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Economic Perspective in the Production of Magnetite (Fe_3O_4) Nanoparticles by Co-precipitation Method

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ABSTRACT

Magnetite contains both types of iron namely ferrous and ferric, so it is usually described as Iron$^{II, III}$ Oxide. Nano-sized Magnetite (Fe_3O_4) not only increases lattice parameters and unit cell volumes but also the effective area and surface area have definitely increased. Magnetite can improve the electrical properties of a polymeric material through the copolymers synthesis method. Therefore, there is a need for the feasibility study for generating industries for the production of Fe_3O_4 especially in the developing countries. This study aimed to evaluate the prospect for the production of iron oxide (Fe_3O_4) nanoparticles in practical uses. This study was done to confirm whether the large-scale production of Fe_3O_4 is profitable or not. The evaluation was done using two types of feasibility studies: engineering analysis and economic evaluation. The estimation of the project was also completed with the calculation from ideal conditions to the worst cases of production from changes of raw material prices. The engineering analysis gave information the potential large-scale production since the process can be applied using commercially available and inexpensive apparatuses. The economic evaluation based on various economic evaluation parameters (such as gross profit margin, break-even point, payback period, etc) showed the potential profitability for the project. All evaluation parameters gave positive points. The project also used relatively inexpensive total cost of purchased equipment. Although further developments must be also added especially regarding the additional strategies to boost the profit to attract the investors, this study provides a quite promise for the possible fabrication of Fe_3O_4 in developing countries.

Keywords: *Iron Oxide, Nanoparticles, Economic evaluation, Feasibility study.*

1. INTRODUCTION

Magnetite contains both types of iron namely ferrous and ferric, so it is usually described as Iron$^{II, III}$ Oxide (Blaney, 2007). Iron oxide is present in the form of magnetite (Fe_3O_4), maghemite (γ-Fe_2O_3), and hematite (α-Fe_2O_3) (Mairoza, 2016). Nano-sized Magnetite (Fe_3O_4) not only increases lattice parameters and unit cell volumes but also the effective area and surface area have definitely increased. Magnetite can improve the electrical properties of a polymeric material through the co-polymers synthesis method (Blaney,2007).

There were many magnetite properties, but the main focus in recent years is the magnetic properties which getting stronger as particle size decreases (Fajaroh *et al*., 2009). This reduction in size affects the Curie temperature which is the critical temperature at which magnetization changes from ferromagnetic to supermagnetic. The synthesis that is often used to make Magnetite nanoparticles is co-precipitation which is simply a reaction of ferro and ferric species (Blaney, 2007). Magnetite (Fe3O4) are commonly used for the synthesis of magnetic nanoparticles because they present stable magnetic response, are biodegradable and biocompatible, and present superparamagnetic effects (Silva et al., 2013). The co-precipitation method is a simple and inexpensive method of operating costs, so this method is one of the preferred techniques for making nanoparticles. Nanoparticles produced from the co-precipitation method are usually polydisperse with spherical morphology (Permana *et al*., 2017).

To evaluate the production nanoparticles magnetite (Fe_3O_4), this study synthesis method is used from literature (Wu S *et al*., 2011). This method was evaluated from engineering and economic evaluation perspectives. The economic evaluation in this study is supported by some of economic evaluation parameters such as

(i) gross profit margin (GPM; to predict the rough analysis of the economic condition),
(ii) internal rate return (IRR; to ensure the condition of economic),
(iii) payback period (PBP; to estimate the possibility for the year of profit),
(iv) cumulative net present value (CNPV; to predict the condition of the project as a function of year of production),
(v) break-even point (BEP; to get the minimum requirement of the production capacity),
(vi) profitability index (PI, to obtain information about the profit).

2. METHODS

2.1 Theoretical Synthesis of Fe_3O_4 Nanoparticles

Iron oxide nanoparticles (Fe_3O_4) were synthesized by the co-precipitation method based on the literature (Wu S *et al*., 2011) by mixing the precursor which are ferric chloride ($FeCl_3$) and ferrous sulfate heptahydrate ($FeSO_4.7H_2O$) solution. The $FeCl_3$ solution is reacted with $FeSO_4$ solution to form ions Fe^{3+} and Fe^{2+}, respectively. Where these ions will react with bases to form precipitation. The designed process is illustrated by **Fig. 1**.

