根据 ASTM G185 标准,使用 Autolab 旋转圆筒电极 (RCE) 测量湍流条件下的缓蚀剂效率

INTRODUCTION

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 ρ = 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.

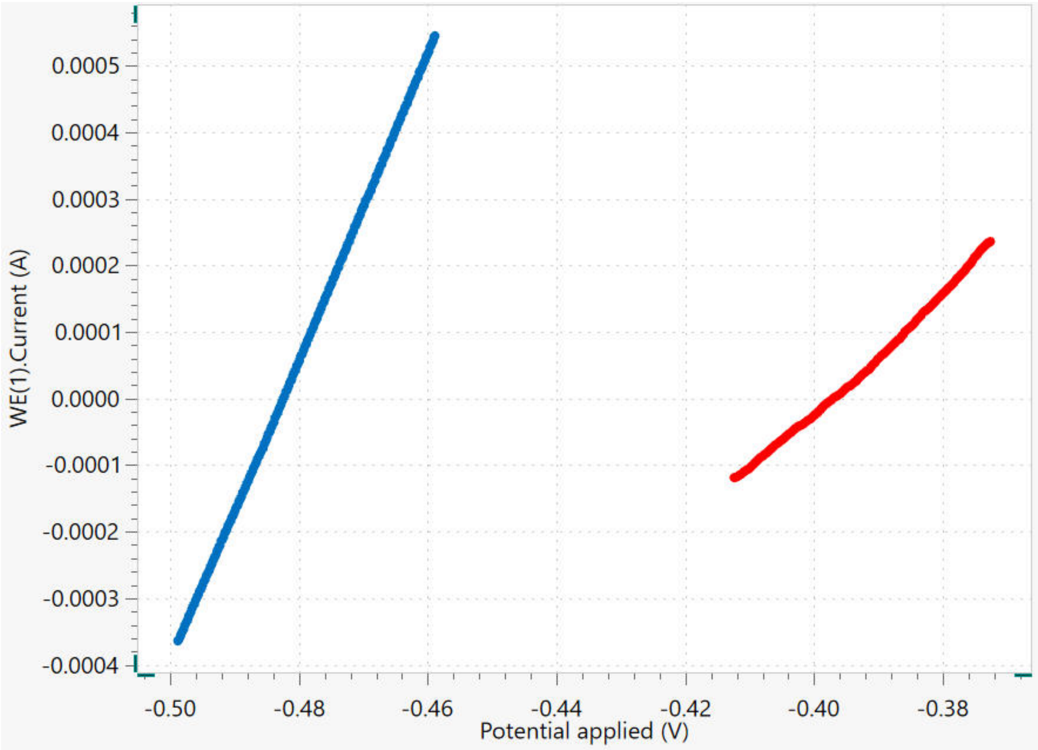

Figure 2. The voltammograms of the linear polarizations. The data is measured without the inhibitor (blue), and with the inhibitor in the electrolyte (red).

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.

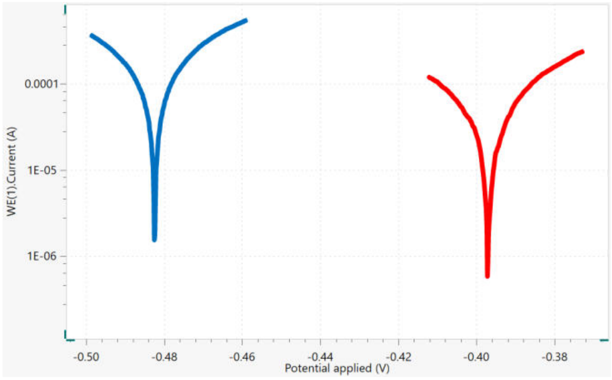

Figure 3. The Tafel plots of the data measured without the inhibitor (blue) and with inhibitor (red).

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

PGSTAT204 结合了小巧规格和模块化设计。该仪器包括基本恒电位仪/恒电流仪,其顺从电压为 20 V,最大电流为 400 mA 或 10 A,与 BOOSTER10A 组合使用。此恒电位仪可随时用附加模块进行扩展,例如 FRA32M 电化学阻抗谱(EIS)模块。
PGSTAT204 是一款经济实惠的仪器,可置于实验室的任何位置。具有模拟和数字输入/输出,可控制 Autolab 附件和外部设备。PGSTAT204 包括内置模拟积分器。与高性能的 NOVA 软件联用,可用于大多数标准电化学技术。

Autolab PGSTAT302N

该恒电位仪/恒电流仪,具有 30 V 顺从电压,带宽为 1 MHz,可与我们的 FRA32M 模块联用,专门针对电化学阻抗谱而设计。
PGSTAT302N 是流行的 PGSTAT30 的后继款型。最大电流为 2 A,借助 BOOSTER20A 电流范围可扩展至 20 A,当电流范围为 10 nA 时电流分辨率为 30 fA。

0.250 L

完整的腐蚀测量池,250 mL。

(RCE)

Autolab **旋转圆柱电极** (RCE) 具有 **非碳液体接触面,** 可提供**无噪声腐蚀性** 测量。RCE 的 Hg 接触面,可以得到流畅准确的数据,您的实验室无需特殊的处理或工具。

在现有各种市售系统中,Autolab 的旋转圆柱电极具有**较高的旋转速度**,这允许您在您的实验室中,模拟种类较为广泛的管道流动状况。**RCE 的旋转速度**是任何**其他 12 mm 旋转圆柱电极** 的 2 倍,因此可实现的流速比任何其他市售 RCE 高 50%。

最大模拟湍流流速:
1 inch/2.66 cm Schedule 40 管道为 365 cm/s
24 inch/57.48 cm Schedule 40 管道为 566 cm/s

Autolab RCE **非常紧凑**, 只有其它市售 RCE 体积的十分之一。您可以获得带 12 mm 圆柱的 Autolab RCE (100-5000 rpms) 的全速的转速。

运行温度范围: 较高 40 C°
暴露样品表面: 3 cm^2

图片显示了 RCE 和控制器、RRDE 池、PGSTAT204 和 NOVA 软件。

关键词:旋转圆柱电极、腐蚀、RCE、管流、湍流、管内腐蚀、管路、雷诺数、圆柱样本。