0.003
2		10	26.2404	26.2326	0.0078
3		15	26.2326	26.2191	0.0135
4		20	26.2191	26.2168	0.0023
5		25	26.2168	26.1993	0.0175
6		30	26.1993	26.0835	0.1158

Table (7): The flow meters (0.5 ft^3/hr) for Aluminum specimen.

Test no.	Specimen material type	Corrosion Time(Hours)	W_1	W_2	ΔW
1	Aluminum	5	15.7422	15.7417	0.0005
2		10	15.7417	15.7412	0.0005
3		15	15.7412	15.7409	0.0003
4		20	15.7409	15.7406	0.0003
5		25	15.7406	15.7398	0.0008
6		30	15.7398	15.7391	0.0007

Table (8): The flow meters (0.5 ft^3/hr) for Copper specimen.

Test no.	Specimen material type	Corrosion Time(Hours)	W_1	W_2	ΔW
1	Copper	5	54.5232	54.5231	0.001
2		10	54.5231	54.5221	0.001
3		15	54.5221	54.5219	0.0002
4		20	54.5219	54.5219	0
5		25	54.5219	54.5219	0
6		30	54.5219	54.4974	0.0245

Table (9): The flow meters (0.5 ft^3/hr) for Brass specimen.

Test no.	Specimen material type	Corrosion Time(Hours)	W$_1$	W$_2$	ΔW
1	Brass	5	27.3131	27.3095	0.0036
2		10	27.3095	27.3089	0.0006
3		15	27.3089	27.3081	0.0008
4		20	27.3081	27.3072	0.0009
5		25	27.3072	27.3055	0.0017
6		30	27.3055	27.3004	0.0051

Table (10): The flow meters (0.75 ft^3/hr) for Medium Carbon Steel specimen.

Test no.	Specimen material type	Corrosion Time(Hours)	W$_1$	W$_2$	ΔW
1	Medium Carbon Steel	5	25.6606	25.6570	0.0036
2		10	25.6570	25.6474	0.0096
3		15	25.6474	25.6318	0.0156
4		20	25.6318	25.5294	0.1024
5		25	25.5294	25.5081	0.0213
6		30	25.5081	25.3731	0.135

Table (11): The flow meters (0.75 ft^3/hr) for Aluminum specimen.

Test no.	Specimen material type	Corrosion Time(Hours)	W$_1$	W$_2$	ΔW
1	Aluminum	5	15.7593	15.7579	0.0014
2		10	15.7579	15.7575	0.0004
3		15	15.7575	15.7572	0.0003
4		20	15.7572	15.7571	0.0001
5		25	15.7571	15.7566	0.0005
6		30	15.7566	15.7558	0.0008

Table (12): The flow meters (0.75 ft^3/hr) for Copper specimen.

Test no.	Specimen material type	Corrosion Time(Hours)	W$_1$	W$_2$	ΔW
1	Copper	5	55.1425	55.1397	0.0028
2		10	55.1397	55.1393	0.0004
3		15	55.1393	55.1385	0.0008
4		20	55.1385	55.1370	0.0015
5		25	55.1370	55.1352	0.0018
6		30	55.1352	55.1035	0.0317

Table (13): The flow meters $(0.75 \, ft^3/hr)$ for Brass specimen.

Test no.	Specimen material type	Corrosion Time(Hours)	W_1	W_2	ΔW
1	Brass	5	27.3787	27.3774	0.0013
2		10	27.3774	27.3774	0.0002
3		15	27.3774	27.3767	0.0005
4		20	27.3767	27.3762	0.0005
5		25	27.3762	27.3742	0.002
6		30	27.3742	27.3736	0.006

8- Using the loss weight method to calculate the impact of corrosion of the variable flows of ozone on each specimen.

9- Chemical cleaning test specimen's procedure which shows in Table (14) [10]:

Table (14): Chemicals used for cleaning the specimens and the immersion time for each material **[10].**

Designation	Material	Solution	Time	Temperature
C 1.1	Aluminum and Aluminum alloys	HNO_3	5-10 minutes	20-25°C
C 1.2	Copper and copper alloys	500 ml H_2SO_4Reagent water to make 1000ml	1-5 min.	20-25°C
C 3.1	Iron and steel	500ml HCl+1000ml distilled water	1-25 min.	20-25°C

10- For the microstructure test the specimen were grinded by emery paper (200, 400, 600, 800 and 1200) by using grinding machine then polished by using alumina particles (0.35µm) by using polishing machine then etched by using Table (15) .for each specimen etching [11].

Table (15): The etchant compositions [11].