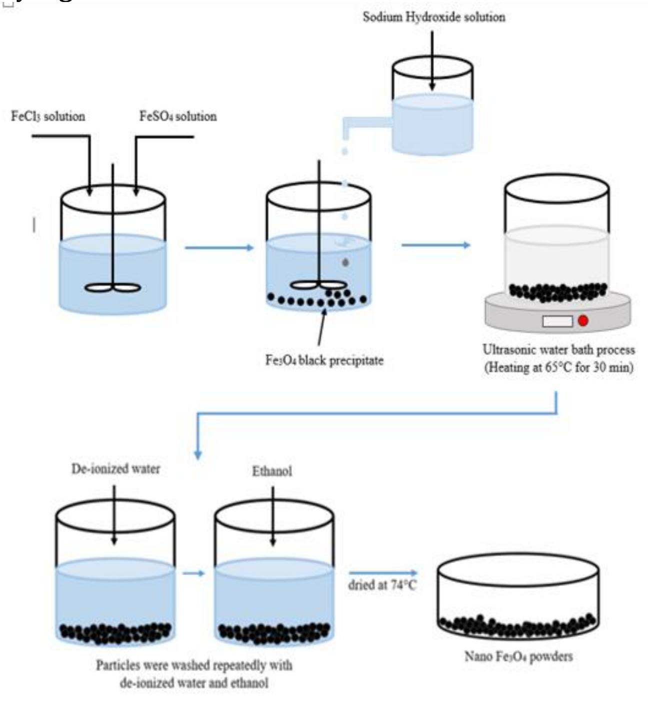

Fig. 1. Scheme of the process of making Fe_3O_4 nanoparticles by the co-precipitation method

The synthesis process of Fe_3O_4 particles is based on the reaction between $FeCl_3$ and $FeSO_4$ solution to formed their ions Fe^{3+} and Fe^{2+}, respectively. Sodium hydroxide (NaOH) is dissolved in de-ionized water become NaOH solution. Then, Fe^{3+} and Fe^{2+} with a molar ratio of 1.5: 1 are reacted with NaOH solution aided by ultrasonic agitation, so that black precipitate is formed which is coal-black Fe_3O_4 particles. Obtained Fe_3O_4 precipitate was placed at 65°C for 30 minutes under ultrasonic agitation. To obtain the pure of Fe_3O_4 nanoparticles, the sample were washed repeatedly with de-ionized water and ethanol until reached pH level of 7. Particles were dried at 74°C at vacuum. The mechanism of the reaction that occurs during the synthesis process:

$FeCl_3(s) \rightarrow Fe^{3+}(aq) + 3Cl^-(aq)$
$FeSO_4.7H_2O \rightarrow Fe^{2+}(aq) + SO_4^{2-}(aq) + 7H_2O(l)$
$NaOH(s) + H_2O(l) \rightarrow Na^+(aq) + OH^-(aq)$
$Fe^{3+}(aq) + 3OH^-(aq) \rightarrow Fe(OH)_3(s)$
$Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$
$2Fe(OH)_3(s) + Fe(OH)_2(s) \rightarrow Fe_3O_4(s) + 4H_2O(l)$

2.2 Economic Evaluation

The data of price, utilizing components, and specifications for apparatuses used in the analysis method were taken from one of online shopping web such as alibaba. All data are calculated by a simple mathematical calculation to get economic evaluation parameters, including GPM, IRR, PBP, CNPV, BEP, and PI sales to investment. The calculation was obtained using the following formulas:

(1) GPM was calculated by substracting sales and raw material cost
(2) IRR was from the following equations:
$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o \quad (1)$$
Where:
Ct = the net cash inflow during the t period
Co= total investment costs
r = the discount rate
t = time (as year)
(3) PBP is the length of time required to recover the cost of an investment. The simplest way to obtain PBP is gained from the CNPV curve. The value of PBP was determined by understanding the time when value of CNPV/TIC reaches zero for the first time.
(4) CNPV is the values gained from the net present value (NPV) at a specific time. In short, the CNPV was obtained by adding the value of NPV from the beginning of the project. The NPV was calculated by multiplying cash flow with discount factor.
(5) BEP was calculated by dividing fixed cost and profit.
(6) PI was estimated by dividing CNPV and total investment cost or sales, corresponding the PI types of profit to investment or profit to sales, respectively.

Then, the result was used for evaluating economic in different conditions of raw material price.

3. RESULTS AND DISCUSSION

Energy and Mass Balance Analysis

To calculated energy and mass balance based on **Fig. 1**, the synthesis need some assumptions:

- The process carried out is the co-precipitation method.
- The temperature at the ultrasonic process is 65 ° C.
- Reduced mass of Fe_3O_4 nanoparticles during the washing and centrifugation process is assumed to be 5%.
- The conversion of Fe_3O_4 nanoparticles formation after going through the co-precipitation process is as much as 85%.
- When the co-precipitation process, $FeCl_3$, $FeSO_4.7H_2O$, and NaOH are assumed to be lost by 10%.
- All products produced are magnetite-type Fe_3O_4 nanoparticles.

