

Inhibitory Effect of *Trigona* Sp. Propolis Extract on Corrosion Rate of API 5L-B Steel in a Corrosive Medium

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Abstract— The effectiveness of inhibitor extract of *Trigona* sp. propolis (IETP) as the corrosion inhibition of API 5L Grade B steel was studied in the corrosive environment of 3.5% NaCl solutions is systematically presented. The use of selected organic corrosion inhibitors is a new alternative as one type of inhibitor that is non-toxic, inexpensive, available in nature, and environmentally friendly. IETP as an organic corrosion inhibitor has been characterized and analyzed in this study. The main compound in the inhibitor was identified based on the Fourier transform infrared spectroscopic analysis. The chemical compound of the propolis solution is flavonoid-rich in oxygen atoms, which play an important role in the inhibition process. Inhibition behavior was investigated through weight loss testing and the polarization methods on API 5L Grade B steel material in 3.5% NaCl media with variations of the addition of inhibitors 0 ml, 2 ml, 4 ml, 6 ml, 8 ml, and 10 ml into the solution. The results showed that the IETP was quite effective in corrosion medium with a solution of NaCl 3.5%. The 10 ml IETP had the highest effect decreasing the corrosion rate from 3.469 to 2.272 mpy. Optimal and effective levels in the use of IETP is 10 ml with the highest level efficiency of 79%. The polarization curve through the potentiodynamic technique showed that the inhibitor has a tendency for the cathodic inhibitor mechanisms by absorption and simply blocking the reaction on the metal surface.

Keywords—Organic inhibitors; *Trigona* sp. propolis extract; polarization curve; API 5L Grade B.

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I. INTRODUCTION

The use of piping with the American Petroleum Institute (API) Spec 5L specification (API 5L-B Steel) is widely used in mining industries, the process of equipment industry as a pipeline for gas, liquids and oil transportation applications, and distribution of exploration and production processes. However, the widespread use of API 5L pipes has not been accompanied by specific improvements in maintenance, especially in protection against corrosion. The main challenge in the problem of corrosion in piping systems is internal corrosion, as the moving fluid includes several substances, such as oxygen, sulfide acids, carbon monoxide, and sulfate [1], [2]. Corrosion can cause material failure [3], [4] causing failures in pipelines. They are costly to restore, costly in terms of damaged or tainted goods, in terms of environmental impact, and likely costly in terms of human health [1]. Corrosion causes a decrease in the quality of metals due to the electrochemical reaction of metals with the environment [5].

Corrosion cannot be stopped, but corrosion can be reduced and inhibited in various ways, namely using corrosion inhibitors [6], cathodic protection [7], and coating [8]. Recent developments indicate that inhibitors are the most effective and efficient way to protect corrosion in metals [9]. A corrosion inhibitor is a chemical substance that can reduce metal corrosion [6]. Some synthetic compounds from inorganic elements have proven quite effective as metal corrosion inhibitors such as phosphate [10], silicate and phosphonate [11], tungstate [12], and molybdate [13]. During processing, the cost and nature of the hazardous toxin as an implication of its use have forced researchers to look for alternative corrosion inhibitors. These namely organic inhibitors are environmentally friendly, non-toxic and low cost for metal corrosion protection (green inhibitor) [14]. Many organic corrosion inhibitors have been developed from environmentally friendly natural materials which are used as part of plants [15], such as *Mangosteen*, extracts of *Aningeria robusta*, *Camellia sinensis*, *Quercus robur* and *Pomegranate*

peels extract [16]. Propolis is a bee product that used to build and protect the nest. The propolis has been reported slow the corrosion rate of bronze, copper, carbon steel alloys, stainless steel and aluminum in corrosive environments [17].