Material	Composition
Steel specimen	2 cm^3 nitric acid; 98 cm^3 ethanol 2%Nital
Aluminum	1 g sodium hydroxide; 99 cm^3 water(Caustic soda Solution
Coppers, brasses	5 parts HNO_3, 5 parts acetic acid, 1 part H_3PO_4 Immersion, 3s

3. Corrosion

3.1. Corrosion Medium:

After prepare the specimens for corrosion test, the specimens marked to recognize one from another and immersed in medium using backer with (1000 mm) capacity, and the flowchart for piping system shown in Fig. (2).
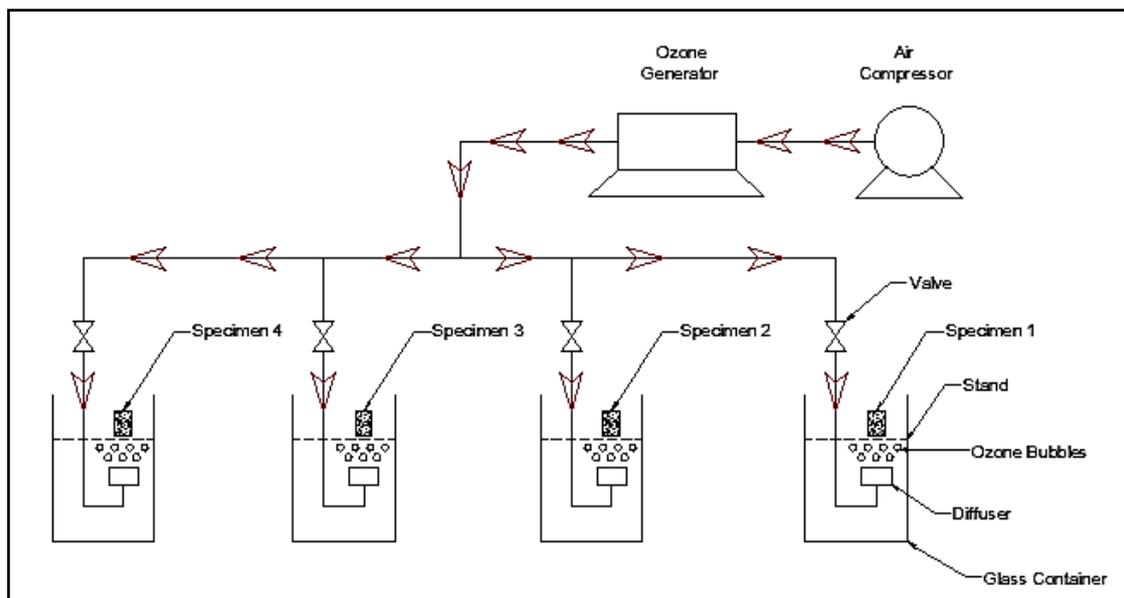
Fig. (2): Schematic flow diagram of the system used in this work.

3.2. Corrosion Rates Calculation:

1-To calculate the value of corrosion rates, the weight losses of the samples must be found by weighing the weight before and after immersion in corrosion mediums for each sample. After taken the samples from corroded medium the samples cleaned from the oxidation layers which caused by smooth brush and then immersed in selected medium which shown in Table (3) then washed by distilled water and dried, the obvious steps repeated at the end of each corrosion intervals. The equation (1) was used to find the value of corrosion rates [12]:

$$\text{Corrosion rates (Mils per year)} = 534\,W / DAT \tag{1}$$

Where 534: Constant

W: The losses in weight in mg.

D: Specimens density in g/cm^3, (2.71) for aluminum specimens, (7.87) for Medium carbon steel, (8.96) for Copper & (8.53) for Brass [13].

A: The area of the specimen in Sq. in.

T: The exposure time to the corrosion medium in hour.

2-Total corrosion rates (CrT) also calculated from the equation (1) by substitute instead of (W) the difference between the initial weight and the last weight, and instead of the time the total exposure time to corrosion medium which was (35hrs).

4. Results and Discussion

The following results were obtained:

