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Application of nonionic surfactant as a corrosion inhibitor for zinc in alkaline battery solution

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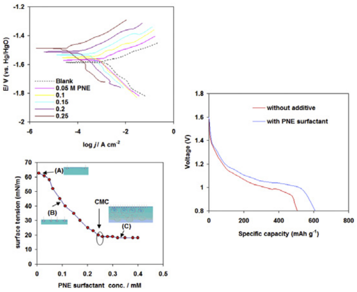
HIGHLIGHTS

- Nonionic surfactant acts as inhibitor for zinc corrosion in alkaline electrolyte.
- The battery containing PNE surfactant exhibits better performance.
- The inhibition efficiency reaches a maximum value at CMC of surfactant.
- Nonionic surfactant works as a mixed-type corrosion inhibitor.
- Inhibition mechanism supported by SEM and FTIR analysis.

GRAPHICAL ABSTRACT



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ABSTRACT

Polyoxyethylene (40) nonylphenyl ether as nonionic surfactant (PNE) has been tested as an inhibitor for zinc corrosion in alkaline electrolyte (7.0 M KOH) via potentiodynamic polarization together with electrochemical impedance spectroscopy (EIS) measurements. The surface characterization of zinc has been examined with scanning electron microscopy (SEM) and confirmed by infrared spectroscopy (FTIR). The Results show that PNE surfactant inhibits zinc corrosion in 7.0 M KOH solution and indicate that the inhibition capability increases with the concentration of PNE surfactant. The maximum inhibition efficiency has been obtained near to critical micelle concentration of PEN surfactant (CMC = 0.25 mM). The battery containing PNE surfactant exhibits better performance. PNE surfactant works as a mixed type inhibitor by physical adsorption. This adsorption obeys Freundlich adsorption isotherm.

1. Introduction

Alkaline batteries are a type of primary batteries dependent upon the reaction between zinc and manganese dioxide (Zn/MnO_2). The alkaline battery gets its name because it has an alkaline electrolyte of potassium hydroxide. Alkaline batteries account for 80% of manufactured batteries in the world (over 10 billion individual units) [1–3].

In the absence of inhibitors, the zinc electrode corrosion is the major reason for battery leakage [4].

The traditional corrosion inhibitor for alkaline batteries is mercury metal. Environmental worry has mostly excluded the use of mercury in alkaline batteries [5,6].

The employment of environmentally friendly surfactants, as corrosion inhibitors is gaining large preference and interest due to its safe effect, practical use and low cost [7–10]. Most of the surfactants used as corrosion inhibitors are organic molecules [11–13]. It was found that these substances have noteworthy inhibition efficiency close to their CMC values [14].

The metal corrosion inhibition by surfactants is due to surfactant adsorption. The status of adsorption depends on metal type,

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surface condition, inhibitor molecular structure, and corrosion media [15]. Various researchers demonstrated that most surfactants are adsorbed on the surface of metal by dislodging H_2O molecules which standing on the metal superficial [16,17].

The Target of this work is evaluating the efficiency of nonionic surfactant (Polyoxyethylene (40) nonylphenyl ether), abbreviated as (PNE),as corrosion inhibitors for zinc in alkaline electrolyte (7.0 M solution of KOH).

PNE can be considered as adequate probable inhibitor. This because of PNE molecule contains oxygen atoms, alkyl groups and aromatic ring. In addition, it is non-toxic. Nevertheless, no works up to now concerning with the using PNE surfactant as an inhibitor for zinc corrosion in alkaline electrolyte.

In order to explore such a possibility for PNE surfactant to act as an inhibitor to retard the corrosion of zinc, potentiodynamic polarization, EIS, SEM and FTIR inspections were used. Furthermore, the effect of PNE additive on the discharge performances of the battery is tested.

2. Experimental

2.1. Materials and chemicals

The experiments were carried out on zinc specimens with a composition (in wt. %) as follows: Zn (98.55), Mn (0.005), Sn (0.070), Cd (0.520), Pb (0.18) and Fe (0.035). It was supplied by Precision Sheet Metal Co., Ltd. (China). For electrochemical measurements, zinc specimen was coated with Teflon with an uncovered area equal 0.655 cm^2. The surface pre-working was achieved by different degree of emery sheets, which ended with the 1200 grade. The surface of specimens was washed by distilled water and different solvents.

The aggressive solution 7.0 M KOH was prepared using 99% KOH.