Trigona sp. It is a species of stingless bee that produce propolis. It has been found that propolis can inhibit corrosion [17]. This study aims to investigate the potential of propolis from the *Trigona* bee as a corrosion inhibitor. The *Trigona* bee is widely spread in Indonesia and Bali island [18], [19]. The *Trigona* bee belongs to the Family of Apidae, the Subfamily of Meliponini, which are found mostly nested in crevices of rocks and trees. *Trigona* bee in Bali is famously called *Kele-Kele* [19]. Propolis is a side product of bee that is in *Trigona* bee used to repair and build the nest. The propolis is made of resin and other plant exudates collected by the bee [20]. Propolis has been found as antimicrobial [21] and has antioxidants. Propolis has been identified as containing flavonoids, terpenes, phenols, and esters. Antimicrobials of propolis are predicted due to its playanoid contents and functions as antioxidants, antimicrobials, and other biological activities as well as phenolics [22]. Corrosion inhibitors are mostly derived from flavones flavonoids [23].

This study aimed to investigate the effectiveness of inhibitor extract of *Trigona* sp. propolis (IETP) of *Trigona* for corrosion of API 5L-B steel in an environment of 3.5% sodium sulfate (NaCl). The characteristics and function of propolis *trigona* extract as an inhibitor on steel were investigated through FTIR spectroscopy. The Potentiodynamic Polarization technique investigated increased corrosion rate and inhibitory efficiency through weight loss methods. The microstructure of corrosion on steel was characterized by scanning electron microscopy (SEM). This work was expected to make a valuable contribution to the study of prevention of organic corrosion with the prospect of using propolis as an alternative way to inhibit corrosion in mild steel pipes, most of which are used in the oil and natural gas industry.

II. MATERIAL AND METHOD

A. Materials and Equipment

The API 5-L grade B samples contain the elements such as 0.148% of C, 0.198% of Si, 0.004% of S, 0.012% of P, 0.425% of Mn, 0.010% of Ni, 0.008% of Cr, <0.005% of Mo, <0.002% of Ti, <0.007% of Cu, <0.002% of Nb, <0.002 of V, <0.002% of Al, others Fe. The composition of API 5-L Grade B steel consists of four dominant elements, namely C, Mn, P, S. The sample is prepared in a size of 1.5 cm x 1.5 cm, then in a circle with a size of 1 cm². All samples were sanded to the leveling and surface smoothing with 120, 140, 400, 600, and 800 sandpaper. IETP extract was prepared by the maceration method. Maceration results were put into storages containing 70% ethanol.

The immersion results were filtered using filter paper to obtain the filtrate. It was evaporating the filtrate from maceration results using a rotary evaporator with a speed of 200 rpm and a temperature of 50°C to produce a concentrated extract. The solution used in this study was NaCl 3.5% (seawater), obtained by mixing a 500 ml volume of distilled water with 35 grams of technical NaCl to produce a 3.5% NaCl solution.

B. Fourier Transform Infra-Red Spectroscopy Testing

Fourier transforms infrared (FTIR) spectroscopy has been developed for analysis characteristics of the functional group in the propolis extract from the *Trigona* bee. In testing using FTIR spectroscopy, the light source is medium infrared. The detector used is deuterated lanthanum triglycine sulfate (DLATGS). Sample preparation used a basting technique which involved a propolis sample in a window of 1 drop (0.2 ml) until it could be penetrated by light. The spectrum of the propylene glycol solvent that functions as a background was stored as a reference. FTIR tool operations were operated until a spectrum was obtained from the sample holder. In addition, the sample also analyzed the spectrum of commercial propolis as a comparison. The infra-red spectrum in OPUS format was stored in a data point table format that can be opened using Microsoft excel software. The spectrum data used was the overall absorption data.

C. pH Measurement

In this stage, there were 12 samples used each part with inhibitor concentrations of 0 ml, 2 ml, 4 ml, and 6 ml. The solution's acidity was initially measured before and after the immersion of the metal at room temperature by pH meter *Oaklon*TM. The final pH values were measured after seven days of immersion in the non-inhibited and inhibited environments.

