Anti-corrosion inhibition of API 5L in hydrochloric acid solution by ethanol extract of *Phyllanthus niruri* leaf

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Abstract

The inhibitory effects of *Phyllanthus niruri* leaf extract (PNLE) on API 5L pipeline steel in hydrochloric acid (HCl) solution were investigated using an electrochemical technique, namely Tafel polarization. The surface of API 5L was examined by scanning electron microscopy (SEM), and the surface's elemental composition after exposure to the HCl solution was analyzed with the help of energy-dispersive X-ray spectroscopy (EDX). The presence of many active components with phenol functional groups in the extract of PNLE was shown by Fourier transform infrared spectroscopy (FTIR), gas chromatography-mass spectrometry (GCMS), total phenolic content (TPC), total flavonoid content (TFC), and phytochemical screening. In this work, the concentration of PNLE, temperature, and immersion time were varied as experimental parameters. The results show that *Phyllanthus niruri* leaves extract could effectively inhibit the corrosion of API 5L in the HCl solution. Excellent inhibition with protection efficiency of about 90% was achieved on 500 ppm of PNLE concentration at longer immersion time and medium temperature, *i.e.*, 30 min and 40°C, respectively. The obtained outcomes of SEM with EDX analyses proved that PNLE molecules adsorption on the metallic surface considerably reduced its dissolution rate and resulted in a clean and smooth surface. Moreover, FTIR and phytochemicals confirmed that *Phyllanthus niruri* leaf extract contains compound hydroxyl group, phenolic, and flavonoid content which can enhance the antioxidant properties of PNLE and increase the possibility of PNLE to adsorb in the steel surface. This research interests many experimental and theoretical groups and has great application potential in industries.

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Introduction

One of the most commonly used materials of pipeline in oil extraction is API 5L steel, which contains low carbon contents (0.08−0.12 wt%) and low alloying elements (like V, Ti, Nb) [1, 2]. API 5L steel is widely used for pipeline materials due to their relatively low cost, high ductility, malleability, good mechanical resistance, and easy availability [3–5]. Despite these advantages, the main disadvantage of API 5L is that it must be submerged in an acidic medium, causing it to undergo corrosion and lead to damage with more expensive repairs costs [6–9]. It has become an important topic to reduce pipeline steel in-service corrosion failures.

Hydrochloric acid has frequently been used as acid cleaning in various industries, such as exchange tubes, oil pipelines, power generation, and chemical processing plants [10]. Acid cleaning or pickling is widely used to remove undesirable scales, oxides, and other impurities and contaminations from the metal surface [11, 12]. Hydrochloric acid also plays a crucial role in the oil and industry's acidizing stimulation. This process was required for dissolving contaminants in the well to clear the way for the oil and gas to flow into the well [13]. However, the presence of hydrochloric acid can corrode pipes, leading to a decrease in oil production [14].

To avoid corrosion of pipeline material due to acidic corrosion, during the pickling or acidizing applied with inhibition treatment by the corrosion inhibitor. Corrosion inhibitors are substances containing groups that have free electron pairs, such as nitrite, chromate, phosphate, urea, phenylalanine, imidazoline, and amine compounds [8, 15]. Many organic inhibitors contain oxygen atoms, nitrogen atoms, conjugated double bonds, heterocycles, and aryl rings and can be used in acidic environments [16–18]. These moieties may act as adsorption centers and form a protective layer on the metal surface; thus, they can protect it from corrosion attacks [19]. Unfortunately, some organic and inorganic chemical inhibitors are restricted since they are costly and toxic to humans and the environment [20–23]. Consequently, researchers have researched eco-friendly, less toxic, and natural corrosion inhibitors [24–26].

Several studies have been conducted using plant extracts as natural corrosion inhibitors. One of the plant extracts used as corrosion inhibitors is usually obtained from leaves. For instance, *Ginkgo* leaf extract [27], Chicory leaves extract [28], *Amorphophallus paeoniifolius* leaves extract [20], *Andrographis echioides* leaves extract [29], and *Aquilaria subintegra* leaves extract plant-based based natural inhibitors have numerous advantages including being easily accessible, biodegradable, produced/extracted easily and cheaply, and renewable source of the material [30, 31]. Therefore, using leaf extracts helps to increase environmental values by reducing the toxicity of corrosion inhibitor.

Phyllanthus niruri is a weed plant that belongs to the *Phyllanthaceae* family and is widely distributed throughout subtropical and tropical countries of the world and even in the coastal areas of Indonesia [32]. *Phyllanthus niruri* can live on any land in rocky, damp places such as along waterways or between grass and bushes. It also grows in the highlands up to 1000 m above sea level [33]. Previous research reported that *Phyllanthus niruri* contains

numerous bioactive phytochemicals such as alkaloids, flavonoids, tannins, glycosides, lignans, terpenes, phyllanthin, hypophyllanthin, steroids, phenylpropanoids, phyltetralin, and phenolic compound [34, 35]. Based on the above studies *Phyllanthus niruri* leaves extract was selected as a natural corrosion inhibitor. Another literature indicated that the combination of *Phyllanthus niruri* with silver nanoparticles can protect stainless steel 304 from corrosion in 3.5 wt% of NaCl solution [36].

This work aimed to prevent corrosion of API 5L in an HCl solution with *Phyllanthus niruri* leaves extract (PNLE) as a safe, cheap, and eco-friendly corrosion inhibitor. Tafel polarization and electrochemical impedance spectroscopy (EIS) were used as electrochemical approaches. Then, the surface analysis was conducted using a scanning electron microscope (SEM) and atomic force microscope (AFM). The adsorption isotherm was also studied.

Materials

Corrosion inhibitor preparation

500 g of *Phyllanthus niruri* dried leaves was percolated with ethanol for 24 hours at room temperature. After 24 h, the solution was passed from the filter to separate the big parts of *Phyllanthus niruri* from the solution. The solution was concentrated using the rotary evaporator at 40°C to a paste form. To obtain corrosion inhibitor, the paste was dried in an oven at 35°C until there was no change in mass.

Specimen and solution preparation

The material used in this research was API 5L carbon steel with chemical composition, as shown in Table 1.

