

Corrosion of Oil and Gas Pipelines in some selected oil prospecting Environments in Nigeria

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Abstract: Oil and gas transportation pipelines usually pass through many environments from the point of production to refinery and distribution. Most of these environments are aggressive towards the pipeline materials and often lead to corrosion, and eventual failure of the facilities in service. This paper investigates the effects of different environments on the corrosion behaviors of paint coated and uncoated samples of mild steel used for oil and gas transportation pipelines using weight loss method. The results obtained showed that corrosion effect was higher in the diluted acidic environment and apparently more noticeable in the uncoated samples compared to the coated samples. Hence the authors recommend that coating of pipeline steels with paint will assist in lowering the corrosion rates of mild steels used as oil and gas transportation pipelines.

Keywords: Corrosion; Coated and uncoated pipeline; Mild steel; Environment; Corrosion rate

1 INTRODUCTION

It was recognized that the majority of pipelines deterioration or failure was caused by corrosion which is mainly initiated by the ingress of chloride ions from deicing salts. The corrosion of pipelines has historically been of significant cost to the oil and gas industries at large. The rust formation from the corroding pipeline steel results in bond deterioration between the steel and the fluid being transported. In the past, several solutions, both rehabilitative and preventive, were developed to reducing corrosion damages in pipelines.

The overall study of corrosion and its prevention cannot be over-emphasized as though it has induced a marginal relevance engagement in the field of engineering. This has led to problems of great interests in the engineering industries like oil production and refining, construction industries, marine industries, offshore industries and power plant industries. Many producers and end users of such engineering material would rather find it difficult to survive a day to day operational activity without the knowledge of corrosion and its prevention. The mechanical properties of a metal experience a severe degradation due to corrosion.

MMFX steel has a high corrosion resistance as a result of the patented and proprietary steel microstructure that is formed during its production [1]. This unique physical feature minimizes the formation of micro galvanic cells in the steel structure, thereby minimizing corrosion initiation. MMFX's steels are highly corrosion resistant

and are equal or better than existing steels in their mechanical properties (yield strength, energy absorption, toughness, brittleness, ductility, weldability, hardness and formability).

An increasing number of offshore developments are based on transporting unprocessed or partially processed multiphase well streams from satellite wells to main platforms, existing installations on neighbouring fields or onshore processing facilities. Corrosion, scale formation and salt accumulation represent increasing challenges for the operation of subsea multiphase pipelines. Corrosion-resistant alloys such as 13% Cr steel and duplex stainless steel are often used for downhole and, recently, also for short flowlines. Carbon steel is the only economically feasible alternative for long-distance, large-diameter pipelines, and corrosion has to be controlled by chemical additives to the transported fluids. The pipeline costs are a considerable part of the investment in subsea projects, and for long-distance, large-diameter pipelines, can become prohibitively high if the corrosivity of the fluid necessitates the use of corrosion-resistant alloys instead of carbon steel. Better understanding and control of the corrosion of carbon steel can increase its application range and therefore have a large economic impact.

There are several remedial methods that can be used in the rehabilitation of existing pipeline structures that are damaged by corrosion due to chloride ingress or carbonation. Based on the nature of repair procedures, the rehabilitation methods can be classified into two types, i.e., conventional and unconventional rehabilitation

methods. Conventional rehabilitation methods are carried out by providing barrier on the surface of damaged pipeline to protect them from further ingress of chloride ions, moisture, and oxygen. There are several rehabilitation methods available [2-4], which can be grouped as two categories: Removal of distressed pipe component and without the pipe removal. In the first category, portions of the pipe section need to be removed. This type of repair method for corrosion damage should be used when significant amounts of pipe have cracked and repairs are necessary for safety considerations or continuity of operations. In the second category, no pipe removal is performed; overlay membranes and sealers are applied on the surface of the pipe. This type of repair method for corrosion damage should be used, for instance, on pipeline structures in harsh environments, either as an initial treatment or when the structure has been exposed for some time to the environment, but no significant distress has occurred.

Membranes and sealers help prevent further ingress of chloride ions. Some examples of preventive membranes are urethanes, neoprenes, and epoxies. They are usually applied in multiple layers and have the ability to bridge cracks in concrete. Since there are many different products, the performance of these methods can vary significantly [5-7]. Some products are solvent based, which may not be suitable for some areas. Most sealers are not suitable for sites where abrasion occurs. It also should be noted that the effectiveness of these methods decreases over time. Thus, they must be reapplied after a certain period. The length of the period varies, and it depends on the performance of the membranes.

The cases of significant external corrosion of offshore pipelines are extremely rare [8,9]. This is due to homogeneity of the offshore environment and the predictability of coating and cathodic protection [10-12]. Although, the offshore environment is very uniform in composition, and has high conductivity, thus enabling the uniform and consequently effective application of cathodic protection. However, the alkaline environment produced by the cathodic protection causes calcareous deposits (magnesium carbonate) to precipitate at the coating holidays (Holes), essentially plugging the holidays and separating the steel from the water. The failures that usually occur on the offshore pipelines are peculiar to the riser due to corrosion. And this is however caused by the consistent wetting and drying in the splash zone (S_2). Therefore, risers usually fail often, but the

failure is rarely severe and downtime is usually minimal compared with onshore pipeline failure caused by corrosion.

