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Evaluation of a novel cationic surfactant based on 2-(2 (dimethylamino)ethoxy)ethanol as a corrosion inhibitor for carbon steel 1018 in 1.0 M HCl solution

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ABSTRACT

Corrosion inhibition of a novel cationic surfactant namely, N-(2-(2-hydroxyethoxy)ethyl)-N,N-dimethyl dodecan-1-aminium bromide (HEDDB) was evaluated as a corrosion inhibitor for carbon steel in 1.0 M HCl by electrochemical frequency modulation (EFM), potentiodynamic polarization, electrochemical impedance spectroscopy (EIS) and weight loss measurements. Results of Tafel polarization exhibit that the synthesized surfactant HEDDB behaves as mixed-type inhibitor. The effectiveness of temperature on the corrosion rate which evaluated by chemical technique (weight loss) was investigated and assessed. Langmuir's adsorption isotherm was the preferable fitted isotherm. The results of weight loss clarified that the efficiency of the synthesized surfactant increases with raising both the concentration of the surfactant and the temperature. HEDDB effectiveness on the morphology of metal surface was monitored by Atomic Force Microscopy (AFM) and Scanning Electron Microscope (SEM) techniques. Quantum chemical technique has been employed to discuss the inhibition efficiency by effectiveness of molecular structure of the synthesized inhibitor. The various techniques which used in this research have inhibition efficiency (IE) with the same direction.

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1. Introduction

Carbon steel is considered a vital structural material, and is one of the most widespread and popular construction materials across a number of industries; it has played an important role in national economic development, and accounts for approximately 85% of annual steel production worldwide [1,2]. Corrosion is a natural phenomenon or process that keeps track of the science laws, so the reality that corrosion exists should not be a surprise to us. Various materials are expected to deteriorate with time when exposed to specific conditions. For instance, when iron or steel are exposed to air and water, we can expect to see rust develop within a few hours, showing the familiar red-brown color of iron oxide. Corrosion of materials usually takes place in the existence of many variables like oxygen, aggressive medium and moisture where two electrochemical reactions occur, oxidation at anodic sites and

hydrogen evolution at the cathodic site [3–6]. The damage due to corrosion of metals engenders high cost for renovation, replacement of different equipment and causes public and environmental risks. Metal corrosion in the existence of water is a general problem across many industries. The oil and the gas production mainly accompanied by co-produced water, which makes the corrosion a pervasive issue across the industry. Acid solutions used in large extend for removal of undesirable scale and rust in various industrial cleaning, oil well acidifications and in the petrochemical processes [7]. Many of methods have been applied to inhibit or minimize the corrosion of metals such as cathodic or anodic protection, inhibitor application, coating, etc. [8,9]. The one of the most practical methods for protection versus corrosion damage is using of inhibitors in aggressive media. The properties of the effective inhibitor, it must adsorb on the metal surface and go away water molecules from the surface and react with cathodic or anodic reaction sites to postpone the reduction and oxidation reaction. Inhibitors, which reduce corrosion on metallic materials, can be divided into three types: (i) inorganic inhibitors (ii) organic inhibitors and (iii) mixed material inhibitors.

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The suitable inhibitor selected for a specific system is a very difficult mission due to the wide variety of corrosive environments and the selectivity of the inhibitors. Thus, many types of inhibitors were progressed to be compatible with the distinct types of corrosion processes and furthermore the medium where the corrosion happen [10]. The significant category of organic compounds that can be utilized as corrosion inhibitors is surface-active compounds (surfactants) [11–13]. This brand of organic corrosion inhibitor characterized by their high capability to adsorb on the metal surface or interface because of its high surface effectiveness, the output of the surfactant molecules adsorption at the interface [14–22].

In our investigation, we synthesized an effective corrosion inhibitor through simple and direct method. The corrosion inhibition efficiency of C1018 steel in 1.0 M corrosive medium of HCl was determined and confirmed by utilizing various measurements; Tafel polarization, weight loss, and electrochemical impedance. The created film on the surface of the metal is distinguished by scanning electron microscope (SEM) and atomic force microscopy (AFM) methods. Furthermore, the adsorption isotherm of the inhibitor was appreciated.

2. Materials and experimental techniques

2.1. Composition of the studied specimen

C1018 carbon steel type used in oil and gas fields is performed in our experiments. Its chemical composition is 0.2% C, 0.003% Si, 0.04% P, 0.05% S, 0.6% Mn and the iron is the rest.

2.2. Corrosive solution

A stock solution 5.0 M was prepared from a pure grade of hydrochloric acid and standardized with sodium carbonate solution to determine the concentration of the prepared acid. For our study, 1.0 M HCl aggressive solution was prepared by dilution of the prepared 5.0 M HCl with doubly deionized water.

