



## Tobacco Extract for Inhibition of Carbon Steel Corrosion in H<sub>2</sub>S-contained NaCl Solution

Hary Devianto<sup>1</sup>, Isdiriayani Nurdin<sup>1</sup>, Pramujo Widiatmoko<sup>1\*</sup>, Della Silvia<sup>1</sup>,  
Clarissa Prakarsa<sup>1</sup>

<sup>1</sup>Chemical Engineering Program, Faculty of Industrial Technology, Institut Teknologi Bandung, Bandung 40132 Indonesia

**Abstract.** This study explored the effectiveness of tobacco extract as a corrosion inhibitor for carbon steel in an H<sub>2</sub>S-containing NaCl solution. The experiments were conducted at room temperature and atmospheric pressure, with a variation in inhibitor concentration and rate of fluid flow. Results showed that the tobacco extract decreases the corrosion rate of carbon steel in the 3.5% NaCl solution. Increasing flow rate and inhibitor concentration significantly affect the corrosion rate of carbon steel. In the NaCl solution, crystalline corrosion product formation of magnetite (Fe<sub>3</sub>O<sub>4</sub>) was mainly detected. Furthermore, the presence of H<sub>2</sub>S leads to forming of a mackinawite (FeS) structure. The inhibition efficiency of 1000 and 2000 ppm tobacco extract in NaCl solution with the presence of H<sub>2</sub>S is in the range of 24 to 69%.

**Keywords:** Carbon Steel; Corrosion; Flow rate; Hydrogen sulphide; Inhibitor; Tobacco extract

### 1. Introduction

Chemical industries produce daily necessities as a vital part of human life. The involvement of corrosive fluid in chemical processing, both in static and dynamic flow, leads to corrosion of the process equipment. Corrosion is a spontaneous metal deterioration process due to environmental interaction (Roberge, 2008). In industries, carbon steel is common material widely used for various purposes (Kurniawan, Mitha, and Fikri, 2018) because of its satisfactory performance and attractive cost (Gandy, 2007). However, carbon steel is susceptible to corrosion (Dwivedi, Lepkova, and Becker, 2017). Components such as sodium chloride and hydrogen sulfide in oil and gas industries (Al-Janabi, 2020) increase the corrosivity of process fluids to the carbon steel. The corroded carbon steel leads to equipment failures, loss of containment, product contamination, and work accident. Therefore, a study on carbon steel corrosion in NaCl and H<sub>2</sub>S environments is crucial, especially in the petroleum industry, to reduce costly social, economic, and even human losses (Zúñiga *et al.*, 2011; Sosa *et al.*, 2003).

Adding corrosion inhibitors can reduce corrosion risk. The inhibitors are a small quantity of a compound that controls, reduces or prevents reactions between a metal and its surroundings (Fouda *et al.*, 2014; Bentiss *et al.*, 2002). The inhibitor could be a synthetic organic corrosion inhibitor or a green corrosion inhibitor extracted from natural

\*Corresponding author's email: [pramujo@itb.ac.id](mailto:pramujo@itb.ac.id), Tel.: +62-22-2500989, Fax.: +62-22-2500143  
doi: [10.14716/ijtech.v14i5.5272](https://doi.org/10.14716/ijtech.v14i5.5272)

Resources (Rani and Basu, 2012). Organic inhibitors, such as thiourea derivatives, are effective in an acid environment (Shetty and Shetty, 2017). In seawater, sodium benzoate also has been used as an inhibitor (Nik *et al.*, 2010). However, the application of synthetic organic corrosion inhibitors is hindered by their toxicity effect (Popoola, 2019), despite their high effectivity. On the other side, green organic inhibitors have recently become an attractive alternative in corrosion prevention research due to their availability and relatively low cost (Kurniawan, Mitha, and Fikri, 2018).

The green corrosion inhibitors are biodegradable and do not contain heavy metals or other toxic compounds. Extracts of a plant contain a wide variety of organic compounds. Most of them contain heteroatoms such as P, N, S, and O (Shalabi *et al.*, 2014; Bhawsar, Jain, and Jain, 2013). A significant number of scientific studies have been dedicated to the corrosion inhibition of carbon steel in acidic media by natural products as corrosion inhibitors (Shalabi *et al.*, 2014; Bhawsar, Jain, and Jain, 2013; Ramananda, 2013; Majidi *et al.*, 2011; Eddy and Mamza, 2009; Prabhu *et al.*, 2008). In example, *Nicotiana tabacum* extract oil has been studied as a corrosion inhibitor of mild steel in 2 M H<sub>2</sub>SO<sub>4</sub> solution, with an efficiency of 94.13% at 10 g/L, 303K. *Atropa Belladonna* extract has also been investigated on the corrosion of carbon steel in 1 M HCl. It shows 96.6% at 500 ppm using the Tafel polarization technique. Pradityana *et al.* (2017) also used 300 mg/L *Myrmecodia Pendans* extract as a green inhibitor of mild steel corrosion in 1 M H<sub>2</sub>SO<sub>4</sub> media with an efficiency of 64.68%.

