The Inhibitive and Adsorptive Characteristics of Orange Peel Extract on Metal in Acidic Media

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ABSTRACT

The potential of orange peel extract (OPE) to inhibit corrosion is investigated to replace the current toxic inhibitors. OPE contains inhibitor molecules that are able to adsorb onto the metal surface and form a protective film, restricting the corrosion attack. In this research, a screening between ethanol and distilled water was conducted for the selection of the best extracting solvent for orange peel extraction. It was found that ethanol extracted more functional groups and enhanced the inhibitive efficiency of OPE as compared to distilled water. The inhibitive performance of OPE was further studied with four parameters, which were orange peel to solvent ratio (0.5:100 – 10:100), contact time (0.5 hr – 3 hr), temperature (30°C – 60°C), and acid concentration (0.1 M – 10 M). It was found that the optimum conditions for the inhibition effects were at orange peel to solvent ratio of 10:100, contact time of 2 hr, temperature of 30°C at acid concentration not more than 1 M. Through the characterization studies, the properties and characteristics of inhibitor molecules in OPE responsible for adsorption were identified through FTIR and phytochemical analysis. FTIR scanning revealed that the OPE contained abundant oxygen containing groups and the functional groups contained heteroatoms that have tendency to donate their unpaired electrons to the metal surface. This could explain the formation of protective film via the adsorption of the inhibitor molecules onto the metal surface, thus reducing corrosion attack. The presence of flavonoids, saponins and phenols was also detected in OPE by conducting phytochemical analysis. These phytochemicals contained heterosides structures that have antioxidant properties which could enhance the adsorption tendency. The experimental data were analyzed by Langmuir, Freundlich, and Temkin isotherm models. The results had shown that the adsorption of OPE obeyed Langmuir adsorption isotherm model with the highest regression coefficient value ($R^2 = 0.9973$). The findings in this research showed that OPE demonstrated the adsorptive and inhibitive characteristics on mild steel in acidic media, suggesting it as a potential green and sustainable option in corrosion inhibition.

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1.   Introduction

Corrosion is a natural phenomenon and it is a demanding issue faced by the global and domestic industries [1]. It is defined as the destruction or deterioration of a material and its properties by chemical reaction with the environment [2]. The effect of corrosion compromises operating and maintenance costs, health and structure safety. Kermani and Morshed [3] had reported that up to 25 % of all safety accidents in oil and gas industry were caused by corrosion failures. The corrosion of metals is an undesired issue in the industry as it usually causes harmful and damaging effect to the processes and environment. Metals are easily corroded in acidic media, especially when exposed to acids that are stronger oxidizing agent than the metals. The presence of high electrical potential difference between the acidic medium and metal will cause the metal to corrode. As a result, contamination of the dissolved metal ions in the products will affect their purity and quality. This contributes to the loss of product's value and incurs high maintenance and operating costs for the application of corrosive protection. According to Koch et al. [4], the global cost of corrosion was estimated to be 2.5 trillion dollars for the year 2016. By using the available corrosion control practices, it is estimated that savings of between 375 and 875 billion dollars annually on a global basis are possible [4].

Corrosion is indeed unavoidable, but it is controllable with the aid of inhibitors. Industrial acid cleaning, descaling and pickling of the metals depend upon the use of corrosion inhibitors to control the corrosion attack on metallic structures in these acidic environment [5]. Among all, antimony oxide (Sb_2O_3) and antimony trioxide (Sb_2O_3) have been utilized as chemical corrosion inhibitors in acidic media. The adverse effects of corrosion are suppressed through the reduction of electro-positive ions and on the metal surface and lowering of over-voltage on the main cathodic depolarization reaction [3]. In addition, heavy metal ions such as Pb^{2+}, Ti^+, Mn^{2+} and Cd^{2+} have been reported as the effective corrosion inhibitors of iron in acids as well. The use of chemical inhibitors (organic or inorganic chemical compounds) does show high inhibition efficiency, but most of them are expensive and pose environmental and health hazards [6]. Many of the inhibitors, especially those containing chromate, phosphate and other heavy metals, have high toxicity and are being gradually restricted as they do not satisfy the requirements set by the environmental protection standards. The toxicity of the chemical inhibitor may manifest during its synthesis or during its usage. These toxic inhibitors may cause temporary or irreversible damage to the human body [7]. The latest generation of the environmental standards require the replacement of toxic corrosion inhibitors with green inhibitors [8]. Plants and their products such as fruit, leaves and seeds, are being studied extensively for their anticorrosive properties to replace the current industrial inhibitors [9].

Plant extracts are found to be rich in naturally synthesized compounds that are useful for corrosion inhibition, and to be as effective as the synthetic inhibitors [10]. The compounds are easily extracted from plants by simple procedures that are cost effective compared to the synthetic inhibitors [11]. Hence, the replacement of synthetic inhibitors with green inhibitors is deemed beneficial for the economy, social and environmental sustainability. Marín et al. [12] had reported that almost 50 to 60 % of the total mass of oranges that had been processed for juice production, ends up as wastes that are composed of peel, seed and segment membrane. These solid wastes are estimated to be generated each year in the range of 15 to 25 million tons [12]. The generation of the solid wastes impacts both economic and environmental aspects such as high transportation cost, lack of waste-disposal site, and accumulation of high content of organic matter [13]. The alternative usage of the orange peel wastes as environmentally friendly inhibitors had been reported by Rocha et al. [14] and M'hiri et al. [15] who discovered the corrosion inhibition behaviours of orange peel extract (OPE) on carbon steels in acidic solutions.