D. Weight Loss Analysis and Electrochemical Tests

The Corrosion process and determination of inhibition efficiency corrosion of various steels have some solutions. Corrosive media by organic inhibitors, extracts and ions and effects synergistic inhibitor using weight loss, potentiodynamic polarization, and electrochemical impedance spectroscopy (EIS) [24]. The corrosion rate in various reports was determined using weight loss measurement as standard procedure [25]. This method calculates the difference between weight steel lost during deep immersion and corrosive mediums containing extracts or compounds of certain chemistry. In this stage, there were 12 samples used; each part is with a concentration of inhibitors 0 ml, 2 ml, 4 ml, and 6 ml. The sample was cleaned of impurities and dried, then weighed the mass after soaking. The corrosion rate was calculated using the weight loss per density, unit area, and time, as indicated in equation 1.

$$Cr = \frac{87.6 \cdot W}{\rho \cdot A \cdot t} \quad (1)$$

$$1 \text{ mpy} = 0.0254 \text{ mmpy}$$

Evaluation of inhibitor efficiency has been determined by using the following relationship as shown in equation 2.

$$EI = (W_o - W_i) / W_i \times 100 \quad (2)$$

Where W_o is the weight loss without inhibitor and W_i is the weight loss with inhibitor. Evaluation of surface coverage (Θ) obtained by the following equation 3.

$$\Theta = (W_b - W_{bi}) / W_b \times 100 \quad (3)$$

Where W_b and W_{bi} are the weight losses per unit time without and with inhibitor, respectively.

The potentiodynamic polarization method is used to determine the corrosion properties of metals and steels based on a potential and current relationship, anodic or cathodic. Corrosion metal occurs when an anodic current is equal to a cathodic current. This matter is due to the potential difference between a metal with electrolyte solution as the medium. The potential difference is the resulting corrosion potential, while EIS is an experimental electrochemical technique in research corrosion. In principle, the EIS can determine the number of parameters related to electrochemical kinetics, such as resistance polarization, solution resistance, and capacitance electric double layer. The electrochemical test used the Tafel polarization method and EIS. Electrochemical testing using a potentiostat test apparatus according to ASTM G-87 was used to determine corrosion rate. The electrochemical cell consisted of a conventional three-electrode configuration with graphite as the counter electrode and a saturated calomel electrode (SCE). The polarization curve determined the corrosion rate (the magnitude of potential transition due to the total current supplied) resulting from a dynamic polarization scan. When the potential on a metal surface is polarized, this is referred to as anodically polarized in the positive direction. If the metal surface potential is polarized negatively, it is cathodically polarized. The polarization of the activation regulates corrosion reactions. Polarization activity indicates a straight line on the drawing following the Tafel equation as indicated in equation 4.

$$V = a + \beta \log I \quad (4)$$

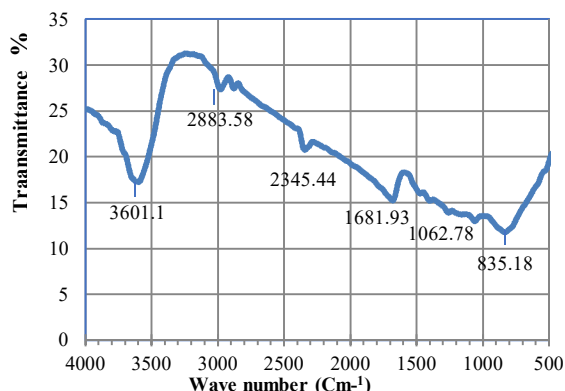


Fig. 1 Characteristics of the Functional group in the propolis extract from *Trigona* bee (*Kele-kele*)