Table 1. Chemical composition of API 5L carbon steel used in this study.

C	Si	Mn	P	S	Cr	Al	Ni	Cu	Fe
0.046	0.003	1.046	0.007	0.003	0.002	0.033	0.011	0.016	98.46

The specimen with the exposure of 1 cm^2 was polished using 120, 240, 400, 600, 800, and 1200 emery papers, then rinsed with distilled water before the electrochemical test.

Analytical reagent-grade HCl with 37% concentration was purchased from MERCK for preparing the solution. 0.1 M concentration of HCl was prepared by using double distilled water. PNLE with concentrations from 100 to 500 ppm was diluted to 0.1 M HCl. 200 ml of solution with various temperatures (30, 40, and 50°C) was used for each specimen.

Extract Content Analysis

To identify the functional molecules present in PNLE, Fourier transforms infrared (FTIR) and gas chromatography-mass spectrometry (GCMS) analyses were carried out. Further,

total phenolic content (TPC), total flavonoid content (TFC), and phytochemical screening were also done. The FT-IR analysis was carried out using a SHIMADZU infrared spectrophotometer (4000–400 cm^{-1}; resolution: 1 cm^{-1}). The GC-MS was accomplished on PNLE by a GC-MS apparatus model Agilent 7890B (GC) and 5977A (MSD). Column type: Agilent, Type 19091S-433:93.92873 DB-5MS UI 5% Phenyl Methyl Silox with a capillary column (30 m×250 μm×0.25 m). Dimensions 0–325°C. Processing temperature: initial 40°C, Hold time 1 min, post run 300°C. Injection volume 1 mL.

The total phenolic content (TPC) was determined by the Follin–Ciocalteu Reagent (FCR) method [37, 38]. Four mg of PNLE was dissolved in 4 mL of ethanol to obtain the sample concentration of 1000 g/mL. 1 mg gallic acid was weighed and dissolved in 1 mL ethanol (1000 g/mL) to make a standard solution. A total of 500 μl sample solution and standard gallic acid solutions (25, 50, 100, 150, and 200 μl) were pipetted into a test tube, then mixed with 4 mL of distilled water and 250 μl FCR. After 8 minutes, 750 μl of 20% was added and mixed thoroughly. The mixture was then allowed to stand at room temperature for 2 hours. The TPC value of PNLE was measured twice at a wavelength of 765 nm. The phenol concentration was expressed as equivalent gallic acid ($mg \cdot g^{-1}$ extract) based on the regression equation from the calibration curve.

The total flavonoid content (TFC) of PNLE was calculated using the colorimetric method of aluminum chlorid [39, 40]. Four milligrams of quercetin were dissolved in ethanol and then diluted to 25, 50, 100, 150, and 200 μl. About 0.5 ml of sample solution was taken, and 1.5 ml of ethanol, 0.1 ml of 10% aluminum chloride, 0.1 ml of potassium acetate, and 2.8 ml of water were added. The mixture was incubated for 30 minutes at room temperature. The absorbance of the solution was measured at 415 nm with a UV-Vis spectrophotometer. The content of total flavonoid compounds was determined as quercetin equivalent ($mg \cdot g^{-1}$ extract)) based on the regression equation from the calibration curve.

Phytochemical screening of the PNLE was carried out using standard procedure [41]. It is a qualitative analytical study to reveal tannins, saponins, flavonoids, and alkaloids contained in the extract of *P. niruri*. To evaluate the presence of tannin content, 1 mg of PNLE was mixed with hot water and then heated to a boil. After that, a drop of ferric chloride solution ($FeCl_3$) 1% was added to the solution. The appearance of the green band's lack of color confirms the presence of tannins. Saponin content was revealed by mixing 5 mg of PNLE with 10 ml of distilled water, stirring for 20 s and leaving to rest for 15 min. The appearance of persistent foam greater than 1 cm in height indicates the presence of saponin in the extract. 4 mg of PNLE, 3 ml of ethanol, and 2 ml of 2 N hydrochloric acid were added, respectively, to reveal the existence of flavonoid content. A pinkish-orange indicates the presence of flavonoids. Alkaloid content was identified by adding 6 ml of HCl 1% to 15 mg of PNLE. After filtration, 1 ml of (Mayer's reagent) was added, and a cream-colored precipitate indicated the presence of alkaloids [42].

Electrochemical test

Electrochemical experiments were carried out using the corrosion measurement system Gamry G750 in a conventional three-electrode glass cell with API 5L specimen as a working electrode. The saturated calomel electrode and platinum served as reference and counter electrodes, respectively. The Tafel polarization test was performed from a cathodic potential of –250 mV to an anodic potential of +250 mV for corrosion potential at a sweep rate of 0.6 mV/sec. The electrochemical test was carried out at 30, 40, and 50°C, the inhibitor variations were performed at 100, 200, 300, 400, and 500 ppm, and immersion time at 30 min before the Tafel polarization testing.

Surface Analysis

The surface morphologies of API 5L surface before and after exposure to HCl solution in the absence and presence of PNLE extract for 3 h were examined using SEM. Before surface analysis, samples were polished using 120 to 1200 sandpaper in turn and ultrasonically cleaned in ethanol. Then the clean and flat sample was dipped in the blank HCl solution and the 500 ppm inhibitor at room temperatures for 3 h, while the pre-treated samples were used directly without a dip in the HCl solution.

Results and Discussion

Fourier Transform Infrared Spectroscopy (FTIR) consideration

FTIR was employed to identify the existence of functional groups bonding in the PNLE. The result of FTIR spectrum is in the form of bands, where the position of the band is expressed as x-axis of the graph, and the intensity of the band is expressed as y-axis. Figure 1 shows the FTIR test result of PNLE.