In 2017, Chen and Jing [16] reported that orange peel is rich in compounds that contain abundant heteroatoms, such as oxygen and nitrogen atoms, contributing to the inhibition of metals from corrosion. With the commercialization of green inhibitors, the dependence on organic synthetic inhibitor can be uplifted, reducing wastes and producing sustainable corrosion inhibitors for the industry. Therefore, the present paper aims to investigate the characteristics of OPE that contribute to mild steels corrosion inhibition in acidic media, and the effect of various process parameters in affecting the OPE inhibition efficiency. The adsorption mechanism between the OPE and the mild steels substrate is investigated as well.

2.   Methodology and Experimental Setup

2.1   *Extraction of Orange Peel Extract (OPE)*

The preparation of orange peel extract (OPE) was performed based on the method as reported by M'hiri et al. [15] with slight modifications. Orange peels were dried in the oven at 80˚C for 2 hours and then ground to powder. The powdered orange peels were extracted with 100 mL of extracting solvent by using ultrasound for 30 min at 60˚C. Subsequently, the extraction solutions were cooled for 30 min to room temperature. After cooling, the mixture was filtered to recover the supernatant (OPE) for the experiments whereas the insoluble extracts were discarded.

2.2   *Screening of Extracting Solvent*

The extraction process was performed as described in Section 2.1. Briefly, 5 g of powdered orange peel were immersed in 100 mL of distilled water for the extraction of OPE. The supernatant recovered after filtration were used to investigate its corrosion inhibitive efficiency on mild steel coupons. The procedures were repeated with ethanol as the extracting solvent. The performance criteria, which were inclusive of corrosion rate, inhibition efficiency and surface coverage, were compared between the solvents used. The solvent which resulted in better corrosion inhibitive efficiency were selected for subsequent analysis.

2.3   *Investigation of OPE Corrosion Inhibition Efficiency*

Four parameters were studied to investigate the corrosion inhibitive efficiency of OPE, which were the effects of orange peel to solvent ratio, contact time of extract and mild steel coupons, contact temperature of extract and mild steel coupons, and acid media concentration. The inhibitive efficiency of OPE was calculated using weight loss method. At the same time, the corrosion rate (CR), inhibition efficiency (IE) and degree of surface coverage (θ) were also determined.

Weight loss method was used to estimate the inhibitive efficiency of the OPE. The weighed sample of the mild steel was removed from the corrosive environment and wiped dried to remove corrosion products before reweighing. The weight loss of the mild steel before and after exposure was calculated using Eq. (1) [17]:

$$\Delta W\ (g) = W_b\ (g) - W_a\ (g) \tag{1}$$

where, W_b was the weight of mild steel before exposure and W_a was the weight of mild steel after exposure.

The corrosion rate of the mild steel coupon was determined by using Eq. (2), while the percentage of inhibition efficiency and surface coverage of the extracts were computed using the Eq. (3) and (4), respectively [18].

$$Corrosion\ Rate\ (mpy) = \frac{534\ \Delta W\ (g)}{A\ (cm^2) \times t\ (hr) \times \rho\ (g/cm^3)} \qquad (2)$$

where, ΔW was the change in weight, A was the total area of the sample exposed, t was the total exposed time and ρ was the density of the mild steel coupon.

$$Inhibition\ Efficiency\ (\%) = \frac{W_o\ (g) - W(g)}{W_o\ (g)}\ x\ 100\ \% \qquad (3)$$

$$Surface\ coverage\ (\theta) = \frac{W_o\ (g) - W(g)}{W_o\ (g)} \qquad (4)$$

where, W_o was the weight loss in the absence of the inhibitor and W was the weight loss in the presence of the inhibitor.

2.3.1 *Effect of Orange Peel to Solvent Ratio*

The inhibitive efficiency of OPE was investigated by exposing the mild steel coupon to OPE that were extracted using different orange peel to solvent ratio (g/mL), which were 0.5:100, 1:100, 5:100 and 10:100. The extraction of OPE was carried out at 30°C for 1 hour. The mild steel coupon coated with OPE extract were then immersed in 1 M of HCl for 1 hour. The inhibitive efficiency of the respective OPE was calculated as described in Section 2.3.

2.3.2 *Effect of Contact Time Between OPE and Mild Steel Coupon*

With the optimum orange peel to solvent ratio determined in Section 2.3.1, the inhibitive efficiency of OPE was investigated by exposing the mild steel coupon to the extract for different period. The mild steel coupon was exposed to the OPE for 0.5, 1, 2 and 3 hours at 30°C. Subsequently, they were immersed in 1 M of HCl for 1 hour. The inhibitive efficiency of OPE was calculated as described in Section 2.3.

2.3.3 *Effect of Contact Temperature Between OPE and Mild Steel Coupon*

The effect of contact temperature between OPE and the mild steel coupon was investigated within the range of 30°C to 60°C. The contact time between the OPE and mild steel coupon was decided based on the results in Section 2.3.2. The mild steel coupon was then immersed in 1 M of HCl for 1 hour. The inhibitive efficiency of OPE was computed as described in Section 2.3.

