Review Article

A Review: Weight Loss Studies on the Corrosion Behavior of Some Metals in Various Media

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Abstract

Many scientists have through time developed interests in undertaking researches related either directly or indirectly to corrosion, which could be attributed to increasing cases of material breakdown as a result of corrosion. There are therefore several published works focused on studies of the corrosion behavior and mechanism of various metals in several different environments or media. In this review paper, we explored and analyzed the various recent research works on corrosion kinetics using weight loss method, and to a certain extent about corrosion inhibition.

Keywords: Corrosion, weight loss method, concentration, metals, time

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Introduction

Every given environment can practically be regarded as corrosive to a certain degree, even though the extent of corrosion depends on a number of factors. These environments include among many others the atmosphere, a mixture of air and moisture, fresh and salty water, and the industrial atmospheres (gases, alkali, acids, etc). Corrosion is tremendously destructive to metals and undoubtedly one of the largest consumers of metal known to man. A number of industrial designs of materials are not carried out unless keen considerations are given to the effect of corrosion on the materials' life spans.

Corrosion which is derived from the Latin word "corrodere (meaning to eat away)" occurs when a metal or alloy undergoes a chemical or electrochemical reaction with the surrounding environment, resulting in a gradual deterioration, destruction, or in extreme cases structural failure of the metal.

Corrosion is mostly monitored using the weight loss method which involves exposing metal specimen to a given environment for a specific period of time, after which the specimen is removed from the environment and change in its weight before and after exposure is then determined. In this paper, there is a literature review of several works in which the weight loss method has been used in determining the corrosion behavior of certain metals in a number of environments or corrosion media.

Literature Review

Patil and Sharma have undertaken a study on the corrosion kinetics of iron in acidic and basic media using weight loss method [1]. Potassium hydroxide, sulfuric acid, and nitric acid solutions were used in carrying out the research. The study was done at different intervals of time, within a temperature range of 25.0 °C to 30.0 °C. They observed that there was a variation in the rate of corrosion with different time intervals and different acid-base concentrations, and that iron corroded most in nitric acid, followed by sulfuric acid, and lastly potassium hydroxide which was the least corrosive of the three solutions. By further studies, they noticed a first order kinetics for iron in all three solutions.

In order to investigate how petroleum pipelines are affected by corrosion, Badmos *et al* have researched on mild steel corrosion in petroleum and refined petroleum products namely Premium Motor Spirit (PMS), Dual Purpose Kerosene (DPK), Automotive Gas Oil (AGO), and lubricating or engine oil [2]. In an exposure time spanning 60 days, weight loss method was used to measure amount of weight loss at a 10 day interval. The corrosion rate was also determined, and the results obtained show zero weight loss and zero corrosion rate for engine oil while both quantities were relatively significant in this order: PMS > DPK > AGO > Crude Oil. In addition, it was discovered that weight loss and corrosion rate of mild steel in petroleum products increased with significant decrease in the density and increase in the weight percent of hydrogen in the hydrocarbon products. The weight loss plots for all the media are depicted in Figure 1.

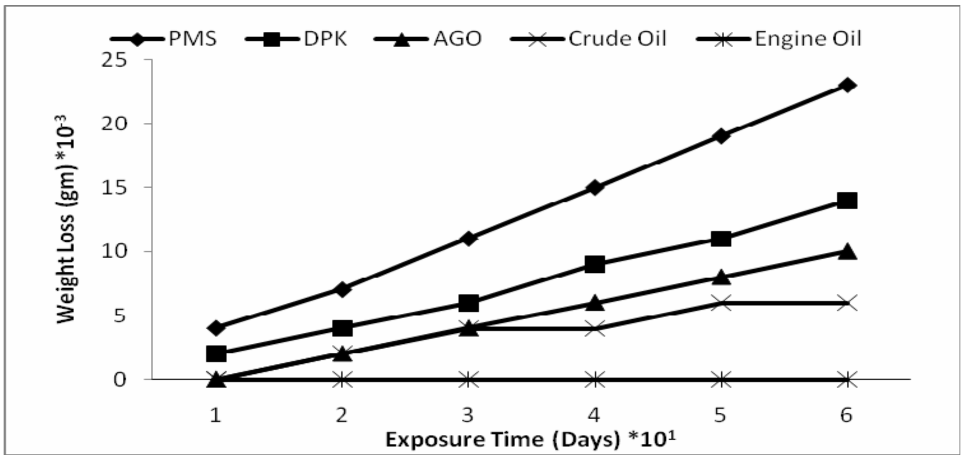


Figure 1 Variation of weight loss Vs Exposure Time for all Media (Badmos *et al*, 2009).

