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## Determination of Mild Steel Corrosion Rate under Turbulent Flow in Highly Acidic Solution

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**Abstract:** The corrosion rate for mild steel in 2.5 M H<sub>2</sub>SO<sub>4</sub> at 30°C for different flow velocities was determined. Electrochemical techniques such as Tafel polarization and electrochemical impedance spectroscopy (EIS) were carried out to study the effects of flow velocity on corrosion rate of mild steel. The turbulent conditions experiments were simulated using rotating cylinder electrode (RCE). Results obtained from Tafel polarization and EIS were in good agreement. The study revealed that the mild steel corrosion rate decreased with increases in flow velocity due to improvement of the passivation by an increase of the oxygen supply. Corrosion potentials were shifted toward the cathodic values and the magnitude of the impedance was rose with flow velocities.

**Key words:** Tafel polarization, rotating cylinder electrode, sulfuric acid

### INTRODUCTION

As we know, carbon steel is widely used as a constitutional material in many industries due to its good mechanical properties and low cost. Excessive corrosion attack is known to occur on mild steel in acidic aqueous media. Acid solutions are widely used in different industrial processes, for example, in acid pickling of iron and steel, scale removal in metallurgy, acid cleaning of boilers and oil-well acidizing, therefore the study of corrosion of mild steel in acid solutions has practical importance.

Most of the investigations on mild steel have been investigated under static conditions. There are few studies in the literatures on the effect of hydrodynamic conditions on performance of mild steel under laminar or turbulent flow. Some authors have investigated the effect of flow on corrosion of metals and alloys such as nickel-aluminium-bronze (NAB) (Kear *et al.*, 2004; Wharton *et al.*, 2005) stainless steel (Rybalka *et al.*, 2006; Sidorin *et al.*, 2005), Cu-Ni alloys (Maciel and Agostinho, 2000; Martinez and Metikos-Hukovic, 2006; Kear *et al.*, 2007; Roberge and Beaudion, 1988) and carbon steel (Luis *et al.*, 2007) in different corrosive solutions. Fluid velocity is one of the most important parameters to be considered during corrosion of metals, due to the flow affects both in the anodic and cathodic reactions.

In the investigation described working, a rotating-cylinder electrode was used to simulate the effect of hydrodynamic conditions on the mild steel corrosion in 2.5 M H<sub>2</sub>SO<sub>4</sub> at 30°C. The corrosion rate of mild steel was determined using Tafel polarization and Electrochemical Impedance Spectroscopy (EIS).

### MATERIALS AND METHODS

The working electrode employed in this work is made from mild steel, with the chemical compositions to be as follows: 0.08 wt.% C, 0.25 wt.% Si, 0.45 wt.% Mn, 0.03 wt.% P, 0.03 wt.% S and the balanced with Fe. The rotating cylinder electrode was designed for application with a Gamry Instrument Potentiostat/Galvanostat/ ZRA, model AFMSRCEP rotator. The dimensions of the RCE were 1.2 cm in diameter and 0.78 cm in length. The RCE effective area is 2.94 cm<sup>2</sup>. The experiments were performed at flow velocities of U<sub>1</sub>= 0, U<sub>2</sub>= 50, U<sub>3</sub>= 75 and U<sub>4</sub>= 100 cm sec<sup>-1</sup> at 30°C in aerated 2.5M H<sub>2</sub>SO<sub>4</sub> solution. The Reynolds number for a rotating cylinder electrode with outer diameter, d (cm) was calculated according to the relation (Gabe, 1974):

$$Re = \frac{Ud\rho}{\mu} \quad (1)$$

where  $\rho$ ,  $\mu$  and  $U$  are the solution density, absolute viscosity of the solution, and linear velocity (cm sec<sup>-1</sup>). In

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Table 1: Variation in Reynolds number for various flow velocities in 2.5 M H<sub>2</sub>SO<sub>4</sub> at 30°C

$\mu$ (g cm <sup>-1</sup> sec <sup>-1</sup> )	$\rho$ (g cm <sup>-3</sup> )	U (cm sec <sup>-1</sup> )		
		50	75	100
0.0175	1.1718	4017	6026	8035

general, for a rotating cylinder, when the Reynolds number is greater than 200, the flow may be considered asturbulent. The calculated Reynolds number values as presented on Table 1 confirmed that the experiments were performed under turbulent flow conditions in both acid pickling solutions.

The working electrode was first mechanically polished using SiC paper in successive grades from 200 to 1500, washed with deionized water thoroughly and degreased with absolute ethanol and dried at room temperature. A glass water jacket cell with 175 mL capacity made of Gamry consist of three electrodes namely for working, graphite bar counter and reference electrodes was used. The reference electrode was a saturated calomel electrode (SCE).

