

The Inhibitory Effect and Adsorption Mechanism of Roasted *Elaeis guineensis* as Green Inhibitor on the Corrosion Process of Extruded AA6063 Al-Mg-Si Alloy in Simulated Solution

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Abstract The green roasted *Elaeis guineensis* oil was tested as a natural inhibitor for Al-Mg-Si in simulated 3.5 % sodium chloride solution by linear potentiodynamic polarization and gravimetric method in the inhibited concentration variation between 5 % and 15 %. SEM/EDX studies were used to examine the surface morphology of the corrosion process and adsorption corrosion product that retards the degradation activities. From the experimental result, the adsorption of surface active compounds at the metal surface proved to create an organic protective film leading to efficient corrosion inhibition. The inhibitory effect significantly improved with about 98 % efficiency and the adsorption of *Elaeis guineensis* surfactants extract was found to follow the Langmuir adsorption isotherm.

Keywords Adsorption · Extruded aluminium alloy · *Elaeis guineensis* · Inhibitory efficiency

1 Introduction

The enormous demand of Al-Mg-Si for various engineering purposes is basically because of its excellent chemical and mechanical properties [1–6]. Typically, aluminium has superior corrosion resistance behavior due to oxide formation on its surface. However, in an acidic and strong

chloride environment, the failure of the protective films happens due to high hydrogen and chloride ion which tend to forcefully find their way into aluminum intermediates [7]. This breakdown due to the sulphates, chloride and other oxides ion has necessitated great concern by researchers over the years and it has been reported that an inhibitor is one the way to mitigate such occurrences [7–13]. Quite a number of inhibitors have been proven to be effective but quite dangerous to health [14–16]. The toxicity, cost value and non-decomposable tendency of most inhibitors have been unbearable [15–19]. Since corrosion inhibitors in the medium are significant to metal-medium interaction no matter how small the concentration might be, they go a long way to alter the detrimental effect that the metal otherwise might incur.

Moreso, corrosion inhibitors are carefully chosen on the basis of solubility or wettability in the solutions which are to be inhibited [7, 14–19]. In most cases, the inhibitory effect on a metal surface depends on the nature and inhibitory consistence of the inhibitor. Another major challenge is the right selection of inhibitor for specific environment which also cause real detriment to metal life. Regrettably, some of the organic inhibitors used are extremely costly and hazardous in nature. In view of this, concern to find very low-cost and eco-friendly type of inhibitor for protection of metals against corrosion has been remarkable recently by corrosion experts [20–22].

According to [17, 18] Plant extracts are incredibly rich sources of naturally synthesized chemical compounds with, glucosinolates, alkaloids, polyphenols, and tannins and most are known to have good inhibitive activities. From the open literature, enormous use of this essential oil and plant extracts has play major role in the protection of metals against corrosion. In our previous studies [1], *Arachi hypogaeae* natural oil has been attested as efficient green

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inhibitors in acidic and chloride corrosion medium. The use of *Azandi rachtaindica* extract as inhibitor has also been evaluated and found to possess excellent inhibitory performance [21].

Palm kernel oil comes from the seed of the oil palm (*Elaeis guineensis*). It is a common cooking oil in tropical regions such as Southeast Asia and Central Africa. Palm kernel oil is more popular in Africa especially in Nigeria due to its low manufacturing cost relative to that of other cooking oils. Palm kernel oil is one of the few vegetable oils that are high in saturated fat, which makes it semisolid at room temperature. In this study, we attempt to assess the inhibitory corrosion performance of *Elaeis guineensis* oil (EGO) and its active action toward the existence of pitting corrosion in simulated solution using linear polarization and gravimetric technique with the hope of providing reference for inhibitory-metal interface in surface science application.