PNE surfactant (Fig. 1) was provided by SIGMA-ALDRICH. The range for the concentrations of PNE surfactant used for the study was 5.0×10^{-5} to 25×10^{-5} M.

2.2. Methods

2.2.1. Electrochemical experiments

The Electrochemical experiments were completed in a regular electrochemical cell. The working electrode was as mentioned above and mercury/mercury oxide (Hg/HgO in 7.0 M KOH) and Pt wire were as reference and auxiliary electrode, respectively. Potentiostat/Galvanostat (model: EG&G 273) was employed to perform all electrochemical measurements.

Potentiodynamic polarization was performed with a constant sweep rate equal 1.0 mV s^{-1} in the range of -250 to $+250$ mV with respect to E_{corr}.

EIS experiments were conducted at E_{corr} with amplitude 10 mV after immersion for 2 h in the corrosive media in the frequency limits 1.0 Hz 100 kHz with 10 points/decade. The obtained EIS data points were fitted using M 398 impedance software.

2.2.2. Surface tension measurements

Critical micelle concentration (CMC) of PNE surfactant was detected at 298 K by measuring surface tension values using Du-Nouy Tensiometer (model: 8451).

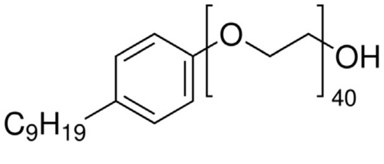

Fig. 1. The chemical structure of PNE surfactant.

2.2.3. SEM&FTIR investigations

The zinc surface morphology of tested specimens was detected after the required tests by using scanning electron microscopy (model: JEOL-JEM 1200 EX II electron microscope).

For FTIR spectra, the surface film was accurately separated with acute edged glass rod and well mixed with KBr. FTIR spectra were recorded on JENWAY 6300 spectrophotometer.

2.2.4. Battery performance measurement

The effect of PNE additive on the discharge performances of the battery was measured on an AA-sized Zn/MnO_2 battery. The detailed characterization of the cell building has been record elsewhere [18]. The effects of PNE additive on the discharge capacity were examined by the addition of 0.25 mM of PNE surfactant into the anode gel.

3. Results and discussion

3.1. Potentiodynamic polarization measurements

Fig. 2 shows potentiodynamic polarization plots for zinc in 7.0 M KOH solution in the absence and presence of PNE surfactant at scan rate 1.0 mV s^{-1} and at 298 K. The active dissolution and passivation of zinc in the alkaline solution decrease its activity in alkaline battery. The composition of the passive layer may be $Zn(OH)_2$ and/or ZnO [19].

From the polarization curves in Fig. 2, it is clear that the addition of PNE surfactant decreases the corrosion rate of zinc in alkaline solution. The electrochemical parameters extracted from polarization curves are given in Table 1. These parameter include corrosion current density (j_{corr}), corrosion potential (E_{corr}), cathodic (b_c) and anodic (b_a) Tafel slopes.

The efficiency of PNE surfactant ($P_P\%$) as the corrosion inhibitor can be determined using:

$$P_P\% = \frac{j^0_{corr} - j_{corr}}{j^0_{corr}} \times 100 \tag{1}$$

where j^0_{corr} and j_{corr} represent the current density values in the blank solution and in the blank solution contains PNE surfactant,

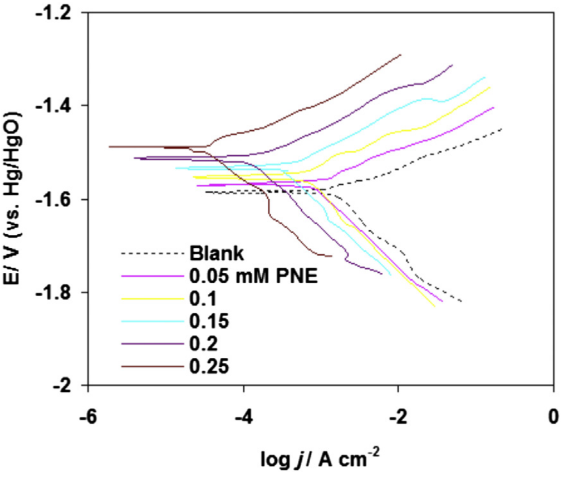

Fig. 2. Potentiodynamic polarization curves for zinc in 7.0 M solution of KOH in the absence and presence of PNE surfactant at scan rate 1.0 mVs^{-1} and at 298 K.