Electrochemical measurements were performed using Gamry Instrument Potentiostat/Galvanostat/ ZRA, these include Gamry framework system based on the Ref 600, Gamry applications that include OCP, potentiodynamic scan and EIS are DC105 and EIS300 software. The potentiodynamic current-potential curves were swept from -0.2 to 0.2 V<sub>SCE</sub> at a scan rate of 0.166 mV s<sup>-1</sup>. Impedance measurements were carried out using AC signals of amplitude 10 mV peak to peak at OCP in the frequency range 1MHz to 0.1Hz. The corrosion rate (C.R), in (mm/year) is calculated using the relation:

$$C.R = \frac{K \times i_{corr} \times Equivalent.Weight}{density} \quad (2)$$

where, K is 3272 a constant that defines the unit of corrosion rate,  $i_{corr}$  is current density in A cm<sup>-2</sup> and density is in g cm<sup>-3</sup>.

**RESULT AND DISCUSSION**

**Polarization measurements:** The current-potential curves obtained for four flow velocities of 0, 50, 75 and 100 cm sec<sup>-1</sup> in solution of 2.5M H<sub>2</sub>SO<sub>4</sub> are as shown in Fig 1. The numerical values of the variation of corrosion current density ( $i_{corr}$ ), corrosion potential ( $E_{corr}$ ), anodic Tafel slope ( $\beta_a$ ) and cathodic Tafel slope ( $\beta_c$ ) with flow velocity at 30 °C are depicted in Table 2. In Fig. 1, the flow velocity caused a shift in corrosion potential toward the cathodic values, thus the cathodic current densities decreased and the anodic current densities decreased

Table 2: Tafel and EIS fitted data for mild steel in 2.5 M H<sub>2</sub>SO<sub>4</sub> solution with different flow velocities

U (cm sec <sup>-1</sup> )	$i_{corr}$ (μ A.cm <sup>-2</sup> )	$E_{corr}$ (mV)	$R_{ct}$ (Ω.cm <sup>2</sup> )	(mm/y)
0	6370	426	4.36	73.94
50	2860	463	10.21	33.19
75	1030	469	10.48	11.95
100	800	462	12.17	9.28

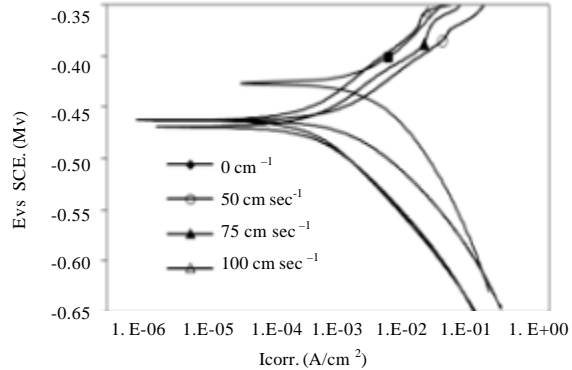


Fig. 1: Polarization curves for mild steel in 2.5M H<sub>2</sub>SO<sub>4</sub> solution at different flow velocities

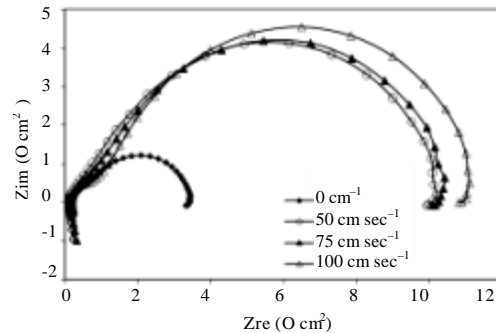


Fig. 2: Nyquist plots for mild steel in 2.5M H<sub>2</sub>SO<sub>4</sub> solution at different flow velocities

(Popova and Christov, 2006). It’s obvious from Table 2, the corrosion rate decreased with flow velocity which may be attributed to an improvement of the passivation by an increase of the oxygen supply Streicher (Ochoa *et al.*, 2005).

**EIS measurements:** To quantify turbulent flow influence on mild steel corrosion, EIS spectra were recorded on the working electrode for four flow velocities by Nyquist format in acid solution, Fig 2. The impedance spectra shows that the Nyquist plot has tow loops: one loop of which is much smaller than the other one in high frequency range, and one loop in low frequency range with inductive behavior. The high and intermediate frequencies (HF and MF) arc, located between 1 Hz and 1 MHz, can be attributed to the charge transfer process; while, that observed in the Low-Frequency (LF) region

below 1 Hz can be attributed to the relaxation process obtained by adsorption of species like  $(\text{SO}_4^{2-})_{\text{ads}}$  and  $(\text{H}^+)_{\text{ads}}$  on the electrode surface (Ashassi-Sorkhabi and Asghari, 2008).

It may also be attributed to the re-dissolution of passivated surface. The magnitude of the impedance increases from the beginning and up to the end of the experiments, this suggests that the flow velocity greatly but gradually changed the corrosion kinetics on the electrode surface. The equivalent circuit models used to fit the experimental results are previously reported by Moretti *et al.* (2004). The values of the parameters, obtained from the fit, are reported in Table 2. It can be seen that  $R_{ct}$  increased with flow velocity. These results are in line with those obtained from polarization measurements.

### CONCLUSION

Corrosion rate for mild steel in 2.5M  $\text{H}_2\text{SO}_4$  under turbulent flow was determined using Tafel technique. The effects of flow velocity on mild steel corrosion were studied using EIS measurements. Corrosion rate and impedance were decreased and increased with flow velocity, respectively.

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