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Study of Corrosion Inhibition of a Corrosion Inhibitor Prepared from Duomeen-T®, Ethylene Oxide and Benzyl Chloride for Carbon Steel in Acidic Water

Rafaa M. R. Esmaael[1*], Dawod H. Elabar[2], Abdelkarem Elgazali[3], Abdalfattah A. Khalil[4]

***Corresponding author:** Rafaa.esmaael@omu.edu.ly, Department of Materials Science and Engineering Faculty of Engineering, Omar Al-Mukhtar University, Libya.

[2, 3] Environmental and Biological Chemistry Research Center (EBCRC), Tocra, University of Benghazi, Libya

[4] Department of Materials Science and Engineering Faculty of Engineering, Omar Al-Mukhtar University, Libya.

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Abstract

The research presents the effect of corrosion inhibition of a corrosion inhibitor formulated by blending Duomeen-T®, ethylene oxide (EO), and benzyl chloride on carbon steel in oilfield production facilities. The experiments were conducted in an environment with Sharara oilfield formation waters saturated with CO_2. Duomeen-T® acted as a hydrophobic agent, while EO enhanced the performance of the inhibitor by improving the stability of the protective film on the metal surface. The effectiveness of the inhibitor was assessed using the ACM linear polarization bubble test corrosion system. Findings reveal remarkable inhibition efficiency, even at lower concentrations, achieving over 95% inhibition in some cases at just 15 ppm of corrosion inhibitor.

Keywords: Duomeen-T®, Ethylene Oxide (EO), LPR, Formation Water, Benzyl Chloride.

INTRODUCTION

Corrosion is the degradation of materials, usually metal, owing to chemical reaction with the environment, which results in a functional failure of a component. It poses significant challenges in oil and gas production facilities. Ongoing research aims to develop new corrosion inhibitors to address corrosion problems faced in the petroleum industry (Samuel, Etim, Nweke-Maraizu, Bako, & Shinggu, 2023). When process equipment and other facilities in oil production and processing are made of steel exposed to a corrosive environment, studies estimate that around 2.2 pounds of steel are lost for every 7.46 barrels of processed oil. This shows the need for the implementation of effective corrosion mitigation strategies for maintaining mechanical integrity management of the assets. The losses due to corrosion in the petroleum industry are substantial, necessitating the implementation of preventive measures. Among the various approaches available for corrosion prevention, the addition of corrosion inhibitors is a cost-effective and efficient solution (Al-Otaibi et al., 2014). A corrosion inhibitor is a chemical agent that diminishes or prevents the interaction between metals and their environment, even when added in small quantities. These inhibitors are commonly used in various systems, such as oil and gas production, cooling, and refining operations. Compared to other corrosion protection techniques, corrosion inhibitors are regarded as one of the most practical and economical options available (Hassan, Abdelghani, & Amin, 2007)

Classification of Corrosion Inhibitors:

The corrosion inhibitors are classified in different ways. The primary classification of corrosion inhibitors is based on their chemical composition and their mode of action. The classification is given below:

- Organic or inorganic corrosion inhibitors
- Anodic or cathodic corrosion inhibitors.
- Oxidants or non-oxidant corrosion inhibitors

Inorganic corrosion inhibitors typically exhibit either anodic or cathodic behaviors, while organic corrosion inhibitors function as protective film formers that envelop the entire metal surface, exhibiting both anodic and cathodic characteristics. Compounds such as amines, imidazolines, and quaternary ammonium substances act as organic film formers, mitigating corrosion through adsorption on the metal surface and effectively blocking corrosive agents from contacting the metal. These types of inhibitors are commonly used in the oil and gas sector (Al-Amiery, Yousif, Isahak, & Al-Azzawi, 2023; Alamiery, 2021; Dawood et al., 2021). The classification of organic inhibitors is generally influenced by their interactions with the metal surface and their impact on the potential of that surface. The chemical structure of the inhibitor molecule plays a crucial role in determining its effectiveness (Obot, Obi-Egbedi, & Umoren, 2009)

The efficacy of organic inhibitors is contingent upon various factors, including:

- The molecular shape and functional groups.
- The presence of aromatic structures and bonding types.
- The length of the carbon chain.
- The adhesion strength to the metal surface.
- The density and cross-linking characteristics of the protective layer. Organic corrosion inhibitors can be categorized into two main types: (a) water-soluble and oil-dispersible, and (b) oil-soluble and water-dispersible corrosion inhibitors. Their use depends on which liquid phase is predominant within the production system.