Tobacco plants produce more than 4,000 chemical compounds, including terpenes, alcohols, carboxylic acid, nitrogen-containing compounds, and alkaloids (Loto and Popoola, 2011). These components may inhibit electrochemical activity by chemisorption of the extract components onto the steel surface. It can reach up to 91.5% on inhibition efficiency, higher than black wattle (66-87%) and orange peel (80% IE). the chemisorption of tobacco extract components provides higher effective protection due to the reduction of the reactivity of metal at the attached sites (Guo *et al.*, 2018; Shehata, Korshed, and Attia, 2018). Kurniawan, Mitha, and Fikri (2018) used tobacco extract as an inhibitor in a 3,5% NaCl environment with CO<sub>2</sub> with excellent results. In this work, we also use tobacco due to its abundant availability in Indonesia. The H<sub>2</sub>S is used as an impurity instead of CO<sub>2</sub>. The tobacco extract was obtained from Virginia tobacco leaves using the maceration technique with demineralized water as solvent. We evaluated the efficiency of tobacco extract as a green corrosion inhibitor using electrochemical techniques.

## 2. Methods

### 2.1. Preparation of Tobacco Extract

The dried and ground Virginia tobacco leaves (100 g) were soaked in 100 mL demineralized water for 72 hours under a room temperature of 27°C. The extract solution was filtered through filter paper and heated at 50 °C for 3 hours. The extract of tobacco leaf obtained was used as an inhibitor.

### 2.2. Preparation of Metal Specimens

The material tested was AISI 1018 carbon steel. Two types of specimens were prepared, i.e. specimens to measure the corrosion rate (in the form of a solid cylinder with a diameter of 3 mm and a length of 20 mm) and specimens to determine the inhibition mechanism (in the form of a 10 mm x 10 mm plate). The carbon steel cylinder is coated with Teflon®, which acts as an insulator so that only one side of the surface is in contact with the fluid. The plate specimens are connected by cables and covered with resin so that only

one side is exposed. Before testing, the electrode was polished using different abrasive papers (up to 2000 grit) and cleaned with demineralized water and alcohol.

### 2.3. Preparation of Test Media

All chemicals were obtained from Merck, Germany, without prior treatment. The electrolyte solution is NaCl solution at a concentration of 35,000 ppm. The solution volume is 50 mL, with and without adding 600 ppm H<sub>2</sub>S. Concentrations of tobacco extract are varied at 0, 1000 and 2000 ppm. As in previous research, the H<sub>2</sub>S gas is made by reacting Na<sub>2</sub>S solid with 3 M of HCl solution using Kipp's apparatus (Rachmawati *et al.*, 2011). The formed H<sub>2</sub>S gas is flowed into the NaCl solution for a specific time to obtain the determined H<sub>2</sub>S concentration.

### 2.4. Corrosion Test

Corrosion rate was measured using the potentiodynamic method and determining the corrosion inhibition mechanism by using Cyclic Voltammetry (CV), Electrochemical Impedance Spectroscopy (EIS), X-Ray Diffraction (XRD), and Scanning Electron Microscope (SEM) analyses. The conventional three-electrode cell is used for the polarization curve, CV and EIS experiments. Pt-Ir electrode was used as the auxiliary electrode, a saturated calomel electrode (SCE) was used as the reference electrode, and the sample was used as the working electrode. All polarization curve tests were conducted at a scan rate of 5 mV/s. The Gamry Framework and Echem® Analyst software analyzed the polarization curves. The EIS measurements were performed with frequencies ranging from 50,000 Hz to 1 Hz, and EIS results were analyzed using the Gamry Echem® Analyst software. After the corrosion test, the surface morphologies were observed using SEM. Corrosion phases were detected using XRD and identified by matching peak positions automatically with Match! Software.

Corrosion rate measurement experiments were carried out by varying the flow rate, the presence of H<sub>2</sub>S, and the concentration of tobacco extracts under room temperature. Then, experiments to determine the corrosion inhibition mechanism were carried out by varying the immersion time. The studied carbon steel samples were immersed in 3.5% NaCl solution with the addition of tobacco extract as an inhibitor for an hour and a week. The corrosion mechanism was analyzed based on CV and EIS analyses.

## 3. Results and Discussion

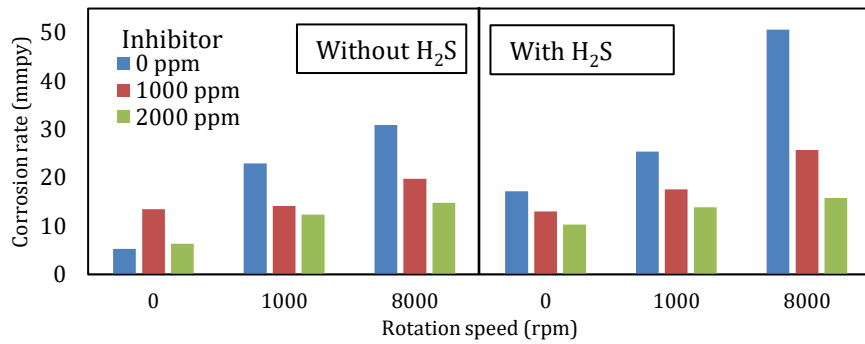
### 3.1. Corrosion Rate of Carbon Steel in 3.5% NaCl Solution

The corrosion rate of carbon steel was determined using the potentiodynamic polarization method against variations in the flow rate of the solution, the presence of dissolved H<sub>2</sub>S, and the concentration of tobacco extract in the electrolyte solution. The result is shown in Figure 1.