Some metals and brass alloy have been studied under different media by Kumar *et al* for their corrosion and electrochemical behavior [3]. The research was done using aluminum, copper, and brass alloy; and solutions of nitric acid, hydrochloric acid, ethanoic acid, phosphoric acid, sulfuric acid, sodium hydroxide, potassium hydroxides, saturated sodium and potassium chlorides; sea and tap waters. The different concentrations (in units of normality) used for some of these solutions were 0.1N, 0.5N, 1N, and 4N; and at different times (1 to 5 hours). The following conclusions were reached from the research: the rate of corrosion increased with increasing concentration; the rate of corrosion increased with increasing time; the order of corrosion in acids was obtained as- HNO_3 > H_3PO_4 > H_2SO_4 > HCl > CH_3COOH; bases NaOH and KOH show comparatively less corrosion rate than these acids; and finally the order of corrosion in metals was determined as- Al > Fe > Cu > Brass.

Abdulmaruf and Dajab have used weight loss method to highlight how copper corrodes when it has been exposed to three different environments namely hydrochloric acid solution (HCl), sodium chloride (NaCl) in rain water solution, and atmospheric conditions [4]. The rates of weight loss and corrosion were both determined in exposure time between 72 and 360 hours. The entire reaction conditions had been maintained at a temperature of 25 °C to 28 °C, and results showed that the weight loss was most pronounced in HCl solution (concentration 0.02M), followed by NaCl solution (concentration 0.0075M), and lastly the atmosphere.

Mohammed *et al* have investigated the effectiveness and efficiency of ethyl ester of lard in inhibiting the corrosion of mild steel in a mixture of petroleum and water [5]. They carried out weight loss tests at different inhibitor concentrations (0.1, 0.2, 0.3, 0.4, and 0.5 g/L), and different temperatures (303, 313, 323, and 333 K). They concluded that the efficiency of inhibition increased with an increase in inhibitor concentration and a decrease in temperature conditions, and that the inhibition approximated a first order reaction.

Groysman and Erdman have carried out a study on the corrosion of mild steel in mixtures of petroleum distillates and electrolytes [6]. The purpose of the study was to determine minimal (or critical) water content and corrosive type resulting in high corrosiveness of petroleum distillates. The research was conducted using mixtures of light petroleum distillates (naphtha and gasoline) with water content less than 5% in volume, and in some cases with 10 ppm sodium chloride solutions. It was confirmed from the work the electrochemical origin of the corrosion mechanism. It also showed that the main cause of corrosion in the petroleum distillates-electrolyte mixtures was the presence of water and dissolved oxygen. Salts (chlorides, sulfates, and nitrates) and organic acids (formic acid [HCOOH] and acetic [CH_3COOH] had been extracted from the naphtha and gasoline by the aqueous phase and were responsible for the severe corrosion of these petroleum distillates.

The kinetics of mild steel corrosion in aqueous acetic acid solutions has been studied by Singh and Mukherjee using weight loss and polarization techniques at 25, 35, and 45 °C; and an exposure time of 24 and 168 hours [7]. The results revealed that mild steel corroded significantly at room temperature (25 °C). Mild steel therefore showed poor corrosion resistance in acetic acid. Maximum corrosion rate was observed in 25% acetic acid solution at all three experimental temperatures. There was a decrease however in the rate of corrosion after the attainment of a maximum value, and this could be attributed to the deposition of corrosion product on the surface. In conclusion, there was an observed dependence on concentration for the corrosion behavior of mild steel.