2.3.4 *Effect of Acid Media Concentration*

The inhibitive efficiency of OPE was determined by immersing the mild steel coupon in different concentrations of acid solution. With the optimum parameters obtained from Section 2.3.1 – 2.3.3, the coupon was immersed in HCl at the concentration of 0.1 M, 1 M and 10 M respectively. The inhibitive efficiency of OPE was calculated as described in Section 2.3.

2.4 *Characterization of OPE*

2.4.1 *Fourier Transform Infrared Spectroscopy (FTIR) Analysis*

The functional groups present in the OPE was identified using Fourier Transform Infrared Spectroscopy (FTIR) analysis. The FTIR spectrum of the OPE was observed in the range of 500 – 4000 cm^{-1} by using an infrared spectrophotometer.

2.4.2 *Photochemical Analysis*

The phytochemical analysis of the OPE identifies the present main groups of chemical structure that contributes to corrosion inhibition [18]. The analysis consisted of three different tests to identify the presence of flavonoids, saponins and phenols. The procedures were performed as suggested by Okewale and Olaitan [18] with slight modifications. For the presence of flavonoids, 0.05 g of magnesium powder and two drops of concentrated HCl were added to 3 mL of the OPE. The presence of flavanones was indicated by a red coloration of the mixture. In investigating the presence of saponins, 5 mL of distilled water was added to 0.2 mL of OPE and the mixture was well shaken. The presence of saponins was noted by frothing of the mixture. Finally, in confirming the presence of phenols, 0.2 mL of the OPE was dissolved in ferric chloride solution. The presence of phenols was indicated by a green coloration of the mixture.

2.5 *Adsorption Mechanism*

In this study, three two-parametric kinetic models namely Langmuir, Freundlich and Temkin adsorption isotherm models were used to study the adsorption mechanism between the OPE and the mild steel substrate [18]. The experimental results of the OPE adsorption onto the metal surface were analyzed using the linearized equations of the selected empirical kinetic models as summarized in Table 1. The model parameters for each isotherm were calculated by linear regression using Microsoft Excel software. Subsequently, the best fit isotherm model was selected based on the highest regression coefficient R^2 value [19]. Higher regression coefficient (R^2) value showed higher accuracy and better representation of the kinetic model to the adsorption of OPE onto the mild steel.

Table 1 Proposed empirical kinetic models in linearized forms

Model	Model Equation	Linearized Equation
Langmuir	$\dfrac{\theta}{1-\theta} = KC$	$\dfrac{C}{\theta} = \dfrac{1}{K} + C$
Freundlich	$\theta = KC^n$	$\ln \theta = \ln K + n\ln C$
Temkin	$\theta = \dfrac{1}{f} \ln(KC)$	$\theta = \ln C + \ln K$

* C was the inhibitor concentration (g/mL), θ was degree of the surface coverage and K was the adsorption constant (M^{-1}).

3.   Results and Discussion

3.1 *Screening of Extracting Solvent*

Powdered orange peels were extracted by distilled water and ethanol to investigate the weight loss of mild steel coupon in 1 M HCl solution. The results are presented in Table 2.

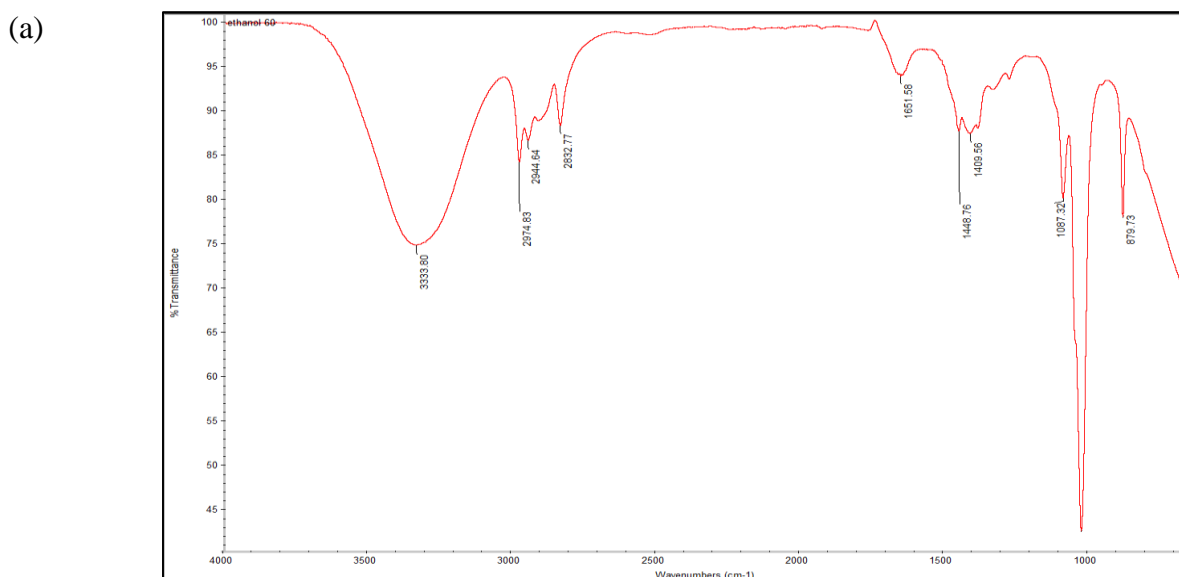**Table 2** Corrosion inhibition efficiency of different extracting solvent