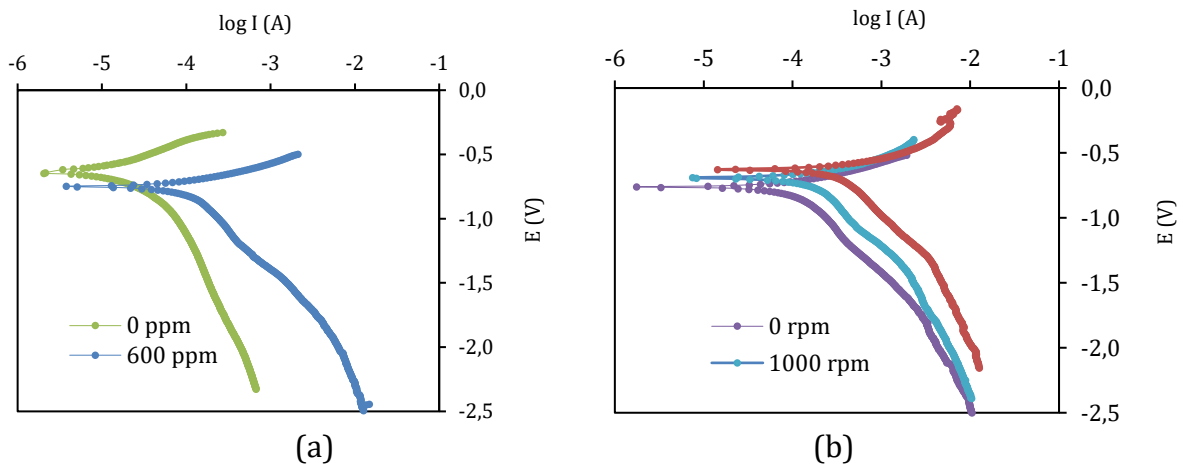
*Effect of H<sub>2</sub>S* - The polarization curve of carbon steel in NaCl solution with the presence of H<sub>2</sub>S can be seen in Figure 2a. The presence of H<sub>2</sub>S in the 3.5% NaCl solution increased the corrosion rate. This is due to the dissociation of dissolved H<sub>2</sub>S into H<sup>+</sup> and HS<sup>-</sup>. The increased concentration of H<sup>+</sup> ions in the solution increases the corrosion rate because the H<sup>+</sup> ions can oxidize carbon steel (Rachmawati *et al.*, 2011).

*Effect of flow rate* - In general, increasing the flow rate (related to the rotational speed of the electrode) of the solution will increase the corrosion rate of the carbon steel. The polarization curve in Figure 2b indicates increased dissolved oxygen as the fluid flow rate increases (Roberge, 2008). The cathodic curve moves to a higher current with increasing rotational speed.

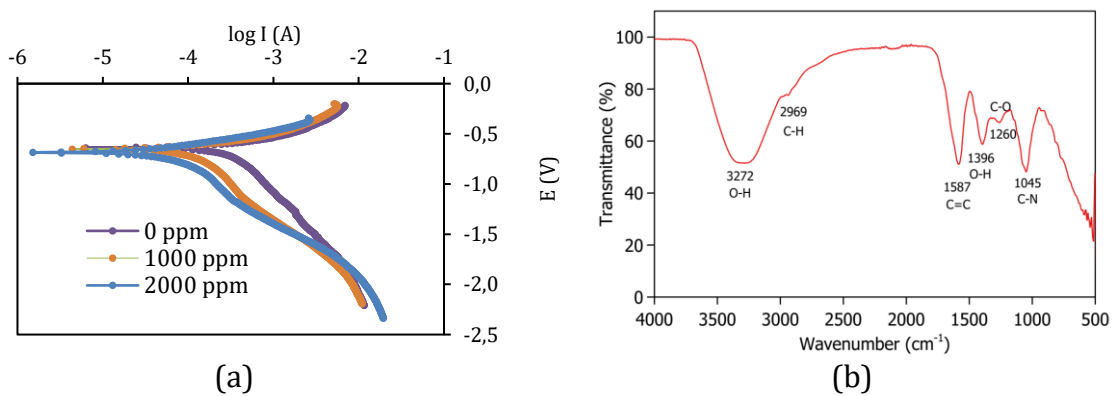
*Effect of tobacco extract* - The polarization curve of carbon steel in NaCl solution with the presence of tobacco extract is presented in Figure 3a. The addition of tobacco extract decreased the corrosion rate of the steel in the NaCl solution containing H<sub>2</sub>S. Adsorption of C-O, N-H, and O-H functional groups from the compounds in the tobacco extract onto the metal surface forms metal protective layers. The presence of these groups in the extract is detected in the Fourier-Transform Infrared Spectroscopy (FTIR) spectrum, as shown in Figure 3b.



