Effect of Cardamom Extract on leaching of Aluminum Cookware

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To estimate the contribution of cardamom extract (CE) on Aluminum (Al) leaching, Al release from cookware was investigated using two Aluminum alloys (Indian and Egyptian). This study was done in aqueous solutions in presence and absence of 1% NaCl using weight loss at 90 °C to imitate cooking conditions. Moreover surface study and electrochemical methods: Open Circuit Potential (OPC) and Tafel plot were applied. For the electrochemical methods pure Aluminum (Al) was used for comparison in addition to the two Aluminum alloys. The corrosion resistance of pure Al was less than that of the Indian alloy due to alloying elements. The increasing concentrations of CE and temperature gave rise to increasing corrosion rate (CR). The addition of 1% NaCl to CE solutions increased the corrosion rates for weight loss and electrochemical method. The apparent activation energy values, E_a for CE was more than that for CE+NaCl which is in agreement with weight loss results and Tafel plots. The effect of cardamom extract on Al leaching was significant even at low concentrations (less than 5%) where it caused pits and blisters as shown from the surface study.

Keywords: Cardamom extract; Al leaching; Aluminum alloys; Weight loss method; Electrochemical methods.

1. INTRODUCTION

Aluminum (Al) is now known to be a neurotoxin agent due to its accumulation in brain, bones and liver. Human beings are exposed to Al due to its ubiquitous character. Elevated levels of Al have been implicated in the etiology of Alzheimer's disease, Parkinson's disease, and diseases like dialysis encephalopathy, bone disorder and other disorders [1]. Many studies were conducted about exposure assessment of Al via food and Al kitchenware [2-4].

Al exhibits a passive behavior in aqueous solutions due to the thin compact oxide film (1nm) which exists naturally on the metal surface ($\Delta H_{f}^{\circ} = -1676 \text{ k J/mol}$). The aluminum oxide solubility increases in acidic and alkaline medium. It is well established that Al dissolution is highly dependent on pH, temperature and the presence of complexing agents.

Al leaching in aqueous solutions may be explained by the following chemical reactions occurring on the surface of the Al cookware:

 $Al_2O_3 + 6H^+ = 2Al^{+3} + 3H_2O$

The free Al ions in solution may react with organic acids and other complexing agents found in food. It was established that cooking acidic foods in Al utensils causes high Al dissolution and leaching of Al into food [5, 6].

Thus it is important to shed some light on Al dissolution in aqueous solutions containing some food additives like cardamom. Cardamom (or cardamon) refers to several plants of the ginger family Zingiberaceae. The word "cardamom" is derived from the Latin cardamomum. Cardamom pods (green and black) are the third most expensive spices after saffron and vanilla. India and Guatemala are the biggest producers of cardamom while the main consumers are the Middle East and Scandinavian countries. The chemical constituents of Cardamom include essential oils like α –Terpineol[7].

The purpose of this paper is to study the leaching behavior of Al alloys in aqueous solutions containing cardamom extract (CE). Weight loss at 90 °C was used to imitate real cooking conditions. Moreover surface study and electrochemical methods (Open Circuit Potential and Tafel plots) were applied. For the electrochemical methods pure Aluminum (Al) was used for comparison. To accomplish this it was important to find the best way for extracting cardamom in aerated aqueous solution in presence and absence of 1% NaCl.

2. EXPERIMENTAL PROCEDURE

2.1. Materials

1. The Indian green cardamom used in this study was bought from the local market. The constituents of Cardamom are husk (about 25%) and seeds (about 74%); these percentages differ slightly according to the age of the product and country of origion [7]. The main chemical constituents are volatile oils, non volatile ether extracts, starch, crude fibers and protein [7]. The content

of volatile oil in the seeds is dependent on storage conditions, with an average yield from 2 to 5%. The main volatile oils are 1,8-Cineole and α -Terpinyl acetate which constitute about 60%[7]

2. Pure Al (99.99%) from Good fellow was used in addition to two kinds of Al cook wares chosen from the local market: India (In. alloy) and Egypt (Eg. alloy). The percentage of Aluminum alloying elements were determined using Atomic Absorption instrument (Shimadzu A.A. 6701F)) and shown in **Table 1.**

3. NaCl (AR) from BDH.

2.2. Methods

2.2.1. Extraction method

Five different extraction methods were applied to obtain the cardamom extract (CE):

1. The first method was grinding the cardamom seeds to prepare extract stock solution of each concentration in distilled water. It was applied and rejected due to the loss of some volatile oils by grinding.