Coatings are needed to reduce the amount of exposed area as much as possible. Although, coatings on the other hand, would alone be totally ineffective as it is impossible to produce a perfect coating over the entire pipeline. This is usually due to the fact that coatings would damage during the construction and probably degrade over time. Therefore, cathodic protection in turns needed to prevent corrosion at the breaks (i.e. holidays) in the coating. This project primarily focuses on “the investigation of environmental effects on corrosion rate of oil and gas pipelines of coated and uncoated pipe with a view to determining the aggressiveness of these environments and the effectiveness or otherwise of paint coatings on pipeline.

2 MATERIALS AND METHODS

Samples of coated and uncoated mild steel used for oil and gas pipeline were obtained from Pipeline and Product Marketing Company (PPMC) Nigeria, National Petroleum Corporation Mosimi, Sagamu Ogun State in Nigeria. The samples were cut into ~~4mm~~ x 4 mm specimens and weighed on an electronic weighing machine. Four holes were dug two meters each of two marshy grounds, and the other two brown sandy grounds in Warri, Delta State Nigeria which is an oil prospecting environments. The paint Coated and uncoated specimens were buried in the first two holes (marshy grounds), while another coated and uncoated were also buried in the third and the fourth holes (brown sandy) respectively. Other samples were immersed in: salt water (NaCl), dilute sulphuric acid (H_2SO_4), swamp soil, and pure water. The specimens were removed and weighed at intervals of ten days for a period of sixty days. This was done by cleaning the specimens with tap water and dried using laboratory hand dryer before taking the weight. The weight loss for all the samples were calculated and used for the computation of the corrosion rates.

3 RESULTS AND DISCUSSION

The spectrometry analysis of the pipeline material shown in Table 1 indicates that the pipeline steel is a low carbon steel with high Manganese content sufficient for good workability into the pipeline shape. The chromium and nickel contents are low; hence the material may not be totally passive to the aggressiveness of the environment. This is evident in the corrosion tests results shown in Figures 1-6. In all the plots, both the coated and uncoated samples corrode progressively in all the environments with the highest corrosion rates experienced by the uncoated. Paint coatings will therefore extend the life of the material in any environment. Figures 7 and 8 showed the corrosion behaviors of the steel samples in soils and liquid environments. Dilute acid has the greatest aggression on the steel followed by marshy soil while the fresh water had least corrosion rate. This suggests that active corrosion agents such as chlorides ions can be in either forms of the environment. Figures 11 and 12 give comparisons of the corrosion rates of the coated and uncoated samples in all the environments, respectively. In the salt water sample (Figure 1), there is no obvious corrosion during the first ten days (240 hours) of exposure on both coated and uncoated specimen. Corrosion was found on the uncoated sample by the fifteenth day (480 hours) of setting up the experiment. Thus, corrosion was seen to be higher on the uncoated sample than the coated sample throughout the rest of the days of the experiment in salt water environment. On initiation, the rate of corrosion in both coated and uncoated samples exposed in salt water kept increasing with days.

However, in Figure 2, the corrosion rate samples immersed in dilute acid initiated earlier on the uncoated sample than any other uncoated samples used in the different medium of exposure. This is due to the aggressiveness of chloride ions on the steel which is higher than those of others. The margin difference between corrosion rates in the coated and uncoated samples are far apart. Corrosion rates on the uncoated samples are more than fifty percent greater than the corrosion rates found on the coated samples at different days. The rates of corrosion on the coated samples are very small and the increments with days are not significant.

In a similar vein, the corrosion rates on the specimen buried in swampy soil started after two days (48 hours) on the uncoated sample and after four days (96 hours) on the

coated sample. From Figure 3, after initiation, the rate of corrosion rate rose after fifty days and fall a little between the tenth and twentieth. Whereas on the coated sample, the rate of corrosion initiation at the fifth day and made appreciable increase. As the rate of corrosion falls between the fifth and the twenty fifth day and maintain constant increasing for the rest of the days of exposure of uncoated steel in dilute acid while, the coated steel corrosion rate increases from the initiation day till the fortieth day before falling gradually to the last day. The corrosion rate graph becomes sinusoidal after the thirtieth day of exposure while the uncoated sample remains on the constant increase rate except at the initial stages before thirty days.

Deterioration of the steels samples immersed in swampy soil started on the uncoated steel by the fifth day and fifteenth day on the coated steel. For the uncoated steel (Figure 3) the corrosion rate increased constantly from onset through the end, but on the coated steel, the corrosion rate increased from initiation up to the fifty-fiftieth day and fell sinusoidally.

Considering the samples immersed in fresh water, degradation of the uncoated and the coated steels started by the tenth and twentieth day respectively (Figure 4). On initiation of degradation, the rate of corrosion on the uncoated steel fell a bit for fifteen days before it started increasing till the last day. Even though the degradation of the coated steel sample commenced by the twentieth day of the experiment, the corrosion rate kept, forming almost a straight line, until the fourth-fifth day when the rate of corrosion fell gradually.

In Figure 5, the deterioration in the steel samples exposed to brown sandy soil started by the tenth day on the uncoated steel and it rose to maximum by the twentieth day thereafter, it started falling gradually. Similarly, degradation commenced on the coated steel after thirtieth day of exposure. It increases at a constant manner, forming a straight line until the fiftieth day before it started falling constantly forming a straight line as well.