2 Experimental Results

2.1 Materials and Sample Preparation

Al-Mg-Si test coupons with chemical composition as shown in (Table 1) below was cut to dimensions of (40 × 20 × 3) mm with a 2 mm diameter hole drilled on one end for suspension in the NaCl test media. The coupons were fairly polished with emery papers cleaned in acetone, dried and weighed with an analytical balance. The initial weight of each sample was recorded and labeled appropriately with suspension string directly to the coupon into the chloride medium. The 3.5 % simulated sodium chloride solution was prepared and the essential *Elaeis guineensis* oil used was obtained from the material design laboratory, Ota, Ogun State Nigeria with molecular structure shown in Fig. 1. The electrochemical investigation was performed at 30 °C ambient temperature.

2.2 Gravimetric Measurement

50 ml of the test simulated salt at varying concentration of inhibitor at room temperature for 216 h was setup for gravimetric measurements. The weighed coupon sample immersed in 50 ml with and without addition of *Elaeis guineensis* oil was evaluated at 30 °C. The test specimens was sequentially taken out in every 72 h to be washed with water, rinsed, dried and re-weighed with acetone,

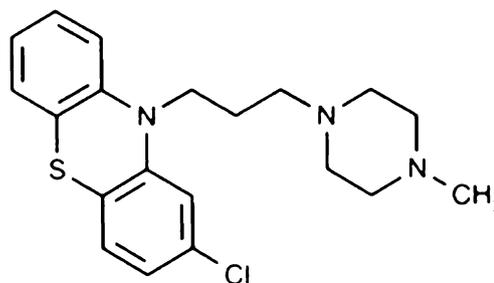


Fig. 1 Molecular structure representation of *Elaeis guineensis*

laboratory dryer and weighing balance, respectively. A typical Plot of weight-loss against exposure time was shown in Fig. 2. Percentage inhibition efficiency (%IE) versus time of exposure (hours) and percentage inhibitor concentration were evaluated from Table 2.

The corrosion rate (R) fittings were calculated from the formula below:

$$CR = \frac{KW}{TAD} \quad (1)$$

Hence

$$CR = \frac{87.6W}{DAT} \quad (2)$$

Where

W is the weight loss in milligrams,

D is the density in g/cm³,

A is the area in cm², and

T is the time of exposure in hours.

The total surface area covered by the inhibitor and % inhibitor efficiency, (I.E), was calculated from the combine relationship

$$\Theta = \frac{W1 - W2}{W1} \quad (3)$$

And

$$I.E\% = \frac{W1 - W2}{W1} \times 100 \quad (4)$$

Where, W2 and W1 are the corrosion rates in the presence and absence, respectively.

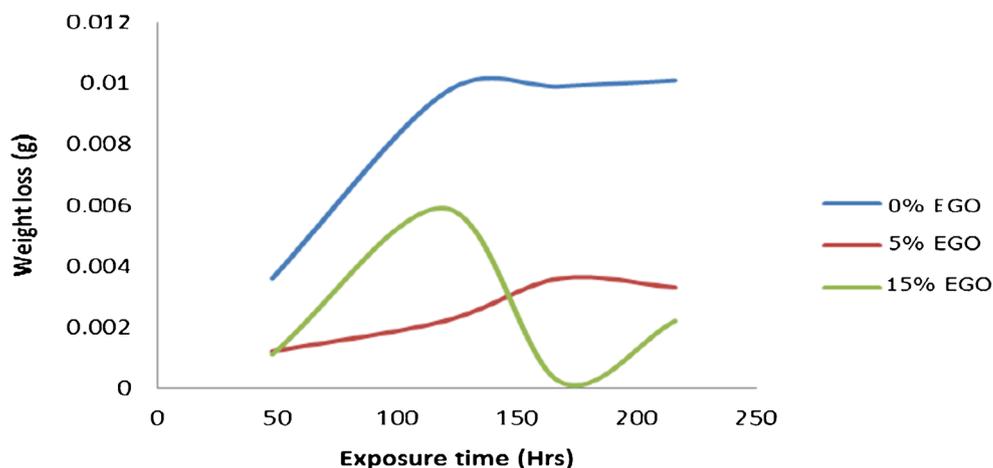
2.3 Linear Polarization Resistance

Potentiodynamics linear polarization measurements were carried out using, a sectioned rectangular aluminium coupon. The coupons were mounted with resin and the