2. The second method was weighing each percentage alone which was found to be inefficient because of the difficulty of obtaining reproducible results due to the minor difference in the chemical constituents of the cardamom seeds.

3. The third method was extracting the organic constituents by using 96% of ethanol and water to prepare 10% stock solution. Although this method was able to extract most of the organic constituents in ethanol which does not dissolve in water, it does not imitate real cooking conditions so it was not used.

4. The fourth method was heating cardamom seeds for five hours at 90°C. Although this method was able to extract the major chemical constituents it took long times and does not imitate real cooking conditions.

5. The fifth method which was adopted was heating cardamom seeds at 90 °C in distilled water for an hour to make 10 % w/w solution. This cardamom extract stock solution was used to prepare the following concentrations (1%, 2%, 3%, 4%, 5%).

Table 1. Percentage of Aluminum alloying elements

%	Ti	Sn	Co	Cu	Cr	Ni	Mo	Fe	Mg	Si
In. Al=95.95	0.19	0.99	0.36	0.21	0.19	0.14	0.09	0.65	0.67	0.56
Eg. Al=96.55	0.92	0.59	0.10	0.12	-	0.20	0.06	0.50	0.46	0.60

2.2.2. Weight Loss method

In the present work weight loss method (WL) was employed to study Al leaching of Al alloys in presence of CE solutions. The study was done at 90 °C to imitate real cooking conditions. The mean of two to three replicate experiments was reported. The two Al cook wares were cut into rectangular specimens of dimensions 2x2.2 cm and 2 mm thickness. The average exposed area was 9 cm² \pm 0.20. These specimens were treated in the following method prior to each experiment: wet polishing with SiC up to 1200 grade, washing with distilled water, then ultrasonic cleaning in acetone (ultrasonic cleaner from Cole Palmer) for 2 minutes before drying. The Al samples were weighed in a balance (\pm 0.0001g from Metler Toledo) then immersed in the hot CE solution for 1 hour. All experiments were performed in aerated solutions and maintained at 90 °C±1. After the leaching experiments the Al samples were immersed in the hot cleaning solution of 2%CrO₃ + 5% H₃PO₄ at 80°C for 10 minutes to remove the reaction products from the Al surface. Finally it was washed generously with distilled water (DW) then acetone. The dry Al sample was weighed again to determine the weight loss. The pH of the CE solution was measured before and after the experiments.

2.2.3. Surface study

After WL experiments for 5% CE solutions w/without NaCl using the In. alloy, the Al samples were washed with DW and dried. The surface morphology of Al samples was studied using a Scanning Electron Microscope (SEM) from (Joel-JSM-6380). Moreover the surface was analyzed by Energy Diffraction X-Ray) (EDX).

2.2.4. Electrochemical method

This method was applied to estimate small changes of Al leaching using a galvanostat /potentiostat (from ACM). Two cells were used here. The first one was a three electrode cell where the working electrode was Pure Al (99.99%) with an exposed surface area of 0.20cm^2 . The second cell was a sample holder from Radiometer. The two Al cook wares were cut into circular disks of 1.4cm diameter and an exposed area of 1.13cm^2 . The Al disk (as the working electrode) was fitted into a thermo stated sample holder cell. For both cells, the reference electrode was saturated Calomel electrode (SCE) and the auxiliary electrode was Platinum. All electrochemical experiments were performed in aerated solutions and maintained at $60^{\circ}\text{C} \pm 1$ using a circulating water bath (from Haak). After performing open circuit potential for 1 hour, polarization measurements were done to obtain corrosion current density from Tafel method by scanning the potential, $E_{ss} \pm 250$ mv at a rate of 1 mv/s.