After the corrosion initiation by the tenth and twentieth day on the uncoated and coated steels respectively (Figure 6), the corrosion rate in both samples behaves alike as they increases almost at the same proportion, maintaining constant corrosion rate difference from the twentieth day

through the fiftieth day before that of the coated steel broke out and started decreasing whereas the corrosion rate of the uncoated steel kept increasing forming a gradient line.

In this experiment, the coated samples exposed to the soil (Brown sandy and Marshy) have similar behavior (Figure 7). It was observed that corrosion commenced on the steel sample exposed on Marshy soil by the twentieth day and on the Brown soil by the thirtieth day. The rate of corrosion in both Brown sand and Marshy soil behaved much alike by increasing at the same pace, hitting their peak at the same day and started falling in the same day, all at equal proportion.

Besides, the uncoated samples exposed in soil environment exhibited similar characteristics from the beginning, initiated steel degradation at the same tenth day of exposure and the rate of corrosion increased almost at the same proportion up till the twentieth day when there was sporadic deviations obvious in the opposite features exhibited. As the corrosion rate of the uncoated sample in Marshy soil increases till the end, the rate of corrosion on the uncoated sample started decreasing gradually till the last experimental day.

Among all the samples exposed in liquid /wet environment (Figure 9), the coated specimen immersed in acid reacts more vigorously, thereby giving way for corrosion. This sample is followed by the coated specimen exposed in swampy soil. Both coated and uncoated specimen examined in salt water and fresh water exhibited similar characteristics from onset up till the fourth-fiftieth day, when the corrosion rate in the coated sample started decreasing, appearing in a sinusoidal way, while the coated salt water sample kept increasing throughout the experimental days.

Moreover, all the uncoated samples examined in a liquid/wet environment (Figure 10) showed closer features as the corresponding coated counterparts. The

uncoated specimen exposed in dilute acid recorded the highest corrosion rate all through the experiment, followed by the uncoated specimen studied under swampy soil. The major distinction is seen in the uncoated specimen examined in salt water and fresh water in this case, the difference which lies in their characteristics is found between the first day and the twenty-fifth day of exposure and in the later days of the experiment

In comparison, corrosion rate variations across all the coated samples studied in corrosive environment could be found to be more in coated sample exposed to acid medium, which also degraded earlier than the other coated samples studied in other medium. The coated samples studied in swampy soil and fresh water has analogous trend pattern but there was a small difference in the rate of corrosion. The coated sample in fresh water behaved much like that of salt water from the start up till the forty-five days of exposure, while it continued to maintain an increase in corrosion rate, the salt water sample started falling to form a gradient line. Both coated samples exposed in brown sandy soil marshy soil behaved much alike from the beginning through the end of the experiment.

In a like manner, Figure 12 provides the corrosion rate variations across all the uncoated samples examined in an environment prone to degradation with the uncoated samples immersed in dilute acid recording the highest corrosion occurrence. In this group, corrosion initiated the same day of expose in all the samples tested. The swampy soil coated specimen is next to acid sample in corrosion rating, though the uncoated sample in the swampy soil, fresh water and salt water behaved similarly from the first day of exposure up to the twentieth day before the rate of corrosion in swampy soil rose up whereas, the salt water and fresh water samples maintained closer characteristics till the end. The uncoated samples studied in the brown sandy soil and marshy soil had very related features right from the first day of exposure till the end of the experiment.

Table 1: Spectrometry Analysis of the Mild Steel Sample

Steel Quality	C	W	As	Sn	Co	Al	Pb	Zn	Fe
ST 44-2	0.1828	0.0017	0.0011	0.0030	0.0024	0.0123	0.0005	0.0033	98.8619%

Si	S	P	Mn	Ni	Cr	Mo	V	Cu
0.1366	0.2187	0.0171	0.6892	0.0192	0.0118	0.0010	0.0005	0.0065

