Metrohm Autolab

Application Area: Corrosion

Corrosion Rates Measurements in Quiescent and Turbulent Flow conditions by using Rotating Cylinder Electrode (RCE)

Keywords

Rotating cylinder electrode, RCE, corrosion, corrosion rate, turbulent flow, ASTM G185.

Introduction

The corrosion of the inner walls of pipelines is due to the electrochemical interaction between the pipe material and the fluids flowing through the pipes. Such corrosion is significantly enhanced by the turbulent nature of the flow inside the pipelines.

The rotating cylinder electrode (RCE) is successfully used to generate a turbulent flow at the surface of a sample, in a laboratory environment, simulating the real-world pipe flow conditions. In other words, the turbulent flow of a liquid moving with a known flow rate through a pipeline of given internal diameter and its effect on the material surface can be reproduced in a laboratory by using and RCE with a given cylinder size (made of the same material as the pipe) which spins at a well-defined rotation rate.

In this application note, the corrosion rate is measured and compared between quiescent and turbulent flow conditions, while keeping all the other experimental conditions unchanged. The linear polarization (LP) technique was used together with the RCE both with and without rotation.

Experimental Setup

A Metrohm Autolab PGSTAT302N, equipped with the Metrohm Autolab motor controller, rotator, and a rotating cylinder electrode was employed.

The Metrohm Autolab RCE uses a sample cylinder with the outer diameter of $12\ mm$, surface area of $3\ cm^2$, fixed in a PEEK holder with Viton O-rings. Schematics of a Metrohm Autolab RCE together with the turbulent flow lines are shown in Figure 2.

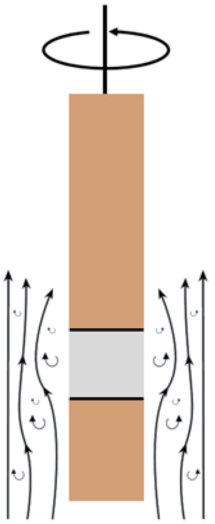

Figure 1 – The schematics of an RCE. In gray, the metallic insert; in black the Viton O-rings; in beige, the PEEK holder. The arrows on the side represent the turbulent flow generated by the electrode rotation.

In general, for an RCE, the turbulent flow is achieved with Reynolds number $R_e > 200$. Considering the 12 mm outer diameter of the cylinder, turbulent flow is already reached at 100 RPM[1].

For the measurements presented in this application note, the RCE electrode was rotated at 500 RPM, corresponding to a fluid velocity $v = 82.3\ cm\ s^{-1}$ inside a schedule 40 pipe, with an internal diameter of $30.32\ cm\ (12'')$.

The material of the RCE cylindrical insert was 1018 carbon steel (density $\rho = 7.87\ g\ cm^{-3}$; equivalent weight $EW = 27.93$).

The electrochemical cell was completed with an Ag/AgCl 3 mol/L KCl reference electrode and two symmetrically placed stainless steel rods as counter electrodes.

1 For more details, please see the dedicated White Paper: "*Corrosion Best Practice. Creating Pipe-flow Conditions Using a Rotation Cylinder Electrode*".

An aqueous solution of 0.5 mol/L HCl and 0.5 mol/L NaCl prepared as the electrolyte and the experiments were carried out at room temperature.

Prior to the experiments, the samples were kept into the electrolyte solutions overnight for stabilization purpose.

After recording the open circuit potential (OCP) for five minutes, linear polarizations were conducted from $-20\ mV$ and $+20\ mV$ vs. OCP, with a scan rate of $1\ mV\ s^{-1}$. In corrosion, the OCP is also called corrosion potential, E_{corr}.

All data was measured and analyzed with the NOVA software.

All the potentials are measured versus the Ag/AgCl 3 mol/L KCl reference electrode.

Results and Discussion

A corrosion potential $E_{corr} = -0.483$ V was observed in the in the quiescent conditions, while a corrosion potential of $E_{corr} = -0.479$ V was observed at 500 RPM.

In Figure 2, the comparative linear polarization (LP) data measured in the quiescent solution and at 500 RPM conditions are shown in blue and red, respectively.