**Figure 1** Corrosion rate of carbon steel in 3.5% of NaCl solution and tobacco extract inhibition efficiency with 600 ppm H<sub>2</sub>S and various inhibitor concentrations in various electrolyte flowrate



**Figure 2** (a) Polarization curve of carbon steel in NaCl solution with and without H<sub>2</sub>S (b) with the addition of 600 ppm of H<sub>2</sub>S under various rotation rates



**Figure 3** (a) Polarization curve of carbon steel in NaCl solution with H<sub>2</sub>S and various concentrations of tobacco extract (b) FTIR spectra of tobacco extract sample

To be noted, the addition of tobacco extract into NaCl solution in the absence of H<sub>2</sub>S and under static conditions increases the corrosion rate. This condition is caused by the acidity of tobacco extract, which increases the corrosivity of the solution. The NaCl solution with 1000 and 2000 ppm tobacco extract has pH of 6.4 and 5.9, consecutively. Formation of a stable, protective layer due to the acid environment, however, is hindered due to the slow diffusion and adsorption of tobacco extract's protective compounds onto the steel surface. The addition of disturbances in the form of flow rate and the presence of H<sub>2</sub>S resulted in tobacco extract forming a better protective layer. It inhibits steel corrosion with an efficiency of 24% to 69% at tobacco extract concentrations of 1000 ppm and 2000 ppm, respectively.

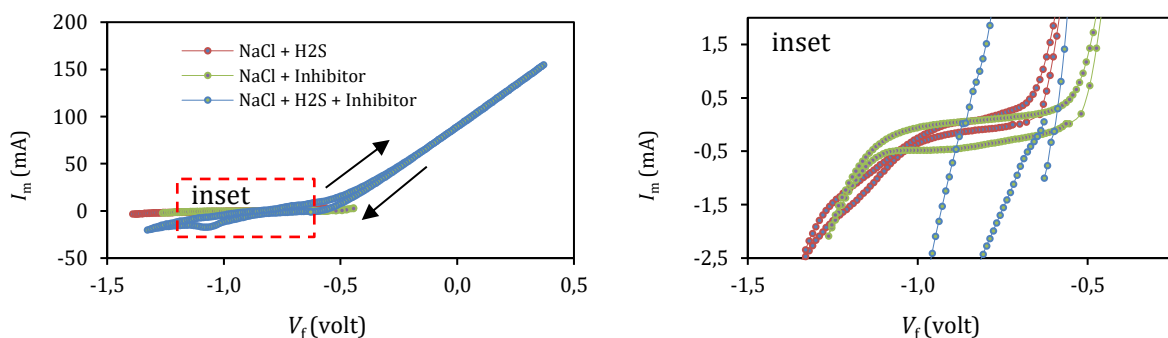
### 3.2. Corrosion Inhibition Mechanism of The Tobacco Extract

Based on the voltammogram in Figure 4, the corrosion product is unstable since the current ratio at the cathodic peak to the current at the anodic peak is not equal to 1. The reaction is also considered irreversible because the potential difference at the anodic and cathodic peaks exceeds 59 mV. Two cathodic peaks in the voltammogram of samples in the NaCl solution with H<sub>2</sub>S and inhibitor solution indicate the reduction occurred through two reaction stages. Meanwhile, one anodic peak on the voltammogram indicates that the oxidation reaction occurs in a single stage.

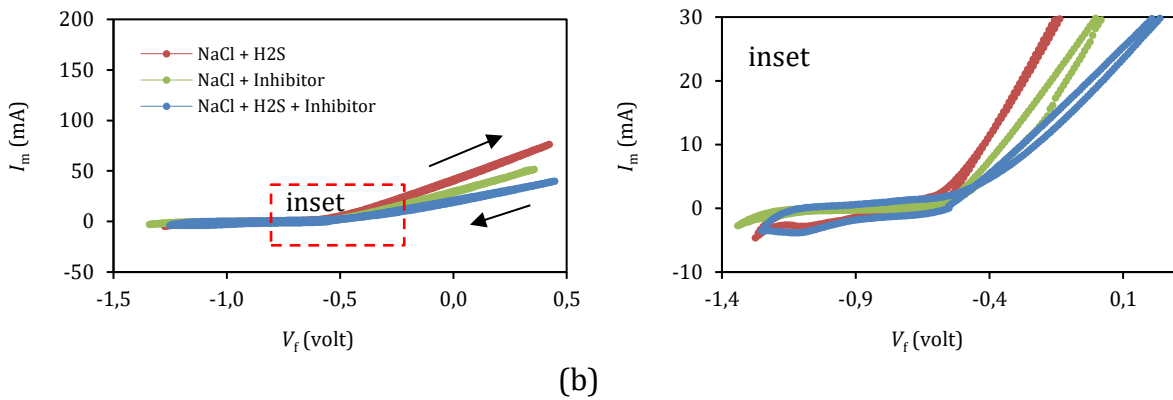
Figure 4a shows that within the same potential window and 1-hour immersion, the carbon steels show low corrosion current, both in a solution of NaCl with 600 ppm of H<sub>2</sub>S and NaCl with an inhibitor. The low current indicates a slow corrosion rate of carbon steel. In Figure 4b, it appears that the anodic current of carbon steel immersed in a solution of NaCl with 600 ppm of H<sub>2</sub>S and 2000 ppm of inhibitor for a week (40 mA) is smaller than the anodic current of steel after immersion for 1 hour (160 mA). This indicates that the tobacco extract, together with the presence of H<sub>2</sub>S, can function as an inhibitor. Figure 4b also shows that within a long exposure time, the corrosivity of H<sub>2</sub>S is higher than in tobacco extract.

