



## Corrosion studies on Stainless Steel-304 in brackish environment

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### ABSTRACT

Corrosion on SS-304 in brackish environment. Any compound capable of donating free chlorine ions (Cl<sup>-</sup>) to an aqueous (water-based) solution has the potential for causing failure in stainless steels. The chlorine ion is extremely electronegative, therefore very reactive with certain compounds and elements. This reactivity is part of its usefulness in certain situations, but becomes a double-edged sword where stainless steel is concerned. Experimental corrosion studies on commercial SS - 304 have been carried out. The experiments were carried in brackish environment with a concentration variation, pH variation and contact time variation. The experiments were carried out by weight loss method, gasometry study and open circuit polarization studies. The post corrosion sample's micro structures were analyzed with the aid of EDS (Energy dispersive spectroscopy) equipped SEM (Scanning Electron Microscope) EDS (Energy dispersive spectroscopy) instrument to detect the morphology of corrosion by-products. For further verification x-ray diffraction method was also used to detect any possible emerging corrosion by products on the sample's surface. Experimental results confirmed that SS-304 immersed in brackish environment with a variation of concentration, experience very little corrosion. EDS study and x-ray diffraction results indicate that the possible ensuing corrosion by products are Iron oxides, chrome oxides, iron chloride and nickel hydride oxide

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### Introduction

In general, the corrosion behaviour of 304 SS has been very well documented<sup>1,2,3</sup>. The recent literature alone is replete with studies of general and localized corrosion of 304 SS exposed to sodium chloride (NaCl) solutions<sup>4,9</sup>. Weight loss measurements were performed in NaCl environments<sup>10-13</sup> environments. Moreover, publication of potentiodynamic polarization curves in NaCl environments has been scant. Matantsev<sup>14</sup> produced potentiostatic polarization curves for a 17 Cr - 10 Ni - 0.5 Ti steel that appeared to indicate that increasing NaCl concentration resulted in increased passive current densities during exposure. The curves, unfortunately, are composed of few data points and thus results are somewhat speculative. Gorodnichii and Rozenblyum<sup>15</sup> examined the corrosion behaviour of an 18 Cr - 10 Ni - 0.7 Ti steel and found that increased NaCl concentrations promoted a passive-to-active transition. Additionally, the corrosion behaviour was mapped as a function of NaCl concentration for alkali pH levels. The methodology used to generate these maps is unclear. It was found that the material could be active, passive, active/passive, or exhibit pitting depending on pH. Petit *et al.* also mapped the corrosion behaviour of 304 SS as a function of NaCl concentrations<sup>16</sup>. They inferred regions of stress corrosion cracking, passivity, activity, and pitting/intergranular attack from scanning electron microscopy investigations that followed 120 hours of immersion in boiling solutions at various stress states. The method for delineation of the individual regions is unclear as pitting was noted in each region. However, their

results indicated no pitting below 0.5 M NaCl concentrations ranging from 0.1 to 5 M. Matsuda and Uhlig<sup>17</sup> (using Fe - 0.023 C) inferred pitting susceptibility from weight loss measurements for a wide variety of NaCl solutions. Greene and Fontana<sup>18</sup>, using 304 SS, reported that nitrate ions effectively prevented pit initiation in chloride solutions but accelerated pit growth when the HNO<sub>3</sub> was added after pit initiation.

#### Experimental Details:

##### Weight loss method:

The pure stainless steel (SS - 304) specimens used for the study, were polished with emery papers of different grades. The specimens were washed thoroughly with detergent and distilled water and cleaned by acetone solvent for about 2 - 3 minutes and dried with filter papers. The chemicals used were of analar grade. All solutions were prepared in double distilled water. The self corrosion studies were made with the stainless steel (SS - 304) specimens of size 2.5 x 2.5 x 0.1 cm<sup>3</sup>. The metal coupons were weighed and immersed in 80 ml and 3.5 % and 3 % NaCl solution without the inhibitor for a stipulated period of time. It was removed from the solution. The stainless steel (SS - 304) samples were cleaned by brushing under running tap water to remove the corrosion products, dried and found out the weight loss. The experiments were carried out in triplicate to ensure reproducibility. The mean value of weight loss was calculated. From the weight loss values the percentage of corrosion (P.C) was calculated using the following equation

$$P.C = \frac{W_o - W_i}{W_o} \times 100$$

Where  $W_o$  and  $W_i$  are the weight loss before and after corrosion respectively.

