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Prediction of corrosion rate of steel AP5LX using curve fitting method

The corrosion rates of carbon steel in petroleum product and water mixture were estimated by different methodologies viz stirring test, flow loop test and rotating cage test for evaluating the efficiency of the methodology. Based on the data collected under these three test conditions polynomial expressions were developed relating the corrosion rate (mm/y) and the number of days (time) for finding out the corrosion rate at any time and vice versa. Corrosion rates were calculated using the developed equations and compared with the experimental data and found satisfactory. The data calculated from the developed equation reveals that there is no significant variation between the three tests when the duration of the test period is less than 60. Beyond 60 days period the corrosion rate for stirring system and rotating cage system are approximately equal, where as the corrosion rate for the flow loop system is higher than the other systems from the initial period.

Key words: *Petroleum product pipeline, Diesel/water mixtures, Corrosion, Curve fitting.*

1. INTRODUCTION

An important method of preventing corrosion failures in a chemical plant is the provision of a corrosion allowance in the thickness of materials used in the plant construction. The extent of corrosion allowance should normally be based on the anticipated corrosion rate and the required service life [1]. Corrosion rate versus time data is required to provide corrosion allowance. Generally, the corrosion allowance may be calculated from the data collected from the weight loss methods and electrochemical techniques and converting the data in to equivalent thickness loss per unit time extrapolating to the required lifetime. Oil and gas pipeline flow loops are multiphase in nature, containing oil, aqueous (brine water) and gas phases. The corrosion rate is influenced by the flow rate of the liquid, pressure and chemical factors viz chloride, sulphate and phosphate. One of the main risks of operating such pipeline is the internal corrosion, predominately, pitting and uniform corrosion. Hawn [2] used the extreme value method for external pits on pipelines, and extrapolated to 5820 times the inspected area to estimate the probability that a maximum pit size would be no greater than a certain value. Kowaka [3] gives a useful overall text to the statistical method of analysing corrosion date. Papavinasm et al [4, 5] compared some methodologies for evaluating the corrosion inhibitors by gravimetric method for oil pipeline and suggested that rotating cage test is the top ranked methodology based on the severity of the corrosion condition simulation. In the present study, three methods viz stirring test, rotating cage test and flow loop test were employed to compare the efficiency of the methodology. The prediction of corrosion rate has been carriedout by statistical analysis for corrosion of steel in diesel containing water.

Recently Porro et. al [6] proposed a bilogarithmic law relating weight losses and exposure time .Also Nicholls and Stephenson [7] have developed a coating life model on the statistical analysis of coating corrosion loss. The purpose of

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this communication is to present general polynomial expressions relating corrosion rate (mm/y) and the number of days for AP5LX steel from the sampling experimental data. This mathematical expression will help to evaluate the corrosion rate for any time and for the prediction of the life of steel or to find the time for the allowable corrosion rate.

2. EXPERIMENTAL PART

2.1. Corrosion studies

2.1.1. Stirring test

Mild steel (API 5LX grade) coupons of size 2.5 x 2.5cm were mechanically polished to mirror finish and then degreased using trichloro ethylene. In the present study, 500 ml of diesel with 2% of water (120 ppm chloride) was used as the experimental system. The solution (diesel + water) was agitated by means of magnetic stirrer at 200 rpm. Corrosion rates were calculated for various immersion periods viz 10, 20, 30, 40, 50 and 60 days. The final weights of the six coupons in each system were taken and the average weight of the six coupons was used for calculating the corrosion rates.

2.1.2. Flow Loop test

Fig 1 shows the schematic diagram of flow loop assembly. The test solution (diesel and 2% water containing 120 ppm chloride) was kept in a reservoir. A PVDF pump discharged the liquid to the test reservoir after while the liquid was returned to the reservoir. Flow rate (0.552 m/s) was regulated with the valve. The panels were suspended in a PVC tube under at two locations in "H" type assembly as shown in the figure. The eight coupons were placed in such a way in the panels that the thickness of the coupon (1cm^2) was facing the flow loop. A polythene was connected from the pump delivering line and the out let is connected to the bottom portion of the one end of the "H" type PVC arrangement. At one end of the H type assembly the fluid in the upward direction and the other side the fluid was moving down wards. Another polythene tube was connected to the outlet and the PVC tube through which the solution is returned to the solution.