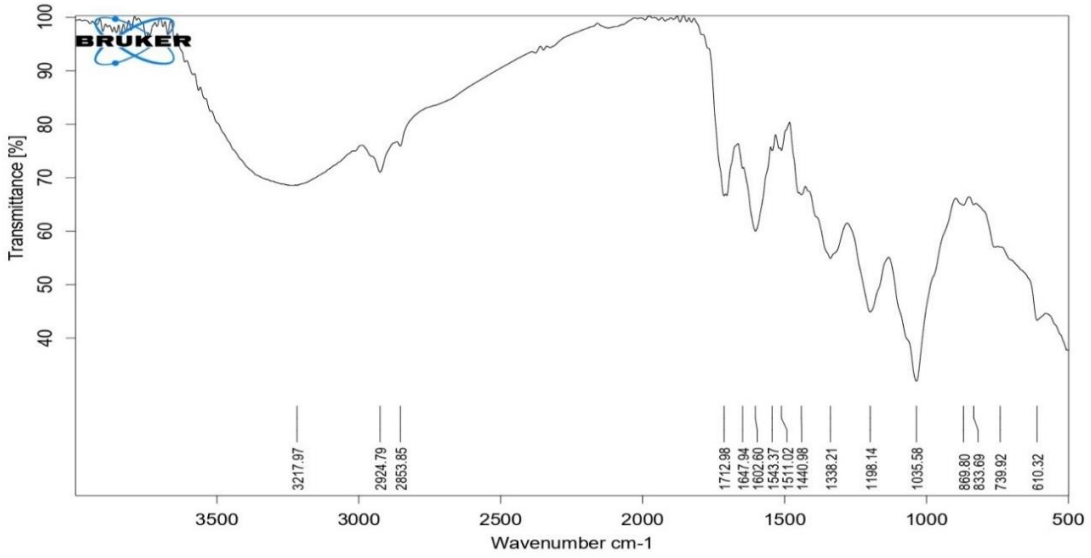

Figure 1. FTIR result of PNLE.

As shown in Figure 1, the broad absorption band at 3217 cm^{-1} was attributed to O–H stretching vibration. The appearance of bands around 2924 cm^{-1} and 2853 cm^{-1} represented C–H stretching. The vibration band confirmed C=O bond at 1712 cm^{-1} and 1647 cm^{-1}. C=C bond was found at 1602 cm^{-1}. N–O asymmetric stretching vibration at 1543 cm^{-1} and 1511 cm^{-1} indicates the presence of the nitro compound. The C–C bend stretching vibration was found to be at 1440 cm^{-1}. The strong band at 1338 cm^{-1}, 1198 cm^{-1}, and 1035 cm^{-1} was due to the C–O stretching vibration. Other absorption bands at 869 cm^{-1}, 833 cm^{-1}, and 739 cm^{-1} were attributed to N–H stretching vibration. Also, a vibration band was located at 610 cm^{-1} and assigned to a –C≡C–H. This result confirmed the presence of the phenol (O–H), amino acid and protein (C=O), aromatic (C=C), nitro (N–O), and amines (N–H) functional group that show high corrosion inhibition performance on the PNLE [43].

Gas Chromatography-Mass Spectrometry (GC-MS) consideration

The chromatogram of PNLE with GC-MS is presented in Figure 2. According to GC-MS result, ethanol extract isolated from leaves of *P. niruri* contained 22 compounds, as listed on the Table 2. The main chemical compounds of PNLE based on Table 2 are linoleic acid (40%), palmitic acid (14.3%), and 9,12,15-octadecatrienoic acid, methyl ester (9.4%).

