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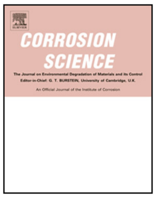

Yttrium 3-(4-nitrophenyl)-2-propenoate used as inhibitor against copper alloy corrosion in 0.1 M NaCl solution

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ABSTRACT

Yttrium 3-(4-nitrophenyl)-2-propenoate has been studied as an effective corrosion inhibitor for copper alloy in 0.1 M chloride solution. The results show that the surface of copper alloy coupons exposed to solutions containing 0.45 mM yttrium 3-(4-nitrophenyl)-2-propenoate had no signs of corrosion attack due to protective film formation, whereas the surface of copper alloy coupons exposed to non-inhibitor and lower concentrations of yttrium 3-(4-nitrophenyl)-2-propenoate containing solutions were severely corroded. A high inhibition performance is attributed to the forming protective inhibiting deposits that slow down the electrochemical corrosion reactions and mitigate corrosion by promoting random distribution of minor anodes.

1. Introduction

Copper and its alloys are ideal materials for tube casting and pipe products due to their good electrical and thermal conducting properties, corrosion resistance, antibacterial nature, weldability, ductility, toughness, nonmagnetic characteristics, and easy to form alloys along with recyclablility [1–3]. Due to these properties, they have been extensively applied to store potable water in buildings and homes as well as for many diverse fluids ranging from oil and chemical processes to marine industries [4–6]. Importantly, copper alloys have high corrosion resistance, machinability and high level of heat transfer which are a major criteria for air-conditioning, refrigeration systems, fire sprinkler systems and fuel gas distribution systems. Unfortunately, pitting of copper alloys is promoted in the presence of ammonia, steam with sufficient levels of CO_2, NH_3, sulfides, chlorides in waters, and iron oxide [7–9].

Copper is a noble metal and more stable in the atmospheric environment in comparison with zinc or iron. During oxidation processes, it can loose one or two electrons to form two types of positively charged ions [10]. These positively charged ions can exist on its own in solution, however, they can also associate with negatively charged ions such as hydroxide, chloride, carbonate, bicarbonate and sulphate ions, as well as organic compounds to form soluble and solid complexes in solutions, which is a major cause for serious corrosion problem related to copper alloys in aggressive environments as expected during operational processes. Therefore, improving the corrosion resistance of copper and its alloys is an interesting topic of studies with a goal of meeting the required corrosion resistance, which is a key for copper and its alloy applications.

Many studies have concentrated on improving the corrosion resistance of copper alloys via various methods such as equal-channel angular pressing [11,12], dynamic plastic deformation [13], surface treatments [14,15], coatings [16,17], alloying elements [18,19] and corrosion inhibitors [20–23]. Among these methods, the use of corrosion inhibitors significantly influences the corrosion resistance of copper alloys due to their cost savings and changes in situ without any interruption of an operational process. For these reasons, many corrosion inhibitors have been investigated and developed [20–26]. Copper corrosion inhibition has been studied for decades and is done extremely effectively with benzotriazole (BTA), which is not particularly toxic. There are numerous studies of BTA action on copper alloy in various corrosion environments such as chloride ions, acidic and neutral solutions [27–32]. Unfortunately, BTA action is weaker in environment containing aggressive ions as well as in highly acidic and alkaline environments.

The recent concepts revealed by various researchers provide guide for various new approaches in terms of designing safer and

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Table 1
Copper pipe alloy compositions were checked by optical emission spectroscopy.

Chemical elements (wt.%														
C	Fe	Sn	Zn	P	Ni	Sb	Al	Mn	Si	S	Cr	Co	B	Cu
0.0369	0.0029	0.0039	0.0338	0.0066	0.0125	0.0041	0.0016	<0.0002	<0.0006	<0.0002	<0.0002	<0.0015	<0.0002	Bal.

environmentally friendly inhibitors. One earlier approach was to use polyphosphate at relatively high levels which was based on undergoing a process of hydrolysis, resulting in calcium orthophosphate deposition. Later on, ortho-, poly-, and organic phosphates have been combined to improve the limitation of polyphosphate systems and provide the desired corrosion protection [33–36]. However, one of concern is associated with calcium phosphate deposition, which makes them problematic. Other approach was to develop synergistic rare earth organic compounds via salvaging a multifunctional inhibition containing inhibitive properties of their components [37–46] resulting in superior inhibition when compared with either of individual components at the same concentration. In addition, the use of thi- and triazolyl compounds has been recommended as corrosion inhibitors for copper alloys due to the generation of protective film on the copper surface [47–49]. Likewise, the potassium ethyl xanthate [50,51], indole [52], 5-chloroindole [53], purine [54–56], adenine [55,56] (AD) and other groups [57–59] can also facilitate the formation of the protective film on the copper surface in aggressive enviroments. Importantly, rare earth organic compounds performed effective corrosion inhibitors for both steel and aluminum substrates. These compounds form both continuous and heterogeneous protective surface film, leading to extremely improved corrosion resistance [37,46]. Therefore, the aim of this present work is to develop yttrium 3-(4-nitrophenyl)-2-propenoate compound, as new inhibitor and discuss their effectiveness in preventing corrosion on copper pipe alloy.

