

Application Note AN-COR-019

# Determining the corrosion rate with INTELLO

## Tafel analysis and more

Tafel analysis is an important electrochemical technique used to understand reaction kinetics. Studying the Tafel slope reveals the rate-determining steps in electrode reactions, aiding fields like corrosion and fuel cell research. This method helps industries optimize processes and improve device performance by tailoring materials and conditions for greater efficiency.

Regarding corrosion, Tafel analysis provides insights into the corrosion rate and mechanisms of different metals in various environments. By examining the Tafel slope, researchers can determine the polarization resistance and corrosion rate as well as the corrosion current and potential, shedding light on how materials interact with their surroundings. This analysis aids industries in selecting the appropriate coatings, inhibitors, and materials to mitigate corrosion, extend the lifespan of structures, and ensure the integrity of metal components in challenging environments.

This Application Note illustrates Tafel analysis in INTELLO with aluminum in artificial seawater.

## EXPERIMENTAL

A 250 mL three-electrode corrosion cell was constructed for this study. An Ag/AgCl reference electrode was used along with two stainless steel rod-shaped counter electrodes, and an aluminum disc mounted on a sample holder served as the working electrode. The electrolyte was artificial seawater (3.5% NaCl).

The default procedure in INTELLO (Linear Polarization – Tafel Analysis) was chosen. First, an open circuit potential (OCP) measurement was made, and then -30 mV vs OCP was applied. A linear sweep to +20 mV vs OCP was programmed. A scan rate of 50 mV/s was used.

## RESULTS

The result of the linear polarization experiment (*j* vs E plot) is shown in Figure 1. Note that the normalized current (current density) is plotted by default.

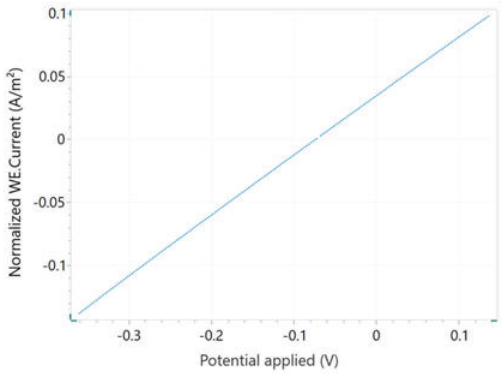



**Figure 1.** Current vs potential plot of aluminum in seawater.

A Tafel plot, Log(I) vs E, is also shown in Figure 2.

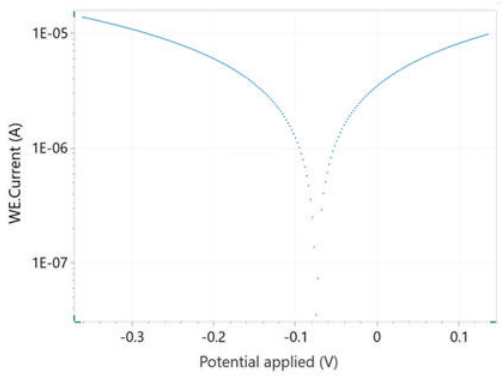



**Figure 2.** Tafel plot which corresponds to the j vs E curve shown in Figure 1.

When selecting the Tafel analysis command, it is possible to specify the density of the sample, its equivalent weight, and the surface area (Figure 3). If these variables are already known, they can also be added in the main parameters window prior to beginning the experiment.

