

Full Length Research Paper

Corrosion behaviour of mild and high carbon steels in various acidic media

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The corrosion behaviour of mild steel and high carbon steel in various concentrations of nitric acid (HNO_3), hydrochloric acid (HCl), and perchloric acid (HClO_4), has been studied. Specimens were exposed in the acidic media for seven days and corrosion rates evaluated, using the weight loss method. It was observed that nitric acid environment was most corrosive to both steels because of its oxidizing nature, followed by perchloric acid, and lastly, hydrochloric acid. The corrodent concentration and *exposure* time affected the corrosion of the metals. The rate of metal dissolution increased with increasing concentration of the corrosion media and exposure time. Corrosion rates of mild steel in all the acidic media studied were found to be higher than that of high carbon steel. This could be attributed to the fact that the carbon content in itself has little if any effect on general corrosion resistance of steels.

Key words: Metals, corrosion.

INTRODUCTION

Corrosion is a prevailing destructive phenomenon in science and technology (Ita and Offiong, 1999). In industries such as pulp and paper industry, power generation, underground structures, chemical and oil industries, metals are used in over 90% of construction process (Osarolube et al., 2004). Iron and steel are the most commonly used materials in the fabrication and manufacturing of oil field operating platforms because of their availability, low cost, ease of fabrication, and high strength (Umezurike, 1998; Nwoko and Umoru, 1998).

Most industrial media are usually rich in elemental gases, inorganic salts, and acidic solutions most of which influence corrosion rates, and mechanisms (Abu and Owate, 2003; Abiola and Oforka, 2005). Metals are usually exposed to the action of bases or acids in the industries. Processes in which acids play a very important role are acid pickling, industrial acid cleaning, cleaning of oil refinery equipment, oil well acidizing and acid descaling (Farina et al., 2004). The exposures can be severe to the properties of the metals and thus lead to sudden failure of materials in service. There is therefore the need to study the corrosion behaviour of metals when

exposed to various environments, as this is an important factor in material selection that determines the service life of the material.

Mild steel and high carbon steels are classified as ferrous metals (they contain a large percentage of iron). Carbon steels are essentially iron-carbon alloys. They are sometimes subdivided by the broad range of carbon content, which include: (a) mild or low carbon steel (0.08 – 0.30% carbon) (b) medium carbon steel (0.3 – 0.5% carbon) and (c) high carbon steel (0.55 – 1.40 carbon).

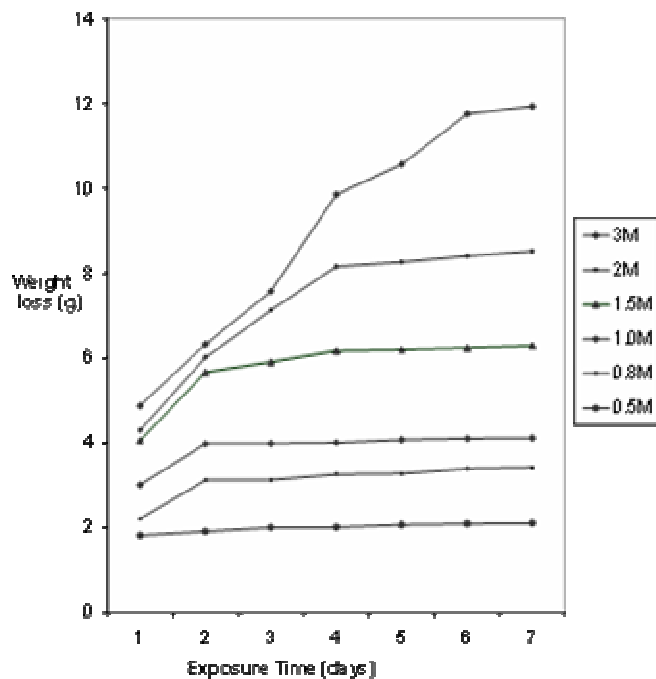
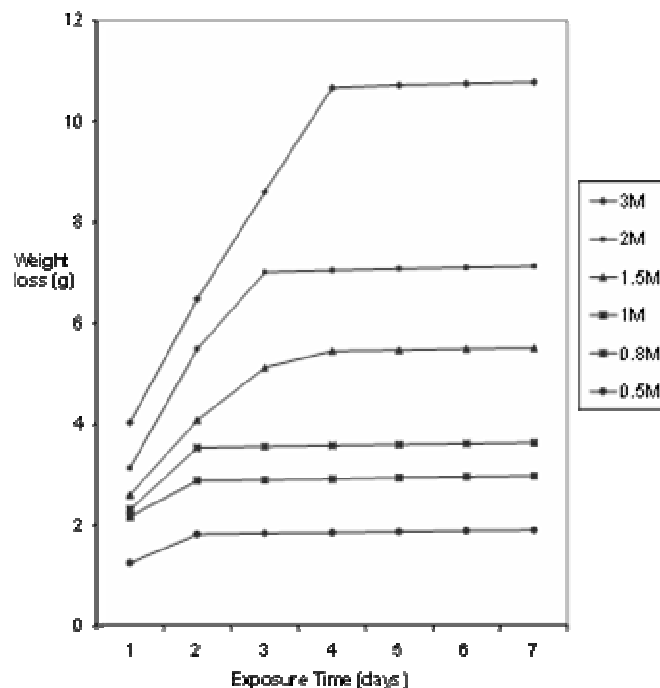
For many years, mild steel plates and rod-sections have been used as structural members in bridges, buildings, pipelines, heavy vehicles, in welded plate form for the construction of ships storage vessels and numerous other applications (Osarolube, 1998; Clark and Varney, 1987). High carbon steel (having a higher carbon content than mild steel) is harder and stronger, and yet least ductile of all the carbon steels. It is mainly used for the manufacture of metal cutting tools like hammers, saws, forging die blocks, axes, knives, drills and wood.

