Application Note AN-COR-014

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.

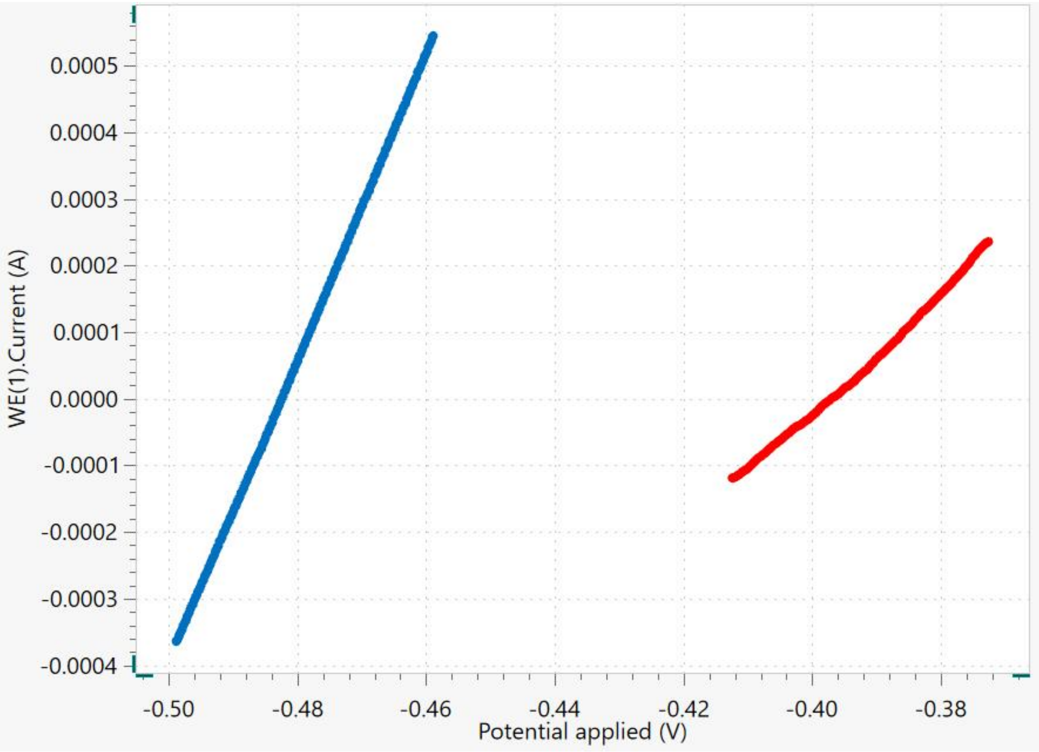

Figure 2. The voltammograms of the linear polarizations. The data is measured without the inhibitor (blue), and with the inhibitor in the electrolyte (red).

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.

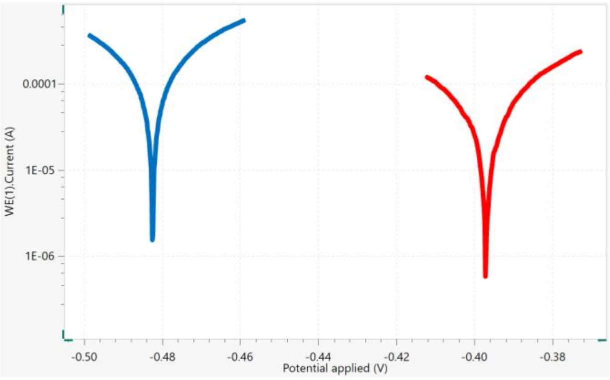

Figure 3. The Tafel plots of the data measured without the inhibitor (blue) and with inhibitor (red).

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

Le PGSTAT204 associe faible encombrement et conception modulaire. Cet appareil comprend un potentiostat/galvanostat de base avec une tension disponible de 20 V et une intensité maximum de 400 mA ou 10 A en association avec le BOOSTER10A. Le potentiostat peut évoluer à tout moment au moyen d'un module complémentaire, comme le module de spectroscopie d'impédance électrochimique (SIE) FRA32M.

Le PGSTAT204 est un appareil d'un prix abordable qui trouve toujours une place dans le laboratoire. Il dispose d'entrées et de sorties analogiques et numériques pour controler les accessoires Autolab et les appareils externes. Le PGSTAT204 comprend un intégrateur analogique intégré. Associé au logiciel performant NOVA, il peut etre utilisé pour la plupart des techniques d'électrochimie standard.

Autolab PGSTAT302N

Ce potentiostat/galvanostat haut de gamme pour courant élevé, avec une tension disponible de 30 V et une bande passante de 1 MHz, associé à notre module FRA32M, est spécialement concu pour la spectroscopie d'impédance électrochimique.

Le PGSTAT302N est le successeur du très populaire PGSTAT30. L'intensité maximale est de 2 A, la gamme d'intensité peut etre étendue à 20 A avec le BOOSTER20A, la résolution de l'intensité est de 30 fA pour une gamme d'intensité de 10 nA.

Cellule de corrosion de 0,250 L

Cellule complète pour mesures de la corrosion, 250 mL.

Électrode à cylindre tournant (RCE)

L'**électrode à cylindre tournant (RCE) Autolab** avec un **contact liquide sans carbone** fournit des mesures de **corrosion supérieures sans bruit de fond**. Le contact de la RCE avec le mercure (Hg) produit des données précises et lissées qui ne nécessitent aucune manipulation particulière ni aucun outil pour l'utilisation dans votre laboratoire.

Avec la **vitesse de rotation la plus élevée** des systèmes disponibles sur le marché, l'électrode à cylindre tournant Autolab vous permet de simuler dans votre laboratoire de multiples conditions de débit dans des conduits. La **RCE double la vitesse de rotation** de toute autre **électrode à cylindre tournant de 12 mm**, ce qui permet d'atteindre des débits d'écoulement50 % plus élevés que ceux d'autres RCE disponibles dans le commerce.

Débit turbulent maximum simulé :

conduit de 1 po/2,66 cm de catégorie 40 est de 365 cm/s

conduit de 24 po/57,48 cm de catégorie 40 est de 566 cm/s

L'électrode RCE Autolab est **très compacte**, elle ne fait qu'un dixième de la taille des autres RCE disponibles dans le commerce. Vous pouvez atteindre la pleine vitesse de rotation de l'électrode RCE Autolab (100-5000 rpms) avec un cylindre de 12 mm.

Gamme de température de service : max. 40 °C

Surface exposée de l'échantillon : 3 cm^2

La figure montre la RCE et le controleur, une cellule RRDE, le PGSTAT204 et le logiciel NOVA.

Mots-clés : électrode à cylindre tournant, corrosion, RCE, débit dans conduit, débit turbulent, corrosion dans conduits, conduits, nombre de Reynolds, échantillon cylindrique.