Jurnal Sains dan Teknologi
Volume 12 Number 1, Tahun 2023, pp. 1-10
P-ISSN: 2303-3142 E-ISSN: 2548-8570
Open Access: https://doi.org/10.23887/jstundiksha.v12i1.51385

Utilization of Chitosan as an Inhibitor to Improve the Corrosion Resistance of Low-Carbon Steel

Mega Gemala[1], Aulia Fajrin[2], Adhe Aryswan[3], Roni Saputra[4*], Ihsan Saputra[5], Sriyanto[6]

[1,2,3,5] Program Studi Teknik Mesin, Politeknik Negeri Batam, Batam, Indonesia
[6] Laboratorium Metalurgi, Politeknik Negeri Batam, Batam, Indonesia
[4] Program Studi Kesehatan Lingkungan, Universitas Ibnu Sina, Batam, Indonesia

ARTICLE INFO

Article history:
Received October 02, 2022
Revised November 29, 2022
Accepted January 14, 2023
Available online April 25, 2023

Kata Kunci:
Korosi, Baja Karbon Rendah, Kitosan

Keywords:
Corrosion, Low Carbon Steel, Chitosan

ABSTRAK

Material industri Batam adalah baja, material paduan antara besi dan karbon, dan beberapa elemen lainnya. Baja karbon rendah adalah salah satu jenis logam. Namun, baja karbon rendah ini memiliki kelemahan ketahanan terhadap korosi, terutama jika diaplikasikan pada lingkungan yang korosif. Dalam pemanfaatan baja karbon rendah di spesimen, korosi dapat menimbulkan masalah dan membutuhkan biaya yang besar dalam pemeliharaannya. Chitosan yang terkandung dalam hewan spesimen diprediksi mampu mencegah korosi sebagai inhibitor. Penelitian ini bertujuan untuk menganalisis kondisi optimal inhibitor kitosan terhadap laju korosi baja karbon rendah pada lingkungan dengan variasi lama perendaman spesimen pada media korosif. Penelitian ini merupakan spesimen true-experimental dengan desain pre-post-test. Penentuan kondisi optimal penghambatan korosi spesimen pelat baja karbon rendah dengan kitosan dilakukan dengan variasi parameter konsentrasi HCl, waktu perendaman spesimen, dan konsentrasi kitosan. Analisis yang dilakukan adalah pengukuran kehilangan berat spesimen pada setiap parameter dengan menentukan selisih berat sebelum dan sesudah percobaan serta menentukan efisiensi inhibitor. Hasil percobaan menunjukkan bahwa kondisi optimal penghambatan korosi adalah pada HCl 1M, kitosan 400ppm, dan waktu perendaman 3 hari dengan efisiensi 48%. Nilai efisiensi penghambatan korosi kitosan yang optimum pada baja karbon rendah ini adalah 48%. Untuk meningkatkan efisiensi penghambatan korosi, perlu dilakukan penelitian lebih lanjut dengan akurasi yang lebih tinggi.

ABSTRACT

The Batam industry materials are steel, an alloy material between iron and carbon, and a few other elements. Low-carbon steel is one type of metal. However, this low-carbon steel has the disadvantage of corrosion resistance, mainly if applied to corrosive environments. In the utilization of Low carbon steel in the industry, corrosion can cause problems and cost a lot of money in its maintenance. Chitosan contained in invertebrate animals is predicted to be able to prevent corrosion as an inhibitor. This study aims to analyze the optimal conditions of chitosan inhibitors against the corrosion rate of low-carbon steel in environments with variations in the length of immersion of specimens in corrosive media. This study is a true-experimental study with a pre-post-test design. The determination of the optimal conditions of corrosion inhibition of low-carbon steel plate specimens by chitosan was carried out with variations in the parameters of HCl concentration, specimen immersion time, and chitosan concentration. The analysis carried out is the measurement of specimen weight loss in each parameter by determining the difference in weight before and after the experiment and determining the efficiency of the inhibitor. The experiment's results showed that the optimal conditions of inhibition of corrosion were at 1M HCl, 400ppm chitosan, and a soaking time of 3 days with an efficiency of 48%. The efficiency value of this optimum corrosion inhibition of chitosan in low-carbon steel is 48%. To improve the efficiency of corrosion inhibition, it is necessary to further research with higher accuracyTo determine the effect of inhibition of corrosion using chitosan on the quality of steel surfaces, it is necessary to analyze the steel surface structure using ultrasonic testing or using XRD Analysis.

1. INTRODUCTION

Riau Islands, especially Batam, is one of the regions bordering neighboring Malaysia, Singapore, and Vietnam. Batam has waters that have become world trade routes. Batam has excellent potential to become a place for industrial development. Some industries that have grown and developed in Batam are the shipbuilding and oil and gas industries (Hendrayady, 2018). The Batam industry materials are steel, an alloy material between iron and carbon, and a few other elements. Low-carbon steel is one type of metal.

*Corresponding author.
E-mail addresses: ronniegodzilla@gmail.com (Roni Saputra)

However, this low-carbon steel has the disadvantage of corrosion resistance, mainly if applied to corrosive environments (Dinov, 2022; Saputra & Oktarizal, 2017). Corrosion is one of the great enemies in the industrial world. Many losses are caused by corrosion, such as a decrease in material strength, resulting in repair costs rising much more significantly than expected (Herdianti et al., 2020; Siregar et al., 2021).