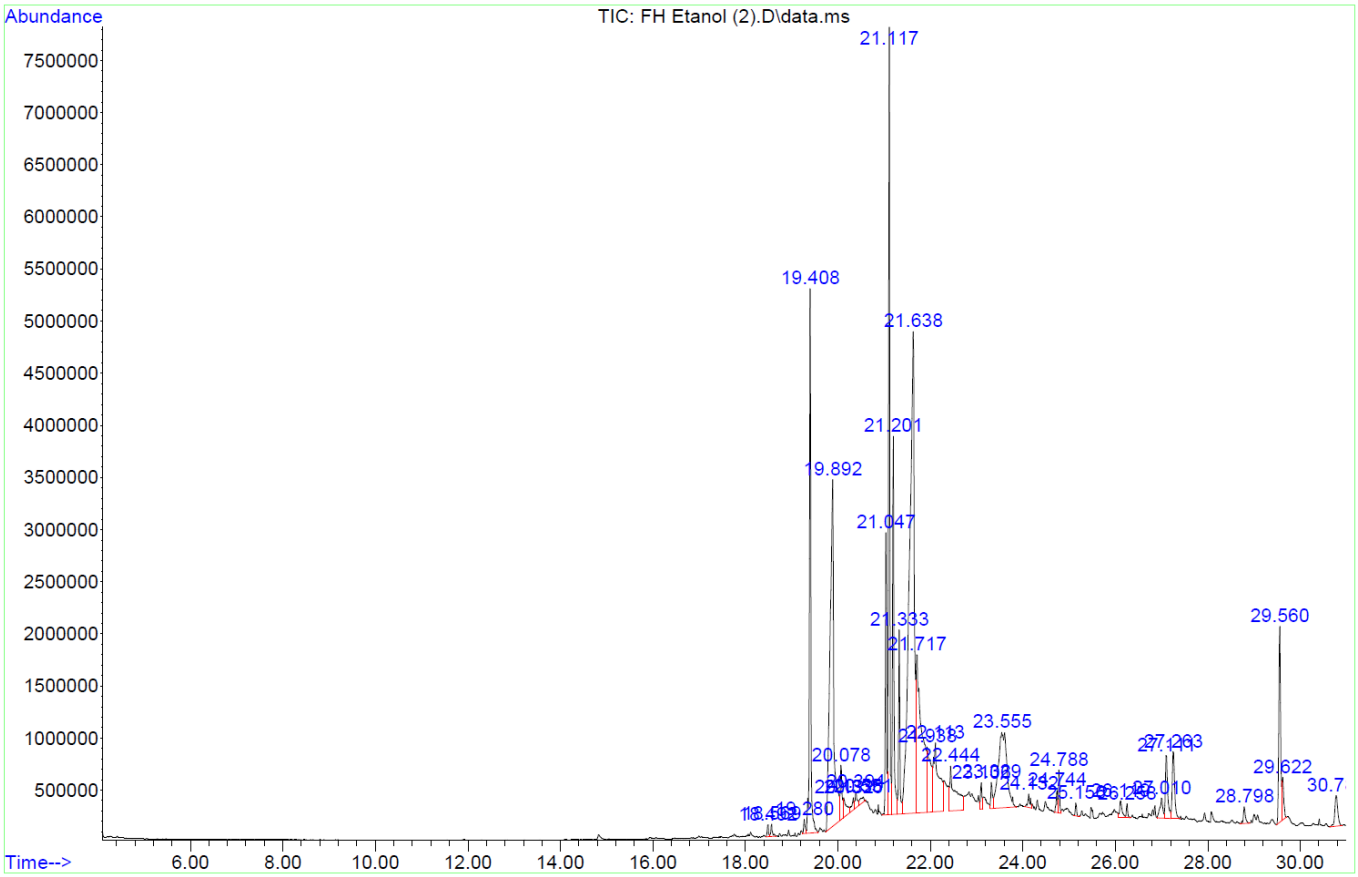

Figure 2. GC-MS result of PNLE.

Table 2. Chemical compounds of PNLE identified by GC-MS.

No.	RT	Chemical compound	% Region	Similarity index
1	18.4925	Neophytadiene	0.1593	91
2	18.5681	2-Pentadecanone,6,10,14-trimethyl	0.2025	89
3	19.2739	7,9-Di-*tert*-butyl-1-oxaspiro(4,5)deca-6,9-diene-2,8-dione	0.2007	99
4	19.4076	Hexadecanoic acid, methyl ester	7.5163	99
5	19.8915	Palmitic acid	14.2984	99
6	20.0805	Hexadecanoic acid, ethyl ester	0.9305	93
7	21.0510	9,12-Octadecadienoic acid	3.2025	99
8	21.1170	Lenoleic acid	40.0997	99
9	21.2022	Phytol	3.8274	99
10	21.3282	Methyl stearate	2.2061	99
11	21.6383	9,12,15-Octadecatrienoic acid, methyl ester	9.4040	99
12	23.1053	Eicosanoic acid, methyl ester	0.3817	96
13	23.3321	Cyclohexanol, 1-(1,2-propadienyl)	0.4342	45
14	23.5590	Sitoserol	6.4631	99
15	24.7436	Docosanoic acid, methyl ester	0.3004	96
16	24.7940	Bis(2-ethylhexyl) phthalate	0.4827	87
17	25.1595	Tetracosamethyl-cyclododecasiloxane	1.3894	95
18	26.2560	Tetracosanoic acid, methyl ester	0.1720	99
19	27.1130	alpha.-Tocospiro B	3.0008	99
20	28.7980	beta.-Tocopherol	0.3254	94
21	29.5605	dl-alpha.-Tocopherol	4.1202	99
22	30.7805	Campesterol	0.8830	99

Constituents of PNLE, such as Linoleic acid, Palmitic acid, and Octadecadienoic acid, were fatty acids that have been studied as corrosion inhibitors [21]. These GCMS results prove that PNLE can be used as a corrosion inhibitor.

Total phenolic and flavonoid content consideration

The total phenolic content in the ethanol extract of PNLE was estimated spectrophotometrically in the presence of Folin–Ciocalteu's reagent. Table 3 determine the absorbance of various concentrations of PNLE at 765 nm. The data in Table 3 can be summarized using a graph in Figure 3. The best linear fitting of a graph in Figure 3 gave

$y = 0.1139x + 0.0235$ with $R^2 = 0.9989$. The total phenolic content (TPC) was calculated as gallic acid equation (mg GAE /g extract) using equation (1) [44].

$$TPC\left(\frac{\text{mg}}{\text{g extract}}\right) = \frac{C \cdot FF \cdot V}{m} \quad (1)$$

where C is the concentration of gallic acid from the graph (mg/ml), FF is dilution factor, m is the weight of the extract (g), and V is the volume of the extract (ml).

Table 3. Absorbance data of TPC test.

Concentration (µg/ml)	A1	A2	Average
0	0.0565	0.0569	0.0567
5	0.5498	0.5433	0.05466
10	1.1586	1.158	1.1583
15	1.7480	1.7414	1.7447
20	2.3019	2.3064	2.3042

The ethanol extract of PNLE contains an average TPC of 40.78±0.71 mg GAE/g extract. This result suggests that PNLE contains phenolic compounds. The phenols are main source of antioxidants and free radical scavengers hence, there should be enhance the possibility for the PNLE to adsorb on the metal surface.

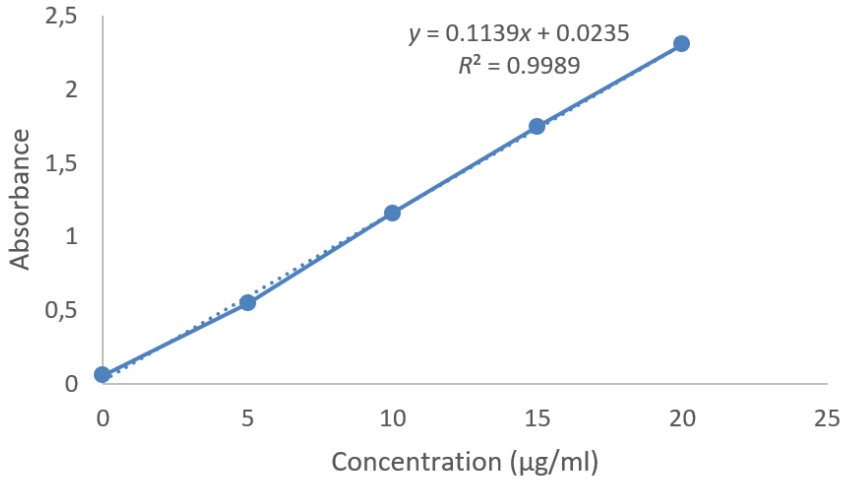

Figure 3. Linear fitting of gallic acid calibration curve.

Meanwhile, the total flavonoid content (TFC) of PNLE was estimated by the regression equation of the quercetin as shown in Figure 4 ($y = 0.0102x + 0.0866$) with correlation coefficient $R^2 = 0.9771$. TFC was expressed as mg of quercetin equivalent per gram of extract (mg QE/ g extract). The total flavonoid content of PNLE was 21.06±0.74 mg QE/ g extract.