**OCP Measurements:**

The potentials of stainless steel (SS - 304) coupons, immersed in the test solutions were measured, under open circuit condition, as a function of time against a saturated calomel electrode used as a reference electrode. The measurements were made until a steady state potential value was obtained. The galvanostatic polarisation studies were carried out in a beaker containing three electrodes, stainless steel (SS - 304) electrode as the working electrode, a saturated calomel electrode as the reference electrode and graphite rod electrode as the auxiliary electrode. Polarisation experiments were carried out using stainless steel (SS - 304) coupons with 6.25 cm<sup>2</sup> working area. The stainless steel (SS - 304) electrode was dipped in NaCl solution (3 % & 3.5 %) without inhibitor. To minimise the ohmic IR drop, the distance between the calomel electrode and the luggin capillary was kept constant throughout the experiments. The experiments were made in aerated unstirred test solution throughout the studies.

The power supply was a galvanostat. The potential values were recorded by means of high impedance multimeter. After measuring the steady OCP, the specimen was first cathodically polarised by passing known value of current increasing in the range of 10 mA / 3days and steady potential were measured at each current density. After cathodic polarisation over, the stainless steel (SS - 304) electrode was brought back to OCP and then polarised anodically to derive the corresponding polarisation curve. The corrosion current and corrosion potential values were evaluated. The measurements were repeated until reproducible data were obtained.

**Results and discussion:**

**Weight loss method:**

Concentration of NaCl : 3.5%  
PH : 7.99

S.No	Contact Duration in Days	Weight in gms Before corrosion	Weight in gms After corrosion	Weight loss in gms	% of Weight Loss
1	6	5.23	4.6489	0.5811	11.1111
2	12	5.20	4.1666	1.0334	19.8723
3	18	5.25	3.9626	1.2874	24.5213
4	24	5.30	3.8700	1.4300	26.9814
5	30	5.28	3.8491	1.4309	27.1010

**Table 1**

Concentration of NaCl : 3.0 %  
PH : 7.98

S.No	Contact Duration in Days	Weight in gms Before corrosion	Weight in gms After corrosion	Weight loss in gms	% of Weight Loss
1	6	4.83	4.4873	0.3427	7.0960
2	12	4.88	4.3460	0.5340	10.943
3	18	4.82	4.0856	0.7344	15.236
4	24	4.95	4.0512	0.8988	18.158
5	30	4.86	3.9049	0.9551	19.652

**Table 2**

**OCP Method:**

Concentration of NaCl : 3.5%  
PH : 7.99

S.No	Contact Duration in Days	OCP in Volts	E <sub>Corr</sub> In Volts	I <sub>Corr</sub> in mAcm <sup>-2</sup>	% Corrosion
1	6	1.36	1.37	4.481	10.97
2	12	1.38	1.38	6.049	21.39
3	18	1.38	1.39	7.389	27.10
4	24	1.39	1.39	8.671	30.26
5	30	1.38	1.40	8.935	31.23

**Table 3**

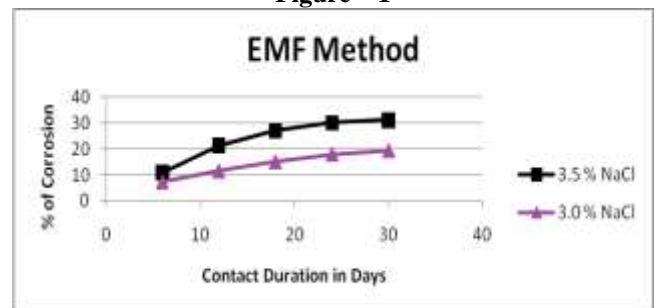
Concentration of NaCl : 3.0%  
PH : 7.98

S.No	Contact Duration in Days	OCP in Volts	E <sub>Corr</sub> In Volts	I <sub>Corr</sub> in mAcm <sup>-2</sup>	% Corrosion
1	6	1.54	1.55	3.320	7.25
2	12	1.58	1.57	5.474	11.59
3	18	1.59	1.58	6.110	15.22
4	24	1.58	1.59	6.171	18.12
5	30	1.58	1.60	7.389	19.57