Some methods that can be done to reduce the corrosion rate in essential equipment are cathodic protection (sacrificial anode and impressed current) and the use of inhibitors (Saputra, 2019; Sari et al., 2021). One of the easiest and cheapest ways is to add inhibitors to the substrate. Inhibitors are compounds that, when added with a minor concentration into the electrolyte environment, will lower the corrosion rate (Gemala, 2018; Ilyas, 2019). The mechanism of action of the inhibitor is to form a single molecular layer of the inhibitor adsorbed on the metal surface. The use of inhibitors is the most effective step to protect steel used as a piping material from internal corrosion(Ali et al., 2014; Sari et al., 2021).

Organic matter that can be used as a solution for corrosion inhibitors in low-carbon steels is chitosan which has a molecular formula $[C_6H_{11}NO_4]_n$ (Anam et al., 2019; Pambudi, 2018; Sofika, 2017). Chitosan was isolated from the skeleton of invertebrate animals and some groups of fungi (Bilaut et al., 2019). In addition, chitosan is also found in the shells of shrimp, lobsters, crabs, and marine animals (Sakinah, 2020). The use of chitosan as an inhibitor solution in an acidic environment shows quite effective results in reducing the corrosion rate in low carbon steel materials. The efficiency of corrosion inhibitors using chitosan will be better with the increased concentration of chitosan used to a particular concentration (Hidayatullah et al., 2019).

Previous studies have applied chitosan as a corrosion inhibitor in ordinary steel, where the results of the study state that the busiest chitosan can be used as an inhibitor of the corrosion rate in steel (El-Haddad, 2013; Hasanin & Al Kiey, 2021; M. Ways et al., 2018). But in the study, the optimal conditions of using chitosan as an inhibitor of corrosion in steel have not been studied. In this study, we will also use chitosan as a corrosion inhibitor, but the object to be used is mild steel with low carbon. Where in this study will also be determined the optimal condition of chitosan in the process of inhibition of mild steel corrosion. This study aims to analyze the protection mechanism and influence of chitosan inhibitors on the corrosion rate of low carbon steel in the environment with variations in the length of immersion of specimens in corrosive media in the form of HCl and variations in HCl concentrations. Another benefit is to analyze the efficiency of chitosan inhibitors in the environment with variations in the concentration of acidic solutions.

2. METHOD

This research is an experimental study with a one-group pre-posttest design. The research subjects used were low-carbon mild steel (ASTM G31-72) and chitosan as research objects to be used as inhibitors of steel corrosion. The experimental parameters in this study include variations in HCl concentrations (0.25 M, 0.5M, 1M, 2M, and 4M) as corrosive media, variations in chitosan concentrations (100 ppm, 200 ppm, 300 ppm, 400 ppm, and 500 ppm) as corrosion inhibitors, and the immersion time of specimens in corrosion media with inhibitors compared to without inhibitors (3 days, 5 days, seven days, and nine days).

The data analysis carried out is the determination of inhibitor effectiveness (EI) by weight loss testing or better known as the mass reduction method, is a method carried out to determine the amount of corrosion rate (mpy unit) in a material based on the reduction of the initial mass and the final mass (Sinaga & Manurung, 2020) according to equation (1).

$$EI = \frac{Initial\ Weight - Final\ Weight}{Initial\ Weight}\ x\ 100\% \qquad (1)$$

Several stages are carried out before conducting corrosion inhibition experiments with the above parameters. The first stage is to prepare low-carbon steel specimens. The low carbon steel plate material is cut into 2 cm × 2 cm × 0.2 cm. The specimen size is adjusted to the glass vial used for dyeing. Based on ASTM G31-72, the minimum solution volume to soak a sample is 0.4 times the sample's surface area. Specimens are cut and drilled using laser cutting machines.

The second stage is specimen surface smoothing. After obtaining the appropriate dimensions, sanding is carried out on the entire surface so that the corrosion products in the sample are reduced. Specimen sanding uses grit sandpaper 60 and 600 to speed up the cleaning and smoothing of specimens from impurities and rust. Sanding specimens also uses a polishing machine. The third stage measures the specimen's initial mass using a digital balance sheet as the initial test data.

The next stage is to carry out the Preparation of Inhibitors and Corrosion Media. Chitosan was prepared as an inhibitor with concentrations of 100 ppm, 200 ppm, 300 ppm, 400 ppm, and 500 ppm. The corrosion medium uses a hydrochloric acid (HCl) diluted with aquades to obtain a concentrated solution of 0.25 M; 0.5 M; 1 M; 2 M; and 4 M. Corrosion medium is placed inside the glass vial bottle. Preparation of

inhibitors and HCl corrosion media using a titration method.

Finally, it is continued by conducting experiments and determining weight loss which is carried out in order; determination of the optimum concentration of corrosion media, determination of the optimum immersion time, and the last is the determination of the optimum concentration of chitosan inhibitors at each stage of the experiment followed by weighing the final weight of the specimen. Then EI is determined by equation (1).

3. RESULT AND DISCUSSION

Result

Weight Loss Testing on HCl Concentration Variations

The Weight Loss Test experiment with variations in HCL concentrations (0.25 M, 0.5M, 1 M, 2M, 4 M) was carried out as many as three repetitions (Triplet) at inhibitor concentrations of 0 ppm (Blank) and 100 ppm with a duration of soaking for one day (Table. 1). The inhibitor concentration and soaking duration are made constant to obtain optimal concentration results of HCl as a corrosive medium. The results showed that chitosan inhibitors had the best efficiency at HCl concentrations of 1M with an EI of 22.24%. The corrosion rate calculation based on the reduction in metal mass during weight loss testing is formulated according to the ASTM G1 standard, as seen in Table 2, and Figure 1.