The mechanism by which organic corrosion inhibitors function involves the adsorption of electrically charged organic groups at the interface between the metal and the solution. The adsorption process is influenced by several factors, including the chemical structure of the molecules, the type of solution, the characteristics of the metal substrate, and the nature of the electrical double layer, whether it is positively or negatively polarized. There are various modes of adsorption, including:

- Pie-bond orbital adsorption.
- Electrostatic adsorption.
- Chemisorption.

Organic inhibitors generally function by their adsorption onto the metal surface, and their effectiveness can depend on how well they interact with active locations (Trabanelli, 2020)

Inhibition Efficiency Measurements:

The effectiveness of corrosion inhibitors is monitored through methods such as mass loss corrosion coupons and various electrochemical techniques. These electrochemical techniques include linear polarization resistance (LPR) tests, electrical resistance (ER) probes, potential measurements, potentiodynamic tests, and electrochemical impedance spectroscopy.

Linear polarization resistance technique:
The linear polarization resistance method is widely recognized as the most utilized technique in electrochemical testing. In this approach, the working electrode is subjected to positive and negative polarization, typically set at ±20 mV from the open circuit potential (E_{cor}). Within this voltage range, the polarization curve is regarded as linear. This testing can be performed in laboratory settings and in the field. The total current density (i) at the metal electrode interface, which is the difference between the anode and cathode current densities, can be expressed as follows:
$i_{net} = i_a - i_c$
Where:
The anodic and cathodic current densities are represented by i_a and i_c, respectively, while i_{net} signifies the total current density at the interface. As described below, both the anodic and cathodic current densities depend on the potential difference and the slope of the polarization curve.

$$i_a = i_0 \exp\left[{(E - E^0)}/{\beta_a}\right]$$
$$i_c = i_0 \exp\left[{(E^0 - E)}/{\beta_c}\right]$$

The final form of the equation can be expressed as:

$$i_{net} = i_{cor}\left[\exp\left({\eta}/{\beta_a}\right) - \exp\left({\eta}/{\beta_c}\right)\right], \quad \eta \text{ is the over potential}$$

The equation outlined earlier indicates that the overall current density (i) has an exponential relationship with the overpotential, based on the following assumptions:

- The movement of charge at the boundary between the electrode and the electrolyte influences the process of electrochemical corrosion.

- The solution resistance is considered negligible.
- Concentration polarization is ignored.
- There are no secondary electrode reactions.

Under these assumptions, the corrosion current density can be represented as follows: (Esmaael & Alkathafi, 2019)

$$i_{cor} = {b_a b_c}/{2.303(b_a + b_c)\left({\delta i}/{\delta E}\right)} = {B}/{R_p}$$

B is a constant derived from calibrating measurements of mass loss due to corrosion, while b_a and b_c are referred to as Tafel slopes. To measure polarization resistance R_p, the working electrode is polarized ± 20 mV in both anodic and cathodic directions, starting from the open circuit potential (E_{cor}) (Yıldırım & Cetin, 2008).

MATERIALS AND METHODS

Chemicals Used:
All chemicals used in this study are reagent grade. The following chemicals are used in the formulation of corrosion inhibitors:

Duomeen-T® - It is a commercial product manufactured by the Nouryon company. The general chemical formula of Duomeen-T® is alkyldiamine (R-NH-$(CH_2)_3$- NH_2), where R is an alkyl group. The main function of this compound in the formulation of corrosion inhibitor is a dispersant agent.

Ethylene oxide - Ethylene oxide is a reactive compound often used in the synthesis of surfactants, emulsifiers, and other chemicals. In the formulation of the present corrosion inhibitor to create ethoxylated compounds are created to improve the solubility and effectiveness of the inhibitor in aqueous systems. The other benefit of ethylene oxide is to modify metal surface absorption and make the surface less susceptible to corrosion. It is also slightly buffers the organic acids.

Benzyl chloride – Benzyl chloride-derived compounds can adsorb onto metal surfaces, forming a hydrophobic layer that blocks corrosive agents such as water and oxygen from reaching the metal surface. It has been widely accepted that Benzyl Chloride shows an outstanding corrosion protection performance.

Formulation of Corrosion Inhibitor

The chemical formulation of the corrosion inhibitor used in this study is shown in Table 1.

