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Encapsulation of Acacia Bark Extract (*Acacia mangium*) by Maltodextrin-Carrageenan for Corrosion Inhibition Steel in Sulfuric Acid Medium

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Abstract

Research shows that encapsulation of acacia bark extract with maltodextrin-carrageenan (1:1) effectively inhibits mild steel corrosion in a 0.75 M sulfuric acid solution. To study the inhibition efficiency and adsorption properties using the weight loss method with varying concentrations starting from 0.5 g/L to 2.5 g/L and temperature variations from 303 K to 333 K. The results showed that a higher encapsulation concentration of acacia bark extract caused a lower corrosion rate and higher inhibition efficiency. Adsorption of inhibitors on the mild steel surface follows the Freundlich isotherm. Thermodynamic adsorption parameters show that adsorption occurs spontaneously with increasing temperature. The encapsulation adsorption process of acacia bark extract on the surface of mild steel is exothermic and shows the irregularity of the adsorption process on the steel surface.

Keywords: Encapsulation, Corrosion, Inhibitor, Adsorption Isotherm

1. Introduction

Corrosion is defined as a decrease in metal quality due to electrochemical reactions with the environment. Most metal corrosion occurs in steel materials referring to building construction. Corrosion menaces cause plant shutdowns, waste of valuable resources, reduced efficiency, and costly maintenance. It also jeopardizes safety and inhibits technological [1]

Adding an organic inhibitor is the most practical and economical way to protect and reduce the corrosion rate, even though the environment is aggressive. The most effective organic inhibitors are heteroatom compounds with atoms (such as N, S, P, O), conjugated double bonds well as polar functional groups, able to interact with the metallic surfaces and organic hydrophobic moieties to limit the surface reactions with corrosive media [2] [3].

Organic inhibitors are mostly derived from plant extracts due to plants contain polyphenol macromolecules, which can form complex compounds with metal ions so that they coat the steel surface. The surface layer of steel can inhibit the rate of metal corrosion [4] [5].

Acacia bark extract (*Acacia mangium*) contains secondary metabolites such as polyphenol compounds that can inhibit corrosion rate. However, there are several areas for improvement in viscous extracts, namely impractical storage, difficulty in use, and less stability, so alternative technologies are needed to overcome these problems. One way to protect the activity of the ingredients contained in the viscous extract is through encapsulation technology [6] [7].

Encapsulation is a technology for coating a core substance with a polymer wall layer. This polymer wall layer will protect the core substance from the outside environment. The encapsulated substance is usually called the core material and active substance. A substance used for encapsulating is called a coating material, wrapper, carrier, or wall material. The advantage of encapsulation is that it can protect the core extract ingredients, control the release of the active ingredients of both solid and liquid extracts, is

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easy to use, and has good stability [8]. Encapsulation requires a coating material to protect the active ingredients. The function of the encapsulation material is to cover the core as environmental protection and to increase the stability of the core material. The coating material used must have the ability to mix well with the core material, be inert to the core material, be able to form a layer around the core material, be soluble in a suitable solvent medium, and be stable. The coating ingredients used are maltodextrin and carrageenan. A combination of coating materials in the encapsulation process is used to protect and overcome the weaknesses of the core material, such as sensitivity to temperature, air, and light, which can cause degradation of the active components [9].

Previous research reported that the encapsulation of *Drypetes sepiaria* extract containing Zn^{2+} combined with chitosan as a corrosion inhibitor in 0.5 M HCl media provided significant corrosion resistance with the most excellent inhibition efficiency of 89% with a corrosion rate of 1.50 mpy [10]. Based on previous research, encapsulated extracts can increase corrosion inhibition efficiency, and the protective layers' stability is more stable.

2. Experimental

2.1. Extraction of Acacia Bark (*Acacia mangium*)

The samples were cleaned of adhering dirt and dried in room temperature. The size of the wood and bark was reduced to obtain smaller sawdust. Extraction was carried out by reflux method using 96% ethanol solvent. The liquid extract obtained was collected, then evaporated with a water bath at 50°C until it became a concentrated extract and identified the secondary metabolite compounds in Acacia bark extracts, such as alkaloids, flavonoids, terpenoids, steroids, tannins, quinones, saponins, and phenolics.

