Piper Nigrum (Green Corrosion Inhibitor) as a Modified Quenchant in Heat Treatment of Ductile Iron

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Abstract. Corrosion of ductile iron leads to many consequences in all its application aspects, like a structural failure due to the porosity formation, which is consequenced by corrosive chemical exposure. Hence, this project was carried out to modify the water quenchant using Piper Nigrum (black pepper) essence, as a green corrosion inhibitor, in promoting corrosion resistance towards austenitized ductile iron in hydrochloric acid (HCl). Furthermore, its effects on the hardness and microstructure of austenitized ductile iron were also investigated. The modified quenchant employed in the austenitizing process was modified by diluting Piper Nigrum extract to several concentrations. The corrosion resistance performance of ductile iron quenched by this modified quenchant was tested using the gravimetric method. The samples were exposed to 1 molar (M) of HCl for 2 hours in the method. This study's novelty has proved that the Piper Nigrum extract was successfully used as an alternative quenchant to reduce ductile iron's corrosion rate in HCl and its corrosion resistance performance was equipotential to other synthetic inhibitors practiced conventionally. This approach could replace the use of synthetic inhibitor, which is harmful and costly. The gravimetric test showed that the corrosion rate of austenitized ductile iron decreased to 51.2685 mm/year and inhibition efficiency increased to 72.17% as the extract's concentration of quenchant increased to 15%. This extract's presence as a quenchant in the heat treatment process neither improved nor exacerbated the samples' mechanical properties, and it has not changed the behavior of microstructure transformation.

1. Introduction
In industry nowadays, Ductile Iron (DI) is preferable material and extensively utilized as the pipeline material for the water and chemical transportation system, sewer lines, and automotive components due to its versatile properties. Even though the material has excellent mechanical properties, it is not exempted withstanding the corrosion problem, especially this material widely used in transporting and dealing with corrosive chemicals [1]. The acidic and basic mediums lead to a different mechanism of
corrosion [2][3][4][5]. Other than that, HCl is most commonly used in industry as an acid cleaner and pickling acid [6][7]. Thus, corrosion has weakened the DI by porosity formation on the material’s surface, which resulted from corrosive chemical exposure stemming from this highly corrosive media.

Corrosion is a crucial worldwide problem commonly encountered by many industries and strongly affects the industrial environment. Corrosion is the corroding of material through reduction, oxidation, or other chemical reactions occurred on a material’s surface. Expensive preservation and upgrades, plant shutdowns, productivity loss, and vital energy waste are among corrosion consequences [8]. It commonly occurs when reduction and oxidation have taken place on the surface of the material. DI also showed the same problem in its application [9]. Therefore, surface treatment is an alternative to enhance the material’s surface, inhibit corrosion, and improve material performance [9][10][11].

A heat treatment approach is a versatile tool in improving the mechanical and surface properties of a metal. Heat treatment parameters like operating temperature and period, cooling rate and the type of quenchant, and the atmospheric environment influence the microstructure nucleation and mechanical properties of DI [12][13]. Thus, this approach can be implied to treat DI’s surface, then inhibit oxidation and reduction that caused corrosion.

There have been numerous studies conducted and reported to diminish metal corrosion attacks. Corrosion rate reduction can be made in many practical ways. The corrosion inhibitor application has driven detailed attention and is among the most economical, popular, and acceptable practices against corrosion [8]. However, most corrosion inhibitors are industrial compounds that are costly and environmentally harmful [14][15]. This phenom happens because the organic inhibitor contains heteroatoms (S, N, O) and aromatic rings in their structures, allowing them to be adsorbed on the metal surface [16]. Consequently, natural sources as green corrosion inhibitors for metal corrosion have nowadays taken part in recent research because it is free from toxic contaminants and cost-effective and environmentally safe [8][14][17][18][19]. It is a synergistic action in a plant extract of individual elements [20]. Besides specific corrosion processes, natural products derived from plant sources and certain non-toxic organic compounds containing polar functions containing nitrogen, oxygen, and sulfur atoms in their molecules have been used successfully as inhibitors [21][22]. Since the advantageous outcome given by plant source in inhibiting the corrosion, many researchers extracted the essence from the plant like Musa Sapientum (Banana) [8][21][23], watermelon [24][25][26], Piper Nigrum (Black Pepper) [1][27][28] and Cinnamomum Zeylanicum (Ceylon cinnamon) [29], to be applied as green corrosion inhibitor for metal.