4.1 For Aluminum Specimens:

The three specimens for Aluminum which immersed in ozonated distilled water with three different flow rates, show the maximum corrosion rates in the beginning corrosion intervals and the corrosion rates decrease with increasing exposure time to corrosion mediums, and this behaviors for all specimens 1,2 & 3 clearly shown in Fig. (3, 4 & 5) respectively.
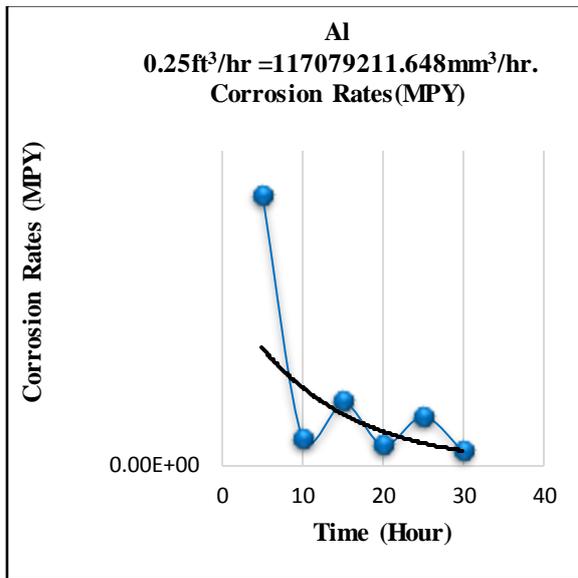
Fig. (3): Represent the corrosion rate for specimens (1), where blue line is actual readings and the black line is exponential fitting line
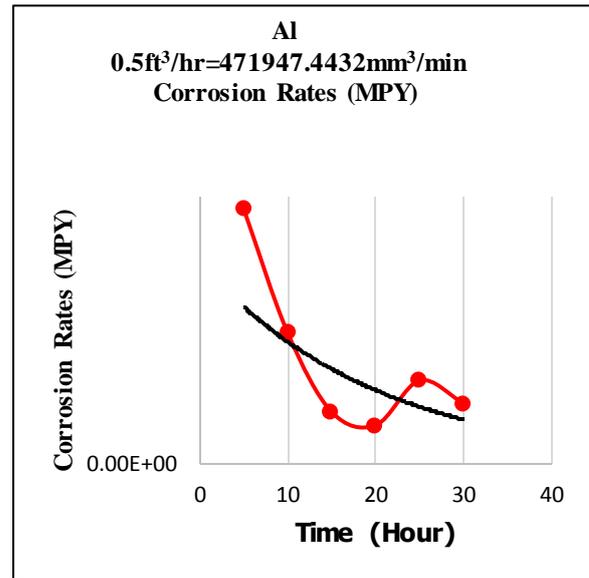
Fig. (4): Represent the corrosion rate for specimens (2), where red line is actual readings and the black line is exponential fitting line.
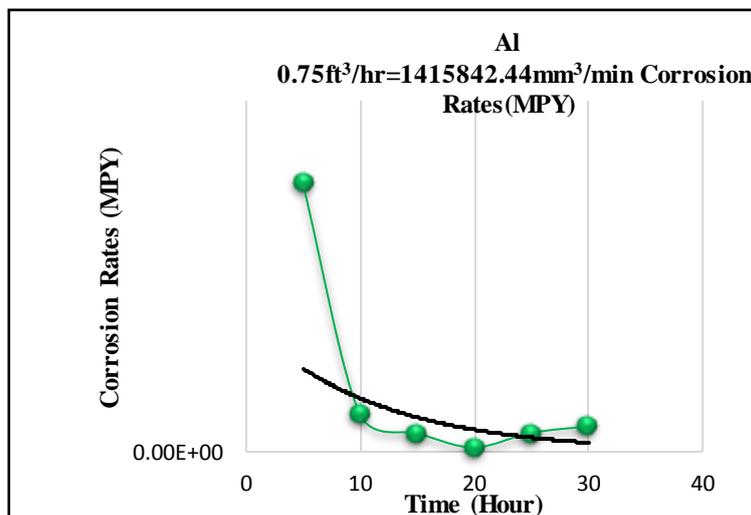
Fig. (5): Represent the corrosion rate for specimens (3), where green line is actual readings and the black line is exponential fitting line.

And in general the corrosion rates for Aluminum specimens decrease with increasing the time exposure to the corroded medium. The public unanimity for Al and their alloys that they are impedance cross erosion in mildly offensive middle. Oxidation layer represent the protective thermodynamic stability of AI in corrosive medium- behaving as a physical

obstacle as well as its capability to incur itself in oxidizing environments if its destroyed [14], the reason may be due to the hydroxide layer also. And the chemical equation done as follow:

$$H_2O + O_3 \rightarrow 2OH^- + O_2$$

$$4Al + 3O_2 \rightarrow 2Al_2O_3$$

$$Al + 3OH^- \rightarrow Al(OH)_3$$
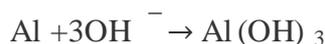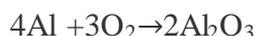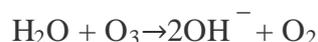
4.2 For Medium Carbon Steel Specimens:

The three specimens for Medium Carbon Steel which immersed in ozonated distilled water with three different flow rates, show the maximum corrosion rates in the beginning corrosion intervals for alloy at flow rate $0.25ft^3/hr$ and the corrosion rates decrease with increasing exposure time to corrosion mediums and in the end of corrosion intervals at time (30 hour) the corrosion rate increase. Meanwhile the alloys which immersed with flow rates (0.5 & 0.75) ft^3/hr shows the minimum corrosion rates at the beginning of the corrosion all these and this behaviors for specimens 1,2 & 3 clearly shown in Fig. (6,7 & 8) respectively. And in general the corrosion rate decrease in flow rate $0.25ft^3/hr = 117986.8608mm^3/min$ due to complete interaction between the iron and corrosive medium, meanwhile the increasing in flow rates or concentration of ozone the corrosion rates increase with increasing time to corrosion exposure. Oxide and hydroxide layers composed of ozonated solutions increase the erosion resistance of medium carbon steel. Layers are minimum preventive in ozonated high concentration solutions than negative layers normally [15]. The specimen (3) at flow rates $(0.75ft^3/hr)$, the test at time (20 hour) has high corrosion rate with respect to other corrosion rates, due to the high moisture rate which was (48%). And the chemical equation done as follow:

$$H_2O + O_3 \rightarrow 2OH^- + O_2$$

$$4\,Fe + 3\,O_2 \rightarrow 2Fe_2O_3 \quad_{\&}\quad 3Fe + OH^- \rightarrow Fe(OH)_3$$
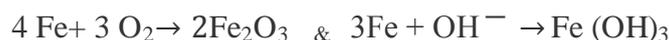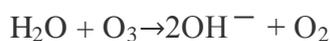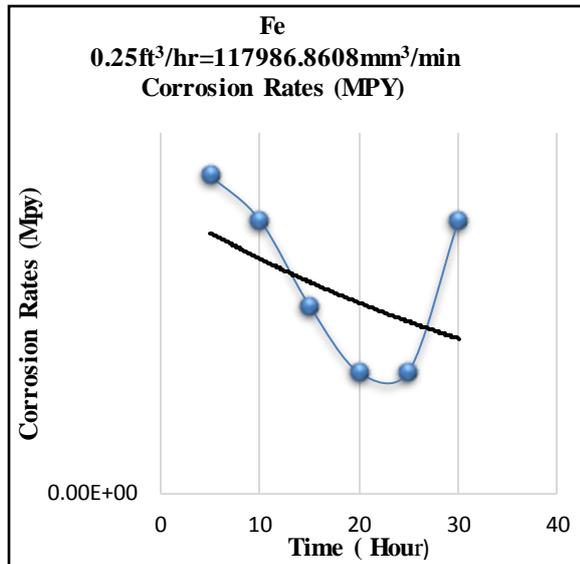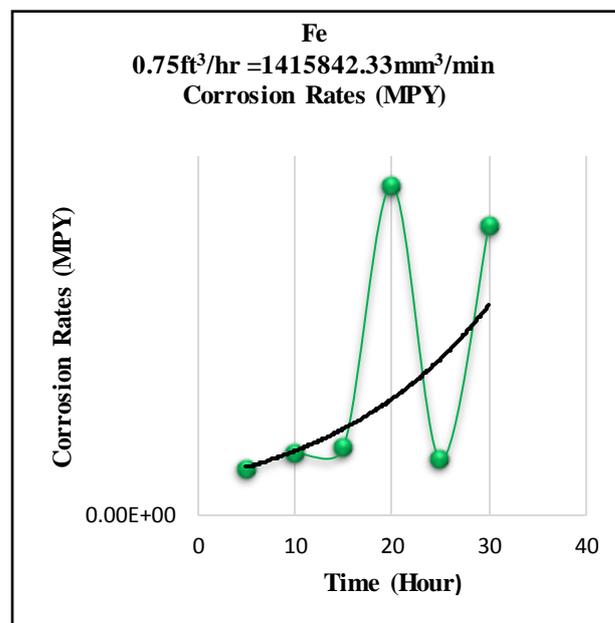
Fig. (6): Represent the corrosion rate for specimens (1), where blue line is actual readings and the black line is exponential fitting line.
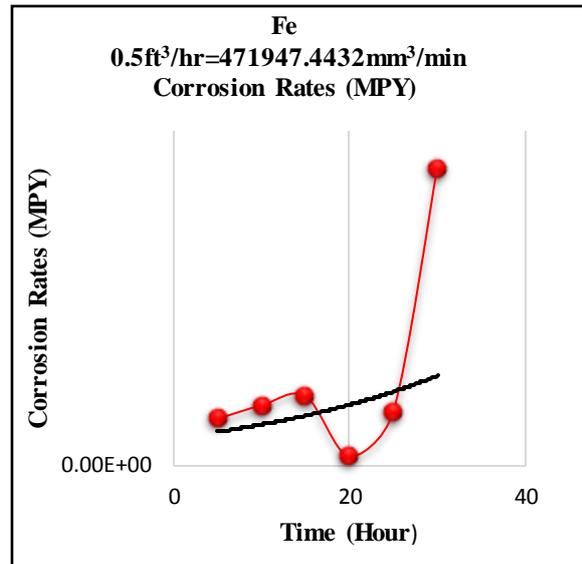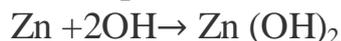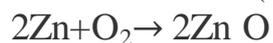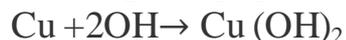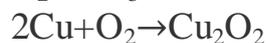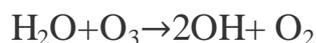
Fig. (7): Represent the corrosion rate for specimens (2), where red line is actual readings and the black line is exponential fitting line.
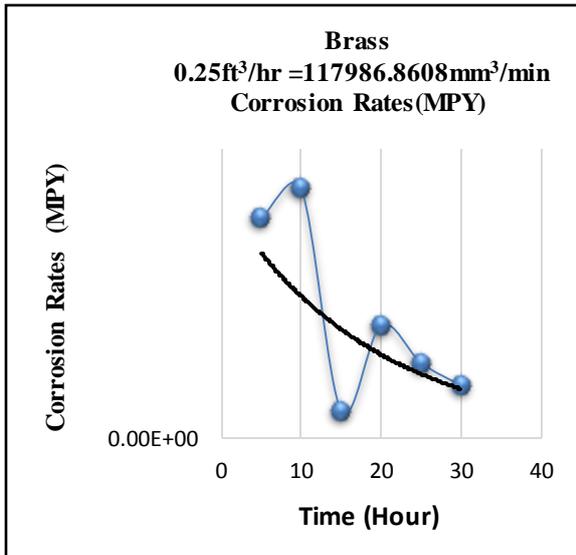

Fig. (8): Represent the corrosion rate for specimens (3), where green line is actual readings and the black line is exponential fitting line.