In the potentiostat test, a reference electrode functions to measure the potential value. A platinum cable functions as a counter electrode. The working electrode is a steel specimen API 5L Grade B. The Tafel polarization test uses 250 ml of test solution containing a variety of IETP inhibitors in a solution of NaCl 3.5 %. In the Tafel polarization test, the polarization curves were performed with a scan rate of 0.2 mVs⁻¹ in the potential range of ± 250 mV proportional to corrosion potential. All the potentials were recorded concerning the SCE. Data analysis using software *Gamry-5.06* repetition is carried out for each test in open room conditions and at room temperature. The specimen was immersed in a corrosion medium at open circuit potential before measurement until it reached steady-state conditions. Corrosion current density (*I_{corr}*) is determined from the intercept of extrapolated cathodic and anodic Tafel

polarization slopes. The corrosion rate (*Cr*) can be calculated using the formula shown in equation 5.

$$Cr = \frac{0.129 \cdot I_{corr} \cdot E}{\rho} \quad (5)$$

Where *M* (g/mol) is the equivalent weight ρ is the specimen's density (g/cm³). Meanwhile, the following equation shows the inhibition efficiency (EI) used to measure the inhibitor's effectiveness at each addition of inhibitor concentration is obtained by the following equation 6.

$$EI = \frac{I_{corr} - I_{corr}(I)}{I_{corr}} \times 100 \% \quad (6)$$

In this method, *E* Vs log *I* plot is made at high overpotentials, as indicated in equation 7.

$$\log I = \frac{[\log I_{corr} + (E - E_{corr})]}{\beta} \quad (7)$$

Where *I_{corr}* is the corrosion current density without an inhibitor, and *I_{corr}* (*I*) is the corrosion current density with the addition of the inhibitor concentration. The EIS measurements are used to determine electrochemical kinetics parameters is related to electrical elements such as resistance, capacitance, and inductance after adding the inhibitor. Measurements were made of the charge transfer resistance and electrical interface of the specimens at the corrosion potential (*E_{corr}*) in the frequency range 10 kHz to 10 MHz with an amplitude of 10 mV. The *E* vs log *I* plot gives a straight line with slope β , and the intercept gives *I_{corr}*. The corrosion rate in mpy, obtained as follows:

$$Cr = \frac{3.2 I_{corr}}{d} \times E \quad (8)$$

III. RESULT AND DISCUSSION

The results of visual observations made on adding propolis extract inhibitor 2 ml, 4 ml, 6 ml into 3.5% NaCl solution after soaking for seven days are as follows. Environmental conditions in non-inhibitor bottles, the solution is orange with more corrosion deposits at the bottom of the bottle. It is brownish, caused by the metal undergoing oxidation and dissolving in its environment to produce metal ions and release electrons simultaneously [26]. At the same time, the observations for the inhibited environment showed a black solution due to the addition of propolis extract inhibitors. It is known that propolis contains flavonoid and phenol compounds [27] which are thought to react with NaCl solution. The addition of propolis extract will form a thin protective layer on the surface. This layer is formed because the propolis extract works according to the working principle of organic inhibitors, namely adsorption on metal surfaces. The thin layer formed on the surface of the inhibited sample serves to inhibit the corrosion rate [28].

Fourier transforms infrared (FTIR) spectroscopy has been developed for analysis characteristics of the functional group in the propolis extract from the *Trigona* bee. The spectrum shows the test results in Fig. 1 following Skoog [29] of O-H stretching vibrations at wave number 3601.1 Cm⁻¹. At the peak of 2883.58, Cm⁻¹, there is a C-H bond in the range of 2500-2000. Organic compound Nitril as a functional group of C≡N appears peaked at 2345.44. The C=O peak appears at

1681.93 within the range of 2000-1500 Cm^{-1} . The C-O was peaked at 1062.78 and C-H at 835.18. The results of FTIR spectra show that *Trigona* bee extracts have inhibitory functional groups of corrosion, namely O-H, C-H, $\text{C}\equiv\text{N}$, C=O, C-O and C-H. The following functional groups produce alcohols, phenols, and flavonoids usually found in natural inhibitors [30]. An effective organic corrosion inhibitor should contain heteroatoms (i.e., oxygen, etc.) with electron pairs free, and within the framework of its structure, there are electrons (aromatic ring and multiple bonds) that are able to interact with metal-free orbitals, namely mild steel. These various factors support each other in the process of adsorption of inhibitors on the surface, as also found by Elias [31].