The presence of flavonoids in the ethanol extract of PNLE could be responsible for their resistance to acidic-medium generally used in corrosion studies [42].

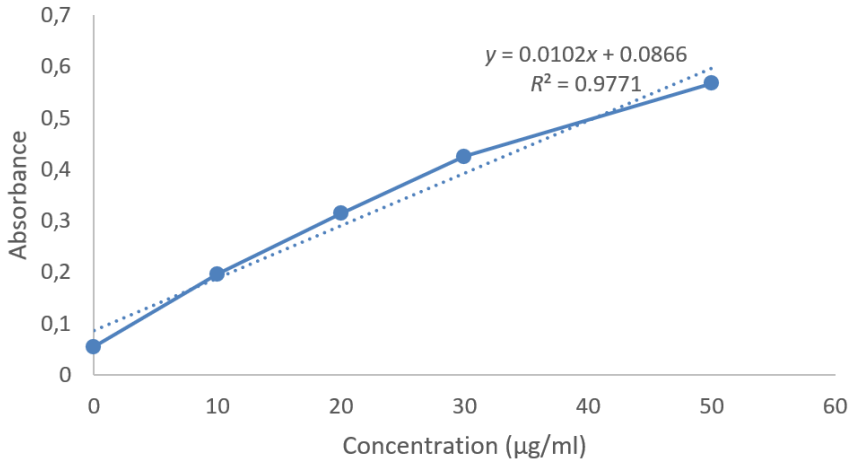

Figure 4. Linear fitting of quercetin calibration curve.

Phytochemical screening consideration

Qualitative phytochemical screening revealed that tannins, saponins, flavonoids, and alkaloids were present in the ethanol extract of *P. niruri* leaves. Table 4 shows the phytochemical screening result of PNLE. Tannins are polyphenolic compounds with O–H groups that can increase the passive layer formation. Flavonoids are antioxidants that can inhibit the oxidation reaction of the steel. Alkaloids contain nitrogen element which is attracted to the steel surface due to the existence of free electrons [45]. These results show that PNLE has high corrosion inhibition performance.

Table 4. Phytochemical screening of PNLE.

No.	Phytochemical	Reactor	Result
1	Tannin	$FeCl_3$	+
2	Saponin	Aquadest + HCl	+
3	Flavonoid	Zn + HCl	+
4	Alkaloid	Mayer	+

Tafel polarization

Tafel polarization can be considered a useful tool for explaining the PNLE inhibition performance in an HCl solution. The result of Tafel polarization curves for API 5L with the absence and presence of inhibitor PNLE as much as 100, 200, 300, 400, and 500 ppm in 0.1 M HCl solution at various temperatures are depicted in Figure 5. Besides, the related parameters such as corrosion potential (E_{corr}), corrosion current (i_{corr}), anodic Tafel slope

(β_a), cathodic Tafel slope (β_c), corrosion rate (*CR*), and inhibitor efficiency (%*IE*) are reported in Table 5.