2. Experimental procedures

2.1. Chemicals and materials

Yttrium 3-(4-nitrophenyl)-2-propenoate ($Y(4NO_2Cin)_3$, "$4NO_2Cin$" is a derivative of 4-nitrocinnamic acid) was synthesized using YCl_3 and 3-(4-nitrophenyl)-2-propenoic acid and used as corrosion inhibitor. Molecular structure of yttrium 3-(4-nitrophenyl)-2-propenoate ($Y(4NO_2Cin)_3$) inhibitor is given in Fig. 1. The compounds including YCl_3 and 3-(4-nitrophenyl)-2-propenoic acid were purchased from Sigma Aldrich. $Y(4NO_2Cin)_3$ was added to 0.1 M NaCl solution to make final concentration of 0.00, 0.02, 0.15, and 0.45 mM using reagent grade sodium chloride, distilled water, and 12 h for stirring. The working electrodes used for the electrochemical tests and copper alloy coupons were machined from a copper alloy with dimension of $10 \times 10 \times 1.5\,mm^3$. The copper alloy electrodes were coated with an epoxy resin and attached to a Teflon holder. The copper alloy compositions were checked by optical emission spectroscopy and given in Table 1. The copper alloy specimens for corrosion tests were finished by grinding with 1200-grit silicon carbide paper with $10 \times 10\,mm^2$ of exposed area.

2.2. Electrochemical investigation methods

Before electrochemical test, the samples were kept in the natural aerated solution for 2 h to stabilize the open-circuit potential (OCP). The electrochemical impedance spectroscopy (EIS) tests were performed at E_{OCP} and conducted every two hour over a period of 20 h. The EIS tests were conducted using a VSP system (BioLogic Scientific Instruments) with a commercial software program for AC measurements. The peak-to-peak amplitude of the sinusoidal perturbation was 10 mV. The frequency ranged from 100 kHz to 10 mHz. Potentiodynamic polarization tests were carried out after EIS. A titanium counter electrode was used with a silver/silver chloride (Ag/AgCl) electrode as the reference electrode. The potential of the electrodes was swept at a rate of 0.166 mV/s ranging from an initial potential of −250 mV vs. E_{OCP} to 500 $mV_{Ag/AgCl}$. Potentiostatic test was performed to further examine the effect of $Y(4NO_2Cin)_3$ on the stability of protective film formed on the alloy surface. The potentiostatic tests were performed at a constant potential of 0 $mV_{Ag/AgCl}$ using Biologic VSP multichannel potentiostat after immersion for 20 h in the solution. To ensure reproducibility, three measurements were run for electrochemical and immersion tests.

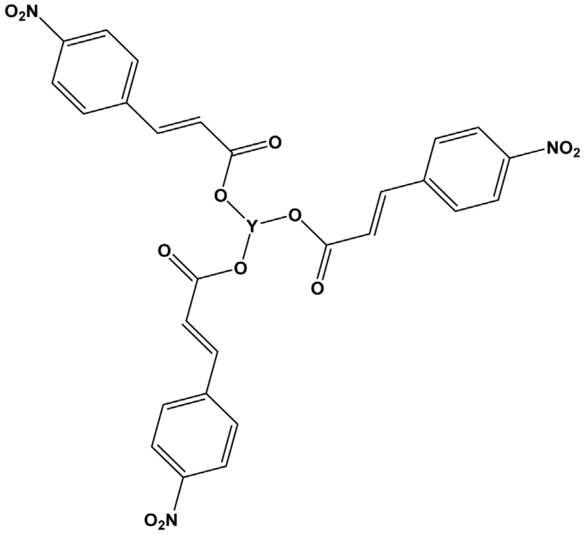

Fig. 1. Molecular structure of yttrium 3-(4-nitrophenyl)-2-propenoate corrosion inhibitor.

2.3. The wire beam electrode

Wire beam electrode (WBE) was used to study the tendency of localized corrosion of copper alloy in the test solutions. The WBE was made from one hundred identical copper alloy wires embedded in epoxy resin, insulated from each other with a thin epoxy layer. Each wire had a diameter of 0.19 cm and acted both as a sensor and as a corrosion substrate. The working area was grinded using 1200-grit silicon carbide paper, rinsed with deionised water and ethanol before being exposed to three liters of 0.1 M NaCl solution at room temperature. After 30 mins of initial corrosion testing, inhibitor were injected into the testing cell with regular addition at every 20 h. Corrosion processes were monitored by mapping galvanic currents between a chosen wire and all the other wires shorted together using a pre-programmed Autoswitch device and an ACM AutoZRA. Galvanic current data were obtained and analyzed. The measurements were taken regularly to examine the changes taking place with the introduction of the inhibitors.