3. RESULTS AND DISCUSSION

3.1. Weight Loss Method

The Al leaching was calculated from the famous Corrosion rate law (CR) using the following equation:

$$CR = \frac{\Delta W}{A * t} \tag{1}$$

Where Δw is the weight loss of Al alloy calculated from subtracting the sample original weight minus the sample weight after immersion (mg) in CE solutions ; A is the surface area of Al sample (cm²) and t is the immersion time (hour).

The weight loss measurements were performed at 90°C to imitate real cooking conditions. The study was done in CE solutions w/without NaCl in the following solutions prepared from 10% stock solution: 1%, 2%, 3%, 4%, 5% as shown in **Table 2.** These concentrations are within the range of

using cardamom in cooking. In addition the study was repeated in tab water + NaCl. The pH of solutions in the present study was in the range of 5-5.5 without NaCl and 6.0-6.9 in presence of NaCl. From gravimetric measurement it is noticed that:

a. CR (Al leaching) of both the In. and Eg. alloys increased with increasing concentrations in all solutions.

b. The addition of NaCl to CE solutions in DW has a different effect in the lower concentrations (1, 2%) decreasing the CR for the Eg. alloy and increasing the CR for the In. alloy.

c. CR for solutions of in Tab +NaCl was lower than DW or DW + NaCl for both alloys.

d. Comparing the CR of both alloys in all solutions, it is noticed that the CR using the In. alloy was higher than the CR of the Eg. alloy at all concentrations except at 1-2%.

Inspection of **Table 2** revealed that the increase in CR with increasing concentration of CE solutions is due to addition of more anions which form different complexes with $Al^{3+}[3]$. Moreover this increase in CR reflected the role of the aggressive species of the CE solutions in thinning and

dissolution of the oxide film which agreed with other studies [8-11]. The pH of the CE solutions was slightly acidic (pH 5-5.5) compared to the neutral solutions containing NaCl (pH 6-6.9).

From **Table 2** the CR of In. alloy using CE solutions only (pH 5.0), CR was 40.15×10⁻⁴ g/cm².day while for CE +NaCl in DW (pH 6.9) it was 32.71×10⁻⁴ g/cm².day. To study the effect of adding NaCl, a 5% CE solution was prepared after adjusting the pH to 6.9, the CR of the In. alloy was 16.17×10^{-4} g/cm².day. Thus the presence of NaCl had doubled the CR of the In. alloy whereas the decrease of pH had increased the CR which is in accordance with Pourbaix diagrams where the CR at low pH was high using DW which reflected the role of CE constituents and agrees with the results of Neelam et al. [8] where using cardamom with vegetables increased the CR of Al cook wares. Moreover the high CR of 5% CE solutions in DW (pH 5.0) compared to pH 6.9 may be attributed to hydrolysis of the CE constituents at low pH values. The major CE constituent which are more than 5% are 1,8-cineole, Linalool, α -Terpineol, α -Terpinyl acetate[7]. To our knowledge these compounds were not reported to have a direct effect on Al dissolution. However some of these compounds contain -OH groups which were reported to form complexes with Al [12]. In another study in HCl medium, adding some alcohols like methanol, ethanol and ethylene glycol had an inhibiting effect on Al corrosion up to 20% concentration [12]. The present results agreed with previous findings of Al Juhaiman [6, 10] that addition of NaCl doubled the CR. and agrees with Tomcsani et al. [13] that chloride ions act as partners in the electrochemical reaction.

The protective Al_2O_3 oxide layer has amphoteric nature which dissolves in acidic and alkaline solutions. In neutral NaCl solutions (pH 6.9) this protective film has low solubility hence the lowest corrosion rate was observed in such solutions (CR=16.17×10⁻⁴ g/cm².day). However, at lower pH values the solubility of the oxide layer was enhanced which lead to higher corrosion rates for Al as shown for CE solutions at pH 5.0(CR was 40.45 g/cm².day). It was noticed that CE solutions were clear solutions in absence of NaCl but turned cloudy after adding NaCl with white precipitate. Another factor, which enhanced the corrosion rate in acidic solutions was the acceleration of cathodic reactions due to the high concentration of H⁺ ions as suggested by Ambat et al. [14].