2.2. Acacia Bark Extract Encapsulation Formulation

Emulsification was carried out by spontaneous emulsification technique. The emulsion system consisted of an organic phase (extract and ethanol 96%) and an aqueous phase (0.5 mL tween-80 0.1%). The organic phase was prepared by mixing 50 mg of Acacia bark extract with 5 mL of 96% ethanol. The spontaneous emulsification technique adds the aqueous phase into the organic phase dropwise (drop by drop). When dropping the aqueous phase into the organic phase, it was stirred using a magnetic stirrer for 3 minutes. The encapsulation consisted of 50 mL of distilled water mixed with 3 g of maltodextrin-carrageenan mixture (2:1, 1:1, and 1:2) (%w/w) and added to the emulsion that had been made previously, then heated at 85°C and stir until the solution is homogeneous. The beads were printed into 0.2 M 100 mL $CaCl_2$ solution, and the syringe height was maintained at 10 cm above the surface of the $CaCl_2$ solution while stirring. A 0.2 M $CaCl_2$ solution was prepared by dissolving 2.2 g of $CaCl_2$ in 70% ethanol until the volume became 100 mL. The granules formed were left for 1 hour and washed with distilled water. The beads were placed in a porcelain cup and dried in an oven at 50°C until a constant weight was obtained. The dried encapsulation is stored in a desiccator.

2.4 Characteristics of Acacia Bark Extract Encapsulates

2.4.1 Moisture Content

Approximately 1 g of the Acacia bark extract encapsulation samples were weighed into a porcelain crucible previously weighed, tared, and cooled in a desiccator to avoid moisture absorption and errors in the results. The samples remained in an oven for five hours at 105°C, placed in a desiccator, and finally weighed on an analytical scale. Moisture calculations were obtained with the following equation [11]:

$$\textbf{Moisture content (\%)} = \frac{(\mathbf{Mc - Mi}) - \mathbf{Mf}}{(\mathbf{Mc - Mi})} \textbf{ x 100\%} \quad \textbf{(1)}$$

where M_c : mass of the crucible without a sample (g); M_i : mass of the crucible with a sample (g); and M_f : mass of the crucible with a sample, final (g).

2.4.2 Solubility of Acacia Bark Extract Encapsulation in 0.75 M Sulfuric Acid

The solubility of the sample is determined based on the time it takes to dissolve in solution. To determine the encapsulation solubility, 1 g of the encapsulates (a) was dissolved in 50 ml of 0.75 M H_2SO_4 with heating at 60°C. The resulting solution was then filtered using filter paper that had been dried in an oven at 105°C for 30 minutes and weighed at a constant weight (b). After filtering, the filter paper and sample residue were dried again in the oven for 3 hours at 105°C. The filter paper was cooled in a desiccator for 15 minutes and weighed (c). The solubility value can be calculated using the following equation:

$$\textbf{Solubility (\%)} = \textbf{100\% - (} \frac{(\mathbf{c - b})}{\left[\frac{\mathbf{100 - M}}{\mathbf{100}}\right] \mathbf{x\ a}} \textbf{ x 100\%)} \quad \textbf{(2)}$$

where a : sample weight (g); b : filter paper without a sample (g); c : filter paper with a sample (g); M : moisture content.

2.4.3 Stability Test

The stability test on the non-encapsulated and encapsulated extracts was carried out on one of the secondary metabolites in Acacia bark extract. One of the secondary metabolites found in Acacia bark extract was chosen to measure the effect of storage

time between the encapsulated and non-encapsulated extracts, in which the selected secondary metabolites were tannins. Encapsulates and extracts were stored in a dark place and at room temperature for 0, 3, 6, 9, 12, and 15 days. The total tannin content was determined with the Folin Denis method using a UV-visible spectrophotometer with absorbance measured at 750,2 nm. A standard curve was drawn with a tannic acid solution.