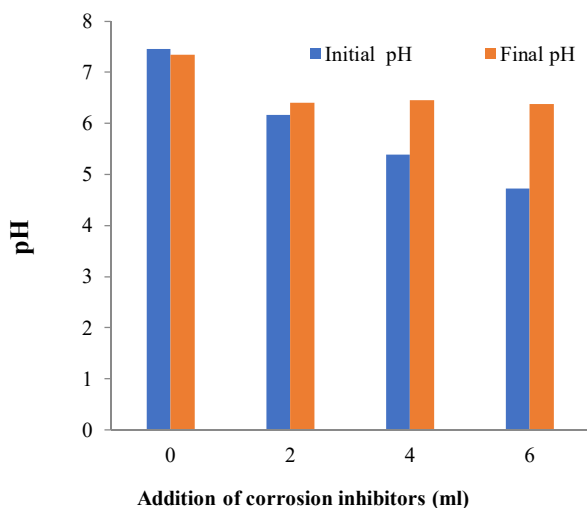


Fig. 2 Initial and Final pH measurement of Non-inhibitory and Inhibitory Solutions

The pH of the non-inhibitory solution was high (7.46) before and after (7.34) immersion. Additional inhibitors applied to the samples found that the pH concentration was decreased gradually as the concentration of inhibitors increased from 6.17 in 2 ml inhibitor to 4.72 in 6 ml inhibitor. The pH was increased after the immersion of the specimen. However, it was below the concentration of the non-inhibitory solution, which was on average of 1.29, 0.78, and 0.67. The pH value increases due to the cathodic reaction in the 3.5% NaCl environment. The reduction of water and oxygen produces OH^- ions, namely $2\text{H}_2\text{O} + \text{O}_2 + 4\text{e}^- \rightarrow 4\text{OH}^-$. Although the ion OH^- will bind with Fe^+ into the compound $\text{Fe}(\text{OH})_2$ [32], the pH value of the environment will become alkaline. An increase in inhibitor concentration in the system causes a decrease in pH (shown in Fig. 2) due to an increase in oxygen binding.

Weight loss analysis is a simple method for monitoring metal corrosion. The weight-loss method is carried out by immersing the metal test object in an electrolyte solution for a certain period [33]. In the measurement of weight loss, the API 5L steel specimen pieces were completely immersed in 100 ml of 3.5% NaCl environmental solution containing propolis extract inhibitor and non-inhibitor. Weight loss testing was carried out for seven days under static conditions. The specimens were then cleaned with rubbing paper and rinsed with ethanol until clean. The metal is then dried in an oven. The amount of weight loss can be calculated based on

the difference in mass before and after immersion. The mass of the specimen was measured using a Mettler Toledo ME54T analytical balance with a readability of 0.1 mg. The weight loss per unit area and time can be calculated using the equation as described in Equation 3.