Table 1: The chemical composition of corrosion inhibitor

Component	Percentage in (wt.%)
Deionized water	75
Duomeen-T® plus 9.5 mol Ethylene oxide	15
Benzyl chloride	10

Water Samples to Prepare Test Solution

The water samples were collected from the Sharara oilfield from the following locations:

a) Water from the discharge of the test separator, and
b) Water from the water source well (WSW 05).

To ensure accurate results, pH, CO_2, temperature, and alkalinity measurements of water samples were recorded at the site during sampling to prevent any alterations in the water characteristics during transportation to the laboratory. A comprehensive analysis of the water was conducted in a laboratory located in Benghazi city using ASTM standard methods. The results of water analysis are presented in Table 2.

Table 2: Results of chemical analysis of water samples

Property	Units	Water from the Outlet of the Test Separator	Water from Water Source Well (WSW 05)
pH	-	5.3	6.8
Sodium ion (Na^+)	mg/L	64241	640
Calcium ion (Ca^{2+})	mg/L	12000	128
Magnesium ion (Mg^{2+})	mg/L	1507	90
Barium ion (Ba^{2+})	mg/L	0	0
Strontium ion (Sr^{2+})	mg/L	0	1
Iron (Fe^{2+})	mg/L	109	0.04
Chloride ion (Cl^-)	mg/L	140500	925
Bicarbonate ion (HCO_3^-)	mg/L	124	155
Sulfate ion (SO_4^{2-})	mg/L	550	625

Test Solution

The test solution was prepared by bubbling carbon dioxide (CO_2) gas in the water samples collected from the Sharara oilfield before starting the study of corrosion measurement to ensure saturation and acidification of the solution. Bubbling of CO_2 in water for one hour in the water samples drops pH to 5. The temperature of the thermostatic bath was maintained at 70°C. This temperature is slightly higher than the field application temperature.

The concentrations of the corrosion inhibitors tested were 0.5, 10, 20, 50, and 100 ppm.

Corrosion Rate Measurement

ACM Gill-12 linear polarization corrosion rig, consisting of twelve capped glass cells of having capacity of one liter each, was used for corrosion measurement in this study. All these cells were dipped in a thermostatic water bath capable of maintaining a stable temperature. Each corrosion cell contains three SAE 2018 carbon steel electrodes that serve as the working, reference, and auxiliary electrodes. A computerized potentiostatic system is connected to each cell for precise measurements. To ensure saturation of the solution, CO_2 is introduced into the system via a gas regulator and rubber tubing. Data collected from the measurements are automatically transmitted to the software for continuous processing and calculation of corrosion rates. Fig.1 shows a complete overview of the ACM corrosion bubble test rig.

Figure: (1). LPR Gill-12 corrosion test system

RESULTS AND DISCUSSION

The test solutions were tested with addition of different concentrations of corrosion inhibitor. The results are presented in Figure 2. The figure displays the corrosion behavior over time, measured in hours, for the test solution prepared from the water obtained from the outlet of the test separator at various inhibitor concentrations ranging from 0 to 100 ppm. The introduction of the inhibitor leads to a notable reduction in the corrosion rate. As the concentration of the inhibitor increases, the corrosion rate of the test solution decreases. The value of approximately 1 mpy corrosion is achieved at the addition of 10 ppm of corrosion inhibitor. For concentrations above 20 ppm, the corrosion rate drops below 1 mpy after 15 hours of immersion. This corrosion rate is also lower than that of the reference sample, as shown in Fig. 2

