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Aluminum and stainless steel corrosion in ethanol and KOH solutions

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Pure aluminum and 316L stainless steel were exposed to alcohol/KOH solutions, called alkoxides, which are commonly used in biodiesel synthesis. The corrosion behavior of these materials was studied through polarization and Electrochemical Impedance Spectroscopy (EIS) measurements. The results show that aluminum behavior in alkoxides is similar to its behavior in an aqueous alkaline solution. It was also observed that stainless steel is more resistant to corrosion than aluminum in alkoxide solutions at different KOH concentrations.

Keywords: Biodiesel; alkoxides; electrochemical impedance spectroscopy (EIS).

Aluminio puro y acero inoxidable 316L fueron expuestos en soluciones de alcohol y KOH conocidas como alcóxidos, empleados comúnmente en la obtención de biodiesel. El comportamiento de la corrosión de estos metales fue estudiado mediante polarización e Impedancia electroquímica (EIS). Los resultados mostraron que el aluminio se comporta de manera similar al aluminio inmerso en una solución alcalina acusa. También se determinó que el acero inoxidable tiene mayor resistencia a la corrosión en una solución alcohólica con diferentes concentraciones de KOH, que la que ofrece el aluminio en la misma solución.

Descriptores: Biodiesel; alcóxidos; espectroscopia de impedancia electroquímica (EIS).

PACS: 29.30.h; 29.30.kv; 82.47.a; 39.30+w; 61.10.Ht; 81.65.kn

1. Introduction

Aluminum and stainless steel are materials used in the fabrication of reactors and automotive pieces [1,2]. Both materials are used directly or indirectly in the biodiesel manufacturing process, and are exposed to biodiesel during their end use. The interest and use of biodiesel is rapidly growing [3] due to decreases in oil reserves, the pollution caused by the excessive use of fossil fuels, and global warming.

Biodiesel is obtained by a reaction between vegetable oil and an alcoholic mixture containing an alkaline catalyst, which is usually KOH or NaOH [4,5]. This alcoholic mixture is called “alkoxide”, and the reaction is known as transesterification.

Several alternative energy sources, such as wind power, solar energy, hydropower and biodiesel, all come from renewable resources. Among alternative energies, biodiesel is the only one that can realistically be depended on today to fuel vehicles and machinery in a cost-effective and practical way.

With the increased production of biodiesel, the alkoxide is rapidly accumulating. While processing biodiesel fuel is essentially safe, it is important to take the necessary safety precautions. For example, methanol is a potentially dangerous chemical when handled improperly. The addition of alkaline compounds gives the alkoxide an aggressive nature toward materials that interact with the solution. This interaction can be direct, as in the case of stainless steel in contact with the alkoxide in the reactor, or indirect, as with residual alkoxide in the biodiesel in contact with automotive parts commonly made from aluminum and its alloys.

There is extensive information on aluminum and stainless steel corrosion in aqueous alkaline media, particularly for applications in alkaline batteries [6,8], but there is little information related to the materials’ behavior in alcoholic alkaline anhydrous media [9]. Therefore, the main objective of this work was to study aluminum and stainless steel corrosion from ethanol at different KOH concentrations. The study was carried out using electrochemical techniques such as lin-
ear polarization and electrochemical impedance spectroscopy measurements.

2. Experimental procedure

2.1. Materials

Pure aluminum (99.99%) and 316L stainless steel (18-Cr, 10-Ni, 3-Mo, Fe-bal), both obtained from Goodfellow Materials Ltd, were used. The materials were obtained in rods of 6 mm in diameter (cross sectional area: 0.28 cm$^2$). The ethoxide was prepared using reagent grade ethanol anhydrous (EtOH) and potassium hydroxide (KOH).

2.2. Electrochemical measurements

The electrochemical measurements were performed with a potentiostate-galvanostate (Gamry PC14-300 Instruments, Inc. USA) in a typical cell of three electrodes, using a platinum wire as the auxiliary electrode and an Ag/AgCl wire as the reference electrode. Aluminum and stainless steel were used as the working electrodes. The metallic samples were mounted in epoxy resin with an exposed cross section. Before each experiment, the exposed surface was polished and cleaned with deionized water, degreased with acetone and

**Figure 1.** Polarization curves for 316L stainless steel immersed in ethanol at different KOH concentrations.

**Figure 2.** Polarization curves for pure aluminum immersed in ethanol at different KOH concentrations.

**Figure 3.** Comparison of Nyquist plots for 316L stainless steel immersed in ethanol solutions at various KOH concentrations (0.5 and 1 M).