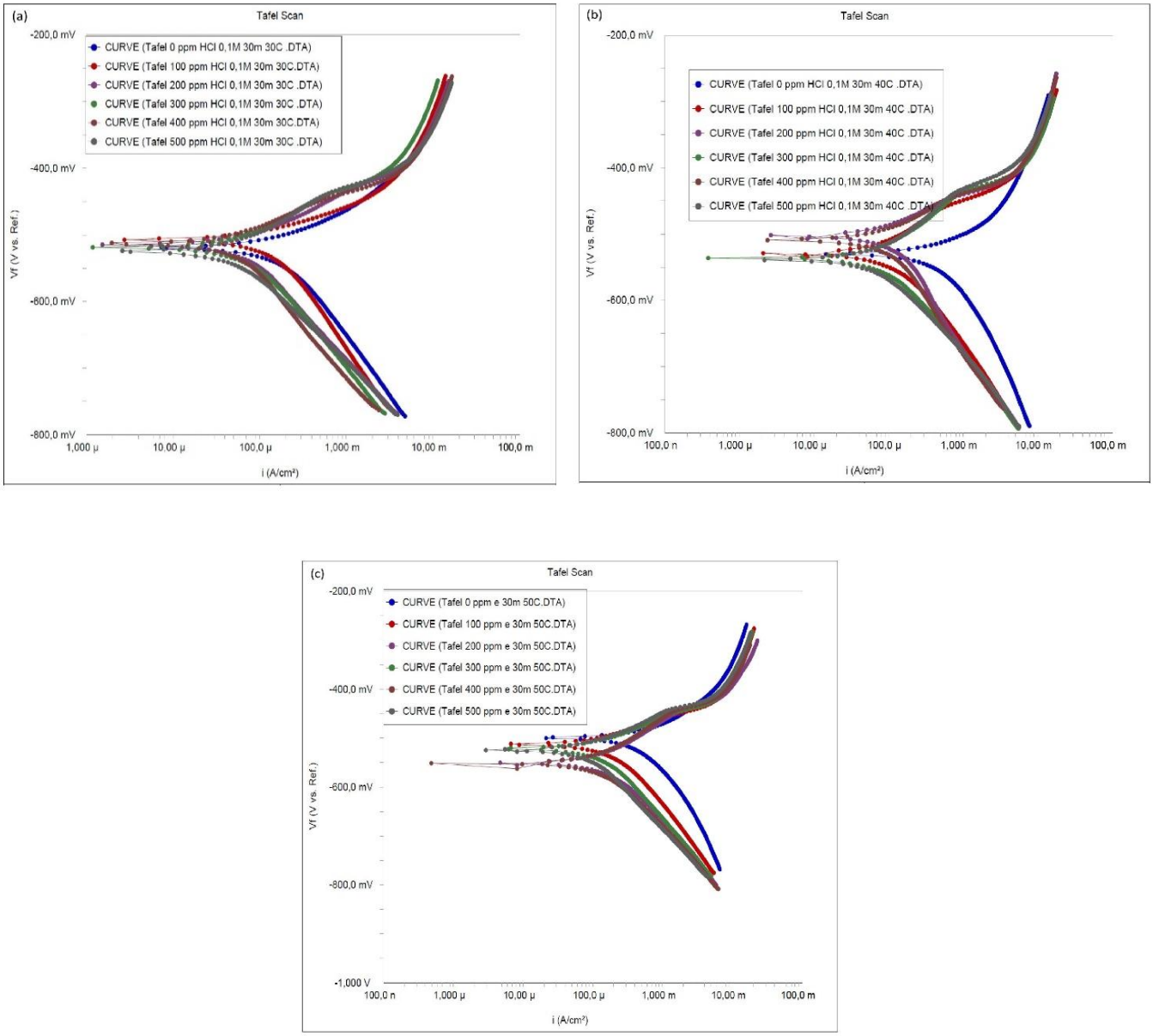

Figure 5. Tafel polarization curve of API 5L in HCl solution with various PNLE inhibitor concentrations at (a) 30°C, (b) 40°C, and (c) 50°C.

Table 5. Tafel polarization curve parameters of API 5L in HCl solution with different temperatures and inhibitor concentration.

T **(°C)**	$C_{inhibitor}$ **(ppm)**	β_a **(mV/dec)**	β_c **(mV/dec)**	E_{corr} **(mV)**	i_{corr} **(mA/cm^2)**	***CR*** **(mpy)**	**%*IE***
30	0	81.0	201.8	–518.1	0.175	94.39	0%
	100	63.0	199.8	–507.0	0.146	66.98	29%
	200	71.4	171.9	–515.0	0.086	39.10	59%
	300	83.2	151.4	–518.7	0.073	33.37	65%
	400	75.5	166.0	–512.1	0.055	25.01	74%
	500	86.4	150.7	–523.9	0.049	22.43	76%
40	0	91.2	230.9	–530.0	0.457	200.9	0%
	100	82.3	124.6	–528.9	0.166	75.70	62%
	200	62.2	144.4	–503.0	0.129	59.17	71%
	300	101.5	140.9	–537.2	0.102	46.60	77%
	400	68.0	162.8	–509.4	0.098	44.84	78%
	500	106.5	143.0	–539.4	0.088	40.23	80%
50	0	106.9	416.9	–499.0	0.842	208.8	0%
	100	60.9	148.7	–513.0	0.246	112.4	46%
	200	82.8	108.9	–551.0	0.223	102.0	51%
	300	64.0	142.7	–521.0	0.164	75.18	64%
	400	56.7	84.2	–551.0	0.149	68.36	67%
	500	64.7	133.7	–524.0	0.089	40.77	80%

As seen in Figure 5, when the PNLE inhibitor was added to the HCl solution, the corrosion current (i_{corr}) decreased significantly at each temperature. Both anodic metal dissolution of iron and cathodic hydrogen evolution reaction was suppressed after the addition of PNLE. This result indicates that corrosion was successfully inhibited by PNLE [46]. The inhibition performance of PNLE was more pronounced on increasing the concentration, indicating that the adsorption mechanism is the main process to postpone the corrosion reactions. According to Table 5, the corrosion rate and %*IE* values increased in the presence of more PNLE concentrations reaching the minimum and maximum values of about 40.77 mpy and 89%, respectively, in the presence of 500 ppm of the PNLE inhibitor at 60°C. The inhibition efficiency values were calculated using equation (2) [47]:

$$\%IE = 100 \cdot \left(1 - \frac{i_{corr}}{i'_{corr}}\right) \quad (2)$$

where i_{corr} and i'_{corr} are the corrosion current density in the presence and absence of PNLE, respectively.

From Figure 5 and Table 5, there is no definite trend in the shift of corrosion potential (E_{corr}), anodic Tafel slope (β_a), and cathodic Tafel slope (β_c) with the PNLE concentration. All the extracts did not displace E_{corr} value of more than 85 mV to blank and, therefore, could be categorized as mixed-type inhibitors [27, 48, 49]. Moreover, it can be seen that with the addition of PNLE at temperatures 60°C, the E_{corr} value shifted slightly toward the cathodic direction of the blank. Therefore, the hydrogen evolution reaction influenced the addition of inhibitor PNLE at 60°C.

In general, increasing temperature can increase the corrosion rate because the rate of diffusion corrosion towards the API 5L substrate increases, and consequently, the corrosion reaction will proceed kinetically [50]. As can be seen in Table 5, the corrosion rate of API 5L without PNLE inhibitor increases with the increasing temperature. However, the efficiency inhibitor enhances at 40 and 50°C due to the improvement of PNLE surface chemisorption [51].

Figure 6 shows that the corrosion rate in each temperature decreases as the immersion time decreases. It shows that the adsorption stability of the PNLE inhibitor in the HCl solution was excellent. At a temperature of 50°C for 30 minutes, the longer immersion time will improve the corrosion resistance of API 5L by up to 80%.

Immersion time is one of the most critical criteria that influence inhibitor performance. The effect of immersion time on the PNLE inhibitor performance was investigated using Tafel polarization. The corrosion rate generated from the Tafel polarization curve is shown in Figure 6. Figure 7 illustrates the Tafel polarization curve of API 5L in HCl solution after 10, 20, and 30 minutes of immersion with 500 ppm PNLE at 30, 40, and 50°C.