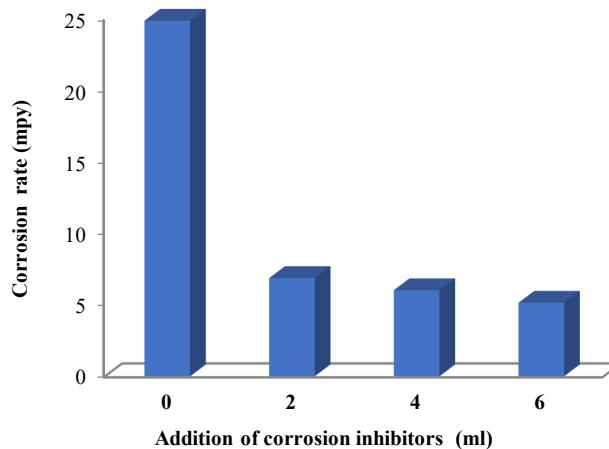


Fig. 3 The addition of corrosion inhibitors Vs. corrosion rate

Results show that propolis as an inhibitor reduced the weight loss and efficiency of IETP. Weight loss in the sample is affected by the addition of propolis inhibitor. The test results show that the solution that is not inhibited is the average weight lost by 0.079 gram, for the addition of 2 ml of inhibitor, the average weight loss is 0.074 gram, for the addition of 4 ml inhibitors, the average weight loss, that is equal to 0.058 gram, while for the addition of 6 ml inhibitors the average is lost weight that is equal to 0.043 gram. The smallest weight reduction occurred at the addition of a 6 ml inhibitor. This result indicates that propolis extract acts as an inhibitor, so protect steel shown by reducing weight loss of API 5L steel sample. The addition of propolis extract shifted the polarization curve to a lower value. The addition of inhibitors in 3.5% NaCl solution can inhibit the anode or cathode reaction, which causes a decrease in the potential corrosion.

Steel surface that has not been corroded and has been corroded analyzed using SEM method, which uses electron beams to describe the surface state of the material analyzed. Image of object surface or material with the help of an electron beam that reflected with high energy. Surface irradiated or beamed material electrons will reflect the beam electrons known as the electron beam secondary in all directions. As shown in Fig. 4, the polished API 5L Steel specimens immersed in 3.5% NaCl solution for inhibition and non-inhibition were examined using SEM. Observations on the blank condition (without inhibitor treatment), the metal surface was corroded with scratched grain boundaries and other corrosion products shown in Fig. 4 (a). The Micrographs indicates that the surface is severely damaged in the absence of inhibitors (active corrosion). However, in the presence of inhibitors, the micrograph indicates a reduction in corrosion sites and pits over the surface of the API 5L Steel specimens (Fig. 4 (b), (c), (d)).

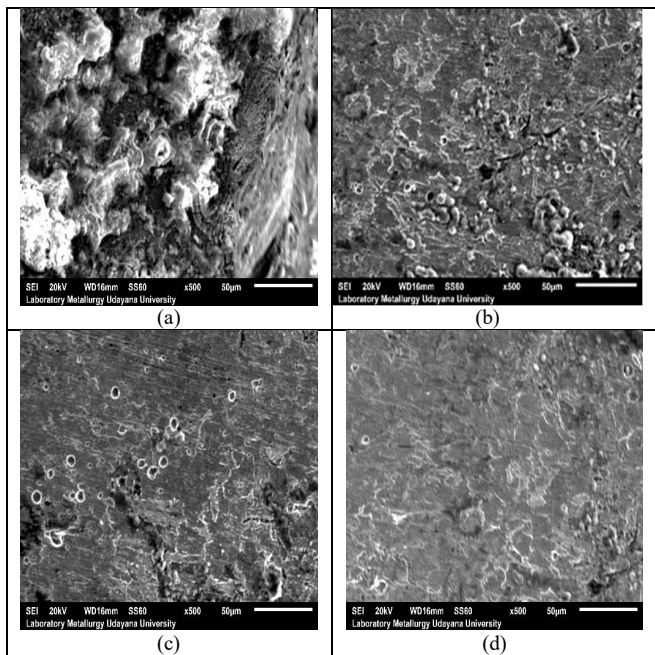


Fig. 4 (a) Image of the results with 500x Magnification of SEM 5L API Steel without inhibitor, (b) with inhibitor 2 ml, (c) 4 ml and (d) 6 ml

This is due to the creation of an adsorption layer of inhibitor on the metal surface. It is well known that the corrosion inhibition exhibited by organic molecules is through adsorption on the corroding metal [34], [35]. Seen damage was decreased gradually as the concentration of inhibitors increased. The results agree with previous work by Xavier Stango [36]. The adsorption process continued corrosion inhibition by forming an organic protective layer on the material's surface. From these observations, the inhibitor tends to give a good inhibition effect for the API 5L Steel and thus confirmed the results obtained from other techniques.