Table 1 Chemical composition of the aluminium alloy used

Element	Al	Si	Mn	Mg	Sr	Bi	Ca	Na	Fe	Ti	P, Cr, Zr, Cu, Zn	B, Ni, Ag, Co
%	99.01	0.157	0.025	0.5	0.0001	0.0024	0.0012	0.001	0.281	0.0046	0.01	0.004

Fig. 2 Variation of weight-loss against exposure time in (0 %–15 %) EGO concentrations



surfaces were made to expose to the medium. The electrochemical measurement was done with an Autolab PGSTAT 101 Metrohm potentiostat/galvanostat. Other accessory are an electrode cell containing 50 ml of electrolyte, with and without inhibitor, graphite rod works as auxiliary electrode and silver chloride electrode (SCE) function as reference electrode. The potentiodynamic potential scan was fixed to run from -1.5 V to $+1.5\text{ mV}$ with a scan rate of 0.012 V/s . (E_{corr}), (j_{corr}) were evaluated from the Tafel plots of E/I . The degree of surface coverage (θ) and the percentage inhibition efficiency ($\%IE$) were calculated as follows

$$\Theta = 1 - \frac{I_{\text{corr}}}{I_{\text{ocorr}}} \tag{5}$$

The percentage inhibition efficiency ($\%IE$) was calculated from corrosion current density values using the equation.

$$\text{And } IE\% = 1 - \frac{I_{\text{corr}}}{I_{\text{ocorr}}} \times 100 \tag{6}$$

Where

Table 2 Data obtained from gravimetric polarization measurements for Al-Mg-Si alloy in 3.5 % NaCl in the presence of different concentrations of the *Elaeis guineensis* oil

Exposure time (h)	Concentration of Inhibitor (%)	Wt	CR (mm/yr)	Inhibitory Efficiency (%)	Degree of Surface Coverage (θ)
48	0	0.0036	0.00304	–	–
	5	0.0012	0.00101	66	0.667
	15	0.0011	0.00092	70	0.697
120	0	0.0097	0.00327	–	–
	5	0.0022	0.00074	77	0.773
	15	0.0059	0.00199	39	0.391
168	0	0.0099	0.00238	–	–
	5	0.0036	0.00086	64	0.641
	15	0.0002	0.00004	98	0.983
216	0	0.0101	0.00189	–	–
	5	0.0033	0.00061	68	0.677
	15	0.0022	0.00041	78	0.783

I_{corr} are inhibited corrosion current densities and I_{ocorr} is un-inhibited corrosion current density, respectively.