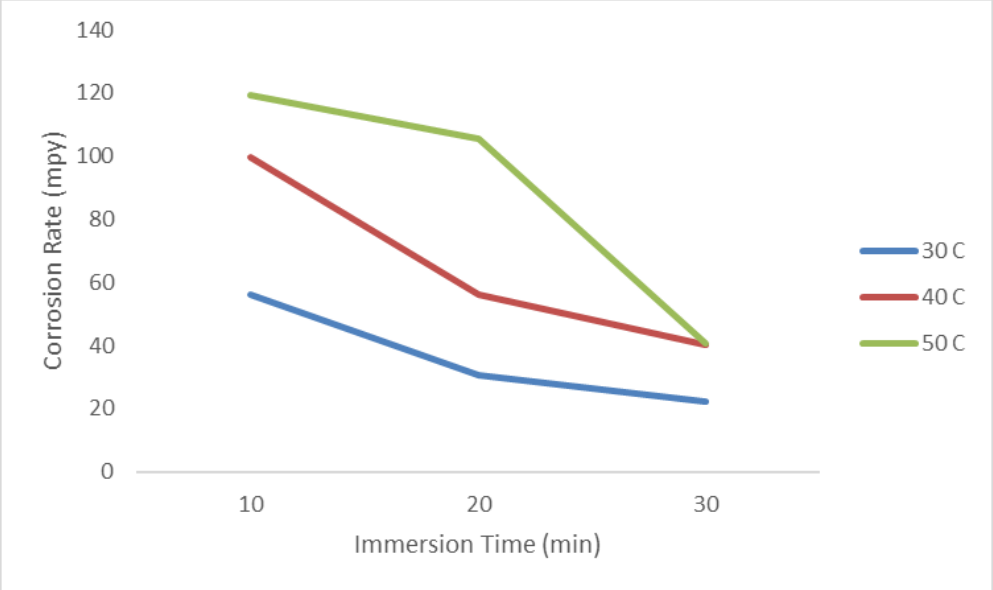

Figure 6. Corrosion rate *vs* immersion time.

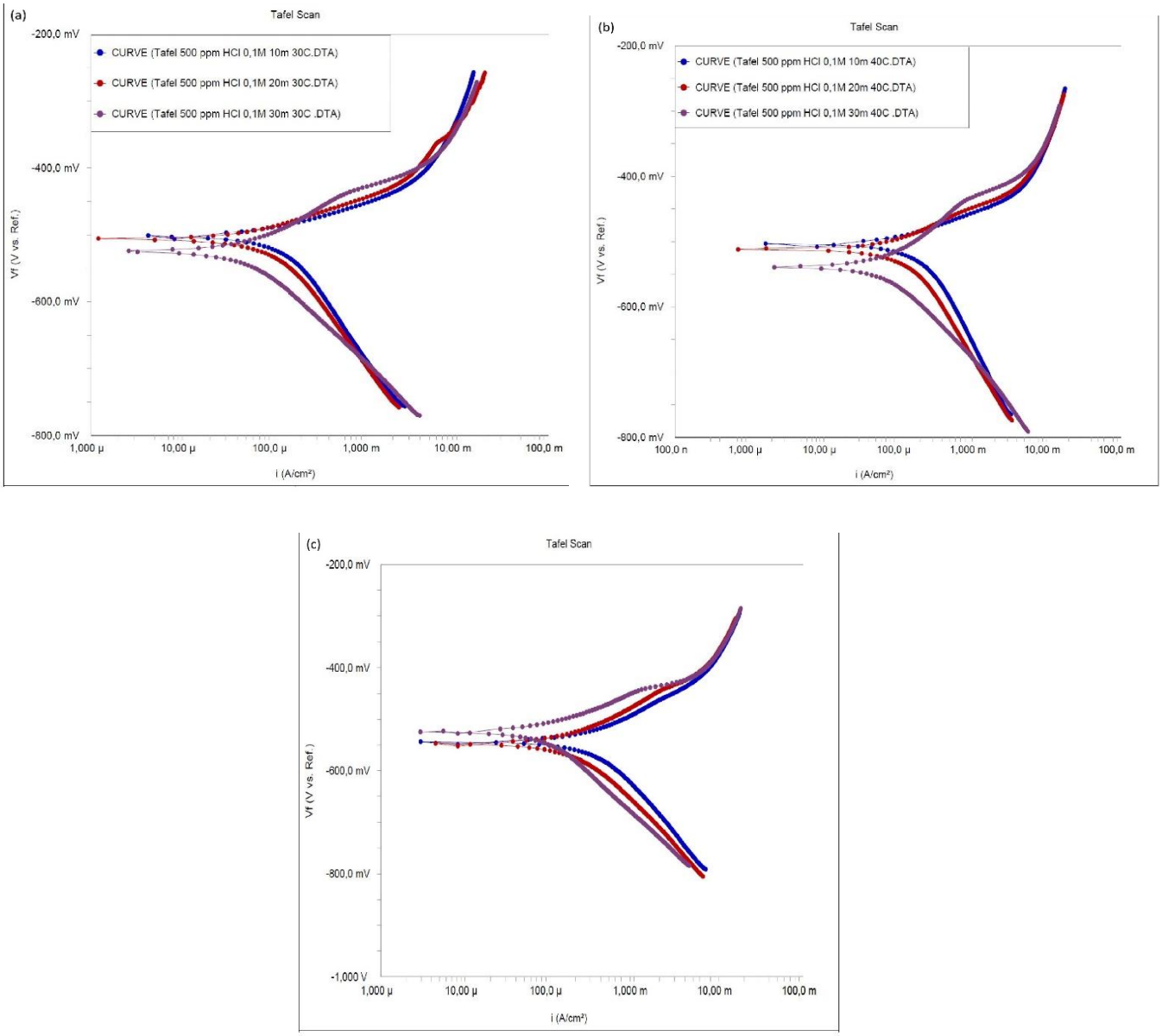

Figure 7. Tafel polarization curve of API 5L in HCl solution with various immersion times and 500 ppm PNLE inhibitor concentration at (a) 30°C, (b) 40°C, and (c) 50°C.

Surface morphology

The surface of API 5L with and without PNLE inhibitors was analyzed to confirm the protective film's presence. Figure 8(a) shows the surface micrograph of API 5L before dipping in the HCl solution. Figure 8(b) and 15(c) display the API 5L surface after 72 h of immersion in HCl solution only and with the addition of the highest concentration (500 ppm) of PNLE inhibitor, respectively. All SEM micrographs were taken at the same magnification (100x) to observe the changes that occurred during the corrosion process.