The polarization test was carried out by evaluating the cathodic and anodic slopes of Tafel on the corrosion medium of 3.5% NaCl solution. The data obtained on the Tafel polarization curve are corrosion rate (Cr), E_{corr} , and I_{corr} . The symmetry of energy limiting in the anodic and cathodic directions, whereas a rule of thumb for the type of inhibitor is the E_{corr} shift for the entire concentration range less than ± 85 mV, they have the same concept as Ganash [37].

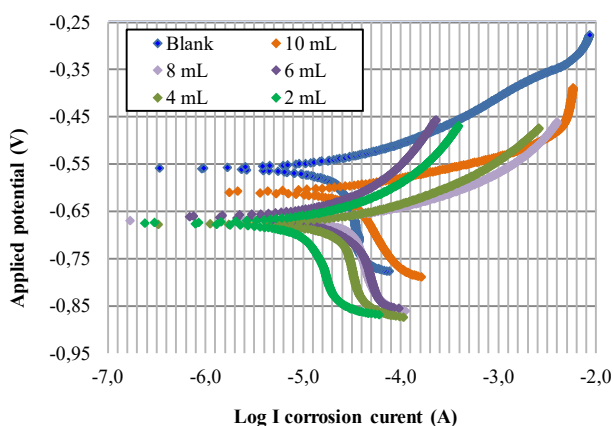


Fig. 5 Polarization curve of API grade 5L API B in a 3.5% of NaCl solution with various concentrations of the Inhibitor Extract of IETP.

Fig. 5 shows the polarization curves with the anode and cathode reaction, where the value of the potential corrosion shifts to the negative direction. This indicates that the corrosion current and the rate of corrosion decreased. The reaction at the branch anode shows no significant changes, indicating that the reaction at the fixed branch anode is directly corroded without forming a passive layer.

The polarization showed a straight line following the Tafel Equation drawing when the corrosion reaction was controlled by activation polarization. The reduction of oxygen in the solution will decrease the reaction of corrosion-oxidation, so increase the function of the inhibitor, as also found by Pradityana [38].

TABLE I
THE CORROSION RATE AFTER THE ADDITION OF VARIOUS INHIBITOR CONCENTRATIONS

Parameters	without inhibitors	Variations in the addition of inhibitors				
		2 ml	4 ml	6 ml	8 ml	10 ml
I_{corr}	9.43	7.61	7.36	6.59	6.49	6.27
E_{corr}	-558.50	-674.57	-676.48	-855.87	-669.64	-608.54
Cr	4.31	3.47	3.25	2.89	2.66	2.27

The variation of potential as a function of current (polarization curve) makes it possible to know the effect of the concentration and activation process at the level at which the anode or cathode reaction can give or receive electrons. Therefore, polarization measurements can determine the rate of reaction involved in the corrosion process. Fig. 5 shows the polarization curve of API grade 5L API B in 3.5% NaCl solution with the addition of a *Trigona* propolis extract inhibitor with 2 ml, 4 ml, 6 ml, 8 ml, and 10 ml, respectively. The polarization curve of the test results shows the reaction at the anode branch and cathode branch during the testing process and values such as corrosion potential (E_{corr}), corrosion current (I_{corr}), and corrosion rate after testing. Oxidation at the anode occurs due to a chemical reaction between iron and oxygen contained in 3.5% sodium sulfate (NaCl). The $Fe(OH)_2$ layer formed, in principle, will cover the surface of the specimen so that the diffusion of oxygen on the surface will be hindered. In order to prevent the reaction at the cathode causing the product to corrode, an adsorbed protective layer is needed on the surface, which is capable of inhibiting the anodic reaction. Heteroatoms such as oxygen which function as electron donor compounds have potential as major adsorption centers in organic compounds due to interactions with metal surfaces. Adsorption can also occur through electrostatic attraction force due to the excess positive charge at this interface between the negatively charged surface provided by the specially adsorbed anion (SO_4^{2-}) on the iron and the positive charge of the inhibitor [39], [40]. Moreover, according to the literature [28], the organic acid component leading to the formation of passive film on the substrate surface from the presented investigations, it can be concluded that the inhibitor is adsorbed on the entire metal surface of the corroding metal, and so prevents the attack from the corrosion. Organic inhibitors are adsorbed on the surface of the metal [41].