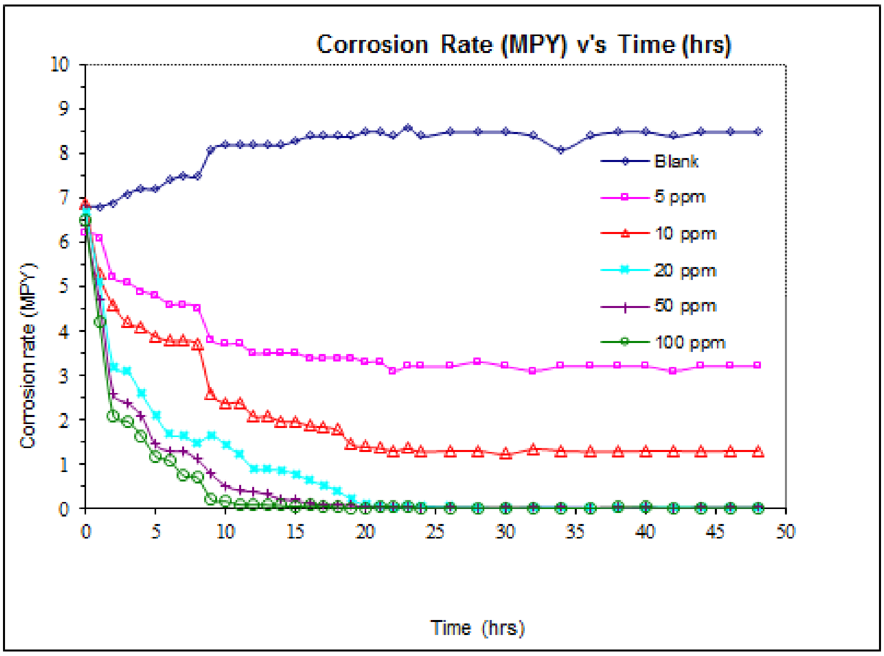

Figure:(2). Corrosion rate vs time for test separator outlet

Fig. 3 depicts the relationship between inhibition efficiency and inhibitor concentration, illustrating that 90% inhibition is achieved at a concentration of 15 ppm.

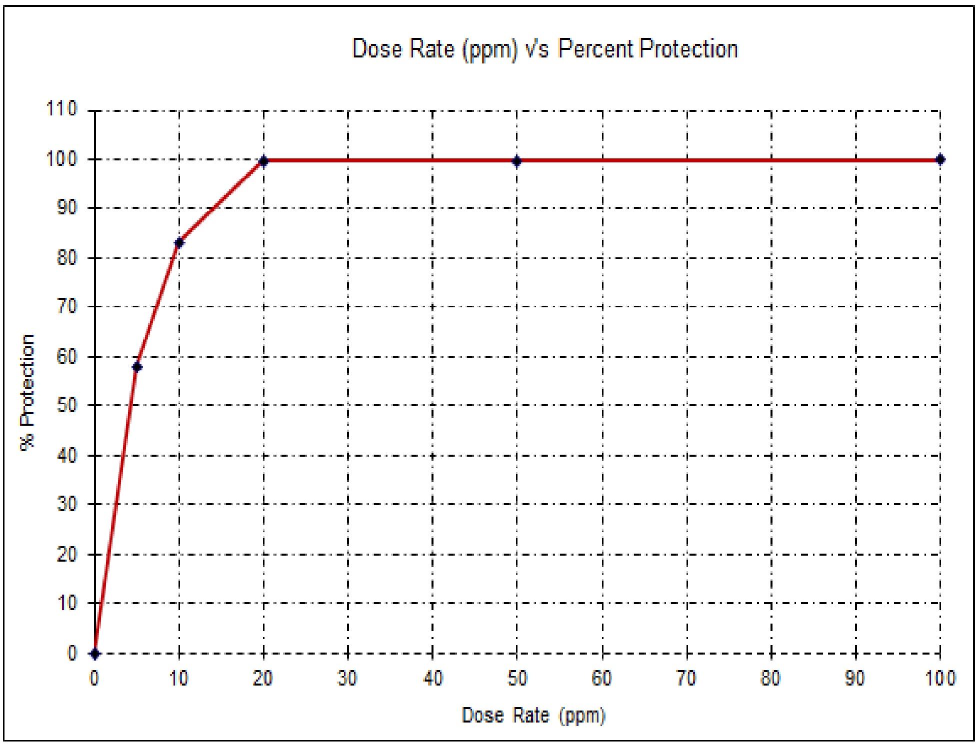

Figure: (3). Corrosion inhibitor dosage rate vs percent inhibition for test separator outlet

The rate of corrosion inhibitor was also evaluated using a test solution prepared from the water obtained from the water source well (WSW05). The results are presented in Figure 4. Linear polarization tests indicate that the corrosion rate decreased from 54 mpy to 13 mpy for 9 hours with an inhibitor concentration of 10 ppm. It was observed that as the concentration of the inhibitor increased, the time required for inhibition also decreased significantly.