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Using tab water which contained many ions (Cu^{+2}, F, Mg^{2+}) instead of distilled water decreased the CR of Al which may be attributed to the competition between these ions and the CE constituents which finally decreased the CR of Al and agreed with Blucher et al. [15].

Table 2. Effect of concentration of CE solutions	on Al leaching of In.	. and Eg. alloys in I	DW and Tab
water w/without NaCl from WL method a	at 90 °C		

Solution	%C	CR (In.)	CR (Eg.)
	(w/v)	$(g/cm^2.days)*E^4$	$(g/cm^2.days)*E^4$
Card.	1	7.45	14.23
(DW)	2	13.77	16.11
	3	18.41	16.67
	4	31.31	16.44
	5	40.45	26.47
Card. + NaCl	1	11.5	13.41
(DW)	2	15.18	15.02
	3	17.36	17.75
	4	19.55	22.33
	5	32.71	24.48
Card. + NaCl	1	4.16	9.59
(Tap W)	2	8.64	8.31
	3	14.5	12.13
	4	19.18	16.11
	5	22.08	21.40

3.2. Surface Study

To investigate the effect of CE solutions, the In. alloy was taken as an example. The surface showed some pits and white precipitate after immersion in 5% CE solution for 1 hour, as shown in Fig.1. Analysis of this precipitate by EDX showed that it contained Si, Mg and Fe. The addition of NaCl showed that these pits turned into blisters as shown in Fig.2. Analysis of these blisters by EDX showed that they contained mainly Na and Cl only.

Brillas et al. [16] found that the local corrosion of Al alloys increased with increasing amounts of magnesium which may be attributed to deposition of the phases Mg_5Al_8 and Al_2CuMg that make anodic phases in the aluminium matrix making them optimum region of dissolution [17] which explained the appearance of blisters in the In. alloy as shown in Fig. 2. The role of Fe resembles that of Mg and agrees with the findings mentioned by Seri [18] that the aluminium oxide around FeAl₃ is weak and prone to local corrosion.



King Saud University

INSTRUMENT: JSM-6380

ACCEL.VOLT(kV):20 Org. Mag. x1000 IMAGE:SEI <SEI> ------DATE:2007-04-18



Figure 1. SEM and EDX of In. alloy after immersion in 5% CE solutions for 1 hour.

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INSTRUMENT: JSM-6380

ACCEL.VOLT(kV):20 Org. Mag. x500 IMAGE:SEI <SEI>

DATE:2007-04-05





Figure 2. SEM and EDX of In. alloy after immersion in 5% CE +NaCl for 1 hour.

The purpose for using this method is to detect any small changes in Al leaching of pure Al and Al alloys. Two methods were applied: Open Circuit Potential Method followed by Tafel.

3.3.1. Open Circuit Potential Method (OCP)

The following CE solutions were prepared: 2%, 5%, 7% and 10%. All experiments were performed in aerated solutions at 60°C±1. The values of steady state potential (E_{ss}) are listed in Table 3. with the values of E_{ss} for pure Al measured at 25°C for comparison. When measuring OCP, the change of potential with time reflected the effect of attack of the environment. The resulting E_{ss} is a mixed potential of all the anodic and cathodic reactions [19]. E_{ss} depends on O₂ concentration, composition of Al, pH and temperature. Values of E_{ss} for pure Al measured at 25°C were more positive than that at 60 °C which indicated that Al dissolution increased with increasing temperature. As an example only OCP of In. alloy with time at different concentrations at 60°C are shown in Fig.3. Open circuit potentials went to increasing potential values until they reach E_{ss} which indicated thinning the pre immersion Al oxide layer [19].