This conclusion is supported by polarization measurements that show that the extract can inhibit the corrosion process by blocking it through forming a thin layer on the metal surface.

The presence of *Trigona Sp.* propolis extract. It is causing a potential shift towards a more positive value indicating that the anodic reaction is inhibited, which is shown by the reduction in I_{corr} . Increasing the inhibitor concentration significantly decreased the I_{corr} value, as shown in Table 1. The lowest I_{corr} value was 6.27 A/cm² at a concentration of 10 ml inhibitor. This pattern indicates that the presence of inhibitors affects the anodic and cathodic reactions [42]. The initial corrosion rate obtained without the inhibitor was 4.31 mpy. Adding a 2 ml inhibitor reduced the corrosion rate to 3.47 mpy. The decrease in corrosion rate continued to occur with the addition of inhibitors up to 2.27 mpy with 10 ml of propolis extract inhibitor. The results of this study indicate that propolis is one of the natural resources. It can be considered a corrosion inhibitor because it is quite abundant and as a by-product. For beekeepers, 10 ml concentration of bee propolis extract was relatively effective in protecting steel from corrosion, as shown in this study.

The constituent structure present in IETP, Anodic inhibition is possible due to the adsorption of the main phytochemical constituents present in the extract via the oxygen atom or ring of oxygen atoms in Flavonoids and others. These organic compounds containing heteroatoms and double bonds in their molecules will facilitate adsorption on the metal surface and form a protective layer on the metal surface, thus preventing contact between the metal and corrosive acids.

IV. CONCLUSION

Testing the addition of *Trigona sp.* propolis (IETP) with the polarization method was successful in its application and effective in reducing the value of the corrosion rate with artificial seawater media NaCl 3.5% on grade 5L API steel B. The addition of IETP 2 ml showed a corrosion rate of 3.47 mpy; the corrosion rate was slightly reduced from the corrosion rate without inhibitors even though the reduction was not significant. The decrease in the corrosion rate continues to occur along with the addition of inhibitors to the NaCl 3.5% addition of IETP, making the corrosion resistance increase. Based on the results of this experiment, we can see that the lowest value of corrosion rate is obtained from the addition of 10 ml inhibitors; from this study, the levels of 10 ml of inhibitors are considered effective.

From observations in this study, IETP is an anodic and cathodic inhibitor with more dominant cathodic effectiveness; the mechanism that inhibits the corrosion rate is forming a thin barrier on the material's surface by inhibitor molecules and oxygen reduction, commonly called oxygen scavenger. Optimal and effective levels in the use of IETP is 10 ml with the highest level of efficiency, 79%. The Corrosion green inhibitor proved effective from an ecological perspective and environment and can play a role important to replace other inhibitors that toxic. More amazing things give big hope that the efficiency of anti-corrosion inhibitor corrosion is the same or even more effective than synthetic inhibitors.

NOMENCLATURE

A	unit area	cm ²
Cr	corrosion rate	mpy
E	the equivalent weight of corroding specimen	g.mol

EI	inhibitor efficiency	%
E _{corr}	corrosion potential	mV
I	applied current	A
I _{corr}	corrosion current	mA cm ⁻²
t	exposure time	hour
V	voltage	v
W	weight losses	mg
W _b	weight losses per unit time without inhibitor	mg.mol ⁻¹
W _{b1}	weight losses per unit time with inhibitor	mg.mol ⁻¹
W _o	weight losses without inhibitor	mg.mol ⁻¹
W _i	weight losses with inhibitor	mg.mol ⁻¹
Greek Letters		
ρ	density of the metal	g cm ³
Θ	surface coverage	%
β	the Tafel slope which provides action mechanism	
Subscripts		
a	specific constants of the electrode system reaction	

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