Materials Chemistry and Physics 152 (2015) 85–94

Contents lists available at ScienceDirect

Materials Chemistry and Physics

journal homepage: www.elsevier.com/locate/matchemphys

Development of a multi-component SG with CTAB as corrosion, scale, and microorganism inhibitor for cooling water systems

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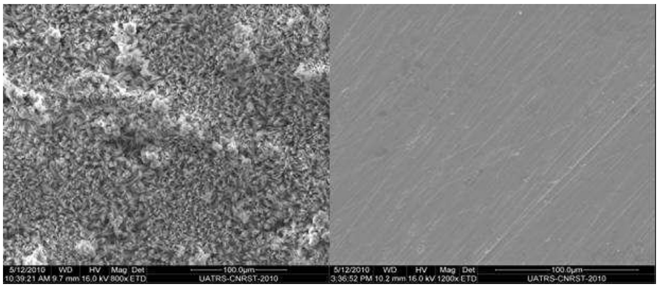
HIGHLIGHTS

- Non-toxic formulation was used to inhibit corrosion, scale and biocorrosion.
- Inhibition efficiency increases with pH, electrode rotation and immersion time.
- Formulation takes its performance at height temperature.
- Formulation takes its inhibition in the presence of corrosion products.
- SEM/EDX confirm the formulation performance inhibitor after 15 days of immersion.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 September 2013
Received in revised form
21 November 2014
Accepted 15 December 2014
Available online 19 December 2014

Keywords:
Corrosion
Organic compounds
Electrochemical techniques
SEM
EDAX

ABSTRACT

This work based on the study of corrosion, scale and microorganism inhibition of low carbon steel in cooling water system by organic compounds (Sodium gluconate (SG) associated with Cetyltrimethylammonium bromide (CTAB)) using electrochemical techniques and SEM/EDX analysis. The polarization curves showed that this formulation acts as mixed-type inhibitor. Its inhibition efficiency was found to enhance with increase of pH, electrode rotation and immersion time due to the formation of the inhibitor film on metallic surface as indicated by electrochemical impedance spectroscopy measurements. However, the formulation takes its performance at high temperature and in the presence of corrosion products. Finally, the SEM/EDX observations confirmed that the formulation was a corrosion, scale, and microorganism inhibitor after 15 days of immersion.

1. Introduction

Water is the most commonly used cooling fluid to remove unwanted heat from heat transfer surfaces. At the present time, some of the demand for better utilization of the limited water supplies is due to population growth and increasing development. Due to this, open recirculating cooling water systems that reuse cooling water are frequently used at large central utility stations.

However, the cooling water systems can present several problems. Corrosion, scale and fouling by micro-organisms can appear when natural waters are used as thermal fluid. These problems can occur jointly, reducing the thermal efficiency of the circuit with significant economic repercussions [1]. To attenuate or eliminate

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http://dx.doi.org/10.1016/j.matchemphys.2014.12.018
0254-0584/

these problems, water used in cooling circuits are treated with inhibitive formulations. So, in order to limit the scaling and fouling phenomena, corrosion inhibitors are usually associated with chemical reagents. Recently, due to new laws to protect the environment, these compounds must be non-toxic and biodegradable [2–10].

The objective of this study was to develop an acceptable multicomponent inhibitor SG/CTAB (Formulation) that would simultaneously inhibit corrosion, scale, and microorganisms. In addition, we are evaluated the operational parameters effect, such as *pH*, temperature, solution velocity, corrosion products and immersion time on the inhibition efficiency of the formulation (10^{-2} M of SG with 20 ppm of CTAB). These studies were evaluated from the polarization curves, electrochemical impedance spectroscopy and SEM/EDX observations.

2. Experimental procedures

2.1. Electrochemical cell and materials

The electrolysis cell was a borrosilcate glass (Pyrex®) cylinder closed by cap with five apertures. Three of them were used for the electrode insertions. The working electrode was a low carbon steel previously used [2,3,11] and its composition is summarized in Table 1. The investigated area of the surface was 0.8 cm^2. Prior to immersion test, the electrode was abraded using emery paper up to 1200 grade, cleaned with acetone, washed with distilled water, and dried finally. The rotating electrode (INF-EL-EDI 101) was used for electrochemical measurements. The rotation speed was fixed at 1000 rpm with CTV 101 (Radiometer analytical). Pt plate as the counter while a saturated calomel electrode (SCE) was used as the reference electrode. All potentials are referred with respect to this electrode. For long exposure experiments, between two measurements, the reference electrode was removed from the test solution to minimize its contamination by chloride ions and the working electrode was set in rotation for one hour before each test.