Samina *et al* have undertaken a research to study the corrosion of iron, copper, and brass alloy in different media by weight loss method [8]. The different media which were used include nitric acid, hydrochloric acid, acetic acid, sulfuric acid, phosphoric acid, benzoic acid, sodium hydroxide, and potassium hydroxide amongst others. The solutions were prepared in concentrations between 0.1 to 4N, and the experiment was carried out for different timings of 1 to 5 hours. The following conclusions had been arrived at from the research: the rate of corrosion increased with increasing concentration of the acid; the rate of corrosion increased with increase in time; the order of corrosion in the media which had been used was- $HNO_3 > H_3PO_4 > H_2SO_4 > HCl > CH_3COOH$ > oxalic acid > benzoic acid > succinic acid > salicylic acid > KOH > NaOH; the corrosion rate increased in the order Fe > Cu > Brass; and finally metals were highly corroded in acids, as compared to bases and neutral solutions.

Realizing the significant use of sulfuric acid during the production of phosphate fertilizers, Singh and Kumar have done a work on the corrosion and corrosion protection of stainless steel in phosphate fertilizer industry [9] The corrosion rate of the metal was determined by weight loss experiment and potentiostat techniques, and the inhibition was determined using organic inhibitors 1-(2-bromophenyl)methanamine and 1-(2-chlorophenyl)methamine at different temperatures in the presence of 15% H_2SO_4 and 15mM concentration of inhibitors. Results obtained revealed that the inhibitors which had been used produced anticorrosive effect in acidic medium.

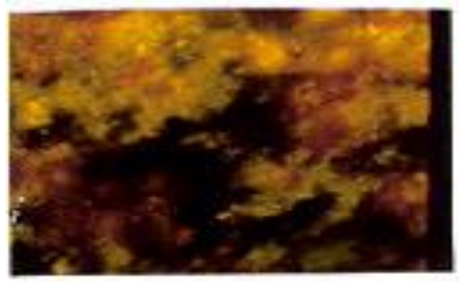
The corrosion behavior of various metals and alloys in marine-industrial environment was researched by Natesan *et al* using weight loss techniques [10]. The work dealt with atmospheric corrosion to assess how ferrous and non-ferrous metals and alloys are degraded by air pollutants. The investigation was carried out using the following materials: galvanized iron, zinc, aluminum, copper, mild steel, and copper-zinc alloys. The research was carried out where the metals had been exposed to marine and industrial environment. Weight loss method was used to determine seasonal (1 to 12 month) metal/alloy losses due to corrosion. Strong corrosion was observed on mild steel, galvanized iron, copper, and zinc. A minor effect was however observed on aluminum and Cu-Zn alloys. Mild steel was in particular observed to have higher degrees of weight loss for every three months increase in time of exposure.

Noor and al-Moubaraki have studied the corrosion behavior and mechanism of mild steel in hydrochloric acid solutions (0.25-2.5 mol dm^{-3}) by chemical (hydrogen evolution, HE and mass loss, ML) and electrochemical (electrochemical impedance spectroscopy and potentiodynamic polarization) methods at 25 °C [11]. The chemical results showed that mild steel corroded in HCl solutions with a reaction constant of 0.56, and the corrosion rate increased with increase in the concentration of HCl. Also, mild steel was found to corrode in HCl solutions with a first order reaction. Furthermore, micro-structural studies (illustrated in Figure 2) exposed pitting and general types of corrosion on the metal, with the former more pronounced at higher levels of HCl concentration.

Before immersion (a)

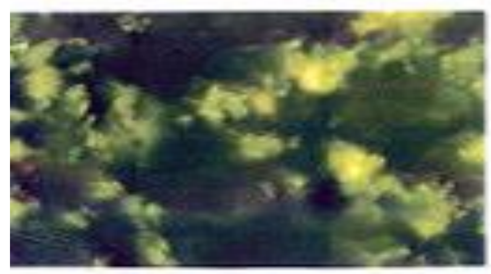
After immersion (b)

(1)



(2)

(3)



(4)

Figure 2 Micrographs for mild steel surface in (a) before and (b) after immersion for 90 min at 25 °C HCl solutions (1) 0.25; (2) 1.00; (3) 1.50 and (4) 2.50 mol dm^{-3} (Noor & al-Moubaraki, 2008a).