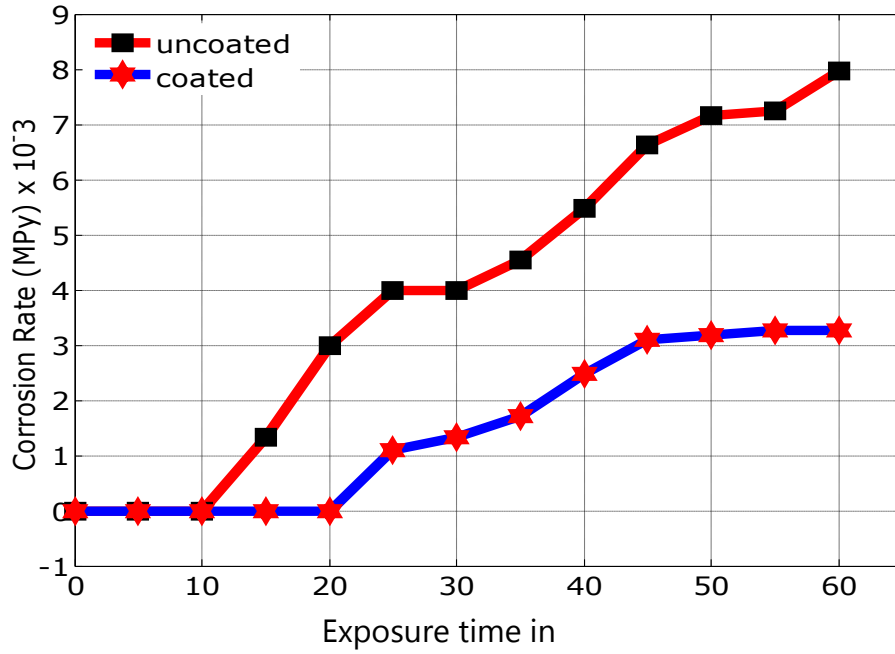
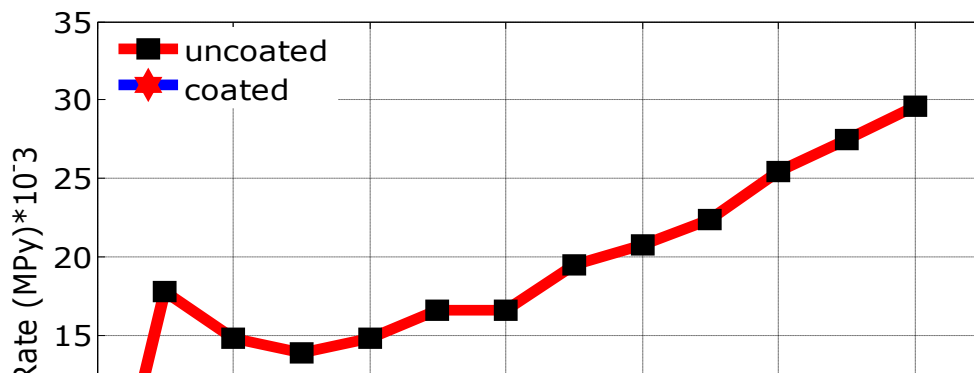


Figure 1- Corrosion rate variations against time for samples exposed in Salt water



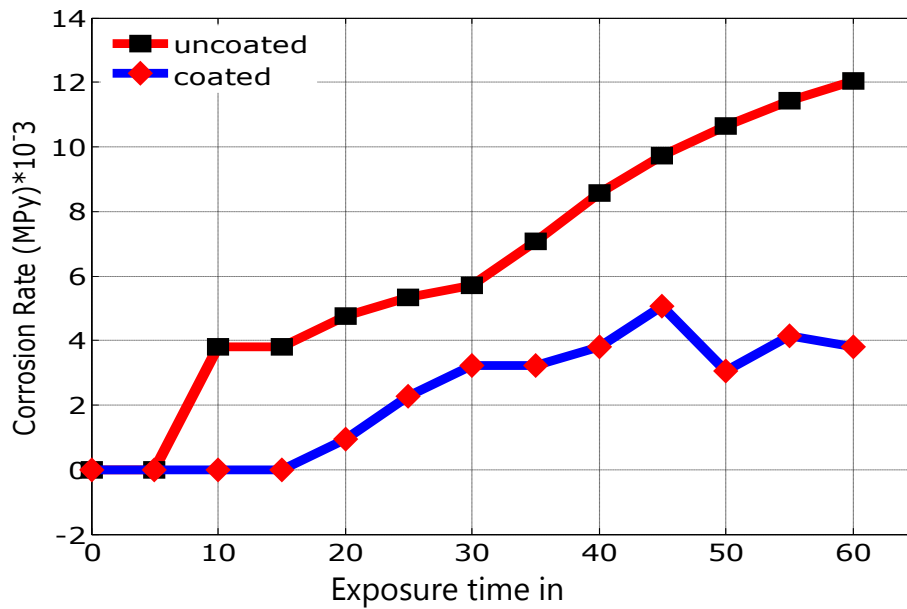


Figure 3 - Corrosion rate variations against time for samples exposed in swampy soil

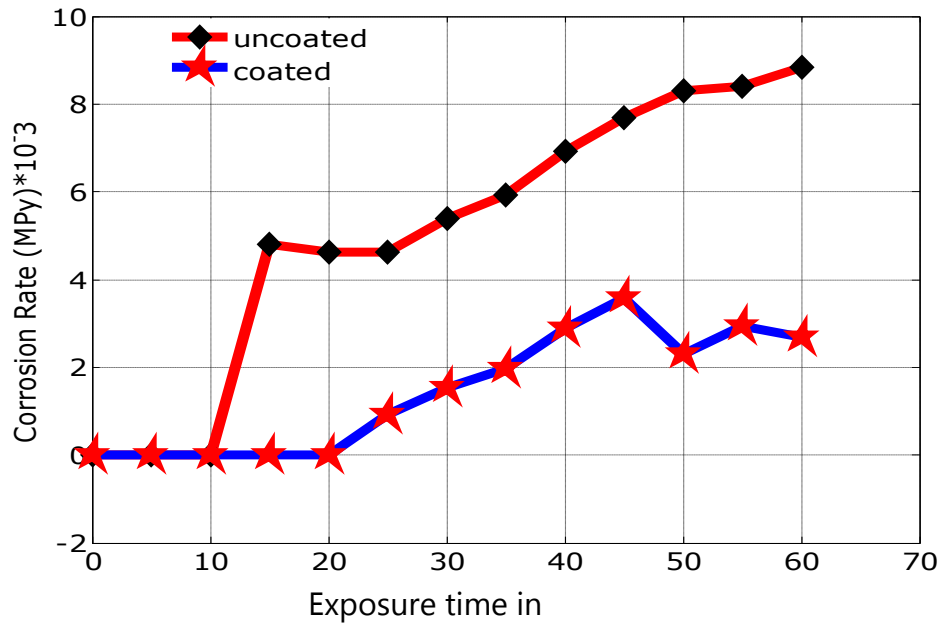


Figure 4 - Corrosion rate variations against time for samples exposed in fresh water