Extracting solvent	Weight loss (g)	IE (%)
Blank (control coupon)	0.0042	-
Ethanol	0.0016	61.11
Distilled water	0.0021	50.79

It was found that the inhibition efficiency of OPE extracted using ethanol was higher than using distilled water. Based on the comparison of pH values for both OPE extracted using ethanol and distilled water (Fig. 1), the OPE extracted using distilled water was found to be slightly more acidic (pH=5) than using ethanol (pH=6). As a consequence, the degree of corrosion in the distilled water extract could be higher, resulting in higher weight loss than the mild steel coupon exposed to the OPE extracted by ethanol. Therefore, ethanol was used as the extracting solvent for OPE in the subsequent experimental stages.

Fig. 1. The pH value of OPE extracted using (a) Ethanol (pH = 6); (b) Distilled water (pH = 5)

The selection of ethanol as the best extracting solvent for OPE was also justified by the FTIR analysis as shown in Fig. 2. By comparing both spectra, it was observed that ethanol solvent had extracted more functional groups from the orange peels as compared to distilled water. Farhan et al. [20] mentioned that the selection of solvent was dependent on the polarity of the extraction content. Hence, it can be deduced that the polarity of ethanol is more suitable in extracting OPE in this context. These functional groups revealed in the analysis contributed to the mild steel corrosion inhibition by the OPE. They will be further discussed in subsequent section (characterization study).
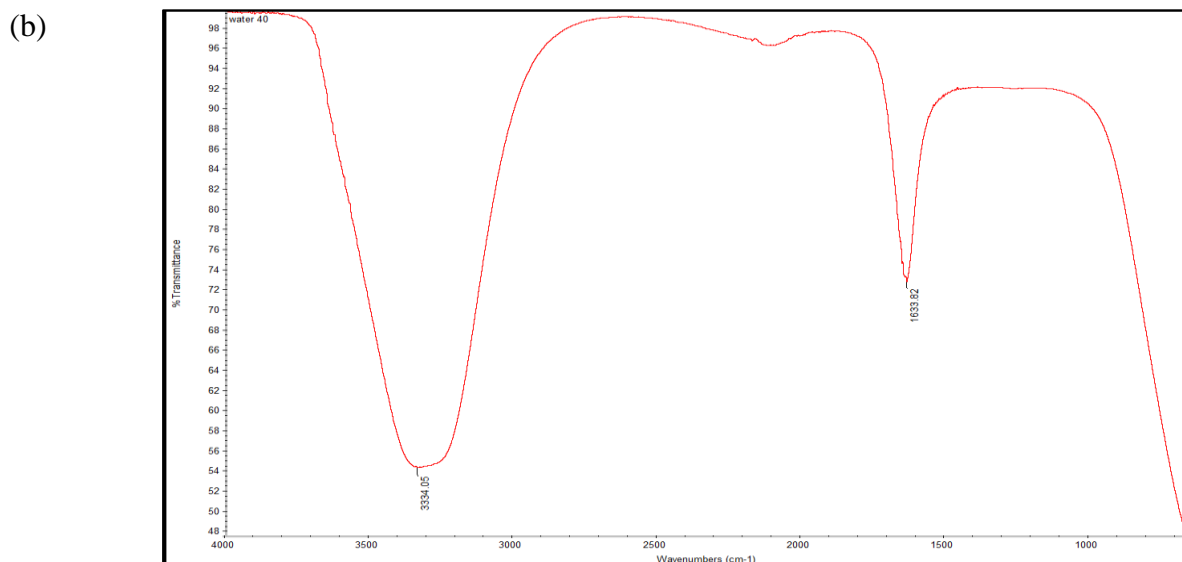
(a)

(b)