2.5 Weight Loss Method

The mild steel was immersed in 0.75 M H_2SO_4 medium and a corrosion inhibitor solution with various concentrations of 0.5, 1, 1.5, 2, and 2.5 g/L. With variations in immersion temperature of 30, 40, 50, and 60°C for 3 hours. The difference from the loss of metal weight can be used to determine the corrosion rate and inhibition efficiency with the following equation [12]:

$$\Delta m = m_1 - m_2 \quad (3)$$

$$Cr = \frac{m_1 - m_2}{A \times t} \quad (4)$$

$$EI = \frac{CR\ uninhibited - CR\ inhibited}{CR\ uninhibited} \times 100\% \quad (5)$$

$$\theta = \frac{CR\ uninhibited - CR\ inhibited}{CR\ uninhibited} \quad (6)$$

Where Δm = difference in weight (mg), m_1 = mass before immersion (mg), m_2 = mass after immersion (mg), Cr = corrosion rate (mg/cm^2.hours), A = surface area (cm^2), t = immersion time (hour), EI = efficiency of inhibitor (%), Cr uninhibited = corrosion rate without inhibitor (mg/cm^2. hours), Cr inhibited = corrosion rate with inhibitor (mg/cm^2. hours).

2.6 Adsorption Isotherm

An explanation of the interaction process between the inhibitor and the steel surface can be studied by adsorption isotherms using the Langmuir, Freundlich, Temkin, and Frumkin equations [13]. The following is the Langmuir, Freundlich, Temkin and Frumkin adsorption isotherm equation.

$$\textbf{Langmuir} : \frac{c}{\theta} = \frac{1}{K_{ads}} + C \quad (7)$$

$$\textbf{Freundlich} : \log \theta = \log K_{ads} + n \log C \quad (8)$$

$$\textbf{Temkin} : \log \frac{\theta}{c} = \log K_{ads} - g\,\theta \quad (9)$$

$$\textbf{Frumkin} : \log \frac{\theta}{1-\theta} C = \log K_{ads} + g\,\theta \quad (10)$$

The value of θ = degree of surface covering, K_{ads} = adsorption process constant, C = inhibitor concentration (g/L); g = molecular interaction parameter

3. Results and Discussion

3.1 Phytochemical Screening

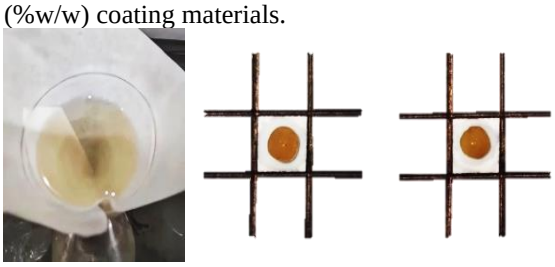
Phytochemical screening was carried out to identify the class of secondary metabolites contained in Acacia bark extracts, such as alkaloids, flavonoids, terpenoids, steroids, tannins, quinones, saponins, and phenolics. Polyphenolic compounds such as flavonoids, tannins, and phenolics can inhibit the oxidation process so that the corrosion rate can decrease.

Table 1: Results of the Phytochemical Screening of Acacia Bark Extract

Secondary Metabolites	Reagent	Result
Alkaloids	Dragendorff	+
Flavonoids	Mg, HCl	+
Terpenoids	HCl, H_2SO_4	+
Steroids	HCl, H_2SO_4	-
Tannin	$FeCl_3$ 1%	+
Phenolic	$FeCl_3$ 1%	+
Quinones	NaOH 1 N	+
Saponins	Aquades	-

3.2 Acacia Bark Extract Encapsulation Formulation

The following is a picture of the results of the encapsulated formulation of Acacia bark extract using maltodextrin and carrageenan (2:1, 1:1, 1:2) (%w/w) coating materials.



(a) (b) (c)

Fig. 1 Encapsulation with coating material (a) maltodextrin-carrageenan (2:1), (b) maltodextrin-carrageenan (1:1), (c) maltodextrin-carrageenan (1:2)

Maltodextrin has a low emulsifying ability, so it is combined with carrageenan to form long-lasting emulsions and improve encapsulation quality. The results of the encapsulation obtained from a variety of coating materials got an unformed (liquid) mixture of maltodextrin-carrageenan (2:1). This is because maltodextrin has a poor emulsification ability, so a combination of other ingredients is needed that can increase the encapsulation emulsification ability, such as carrageenan. Gel strength is the primary physical property because gel strength indicates the power of carrageenan to form gels. Increasing the concentration of carrageenan will accompany an increase in gel strength. Mixed variations of maltodextrin-carrageenan (1:1 and 1:2) form beads

(beads) have a dense texture and bright color. Somehow, in the encapsulation characteristics procedure, only a mixture of maltodextrin-carrageenan (1:1 and 1:2).