The amount of all the components were calculated stoichiometrically, 3 kg $FeCl_3$, 1,5 kg $FeSO_4.7H_2O$, and 1 L NaOH can produce 12,5 kg Fe_3O_4 nanoparticles. Water and ethanol were used during the purification process at least 5 L. The results showed that Fe_3O_4 nanoparticles production could be carried out on a large scale.

Economic Evaluation

From engineering analysis, this research shows favorable results. From an economic perspective also needed to analyze. So that several assumptions are made as follows

- The calculation used fix currency that 1 USD is equal to 10,000 IDR.
- All prices are based on sales in the online market, such as Alibaba and Sigma Aldrich. Prices of $FeCl_3$, $FeSO_4.7H_2O$, and NaOH are 9.300 /g; 7400 /g; and 2400 /L respectively.
  - Labor wages for 5 people for 120,000,000 IDR / year.
  - One cycle of production of Fe_3O_4 nanoparticles takes 8 hours.
  - The length of the project operation was 20 years.
  - Electricity costs are assumed to be IDR 1500 / kWh, electricity that must be paid annually is approximately 7,481,250 IDR
  - The discount rate is 15%
  - The income tax is 10%

Ideal Condition

Fig. 2 shows the ideal condition of the CNPV graph with various economic evaluation parameters for time (years). The curve shows a decrease in income on the 1st to 3rd year, this is reasonable because of the initial capital costs such as the tools needed during the process of producing Fe3O4 nanoparticles. This project takes not too long time to regain its initial investment or to reach the payback period of around 5 years. The analysis of engineering shows that production can be carried out on a large scale. To support the result, economic evaluations such as GPM, PBP, BEP, IRR, etc. are also carried out on **Table 1.**

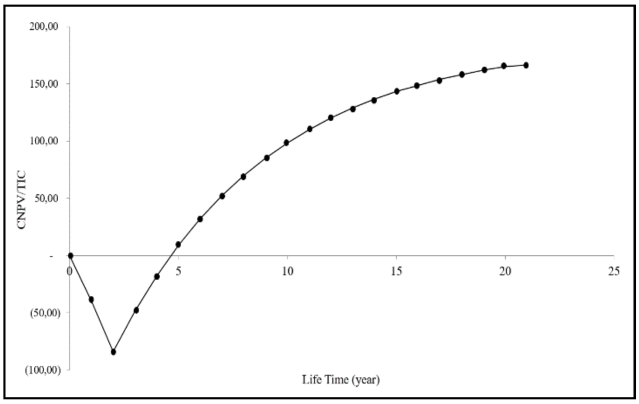

Fig. 2. Ideal condition for CNPV/TIC to Life Time (year)

Tabel 1. The economic evaluation parameters

Economic evaluation parameters	Value
GPM/year	2.515.800.000 IDR
GPM/pack	6.708.800 IDR
PBP	5 years
BEP	62,28 process
Break Even Capacity	6447,78 %
IRR	4,8 %
Last CNPV/total investment	166,23 %
ROI per year	0,11 % /year
Total ROI	11,01 %
PI profit to sales	6,35 % % /year
PI profit to TIC	61,51 % % /year

Effects of raw material (i.e. ferric chloride, ferrous sulfate heptahydrate, sodium hydroxide), product sales, labor, and utility

Fig. 3 shows the results of the analysis to evaluate the effect of raw material prices and sales at the GPM by reducing raw material costs and product sales costs. The curve shows that raw materials and sales are inversely proportional, where sales have a positive influence on GPM, but raw materials have the opposite effect. This means that more sales will benefit the project, while increases in raw material prices will be detrimental to the project. The effect of raw materials which are ferric chloride, ferrous sulfate heptahydrate, and sodium hydroxide is not too much different. However, the most influential parameter in the raw material factor is ferric chloride.

