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Corrosion Behavior of Stainless Steel in Hydrochloric Acid and Nitric Acid Solutions

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ABSTRACT: *A detailed experimental study has been carried out to determine the pitting corrosion of 304 grade steel in acids like hydrochloric acid and nitric acid with different normalities. The corrosion rates have been calculated using weight loss method. In weight loss method without inhibitor, the sample pieces have been weighed and immersed into acids at different normalities like 4N, 5N, 6N, 7N, 8N for different time periods like 48 hours, 76 hours, 92 hours, 120 hours, 144 hours. The study reveals that maximum corrosion rate 0.64 mm/y of hydrochloric acid and 0.625mm/y in nitric acid occurred at the time period of 48 hours and at the normality of 8N. The inhibitor 2-Dimethyl amino ethanol for 8N is also applied to study the efficiency of the inhibitor. The results are also confirmed using the polarisation and FTIR studies.*

Keywords: **S**tainless steel; Corrosion; Hydrochloric acid; Polarization

1. INTRODUCTION

Austenitic stainless steels are among the most widely used types of stainless steel. The most commonly used grades are 300 series of alloys according the American Iron and Steel Institute (AISI). Starting from the basic 304 alloy (Fe-19Cr-10Ni), Mo is added to improve resistance to pitting (2-3 wt.% in the case of type 316 and 3-4 wt.% in type 317). Sensitization due to Cr depletion during welding and other heat treatments, and the possible resultant intergranular corrosion, can be avoided through the use of low-carbon grades (304L, 316L, 317L, in which C is limited to 0.03 wt.% max.) or by adding Ti (type 321) or Nb and Ta (type 347) to precipitate C at higher temperatures. The addition of Cr also imparts greater oxidation resistance, whilst Ni improves the ductility and workability of the material at room temperature (F. King, 2009). Stainless steel has important characteristics such as versatility, durability, attractiveness and high mechanical and corrosion resistance.

2. MATERIALS AND METHODS

Corrosion data here reported have been obtained through weight loss experiments of steel rod specimen.

Table 1. Composition of Stainless Steel (304)

Element	C	Mn	Si	P	S	Cr	Ni	N	Bal
%wt	0.08	2.00	0.75	0.045	0.03	18.00	9.00	0.1	Fe

Before weight loss and electrochemical measurements the sample were abraded with 600 grit SiC paper, washed with demonized water and acetone and dried. The dimensions of the samples are hexagon cross section of having 2.89 mm of side, Length 50 mm. Hydrochloric Acid and Nitric Acid both are used as 4N, 5N, 6N, 7N and 8N solution by mixing it with a specified ratio with the distilled water. And the solutions are made for 100 ml for every sample of testing.

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The samples are immersed into the acids for various time periods for testing. The time period taken into account for corrosion testing is 48 hrs, 72 hrs, 96 hrs, 120 hrs and 144 hrs. Diethyl amino ethanol is used as an inhibitor in stainless steel of grade 304. The usage of inhibitor on the corrosion medium is given below. Here the inhibitor has mixed in the solution by 10% that means 10 ml is added to the every 100 ml to get the various normality solutions. Polarization is an extremely important parameter because it allows useful statements to be made about the rates of corrosion process. In polarization studies 5%, 10%, 15% of inhibitor is mixed with the acid and inhibitor concentrations are tested. The polarization curves are drawn for the above said samples for stainless steel in the medium of 8N Hydrochloric Acid and 4N Nitric Acid.

A weighed sample of the metal or alloy under consideration is introduced into the process, and later removed after a reasonable time interval. The sample is then cleaned of all corrosion products and is reweighed. The weight loss is converted to a corrosion rate (CR) or metal loss (ML).The simplest way of measuring the corrosion rate of a metal is to expose the sample to the test medium and measure the loss of weight of the material as a function of time.

The weight loss is converted to a corrosion rate by the following formula.

$$\text{Corrosion rate} = \frac{K.W}{A.D.T}$$

Where,

K is a constant = 87.6

W is the weight loss in grams.

A is the surface area cm^2.

D is the density of the metal $gram/cm^3$.

T is the time in hours.