Table 1. Weight Loss Testing Result (Triplets) on HCl Concentration Variations

M HCl*	Initial Weight (g) with Inhibitor (ppm)		Final Weight (g) with Inhibitor (ppm)		Weight Loss (mg) with Inhibitor (ppm)		Corrosion rate (mpy)	
	Blank	100 ppm	Blank	100 ppm	Blank	100 ppm	r1 (Blank)	r2
0.25 (a)	1.6048	1.8424	1.5912	1.8234	13.6	19.0	680.0	950.0
0.25 (b)	1.6608	1.8167	1.6249	1.7926	35.9	24.1	1795.0	1205.0
0.25 (c)	1.3968	1.7111	1.3818	1.6820	15.0	29.1	750.0	1455.0
0.50 (a)	1.6674	1.6247	1.6088	1.5851	58.6	39.6	2930.0	1980.0
0.50 (b)	1.8364	1.6371	1.7733	1.5596	63.1	77.5	3155.0	3875.0
0.50 (c)	1.7133	1.6264	1.6343	1.5720	79.0	54.4	3950.0	2720.0
1.00 (a)	1.5606	1.7771	1.4946	1.7062	66.0	70.9	3300.0	3545.0
1.00 (b)	1.8134	1.7683	1.7113	1.7118	102.1	56.5	5105.0	2825.0
1.00 (c)	1.7869	1.7019	1.6906	1.6237	96.3	78.2	4815.0	3910.0
2.00 (a)	1.8435	1.4829	1.7581	1.4129	85.4	70.0	4270.0	3500.0
2.00 (b)	1.5151	1.5978	1.4304	1.5133	84.7	84.5	4235.0	4225.0
2.00 (c)	1.4348	1.6821	1.3597	1.6084	75.1	73.7	3755.0	3685.0
4.00 (a)	1.6235	1.6681	1.5031	1.5548	120.4	113.3	6020.0	5665.0
4.00 (b)	1.7197	1.6546	1.5962	1.5337	123.5	120.9	6175.0	6045.0
4.00 (c)	1.7130	1.6179	1.5876	1.5338	125.4	84.1	6270.0	4205.0

Note: (a). First try; (b). Second try; (c). Last Try; r1. Corrosion rate at blank; r2. Corrosion rate at 100 ppm

Table 2. Average Corrosion Rate on HCl Concentration Variations

M HCl	Average Corrosion Rate (mpy)		IE (%)
	r1	r2	
0.25	1075000	1203.33	-11.94
0.50	3345000	2858.33	14.55
1.00	4406067	3426.67	22.24
2.00	4086067	3803.33	6.93
4.00	6155000	5305.00	13.81

Note: r1. Corrosion rate at blank; r2. Corrosion rate at 100 ppm

After obtaining the value of the corrosion rate (Table 1), the inhibitor efficiency calculation is carried out using the percentage difference in the corrosion rate before the inhibitor is added with the corrosion rate after the inhibitor is added and then divided by the corrosion rate before the inhibitor is added (Table 2). The quality of the inhibitor can be known from the results of the calculation of the efficiency of the inhibitor, where the more significant the efficiency value, the better the quality of the inhibitor in reducing the corrosion rate.

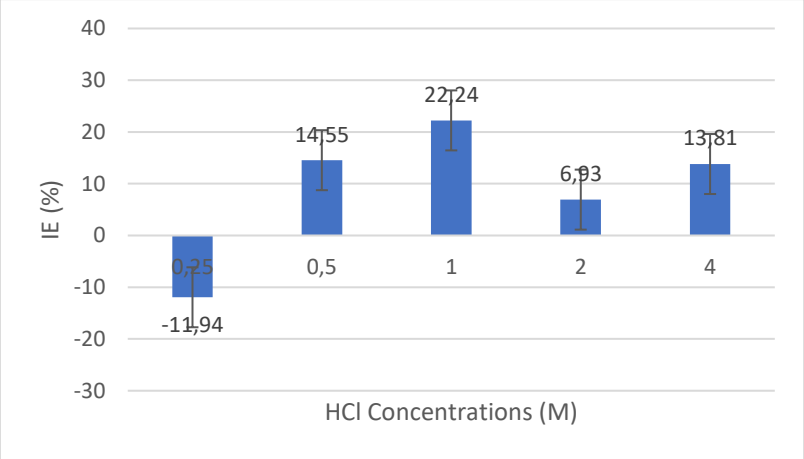

Figure 1. The Efficiency of Inhibitors on HCl Concentration Variations

Figure 1 shows that in the 1M HCl variation, the highest inhibitor efficiency (IE) is 22.24 % with an inhibitor concentration of 100 ppm with immersion for one day. The efficiency value of this best inhibitor will reduce the corrosion rate to be smaller compared to variations in HCl concentrations of 0.25M, 0.5M, 2M, and 4M. At an HCl concentration of 0.25M and an inhibitor concentration of 100 ppm, the inhibitor efficiency is only -11.94%, while at an HCl concentration of 0.5M, the inhibitor efficiency value rises to 14.55%. At the HCl concentration of 2M, the inhibitor's efficiency value dropped to 6.93%, then roincreasedack to 13.81% at the HCl concentration of 4M. Based on the results of the weight loss test, it can be stated that the efficiency of the inhibitor increases along with the increase in the concentration of HCl as a corrosion medium. However, at a concentration of 2M, the efficiency of the inhibitor again decreases. The decrease in efficiency value occurs because the quality of organic chitosan inhibitors tends not to be long, so it is not effective enough to reduce the corrosion rate of low carbon steel in HCl solutions with a concentration of 2M.

Weight Loss Testing on Immersion Time Variations

Weight Loss testing on immersion time variations was carried out at the optimal corrosive media concentration (HCl) obtained in the previous experiment and the concentration of chitosan inhibitors at 0 ppm (Blank) and 100 ppm constantly. The results of weight loss testing for variations in the length of immersion of specimens in HCl solution can be seen in Table 3.