The values of E_{ss} decreased (becoming more negative)with increasing concentrations of CE solutions for pure Al and Eg. alloy. This indicated the increasing effect of the corrosive constituents and agreed with WL results. However for the In. alloy changing the concentration did not affect the values of E_{ss} , it was almost constant. At 60°C, it was noticed that for the same concentration, the values of E_{ss} for the Eg. Alloy were less than the In. alloy and pure Al. This difference between the two alloys is due to the difference in the alloying elements shown in Table.1 which agrees with other studies [5,20,21].

To study the effect of change of temperature from 10-60°C on OCP only pure Al with 5% CE solutions w/without NaCl was studied as shown in Table. 4. Values of E_{ss} decreased after addition of chloride ions and decreased with increasing temperature which indicated thinning of the pre immersion oxide film [19].

The decrease of E_{ss} or thinning the pre immersion Al oxide layer indicated the following reactions:

$Al \Rightarrow Al^{3+} + 3e^{-}$	$(E^{o} = -1.66 V(SCE))$	(2)
Assuming some cathodic reactions that may occur:		
$O_2 + 2H_2O + 4e^- \Rightarrow 4OH^-$	$(E^{o} = +0.9 V(SCE))$	(3)
$2H_2O+2e^- \rightarrow H_2\uparrow + OH^-$	$(E^{o} = -0.83V(SCE))$	(4)
$Al + 3OH^- \Rightarrow Al(OH)_3 + 3e^-$	$(E^{o} = -2.30 V(SCE))$	(5)
$Al + 3Cl^- \Rightarrow AlCl_3 + 3e^-$	$(E^{o} = -0.85 V(SCE))$	(6)
In our opinion, the anodic reactions may be:		
$Al \rightleftharpoons Al^{3+} + 3e^{-}$	$(E^{o} = -1.66 V(SCE))$	(2)
$2AI + 3H_2O \Rightarrow AI_2O_3 + 6H^+ + 6e^-$	$(E^{o} = -1.55 V(SCE))$	(7)



Figure 3. Change of OCP of In. alloy with time at different CE concentrations at 60°C.

Table 3. Effect of change of concentration on OCP for Al alloys

Alloy	<u>C</u> (w/v)	E_{ss} (mV)				
Alloy	$T(^{\circ}C)$	2%	5%	7%	10%	
Pure Al	25	-691	-787	-680	-765	
Pure Al	60	-732	-754	-769	-782	
Eg Al	60	-764	-845	-873	-894	
In Al	60	-745	-731	-740	-753	

Table 4. Effect of change of temperature on OCP of pure Al for 5% CE solutions w/without NaCl.

T (°C)	10	25	45	60
E_{ss} (mV) Card.	-569	-787	-804	-778
E_{ss} (mV) Card. + NaCl	-687	-703	-801	-807

The relation between E_{ss} and concentration at 60°C was opposite, as the concentration increased the value of E_{ss} decreased. This linear relation may be summarised as:

(8)

$$E_{ss} = a - b \log C$$

where a is the intercept, b is the order of reaction and C is the concentration. Applying this equation gave a linear relation for the In. alloy and the Eg. alloy as shown in Fig.4. The same relationship was applicable by another study by Al-Mayouf using sodium citrate [22] and by Sherif and Park using 1,4-Naphthoquinon[23]. However, it was reported that it was difficult to define the order of reaction of a specific compound in aerated solutions because they contain many constituents, the order represent the total order of all constituents



Figure 4. Relation of log C with E_{ss} for the In. alloy and Eg. alloy at 60°C.

When studying the effect of temperature on E_{ss} , it was noticed that at 10°C and 25°C there were strengthening of pre-immersion oxide film. At 60°C, there was thinning of pre-immersion oxide film. However at 45°C it was in the middle which is similar to the behaviour found by Garrigues for 8-Hydroxy quinoline [24].