The simulated cooling water solution is used previously [2,3,11] and its composition is displayed in Table 2. This composition represents the average amount of various ions present in the waters used in Moroccan cooling waters system. According to the literature [6,7], this solution was corrosive and scaling. The temperature was adjusted at 32 ± 2 °C except for the study on the temperature effect. The electrolyte was in contact with air without any purging of dissolved oxygen.

The sodium gluconate (SG) is a commercial product and was used as corrosion inhibitor. The cetyltrimethylammonium bromide ($C_{19}H_{42}BrN$), is a commercial product, courteously purchased from FLUKA Company (Denmark), its purity is 96% and was used as corrosion and biofilm inhibitor. It was evaluated using the minimal inhibitory concentration (MIC) techniques [12,13]. The chemical structures of these two compounds are presented in Fig. 1.

Table 2
Composition of simulated cooling water.

Salts	$MgCl_2$, $6H_2O$	$CaCl_2$, $2H_2O$	$Ca(NO_3)_2$, $6H_2O$	$MgSO_4$, $7H_2O$	$NaHCO_3$
Concentration (mM)	2.85	3.64	0.566	1.56	3.77
Conductivity ($\mu S\ cm^{-1}$) at 299 K	1678				

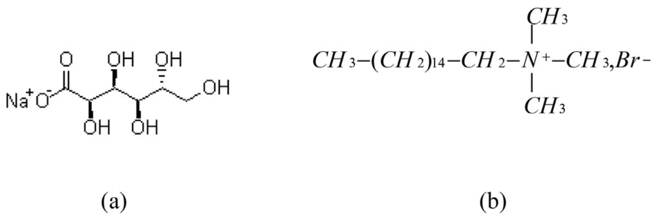
(a) (b)

Fig. 1. Chemical structure of the inhibitors: (a) Sodium gluconate (b) cetyltrimethylammonium bromide.

2.2. Polarization measurements

The working electrode was immersed in test solution under rotation at 1000 rpm during one hour until the steady state corrosion potential (E_{corr}) was reached. The cathodic polarization curve was recorded by polarization from E_{corr} towards more negative direction with a sweep rate of 1 mV/s. After this scan, the same electrode was remained in solution until the obtaining of the steady state corrosion potential ($E_{corr} \pm 0.002$ V), and then the anodic polarization curve was recorded from E_{corr} to positive direction with the same sweep rate. The obtained polarization curves were corrected for ohmic drop with the electrolyte resistance determined by electrochemical impedance spectroscopy. These measurements were carried out using Potentiostat/Galvanostat/Voltalab PGZ 100 monitored by a personal computer. For each concentration three independent experiments were performed. The mean values and the standard deviations are reported as well.

The overall current density values, *i*, were considered as the sum of two contributions, anodic and cathodic current i_a and i_c, respectively. For the potential domain not too far from the open circuit, it may be considering that both processes follow the Tafel law [14]. Thus, it can be derive:

$$i = i_a + i_b = i_{corr} \times \{exp[b_a \times (E - E_{corr})] - \exp[b_c \times (E - E_{corr})]\} \tag{1}$$

where i_{corr} is the corrosion current density (A cm^{-2}), b_a and b_c are the Tafel constant of anodic and cathodic reactions (V^{-1}), respectively. These constant are linked to the Tafel slope β (V/dec) in usual logarithmic scale by:

$$\beta = \frac{\ln(10)}{b} = \frac{2.303}{b} \tag{2}$$

The corrosion parameters were then evaluated by means of nonlinear least square method by applying this equation using Origin software. However, for this calculation, the potential range applied was limited to ±0.100 V around the E_{corr} else a significant systematic divergence was sometimes observed for both anodic and cathodic branches.

The inhibition efficiency (η_{PP}) was calculated using the following equation:

Table 1
Chemical composition of low carbon steel in wt-%.

C	Si	Mn	Cr	Mo	Ni	Al	Cu	Co	V	W	Fe
0.11	0.24	0.47	0.12	0.02	0.1	0.03	0.14	<0.0012	<0.003	0.06	Balance