This work examines the corrosion behaviour of mild steel and high carbon steel when exposed to various concentrations of nitric acid, hydrochloric acid, and perchloric acid. The corrosion rates in these media are also calculated to study their stability when similar industrial environments are encountered.

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Table 1. Chemical compositions of mild steel and high carbon steel samples.

Material	Compositions, wt (%)								
	C	Si	Mn	P	S	Cu	N	Cr	Fe
Mild steel	0.14	0.18	0.48	0.017	0.005	0.03	0.007	0.79	Bal.
High carbon steel	0.70	0.18	0.50	0.017	0.005	0.03	0.007	16.5	Bal.

**Figure 1.** Variation of weight loss (g) with time (days) for mild steel in different concentrations of HCl solution.**Figure 2.** Variation of weight loss (g) with time (days) for mild steel in different concentrations of HClO₄ solution.

EXPERIMENTAL PROCEDURES

Material preparation

The materials used for this work are mild steel and high carbon steel obtained from the mechanical workshop of the University of Science and Technology, Rivers State, Nigeria. The chemical compositions of these materials are as shown in Table 1. The mild steel sheet of 1 mm thickness was mechanically press-cut into 5 × 5 cm coupons while the high carbon steel strips of same thickness were press-cut into 5 × 2.5 cm. The preparation of the coupons is described in detail as reported previously (Osarolube et al., 2004; Abiola and Oforika; 2005; Oforika et al., 2005).

Nitric acid, hydrochloric acid, and perchloric acid solutions were prepared to the following molarities using standard procedures (Dosunmu and Alaka, 1992; Martiez and Stern, 2002; Oforika et al., 2005): 0.5, 0.8, 1.0, 1.5, 2.0, and 3.0 M, for mild steel; and 0.3, 0.5, 0.8, 1.0, 1.5, and 2.0 M for high carbon steel. All reagents were of analar grade and distilled water was used for the preparation of all solutions. Six sets of experiments were performed. Each set consisting of 42 x 250 ml beakers.

Weight loss measurements

Previously weighed coupons were immersed in beakers containing

200 ml of test solutions maintained at room temperature. The coupons were retrieved at 24 h intervals progressively for 168 h (7 days). The difference in weight was noted as the weight loss in grams. The procedure for weight loss determination was similar to that reported previously (Osarolube et al., 2004; Abiola and Oforika, 2005).