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4.3 For Brass (Cu-30Zn) Specimens:

The three specimens for Brass which immersed in ozonated distilled water with three different flow rates, show the maximum corrosion rates in the beginning corrosion intervals and the corrosion rates decrease with increasing exposure time to corrosion mediums, and all these behaviors for specimens 1,2 & 3 clearly shown in Fig. (9, 10 & 11) respectively. The major problems with higher zinc alloys are , in dezincification, a spongy layer of zinc free material is composed at a specific location or within the layers or on the surface. Zinc is added to copper in those alloys at a rate of 95-4505. As a common rule, the resistanceto corrosion decreased as zinc content maximizes. It is frequent to differentiate between those alloys having less than 15% zinc (superior corrosion resistance and others with higher amounts) [15].And in general the corrosion rates decrease with increasing the time exposure to the corrosion medium, due to forming oxide and hydroxide film which not damage by increasing the flow rates. The erosion resistance of copper and copper alloys has been referred to a preventive cuprous brazen oxide layer, Cu_2O, composed during the exposure. Yet those alloys can degrade due to the composition of biofilm, which its polymeric structure permits local gradients of pH and O_3 [16]. The chemical reactions were done:

$H_2O+O_3 \rightarrow 2OH+ O_2$
$2Cu+O_2 \rightarrow Cu_2O_2$
$Cu +2OH \rightarrow Cu (OH)_2$
$2Zn+O_2 \rightarrow 2Zn\ O$
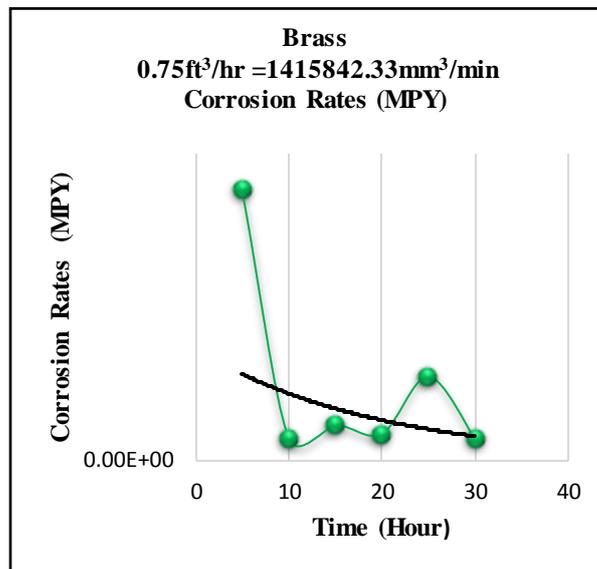$Zn +2OH \rightarrow Zn (OH)_2$

Fig. (9): Represent the corrosion rate for specimens (1), where blue line is actual readings and the black line is exponential fitting line.
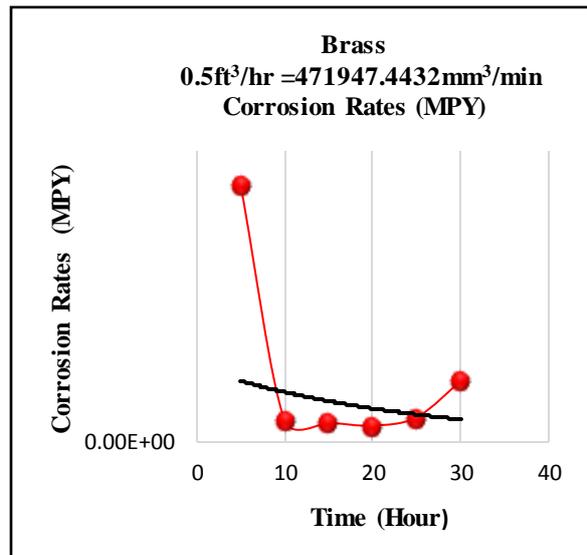
Fig. (10): Represent the corrosion rate for specimens (2), where red line is actual readings and the black line is exponential fitting