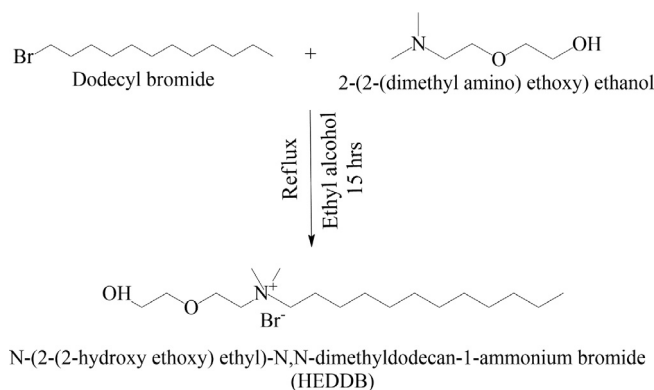
2.3. Chemical inhibitor

10^{-2} M stock solution of cationic surfactant HEDDB was prepared (250 ml) by dissolving a proper weight of synthesized surfactant (0.95607 g) in a certain volume of 1.0 M HCl, then the solution completed up to the 250 mark with aggressive solution (1.0 M HCl). The tested concentrations, which ranged from 1×10^{-3} to 5×10^{-6} M, have been prepared by dilution of the stock solution.

The cationic surfactant was synthesized through simple one direct method. The 2-(2-(dimethylamino)ethoxy)ethanol 0.02 mol (2.66 g) was refluxed with 0.02 mol from dodecyl bromide (4.98 g) in 150 ml absolute ethanol as solvent for 15 h. After evaporating the whole alcohol, the residuum was purified with diethyl ether [23]. The acquired surfactant labeled (HEDDB) and the method of preparation represented in Scheme 1.

2.4. Measurement techniques

Various techniques have been used for monitoring the corrosion of C1018 carbon steel in the aggressive solution (1.0 M HCl) with and without the presence of the HEDDB as a corrosion inhibitor. These techniques are electrochemical measurements, chemical measurement (weight loss) and surface morphology measurements.



Scheme 1. Preparation of newly cationic surfactant.

2.4.1. Electrochemical techniques

Electrochemical techniques namely, electrochemical impedance spectroscopy (EIS), electrochemical frequency modulation (EFM) and potentiodynamic polarization were utilized in our study to demonstrate the corrosion behavior. In these experiments, typical three chambers glass cell were utilized. It is consisted of saturated calomel electrode (SCE) as a reference electrode, a platinum blade (1 cm^2) as a counter electrode and carbon steel specimen as working electrode (1 cm^2). The working electrode was polished with several stages of emery paper sizes from 320 to 2000 and then rinsed with deionized water and acetone. The cell was aerated and the measurement was determined at 25°C under static conditions. All potential values have been recorded versus saturated calomel electrode.

Tafel curves acquired by altering the potential of the electrode automatically from -900 to -150 mV with consideration of steady state potential at a scan rate 0.5 mV s^{-1} . The corrosion potential (E_{corr}) and corrosion current density (i_{corr}) acquired by extrapolation the cathodic and anodic Tafel segments. The I_{E_p} and θ were calculated with the following Eq. (1) [24,25]:

$$I_{E_p}\% = \left(\frac{i_{\text{corr}}^{\circ} - i_{\text{corr}}}{i_{\text{corr}}^{\circ}} \right) \times 100 = \theta \times 100 \quad (1)$$

Where, i_{corr} and i_{corr}° are the corrosion current densities in the presence and absence the studied cationic surfactant, respectively.

By using AC signals, EIS experiments were achieved at a certain corrosion potential in a frequency range of 100 kHz to 100 mHz with capacity of 5 mV peak to peak. The efficiency of the inhibition ($I_{E_{\text{EIS}}}$) obtained using Eq. (2) [26]:

$$I_{E_{\text{EIS}}}\% = \left(\frac{R_{\text{ct}} - R_{\text{ct}}^{\circ}}{R_{\text{ct}}} \right) \times 100 = \theta \times 100 \quad (2)$$

where, R_{ct} and R_{ct}° are the charge transfer resistance with and without the presence of HEDDB, respectively.

The values of interfacial double layer capacitance (C_{dl}) were acquired by the following Eq. (3) [27]:

$$C_{dl} = \frac{1}{2\pi f_{\text{max}} R_{\text{ct}}} \quad (3)$$

where, f_{max} is the frequency at maximum imaginary component of the impedance.

EFM can be achieved as a fast and a nondestructive technique for measurement of corrosion rate. The corrosion current density (i_{corr}), the Tafel slopes (β_a & β_c) and the causality factors (CF-2 & CF-3) can be obtained by the larger peaks [28,29]. The corrosion inhibition efficiency ($I_{E_{\text{EFM}}}$) was calculated according to Eq. (1).

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