RESULTS AND DISCUSSIONS

Mild steel and high carbon steel were found to corrode in different concentrations of HNO₃, HCl, and HClO₄ solutions. This was evidenced by the decrease in the original weight of the metal coupons. HNO₃ was found to be more corrosive, followed by HClO₄ and lastly HCl. The findings are shown in Figures 1 - 6. The corrosion of mild and high carbon steels in HCl, HNO₃ and HClO₄ solutions are attributed to the presence of water, air, and H⁺ which accelerated the corrosion process. The figures also reveal that the weight loss of both steel samples increased with time and concentration. This observation is attributable to the fact that the rate of a chemical reaction increases with increasing concentration (Ita and Offiong,

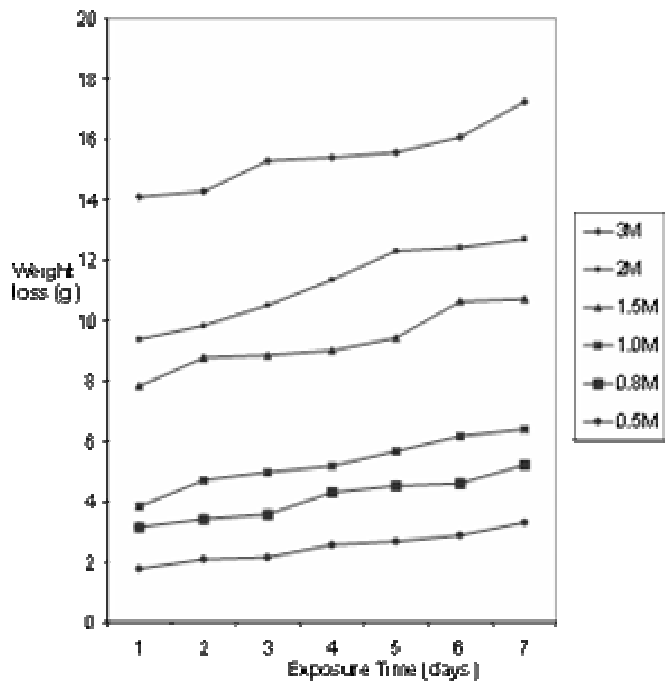


Figure 3. Variation of weight loss (g) with time (days) for mild steel in different concentrations of HNO₃ solution.

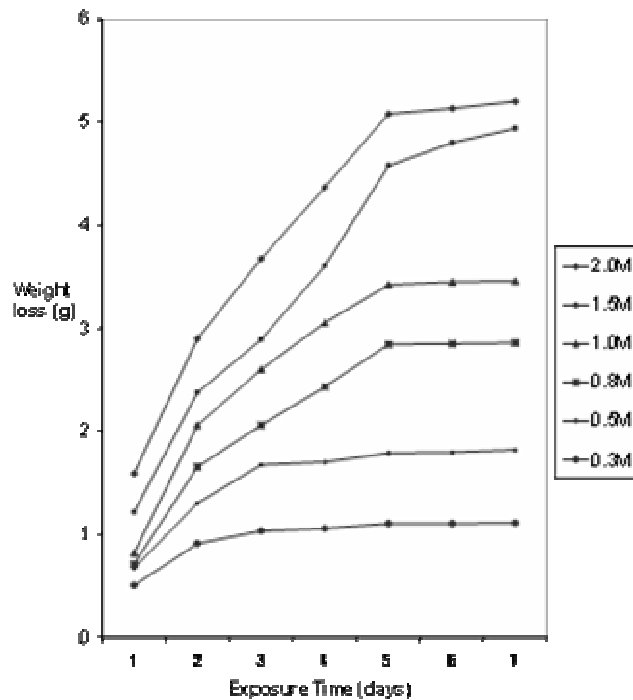


Figure 5. Variation of weight loss (g) with time (days) for high carbon steel in different concentrations of HClO₄ solution.

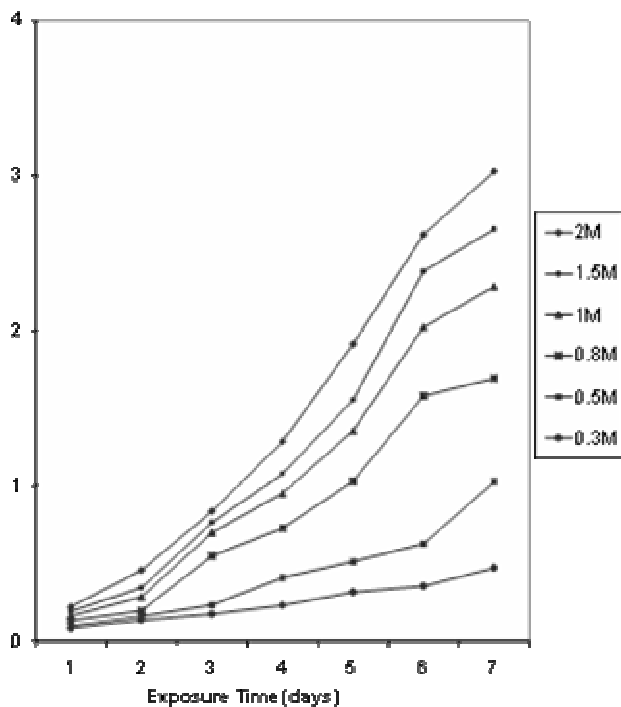


Figure 4. Variation of weight loss (g) with time (days) for high carbon steel in different concentrations of HCl solution.

