Corrosion Inhibitor Efficiency Measurement in Turbulent Flow Conditions with the Autolab Rotating Cylinder Electrode (RCE), According to ASTM G185

The rotating cylinder electrode (RCE) is a technique used in corrosion research to simulate in a laboratory environment the turbulent flow, which usually occurs when liquids are transported through pipelines.

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

The rotating cylinder electrode (RCE) is used to generate a turbulent flow at the surface of a sample, in a laboratory environment, simulating the pipe flow conditions. In other words, the turbulent flow of a liquid with known flow rate through a pipeline of given internal diameter and its effect on the material surface can be reproduced in a laboratory environment 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.

Therefore, one of the main applications of RCE is to test the efficiency of corrosion inhibitors and the corrosion susceptibility of pipe materials in simple and fast electrochemical experiments, simulating the pipe flow conditions.

Experiments that involve an RCE are regulated by the ASTM G185 standard [1].

In this application note, The RCE with a 1018 carbon steel cylinder sample was used with the linear polarization (LP) measurement technique. Two LP experiments were conducted, one without a corrosion inhibitor and the other with a corrosion inhibitor added to the electrolyte.

EXPERIMENTAL SETUP

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

The Metrohm Autolab RCE uses a sample cylinder with the outer diameter (OD) of 12 mm that is fixed in a PEEK holder with Viton O-rings. A Metrohm Autolab RCE is shown in Figure 1.

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 reached already at 100 RPM [2].

The material of the RCE cylindrical insert was 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.

Figure 1. Rotating cylinder electrode showing the metallic insert, the Viton O-rings (black) and the PEEK holder.

The electrolyte was composed of an aqueous solution of 0.5 mol/L HCl and 0.5 mol/L NaCl.

Another electrolyte solution of 0.5 mol/L HCl and 0.5 mol/L NaCl was prepared, adding also 4 mL of the inhibitor solution, composed of ethanol and 1000 ppm (0.78 mol/L) of tryptamine was added.

The RCE electrode was rotated at 500 RMP, corresponding to a fluid velocity $v_{RCE} = 82.3\ cm\ s^{-1}$ ($2.7\ ft\ s^{-1}$) inside a schedule 40 pipe, with an internal diameter of 30.32 *cm* (12′′).

Prior the experiments, for stabilization purposes, the samples were kept overnight in the electrolyte without the inhibitor.

After recording the open circuit potential (OCP) for five minutes, LP measurements were conducted from –20 *mV* and +20 *mV* vs. OCP, with $1\ mV\ s^{-1}$ scan rate.

In the case of corrosion, the OCP is also called corrosion potential, E_{corr}.

All the data was recorded and analyzed with the NOVA software.

All the potentials are recorded versus the potential of the reference electrode, i.e., versus Ag/AgCl 3 mol/L KCl.

All experiments were conducted at room temperature.

RESULTS AND DISCUSSION

The corrosion potential E_{corr} (V) was measured, as being $E_{corr} = -0.479$ V in the case of the electrolyte without inhibitor, and $E_{corr} = -0.392$ V in the case of the electrolyte with the inhibitor.

In Figure 2, the voltammograms resulting from the Linear Polarization (LP) experiments are shown. In blue, the data measured without inhibitor, and in red the data measured with the inhibitor added to the electrolyte are presented.