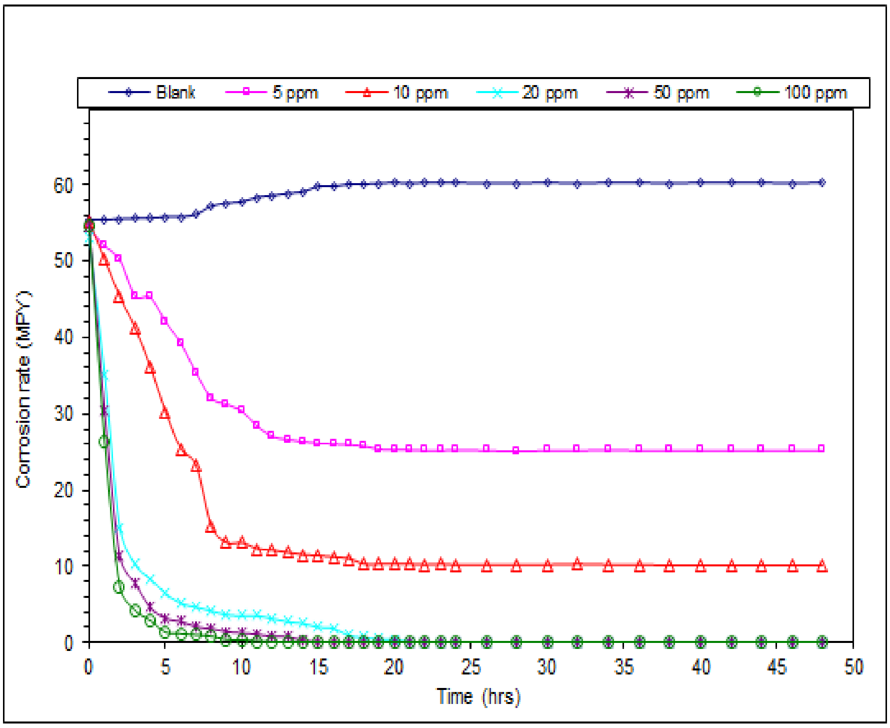

Figure: (4). Corrosion rate vs time for test solution prepared from water source well WSW 05

Figure 5 presents the results of inhibition efficiency with the inhibitor concentration for test sample prepared from the water obtained from WSW05 water source well, where approximately 98 % inhibition was reached at an inhibitor concentration of around 20 ppm.

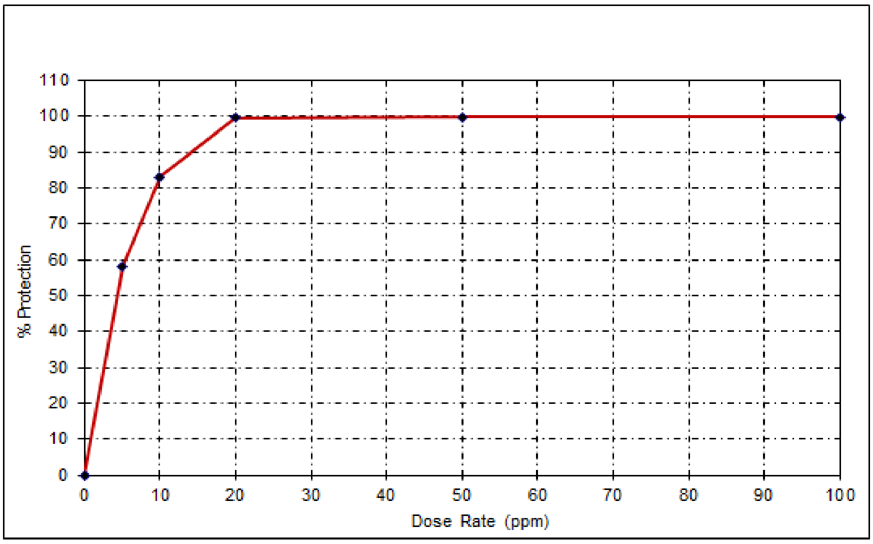

Figure: (5). dosage rate of corrosion inhibitor vs percent corrosion inhibition for the test solution prepared from water obtained from the WSW05 water source well

CONCLUSION

The findings of this study indicate that the corrosion inhibitor formulated with mixing duomeen-T®, ethylene oxide, and benzyl chloride offers exceptional corrosion inhibition for carbon steel in harsh oilfield production environments that are saturated with CO_2. Each component in the formulation and application plays a distinct role: they enhance the dispersion of the inhibitor in the corrosive medium, modify the metal surface, improve the adsorption of the inhibitor, and increase the durability and adhesion of the protective film on the metal surface**.**

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