Fig. 2. FTIR spectrum of OPE extracted by (a) Ethanol; and (b) Distilled Water

3.2 *Investigation of OPE Corrosion Inhibition Efficiency*

3.2.1 *Effect of Orange Peel to Solvent Ratio*

The effect of orange peel to solvent ratio on the corrosion inhibition performance of OPE is presented in Fig. 3. It was found that the corrosion inhibition of OPE increased with the increase in the amount of orange peel used. The finding was consistent with the results reported by Kumar and Yadav [9], which they had reported the increase of *Citrus sinensis* peels concentration provided better inhibition efficiency on mild steel in acidic media. Higher orange peel to solvent ratio provided higher number of inhibitor molecules to be adsorbed onto the metal surface area. In other word, increasing number of inhibitor molecules also provided more active sites to be adsorbed onto the vacant sites of the metal surface [5]. The surface area for adsorption was therefore directly proportional to the mass of adsorbent in the solution since the particle size of adsorbents were consistent and homogeneous [21]. In addition, Okewale and Olaitan [18] reported that the more inhibitor molecules adsorbed acted as stronger physical barrier for the metal, and inhibited corrosion attack from acid more efficiently. Therefore, the orange peel to solvent ratio of 10:100 (w/v) was chosen for the subsequent analysis in this study.
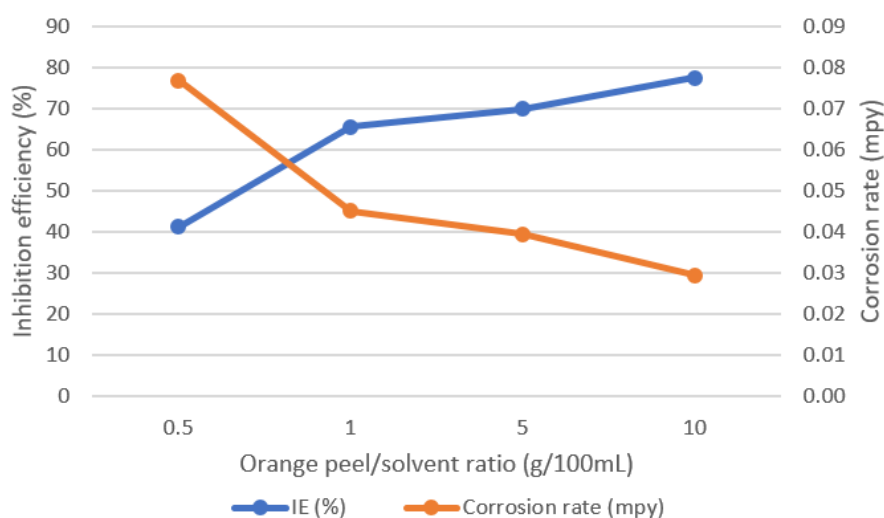

Fig. 3. Inhibition efficiency and corrosion rate against the orange peel to solvent ratio

3.2.2 *Effect of Contact Time Between OPE and Mild Steel Coupon*

The mild steel coupons were left to expose to OPE for 0.5, 1, 2 and 3 hours, before they were exposed to acid media. Based on the experimental results, the corrosion inhibition was enhanced as the contact time increased from 0.5 to 2 hours (Fig. 4). This finding was supported by the results obtained by Abdallah et al. [17] and Solmaza et al. [22], who reported the longer exposure time improved the inhibition efficiency of plant extracts. The longer the contact time between metal coupon with OPE contributed to higher accumulation of inhibitor molecules adsorbed onto the metal surface, and the protective film was formed more effectively against the acid corrosion attack [22]. Stango and Vijayalakshmi [5] added that the number of vacant sites on the metal surface being occupied by the inhibitor molecules increased as longer time was allowed for the contact. However, in this research, at 3 hours of exposure time, the corrosion inhibition was found to be lower as compared to the exposure time of 2 hours. This observation could be due to the partial desorption of the adsorbed inhibitor molecules from the mild steel coupon surface [23]. Consequently, in this study, it is deduced that the contact time of 2 hours between mild steel and OPE was the optimum period for high efficiency of inhibition, and it is selected for the subsequent analysis.
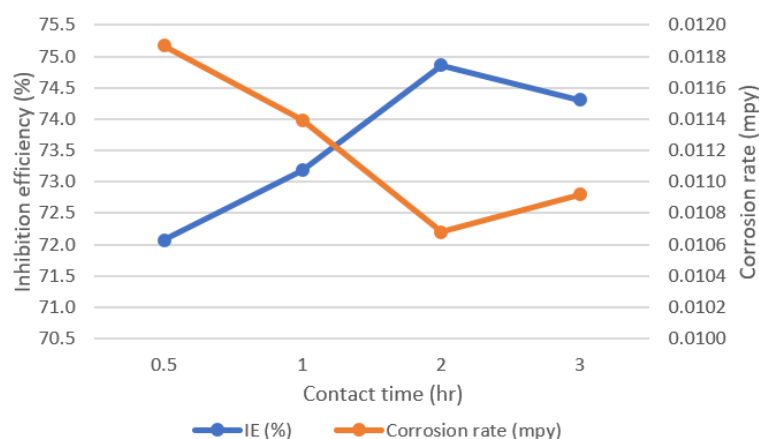