Due to the growing need to invent the new low environmental impact practice incorporated with non-toxic and effective inhibitors in protecting metal from corrosion, this present study was thus conducted to explore the potential of Piper Nigrum extract (green corrosion inhibitor) as a quenchant in heat treatment (Austenitizing) process for DI in promoting corrosion resistance towards HCl. Furthermore, its effect on the hardness and microstructure of DI also were evaluated. The Piper Nigrum was chosen in this research because this naturally occurring plant product is easy to get, less toxic, eco-friendly, and biodegradable, promising the tremendous effect in inhibiting corrosion [22][30]. A hybrid process approach was invented to achieve the most desirable result where the Piper Nigrum extract was applied as modified quenchant in the DI’s heat-treatment process. The advantages of mechanical and inhibition properties drawn by the heat treatment process and green inhibitor respectively were envisaged could be combined, thus giving benefits to the material.

2. Research Method

2.1. DI Sample and Specimen Preparations

The DI sample was cast using the standard CO2 sand casting method, and Ferrosilicon Magnesium was added to the molten metal as a graphite nucleating agent. The produced samples were in the form of a double cylindrical shape with 300 mm long and 25±2 mm diameter. The chemical composition of the material, as shown in table 1, was obtained through the spectrometer test.
The specimens dimension of the gravimetric test were prepared in 30 mm diameter and 1 mm thickness. These specimens were ground using metallography silicon carbide sandpaper with 180, 240, 320, 600, and 800 grades subsequently before performing the test.

Table 1. The chemical compositions (wt.%) of DI

| Element | C    | Si   | Mn   | P    | S    | FE   |
|---------|------|------|------|------|------|------|
| wt. %   | 3.49 | 2.62 | 0.55 | 0.069| 0.0074| Balance |

2.2. *Piper Nigrum* Extraction

The raw *Piper Nigrum* was washed and rinsed with distilled water and dried for 24 hours at room temperature. Then they were ground into a fine powder form before extracted with 2-propanol by using the refluxing method for 2 hours at 85 °C. The resulted solution was filtered to separate the residual. The evaporation process was employed to remove the alcohol in the solution producing the final *Piper Nigrum* extract. The extract was stored in the chiller at 3°C to avoid contamination.

2.3. Quenchant Preparation & Heat Treatment Process

The *Piper Nigrum* extract was diluted by distilled water to produce green corrosion inhibitor modified quenchant with the initial variation concentration of 5, 10, and 15%. These quenchants were employed in a heat treatment process of DI.

In the heat treatment process, the DI specimen were austenitized at 850 °C for an hour in a Carbolite furnace. The DI specimens were then rapidly cooled by quenching in conventional water quenchants, and modified quenchants composed different initial concentrations of *Piper Nigrum* extract to room temperature. The schematic diagram of the heat treatment process is shown in figure 1.

![Figure 1: Schematic representation of heat treatment process](image)

2.4. Fourier Transform Infrared Spectroscopy (FTIR) Analysis

Fourier Transform Infrared Spectroscopy (FTIR) analysis was used to characterize the chemical bond and functional group in the *Piper Nigrum* extract. The equipment used for FTIR was VERTEX Series FTIR Spectrometer. For the measurement, Infrared (IR) absorbance spectra were taken between 500 and 4000 cm\(^{-1}\) at a resolution of 4 cm\(^{-1}\).

2.5. Gravimetric Test

The Gravimetric test was performed to analyze the corrosion behavior of the sample in acidic media. 1M HCl solution as corrosive media was prepared in the volumetric flask. The as-austenitized samples
were wholly immersed in 100 ml of corrosive media and gently shaken in an incubator for 2 hours at a temperature of 30ºC. The samples' mass was then measured before and after immersing in the corrosive media using an electronic scale. The density of this material was measured, and it was 7.0887 g/cm³. The corrosion rate (CR) and inhibition efficiency (IE) were calculated by using formulae (1) and (2), respectively, according to the standard of the American Society for Testing Material G1-03.

\[
\text{Corrosion Rate (mm/yr), } CR = \frac{87600W}{PA\ell}
\]

(1)

where \( W \) is the weight loss (g), \( \rho \) is the density (g/cm³), \( A \) is the exposed area of the specimen (cm²), and \( t \) is the immersion time (h).

\[
\text{Inhibition Efficiency (\%) = } IE = \left( \frac{W_0 - W_i}{W_0} \right) \times 100\%
\]

(2)

where \( W_o \) is the weight loss (g) in blank etchant \( W_i \) is the weight loss (g) in etchant composed of \textit{Piper Nigrum} extract.