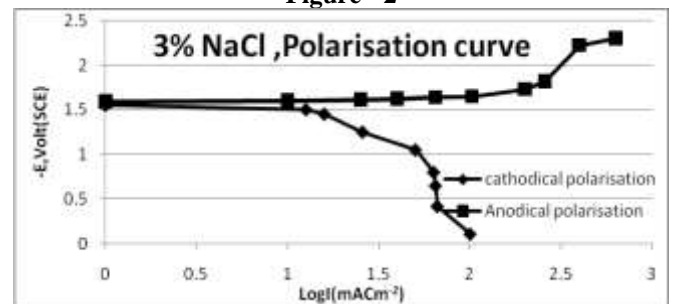
**Table 4**



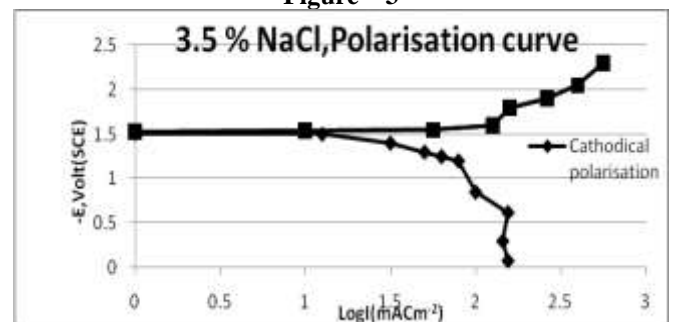
**Figure - 1**



**Figure - 2**



**Figure - 3**



**Figure - 4**

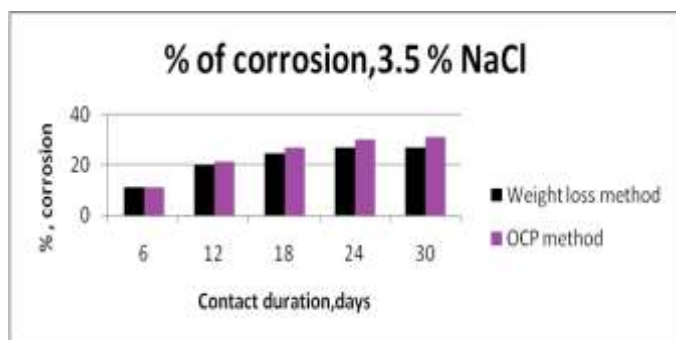


Figure -5

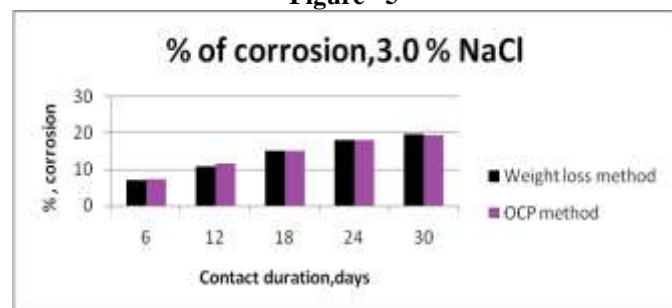


Figure -6

The rate of corrosion of stainless steel 304 grade in the brackish environment was analysed by the weight loss method and open circuit polarisation method. Brackish environment of two different concentration of sodium chloride (3 % and 3.5 % NaCl) Content were used. The initial corrosion status was measured after six days. The study was carried out with the same interval of time for 30 days. The results showed that the rate of corrosion increased from 11 % to 27 % in 3.5 % NaCl solution (Table - 1 & Figure -1). The rate of corrosion increased from 7 % to 19 % in 3.0 % NaCl solution (Table - 2 & Figure -1). After 30 days duration, no remarkable change in the rate of corrosion was observed. The PH of the NaCl solution was found to be 7.8 to 8.0 throughout the experiment at room temperature. Therefore the corrosion takes place in slightly alkali medium.

The open circuit polarisation studies were carried out in the same brackish environment with two different concentrations of sodium chloride (3 % and 3.5 % NaCl) at PH value of 7.8 to 8.0 ranges throughout the experiment at room temperature. The corrosion current  $I_{Corr}$ , Corrosion potential  $E_{Corr}$  and OCP values were measured. The corrosion current increases with subsequent increase in contact duration. The corrosion potential values are in steady state. The OCP and corrosion potential values are around 1.52 to 1.6 Volts. The polarisation of the anode is greater than that of the cathode (Figure 3 for 3.5 % NaCl and Figure 4 for 3 % NaCl). Thus it is clear that the corrosion process is predominantly under the anodic control in the absence of inhibitor. However the slopes of both anodic and cathodic polarisation curves may be changed by the addition of

inhibitor. The percentage of corrosion found from this method is from 10.97 % to 31.23 % for 3.5% NaCl (Figure - 5) and it ranged from 7.25 % to 19.57 % for 3.0 % NaCl solution (Figure - 6). The results obtained from both weight loss method and open circuit polarisation methods are found to be more or less equal.

### Conclusion

Experiments were carried out to study the synergetic influence of 3.0 %, 3.5 % of sodium chloride on corrosion of 304 Stainless steel by weight loss and polarisation measurements. The percentage of corrosion values, determined from these techniques, showed fairly good agreement. The corrosion of stainless steel 304 in 3.0 %, 3.5 % NaCl was found to be predominantly under anodic control in the absence of inhibitor. The corrosion was found to be pitting type.

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