The purpose of this study was to design a reactor for the formation of Fe$_3$O$_4$ nanoparticle compounds. The method used in this study is based on computational analysis of the results of mathematical calculations with the Microsoft Excel application. The results obtained are that the dimensions of the liquid phase reactor for the reaction process in the production of Fe$_3$O$_4$ nanoparticles can be calculated. The dimensional calculation results obtained for the inner diameter, outer diameter, height, and tank thickness are 1.86, 1.87, 7.24, and 0.001 m respectively. In addition, the agitator dimensions such as agitator diameter and agitator height from the bottom of the tank are 0.93 and 0.62 m respectively. The reactor is equipped with 1 stirrer with a shaft length of 1.04 m. Therefore, this research can be used as a standard in reactor design for the production of Fe$_3$O$_4$ nanoparticles.

**Keyword:**
- Fe$_3$O$_4$ nanoparticles
- Liquid phase reactor
- Mass balance
- Tank design
- Stirrer design

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1. **INTRODUCTION**

Fe$_3$O$_4$ nanoparticles are compounds that have an important role in human life because they have the main function for biomedical applications, such as magnetic resonance imaging, photothermal therapy, controlled drug delivery, protein separation, biosensors, DNA detection, and immunosensors (1). Over the past few years, many articles have described effective chemical methods for producing stable Fe$_3$O$_4$ nanoparticles of the required size. These methods include coprecipitation, thermal decomposition, reverse...
micelle technique, and solvothermal methods (2). However, these methods have drawbacks such as the formation of large amounts of toxic compounds (3), low product stability (4), and a long reaction process (5).

Recently, a new production method for Fe$_3$O$_4$ nanoparticles has been developed, namely the liquid phase reactor. In general, chemical reactors are an important point of most chemical processes in industry, where it is at this stage that the raw materials react to form the required products (6). There are various types of reactors adapted to very varied operating conditions. The reactor used needs to consider the chemical species involved and the physical conditions of the operating phase while meeting optimal conditions, economic costs, and environmental factors. In order for a chemical reactor to function effectively and efficiently, it must be able to perform two roles, namely, the chemical reactor must provide the necessary residence time for the reactants to complete the chemical reaction and to allow the heat exchange necessary for the reaction rate to be optimal so that the reaction can take place (7). Liquid phase reactor is a type of reactor with a liquid phase and high pressure (8). Some of the advantages of a liquid phase reactor are a very flexible operating process where the same reactor can produce one product at one time and a different product at a later time (9). In addition, other advantages of this method are obtaining a large amount of product, better selectivity, and mild reaction conditions (10). Therefore, this study aims to design a reactor design in the production of Fe$_3$O$_4$ nanoparticles in order to produce products in large quantities effectively and efficiently.

2. RESEARCH METHOD

2.1. Manufacturing of Fe$_3$O$_4$ Nanoparticles

In the process of making Fe$_3$O$_4$ nanoparticles, the implementation refers to research that was previously carried out by (11) in which the steps involved were mixing 8 g of ferric chloride tetrahydrate (FeCl$_2$·4H$_2$O) in 150 mL of deoxygenated acid water and 16 g of ferric chloride hexahydrate (FeCl$_3$·6H$_2$O) in 200 mL deoxygenated acid water which was dissolved separately and then heated at 70 – 80°C. After the Fe$_3$O$_4$ nanoparticles were formed, the precipitate was filtered using filter paper and washed several times with distilled water and ethanol until the pH was neutral. The shape of the process flow diagram of the Fe$_3$O$_4$ nanoparticle synthesis process is shown in Figure 1.

2.2. Mathematical Model for Reactor Design

It is assumed that the type of reactor and stirrer used in the design of this reactor is a liquid phase reactor with an upright cylindrical shape, a standard dish top cover and a conical bottom cover with a peak angle of 120° and a stirrer type, namely axial turbine 4 blades with an angle of 45°. The construction material used for the reactor is Stainless steel SA 240 Grade M Type 316 and for the stirrer is Hight Alloy Steel SA 240 Grade M type 316. Another assumption used to design this reactor is that a reactant volume of 100.00 m$^3$ is used and a reactor volume of 125.00 m$^3$ with a liquid hydrostatic pressure of 1 atm.