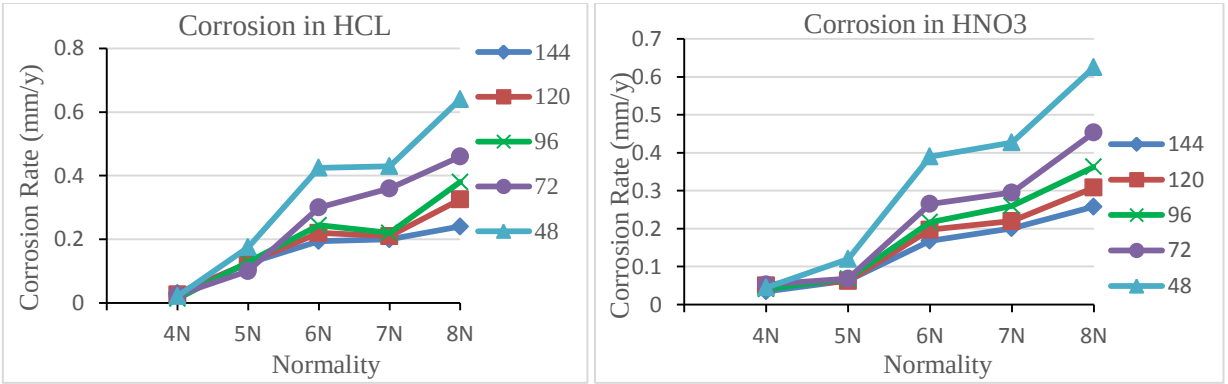
Fourier Transform Infrared Spectroscopy (FTIR) is a powerful tool for identifying types of chemical bonds in a molecule by producing an infrared absorption spectrum that is like a molecular "fingerprint".

FTIR is most useful for identifying chemicals that are either organic or inorganic. It can be utilized to quantify some components of an unknown mixture. It can be applied to the analysis of solids, liquids, and gasses. The term Fourier Transform Infrared Spectroscopy (FTIR) refers to a recent development in the manner in which the data is collected and converted from an interference pattern to a spectrum. Today's computerized FTIR instruments make them faster and more sensitive than the older dispersive instruments.

3. RESULTS AND DISCUSSION

3.1. RESULTS OF WEIGHT LOSS METHOD

The weight loss of the stainless steel in HCL and HNO_3 at different normalities is measured with and without inhibitor. The corrosion rate are calculated from the weight difference of the samples. The corrosion rate along with the weights before and after corrosion is tabulated in the following tables. Two samples in each category were considered and the average of the two is tabulated. Graphs are drawn based on the test timing. The graph is drawn between corrosion rate and normality of the acids where corrosion rate is taken in y-axis and normality of the acids are taken in x-axis. Two graphs are drawn for acids like HCL and HNO_3 separately.



The above graph shows the rate of corrosion of 304 grade stainless steel in hydrochloric acid with respect to the normality of acid. The rate of corrosion is taken in Y-axis and the normality is taken in X-axis. Here the rate of corrosion for time period of 48 hours is very high as it reaches 0.65mm/y in 8N HCL solution and the corrosion rate value reduces as the normality reduces. The corrosion rate for time period 144 hours is very low when compared to other time periods. It reaches the corrosion rate of 0.23 mm/y in 8N solution and it further decreases when the normality decreases. The corrosion rate in 144 hours is less and more in 48 hours because at initial stage the colliding atoms will be very high and after the oxidation, the atoms will be less and the corrosion rate will be less when the time period increases.

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The above graph shows the rate of corrosion of 304 grade stainless steel in nitric acid with respect to the normality of acid. The rate of corrosion is taken in Y-axis and the normality is taken in X-axis. Here the rate of corrosion for time period of 48 hours is very high as it reaches 0.62 mm/y in 8N HCL solution and the corrosion rate value reduces as the normality reduces. The corrosion rate for time period 144 hours is very low when compared to other time periods. It reaches the corrosion rate of 0.258 mm/y in 8N solution and it further decreases when the normality decreases. The corrosion rate in 144 hours is less and more in 48 hours because at initial stage the colliding atoms will be very high and after the oxidation, the atoms will be less and the corrosion rate will be less when the time period increases.