Testing using EIS is carried out to determine the electrical circuit equivalent of the ongoing corrosion process. Three equivalent electrical circuits are generated depending on the type of electrolyte solution used. The Nyquist plot is shown in Figure 5. Meanwhile, the equivalent circuit and correlated electrical double layers on the electrode's surface are presented in Figure 6. Table 1 lists the fitting of the electrochemical impedance parameters of each configuration.

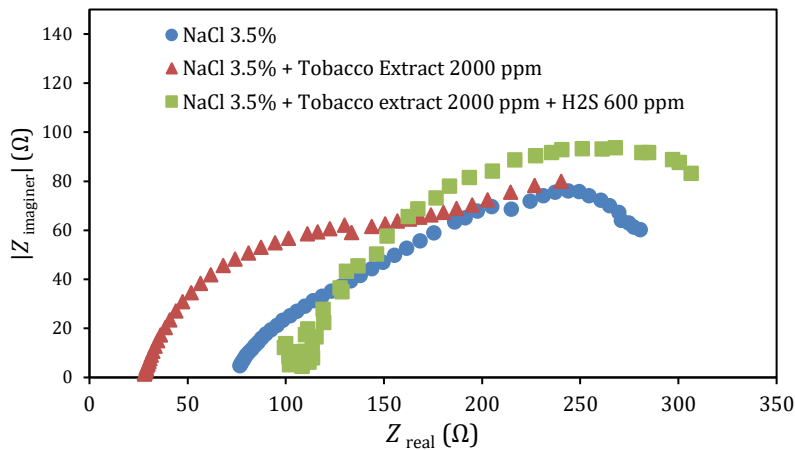
The EIS method test results show that (in Figure 6a) no protective layer was formed during the corrosion event. Figure 6b shows the formation of a dense protective layer on the metal surface. The presence of H<sub>2</sub>S and tobacco extract (Figure 6c) produce a porous protective layer. The  $R_s$  is the electrolyte resistance,  $R_{mol}$  is the resistance to the corrosion product layer formed,  $R_{ct}$  is the load transfer resistance, and CPE represents the electrical double-layer capacitance.



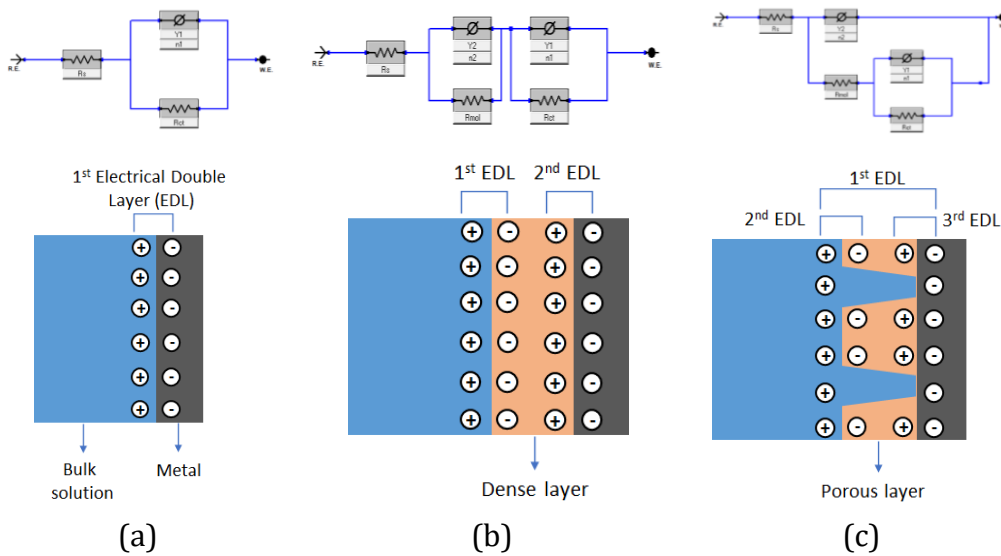
(a)



**Figure 4** Cyclic voltammogram of AISI 1018 carbon steel after immersion for (a) 1 hour; and (b) 1 week. The concentration of H<sub>2</sub>S and inhibitor are 600 ppm and 2000 ppm, respectively. The right side are inset pictures of the dotted line boxes