The mathematical equations that form the basis for calculating data processing in this study are shown in Table 1.
Figure 1. Process flow diagram of the Fe₃O₄ nanoparticles synthesis process

Table 1. Calculation of reactor parameters

<table>
<thead>
<tr>
<th>Section</th>
<th>Parameters</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor</td>
<td>Total volume (Vt)</td>
<td>$V_t = \frac{\pi d_i^2}{24 \tan \frac{1}{2} \alpha} + \frac{\pi d_i^2}{4} \times L_s + 0.0847 \times d_i^3$</td>
</tr>
<tr>
<td></td>
<td>Hydrostatic pressure (Pi)</td>
<td>$P_i = P_{\text{operation}} + P_{\text{hydrostatic}}$</td>
</tr>
<tr>
<td></td>
<td>Tank Thickness (ts)</td>
<td>$ts = \frac{P_i \times d_i}{2(F_0 - 0.691)} + C$</td>
</tr>
<tr>
<td></td>
<td>Tank Inner Diameter (di)</td>
<td>$di = \left( \frac{\sqrt{\frac{V_t}{1.3377}}}{3} \right) \times 12$</td>
</tr>
<tr>
<td></td>
<td>Tank Outer Diameter (do)</td>
<td>$do = di + (2 \times ts)$</td>
</tr>
<tr>
<td></td>
<td>Tank Height (Ls)</td>
<td>$L_s = \frac{V_t}{d_i}$</td>
</tr>
<tr>
<td>Stirrer</td>
<td>Impeller Diameter (Da)</td>
<td>$Da = Dt \times 0.5$</td>
</tr>
<tr>
<td></td>
<td>Impeller Height from The Bottom of The Vessel (Zi)</td>
<td>$Zi = \frac{1}{3} \times di$</td>
</tr>
<tr>
<td></td>
<td>Impeller Width (W)</td>
<td>$W = 0.20 \times Da$</td>
</tr>
<tr>
<td></td>
<td>Impeller Length (L)</td>
<td>$L = \frac{1}{4} \times Da$</td>
</tr>
<tr>
<td></td>
<td>Power (P)</td>
<td>$P = \frac{\rho \times \pi \times d_i^5}{6 \times g \times e}$</td>
</tr>
<tr>
<td></td>
<td>Shaft Length (L)</td>
<td>$L = h + l - Zi$</td>
</tr>
</tbody>
</table>
3. RESULTS AND ANALYSIS

3.1. Main Reaction

The main reactions expected to occur in this process are:

\[
2\text{FeCl}_3\cdot6\text{H}_2\text{O} + \text{FeCl}_2\cdot4\text{H}_2\text{O} + 8\text{NH}_4\text{OH} \rightarrow \text{Fe}_3\text{O}_4 + 20\text{H}_2\text{O} + 8\text{NH}_4\text{Cl}
\]

The reaction shows that this reaction occurs with the precursors iron (III) chloride hexahydrate, iron (II) chloride tetrahydrate, and ammonium hydroxide with products in the form of iron oxide as the main product, water, and ammonium chloride so that the reaction proceeds as desired without the formation of a side reaction.

3.2. Reactor Type

Reactor is a series of tools used to assist in the ongoing reaction, both in small sizes (laboratory scale) to large sizes (industrial scale). In this study a series of reactors was arranged for use on an industrial scale. The type of reactor used is the liquid phase reactor.

Liquid phase reactor is a type of reactor with a liquid phase and high pressure. This type of reactor was chosen because it has a number of advantages such as a very flexible operating process where the same reactor can produce one product at one time and a different product at a later time. In addition, other advantages of this method are obtaining a large amount of product, better selectivity, and mild reaction conditions.

3.3. Effect of Heat on Reaction Rate and Equilibrium Shift

The influence of the initial reactor temperature will affect the rate of reaction and changes in equilibrium. Theoretically, the higher the initial temperature of the reactor, the higher the heat of reaction of the liquid in the reactor. This is because the transesterification reaction is exothermic which requires the refrigerant to be introduced at an initial temperature of 60°C. Thus, when the reactor is connected to a heat exchanger, the dynamic heat exchanger will increase its temperature because the heat exchanger absorbs the heat released by the reaction of the reactor. The higher the reactor temperature, the higher the heat exchanger consumption.