Raja muthu kumar *et al* have studied the corrosion of stainless steel-304 in brackish environment with variation in concentration, pH, and contact time [12]. Weight loss method, gasometry study, and open circuit polarization studies were used to carry out the experiment in 3.0% and 3.5% sodium chloride. It was confirmed from experiment results that stainless steel-304 immersed in brackish environment with a variation in concentration, experienced very little corrosion. In addition, EDS (Energy Dispersive Spectroscopy) study and x-ray diffraction results showed that the possible ensuing by-products of the corrosion were iron oxides and chloride, chrome oxides, and nickel hydride oxide. Also, the corrosion was observed to be predominantly under anodic control and a pitting type.

Noor and al-Moubaraki have studied the corrosion and inhibitor adsorption processes in mild steel/1-methyl-4[4'(-X)-styryl] pyridinium iodides (X: −H, $-CH_3$ and $-OCH_3$)/hydrochloric acid systems at temperatures between 25 °C and 60 °C via hydrogen evolution (HE) and weight loss (WL) measurements [13]. They discovered that the efficiency of inhibition is directly and inversely proportional to concentration of inhibitors and temperature respectively. They also discussed on an observed increase in the rate at which mild steel corroded with every 10 °C rise in temperature. Based on the inhibitors that they studied, they obtained that the inhibitive action at certain concentration and all temperatures followed this order: I-H < II-CH_3 < III-OCH_3.

Johnson has carried out an investigation about the corrosion of certain metals in deionized water at a temperature of 38 °C [14]. The metals used usually have nuclear applications, and they included copper, cadmium, tungsten, titanium, Mallory-1000, 304 stainless steel, 1100 aluminum, tantalum, silver, and boron steel. The results were obtained from chemical analyses of the water sample rather than from physical measurement of the test specimen. The following metals showed no corrosion in the corrodent: 304 stainless steel, titanium, 1100 aluminum, silver, tantalum, and boron steel. While at the above mentioned temperature, copper, cadmium, tungsten, and Mallory-1000 exhibited corrosion in deionized water. In conclusion, it was observed that chemical analyses of the water in which test specimens are immersed provide more useful corrosion information in nuclear applications than physical measurement of weight loss.

The corrosion of aluminum in aqueous chloride and nitrate media, and its inhibition by nitrite has been investigated by Afzal *et al* [15]. The commercial grade aluminum was observed through the potentiodynamic method to be affected in both media at pH 4 and 10. Results showed increase in the corrosion rate of aluminum with increase in concentrations of chloride and nitrate ions. It was also observed that for both media, corrosion behavior appeared to be significant at higher pH value due to the instant dissolution of metal ions as complex. In order words, aluminum was comparatively more corrodible in basic condition than in acidic condition. Finally, it was deduced that nitrite serves as an important corrosion inhibitor in both chloride and nitrate media, and that the inhibition is more prevalent at lower pH and at higher concentrations of nitrite.

Using weight loss techniques, James and Akaranta have evaluated the inhibition efficiency of acetone extract of red onion skin on aluminum in solutions of hydrochloric acid [16]. They obtained that the efficiency of inhibition is dependent upon the inhibitor concentration and temperature. At the temperatures they had done the research, inhibition was found to increase with increase in inhibitor concentration, half life, and activation energy. On the other hand, inhibition was found to decrease with temperature and first-order rate constant.

Mamatha *et al* have presented a paper involving studies on the corrosion resistance properties of Aluminum-7075/Silicon Carbide Particulates metal matrix composites (MMCs) in acid medium [17]. The corrosion tests were conducted by weight loss method for different exposure time where 1N HCl was used as the corrodent. A decrease in corrosion was observed with increase in test duration. It was also observed that the corrosion rate of MMCs was lower than that of matrix Al-7075 alloy under the corrosive atmosphere, basically due to the significant role played by SiC content which reduced the density and increased the strength of the alloy.