Fig. 4. Inhibition efficiency and corrosion rate against the contact time

3.2.3 *Effect of Contact Temperature Between OPE and Mild Steel Coupon*

The effect of the mild steel coupons immersed in OPE at different temperatures before they were exposed to acid solution was investigated. The results showed that the corrosion inhibition of OPE reduced as the temperature of the OPE increased from 40°C to 60°C (Fig. 5). The mild steel coupons exposed to higher temperature resulted in higher weight loss could be due to the decrease in stability of the adsorbed inhibitor molecules on the metal surface [24]. The decrease in inhibition efficiency with increase in temperature could be interpreted by the fact that the inhibitor molecules were physically adsorbed on the mild steel surface [24-26]. According to Verhaverbeke [27], physisorption involved weak Van der Waals attraction between the adsorbate and adsorbent, that was reversible by heating. Hence, as the temperature was elevated from 40°C to 60°C, the adsorption of the OPE molecules onto the mild steel surface could be affected, thus the protective film against the acid corrosion may not be effective as at 30°C. In addition, Okafor et al. [26] also explained that there may be an increased agitation of the solution due to higher hydrogen gas evolution rates at higher temperatures, thereby reducing the effectiveness of the protective film formed by the inhibitor molecules. Another reason for the corrosion inhibitive performance observed was that the OPE inhibitor molecules might be denatured at high temperature [28]. The mild steel coupon exposed to the OPE at 30°C had showed the highest inhibition efficiency compared to other temperatures, thus it was selected to be the optimum temperature to be used for the subsequent analysis.
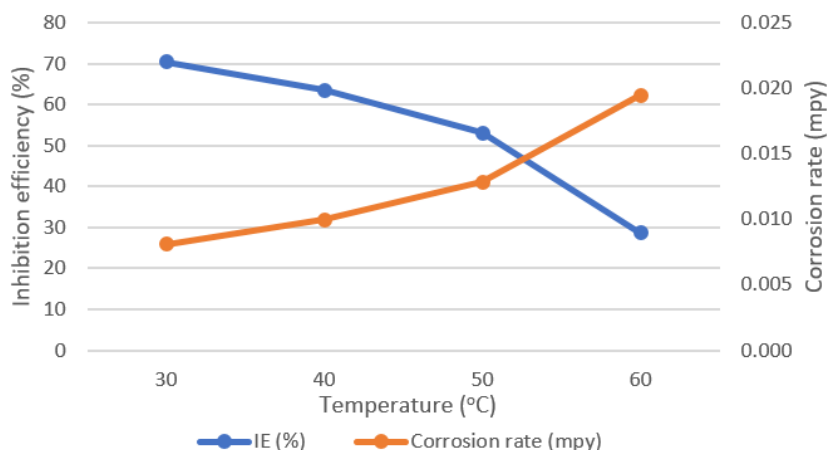
Fig. 5. Inhibition efficiency and corrosion rate against the contact time

3.2.4 *Effect of Acid Media Concentration*

The optimum parameters obtained from Section 3.2.1, 3.2.2 and 3.2.3 were used to investigate the inhibitive performance of OPE on different acid concentrations. The mild steel coupon was immersed into the OPE extracted with orange peel/solvent ratio at 10g/100mL, for 2 hours at 30°C. The mild steel coupon was then exposed to different acid concentration of 0.1 M, 1 M and 10 M. The results are shown in Fig. 6.
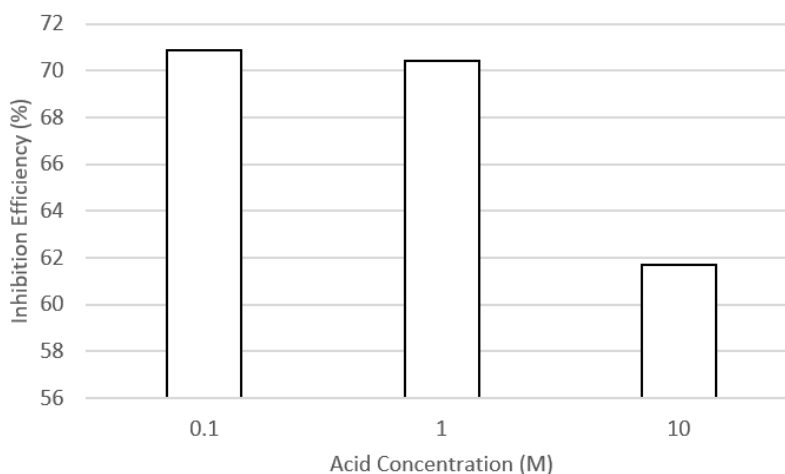

Fig. 6. Inhibition efficiency and corrosion rate against different acid concentrations

The results showed that the corrosion rate of mild steel coupons increased drastically as the acid concentration increased beyond 1 M. The significant increase in corrosion rate (reduction of inhibition efficiency) of the mild steel coupons could be attributed to the ineffective protective film formed by the OPE inhibitor molecules at HCl concentration higher than 1 M. At higher acid concentration, H^+ ions concentration was high. The high diffusion rate of H^+ ions to and from the metal surface might had stressed the condition of the protective film, thus became an ineffective weak barrier to restrict the corrosion attack from stronger acid [18]. Based in these results, it can be deduced that the optimum parameters obtained from Section 3.2.1 to 3.2.3 are not applicable for HCl concentration higher than 1 M.

3.3 Surface Analysis

The corrosion of mild steel coupons in the absence and presence of inhibitor was observed under a light microscope and the images are shown in Fig. 7 (a) – (c). Fig. 7(a) shows the mild steel coupon surface before exposure to the acid solution, which was associated with polishing scratches. It was clear from Fig. 7(b), that the mild steel surface was heavily corroded, whereas in the presence of OPE, the surface condition was comparatively better as shown in Fig. 7(c). Hassan et al. [24] suggested that the surface condition shown in Fig. 7(c) was due to the presence of OPE that protected the mild steel surface via formation of adsorbed layer on the metal surface.
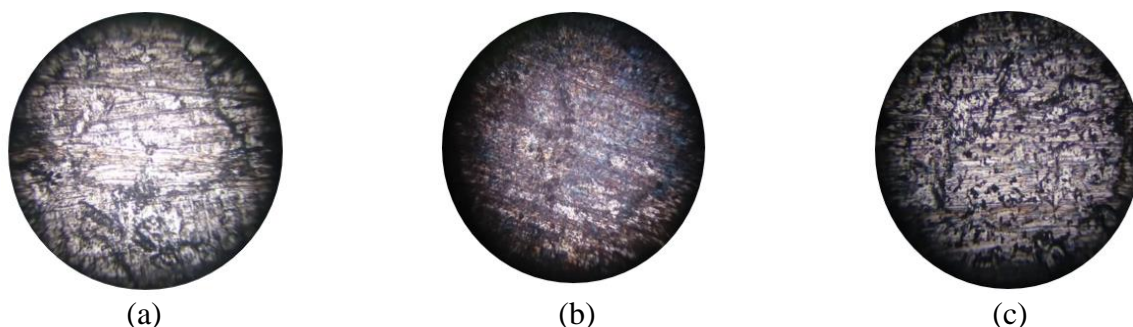
| (a) | (b) | (c) |