Fig. (11): Represent the corrosion rate for specimens (3), where green line is actual readings and the black line is exponential fitting line
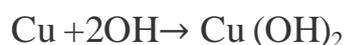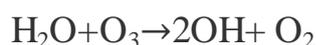
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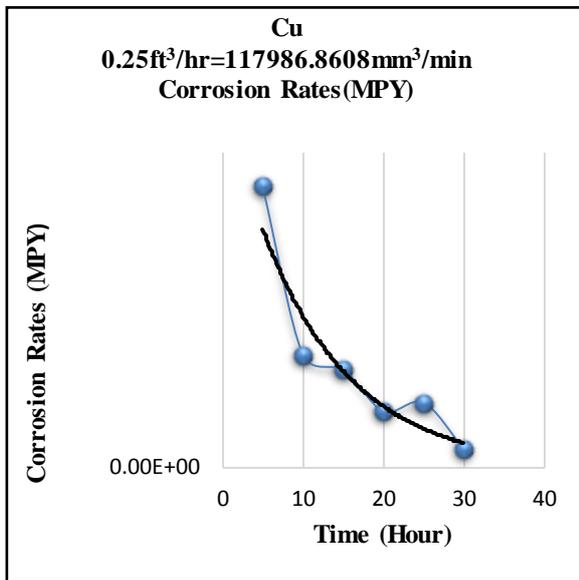**ISSN 1992 – 0849**

4. Copper Specimens

The three specimens for Copper which immersed in Ozonated distilled water with three different flow rates, show the maximum corrosion rates in the beginning corrosion intervals and the corrosion rates decrease with increasing exposure time to corrosion mediums for specimens (1). The erosion resistance of copper and copper alloys has been referred to a preventive cuprous brazen oxide layer, Cu_2O, composed during the exposure. Yet those alloys can degrade due to the composition of biofilm, which its polymeric structure permits local gradients of pH and O_3 [16].

Meanwhile the alloy which immersed with flow rates (0.5 ft^3/hr) shows the minimum corrosion rates at the beginning of the corrosion and increase with increasing the corrosion intervals. However the alloy which immersed with flow rates (0.75 ft^3/hr) shows the maximum corrosion rates at the beginning and in the end of the corrosion intervals due to high moisture rates at the first day of the test which was (60%). All these and this behaviors for specimens 1, 2 & 3 clearly shown in Fig. (12, 13 & 14) respectively.

And in general the corrosion rates decrease with increasing the time exposure to the corrosion medium for specimen (1), due to forming oxide and hydroxide film which not damage by increasing the corrosion time.

Meanwhile for the other two alloy the corrosion rates decrease with increasing the time exposure to the corrosion medium due to forming oxide and hydroxide film which damage by increasing the corrosion intervals, and the chemical equations were:

$$H_2O + O_3 \rightarrow 2OH + O_2$$

$$2Cu + O_2 \rightarrow Cu_2O_2$$

$$Cu + 2OH \rightarrow Cu(OH)_2$$

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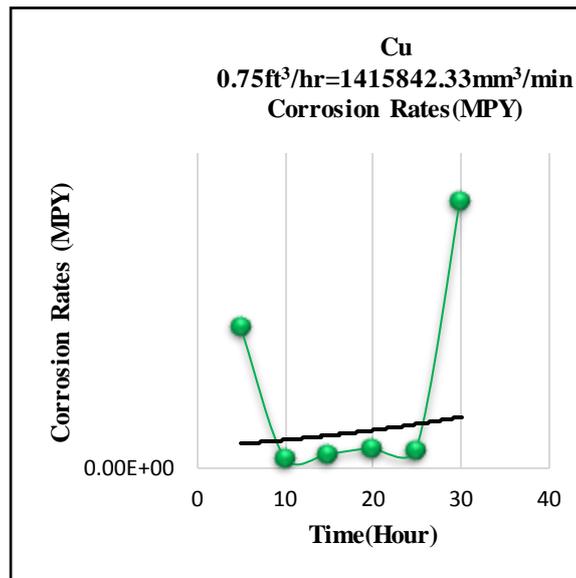
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Fig. (12): Represent the corrosion rate for specimens (1), where blue line is actual readings and the black line is exponential fitting line.
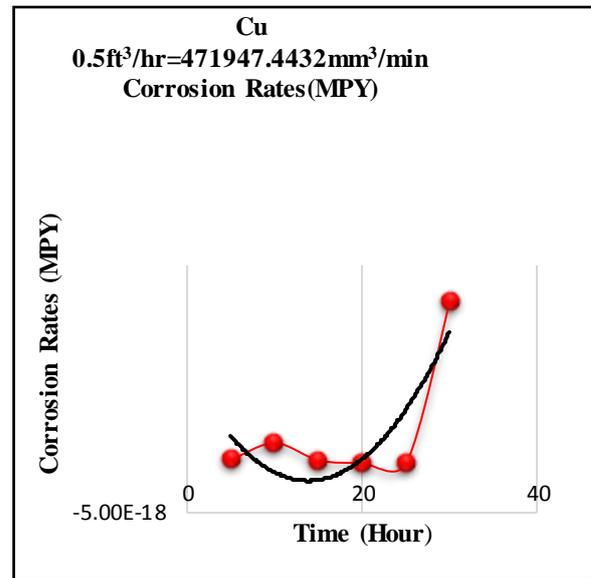
Fig (13): Represent the corrosion rate for specimens (2), where red line is actual readings and the black line is exponential fitting line.