**Figure 5** Nyquist plot for corrosion inhibition of AISI 1018 carbon steel in a static electrolyte



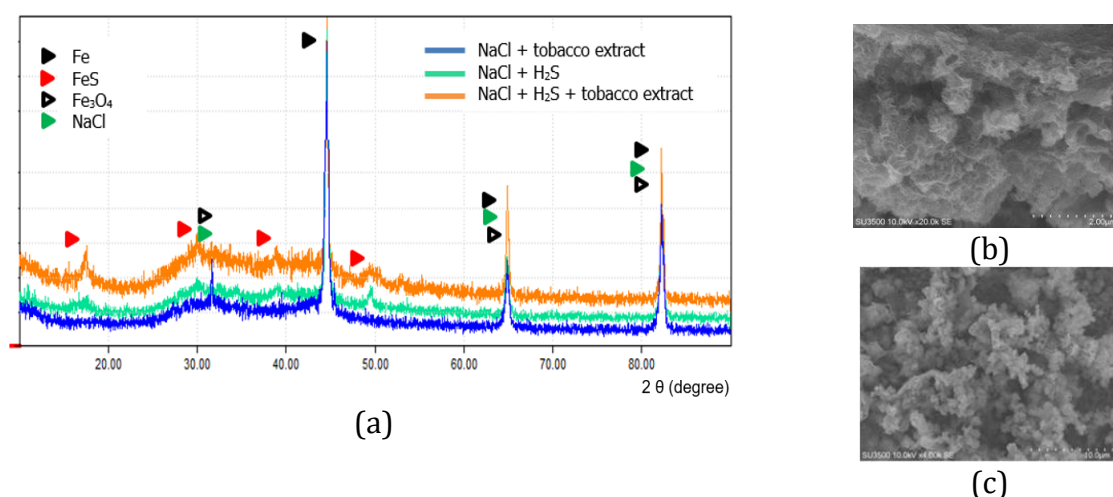
**Figure 6** Equivalent circuit of steel corrosion in 3.5% NaCl solution and correlated electrical double layers: (a) in the absence of tobacco extract as an inhibitor, both with and without H<sub>2</sub>S; (b) with inhibitor; and (c) with inhibitor and H<sub>2</sub>S



**Table 1** The electrochemical impedance parameters of the AISI 1018 steel in 3.5% NaCl solution with varied concentrations of tobacco extract and H<sub>2</sub>S

Medium	Rotating rate (rpm)	Tobacco Extract Concentration (ppm)	R <sub>s</sub> (Ω cm <sup>2</sup> )	CPE <sub>mol</sub>		R <sub>mol</sub> (Ω cm <sup>2</sup> )	CPE <sub>dl</sub>		R <sub>ct</sub> (Ω cm <sup>2</sup> )
				n	C <sub>dl</sub> × 10 <sup>6</sup> (μF)		n	C <sub>dl</sub> × 10 <sup>6</sup> (μF)	
3.5% NaCl + 0 ppm H <sub>2</sub> S	0	0	72.7	-	-	-	0.50	801	300.9
	0	2000	26.0	0.74	84	103.4	0.50	1079	502.0
	8000	0	25.4	-	-	-	0.66	215	277.8
	8000	2000	26.5	0.74	81	111.1	0.53	1197	418.2
3.5% NaCl + 600 ppm H <sub>2</sub> S	0	0	45.9	-	-	-	0.45	900	346.3
	0	2000	56.2	0.59	308	160.4	0.48	4352	955.5
	8000	0	39.7	-	-	-	0.53	768	340.0
	8000	2000	102.9	0.65	260	268.9	0.10	10000	587.1

Electrolyte resistance increased by adding the non-conductive tobacco extract concentration to the electrolyte solution, decreasing electric current and corrosion rate. The addition of tobacco extract and H<sub>2</sub>S also resulted in increasing in R<sub>ct</sub> value. The R<sub>ct</sub> relates to the protective formation layer on the steel surface (Pradityana *et al.*, 2017). A thicker and evenly distributed protective layer inhibits the charge transfer of corrosion reaction (Fouda *et al.*, 2014). The corrosion products of carbon steel in NaCl solution containing H<sub>2</sub>S and tobacco extract after immersion for one week were analyzed using XRD and can be seen in Figure 7a. Magnetite (Fe<sub>3</sub>O<sub>4</sub>) is always present as a corrosion product for the three types of electrolyte solutions used. Immersed in an electrolyte solution of H<sub>2</sub>S, the steel forms an iron sulfide compound, namely mackinawite (FeS).



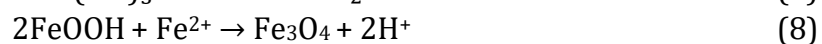
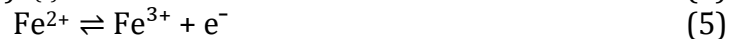
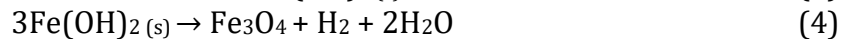
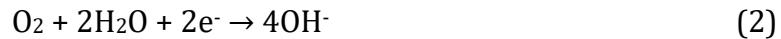
**Figure 7** (a) X-ray Diffraction spectra of the corroded carbon steel after one-week immersion in 3.5% NaCl contains H<sub>2</sub>S and tobacco extract and morphology of (b) mackinawite after one-week immersion in 3.5% NaCl solution contains H<sub>2</sub>S and 2000 ppm of tobacco extract, and (c) magnetite after one-week immersion in 3.5% NaCl solution contains 2000 ppm of tobacco extract