Table 3. Weight Loss Testing Result (Triplets) on Immersion Time Variations

Immersion Time (Days)	Initial Weight (g) with Inhibitor (ppm)		Final Weight (g) with Inhibitor (ppm)		Weight Loss (mg) with Inhibitor (ppm)		Corrosion Rate (mpy)	
	Blank	100 ppm	Blank	100 ppm	Blank	100 ppm	r1 (Blank)	r2
1	1.5606	1.7771	1.4946	1.7062	66.0	70.9	3300.0	3545.0
1	1.8134	1.7683	1.7113	1.7118	102.1	56.5	5105.0	2825.0
1	1.7869	1.7019	1.6906	1.6237	96.3	78.2	4815.0	3910.0
3	1.6387	1.6594	1.3747	1.3794	264.0	280.0	13200.0	14000.0
3	1.8053	1.8046	1.5386	1.5690	266.7	235.6	13335.0	11780.0
3	1.9753	1.7935	1.5425	1.7674	432.8	26.1	21640.0	1305.0
5	1.6977	1.6842	1.4092	1.4178	288.5	266.4	14425.0	13320.0
5	1,7098	1,7570	1,4407	1,4927	269,1	264,3	13455,0	13215,0
5	1,7075	1,7487	1,4333	1,4963	274,2	252,4	13710,0	12620,0
7	1,5737	1,8220	1,2699	1,5349	303,8	287,1	15190,0	14355,0
7	1,5795	1,6570	1,3007	1,4175	278,8	239,5	13940,0	11975,0
7	1,8138	1,8041	1,5918	1,5209	222,0	283,2	11100,0	14160,0
9	1,6294	1,7987	1,3698	1,5351	259,6	263,6	12980,0	13180,0
9	1,7554	1,7481	1,4342	1,4636	321,2	284,5	16060,0	14225,0
9	1,6172	1,7287	1,3685	1,4597	248,7	269,0	12435,0	13450,0

Note: r1. Corrosion rate at blank; r2. Corrosion rate at 100 ppm

Table 4. Average Corrosion Rate on Immersion Time Variations

Immersion Time (Days)	Average Corrosion Rate (mpy)		IE (%)
	r1	r2	
1	4406.67	3426.67	22.24
3	16058.33	9028.33	43.78
5	13863.33	13051.67	5.85
7	13410.00	13496.67	-0.65
9	13825.00	13618.33	1.49

Table 4 shows that at soaking for three days in an HCl 1M solution with an inhibitor concentration of 100 ppm, the inhibitor efficiency value (IE) is optimal at soaking for three days, which is 45%. Soaking on one-day results in an efficiency of 22%, which increases at 3-day soaking. The efficiency of the inhibitor decreased drastically at 5-day soaking, where the IE value was 5%. The IE value further decreases at soaking for seven days by -2%.

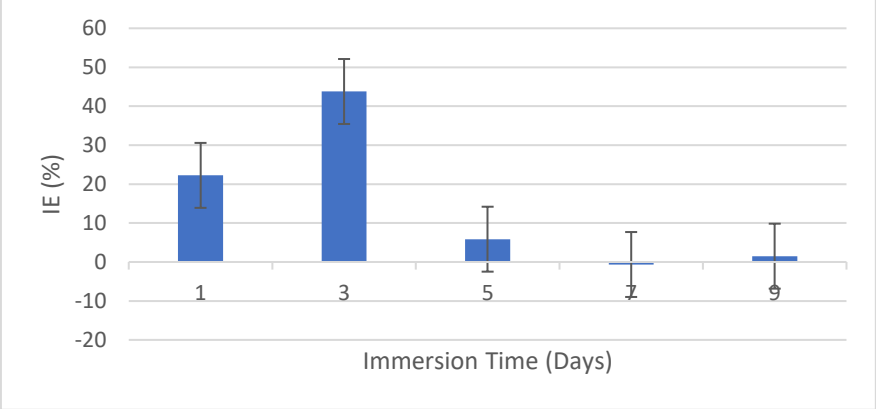

Figure 2. The Efficiency of Inhibitor on Immersion Time Variations

At 9-day soaking, the IE value increases again by 3%. The data from the immersion variation showed that soaking for one day can reduce the corrosion rate of low carbon steel specimens, but not better than the highest efficiency value in soaking for three days, whose value is 45% (Figure 2). Fluctuations in the efficiency value of the inhibitor after three days of soaking occur because the quality and performance of organic chitosan inhibitors tend to decrease with increasing immersion time. Therefore, it takes an optimal soaking time to maximize the inhibitor's performance in reducing the corrosion rate of low carbon steel.

Weight Loss Testing on Inhibitor's Concentration Variations

Weight loss testing on variations of inhibiting concentrations (chitosan concentrations) was carried out at concentrations of 100, 200, 300, 400, and 500 ppm using corrosion media (HCl) with optimal concentrations (1 M) and optimal soaking time (3 days) that had been obtained in previous experiments. Like the previous experiment, the test was performed on a triplet basis (repeated three times) to get a valid mean value from the test. The results of weight loss testing on variations in inhibitor concentrations can be seen in Table 5.