3.3 Characteristics of Acacia Bark Extract Encapsulates

3.3.1 The Encapsulated Moisture Content of Acacia Bark Extract

Table 2 shows that the water content of maltodextrin-carrageenan (1:1) is 5%, and maltodextrin-carrageenan (1:2) is 10%. Products with a higher moisture content will be damaged more quickly because it can cause the growth of bacteria and fungi, reducing the product's quality. Found the lowest water content in the encapsulation with a maltodextrin-carrageenan coating ratio (1:1) of 5%.

Table 2: Moisture Content

Coating Comparison (Maltodextrin : Carrageenan) (%w/w)	Moisture Content (%)
1 : 1	5
1 : 2	10

3.3.2 Solubility of Acacia Bark Extract Encapsulation in 0.75 M Sulfuric Acid

Solubility is affected by the low water content due to the powder becoming more hygroscopic and quickly absorbing water, so the solubility of the powder in water is also more excellent. High solubility indicates the rapid and effective release of active ingredients, thereby providing better protection against corrosion of the protected material. The encapsulation found the highest solubility, with a coating ratio of maltodextrin-carrageenan (1:1) of 94.74%. In terms of formula optimization using maltodextrin and carrageenan coating materials at a ratio of 1:1 and 1:2, the most optimal encapsulated formula at a percentage of 1:1 (formula II) was shown by the results of measuring physical parameters on water content and solubility in sulfuric acid 0 .75 M so that for further tests 1:1 (formula II) is used.

Table 3: Encapsulation solubility

Coating Comparison (Maltodextrin : Carrageenan) (%w/w)	Solubility (%)
1 : 1	94.74
1 : 2	88.89

3.3.3 Extract Stability Without Encapsulation and Stability of Encapsulated Extract

The selected secondary metabolites are tannins. Determining the tannin content in the sample was analyzed using UV-Vis spectrophotometry. The results of the stability test on the encapsulated Acacia bark extract and the encapsulated Acacia bark extract can be seen in Figure 2.

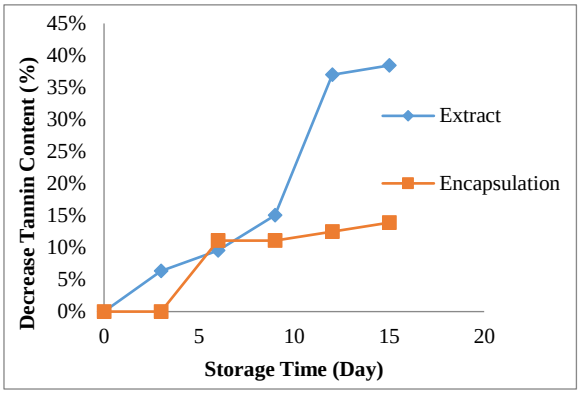


Fig. 2 Graph of the stability comparison of extracts without encapsulation and extracts that have been encapsulated during a storage time of 15 days

Figure 2 shows that the decrease in the levels of tannin compounds in the extract without encapsulation is more significant than that in the encapsulated extract. It shows that encapsulation affects the stability of Acacia bark extract and proves that encapsulation of acacia peel extract can increase strength and protect active components sensitive to damage, with a tendency to control the release of active compounds for optimal effectiveness.

3.4 Effect of Encapsulation Inhibitor Concentration of Acacia Bark Extract and Soaking Temperature on Inhibition Efficiency

Inhibition efficiency is a percentage value that indicates how much the ability of an inhibitor to slow down the corrosion rate. This research was achieved using a 0.75 M concentration of the sulphuric acid medium and varied encapsulation inhibitor concentrations of 0.5, 1, 1.5, 2, and 2.5 g/L. Usually, as the concentration of a corrosive acid media is increased, the corrosion rate is likewise increased due to the amounts of hydrogen ions, which are the active species, being increased as acid concentration is increased [14]

Figure 3 shows that the higher the concentration of inhibitors used, the higher the value of the resulting inhibition efficiency. It is because the more inhibitors added, the more Acacia bark extract encapsulation will absorb on the surface of the steel plate so that the layer formed on the surface of the steel plate can inhibit corrosion on the surface of the steel plate. The presence of secondary metabolites adsorbed on the surface of the steel will form a thin layer. The thin layer protects the steel from the attack

of corrosive ions in an acid solution, reducing the dissolution of iron into the solution so that the corrosion rate decreases and the inhibition efficiency increases [12].