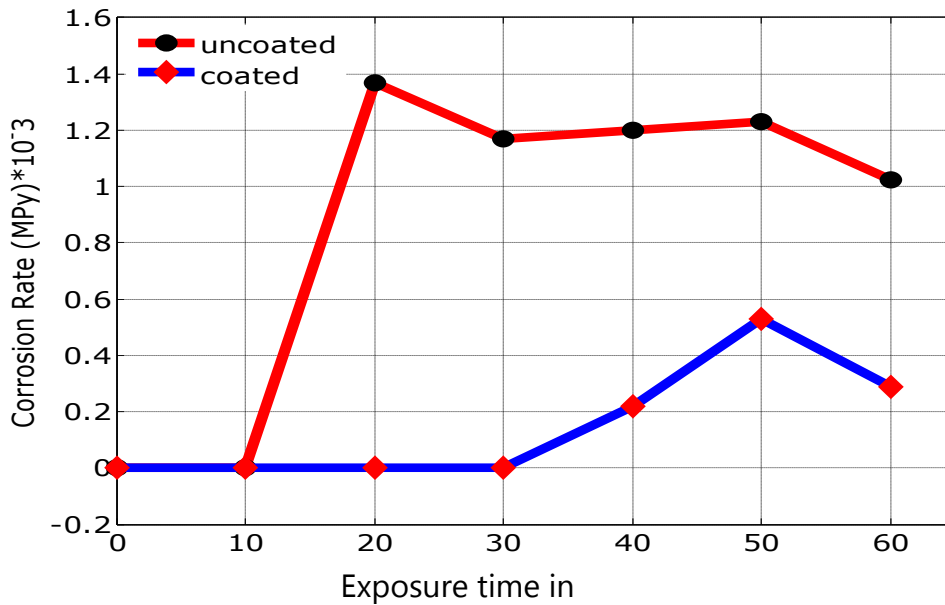


Figure 5 - Corrosion rate variations against time for samples exposed in brown sandy soil

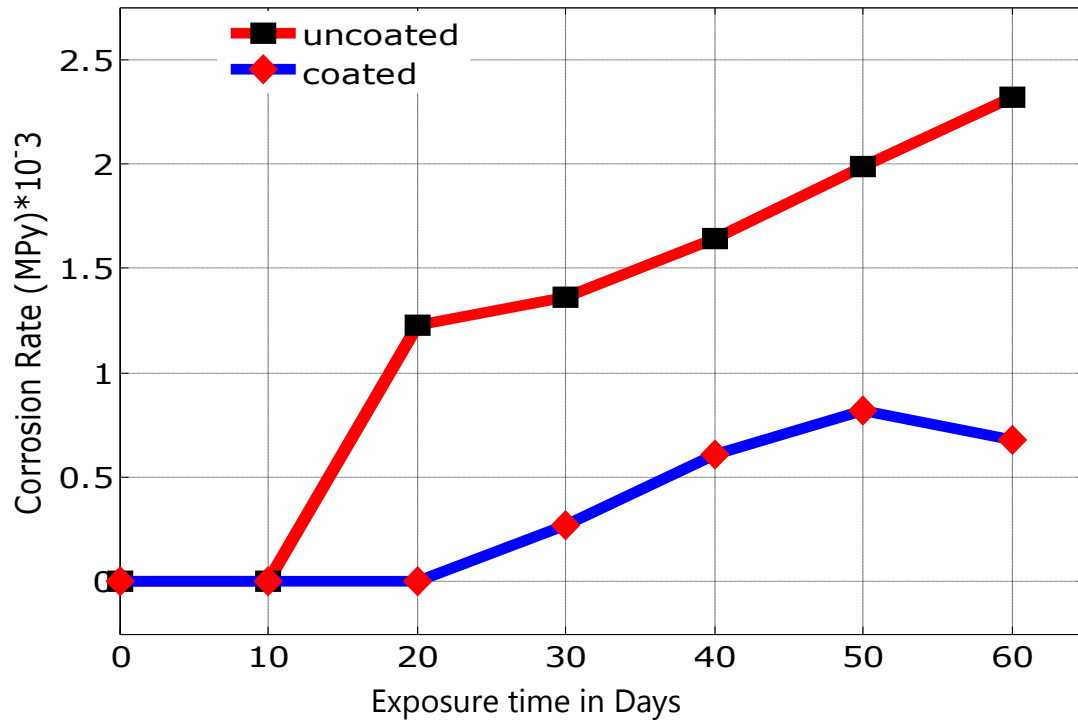


Figure 6 - Corrosion rate variations against time for samples exposed in marshy soil