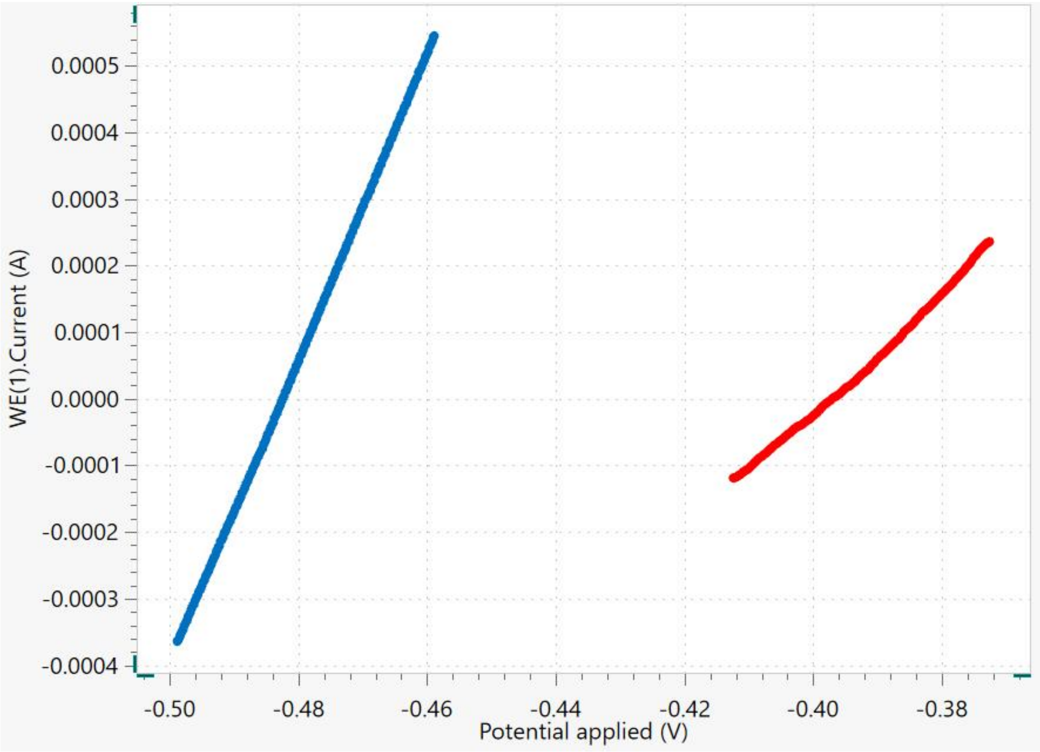

Figure 2. The voltammograms of the linear polarizations. The data is measured without the inhibitor (blue), and with the inhibitor in the electrolyte (red).

Figure 2 shows that the data with the inhibitor appears on the right side of the plot, with respect to the data without inhibitor. This means that in the case of the electrolyte with the inhibitor, the same current values occur at potential higher (more noble) than the electrolyte without the inhibitor.

In LP measurements, the inverse of the slope of the i vs. E plot near E_{corr} can be used to estimate the polarization resistance values (R_p , Ω).

When the inhibitor is added to the system, a decrease in the slope is observed, indicating that R_p has increased.

A linear regression around E_{corr} (not shown here) helped to calculate R_p. In the case of the LP measurements without inhibitor, a value of $R_p = 42.62$ Ω is found. In the presence of the inhibitor, the value of $R_p = 135.96$ Ω is found.

In **Figure 3**, the Tafel plots are shown.

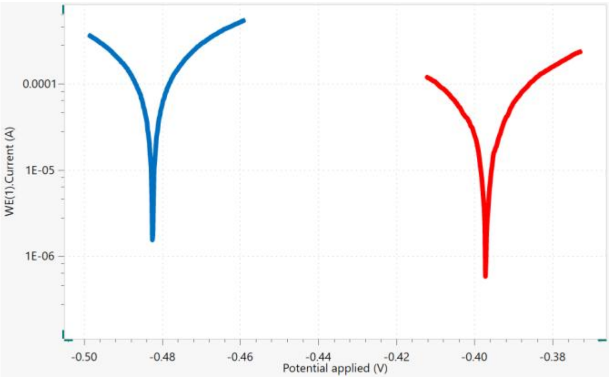

Figure 3. The Tafel plots of the data measured without the inhibitor (blue) and with inhibitor (red).

There, the E_{corr} can be easily determined, being the potential value where the current drops to zero, the position of the negative spike in the log(i) vs E plot.

The data analysis is further performed and additional corrosion parameters can be calculated by using the *Corrosion rate analysis* command in the NOVA software.

The calculated polarization resistance for the sample in the electrolyte without inhibitor was R_p = 43.32 Ω and for the sample in the electrolyte with the inhibitor R_p = 136.39 Ω. The results were similar with those discussed before which were obtained with the linear regression of LP measurements. Table 1 compares the results obtained from the linear regression and the corrosion rate analysis, with and without the inhibitor. The values of the corrosion rates are also listed.

Table 1. Results from linear regression of the LP and corrosion rate analysis from experiments dome with and without the inhibitor.

Parameter	Without Inhibitor	With Inhibitor
E_{corr} (V) from linear regression	-0.479	-0.392
E_{ccor} (V) from corrosion rate analysis	-0.482	-0.396
R_p (Ω) from linear regression	42.62	135.96
R_p (Ω) from corrosion rate analysis	43.32	136.39
Corrosion rate ($mm\ year^{-1}$) from corrosion rate analysis	0.25	0.065

The fact that the value of the R_p calculated with the corrosion rate analysis is close to the value calculated with the linear regression of the LP is an additional indication that the calculated corrosion parameters are valid. It can be seen that the corrosion rate of the material in the solution with the inhibitor (0.065 $mm\ year^{-1}$) is much lower than the corrosion rate measured in the same conditions in the electrolyte without the inhibitor (0.25 $mm\ year^{-1}$).