The reaction rate can increase or decrease as the temperature increases or decreases, depending on the inhibitor used. The effect of temperature on corrosion depends on several factors, including the metal used, the inhibitor used, physisorption, chemisorption, decomposition of the inhibitor, rearrangement of the inhibitor, or rapid desorption of the inhibitor on the metal surface [15]. In this study, the highest inhibition efficiency was at a concentration of 2.5 g/L at 333 K, namely 83.497%.
[12].

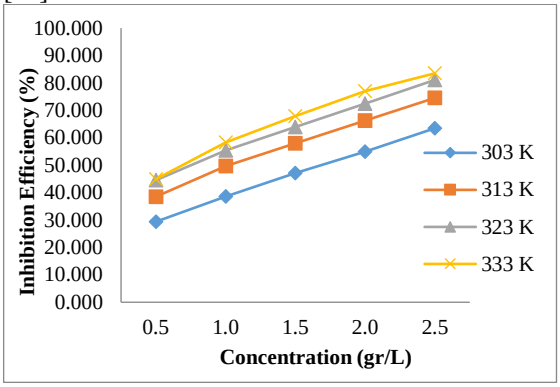


Fig. 3 Effect of encapsulation concentration of Acacia bark extract on inhibition efficiency with temperature variations

The reaction rate can increase or decrease as the temperature increases or decreases, depending on the inhibitor used. The effect of temperature on corrosion depends on several factors, including the metal used, the inhibitor used, physisorption, chemisorption, decomposition of the inhibitor, rearrangement of the inhibitor, or rapid desorption of the inhibitor on the metal surface [15]. In this study, the highest inhibition efficiency was at a concentration of 2.5 g/L at 333 K, namely 83.497%.

3.5 Adsorption Isotherms

Adsorption isotherms provide information about the interaction between the inhibitor and the steel surface. Adsorption of organic inhibitors can provide a protective effect on mild steel because it can form a thin layer that protects the surface of soft steel, thereby inhibiting the corrosion rate on soft steel. To determine the coefficient of determination (R^2) of the Langmuir isotherm, Freundlich isotherm, Frumkim isotherm, and Temkin isotherm, equations 7, 8, 9, and 10 are used.

Table 4: The coefficient of determination (R) and the correlation coefficient (r) obtained from various adsorption isotherms

K	Langmuir		Freundlich	
	R^2	r	R^2	r
303	0.9602	0.9798	0.9912	0.9955
313	0.9784	0.9891	0.995	0.9974
323	0.9787	0.9892	0.997	0.9984
333	0.9904	0.9951	0.9994	0.9996

K	Frumkin		Temkin	
	R^2	r	R^2	R
303	0.9858	0.9928	0.9168	0.9574
313	0.9947	0.9973	0.6904	0.8309
323	0.9965	0.9982	0.9434	0.9712
333	0.999	0.9994	0.9681	0.9839

Based on Table 4, it can be seen that the encapsulation of Acacia bark extract follows the Freundlich adsorption isotherm because the correlation coefficient (r) obtained at each temperature variation is almost close to 1 when compared to the Langmuir, Frumkin, and Temkin adsorption isotherms. The correlation coefficient (r) value, which is close to 1, is a more substantial influence and linkage, and there is a linear relationship between the inhibitor concentration and the degree of surface covering. Freundlich adsorption isotherm explains that a multilayer layer of inhibitor molecules is formed on the metal surface and is heterogeneous; each active group on the metal surface has different adsorption abilities. The bonds that occur in the Freundlich adsorption process are physical (physisorption) [16]

The degree of surface coverage (θ) of various concentrations obtained from weight loss measurements was used to determine the most suitable isotherm to describe the adsorption inhibition process. In this study, a good correlation coefficient was obtained from a straight line between C/θ and C inhibitor obtained using the Freundlich adsorption isotherm with the equation [17]:

$$\text{Log } \theta = \text{Log } C$$

Where Log C refers to the logarithm of inhibitor concentration, while Log θ refers to the logarithm of the steel surface fraction covered by inhibitors.