3.2 POLARISATION CURVE (HCL)

3.2.1 RESISTANCE METHOD

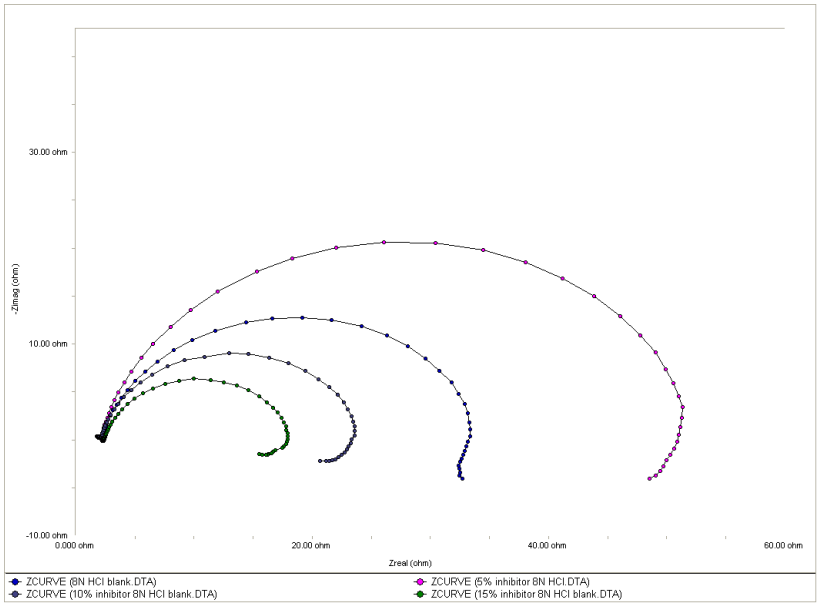

Figure 4.3 Polarisation curve for HCL (Resistance Method)

The above graph describes the polarisation curve by resistance method for various percentage of inhibitors mixed in hydrochloric acid. Here the resistance Zreal is taken in X-axis and the imaginary resistance Zimg is taken in Y-axis. Both the resistances are measured in ohms. When 5% of inhibitor is used, the real resistance value is higher which reaches nearly 52 ohms where the imaginary resistance value is also very high. When inhibitor is not used, the real resistance value reaches 35 ohms and the imaginary value also reaches more than 10 ohms. When 10% inhibitor is used, the real resistance value reaches 22 ohms and when 15% inhibitor is used, the resistance value is less than 20 ohms.

3.2.2 POTENTIAL METHOD

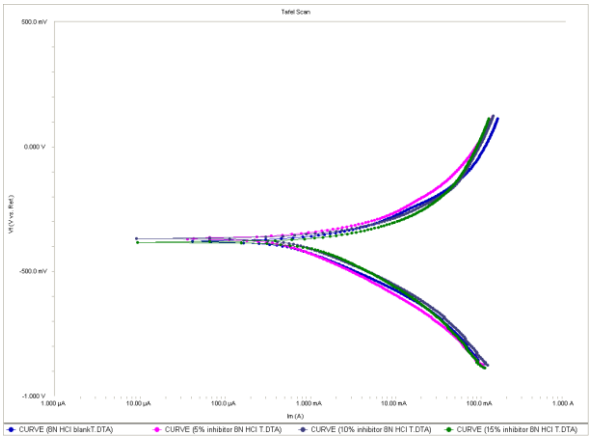

Figure 4.4 Polarisation curve for HCL (Potential Method)

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The above graph describes the polarisation curve by potential method for various percentage of inhibitors mixed in hydrochloric acid. Here the current I is taken in X-axis and the potential difference V is taken in Y-axis. Current is measured in ampere and potential difference is measured in voltage. This graph illustrates minimum difference in current value when any type of inhibitor is used. In every percentage of inhibitor the maximum current value of 120 milliampere is attained. Two curves are obtained in which one curve travels towards positive values of potential difference and another one travels towards the negative values of potential difference. The maximum value of potential value is 200 volts in positive side and 100 volts in negative side.

3.3 POLARISATION CURVE (HNO_3)

3.3.1 RESISTANCE METHOD

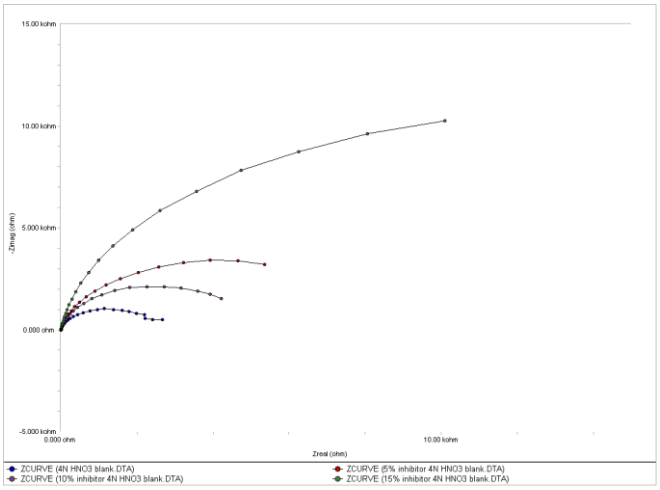

Figure 4.5 Polarisation curve for HNO_3 (Resistance Method)

The above graph describes the polarisation curve by resistance method for various percentage of inhibitors mixed in nitric acid. Here the resistance Zreal is taken in X-axis and the imaginary resistance Zimg is taken in Y-axis. Both the resistances are measured in ohms. When 15% of inhibitor is used, the real resistance value is higher which reaches nearly 11 kiloohms where the imaginary resistance value is also very high. When inhibitor is 5%, the real resistance value reaches 5 kiloohms and the imaginary value also reaches more than 10 ohms. When 10% inhibitor is used, the real resistance value reaches 5 kiloohms and when inhibitor is not used, the resistance value is less than 4 kiloohms.