Fig. 7. Microscope images of mild steel coupon (a) Before immersion in 1 M HCl for 1 hr; (b) After immersion in 1 M HCl for 1 hr; (c) After immersion in 1 M HCl for 1 hr and in the presence of OPE

3.4 Characterization of OPE

3.4.1 Fourier Transform Infrared Spectroscopy (FTIR) Analysis

FTIR analysis was conducted to identify the functional groups present in OPE and the molecular structure responsible for the inhibition of mild steel coupons from corrosion. Table 3 presents the functional groups identified from the FTIR spectrum that is presented in Fig. 2(a).

Table 3 Functional groups identified from FTIR spectrum of OPE

Wavenumber (cm^{-1})	Functional group	Bond	Reference
3333.80	Hydroxyl or amine	-OH or N-H	[16]
2974.83	Carboxylic acid	O-H	[18]
2944.64	Alkane or carboxylic acid	C-H or O-H	[16, 18]
2832.77	Aldehyde	C-H	[16, 18]
1651.58	Carbonyl	C=O	[29]
1448.76	Alkyl	C-H	[18]
1409.56	Ester	-(C=O)-O-	[16]
1087.32	Alcohols, esters, ethers, carboxylic acid, anhydrides	C-O	[16, 24]
879.73	Aromatic	C≡C	[16]

Based on the FTIR scanning, it can be inferred that abundant oxygen containing groups were present in the OPE extracted in this research. This finding was consistent with the results reported by Chen and Jing [16] that OPE comprised of more oxygen containing groups and less nitrogen containing groups. The functional groups identified in Table 3 contained non-bonding electrons, which may be responsible for the adsorption on the mild steel coupon surface. Singh et al. [7] and Chen and Jing [16] suggested that the O atoms, N atoms and aromatic rings had the tendency to donate their unpaired electrons to form covalent bonds with the metal ions. Subsequently, the bonding of the inhibitor

molecules formed a protective film on the metal surface, thus reducing the diffusion of H⁺ ions into the metal surface and hence inhibited corrosion.

3.4.2 *Photochemical Analysis*

Three phytochemical analysis were conducted to determine the presence of flavonoids, saponins and phenols, respectively. The analysis was successful as the presence of the three phytochemical constituents were detected and the results are presented in Fig. 8.
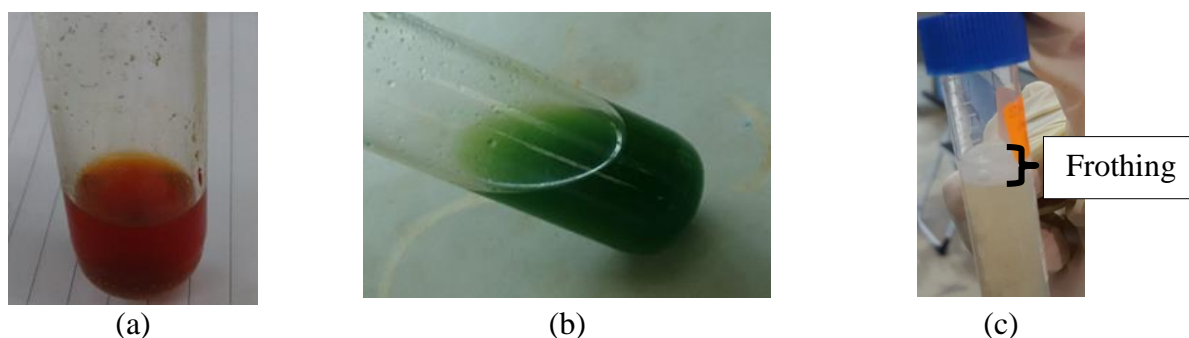

| (a) | (b) | (c) |

Fig. 8. (a) Red coloration indicated the presence of flavonoids; (b) Green coloration indicated the presence of phenols; and (c) Frothing indicated the presence of saponins

Rocha et al. [14] reported that the heterosides structures of flavonoids, saponins and phenols demonstrated antioxidant properties that were accountable for inhibiting action on metals. On the other hand, Okewale and Olaitan [18] stated that these phytochemical constituents contained functional groups of nitrogen and oxygen atoms, and aromatic rings that could form a film on the metal surface to restrict the metal reduction process. The presence of these heterocyclic compounds was claimed to enhance the adsorption of the OPE on the mild steel, leading to an effective corrosion inhibition performance [30]. In a similar research, Philip et al. [31] had investigated the cashew nut shell extract as an inhibitor and found that the negatively charged phenoxide ions underwent electrostatic attraction with the positively charged metal surface. Thus, the presence of flavonoids, saponins and phenols were responsible for corrosion inhibition as they adsorbed onto the metal surface creating a protective film. Therefore, the characterization results supported the mild steel corrosion inhibition performance by OPE obtained in this study.