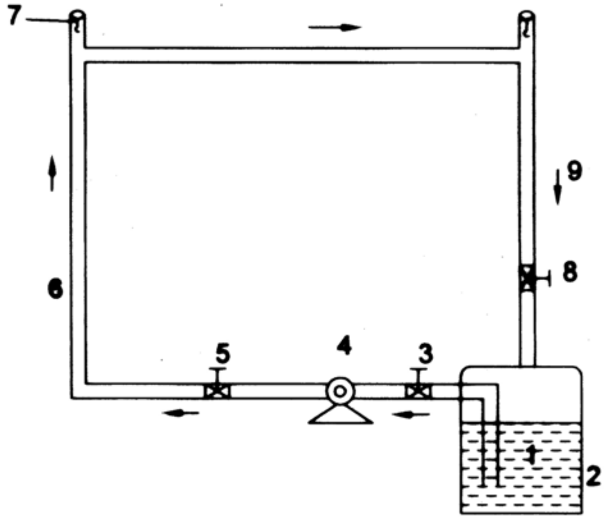

Fig 1. Flow-loop assembly: 1-System fluid (oil and water mixture), 2. Reservoir, 3, 5, 8 – Valves, 4 – Pump, 6 – PVC pipe, 7 – Sample holder, 9 – Flow direction

2.1.3. Rotating cage test

Four coupons are supported by PTFE disks mounted 55 mm apart on the rotatory rod. Holes were drilled in the top and bottom PTFE plates of the cage in order to increase the turbulence on the inside surface of the coupon (0.5338 m/s).

3. RESULT S AND DISCUSSION

3.1. Corrosion Studies

Table 1 shows the weight loss of data for various methodologies of evaluated by corrosion rate. In stirring method, 10th day the corrosion rate was 0.510 mm/y while 60th day the corrosion rate was 1.71 mm/y.

Table1. Experimental Corrosion rate (mm/y) for API 5 LX at different test conditions

Test condition	Time (days)					
	10	20	30	40	50	60
Stirring	0.510	0.7490	0.9891	1.2414	1.3832	1.7142
Flow loop	0.1259	0.3620	0.8620	0.9574	1.1919	1.4018
Rotating	0.3260	0.7217	0.9450	1.3780	1.5720	1.8490

In flow loop method and the rotating cage methods the corrosion rate were also increased with time. The F test was employed to find the significance between the three systems. Table value of 'F' = o.716 ≥ 3.68. Since the obtained value is less than the table value, the null hypothesis is retained and it can be concluded that there is no significant difference between the means of the three methodologies.

3.2. Mathematical modelling and statistical analysis

Curve fitting methods to improve the estimation of corrosion rate or to estimate the minimum thickness over a larger area have been suggested for over 10 years, and have been applied in a few isolated cases. These methods, when combined with reliability methods, offer a potential for obtaining better information from inspections by further analysis of the data collected and can produce predictions of future probability of corrosion. However widespread application is not common, largely because the use of statistics requires specialist knowledge, and no reference standards exist.

Using curve fitting methods the corrosion rate can be described quite accurately by the following expressions for any time for the different methods of evaluation.

$$p_s = 0.02336t + 0.2802 \tag{1}$$

$$p_f = 1.7463 \times 10^{-6} t^3 - 0.0003964t^2 + + 0.046061t - 0.32247 \tag{2}$$

$$p_r = -1.252 \times 10^{-7} t^4 + 1.689 \times 10^{-5} t^3 - - 0.000895t^2 + 0.05266t - 0.1204 \tag{3}$$

where p_s, p_f, p_r denotes the corrosion rates of stirring, flow loop and rotating cage system respectively and t denotes the time in days. Eqs (1) to (3) represent the general expressions for evaluating the corrosion rate for stirring, flow loop and rotating condition respectively. These equations are used to find the corrosion rate for any time. For these three methods of evaluation the experimental values are compared with the calculated values and are given in Table 2.. The corrosion rates calculated by using the Eqs (1) to (3) were compared with the experimental values and found satisfactory.

To predict the life of steel, it is required to express the time in terms of corrosion rate. The following polynomial expressions are developed and used to find the allowance time for any given allowable corrosion rate.

$$t = 42.8082\, p_s - 11.9948 \tag{4}$$

$$t = 12\, p_f^2 + 20 p_f + 7.8 \tag{5}$$

$$t = 32.89 p_r - 2.232 \tag{6}$$

The maximum allowable corrosion rate for steel is 1.2 0 mm/y. Using Eqs (1) to (3) we can predict the life of the steel for the three different test condition conditions. The corrosion rate vs time are also illustrated in Figs 2 to 4.

Table 2 - Experimental corrosion rate Vs calculated corrosion rate from Eq (1) – stirring test, Eq (2) flow loop test and Eq (3) – rotating cage test

Period (days)	Corrosion rate (mm/y)		% of Error
	Experimental data	Calculated value Eq.(1)	
10	0.510	0.5138	0.7
20	0.7490	0.7474	0.2
30	0.9891	0.9810	0.8
40	1.2414	1.2146	2.2
50	1.3832	1.4482	4.7
60	1.7412	1.6818	1.8

Period (days)	Corrosion rate (mm/y)		% of Error
	Experimental data	Calculated value Eq.(2)	
10	0.1259	0.1002	20.41
20	0.3620	0.4542	25.45
30	0.8620	0.7498	13.01
40	0.9574	0.9975	4.18
50	1.1919	1.2079	1.34
60	1.4018	1.3914	0.74