Table 5. Weight Loss Testing Result (Triplets) on The Inhibitor's Concentration Variations

Inhibitor's Concentration (ppm)	Initial Weight (g) (Repeated three times)			Final Weight (g) (Repeated three times)			Weight Loss (mg) (Repeated three times)			Corrosion Rate (mpy) (Repeated three times)		
	1	2	3	1	2	3	1	2	3	1	2	3
0	1.6387	1.8053	1.9753	1.3747	1.5386	1.5425	264.0	266.7	432.8	2640	2667	4328
100	1.6594	1.8046	1.7935	1.3794	1.5690	1.7674	280.0	235.6	26.1	2800	2356	261
200	1.4409	1.7372	1.4612	1.2613	1.5294	1.2559	179.6	207.8	205.3	1796	2078	2053
300	1.5215	1.7124	1.6439	1.3188	1.5255	1.4429	202.7	186.9	201.0	2027	1869	2010
400	1.6956	1.7487	1.2035	1.4945	1.5747	1.0764	201.1	174.0	127.1	2011	1740	1271
500	1.6314	1.6129	1.5942	1.4540	1.4240	1.4093	177.4	188.9	184.9	1774	1889	1849

Table 6. Average Corrosion Rate on The Inhibitor's Concentration Variations

Inhibitor's Concentration (ppm)	Average Corrosion Rate (mpy)	IE (%)
0	3211.70	
100	1805.70	43.78
200	1975.70	38.48
300	1968.70	38.70
400	1674.00	47.88
500	1837.30	42.79

The results in Table 6 showed that in adding chitosan inhibitors with 400 ppm, the highest inhibitor efficiency value (IE) reached 48%. The effects of weight loss with variations in the addition of inhibitors resulted in fluctuating data. At 100 ppm of chitosan inhibitors, IE was 43% and decreased with IE values of 38% at 200 and 300 ppm concentrations. At inhibitor concentrations of 500 ppm, the IE value is 42%, slightly different from IE with inhibitor concentrations of 100 ppm. This shows that the increasing concentration of inhibitors does not result in higher chitosan inhibition in low carbon steels, so an optimal inhibitor concentration value must be added to specimens in corrosion media (Figure 3). Based on weight loss results with variations in inhibitor concentrations, the optimal value of inhibitor efficiency was obtained, namely in the addition of inhibitor concentrations of 400 ppm.

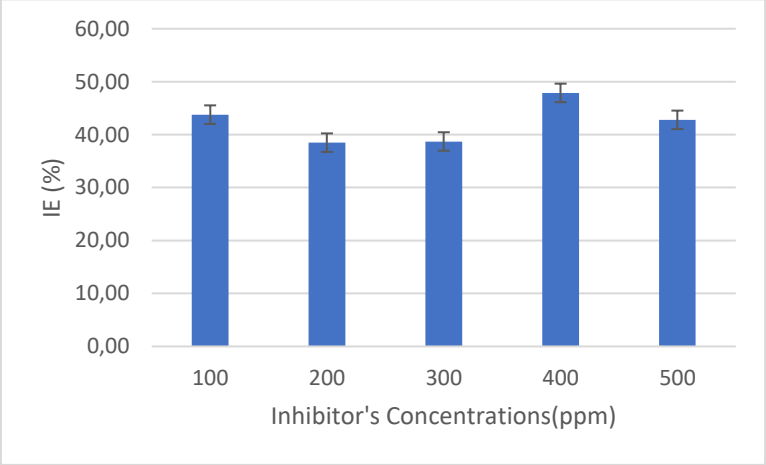

Figure 3. The Efficiency of Inhibitor on Inhibitor's Concentration Variations

Discussion

Figure 1 shows that the greatest inhibition efficiency obtained was at an HCl concentration of 1 M of 22.24%. Meanwhile, efficiency decreases along with the increase in the concentration of HCl media, where the most minor percent efficiency is obtained at the concentration of 2 M HCl media, which is 6.93%. Still, an anomaly occurs at a concentration of 0.25 M where there is a final weight gain, which should be a weight loss. This is because Cl- ions are aggressive ions of the strong acid group capable of damaging the film layer of metal oxides. Iron and its alloys have an oxide layer (FeO) as a corrosion product attached to the metal surface (Megahed et al., 2021; Refait et al., 2020). This passive layer is a protective layer of metal against corrosive environments. A high concentration of Cl- ions will destroy this oxide layer. The greater the concentration of Cl- ions, the more likely they will be adsorbed to the metal surface and destroy the oxide layer (Mobin et al., 2016; Tan et al., 2021). As a result, the direct contact between the metal surface and the HCl environment increases the corrosion rate, which is characterized by a low percent efficiency (Haruna & Saleh, 2021; Odewunmi et al., 2020; Stiadi et al., 2019). Low inhibition efficiency at an HCl concentration of 0.25 M occurs because, at low concentrations, the electrolyte properties of the solution increase, and the electrical conductivity is greater so that the corrosion rate is faster (Cheng et al., 2011; Guo & An, 2005; Venkateswarlu et al., 2013). This causes its inhibition efficiency to decrease (Atkins et al., 2014).

Based on the curve of inhibition efficiency to immersion time (Figure 2), each inhibitor with a different contact time has a different influence on the corrosion inhibition efficiency in soft steels. The efficiency of the largest extract inhibitor was at a contact time of 3 days, which was 45%, then the efficiency began to decrease at a contact time of 5 days, and the smallest at seven days, which was -2%. It is assumed that at a contact time of 3 days, the inhibitor of chitosan has been optimally adsorbed on the steel surface,

while at a contact time of 5 and 7 days, the inhibitor has been saturated so that it is no longer able to inhibit corrosion attacks from the environment (Palumbo et al., 2019; Shamsa et al., 2020). In addition, the organic compounds in the extract are degraded.