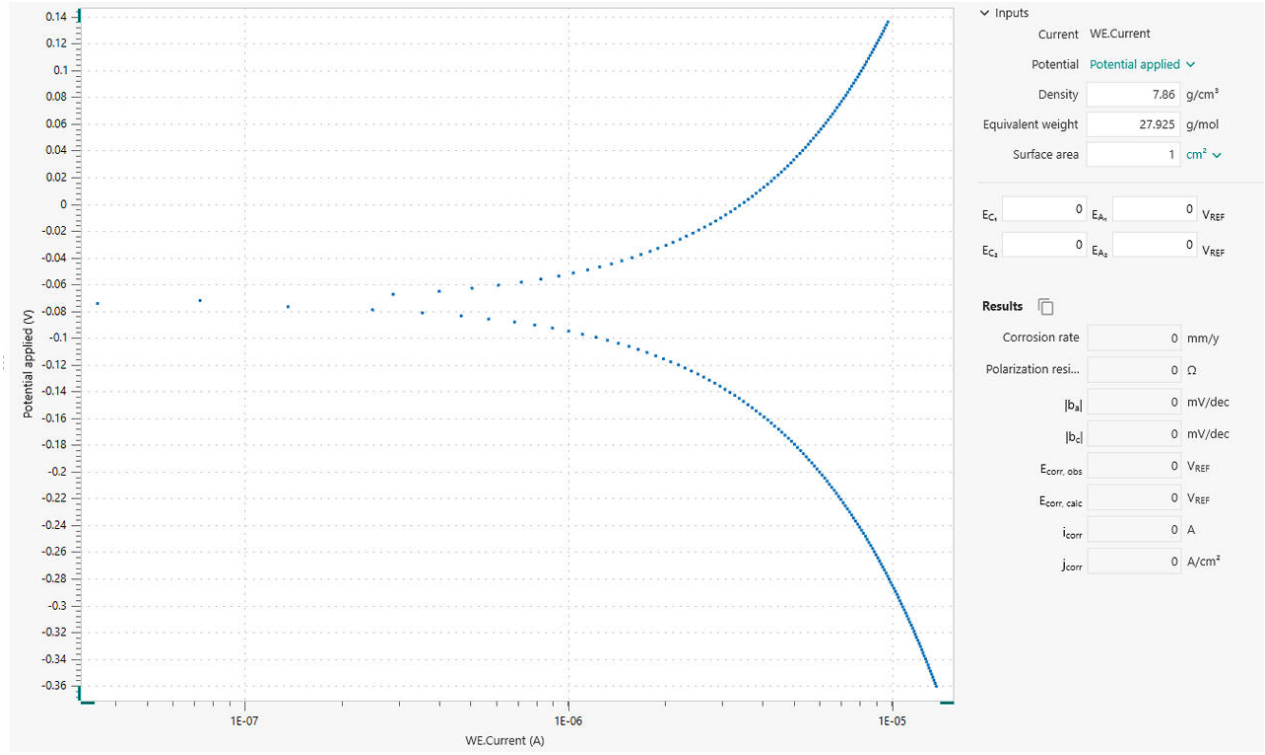



**Figure 3.** Tafel analysis window in INTELLO.

In order to perform a corrosion rate analysis, the linear regions of the anodic and cathodic side of the Tafel plot must be specified. This is accomplished with the help of four markers: two each for the anodic side and the cathodic side. Such markers define the lines for the linear regressions, according to the Tafel equations below.

Once the regions are selected, the linear regressions appear in the plot. The positions can be readjusted by dragging the markers to new positions on the plot. The corrosion potential and the corrosion current correspond to the X and Y coordinates, respectively, of the intersection of the two regression lines (Figure 4).

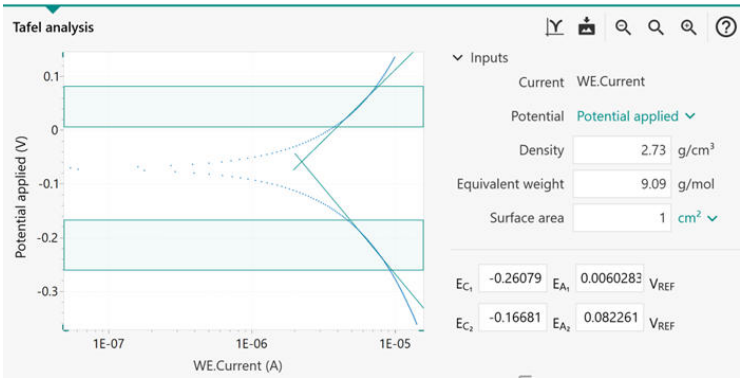



**Figure 4.** Tafel analysis window with the linear regions identified in the shaded area between the horizontal markers. The green angled lines indicate linear regressions.

The results of the Corrosion Rate Analysis command are listed in Figure 5. The Tafel analysis provides a quick estimation of the corrosion rate and the polarization resistance.