**Figure 4.** Comparison of Nyquist plots for pure aluminum immersed in ethanol solutions at various KOH concentrations (0.25, 0.5 and 1 M).
Table I. Average $E_{corr}$, $I_{corr}$ and corrosion rate (CR) values obtained by Tafel analysis.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Concentrations</th>
<th>$E_{corr}$ (mV)</th>
<th>$I_{corr}$ (µA)</th>
<th>Corrosion rate (mpy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>1M</td>
<td>-1930</td>
<td>160</td>
<td>261.92</td>
</tr>
<tr>
<td></td>
<td>0.5M</td>
<td>-1890</td>
<td>41.600</td>
<td>68.099</td>
</tr>
<tr>
<td></td>
<td>0.25M</td>
<td>-1390</td>
<td>19</td>
<td>31.103</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>1M</td>
<td>-686</td>
<td>1.150</td>
<td>1.882</td>
</tr>
<tr>
<td></td>
<td>0.5M</td>
<td>-633</td>
<td>0.501</td>
<td>0.820</td>
</tr>
<tr>
<td></td>
<td>0.25M</td>
<td>-500</td>
<td>0.262</td>
<td>0.428</td>
</tr>
</tbody>
</table>

* (mpy) = mili-inch per year

dried. The measurements were carried out in the following order: open circuit potential (OCP), electrochemical impedance spectroscopy (EIS) in the range of 10 mHz - 100 kHz with an amplitude signal of 10 mV on the open circuit potential and, finally, linear polarization. The measurements were repeated at least three times for each concentration of KOH.

3. Results and discussion

Figure 1 shows the Tafel curves obtained for the 316L stainless steel. It can be observed that the anodic part does not exhibit changes with the KOH concentration. The same behavior is observed for the cathodic part. Therefore, the anodic and cathodic reactions do not change with different KOH concentrations. It was also shown that the corrosion current decreases as KOH concentration decreases, indicating a less corrosive alcoholic solution. Decreasing the KOH concentration also moves the corrosion potential, toward the noble potential region.

Figure 2 shows the polarization curves for the aluminum immersed in the alcoholic solutions at different KOH concentrations. The corrosion mechanism of aluminum in aqueous media involves three stages of electron transfer and one final chemical stage for the formation of Al(OH)$_3$ [10-12]. Aluminum in a methanol/KOH solution behaves similarly to aluminum in aqueous media with KOH [13].

The presence of alkaline compounds is the major cause of corrosion effects on aluminum, where the compound in this case is KOH. Decreasing the KOH concentration decreases the aggressiveness of the media. However, the measured corrosion current region is greater in aluminum than stainless steel, which indicates a greater susceptibility to corrosion for aluminum in the media studied. Table I shows the obtained averages values for $E_{corr}$ and $I_{corr}$, which confirm that aluminum is more susceptible in this media than stainless steel.

Figure 3 shows the Nyquist diagram for the stainless steel, which exhibited typical behavior for a mechanism controlled by the diffusion of species at the stainless steel/solution interface. This behavior confirms the high corrosion resistance of stainless steel in the alkoxide media.

Impedance data for aluminum is shown in Fig. 4. This Nyquist diagram of aluminum in alkoxide is very similar to the Nyquist diagrams reported for aluminum immersed in alkaline aqueous solutions [14-16].

4. Conclusions

Pure aluminum and 316L stainless steel are materials used directly or indirectly in biodiesel synthesis (in a process called transesterification), so were studied in contact with alcoholic solutions at different KOH concentrations. Aluminum corrosion after immersion in alcoholic/KOH solutions is similar to aluminum immersed in water. The results indicate that stainless steel has greater corrosion resistance than aluminum in alkaline alcoholic solutions, called alkoxides, which are used in biodiesel production.

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