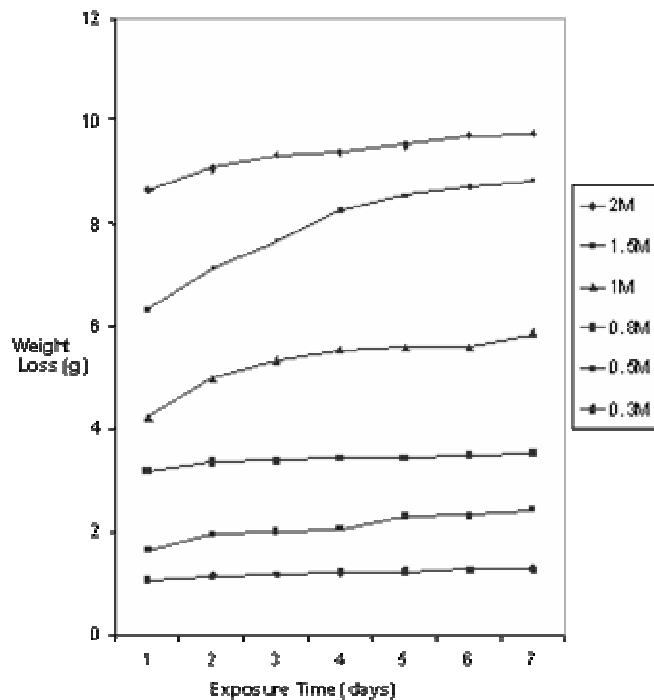


Figure 6. Variation of weight loss (g) with time (days) for high carbon steel in different concentrations of HNO₃ solution.

1997; Onuchukwu and Trasatti, 1994). It is also seen from the figures that the corrosion of mild and high car-

bon steels in the different acidic media was not a simple homogeneous process, but a heterogeneous one. It con-

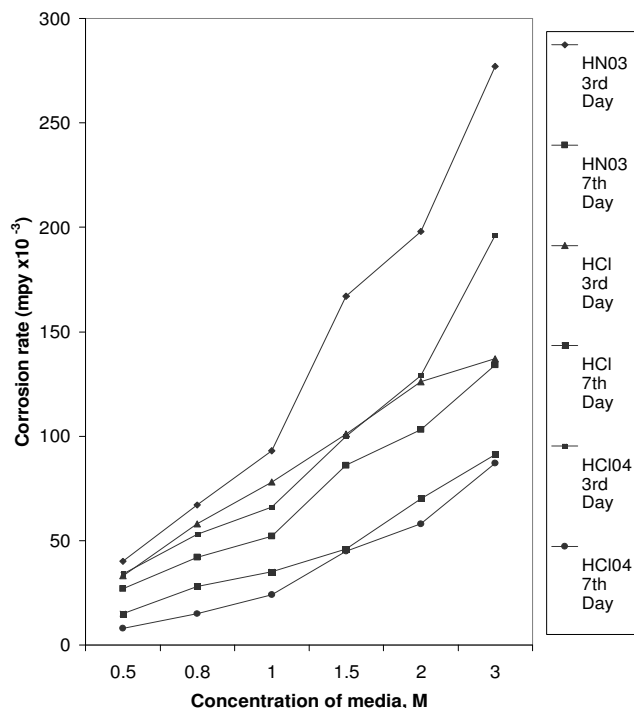


Figure 7. Corrosion of mild steel in different concentrations of HNO₃, HCl and HClO₄.