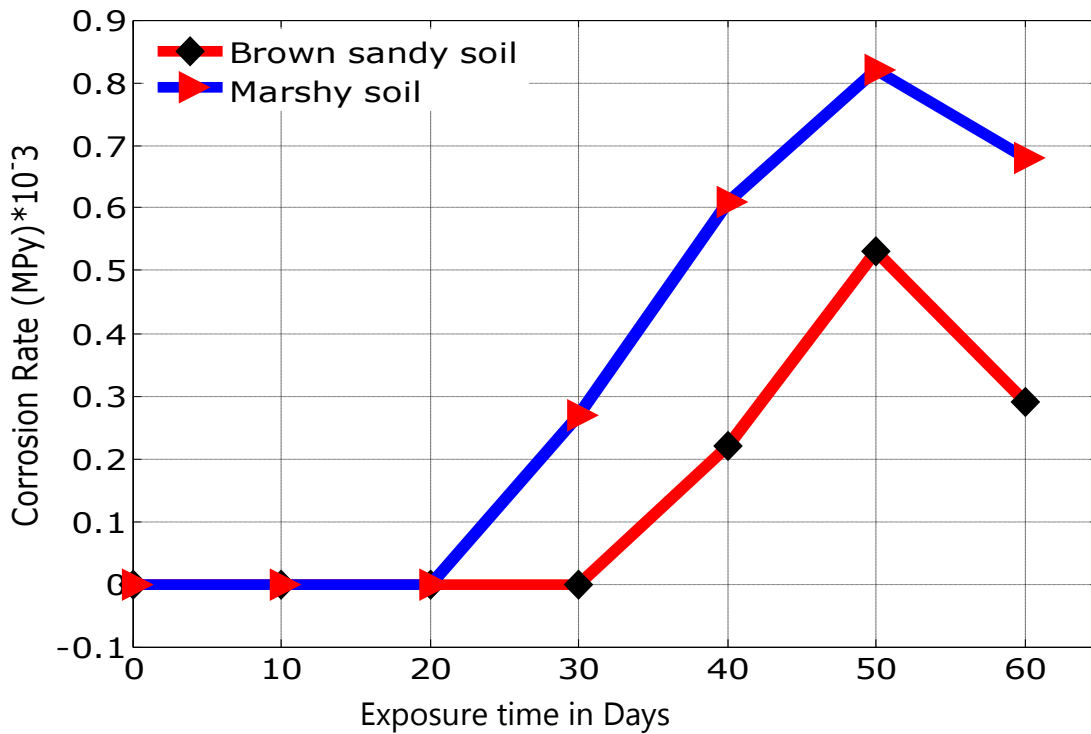


Figure 7 - Corrosion rate variations against time for coated samples exposed in soil

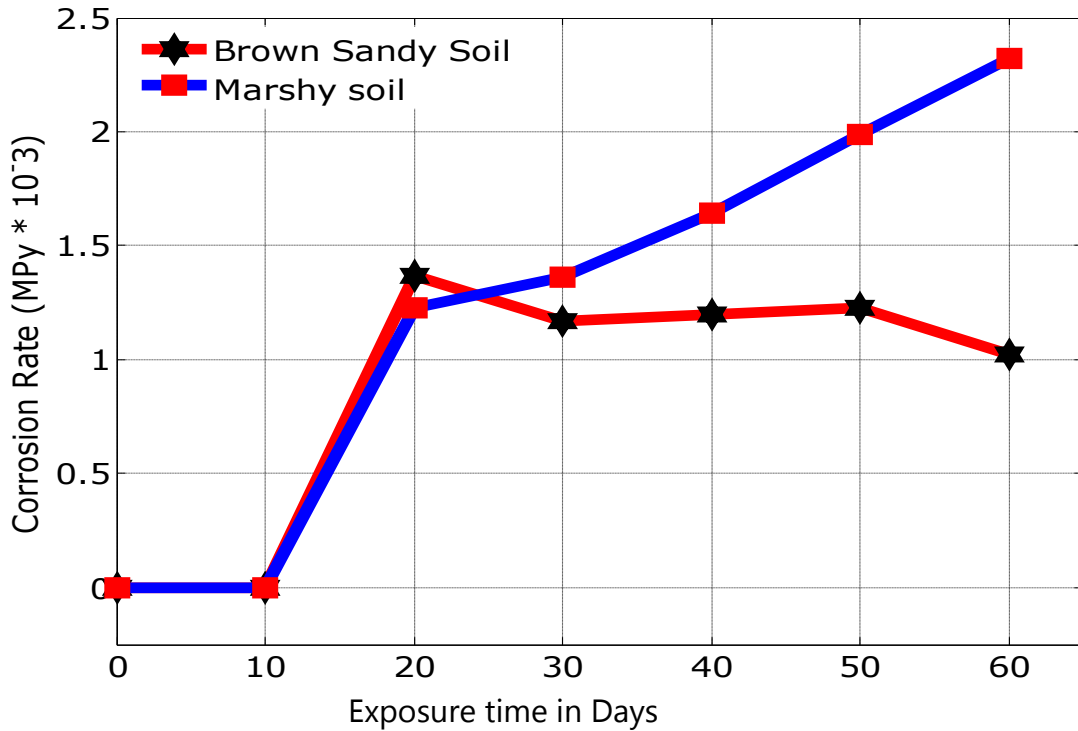


Figure 8 - Corrosion rate variations against time for uncoated samples exposed in soil environment