According to the ASTM standard G185, the inhibitor efficiency can be calculated with the following Equation:

$$\text{Inhibitor efficiency (\%)} = 100 \cdot \frac{CR_{no\ inhib} - CR_{inhib}}{CR_{no\ inhib}}$$

Where $CR_{no\ inhib}$ ($mm\ year^{-1}$) is the corrosion rate calculated without inhibitor, and CR_{inhib} ($mm\ year^{-1}$) is the corrosion rate calculated in the presence of the inhibitor.

Using the corrosion rate from the corrosion rate analysis (**Table 1**), the inhibitor efficiency is calculated at 74%.

CONCLUSIONS

This application note exemplifies a common use of the rotating cylinder electrode in the field of industrial and academic corrosion research. Two electrolytes were employed, one of them containing a tryptamine-based corrosion inhibitor. Linear polarization experiments were performed at 500 RPM rotation rate, corresponding to a fluid velocity v_{RCE} = 82.3 $cm\ s^{-1}$ (2.7 $ft\ s^{-1}$) inside a pipe with schedule 40, with an internal diameter of 30.32 *cm* (12′′). The effect of the inhibitor was evaluated from visual observation, linear regression, and corrosion rate analysis of linear polarization data.

Finally, the inhibitor efficiency was calculated, showing that the corrosion rate in the presence of the inhibitor is 74% lower than without the inhibitor.

REFERENCES

1. ASTM G185-06(2016), Standard Practice for Evaluating and Qualifying Oil Field and Refinery Corrosion Inhibitors Using the Rotating Cylinder Electrode, ASTM International, West Conshohocken, PA, 2016, www.astm.org
2. Metrohm Autolab White Paper: "Corrosion Best Practice. Creating Pipe-flow Conditions Using a Rotation Cylinder Electrode".

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CONFIGURATION

Autolab PGSTAT204

The PGSTAT204 combines the small footprint with a modular design. The instrument includes a base potentiostat/galvanostat with a compliance voltage of 20 V and a maximum current of 400 mA or 10 A in combination with the BOOSTER10A. The potentiostat can be expanded at any time with one additional module, for example the FRA32M electrochemical impedance spectroscopy (EIS) module.

The PGSTAT204 is an affordable instrument which can be located anywhere in the lab. Analog and digital inputs/outputs are available to control Autolab accessories and external devices are available. The PGSTAT204 includes a built-in analog integrator. In combination with the powerful NOVA software it can be used for most of the standard electrochemical techniques.

Autolab PGSTAT302N

This high end, high current potentiostat/galvanostat, with a compliance voltage of 30 V and a bandwidth of 1 MHz, combined with our FRA32M module, is specially designed for electrochemical impedance spectroscopy.

The PGSTAT302N is the successor of the popular PGSTAT30. The maximum current is 2 A, the current range can be extended to 20 A with the BOOSTER20A, the current resolution is 30 fA at a current range of 10 nA.

0.250 L Corrosion Cell

Complete cell for corrosion measurements, 250 mL.

Rotating Cylinder Electrode (RCE)

Autolab Rotating Cylinder Electrode (RCE) with a **non-carbon liquid contact** provides **superior noise-free corrosion** measurements. The RCE's Hg contact produces smooth and accurate data that requires no special handling or tools for use in your lab.

With the **highest rotation rate** among commercially available systems, the Autolab Rotating Cylinder Electrode allows you to simulate the widest variety of pipe flow conditions in your lab. The **RCE has double the rotation rate** of any other **12 mm rotating cylinder electrode** making achievable flow rates are 50% higher than any other commercially available RCE.

Maximum simulated turbulent flow rates:
1 inch/2.66 cm pipe with schedule 40 is 365 cm/s
24 inch/57.48 cm pipe with schedule 40 is 566 cm/s

The Autolab RCE is **very compact**, only a tenth of the size of other commercially available RCEs. You can access the full rotation rate of the Autolab RCE (100-5000 rpms) with a 12 mm cylinder.

Operating temperature range: max 40 C°
Exposed sample surface: 3 cm^2

Image shows RCE and controller, RRDE cell, PGSTAT204 and NOVA software.

Keywords: Rotating Cylinder Electrode, Corrosion, RCE, pipe flow, turbulent flow, corrosion in pipes, pipes, Reynolds number, cylindrical sample.