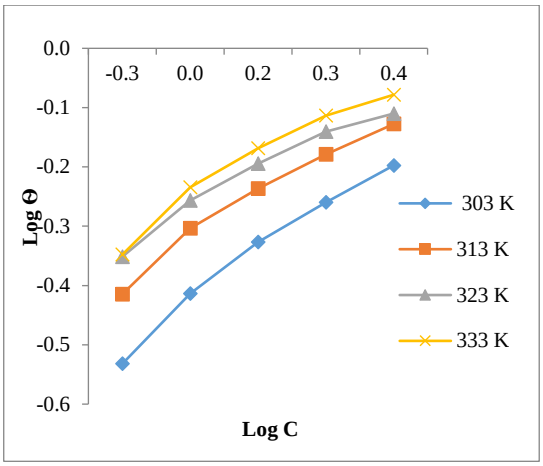


Fig. 4 Freundlich adsorption isotherm for steel corrosion in H_2SO_4 medium with the addition of Acacia bark extract encapsulation with a soaking time of 3 hours.

In Figure 4, Log C increases and Log θ increases, and this indicates more and more inhibitors sticking to the steel surface as the concentration of inhibitors increases. A straight-line equation graph will be obtained from the relationship between Log C and Log θ, which can be used to determine the value of the adsorption constant. The value of K in the adsorption isothermal equation is the adsorption-desorption constant (K_{ads}) obtained from calculating the intercept value on the graph of the adsorption isothermal linear equation:

$$K_{ads} = \frac{1}{1000} \text{Exp} \left(\frac{-\Delta G_{ads}}{RT}\right)$$

The value of 1000 is the water concentration in the solution (g/L). The equilibrium constant associated with the energy of the free standard adsorption (ΔG_{ads}) can be calculated through the equation:

$$\Delta G_{ads} = -RT \ln \left(C_{H_2O} \cdot K_{ads}\right)$$

Where C_{H_2O} is the concentration of water in solution in 1000 g/L^{-1} and R is the gas constant.
From the listed value of K_{ads} and (ΔG_{ads}), standard enthalpy (ΔH_{ads}) and entropy (ΔS_{ads}) of adsorption can be determined using the equation:

$$\ln K_{ads} = \frac{-\Delta H°_{ads}}{RT} + \frac{\Delta S°_{ads}}{R} - \ln C_{H_2O}$$

The value of $\Delta H°_{ads}$ and $\Delta S°_{ads}$ were assessed from the slope and intercept of the plot of $\ln K_{ads}$ versus 1/T [18] [17].

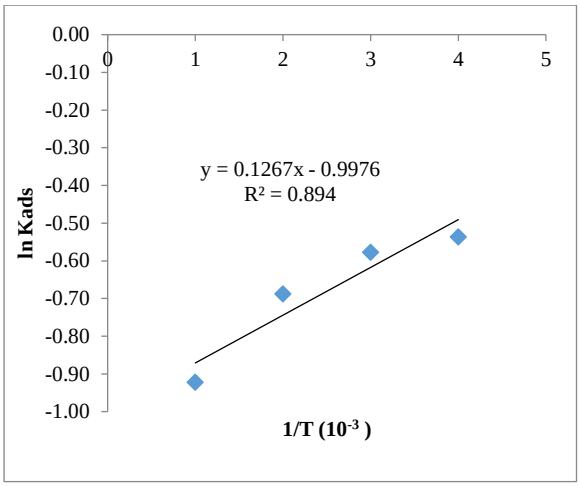


Fig. 5 The Plot between ln K_{ads} and 1/T

Figure 5 shows a graph of the relationship between T and $\Delta G°_{ads}$, the equation used to calculate the values of $\Delta H°_{ads}$ and $\Delta S°_{ads}$. The following are the values for $\Delta G°_{ads}$, $\Delta H°_{ads}$ and $\Delta S°_{ads}$.