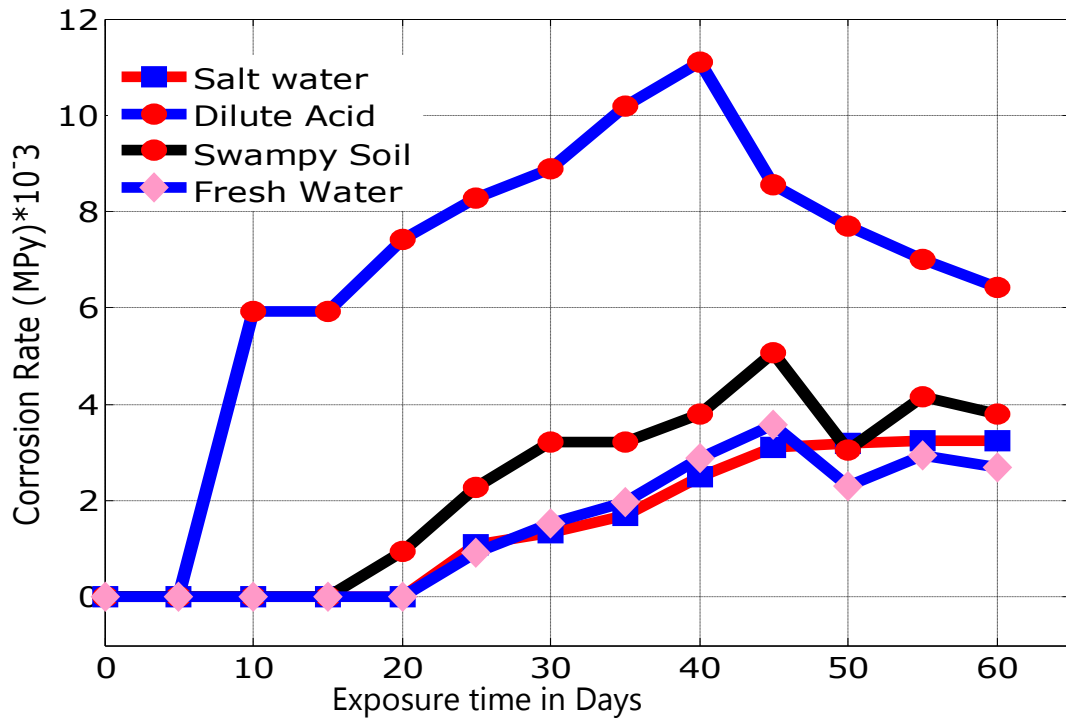


Figure 9 - Corrosion rate variations against time for coated samples exposed in liquid environments

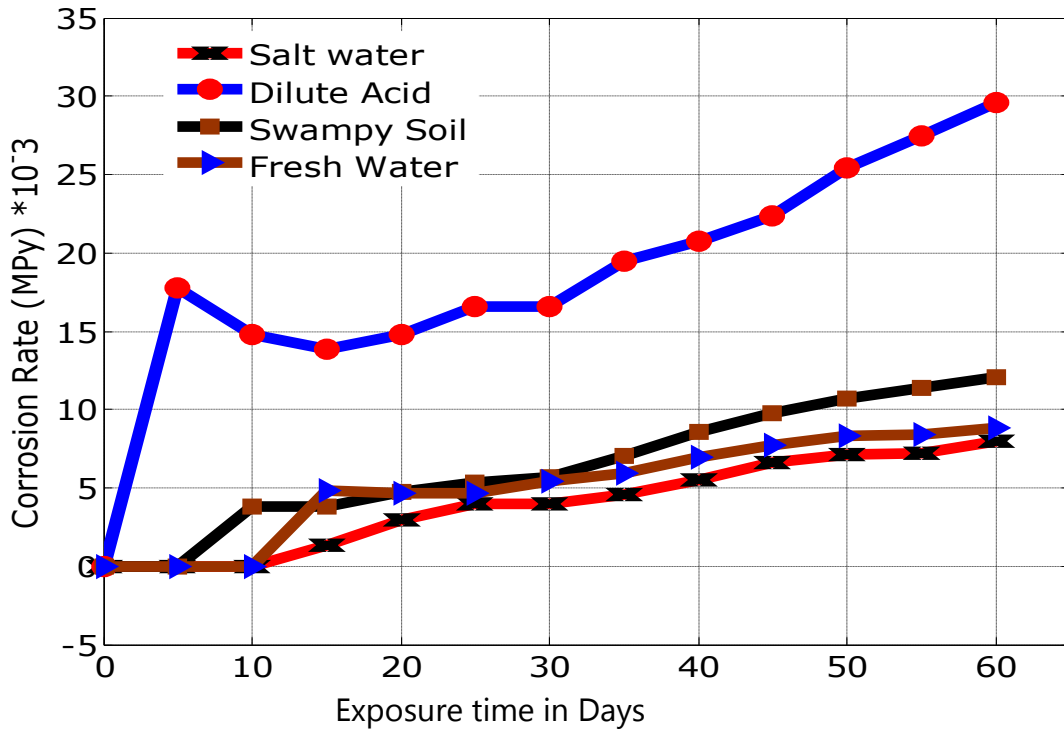


Figure 10 - Corrosion rate variations against time for uncoated samples exposed in liquid environment