In addition, the higher the initial temperature of the reactor, the faster the time to reach steady state. This is because when the initial temperature (Tf) of the reactor is lowered it will affect the dynamic rate of the next reactor temperature. This is also in accordance with the opinion of Arrhenius which states that the higher the temperature, the faster the reaction will reach equilibrium.

3.4. Reaction Product Optimization

In this study, various calculations were carried out to optimize the reaction product. For this, several assumptions are made as follows.

3.4.1. The raw materials used are iron (III) chloride hexahydrate, iron (II) chloride tetrahydrate, and ammonium hydroxide.

3.4.2. The production process of \( \text{Fe}_3\text{O}_4 \) nanoparticles is shown in Figure 2.

3.4.3. The production of \( \text{Fe}_3\text{O}_4 \) nanoparticles was calculated based on the mass balance (Tables 2 and 3).

3.4.4. The type of reactor is a liquid phase reactor.

3.4.5. The reaction process occurs in the reactor tank.

3.4.6. The construction material is stainless steel.

3.4.7. The operating condition temperature is 60°C.

3.4.8. Retention time is 1 hour.
3.4.9. Pressure is 1 atm.
3.4.10. The molecular weights of iron (III) chloride hexahydrate, iron (II) chloride tetrahydrate, ammonium hydroxide, iron oxide, water, and ammonium chloride are 270.33; 35.04; 198.81; 231.53; 18.01; and 53.49 kg/kmol.
3.4.11. Flowrate iron (III) chloride hexahydrate was 1,500 kg/hour, chloride tetrahydrate was 1,300 kg/hour, and ammonium hydroxide was 700 kg/hour.

The reactor for the production of Fe₃O₄ nanoparticles is shown in Figure 2.

![Figure 2. Reactor for the production of Fe₃O₄ nanoparticles (F1-F4 is the feed flow rate)](image)

Based on Figure 2, the results of mass balance calculations on the production design of Fe₃O₄ nanoparticles are shown in Tables 2 and 3.

**Table 2. Mass balance on F1, F2, and F3**

<table>
<thead>
<tr>
<th>No</th>
<th>Component</th>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Massa (kg/h)</td>
<td>Massa (kg/h)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mol (kmol/h)</td>
<td>Mol (kmol/h)</td>
</tr>
<tr>
<td>1</td>
<td>FeCl₃·6H₂O</td>
<td>1,500</td>
<td>1,440</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.55</td>
<td>5.32</td>
</tr>
<tr>
<td>2</td>
<td>NH₄OH</td>
<td>700</td>
<td>7,948.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.52</td>
<td>39.98</td>
</tr>
<tr>
<td>3</td>
<td>FeCl₂·4H₂O</td>
<td>1,300</td>
<td>1,109.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>37.10</td>
<td>31.66</td>
</tr>
</tbody>
</table>

**Table 3. Mass balance on F4**

<table>
<thead>
<tr>
<th>No</th>
<th>Component</th>
<th>Massa (kg/h)</th>
<th>Mol (kmol/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fe₃O₄</td>
<td>1,259.03</td>
<td>5.44</td>
</tr>
<tr>
<td>2</td>
<td>H₂O</td>
<td>1,958.70</td>
<td>108.76</td>
</tr>
<tr>
<td>3</td>
<td>NH₄Cl</td>
<td>2,326.94</td>
<td>43.50</td>
</tr>
</tbody>
</table>

Based on mass balance calculations, it is known that the reactor specifications must be met for the production of Fe₃O₄ nanoparticles. Reactor specifications are shown in Table 4.
4. CONCLUSION

Based on the results of the calculations that have been carried out, it is known that the dimensions of the liquid phase reactor for the reaction process in the production of Fe₃O₄ nanoparticles can be calculated. The dimensional calculation results obtained for the inner diameter, outer diameter, height, and tank thickness are 1.86, 1.87, 7.24, and 0.001 m respectively. In addition, the agitator dimensions such as agitator diameter and agitator height from the bottom of the tank are 0.93 and 0.62 m respectively. The reactor is equipped with 1 stirrer with a shaft length of 1.04 m.

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