FeS layer can be protective in some instances by slowing down corrosion. It is affected by the density and thickness of the coating layer. However, such a protection layer may fail and lead to severe pitting, crevice, or under-deposit corrosion (Saji, 2019a). The organic component of tobacco extract may react with the corrosion product and form an additional

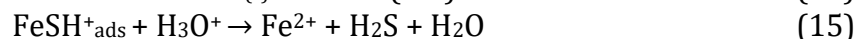
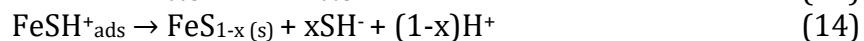
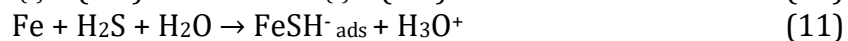
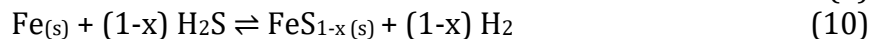
amorphous protection layer (Saji, 2019b). In this study, however, we focused on the crystalline corrosion product. The formation of the two compounds in the corrosion product begins with the oxidation reaction of iron as in reaction (1) (Kim and Kim, 2017; Kahriyan and Srdjan, 2019).



During the formation of magnetite, the reduction reaction (2) occurs, followed by reactions (3) to (8).



Meanwhile, mackinawite (FeS<sub>1-x</sub>) is formed by a reduction reaction (9) (Rachmawati *et al.*, 2011) and followed by reactions (10) to (15) (Wallaert *et al.*, 2018).



The existence of mackinawite and magnetite was confirmed by SEM observations and compared the XRD to the literature, as shown in Figures 7b and 7c.

#### 4. Conclusions

Tobacco extract can reduce the corrosion rate of AISI 1018 steel in a flowing NaCl solution containing H<sub>2</sub>S, with an inhibition efficiency of 24 – 69% for a concentration of 1000 – 2000 ppm. The corrosion mechanism of carbon steel in NaCl solution with and without H<sub>2</sub>S or tobacco extract starts from the oxidation of Fe to Fe<sup>2+</sup> to form an iron oxide compound in the form of magnetite (Fe<sub>3</sub>O<sub>4</sub>). The presence of H<sub>2</sub>S causes the formation of an iron-sulfide compound, namely mackinawite (FeS), as a corrosion product. Future work will be conducted to study the operating temperature's effect on tobacco extract inhibitors' stability and performance.

#### References

- Al-Janabi, Y.T., 2020. An Overview of Corrosion in Oil and Gas Industry. In: *Corrosion Inhibitors in the Oil and Gas Industry*, Saji V.S., Umoren, S.A., (ed.), pp. 1–39
- Bentiss, F., Bouanis, M.M., Marwari, B., Traisnel, M., Lagrenee, M.M., 2002. Effect of Iodide Ions on Corrosion Inhibition of Mild Steel by 3,5-Bis(4-methylthiophenyl)-4H-1,2,4-Triazole in Sulfuric Acid Solution. *Journal of Applied Electrochemistry*, Volume 32, pp. 671–678
- Bhawsar, J., Jain, P.K., Jain, P., 2015. Experimental and Computational Studies of Nicotiana Tabacum Leaves Extract as Green Corrosion Inhibitor for Mild Steel in Acidic Medium. *Alexandria Engineering Journal*, Volume 54, pp. 769–775