The inhibitor efficiency curve at various extract concentrations (Figure 3) shows that the largest percentage of inhibitor efficiency at a contact time of 3 days in an HCl 1 M solution was at an extract concentration of 400 ppm, which was 48%. This is because the extract with a concentration of 400 ppm has been adsorbed on the entire surface so that the steel surface is protected from direct contact with the HCl surface. This means that at the concentration of the extract, inhibition is not optimal because the extract adsorbed to the steel surface is still too little so that the metal surface that has not been protected is still a lot and finally in direct contact with the HCl environment. Then at concentrations of 500 ppm, there is a decrease in inhibition efficiency smaller than that of 400 ppm extract but still more significant than that of 200 ppm extract. This is because the inhibitor of the extract undergoes saturation, so it no longer increases the efficiency of the inhibitor against the corrosion rate in soft steel. The higher the concentration of inhibitors, the greater the efficiency to the optimum concentration, after which the efficiency will drop again (Jalaluddin et al., 2017).

Electrostatic Metal–Inhibitor Interaction

Chitosan contains hydroxyl functional groups (–OH), and carboxyl functional groups (–COOH). It also contains amino acids thus rich in amino (–NH2) and carboxyl groups. In an acid solution, these functional groups are protonated such that the polymer is in equilibrium with its polycation (Bentrah et al., 2014; S A Umoren, 2008; S A Umoren et al., 2006; Saviour A Umoren et al., 2018). Moreover, in an acid solution, chloride ions have a strong tendency to be adsorbed on the positively charged metallic surface (Khaled, 2003). The adsorptions of these anions create an excess of electrons such that the metal surface carries negative charges. The formation of these negative charges facilitates the adsorption of the inhibitor on the metal surface through electrostatic interaction between the Chitosan's molecule and the mild steel surface (Oguzie et al., 2007).

Chemical Adsorption

As mentioned before, a small contribution of the chemical adsorption process is also observed. In a weak acid solution, Chitosan can exist as neutral macromolecules in equilibrium with its polycations. These neutral macromolecules can be adsorbed on the metal surface via the formation of coordinate bonds with the metal surface. In this case, the inhibitor will act as a Lewis base by donating the unshared electrons of the heteroatoms (e.g., oxygen and nitrogen) to vacant d-orbitals of iron atom on steel surface (e.g., Lewis acid). However, it should be noted that this mechanism is more likely to occur in the first hours of the experiment. In fact, as the immersion time increases, the metal surface is progressively covered by a corrosion product layer; therefore, the direct coordination of oxygen to an exposed metal atom decreases (Abdallah, 2004; Messali et al., 2017; Roy et al., 2014). From the results that have been obtained related to the optimal conditions of using chitosan as a corrosion inhibitor of low-carbon steel, it is not yet known exactly how the effect of the corrosion inhibition on the quality of the steel surface. For this reason, it is necessary to carry out further analysis related to the problem using relevant equipment, for example XRD Analysis to determine the surface shape, ultra sonic testing to determine the density of steel and FTIR analysis related to metal chemical bonds formed after treatment.

4. CONCLUSION

Optimum conditions of inhibition of soft steel corrosion in hydrochloric acid by using chitosan as an inhibitor were achieved at an HCl concentration of 1 M, a soaking time of 3 days, and an inhibitor concentration of 400 ppm. The efficiency value of this optimum corrosion inhibition of chitosan in low-carbon steel is 48%. To improve the efficiency of corrosion inhibition, it is necessary to further research with higher accuracyTo determine the effect of inhibition of corrosion using chitosan on the quality of steel surfaces, it is necessary to analyze the steel surface structure using ultrasonic testing or using XRD Analysis.

5. ACKNOWLEDGE

Acknowledgement addressed to the Politeknik Negeri Batam as the main funder of this research that has been listed at contract No. 117/PDI.PL29/III/2022 as Applied Research by P3M Politeknik Negeri Batam. The same remark was given to Roni Saputra from Ibnu Sina University, Batam, who has contributed a lot to the preparation and translation of this article. Finally, thank you to mechanical engineering students who have helped in the data collection and preparation of research samples.

6. REFERENCES

Abdallah, M. (2004). Guar gum as corrosion inhibitor for carbon steel in sulfuric acid solutions. *Portugaliae Electrochimica Acta*, *22*, 161–175. http://www.peacta.org/articles_upload/PEA2222004161.pdf.

Ali, F., Saputri, D., & Nugroho, R. F. (2014). Pengaruh waktu perendaman dan konsentrasi ekstrak daun jambu biji (Psidium guajava, Linn) sebagai inhibitor terhadap laju korosi baja SS 304 dalam larutan garam dan asam. *Jurnal Teknik Kimia*, *20*(1).

Anam, K., Idris, F., & Syakti, A. D. (2019). Analisis Kandungan Logam Berat Pb dan Cd pada Siput Gonggong (Strombus sp) di Perairan Kecamatan Bukit Bestari. *Buana Sains*, *19*(1), 37. https://doi.org/10.33366/bs.v19i1.1525.

Atkins, P., Atkins, P. W., & de Paula, J. (2014). *Atkins' physical chemistry*. Oxford university press.

Bentrah, H., Rahali, Y., & Chala, A. (2014). Gum Arabic as an eco-friendly inhibitor for API 5L X42 pipeline steel in HCl medium. *Corrosion Science*, *82*, 426–431. https://doi.org/10.1016/j.corsci.2013.12.018.

Bilaut, I., Gauru, I., Wogo, H. E., & Lapailaka, T. (2019). Synthesis And Characterization Of Chitosan-Magnesium (Ii) Complex Ions From Shrimp Shells. *Chemistry Notes*, *1*(1), 1–10. https://ejurnal.undana.ac.id/CN/article/view/1574.

Cheng, F., Liang, J., Tao, Z., & Chen, J. (2011). Functional materials for rechargeable batteries. *Advanced Materials*, *23*(15), 1695–1715. https://doi.org/10.1002/adma.201003587.