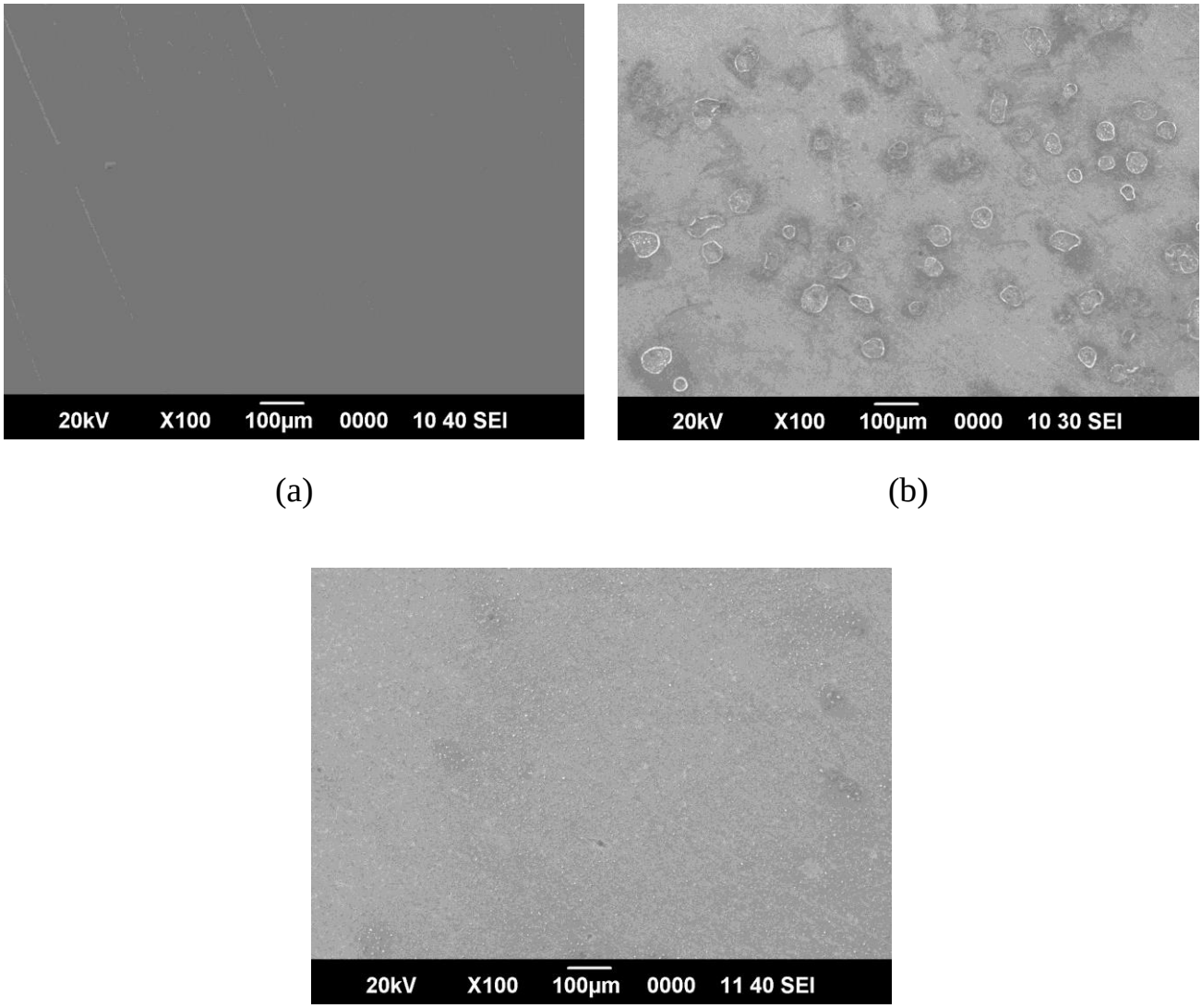

Figure 8. SEM image of API 5L (a) before immersing, (b) without inhibitor, and (c) with 500 ppm PNLE inhibitor in HCl solution.

Similar features on the polished API 5L before immersion in the HCl solution are visible in Figure 8(a), which are related to abrading scratches. It is shown in Figure 8(b) the damage with the appearance of pits caused by HCl solution compared to the surface steel before dipping in HCl solution. On the other hand, in the presence of 500 ppm of PNLE inhibitor (Figure 8(c)), there is less destruction of the API 5L surface. Regarding Figure 8(c), the corrosion effect, including pits, reduced drastically with the addition of 500 ppm PNLE inhibitor.

Table 6. EDX results of Figure 8.

Sample	Fe (%wt)	Cl (%wt)	O (%wt)
a	98.97	0	0
b	92.36	0.31	4.95
c	96.03	0.18	2.69

Table 6 shows the EDX results involving the mass percentage spectra of the composition API 5L. The blank API 5L before dipping in the HCl solution contains a high percentage of Fe without Cl and O elements. In contrast, API 5L that immerse in an HCl solution contains Cl and O elements related to the formation of pits and corrosion product (Fe_2O_3) due to the aggressive environment. A higher percentage of chloride and oxygen on the API 5L surface without inhibitor indicates the corrosive action of the hydrochloric acid attacking the surface. Moreover, adding a PNLE inhibitor reduces the elemental percentage of chloride and oxygen due to the adsorption PNLE inhibitor. PNLE inhibitor prevents the chloride adsorb on the steel surface to diminish the corrosion products and pits. SEM with EDX analysis provided strong evidence of the inhibition effect of PNLE inhibitor.

Conclusion

Electrochemical measurement and surface analysis evaluated the anti-corrosion inhibition performance of *Phyllanthus niruri* leaves. Ethanol extract of *Phyllanthus Niruri* leaves contains phenolic, flavonoid, tannin, saponin, alkaloid, and fatty acids used as corrosion inhibitors. Tafel polarization result demonstrated that the maximum inhibition efficiency of 80% was achieved in an HCl solution containing 500 ppm of PNLE inhibitor at 40°C. *P. niruri* leaves extract is classified as a mixed type inhibitor since the displacement in E_{corr} on the addition of inhibitor is less than 85 mV to the corrosion potential of the blank. According to SEM images, the damage to the steel surface was reduced in the presence of a PNLE inhibitor. EDX calculation shows the percentage composition of oxygen and chloride decrease with the addition of 500 ppm PNLE inhibitor, suggesting the protective action of plant extract in an acid medium.

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