2.6. Hardness test
Vickers hardness test was performed in this study to evaluate the effect of quenchant composed \textit{Piper Nigrum} extract on the surface properties of the sample. The test was performed using a Vickers hardness tester, where the penetration load was 1000 g.

2.7. Microstructure observation
The microstructures of the samples were observed using a series of standard microstructure observation methods. Huvitz HRM-300 microscope and CapturePro software were employed to characterize the samples' surface morphology after quenching with conventional and modified quenchants. Specimens were etched by 2% Nital etchant reagent before observing under the microscope.

3. Results and Discussion

3.1. Characteristic of \textit{Piper Nigrum} Extract
The FTIR spectra of \textit{Piper Nigrum} extract are presented in figure 2. It clearly shows the alcohol group's broad characteristic band at 3369.41 cm⁻¹ is suggested to O-H stretching or N-H stretching. The same absorption peaks were also reported by Qiang et al.[19]. The vital characteristic bands found at 1274.88 cm⁻¹, 1193.82 cm⁻¹, and 1151.43 cm⁻¹ are associated with Benzoates, Ethanoates, and Propanoates groups, respectively, which is due to C-O stretching vibration. Moreover, the characteristic bands located at 1017.55 cm⁻¹ correspond to the C-F halogen group's framework vibration. This analysis proved alcohols, alkaloids, and free compounds (N, O, and F) in \textit{Piper Nigrum} extract. These compounds attribute an inhibitory effect towards corrosion [18]. Furthermore, the carbon-oxygen double bond and carbon-fluoride single bond functional groups attribute the corrosion inhibition efficiency of \textit{Piper Nigrum} extract. All of the functional groups are regarded as excellent cores in corrosion inhibitors.

The presence of heteroatoms, primarily oxygen and nitrogen atoms in these functional groups, gave more evidence on the inhibitory effect of \textit{Piper Nigrum}. Rahuma et al. [28] supported this result, which they used \textit{Piper Longum} (long pepper) fruit as a green inhibitor. The presence of those atoms met the general consideration of usual corrosion inhibitors [19].
3.2. Effect of Piper Nigrum Concentration on Corrosion Behavior

Table 2 displays the variation in the inhibition efficiency and corrosion rate of the as-austenitized DI sample quenched in quenchant at different Piper Nigrum extract concentrations. As-austenitized DI quenched by conventional water quenchant showed a corrosion rate around 189.6962 mm/year. The corrosion rate decreased to 122.0789 mm/year, which showed a 36% reduction when the sample was quenched with a quenchant composed of 5% concentrated Piper Nigrum extract. This phenomenon indicated that the Piper Nigrum extract composed in the quenchant effectively reduced the corrosion rate of as-austenitized ductile iron. The corrosion rate decrement increased around 65%, as the concentration of Piper Nigrum in quenchant was increased to 10%, and the recorded corrosion rate was 66.6087 mm/year. The inhibitor efficiency increased to 72.17%, and the corrosion rate of the sample had decreased to 51.2685 mm/year as the Piper Nigrum extract concentration increased to 15%.

| Sample | Concentration of extraction (%) | Inhibition Efficiency (%) | Corrosion Rate (mm/year) |
|--------|---------------------------------|---------------------------|--------------------------|
| 1      | 0                               | 0                         | 189.6962                 |
| 2      | 5                               | 33.04                     | 122.0789                 |
| 3      | 10                              | 65.22                     | 66.6087                  |
| 4      | 15                              | 72.17                     | 51.2685                  |

Figure 3 depicts the impact of Piper Nigrum extract concentration in quenchant on the as-austenitized DI's corrosion rate. The corrosion process occurred rapidly in the conventional quenchant. It is clearly shown that the corrosion rate steadily decreased with increasing the concentration of Piper Nigrum extract to 5% and significantly decreased as the concentration increased to 10%. This concentration can be considered the equilibrium concentration of the modified quenchant since there was no significant corrosion rate decrease as the concentration increased to 15%. The active compounds in Piper Nigrum extract reacted with DI's surface during quenching to form a layer that avoided corrosion. The compounds contribute to the phenomenon, including piperine, piperidine, piperittine, and thiamine.
These compounds were adsorbed on the sample surface by displacing water or solvent molecules and form a compact barrier film and hence combating metal dissolution to a considerable extent.