Gupta *et al* have investigated the corrosion and inhibition behavior of aluminum in alkaline medium and sodium silicate respectively [18]. Weight loss method was utilized in determining the corrosion rates in an experiment that spanned 24 hours and was maintained at room temperature (25 °C). Obtained results showed weight losses of 16.8 mg and 0.71 mg, and respective corrosion rates of 3.27 and 0.13 mg $cm^{-2}h^{-1}$ x 10^2 after 24 hours with and without sodium silicate inhibitor respectively.

Investigation of weight loss and corrosion rates of bimetals and tri-metal in acidic environment was done by Ikpesu [19]. Samples of bi-metals and tri-metal include aluminum, zinc, and lead, and alloys of aluminum-zinc, aluminum-lead, and zinc-lead. The test coupons after being immersed in beakers containing diluted sulfuric acid were left in the solution for seven days. The rates of corrosion were then determined from the weight losses after these seven days. The results showed a drastic reduction in the weight of tri-metal (Al-Zn-Pb) and Zn-Pb. The bi-metals (Al-Zn and Al-Pb) however showed a good resistance to corrosion. These results are represented in Table 1.

Table 1 Corrosion Rate in mpy of Al, Zn, Pb, Al-Zn, Al-Pb, Zn-Pb & Al-Zn-Pb (Ikpesu, 2014)

SPECIMEN	DAY1 g	DAY2 g	DAY3 g	DAY4 G	DAY5 g	DAY6 g	DAY7 g	CORROSION RATE mpy (x 10^{-3})
Al	18.7	16.2	16.1	15.0	15.8	15.6	15.4	0.088
Zn	48.2	37.4	37.6	37.6	37.6	37.6	37.6	0.298
Pb	51.7	44.5	43.5	43.5	43.2	43.5	43.2	0.122
Al-Zn	20.0	18.4	18.0	17.8	17.7	17.5	17.3	0.556
Al-Pb	28.0	23.6	23.3	23.04	23.04	22.65	22.64	1.412
Zn-Pb	30.9	22.8	22.8	22.8	22.9	22.8	22.9	1.648
Al-Zn-Pb	22.9	14.7	14.4	15.4	14.96	14.8	14.78	1.860

Abdul-Karim *et al* have carried out a study on how certain metals used as roofing sheets corrode to acid rain water in Eleme, Rivers State of Nigeria [20]. Aluminum alloy and galvanized steel were studied using the simple immersion test method to determine corrosion rates by weight loss. There were all indications from results which showed the occurrence of acid rain in that town, with an average pH of 4.34. The respective corrosion rates of aluminum alloy and galvanized steel as shown in Table 2 were 0.0049 g/dm^2.day and 0.0156 /dm^2.day. Due to the great damage on galvanized steel, the author concluded that aluminum alloy is a better choice of material for roofing in Eleme, Rivers State of Nigeria.

Table 2 Corrosion rates for aluminum alloy and galvanized steel in rain water of pH 3.0 and pH 4.34 (Abdul-Karim *et al*, 2009)

Coupons	Corrosion rates (mg/dm^2.day)	
	Rain water with pH 3.0	Rain water with pH 4.34
Aluminum alloy	0.0081	0.0049
Galvanized steel	0.0313	0.0156

The corrosion behavior of unalloyed copper in freely aerated 0.50 M hydrochloric acid pickling solutions has been reported by Sherif in his work “Corrosion Behavior of Copper in 0.50 M Hydrochloric Acid Pickling Solutions and its Inhibition by 3-Amino-1,2,4-triazole and 3-Amino-5-mercapto-1,2,4-triazole” [21]. His weight loss data indicated the rapid dissolution of copper in HCl solution due to the increased weight loss with increasing period or time of exposure.