Fig. (14): Represent the corrosion rate for specimens (3), where green line is actual readings and the black line is exponential fitting line.

5. In general ozone gas flow rate has both positive & negative effect [17].

6. The maximum total corrosion rates was in medium carbon steel (1.35E-16MPY) and the minimum total corrosion rates in copper (6.97E-18MPY) for flow rate (0.25ft^3/hr). The maximum total corrosion rates was in medium carbon steel (1.72E-16MPY) and the minimum total corrosion rates in aluminum (7.09E-18MPY) for flow rate (0.5ft^3/hr).meanwhile the maximum total corrosion rates was in medium carbon steel (3.09E-16MPY) and the minimum total corrosion rates in Brass (5.20E-18MPY) for flow rate (0.75ft^3/hr). In general the Medium carbon steel specimens had the maximum corrosion rates and the other materials which used in previous work all these obviously shown in Fig. (15, a6 & 17). respectively.
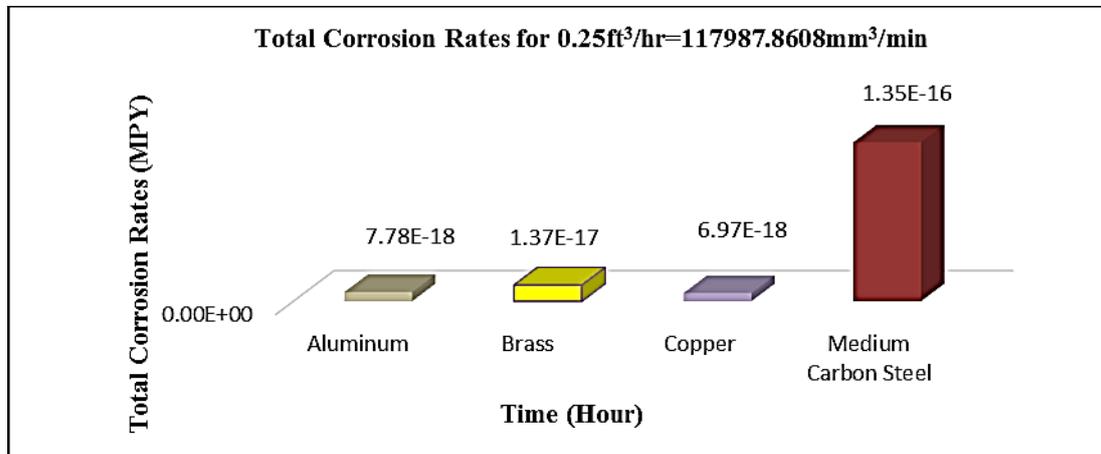

Fig. (15): Represent the total corrosion rate for specimens with 0.25ft^3/hr flow rates.