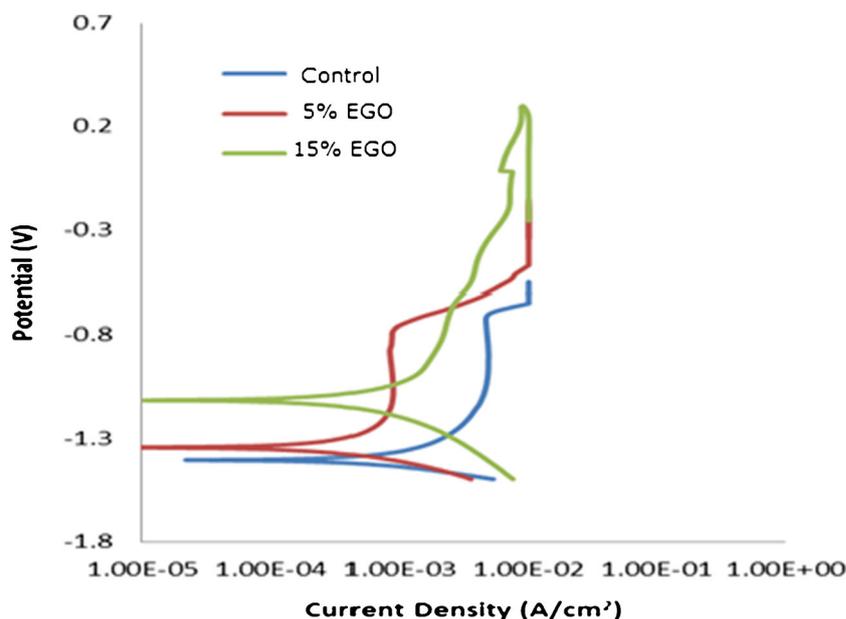
2.4 Photomicrography Characterization

The surface morphology of inhibited Al-Mg-Si alloy and as-corroded uninhibited sample were studied with a scanning electron microscopy equipped with energy dispersive spectroscopy to analyze the elemental composition and corrosion product within the Al interface.

3 Results and Discussion

From the weight loss measurement, the value of the weight lost (wt), corrosion rate (CR) and inhibitory efficiency (IE %) for various concentration of inhibitor is giving in Table 2. It is observed that there are remarkable decreases in weight loss at the end of the electro corrosion-monitoring

Fig. 3 Comparative linear potentiodynamic polarization scans for aluminium in 3.5 % NaCl solution in the absence and presence of different concentrations of *Elaeis guineensis* at 30 °C



process at ambient temperatures. From the weight loss with time of exposure of Al-Mg-Si in 3.5 % simulated NaCl medium result in Fig. 2 there is a significant decrease in weight loss demonstrating a better corrosion inhibition. The inhibitory achievement of *Elaeis guineensis* was due to the presence of complex molecules containing in the oil extract. The curve in Fig. 2 confirmed and established the progress by [10–12] that extract with heteroatoms or related molecules are rich in nature which can provide good adsorption spot onto the metal surface thereby inhibiting the metal in solution and hence offers extensive surface coverage.

Moreover, the trend of inhibition and the decrease in corrosion rate could be associated to the ratio of concentration administer into the corrosive medium which tend to destabilized the penetration of chloride induced which ought to occur within the interface of the substrate. Since [12] affirmed that inhibition efficiency are influenced by the molecular structure of the inhibitor and the molecule adsorption on the metal surface occurs through the heteroatoms such as oxygen in oil. It is however necessary to say that the 98 % efficiency attained through the *Elaeis guineensis* oil from weight loss studies are as a result

of chemical activities and the strong absorbate molecular constituent in the oil which also follow the same trend as reported by other studies [1, 11]. The participation of this atom strangely leads to the shift in the corrosion process of the chemical medium thereby inhibiting the surface and reducing the corrosion rate within time intervals.