Table 5: Thermodynamic Parameters

(K)	K_{ads} (g/L)	ΔG_{ads} (kJ/mol)	ΔH_{ads} (kJ/mol)	ΔS_{ads} (kJ/mol)
303	0,40	-15,08	-0,00105	0,0497
313	0,50	-16,19	-0,00105	0,0517
323	0,56	-17,00	-0,00105	0,0526
333	0,58	-17,64	-0,00105	0,0529

Table 5 shows that the K_{ads} value increases with increasing temperature, which is evidenced by the highest percentage of inhibition efficiency obtained at the highest temperature. An increase in the Kads value indicates the ability of the inhibitor to interact with the steel surface effectively. The higher the K_{ads} value, the more efficient the inhibitor is in forming a protective layer on the steel surface, protecting the steel surface from corrosion that can occur due to a corrosive environment. The value of Gibbs free energy (ΔG_{ads}) is negative; therefore, the inhibitor molecule is adsorbed spontaneously, and the adsorbed layer is stable on the steel surface. At high temperatures, the collision between metal ions and the inhibitor gets more significant, making the inhibitor more easily adsorbed. Values of $\Delta G°_{ads}$ less than -20 kJ/mol are called electrostatic interactions between the inhibitor and the charged steel surface (physisorption), and values greater than -40 kJ/mol or more negatively are also called charge sharing or transfer from the inhibitor to the steel surface and forming coordinate covalent bonds (chemisorption). Based on the results obtained, the value of the Gibbs free energy (ΔG_{ads}) is between -20 kJ/mol, indicating that the type of adsorption that occurs is physisorption [19] [20].

Based on Table 5, it can be seen that the ΔH_{ads} value obtained is -0.00105 kJ/mol. The obtained value indicates that the adsorption process of encapsulation inhibitor molecules of Acacia bark extracts onto the steel surface is exothermic, releasing energy through a physisorption process. Standard adsorption entropy ($\Delta S°_{ads}$) indicates the degree of disorder of an adsorption process. Based on Table 5, it is known that the ΔS°ads value obtained is positive at each temperature variation. The positive $\Delta S°_{ads}$ value is due to the many water molecules desorbed on the steel surface from one inhibitor molecule.

Conversely, a negative $\Delta S°_{ads}$ value indicates an inhibitor accompanied by negligible desorption of water molecules from the steel surface [18]. [20]. So, the data obtained resulted in adsorption that occurred spontaneously and was exothermic, involving the physisorption process and the degree of irregularity in the adsorption process.

3.6 Surface Morphology of the Samples after Corrosion

Characterization using an SEM spectrophotometer was carried out to provide information about the morphology present on the steel surface. Figure 6 shows the structural morphology of the mild steels.

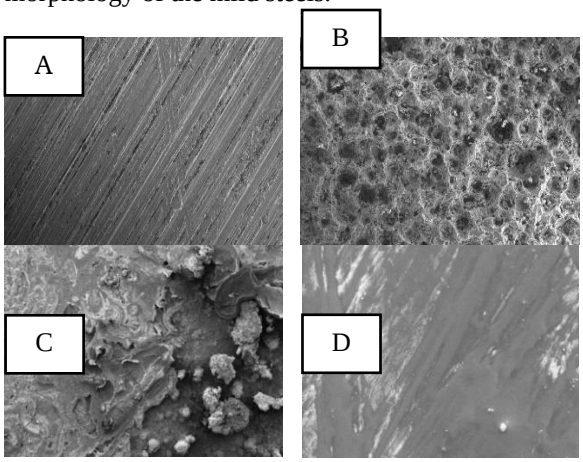


Fig 6. Surface morphology of mild steel a) before treatment, b) in 0.75 M H_2SO_4, c) in 0.75 M H_2SO_4 and 2.5 g/L Acacia bark extract, d) in H_2SO_4 and Acacia bark extract encapsulation 2.5g/L

Figure 6a shows the morphology of the steel surface before treatment, indicating that the mild steel surface before treatment was still smooth, even, and non-porous because there was no interaction with a corrosive environment. Lines are visible due to the smoothing of the steel surface using sandpaper [21]. Figure 6b shows the surface morphology of steel immersed in 0.75 M H2SO4 solution, indicating that the surface is corroded and characterized by a rough, hollow, and uneven texture. It can occur due to the attack of corrosive ions from acid solutions, which cause the steel surface to become corroded.[22]. Figure 6c shows the surface morphology of the steel soaked in Acacia bark extract, showing that the steel surface looks more covered than Figure 6b, although there are lumps and uneven holes. Figure 6 d shows the surface morphology of steel soaked in 0.75 M H_2SO_4 with the addition of Acacia bark extract encapsulation that is evener, smoother, and looks more covered by a protective layer produced by the interaction of inhibitors on the surface of the steel, secondary metabolites present in the encapsulated extract Acacia bark is adsorbed on the steel surface to form a protective layer that can protect the steel surface from corrosive ion attack [23].