Hassan has investigated corrosion in petroleum pipelines by studying how carbon steel corrodes in crude oil and refined petroleum products such as gasoline, kerosene, and gas oil [22]. The weight loss technique was used in this work for a total exposure period of 60 days, with measurements being carried out at 10 days interval. It was observed as shown in Table 3 that corrosion of steel was highest in gasoline, being followed by kerosene, gas oil, and crude oil. It was also observed that corrosion rate increased with decreasing density and increasing weight percent of hydrogen in the hydrocarbon products. Through furthering the study for various temperatures and a constant partial pressure of

CO_2, it was noticed that as partial pressure of CO_2 and temperature increase, corrosion rate also increased as a result of continuous dissolution of iron ion and formation of weak carbonic acid. Finally, it was observed that the presence of hydrogen sulfide (H_2S) as low as 0.4 ppm could increase the rate of corrosion significantly. Figure 3 is an ESEM micrograph showing the surface morphology of the metal in the test media.

Table 3 Corrosion rate of carbon steel in the test media (Hassan, 2013)

Exposure Time (Days)	Gasoline	Kerosene	Gas Oil	Crude Oil
10	2.51	1.24	0.633	0.743
20	2.20	1.24	0.693	0.763
30	2.33	1.24	0.824	0.888
40	2.40	1.45	0.977	0.761
50	2.45	1.40	1.00	0.842
60	2.50	1.50	1.090	0.760

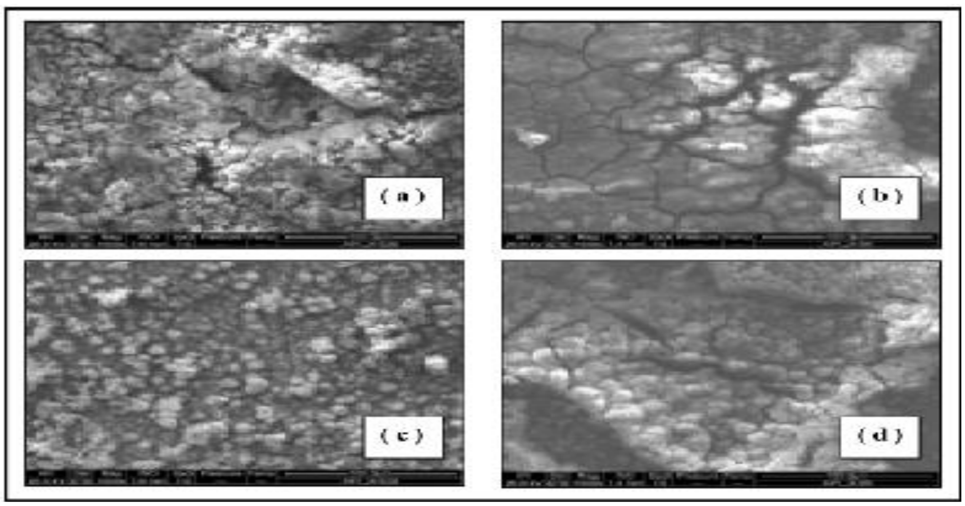


Figure 3 ESEM micrographs showing surface morphology of carbon steel in (a) kerosene (b) gas oil exposed at 90 °C and (c) kerosene and (d) gas oil exposed at 120 °C (Hassan, 2013)

Ukoba *et al* looked into the corrosion mechanism of ductile iron in different environments for an exposure period of six months, using the weight loss technique [23]. The environments used include outside, brackish or salty, air conditioned, and alkaline environments. There was an observed decrease in the corrosion rate with an increase in the exposure period. In all four environments, there had been an initial sharp corrosion rate at the first few months, although there was a decrease in corrosion as more months tended to pass by. The data showed the following order with respect to corrosion in these environments: brackish (NaCl) environment (weight loss of 1.1456g) > outside (weight loss of 1.0284g) > alkaline (NaOH) environment (weight loss of 0.867g) > air conditioned environment (zero weight loss).

Conclusion

Widespread cases of corrosion have opened up ground for scientists to investigate how some metals and alloys behave in a number of corrosive environments. Using the weight loss technique, scientists have published large amounts of data on corrosion kinetics and corrosion inhibition, thus establishing a guiding principle for the corrosion behavior of materials in various applications.

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