Figure 4 depicts the variation of inhibition efficiency with the concentrations of *Piper Nigrum* extract in quenchant. Contrary to the corrosion rate, increasing the concentration of *Piper Nigrum* extract in quenchant resulted in increasing inhibition efficiency. Both trends suggested that the high concentration of *Piper Nigrum* extract was superior to supplement water quenchant. This pattern was most definitely due to the number of potential reaction sites on the sample surface, limited and protected by complex chemical composition extracts. A similar trend was also reported by Arthur and Abechi [14], where the inhibition efficiency of mild steel in HCl increased as the concentration of plant extract increased.

**Figure 3.** Effect of the *Piper Nigrum* extract concentration in quenchant to the as-austenitized DI's corrosion rate.

**Figure 4.** Effect of the *Piper Nigrum* extract concentration in quenchant to the inhibition efficiency

3.3. Ductile Iron Morphology and Characteristics

Microstructure observation was done purposely to evaluate the effect of quenchant composed *Piper Nigrum* extract on the sample's surface. Besides the type of heat treatment process, different quenchant physically and chemically also yields different effects on microstructure and hardenability of a material. The microstructure morphology and transformation of material are essential because they have a close correlation with the material's mechanical properties[11][13].

Figure 5a exhibits the microstructure of as-cast DI. It displays DI's common constituents, comprised of graphite nodules, the sea of ferrite (white region), and the island of pearlite (dark region). On the other hand, figure 5b and figure 5c depict the microstructure of as-austenitized DI samples quenched in conventional quenchant and modified quenchant with *Piper Nigrum*. It is seen that both microstructures consist of martensite and nodular graphite structures. Martensite structure transformed when the austenite structure existed at a temperature higher than eutectoid temperature (Critical), was rapidly cooled (by quenching) to room temperature. The morphology of martensite closely relates to the type of quenchant and cooling method of a heat-treatment process. It is noticed that the distribution of martensite and nodular graphite morphology did not change even though the sample has been quenched in modified quenchant. This result has proven that green inhibitor (*Piper Nigrum*) in quenchant gave a similar effect on the microstructure transformation, as shown in conventional quenchant. The findings likewise suggested that the presence of *Piper Nigrum* extract in water quenchant did not negatively affect the sample morphology behavior and present the almost identical microstructure shown by the sample heat-treated by the conventional method. Since the microstructure is closely related to mechanical properties, this result showed that the mechanical properties of DI unchanged even the quenchant used consisting of *Piper Nigrum* extract. Significant microstructure alteration is sometimes not required to maintain the quality of mechanical properties.
Figure 5. The microstructure of DI: (a) As-cast DI; (b) As-austenitized DI quenched with blank water quenchant; (c) As-austenitized DI quenched with modified quenchant

3.4. Hardness Test

The quenching process and quenchant solution of a heat treatment contribute to the stimulating effect on the material's hardness. Hence, considering the type of quenchant and its element are essential in the hardening process. Vickers hardness test was performed in this study to evaluate the effect of *Piper Nigrum* extract on the surface properties of as-austenitized DI samples. In this analysis, the hardness was measured at several points on the surface of the as-austenitized samples. The average of each sample's readings was then calculated to represent the hardness value of the sample. As shown in figure 6, the graph depicts that the inhibitor's presence did not give a significant consequence on the surface properties of the sample since there is neither significant increment nor decrement is shown. Even though the sample's hardness seemed to decrease as the initial concentration of *Piper Nigrum* extract increases at 10%, the decrease could be considerably low and negligible. The average hardness values of each sample are in the range of 150HV - 167HV. This trend aligns with the as-austenitized samples' morphology behavior, where no significant changes were shown on the microstructure.