3.3.2 POTENTIAL METHOD

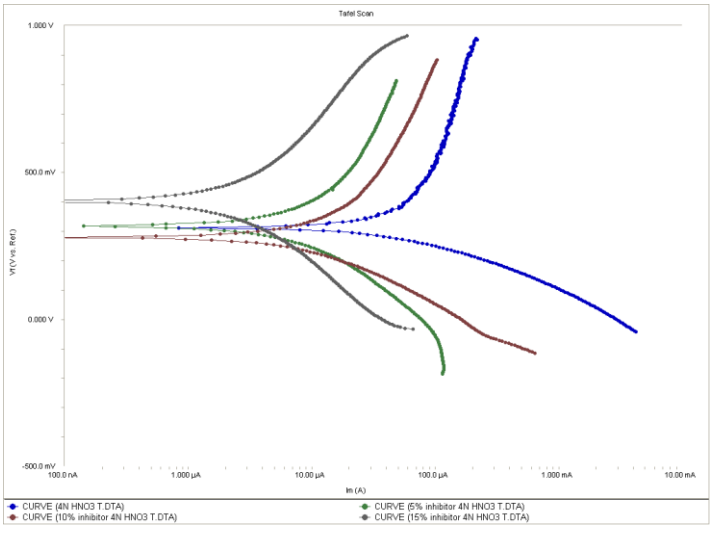

Figure 4.6 Polarisation curve for HNO_3 (Potential Method)

The above graph describes the polarisation curve by potential method for various percentage of inhibitors mixed in nitric acid. Here the current I is taken in X-axis and the potential difference V is taken in Y-axis. Current is measured in ampere and potential difference is measured in voltage. Here each percentage of inhibitor consists of two curves in which one travels towards positive value of potential difference and another one travels towards the negative value of the potential difference. When the inhibitor is not used, the

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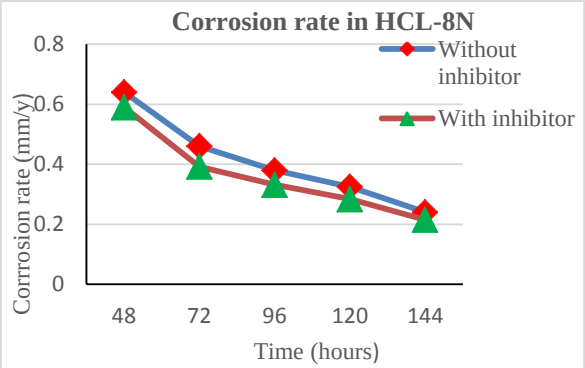
current value reaches a maximum of 8 milliampere in negative side of potential difference. The minimum value of the current is attained when 5% inhibitor is used which is 80 micro ampere in positive side of potential difference.

3.4 Corrosion with Inhibitor



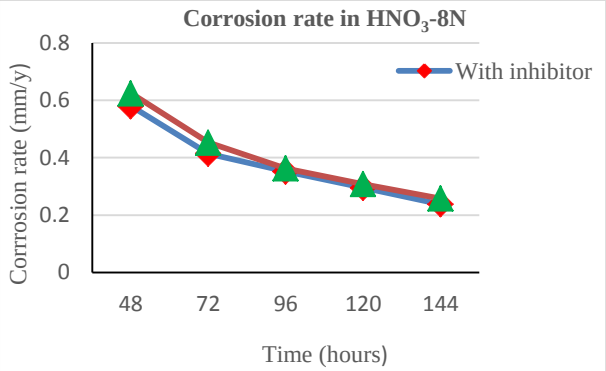


Figure 4.7 Corrosion rate in HCL-8N

Figure 4.8 Corrosion rate in HNO_3-8N

4. CONCLUSION

The corrosion effect of hydrochloric acid and nitric acid on stainless steel of grade 304 has been studied by using weight loss method.

- The study reveals that maximum corrosion rate 0.64 mm/year occurred at the time period of 48 hours and at the normality of 8N of hydrochloric acid and corrosion rate of 0.625 occurred at the time period of 48 hours and at a normality of 8N of nitric acid.
- The corrosion rate decreases if the test time increases and the normality decrease.
- Addition of inhibitor of 10% reduces an amount of 14.78% in corrosion rate.
- The polarisation studies also denote that higher normality has high real resistance value which shows high corrosion rate.

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