Moreover, Brett [25] had studied the electrochemical behavior of Al in presence of NaCl and the effect of temperature using the following equation:

$$\mathbf{E}_{\rm ss} = \mathbf{a} - \mathbf{b} \, [\mathbf{T}] \tag{9}$$

Applying Eq.9 gave a linear relation for temperature with E_{ss} for pure Al at 5% with NaCl ($R^2=0.91$) as shown in Fig.5. On the contrary, the same system without NaCl did not give a linear relation which

reflected the complexity of the system and agreed with another study about the dissolution of Al alloys [9].



Figure 5. Relation of temperature with E_{ss} for pure Al at 5% with NaCl.

Moreover, in neutral solutions Cabot discussed the competition between OH^- and Cl^- [26] which is explained in the following equation:

Al^{+3} (in crystal lattice of the oxide)+2Cl⁻+OH⁻ \Rightarrow Al(OH)₂Cl₂⁻ (10)

The use of aerated solutions in the present study means that the cathodic reaction of oxygen reduction was applicable [19]. Another possible cathodic reaction may be the reduction of hydronium ion H_3O^+ where the pH was 4.5-5.0. Assuming that this was the cathodic reaction with the possible anodic reaction:

$$AI + 3CI^{-} \rightleftharpoons AICI_{3} + 3e^{-}$$
(11)

The resulting mixed potential is close to E_{ss} obtained in the present study.

3.3.2 Tafel Plots Method

A-Pure Aluminum Electrode

After OCP measurements reached E_{ss} , Tafel method was performed to measure current density (I_{corr}). To study the effect of concentration, temperature was kept constant for pure Al, In. and Eg. alloys as shown in Table. 6. The following results were obtained:

1. For pure Al at 25°C, the I_{corr} values increased with increasing concentration which indicated that CE solutions contained corrosive constituents which increased the CR. The values of B_a were almost constant which mean that Al dissolution was the same while B_c increased slightly with increasing concentration following the same trend as I_{corr} . At 60°C the values of I_{corr} were greater than their values at 25°C which are in agreement with other studies [9, 10]. For the values of B_c there were an increase with increasing concentrations up to 7% which indicated that the cathodic reactions were

dominant. However for the high concentrations (7% and 10%) the values of B_c and I_{corr} decreased which may be attributed to the evaporation of the corrosive volatile constituents.

2. For the Eg. alloy the values of I_{corr} increased slightly with increasing concentration. The values of B_c increased slightly while B_a decreased with increasing concentration.

3. For the In. alloy the values of I_{corr} were almost constant with increasing concentration (1.29 μ A/cm²± 0.18). The trend was similar to the trend for E_{ss} . There were no obvious trend for values of B_c and B_a .

The increase of CR (without NaCl) with increasing temperature is in accordance with WL results.

To study the effect of temperature, the concentration of the CE solutions were kept constant at 5% w/without NaCl for pure Al only as shown in **Table.6**. The following results were obtained:

a. For 5% CE solution, the values of I_{corr} increased with increasing temperature. There were no obvious trend for the values of B_c and B_a .

b. For 5% CE+ NaCl, the values of I_{corr} increased with increasing temperature. The values of B_a increased with increasing temperature while the opposite trend was shown for B_c . The values of I_{corr} of CE + NaCl were greater than the values of I_{corr} of CE solutions only for each degree of temperatures which indicated the role of chloride in Al dissolution and agrees with Cl⁻ role in Al dissolution to form compounds like AlCl₄⁻ and Al₂Cl₈⁻² [9, 27].

It is known that attack of Al_2O_3 may occur through voids and defect sites. A previous model by McCaferty considered that penetration of Cl⁻ ions can occur by film dissolution or by migration through oxygen vacancies [28]. These defected sights are more prone to attack at high temperatures [9, 22]. Many studies have shown that Cl⁻ are incorporated to a distance of 10–15 Å from the interphase of oxide/solution[29, 30]. To investigate what may occur to Cl⁻ at the oxide film, Kolice et.al [31] using labeled Chloride found that that they were adsorbed chemically on oxide film and react as a partner in Al dissolution by forming oxy chloride ionic complexes. The increase of I_{corr} with temperature was observed by Al Juhaiman et al. when using amino acids [9] and by Al Mayouf et al. [22]. For B_a and B_c they both increase with temperature but the increase was more prominent with NaCl which indicated that there were a different mechanism[26]. Apparent activation energy values, E_a for pure Al in CE solutions w/without NaCl were calculated from Arrhenius equation:

 $\mathbf{k} = \mathbf{A}\mathbf{e}^{-\mathbf{E}\mathbf{a}/\mathbf{R}\mathbf{T}}$ (12)

by plotting $\ln I_{corr}$ versus 1/T and the results are listed in **Table 7**. E_a values for CE solutions were five times more than E_a with NaCl which is in agreement with the trend of CR of Al dissolution and agrees with WL results.

B-Al alloys:

For the In. alloy it was found that E_{ss} is more positive than the Eg. Alloy which reflected the effect of alloying element and agree with others [9, 31]. In the present study from **Table .5**., the trend for CR was:

Pure Al > Eg Al > In Al

It is noticed from the alloying elements **Table 1** that the In. alloy contained 0.20% Chromium but there were no Cr in the Eg. alloy. The In. alloy also contained 0.21% Copper while the Eg. alloy contained 0.12% Copper. Both Copper and Chromium are known to increase the corrosion resistance of metals. It was hard to attribute the corrosion resistance of the In. alloy to these two alloying

elements because there are other alloying elements in the In. alloy which are not present in the Eg. alloy and vice versa. It is the total effect of all the alloying elements that make the difference.

Alloy	Т	%C	B _a	-Bc	I _{corr}
	(°C)	(w/v)	(mV/dec)	(mV/dec)	$(\mu A/cm^2)$
Pure Al	25	2	77.7	100.5	1.15
		5	73.7	94	1.28
		7	72.3	74	1.87
		10	71.2	82	2.06
	60	2	84.3	87	4.42
		5	82.6	106.5	4.72
		7	87.3	100.7	3.73
		10	88.6	114.3	3.87
Eg Al	60	2	112.4	108.6	2.20
		5	118.6	98.9	2.44
		7	85.3	91.6	2.83
		10	82.5	89.4	2.91
In Al	60	2	59.3	64.8	1.47
		5	90.0	79.8	1.40
		7	69.8	73.6	1.39
		10	70.7	66.8	1.29

Table 5. Electrochemical parameters of Al alloys for CE solutions at different concentration from Tafel method:

Table 6. Electrochemical parameters of pure Al for 5% CE solutions w/without NaCl at different temperatures from Tafel method:

Solution	T (°C)	B _a (mV/dec)	-Bc (mV/dec)	I_{corr} ($\mu A/cm^2$)
5%	10	73.1	84.6	0.665
Card. only	25	83.7	94.5	1.28
	45	83.7	77.6	3.17
	60	66.3	77.2	3.58
5%	10	18.5	213.4	3.27
Card. + NaCl	25	17.3	150.2	4.48
	45	95.1	83.4	4.52
	60	85.2	84.7	5.21

Table 7. Apparent E_a of pure Al for CE solutions w/without NaCl

Sol.	E _a (kJ/mol)	Sol.	E _a (kJ/mol)
CE	161.0	CE+ NaCl	41.38

4. CONCLUSION

1. From WL result, the use of CE solutions at 90°C promoted CR of both the In. and Eg. alloys which increased with increasing concentration in all solutions. The addition of NaCl to CE solutions in DW has a different effect in the lower concentrations (1, 2%) decreasing the CR for the Eg. alloy and increasing the CR for the In. alloy.

2. CR for solutions of CE solutions in Tab +NaCl was lower than DW or DW + NaCl for both alloys.

3. The results of Surface Study are in agreement with WL result.

4. From electrochemical methods it was found that current density using pure Al and Al alloys showed the following trend:

Pure Al > Eg Al > In Al

5. The effect of cardamom extract on Al leaching was significant even at low concentrations (less than 5%) where it caused pits and blisters as shown from the surface study.

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