Figure 6. Effect of the *Piper Nigrum* extract concentration to hardness of sample.

4. Conclusion

In a nutshell, this study has proven that the *Piper Nigrum* extract (green corrosion inhibitor) can be used in quenchant as a new alternative to inhibit corrosion of DI in the acidic condition during the heat-treatment process. The increase of the extract concentration in water quenchant produced increased inhibition efficiency and decreased corrosion rate of DI in the acidic condition. From the economic perspective, a 10% concentration of *Piper Nigrum* quenchant is adequate to give excellent inhibition performance of DI in HCl and offer optimum corrosion rate. This extract's presence as a green corrosion
inhibitor during the heat treatment process neither improved nor exacerbated the mechanical properties and sustains microstructure transformation behavior.

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References
[1] Idham M F, Masor M F, Mohd N, Abdullah B and Alias S K 2018 Performance of Piper Nigrum (Black Pepper) as Corrosion Inhibitor of Ductile Iron International Journal of Engineering and Technology 7 p 115–118.
[2] Yaro A S, Khadom A A and Wael R K 2013 Apricot juice as green corrosion inhibitor of mild steel in phosphoric acid Alexandria Eng. J. 52(1) p 129–135.
[3] Asipita S A, Ismail M, Majid M Z A, Majid Z A, Abdullah C and Mirza J 2014 Green Bambusa Arundinacea leaves extract as a sustainable corrosion inhibitor in steel reinforced concrete J. Clean. Prod. 67 p 139–146.
[4] Mourya P, Banerjee S and Singh M M 2014 Corrosion inhibition of mild steel in acidic solution by Tagetes erecta (Marigold flower) extract as a green inhibitor Corros. Sci. 85 p 352–363.
[5] B. Tan et al. 2021 Papaya leaves extract as a novel eco-friendly corrosion inhibitor for Cu in H2SO4 medium J. Colloid Interface Sci. 582 p 918–931.
[6] Boumhara K, Tabayaoui M, Jama C and Bentiss F 2015 Artemisia Mesatlantica essential oil as green inhibitor for carbon steel corrosion in 1M HCl solution: Electrochemical and XPS investigations J. Ind. Eng. Chem. 29 p 146–155.
[7] Fouda A E A S, Etaiw S E D H, El-Bendary M M and Maher M M 2016 Metal-organic frameworks based on silver (I) and nitrogen donors as new corrosion inhibitors for copper in HCl solution J. Mol. Liq. 213(3) p 228–234.
[8] Rosli N R, Yusuf S M, Sauki A and Razali W M R W 2019 Musa sapientum (Banana) peels as green corrosion inhibitor for mild steel Key. Eng. Mater. 797 p 230–239.
[9] Yang P, Fu H, Absi R, Bennacer R, Lin J and Guo X 2020 Improved corrosive wear resistance of carbide austenpered ductile iron by addition of Cu Mater. Charact. 168(100) p 110577.
[10] Dhillip G and Arul S 2020 Investigation of mechanical properties and wear rate on cryogenically treated austenpered ductile iron Mater. Today Proc.
[11] Wang B, Qiu F, Barber G C, Pan Y, Cui W and Wang R 2020 Microstructure, wear behavior and surface hardening of austempered ductile iron J. Mater. Res. Technol. 9(5) p 9838–9855.
[12] Dhillip G and Arul S 2020 Investigation of mechanical properties and wear rate on cryogenically treated austenpered ductile iron Mater. Today Proc.
[13] Wang B, Qiu F, Barber G C, Pan Y, Cui W and Wang R 2020 Microstructure, wear behavior and surface hardening of austempered ductile iron J. Mater. Res. Technol. 9(5) p 9838–9855.
[14] Idham M F, Abdullah B, Bahari A R, Marwan S H and Yusof K M 2016 Effect of double- quenching heat treatment process on microconstituent and XRD of Ductile iron ARPN J. Eng. Appl. Sci. 11(16) p 9596–9601.
[15] Idham M F, Abdullah B and Yusof K M 2017 Effects of two cycle heat treatment on the microstructure and hardness of ductile iron Pertanika J. Sci. Technol. 25(S3) p 99–106.
[16] Arthur D E and Abechi S E 2019 Corrosion inhibition studies of mild steel using Acalypha chamaedrifoliana leaves extract in hydrochloric acid medium SN Appl. Sci. 1(9).
[17] Sarkar T K, Saraswat V, Mitra R K, Obot I B and Yadav M 2020 Mitigation of corrosion in petroleum oil well/tubing steel using pyrimidines as efficient corrosion inhibitor: Experimental and theoretical investigation Mater. Today Commun. 26 101862.
[18] Tasić Z Z, Petrović Mihajlović M B, Radovanović M B, Simonović A T and Antonijević M M 2018 Cephradine as corrosion inhibitor for copper in 0.9% NaCl solution J. Mol. Struct. 1159 p 46–54.
[19] Hoai N T et al. 2019 An improved corrosion resistance of steel in hydrochloric acid solution using Hibiscus sabdariffa leaf extract Chem. Pap. 73(4) p 909–925.
[20] Zhang X et al. 2020 Evaluation of Idesia polycarpa Maxim fruits extract as a natural green corrosion inhibitor for copper in 0.5 M sulfuric acid solution J. Mol. Liq. 318.
[19] Qiang Y, Zhang S, Tan B and Chen S 2018 Evaluation of Ginkgo leaf extract as an eco-friendly corrosion inhibitor of X70 steel in HCl solution *Corros. Sci.* **133** p 6–16.