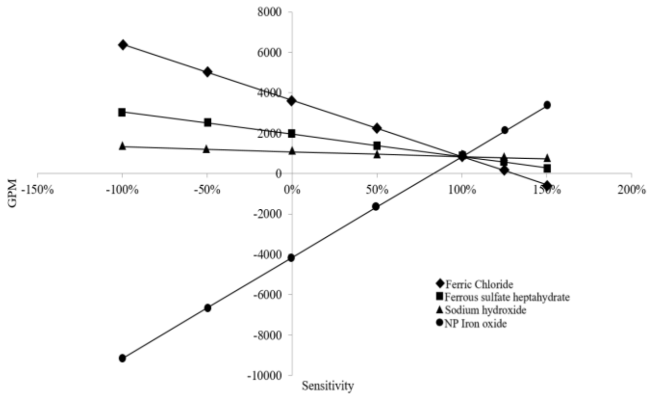

Fig. 3. Raw materials (i.e. ferric chloride, ferrous sulfate heptahydrate, sodium hydroxide) and sales cost on the GPM

Fig. 4 shows the CNPV analysis curve for changes in variable cost. Variable cost is the cost that depends on the amount of production to maintain the project so that it has an important role in profitability

(Nandiyanto *et al*, 2018). It can be seen that if the variable cost decreases, the project will produce more profits. While profits decrease with increasing variable cost. So in order to get a profit, the variable cost must be varied at a maximum value of less than 50%. However, a minimum PBP cannot be obtained when using a production of more than 50% variable cost.

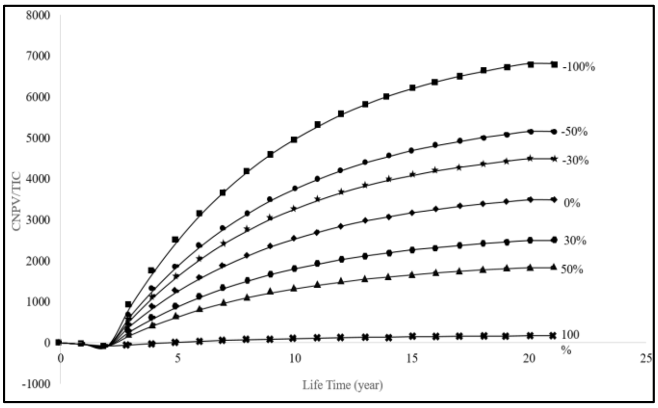

Fig. 4. CNPV curve under various variable costs

Results from Engineering Perspective

The scaling up process was possible from the engineering point of view. This is because the scaling up process can be applied using commercially available and inexpensive apparatuses. Further, by calculating projects with 365 processing cycles per year, the suggested scheme is prospective enough to produce about 456 kg of Fe_3O_4 by consuming consume 1,09 ton of $FeCl_3$ per year. Furthermore, analysis of the total cost of equipment per batch of reactor that can consume 40 L of $FeCl_3$ requires a total equipment purchase cost of USD 34900. Adding Lang Factor to the calculation, TIC must be less than USD 156000. This value is relatively economical and the project requires less investment funds. In the ideal condition, projects can reach 365 processing cycles per year, which can allow the production of Fe_3O_4 products of about 456 kg per year. Adding calculation for 20 years of project life time, the results showed that the whole project can generate 9,12 tons of product in the ideal condition.

Results from Economic Analysis

Based on the analysis, the project under ideal conditions is feasible. However, if there are changes in economic conditions, the project is only profitable in particular economic conditions. All analyses were compared with the condition of Indonesian bank and currency (Nandiyanto, 2018).

In short, if the project is carried out in a specific situation that is different from the certain economic conditions, the project will be failure. Detailed descriptions of different conditions based on the analysis are described as follows:

- The project still be profitable if the increases in the cost of raw material is less than ±125% of the estimated cost of raw material. Based on the analysis in the raw materials, the impacts of Ferrous sulfate heptahydrate and sodium hydroxide on the GPM were almost similar. The most influential parameters in the raw materials is Ferric Chloride.
- The product sales must be as higher as possible to maintain the project. Nevertheless, the increasing sales must be still optimized due to its correlation to the other costs. When there is a condition for reducing the sales, the sales must be still higher than 50% of the estimated value. Otherwise, the project will be failure. If the sales is too low, it will affect the minimum cost for production cannot be fulfilled.

Regarding the final CNPV, the value is high enough for the project with 20 years of life time. But, when adding annual calculation, the CNPV value is relatively low. This result is also strengthened by the fact for the condition with relatively less value for PI. Certainly, this typical long-term investment will give unattractive perspective for investors. After calculation some economic evaluation parameter, the result show that this project is quite promising.

4. CONCLUSION

Based on the results of the analysis, it can be seen that the production of Fe3O4 nanoparticles is quite promising when from an engineering point of view. From an economic perspective it can also be said to be quite promising, but in carrying out the project it takes up to 5 years to return the initial cost or PBP that is not efficient, so this needs to be considered. From the synthesis process, the process of making Fe3O4 nanoparticles produces contamination in the form of a solution containing chloride and sulfate from the reaction between its precursors.

5. ACKNOWLEDGMENTS

You can put your acknowledgements here

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