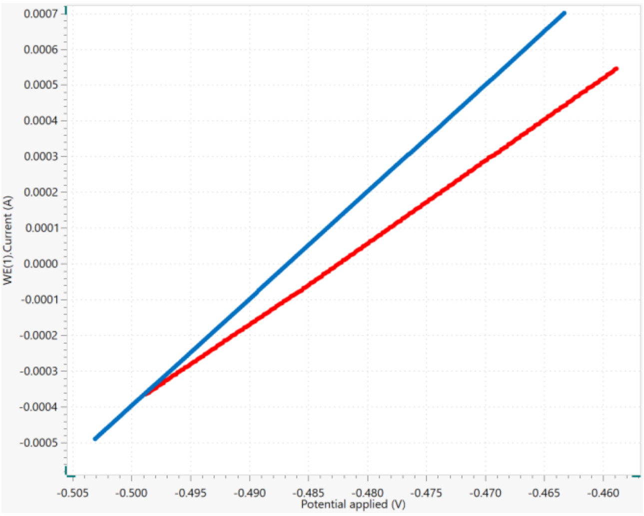

Figure 2 – Linear polarization plots in quiescent solution (blue) and under 500 RMP rotation rate (red). All other experimental parameters were kept the same.

A visual observation of Figure 2 shows that the current values recorded at 500 RPM are shifted towards more positive (noble) potentials than the current recorded in the quiescent solution.

The polarization resistance R_p was calculated by performing a linear regression of the LP plots around 0 V, and calculating the inverse of the slope of the regression line. In the case of the quiescent solution, the polarization resistance was $R_p = 33.4\ \Omega$ while in turbulent conditions, the polarization resistance was $R_p = 42.6\ \Omega$.

The shift in corrosion potential toward more noble potentials and the increase of the polarization resistance, occurring at 500 RPM, could be due to the presence of the turbulent flow, which obstructs the creation of nucleation sites for the corrosion to initiate. This observation is in agreement with data reported earlier in the literature.

In Figure 3, the Tafel plots are shown.

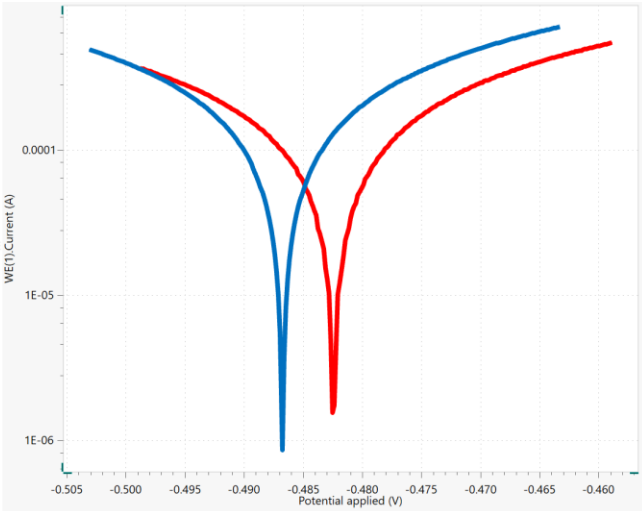

Figure 3 – The Tafel plots corresponding to the measurements done in quiescent electrolyte (blue) and under 500 RMP rotation rate (red). All other experimental parameters were kept the same.

Using the dedicated analysis tools in NOVA, the corrosion rate analysis were performed on the data in Figure 3.

The calculated corrosion potential in quiescent solution is $E_{corr} = -0.487$ V, while the calculated corrosion potential in turbulent flow is $E_{corr} = -0.482$ V.

In Table 1, a summary of all measured and calculated corrosion parameters obtained in quiescent and turbulent flow conditions is presented.

Table 1 – Measured and calculated parameters from linear regression of the LP plot and Tafel analysis for experiments done with and without electrode rotation.

Parameter	No rotation	500 RPM
E_{corr} (V) measured	-0.483	-0.479
E_{corr} (V) from Tafel analysis	-0.487	-0.482
R_p (Ω) from linear regression	33.4	42.6
R_P (Ω) from Tafel analysis	33.5	43.3
Corrosion rate $(mm\ year^{-1})$	0.81	0.25

It can be noted that the polarization resistance values obtained from the Tafel analysis are very similar to the values calculated from the linear regression of the LP plots, which further supports the validity of the calculated results.

Conclusions

In this application note, the effect of the turbulent flow on the corrosion rate was demonstrated by using the rotating cylinder electrode (RCE) to simulate pipe flow conditions on pipelines. The simulated turbulent flow was corresponding to a fluid velocity $v = 82.3\ cm\ s^{-1}$ inside a schedule 40 pipe, with an internal diameter of $30.32\ cm\ (12'')$.

The same electrolyte solution, same sample, and same experimental parameters were used in quiescent conditions as well. The measured and calculated corrosion parameters were compared for the two experiments.

Date

December 2019 AN-COR-015

For more information

More information is available in the RCE dedicated White Paper: "Corrosion Best Practice. Creating Pipe-flow Conditions Using a Rotation Cylinder Electrode".

Information about procedures used for this application note and the associated NOVA software procedure is available from your local **Metrohm distributor**.

Additional instrument specification information can be found at **www.metrohm.com/electrochemistry**.