[20] Anupama K K, Ramya K, Shainy K M and Joseph A 2015 Adsorption and electrochemical studies of Pimenta dioica leaf extracts as corrosion inhibitor for mild steel in hydrochloric acid *Mater. Chem. Phys.* **167** p 28–41.

[21] Kumar H and Yadav V 2020 Musa acuminata (Green corrosion inhibitor) as anti-pit and anti-cracking agent for mild steel in 5M hydrochloric acid solution *Chem. Data Collect.* **29**.

[22] Prabakaran M, Kim S H, Sasireka A, Kalaiselvi K and Chung I M 2018 Polygonatum odoratum extract as an eco-friendly inhibitor for aluminum corrosion in acidic medium *J. Adhes. Sci. Technol.* **32**(18) p 2054–2069.

[23] Ji G, Anjum S, Sundaram S and Prakash R 2015 Musa paradisica peel extract as green corrosion inhibitor for mild steel in HCl solution *Corros. Sci.* **90** p 107–117.

[24] Odewunmi N A, Umoren S A and Gasem Z M 2014 Watermelon waste products as green corrosion inhibitors for mild steel in HCl solution *J. Environ. Chem. Eng.* **3**(1) p 286–296.

[25] Odewunmi N A, Umoren S A and Gasem Z M 2015 Utilization of watermelon rind extract as a green corrosion inhibitor for mild steel in acidic media *J. Ind. Eng. Chem.* **21** p 239–247.

[26] Odewunmi N A, Umoren S A, Gasem Z M, Ganiyu S A and Muhammad Q 2015 L-Citrulline: An active corrosion inhibitor component of watermelon rind extract for mild steel in HCl medium *J. Taiwan Inst. Chem. Eng.* **51** p 177–185.

[27] Tantawy A H, Soliman K A and Abd El-Lateef H M 2020 Novel synthesized cationic surfactants based on natural *Piper Nigrum* as sustainable-green inhibitors for steel pipeline corrosion in CO2-3.5%NaCl: DFT, Monte Carlo simulations and experimental approaches *J. Clean. Prod.* **250**.

[28] Rahuma M N, Amer H and Alfergani M 2014 Corrosion Inhibition of Mild Steel in 11% Hydrochloric Acid Solutions by Using Black Pepper (*Piper Nigrum*) *Chem. Sci.Trans.* **3**(2) 2.

[29] Chemistry A 2019 Cinnamomum zeylanicum Extract as Green Corrosion Inhibitor for Carbon Steel in Hydrochloric Acid Solutions *Prog. Chem. Biochem. Res.* **2**(3) pp 120–133.

[30] Meena O and Chaturvedi A 2020 Corrosion Inhibition of Aluminium by Extract of Aerial Parts of Phyllanthus niruri in Hydrochloric acid and Study of Extract as Antibacterial *13*(7) p 22–32.