Dinov, K. C. (2022). *Analisa Pengaruh Variasi Heat Input Dengan Metoda Pengelasan Smaw Pada Material Baja Karbon S355J2N Dengan Pengujian Hardness Test*. Universitas Islam Riau.

El-Haddad, M. N. (2013). Chitosan as a green inhibitor for copper corrosion in acidic medium. *International Journal of Biological Macromolecules*, *55*, 142–149. https://doi.org/10.1016/j.ijbiomac.2012.12.044.

Gemala, M. (2018). Degradasi Senyawa Carbaryl Dalam Pestisida Sevin 85 S Secara Sonolisis, Ozonolisis Dan Sonozolisis. *SCIENTIA: Jurnal Farmasi Dan Kesehatan*, *8*(2), 130–136.

Guo, H. F., & An, M. Z. (2005). Growth of ceramic coatings on AZ91D magnesium alloys by micro-arc oxidation in aluminate–fluoride solutions and evaluation of corrosion resistance. *Applied Surface Science*, *246*(1–3), 229–238. https://doi.org/10.1016/j.apsusc.2004.11.031.

Haruna, K., & Saleh, T. A. (2021). N, N′-Bis-(2-aminoethyl) piperazine functionalized graphene oxide (NAEP-GO) as an effective green corrosion inhibitor for simulated acidizing environment. *Journal of Environmental Chemical Engineering*, *9*(1), 104967. https://doi.org/10.1016/j.jece.2020.104967.

Hasanin, M., & Al Kiey, S. A. (2021). Development of ecofriendly high performance anti-corrosive chitosan nanocomposite material for mild steel corrosion in acid medium. *Biomass Conversion and Biorefinery*, 1–14. https://doi.org/10.1007/s13399-021-02059-8.

Hendrayady, A. (2018). Strategi Pembangunan Wilayah Perbatasan Provinsi Kepulauan Riau. *Jurnal Ilmu Administrasi Negara (JUAN)*, *6*(1), 1–10. http://ojs.umrah.ac.id/index.php/juan/article/view/777.

Herdianti, H., Sari, N., Saputra, R., & Hariansyah, F. D. (2020). Kalsium Hipoklorit (CaClO2) sebagai Pengganti Larvasida Aedes Aegypti. *Jurnal Kesehatan*, *11*(3), 422–428. https://ojs.umrah.ac.id/index.php/juan/article/view/777.

Hidayatullah, S., Gapsari, F., & Setyarini, P. H. (2019). Perilaku Korosi Besi ASTM A36 pada Asam Klorida (HCl) dengan Inhibitor Kitosan Sisik Ikan. *Prosiding SENIATI*, 336–342. https://ejournal.itn.ac.id/index.php/seniati/article/view/460.

Jalaluddin, J., Ishak, I., & Rosmayuni, R. (2017). Efektifitas inhibitor ekstrak tanin kulit kayu akasia (Acacia Mangium) terhadap laju korosi baja lunak (ST. 37) dalam media asam klorida. *Jurnal Teknologi Kimia Unimal*, *4*(1), 89–99. https://ojs.unimal.ac.id/jtk/article/view/66.

Khaled, K. F. (2003). The inhibition of benzimidazole derivatives on corrosion of iron in 1 M HCl solutions. *Electrochimica Acta*, *48*(17), 2493–2503. https://doi.org/10.1016/S0013-4686(03)00291-3.

M. Ways, T. M., Lau, W. M., & Khutoryanskiy, V. V. (2018). Chitosan and its derivatives for application in mucoadhesive drug delivery systems. *Polymers*, *10*(3), 267. https://doi.org/10.3390/polym10030267.

Megahed, M. M., Abdel Bar, M. M., & El-Shamy, A. M. (2021). Polyamide coating as a potential protective layer against corrosion of iron artifacts. *Egyptian Journal of Chemistry*, *64*(10), 3–4. https://journals.ekb.eg/article_174924.html.

Messali, M., Lgaz, H., Dassanayake, R., Salghi, R., Jodeh, S., Abidi, N., & Hamed, O. (2017). Guar gum as efficient non-toxic inhibitor of carbon steel corrosion in phosphoric acid medium: Electrochemical, surface, DFT and MD simulations studies. *Journal of Molecular Structure*, *1145*, 43–54. https://doi.org/10.1016/j.molstruc.2017.05.081.

Mobin, M., Zehra, S., & Parveen, M. (2016). L-Cysteine as corrosion inhibitor for mild steel in 1 M HCl and synergistic effect of anionic, cationic and non-ionic surfactants. *Journal of Molecular Liquids*, *216*, 598–607.

Odewunmi, N. A., Jafar Mazumder, M. A., Ali, S. A., Aljeaban, N. A., Alharbi, B. G., Al-Saadi, A. A., & Obot, I. B. (2020). Impact of degree of hydrophilicity of pyridinium bromide derivatives on HCl pickling of X-60 mild steel: Experimental and theoretical evaluations. *Coatings*, *10*(2), 185. https://doi.org/10.1016/j.molliq.2016.01.087.

Oguzie, E. E., Li, Y., & Wang, F. H. (2007). Effect of 2-amino-3-mercaptopropanoic acid (cysteine) on the corrosion behaviour of low carbon steel in sulphuric acid. *Electrochimica Acta*, *53*(2), 909–914. https://doi.org/10.1016/j.electacta.2007.07.076.

Palumbo, G., Górny, M., & Banaś, J. (2019). Corrosion inhibition of pipeline carbon steel (N80) in CO2-saturated chloride (0.5 M of KCl) solution using gum arabic as a possible environmentally friendly corrosion inhibitor for shale gas industry. *Journal of Materials Engineering and Performance*, *28*(10), 6458–6470. https://doi.org/10.1007/s11665-019-04379-3.