- Dwivedi, D., Lepkova, K., Becker, T., 2017. Carbon Steel Corrosion: A Review of Key Surface Properties and Characterization Methods. *RSC Advances*, Volume 7, p. 4580
- Eddy, N.O., Mamza, P.A.P., 2009. Inhibitive and Adsorption Properties of Ethanol Extract of Seeds and Leaves of *Azadirachta Indica* on the Corrosion of Mild Steel in  $H_2SO_4$ . *Portugaliae Electrochim. Acta*, Volume 27, pp. 443–456
- Fouda, A.S., Elewady, G.Y., Shalabi, K., Habouba, S., 2014. Tobacco Plant Extracts as Save Corrosion Inhibitor for Carbon Steel in Hydrochloric Acid Solutions. *International Journal of Advanced Research*, Volume 2, pp. 817–832
- Gandy, D., 2007. *Carbon Steel Handbook*. Electric Power Research Institute, California
- Guo, Y., Gao, M., Wang, H., Liu, Z., 2017. Tobacco Rob Extract as Green Corrosion Inhibitor for N80 Steel in HCl Solution. *International Journal of Electrochemical Science*, Volume 12, pp. 1401–1420
- Kahyarian, A., Srdjan, N., 2019.  $H_2S$  Corrosion of Mild Steel: A Quantitative Analysis of the Mechanism of the Cathodic Reaction. *Electrochimica Acta*, Volume 297, pp. 676–684
- Kim, Y.S., Kim, J.G., 2017. Corrosion Behavior of Pipeline Carbon Steel under Different Iron Oxide Deposits in the District Heating System. *Metals*, Volume 7(5), p. 182
- Kurniawan, B.A., Mitha, V., Fikri, N., 2018. Effect of Fluid Flow, Ph and Tobacco Extracts Concentration as Organic Inhibitors to Corrosion Characteristics of AISI 1045 Steel in 3.5% NaCl Environment Containing  $CO_2$  Gas. *American Institute of Physics*, Volume 1945
- Loto, C.A., Popoola, A.P.I., 2011. Synergistic Effect of Tobacco and Kola Tree Extracts on the Corrosion Inhibition of Mild Steel in Acid Chloride. *International Journal of Electrochemical Science*, Volume 6, pp. 3264–3276
- Majidi, L., Znini, M., Cristofari, G., Ansari, A., Bouyanzer, A., Paolini, J., Costa, J., Hammouti, B., 2012. Green Approach to Corrosion Inhibition of Mild Steel by Essential Oil Leaves of *Asteriscus Graveolens* (Forssk.) in Sulphuric Acid Medium. *International Journal of Electrochemical Science*, Volume 7, pp. 3959–3981
- Nik, W.W., Sulaiman, O., Giap, S.E., Rosliza, R., 2010. Evaluation of Inhibitive Action of Sodium Benzoate on Corrosion Behaviour of AA6063 in Seawater. *International Journal of Technology*, Volume 1(1), pp. 20–28
- Popoola, L.T., 2019. Organic Green Corrosion Inhibitors (OGCIs): A Critical Review. *De Gruyter*, Volume 37(2), pp. 71–102
- Prabhu, R.A., Venkatesha, T.V., Shanbhag, A.V., Kulkarni, G.M., Kalkhamkar, R.G., 2008. Inhibition Effects of Some Schiff's Bases on The Corrosion of Mild Steel in Hydrochloric Acid Solution. *Journal of Corrosion Science*, Volume 50, pp. 3356–3362
- Pradityana, A., Sulistijono, Shahab, A., Noerochim, L., 2017. Sarang Semut (*Myrmecodia Pendans*) Extract as a Green Corrosion Inhibitor for Mild Steel in Acid Solution. *International Journal of Technology*, Volume 1, pp. 48–57
- Rachmawati, I.D., Nurdin, I., Widiatmoko, P., Devianto, H., Irmayanti, F., Saptohadi, S., 2020. The Effect of Flow Rate and NaCl Concentration on the Corrosion Behavior of Carbon Steel in NaCl Solutions Containing  $H_2S$ . *IOP Conference Series.: Material Science and Engineering*, Volume 778, p. 012137
- Ramananda, M., 2013. A Green Approach: Corrosion of Mild Steel by Adhatoda Vasica Plant Extract in 0.5 M  $H_2SO_4$ . *Journal of Materials and Environmental Science*, Volume 4, pp. 119–126
- Rani, B.E., Basu, B.B.J., 2012. Green Inhibitors for Corrosion Protection of Metals and Alloys: An Overview. *International Journal of Corrosion*, Volume 2012, pp. 1–15
- Roberge, P.R., 2008. *Corrosion Engineering: Principles and Practice*. McGraw-Hill, New Jersey

- Saji, V.S., 2019a. Research Advancements in Sulfide Scavengers for Oil and Gas Sectors. *Reviews in Chemical Engineering*, Volume 37(6), pp. 663–686
- Saji, V.S., 2019b. Progress in rust converters. *Progress in Organic Coating*, Volume 127, pp. 88–99
- Shalabi, K., Abdallah, Y.M., Hassan, H.M., Fouda, A.S., 2014. Adsorption and Corrosion Inhibition of Atropa Belladonna Extract on Carbon Steel in 1 M HCl Solution. *International Journal of Electrochemical Science*, Volume 9, pp. 1468–1487
- Shehata, O.S., Korshed, L.A., Attia, A., 2018. Green Corrosion Inhibitors, Past, Present, and Future. *Corrosion Inhibitors, principles and Recent Applications*, Volume 6, pp. 121–142
- Shetty, S.D., Shetty N., 2017. Inhibition of Mild Steel Corrosion in Acid Medium. *International Journal of Technology*, Volume 5, pp. 909–919
- Sosa, E., Cabrera, R., Oropeza, M.T., Hernandez, F., Casillas, N., Tremont, R., Cabrera, C., 2003. Electrochemically Grown Passive Films on Carbon Steel (SAE 1018) in Alkaline Sour Medium. *Electrochim Acta*, Volume 48, p. 1665
- Wallaert, E., Tom, D., Iris, D.G., Verbeken K., 2018. FeS Corrosion Products Formation and Hydrogen Uptake in a Sour Environment for Quenched & Tempered Steel. *Metals*, Volume 8(1), p. 62
- Zúñiga, E.M., Veloz, M.A., Uruchurtu, J., Reyes, V.E., 2011. Corrosion of Carbon Steel in Sour Water from the Oil Industry: The Effect of Temperature. *International Journal of Electrochemical Science*, Volume 6, pp. 5016–5030