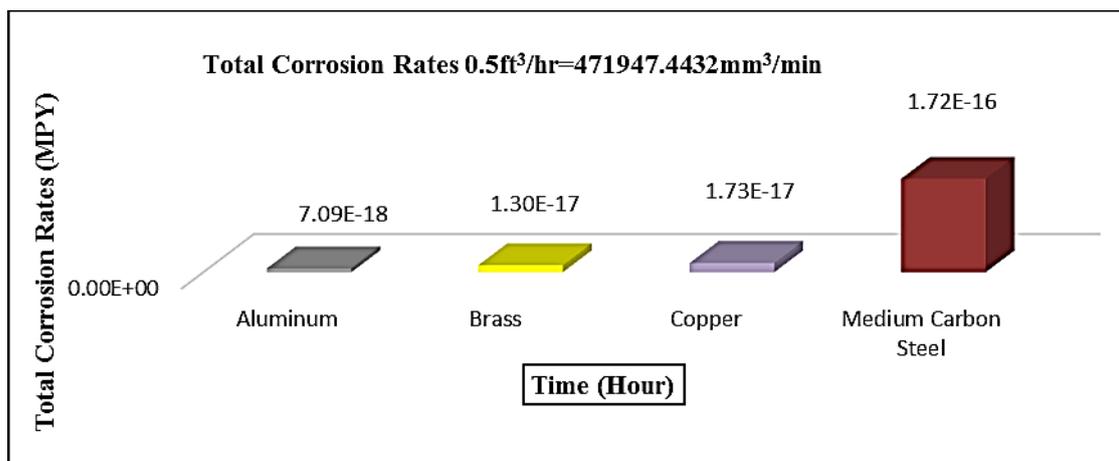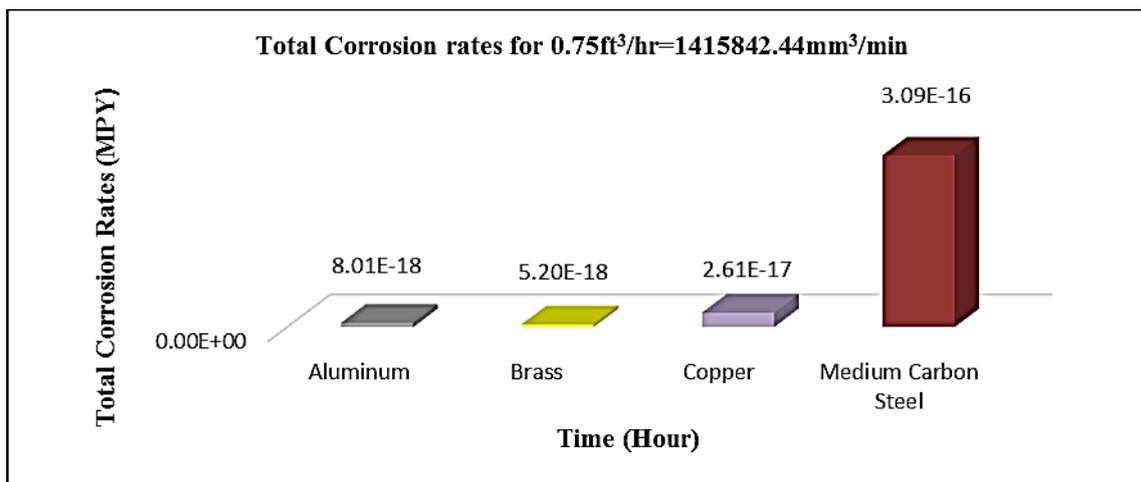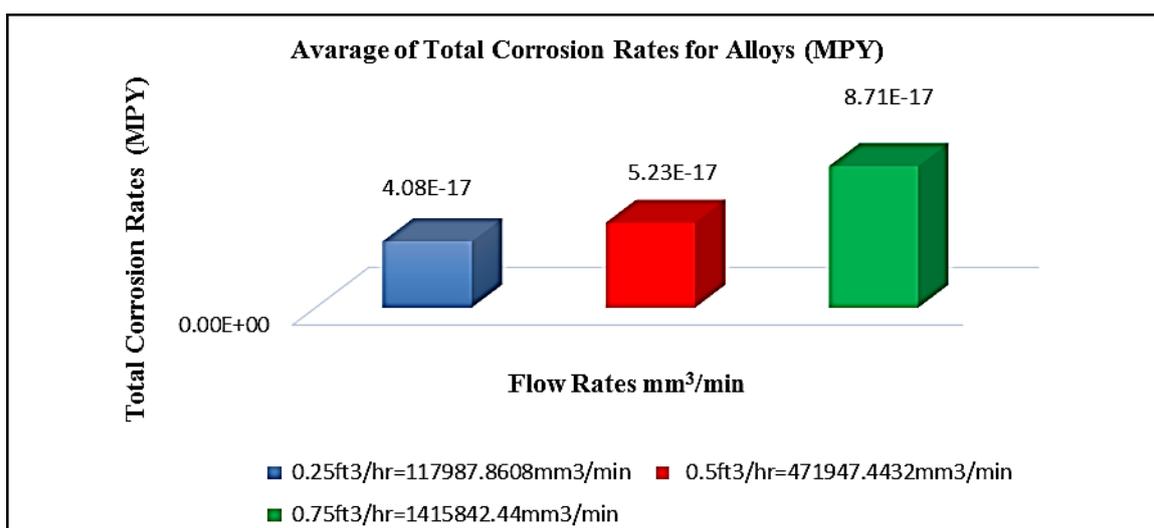**Fig. (16):** Represent the total corrosion rate for specimens with 0.5ft^3/hr flow rates.

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Fig. (17): Represent the total corrosion rate for specimens with $0.75ft^3$/hr flow rates.

7. The average of total corrosion rates for the alloys used in previous work increasing with increase the flow rate of ozone in distilled water and the maximum value was (8.71E-17MPY)meanwhile the minimum was (4.08E-17MPY) which shows clearly in Fig. (18). Ozone considered to be a very powerful oxidant even if in a very small concentration nearly (1 mg/I) elevate the erosion potential and the destroying of the negative films which lead to denting and crevice corrosion [18].

Fig. (18): Represent the average total corrosion rate for specimens in different flow rates.

8. All the tests were done during winter season and the difference in temperature was between (2- 4) ^{o}C, therefor there is no significant effect of temperature on the obtained results.

5. Conclusions

1. Positive & negative effect of ozone gas on specimens.

2. The total corrosion rates were:

   For medium carbon steel & Copper were obeyed the following:

   $0.75\text{ft}^3/\text{hr} > 0.5\text{ft}^3/\text{hr} > 0.25\text{ft}^3/\text{hr}$

   For Brass & Aluminum were obeyed the following:

   $0.25\text{ft}^3/\text{hr} > 0.5\text{ft}^3/\text{hr} > 0.75\text{ft}^3/\text{hr}$

3. The average total corrosion rates of specimens increase with increases the flow rates.

4. Each specimens had its own behavior.

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