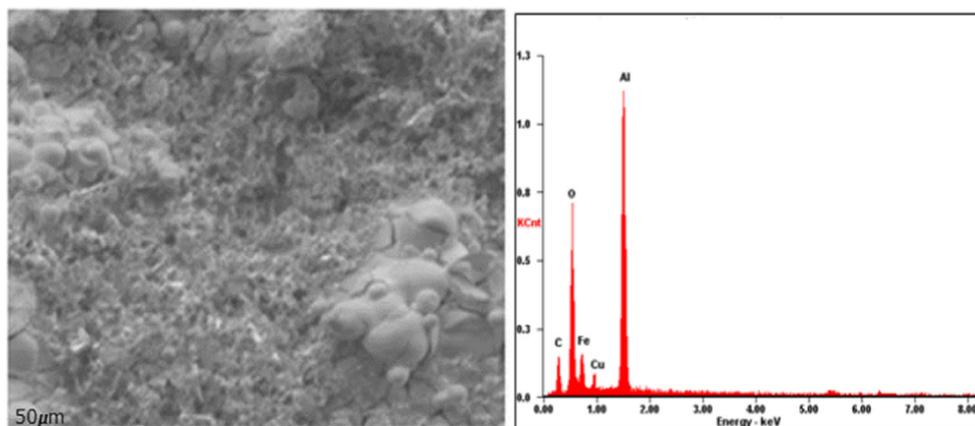
3.1 Linear Potentiodynamic Polarization

Linear potentiodynamic Polarization plots were obtained for Al-Mg-Si electrodes in 3.5 % simulated medium in the absence and presence of different concentrations of *EO* inhibitor at 30 °C (Fig. 3). The kinetic Parameters like corrosion density (i_{corr}), corrosion potential (E_{corr}), tafel extrapolated cathodic and anodic slopes (β_a , β_c), the corrosion current density (I_{corr}), surface coverage (θ) and the percentage inhibition efficiency (% IE) are obtained in Table 3. As clearly noticed from Fig. 3, the significant decrease in both anodic and cathodic current densities rose from the addition of *Elaeis guineensis*. More so, a significant shift in potential was observed for solution with high

Table 3 Electrochemical corrosion data obtained for Al-Mg-Si alloy in 3.5 % NaCl varying concentration of *Elaeis guineensis* environment at 30 °C

Inhibitor conc.	β_a (V/dec)	β_c (V/dec)	E_{corr} , Obs (V)	j_{corr} (A/cm ²)	i_{corr} (A)	CR (mm/y)	R_p (Ω)	E Begin (V)	IE (%)
15 % EG Oil	0.018862	0.016757	-1.1158	3.04E-05	3.04E-05	0.066285	291.49	-1.1288	72
5 % EG Oil	0.052888	0.050122	-1.3444	3.83E-05	3.83E-05	0.078955	126.77	-1.3681	65
Control	0.007837	0.036636	-1.4056	0.000109	0.000109	0.23673	25.825	-1.412	-

Fig. 4 SEM photomicrograph of uninhibited Al-Mg-Si alloy in 3.5 % NaCl solution after 48 h with EDS



percentage concentration of inhibitor although with minimal current density change unlike 5 % EO where both the anodic and cathodic significantly change as the E_{corr} of the materials increases.

More importantly is the trend to which the aggressive simulated solution, both anodic dissolution of aluminium and cathodic chloride progression reaction were introverted with the inhibitor. A quick shift of the E_{corr} value was obtained from the inhibited solutions with -1.4056 to -1.3444 , and improved E_{corr} value of -1.1158 . The increases in the inhibitor concentration tend to reduce drastically the corrosion rate from CR, 0.23673 to 0.078955 and 0.066285 with I_{corr} of uninhibited aluminium of 0.000109. The change in the I_{corr} value to 3.83E-05, and 3.04E-05 for 0.5 % and 1.5 % respectively could also be possibly enhanced by the formation of an insoluble films formed by the oxidation of aluminium which assist in the process of retardation or dissolution processes [13, 14].

Likewise, from the observed change in the Tafel slopes and the corrosion parameter, the inhibition effect seemed to be cathodic or anodic type inhibitor since the displacement of E_{corr} is > 85 mV, with pronounced effect. The inhibition efficiency (IE %) was computed from the corrosion current

density from the below equation with inhibition efficiency of up to 72 % was achieved at 15 % concentration of the EGO.

$$IE(\%) = \frac{I_{corr} - I_{ocorr}}{I_{ocorr}} \times 100 \quad (7)$$

Where I_{corr} and I_{ocorr} are the corrosion current densities in the absence of inhibitor and presence of inhibitor, respectively.

3.2 Photomicrography Studies

Figure 4 shows the deterioration surface behavior of as-received aluminium in the absence of natural oil; while Fig. 5 indicates the formation of a film by the complex active essential oil constituents on the Al interface. The inhibition behavior of the essential oil may be due to the presence of vitamins. More so, it is evidence that some polar complex compounds like O, S, and N, in oil are good corrosion inhibitors [16–19]. Hence, these should be accountable for the preferred blocking interface that retards Cl^- pene-

Fig. 5 SEM photomicrograph of Al-Mg-Si alloy in 15 % *Elaeis guineensis* at 30 °C in 3.5 % NaCl solution after 48 h immersion time with the EDS