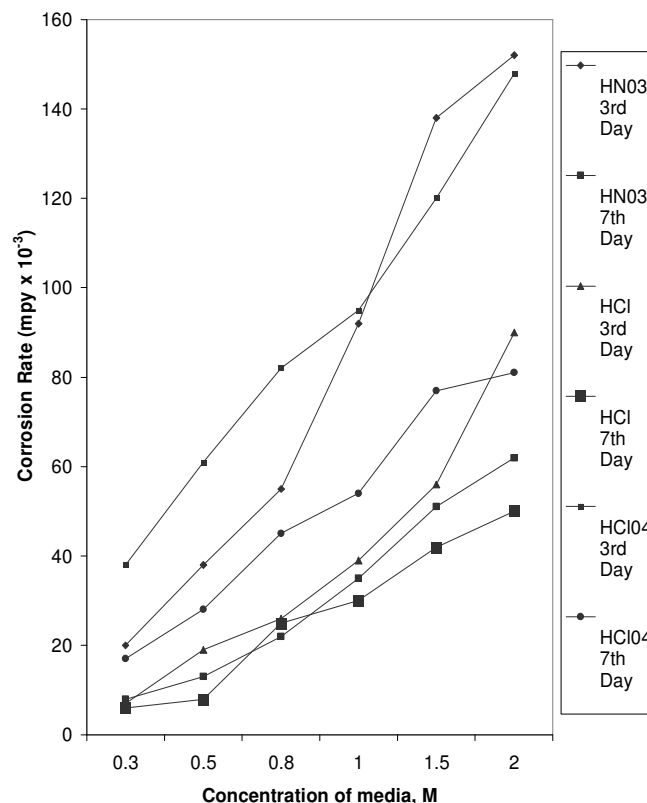


Figure 8. Corrosion of high carbon steel in different concentrations of HNO₃, HCl and HClO₄.

sists of intermediate steps as revealed by the non-uniformity of the plots.

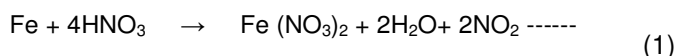
In Figures 7 and 8, a presentation of the corrosion rates of mild steel and high carbon steel has been given respectively in these media after the 3rd and 7th day of exposure. The corrosion rates of the samples immersed in the various environments were determined using the standard mathematical relation (Fontana, 1987; Wranglen, 1985; Vernon, 1992).

Corrosion rate (mpy) = 534w/pAT

Where w = weight loss in mg, ρ = density in g/cm³, A = total surface in cm², T = exposure time in h, and mpy = ml per year. The measured densities of materials used for the study are 7.87 and 7.82 g/cm³ respectively for mild steel and high carbon steel. Figures 7 and 8 show that the corrosion rate is highest in the nitric acid medium, followed by perchloric acid and lastly, hydrochloric acid. The corrosion attack in nitric acid is very significant because nitric acid is known to be a strong oxidizing agent. An autocatalytic mechanism has generally been proposed to explain the high rate of corrosion in this medium (El Ald Haleem et al., 1980; Slabaugh and Parsons, 1976).

The primary displacement of H⁺ ions from the solutions is followed by HNO₃ reduction rather than hydrogen evolution since the acid reduction leads to a marked decrease in free energy. The reaction can be summa-

rized as follows:



This reaction leads to the evolution of nitrogen (II) oxide and production of Fe(NO₃)₂ which led to further coloration of the medium. Corrosion of mild steel in all the acidic media was found to be higher than that of high carbon steel. This result is in agreement with the fact that carbon content in itself has little if any effect on general corrosion resistance of steels (Scully, 1978; Van Delinder, 1984; Ovri, 1998).

Figures 7 and 8 which give the corrosion rates of the coupons after the 3rd and 7th days reveal that dissolution of the metals is faster within the first three days, and then gradually slows down as a result of the formation of passivating corrosion complexes that normally shield the metal surface from the media. The observed trend in the corrosion behaviour of these steels is significant in that the more the material is exposed to the environment, the lower the corrosion rate. This behaviour could be explained from the concept of passivity and the decrease in the strength of the acid as corrosion complexes get formed in the media (Idenyi et al., 2004; Ita and Offiong, 2001; Uhlig and Review, 1985).

Conclusion

The results from this work have clearly shown the following:

- Corrosion of mild steel and high carbon steel is significant in varying concentrations of nitric acid, hydrochloric acid, and perchloric acid; nitric acid being most corrosive, followed by perchloric acid, and lastly, hydrochloric acid.
- The concept of passivity was proposed as the mechanism of corrosion resistance for mild steel and high carbon steel with increase in exposure time for the environments investigated.
- The corrosion rates obtained for mild steel support the fact that carbon content in itself has little if any effect on the general corrosion resistance of steels, as they were higher than that of high carbon steel.

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