3.7 FTIR Analysis Result

Characterization using the FTIR spectrophotometer was carried out to determine the functional groups present in Acacia bark extract, maltodextrin, carrageenan, Acacia bark extract encapsulation, and steel surface product (coating) in 0.75 M sulfuric acid immersion with the addition of Acacia bark extract encapsulation. The infrared wave number used in this study ranges from 4000-650 cm^{-1}. The FTIR characterization results obtained are shown in Figure 7.

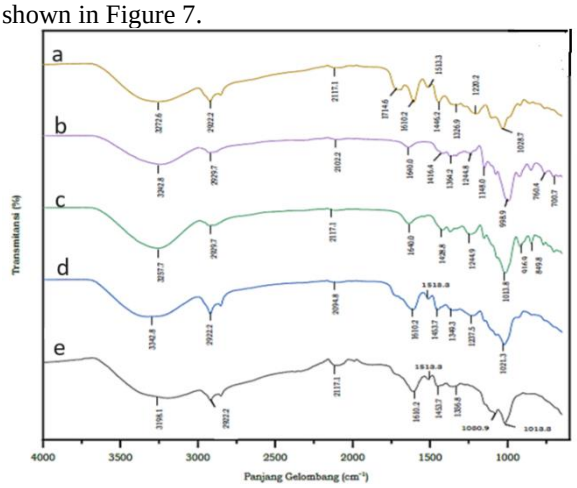


Fig 7. FTIR Spectra a) Acacia bark extract, b) Maltodextrin, c) Carrageenan, d. Acacia bark extract encapsulation, e) Steel surface layer after immersion in sulfuric acid solution-encapsulation of acacia bark extract.

Compounds that can be used as corrosion inhibitors are compounds that have hydroxyl (-OH), carboxyl (—COOH), carbonyl (═CO), —CO—, CH, —C=C—, —C≡C—, — C-Cl, amines (–C≡N) and others that have electron pairs can be adsorbed on the surface of mild steel so that they are effectively used as corrosion inhibitors on steel [24]

The shift in wave numbers in the OH, C-H, C-O, C=C, C≡C functional groups is due to the interaction between these functional groups on the steel surface, where the active group interacts with Fe^{2+} on the steel

surface through coordination bonds, which causes the formation of a protective layer on the steel surface. Steel surface, which can inhibit the rate of corrosion. The reaction of Fe^{2+} with encapsulation inhibitors of Acacia bark extract will produce complex compounds. The encapsulation inhibitor of Acacia bark extract will donate its electron pair to the steel surface when Fe^{2+} ions diffuse into the electrolyte solution.

4. Conclusion

Optimization of the formula using maltodextrin and carrageenan coating materials at a ratio of 1:1 (formula II) is the most optimal encapsulated formula as indicated by the results of physical parameter measurements in percent yield, water content, and solubility in 0.75 M H_2SO_4. The inhibition efficiency value of Acacia bark extract on mild steel in 0.75 M H_2SO_4 medium increased with increasing encapsulation concentration and immersion temperature. The highest encapsulation inhibition efficiency of Acacia bark extract was at a concentration of 2.5 g/L at 333 K, 83.497%.

The interaction of encapsulation of Acacia bark extract on the surface of mild steel follows the Freundlich isotherm with the highest r value of 0.9996 at 333 K. Based on the thermodynamic parameters obtained at 333 K, the value of ΔGads = -17.64 kJ/mol, ΔHads = -0.00105 kJ/mol, ΔSads = 0.0529 kJ/mol.K. Based on thermodynamic parameters, the adsorption process for encapsulation of Acacia bark extract was spontaneous and stable. The adsorption process was exothermic and showed a degree of irregularity in the adsorption process on the steel surface.

SEM analysis of the surface morphology of steel with the addition of Acacia bark extract encapsulation was flatter, smoother, and non-porous. It looked more covered than mild steel soaked in Acacia bark extract inhibitor and 0.75 M H_2SO_4 corrosive medium. FTIR analysis showed a shift in wave indicating an interaction between the encapsulation of Acacia bark extract (*Acacia mangium*), which has the functional groups OH, C-H, C-O, C=C, and C≡C.

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