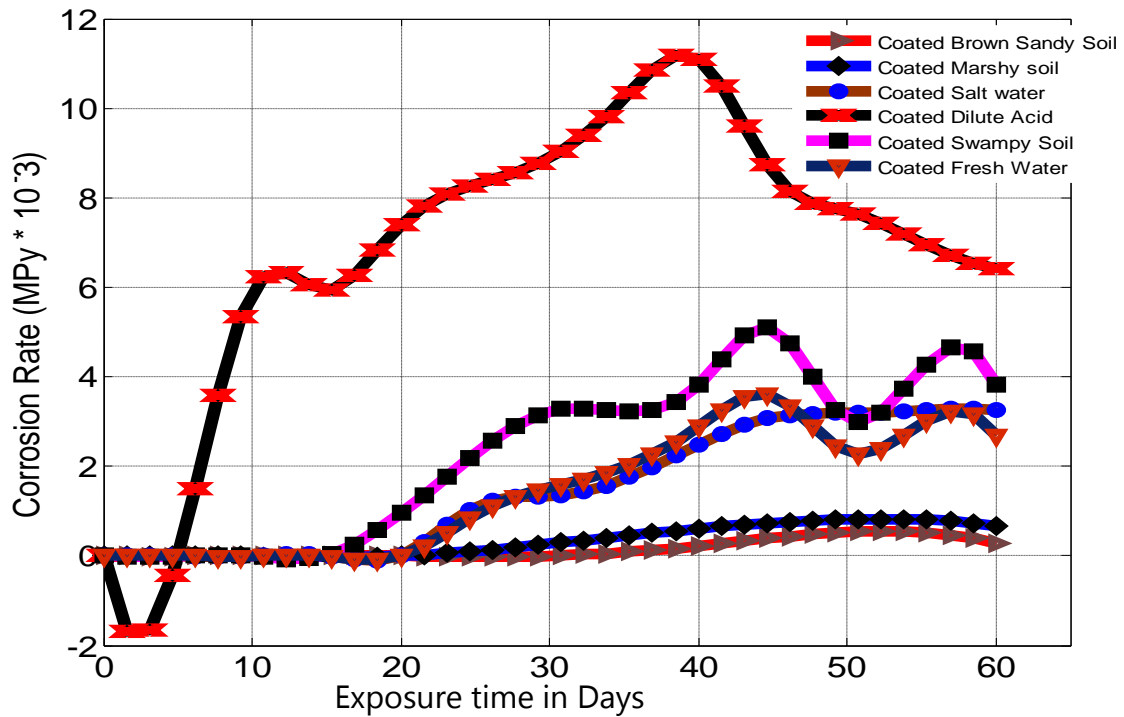


Figure 11 - Corrosion rate variations against time for coated samples exposed in the environment

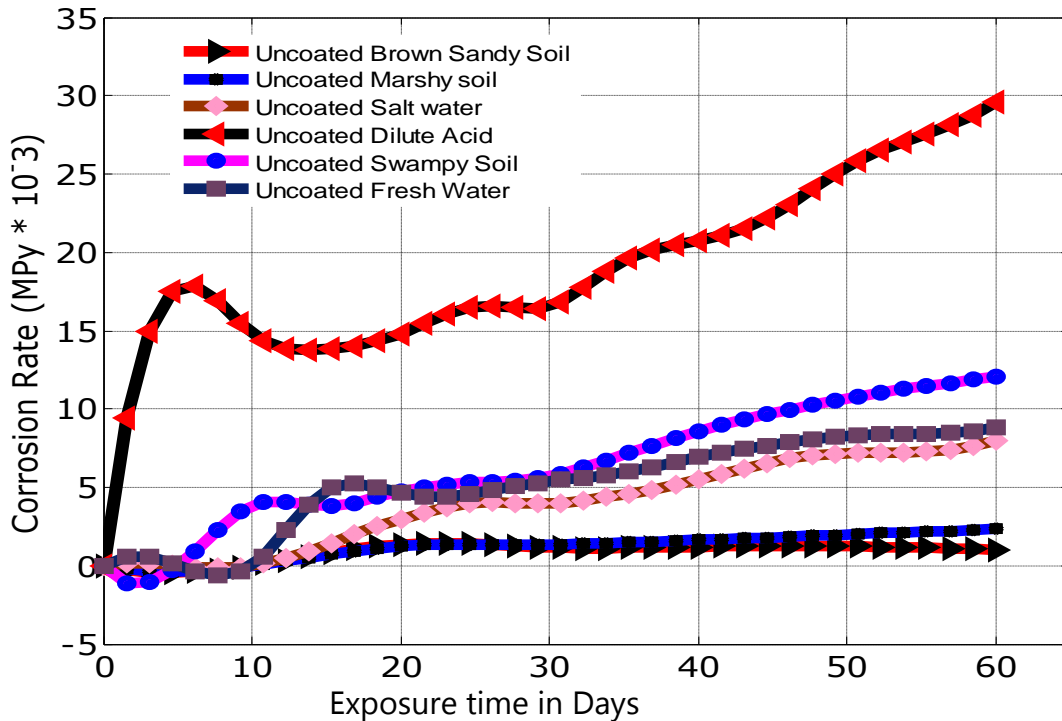


Figure 12 - Corrosion rate variations against time for uncoated samples exposed in all the environment

4 Conclusion

The results obtained in this study shown that:

1. Degradation rate in steel is highest in wet environment, as a result it deteriorates corrosion.
2. Acidic environment reacts more vigorously with steel whether coated or uncoated.
3. Most of the coated samples experienced increment in corrosion rate after thirty-five days of exposure.
4. Paint coated samples possess low corrosion rates than the uncoated samples.
5. Steel samples immersed in fresh water experienced the least corrosion degradation.

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