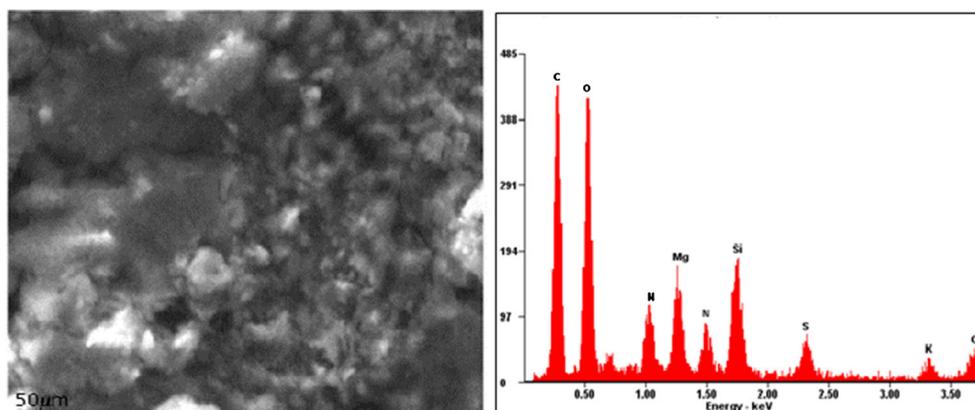
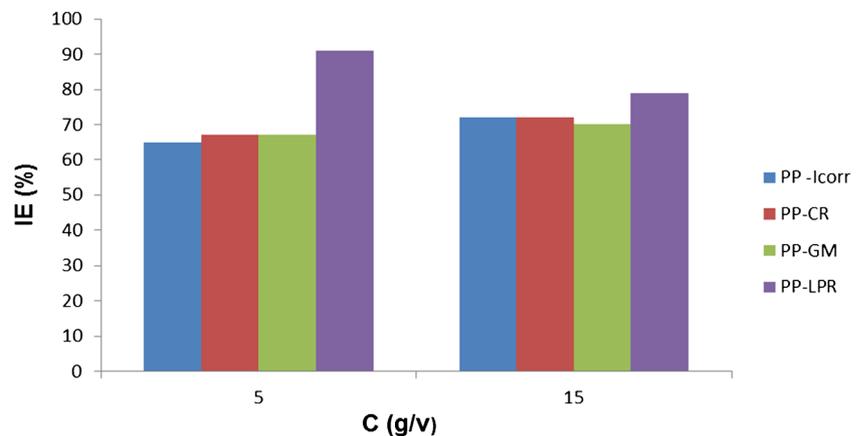


Fig. 6 Comparative evaluation of inhibitor efficiency (IE) for 3.5 % *Elaeis guineensis* concentration obtained from potentiodynamic polarization-corrosion rate (PP-CR), potentiodynamic polarization-corrosion current (PP-Icorr) and linear polarization resistance (LPR)



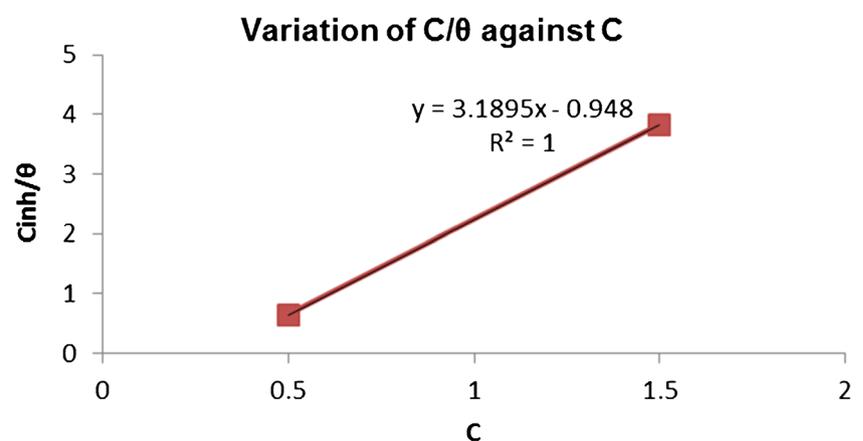
tration which is supposed to extremely cause dissolution of metal ions.