Period (days)	Corrosion rate (mm/y)		% of Error
	Experimental data	Calculated value Eq.(3)	
10	0.3260	0.3323	1.93
20	0.7217	0.6899	4.41
30	0.9450	1.0085	6.72
40	1.3780	1.3144	4.62
50	1.5720	1.6039	2.01
60	1.8490	1.8428	0.34

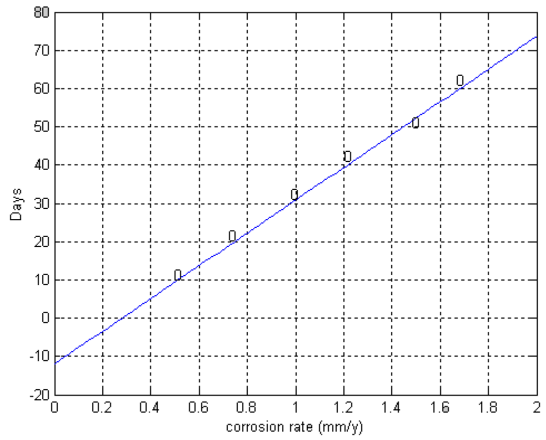

Fig 2 - The function p_s *(corrosion rate for stirring system) vs* t *(days). Open circle denotes the experimental results and solid line represents the linear equation (4)*

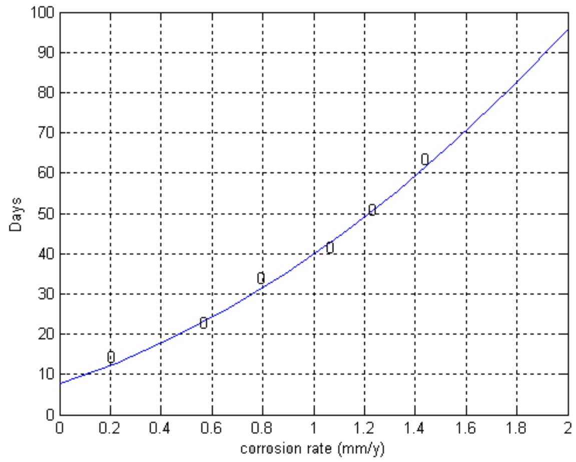

Fig 3 The function p_s *(corrosion rate for flow loop system) vs* t *(days). Open circle denotes the experimental results and solid curve represents the equation (5)*

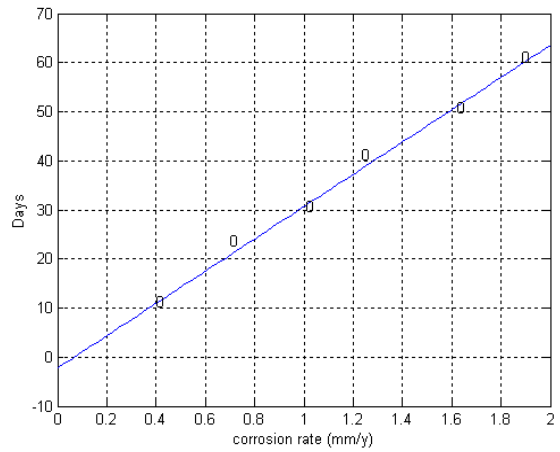

Fig 4 The function p_s *(corrosion rate for rotating system) vs* t *(days). Open circle denotes the experimental results and solid curve represents the equation (6)*

4. CONCLUSIONS

1. The corrosion rate of API 5 LX steel in oil-water system is evaluated for the three different methodologies and are related in terms of the following polynomial expressions.

$$p_s = 0.02336t + 0.2802 \qquad (1)$$

$$p_f = 1.7463\times 10^{-6} t^3 - 0.0003964t^2 + 0.046061t - 0.32247 \qquad (2)$$

$$p_r = -1.252\times 10^{-7} t^4 + 1.689\times 10^{-5} t^3 - 0.000895t^2 + 0.05266t - 0.1204 \qquad (3)$$

Using these three equations we can predict the corrosion rate for any time by the polynomial expressions for the different conditions of testing. For finding the allowable time, polynomial expression have also been developed in terms of the allowable corrosion rate .

$$t = 42.8082\, p_s - 11.9948 \qquad (4)$$

$$t = 12\, p_f^2 + 20 p_f + 7.8 \qquad (5)$$

$$t = 32.89 p_r - 2.232 \qquad (6)$$

Using these equations the allowable time to failure or the life of the system for allowable corrosion rate can be estimated.

2. The corrosion rate evaluation for the stirring system and rotating cage system are to be approximately equal even beyond 60 days. But the corrosion rate for flow loop system is higher than the other two systems beyond 60 days.

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