3.5 Adsorption Mechanism

The adsorption mechanism between the OPE and the mild steel substrate was studied using Langmuir, Freundlich and Temkin adsorption isotherm models. The models correlated the degree of surface coverage (θ) with the inhibitor concentration at constant temperature [28]. Fig. 9 shows the isotherm plots using the equilibrium data for all models. The regression coefficients, R^2 for the three models are tabulated in Table 4.

Table 4 Regression coefficient, R^2 for all isotherm models

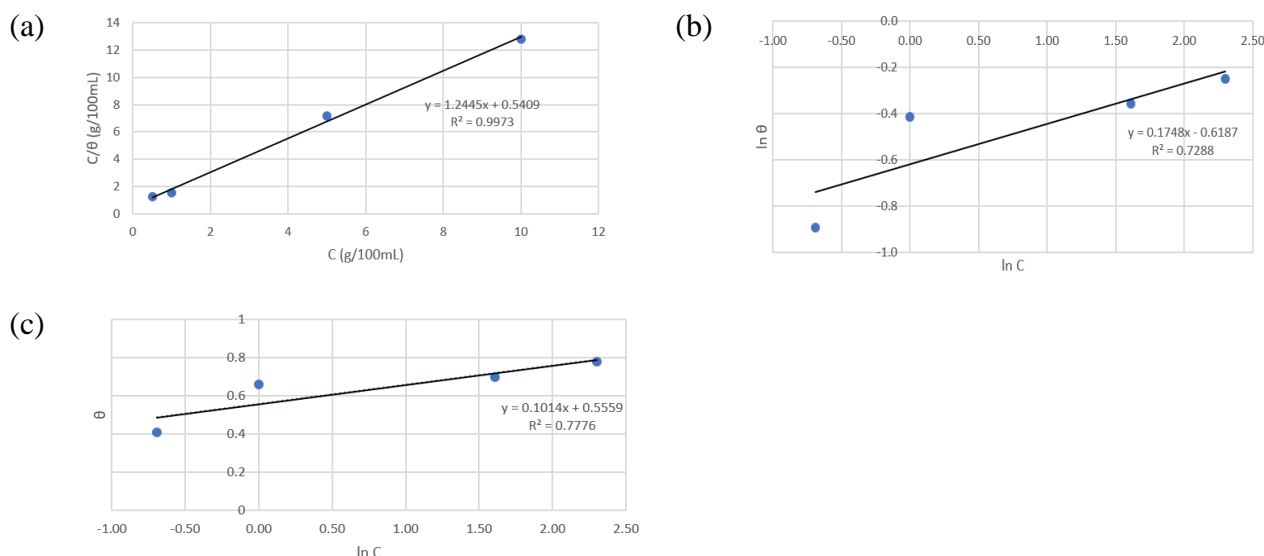| Adsorption Isotherm Model	Langmuir	Freundlich	Temkin
R^2	0.9973	0.7288	0.7776

Fig. 9. Plot of OPE at different concentrations using (a) Langmuir isotherm; (b) Freundlich isotherm; and (c) Temkin isotherm

Based on the plot linearity as shown in Fig. 9, Langmuir model showed the best fit to the experimental data compared to Freundlich and Temkin models. The adsorption mechanism of OPE on mild steel was deduced to obey the Langmuir model. The model assumed monolayer adsorption of OPE molecules on the homogeneous metal surface. This result was in agreement with the report by Saratha and Meenakshi [32] who used Langmuir and Temkin models to investigate the adsorption mechanism of *Sida rhombifolia. L* extracts on mild steel in phosphoric acid. They found that the adsorption behavior of the plant extract obeyed Langmuir model. In addition, Hassan et al. [24] also suggested Langmuir isotherm model to represent the adsorption of *Citrus aurantium* leaves extracts on mild steel in sulfuric acid.

4. Conclusions

The present work attempted to investigate the inhibitive and adsorptive performance of orange peel extract as a corrosion inhibitor to boost up the commercial values of these cheap and easily available waste materials. The usage of many current inhibitors is gradually restricted as they do not satisfy the environmental standards. In this research, it was successfully proven that orange peel extract had the potential to inhibit mild steel from acid corrosion. In the screening of extracting solvent process, ethanol was found to be the most suitable solvent for extraction as the polarity of ethanol was compatible with the orange peel components that were responsible for corrosion inhibition. Subsequently, the effect of various parameters was investigated for the inhibitive efficiency of OPE. The results indicated that parameters such as orange peel to solvent ratio, contact time and temperature imposed significant effects on inhibition performance of OPE. Surface analysis had revealed that the corrosion of mild steel in the presence of inhibitor was not as severe as the mild steel in the absence of the inhibitor. Characterization studies of the OPE had confirmed the presence of functional groups and constituents that were accountable for corrosion inhibiting action on metal. Finally, the isotherm study concluded that the adsorption of OPE was homogeneous, obeying Langmuir mechanism and monolayer coverage of inhibitor molecules was expected on the mild steel surface.

Acknowledgement

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