Equally, the surface structure of uninhibited aluminium in NaCl in Fig. 4 shows pits and cracks within the interface compared with Fig. 5. Eventually with 15 % natural *EG oil* (Fig. 5) less surface pit formation was seen. From the EDX examination, it is evident that the visible appearance of O and S, Na and C is due to the formation of hydroxyl, and active action of complex polar or corrosion product present.

3.3 Comparative Analysis of the Inhibitory Efficiency

The calculated inhibitory efficiency of Al-Mg-Si alloy in NaCl were prepared and representation in a chart as in [14] using polarization-corrosion density (PP-Icorr), potentiodynamic polarization-corrosion rate (PP-CR), gravimetric (GM), potentiodynamic linear polarization resistance (LPR) in Fig. 6. From the evaluation, it was noticed that addition of *Elaeis guineensis* concentration enforces improved inhibition efficiency and better surface area coverage on the metal.

Fig. 7 Langmuir isotherm for the adsorption of *Elaeis guineensis* compounds on the Al-Mg-Si alloy surface in 3.5 % solution obtained from potentiodynamic polarization method at 30 °C



3.4 Mechanism of Inhibition and Adsorption Behavior

Adsorption behavior can well explain the mechanism of inhibition of *Elaeis guineensis* in varying concentration of inhibitor at 3.5 % NaCl for Al-Mg-Si alloy specimen. Basically from the literature, adsorption progression is subjective to the factor of inhibition such as sharing of the molecule, chemical and molecule structure distribution, the nature and surface charge of metal and destructive mode of the environment [15, 22]. A reasonable explanation in this regard can be made that the adsorption of the natural oil inhibitors are mostly governed by some physicochemical compounds and the relative activities of the molecule, ion, hydroxyl and atoms present in relation to their groups.

In the same way, it is this adsorption of the inhibitory molecules on the surface of aluminium, that lead to the establishment of a corrosion protecting film around the surface area. It is obvious that the adsorption of *Elaeis guineensis* on the aluminium surface could occur directly on the basis of exact atomic exchange between the molecules/ions of the adsorbents and the oxide film generated from the aluminum reactivity in the chloride medium.

The active action of *Elaeis guineensis* is also ascribed to the presence of O and S as early stated [12, 17–20]. It is also affirmed that the presence of chloride ion in some way increases this molecules migration as the passive barrier becomes less active. The polarity property and constituent seems to provide efficient active adsorption for the molecule within the interface even at less concentration of inhibitor. In view of this, the adsorption of oil compounds can be described by physio-adsorption interaction of metal surface and the molecular conjugate from the natural oil extract. The Langmuir adsorption isotherm was useful and realistic to describe the adsorption mechanism for EGO compounds as it fits the studies at varying concentrations in Fig. 7.

4 Conclusions

Elaeis guineensis essential natural oil has been proven to be a good inhibitor for Al-Mg-Si in simulated NaCl environment with percentage inhibition efficiency of 98 % at an inhibitor concentration of 15 %. Even after 216 h, the inhibition efficiency still significantly improved beyond expectation with about 78 % inhibitory potential. The kinetics mechanism of this behavior shows that *Elaeis guineensis* behaves as mixed type inhibitor. Inhibitory efficiency is induced by the buildup of surface active compounds and oxide at the metal surface leading to perfect wettability and modified interface. Chloride are naturally expected to cause degradation and multiple pitting, actions was altered due to the oxide films of aluminium phytochemical atoms from the natural oil extract. The adsorption of the compound on the aluminium surface was found to obey Langmuir adsorption isotherm. SEM-EDS examination showed that there was improvement in the surface morphology of inhibited aluminum substrate compared to uninhibited samples.

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