Pambudi, G. B. R. (2018). *Sintesis Kitosan Larut Air Dari Limbah Cangkang Kepiting*. Institut Teknologi Sepuluh Nopember.

Refait, P., Grolleau, A.-M., Jeannin, M., Rémazeilles, C., & Sabot, R. (2020). Corrosion of carbon steel in marine environments: role of the corrosion product layer. *Corrosion and Materials Degradation*, *1*(1), 10. https://doi.org/10.3390/cmd1010010.

Roy, P., Karfa, P., Adhikari, U., & Sukul, D. (2014). Corrosion inhibition of mild steel in acidic medium by polyacrylamide grafted Guar gum with various grafting percentage: Effect of intramolecular synergism. *Corrosion Science*, *88*, 246–253. https://doi.org/10.1016/j.corsci.2014.07.039.

Sakinah, F. (2020). Peningkatan Kualitas Biopolimer (Pla) Nanokomposit Modifikasi Filler Bentonit Dan Kitosan Anti-Bakteri. *Jurnal Sains Dan Teknologi Reaksi*, *18*(01). http://e-jurnal.pnl.ac.id/JSTR/article/view/2235.

Saputra, R. (2019). Pemanfaatan Kulit Pisang Dalam Degradasi Zat Aktif Piridaben Pada Pestisida Samite 135EC. *Jurnal Ipteks Terapan*, *13*(1), 1–11. http://ejournal.lldikti10.id/index.php/jit/article/view/3439-14818.

Saputra, R., & Oktarizal, H. (2017). Pemanfataan Serbuk Sekam Padi Sebagai Adsorben Untuk Menurunkan Konsentrasi Senyawa Piridaben Pada Pestisida Samite 135EC. *Chempublish Journal*, *2*(2), 42–53. https://doi.org/10.22437/chp.v2i2.4475.

Sari, N. H., Suteja, S. T., & Syarif Hidayatullah, S. T. (2021). *Pengantar Inhibitor Korosi Alami*. Deepublish.

Shamsa, A., Barker, R., Hua, Y., Barmatov, E., Hughes, T. L., & Neville, A. (2020). Performance evaluation of an imidazoline corrosion inhibitor in a CO2-saturated environment with emphasis on localised corrosion. *Corrosion Science*, *176*, 108916. https://doi.org/10.1016/j.corsci.2020.108916.

Sinaga, A. J., & Manurung, C. (2020). Analisa Laju Korosi dan Kekerasan Pada Stainless Steel 316 L Dalam Larutan 10% NaCl Dengan Variasi Waktu Perendaman. *Sprocket Journal of Mechanical Engineering*, *1*(2), 92–99. https://doi.org/10.36655/sprocket.v1i2.186.

Siregar, T., Sitorus, E., Priastomo, Y., Bachtiar, E., Siagian, P., Mohamad, E., Gurning, K., Hasibuan, F. A., Destiarti, L., & Marzuki, I. (2021). *Korosi dan Pencegahannya*. Yayasan Kita Menulis.

Sofika, S. (2017). *Aktivitas Anti Jamur Dari Edible Coating Kitosan-Minyak Temu Mangga (Curcuma mangga valeton & zijp) Terhadap Buah Stroberi (Fragaria vasca L.)*.

Stiadi, Y., Arief, S., Aziz, H., Efdi, M., & Emriadi, E. (2019). Inhibisi Korosi Baja Ringan Menggunakan Bahan Alami Dalam Medium Asam Klorida. *Jurnal Riset Kimia*, *10*(1), 51–65. https://doi.org/10.25077/jrk.v12i2.321.

Tan, B., He, J., Zhang, S., Xu, C., Chen, S., Liu, H., & Li, W. (2021). Insight into anti-corrosion nature of Betel leaves water extracts as the novel and eco-friendly inhibitors. *Journal of Colloid and Interface Science*, *585*, 287–301. https://doi.org/10.1016/j.jcis.2020.11.059.

Umoren, S A. (2008). Inhibition of aluminium and mild steel corrosion in acidic medium using Gum Arabic. *Cellulose*, *15*(5), 751–761. https://doi.org/10.1007/s10570-008-9226-4.

Umoren, S A, Obot, I. B., Ebenso, E. E., Okafor, P. C., Ogbobe, O., & Oguzie, E. E. (2006). Gum arabic as a potential corrosion inhibitor for aluminium in alkaline medium and its adsorption characteristics. *Anti-Corrosion Methods and Materials,* 53 (5), 277-282. https://doi.org/10.1108/00035590610692554.

Umoren, Saviour A, AlAhmary, A. A., Gasem, Z. M., & Solomon, M. M. (2018). Evaluation of chitosan and carboxymethyl cellulose as ecofriendly corrosion inhibitors for steel. *International Journal of Biological Macromolecules*, *117*, 1017–1028. https://doi.org/10.1016/j.ijbiomac.2018.06.014.

Venkateswarlu, K., Rameshbabu, N., Sreekanth, D., Sandhyarani, M., Bose, A. C., Muthupandi, V., & Subramanian, S. (2013). Role of electrolyte chemistry on electronic and in vitro electrochemical

properties of micro-arc oxidized titania films on Cp Ti. *Electrochimica Acta*, *105*, 468–480. https://doi.org/10.1016/j.electacta.2013.05.032.

Wildan Ilyas, M. (2019). *Perancangan Sistem Impressed Current Cathodic Protection (Iccp) Anoda Korban Pada Pipa Baja Dengan Prototype Berbasis Arduino Uno (Studi Kasus: Pt. Pln (Persero) Pembangkitan Tanjung Jati B Unit 3&4)*. Vokasi undip.