**Figure 5.** Results of the corrosion rate analysis.

The corrosion rate ($R_M$, mm/year) is calculated in the following equation using the corrosion current, $i_{corr}$.

$$R_M = 3.17E-9\frac{M}{nF\rho A}i_{corr}$$

3.17E - 9: conversion factor from cm $s^{-1}$ to mm $year^{-1}$
M (g $mol^{-1}$): atomic weight of the sample n: number of electrons exchanged in the reaction $\rho$ (g $cm^{-3}$): density of the sample $F$ (96485 C $mol^{-1}$): Faraday constant $A$ ($cm^2$): area of the sample
The ratio M/n is also named equivalent weight.
To calculate $i_{corr}$, the Butler-Volmer equation is employed, as shown here.

$$i_{corr}\left(e^{2.303\frac{\eta}{b_a}} - e^{-2.303\frac{\eta}{b_c}}\right)$$

$i_{corr}$: corrosion current (i.e., the rate of charge transfer at the corrosion potential $E_{corr}$) 2.303: conversion factor between log and $\log_e$ and $\log_{10}$ $\eta$ (V): overpotential, defined as the difference between applied potential $E$ and the corrosion potential $E_{corr}$ $b_a$ (V): Tafel slope of the anodic branch $b_c$ (V): Tafel slope of the cathodic branch
For large anodic overpotentials,

$$\left(\frac{\eta}{b_a} \gg 1\right)$$

the Butler-Volmer equation simplifies to the Tafel equation for the anodic reaction:

$$\eta = b_a \cdot log\left(\frac{i}{i_{corr}}\right)$$

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Analogously, for large cathodic overpotentials,

$$\left(\frac{\eta}{b_c} \ll -1\right)$$

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the Tafel equation for the cathodic reaction is given by:

$$\eta = -b_c \cdot log\left(\frac{i}{i_{corr}}\right)$$

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The Tafel equations predict a straight line for the variation of the logarithm of the current with the potential. Therefore, currents are often shown in semi-logarithmic plots, known as Tafel plots.

Care must be taken when choosing the regions for Tafel slope analysis. A correct estimate of the Tafel slopes is possible only if the linear Tafel region (the shaded regions between each pair of markers in Figure 3) covers at least one decade in current.

In certain cases, the Tafel slope analysis is not possible.

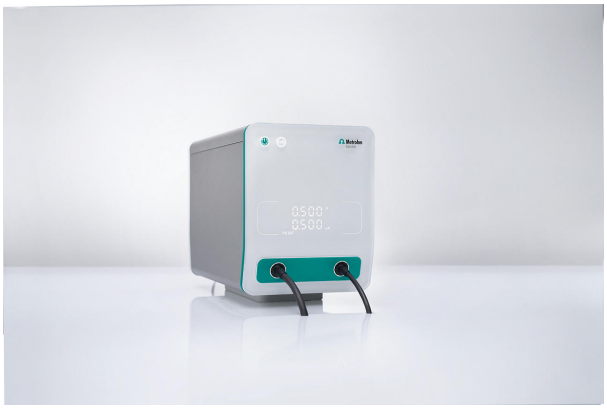
For example, under the diffusion control, the reactants are hampered in reaching the sample surface (e.g., in stagnant solutions). As a consequence, the cathodic reaction does not occur, resulting in $b_c = \infty$.

Similarly, under passivation conditions, the surface of the sample is coated with a protective layer. This prevents the anodic reaction from occurring, resulting in $b_a = \infty$.

## CONTACT

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## CONFIGURATION



VIONIC

VIONIC is our new-generation potentiostat/galvanostat that is powered by Autolab's new INTELLO software.

VIONIC offers the **most versatile combined specifications of any single instrument** currently on the market.

- Compliance voltage: ± 50 V
- Standard current ± 6 A
- EIS frequency: up to 10 MHz
- Sampling interval: down to 1 µs

Also included in VIONIC's price are features that would usually carry an additional cost with most other instruments such as:

- Electrochemical Impedance Spectroscopy (EIS)
- Selectable Floating
- Second Sense (S2)
- Analog Scan