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Techno-Economic Analysis of $NiFe_2O_4$ Nanoparticle Industry Using Sonochemical Synthesis Method

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Abstract. The purpose of this paper is to carry out an economic and industrial evaluation on an industrial scale of $NiFe_2O_4$ production using sonochemical synthesis methods. The method used is to calculate gross profit margin (GPM), payback period (PBP), cumulative net present value (CNPV), total investment cost (TIC) and profitability index (PI). NiFe2O4 nanoparticles were synthesized with the main raw materials being $Fe(NO_3)_3.9H_2O$, $Ni(NO_3)_2.6H_2O$, and NaOH (1:2:8). The calculation results of GPM and CNPV/TIC from the $NiFe_2O_4$ industry using the sonochemical synthesis method show the payback period (PBP) in the third year. So that in the third year onwards it can be predicted that the industry will experience profits. This research is expected to be a reference for technical and economic analysis to produce $NiFe_2O_4$ in humidity sensor applications on an industrial scale.

1. Introduction

To support human life that is safer and more comfortable in using technological devices, the need for sensors is increasing, one of which is a humidity sensor [1]. Recently applications of humidity sensors can be found in broad fields such as in the pharmaceutical industry, food production, electronics industry, paper and sugar industry, agriculture, food storage, climatology, meteorological studies, libraries, chemical industry, museums, nuclear power plants [2,3]. In humidity sensors, there are three main issues such as sensitivity, selectivity and stability. Humidity sensors are usually exposed to the atmosphere and contain various other components. They tend to lose their inherent sensitivity during use as a result of several complex physical and chemical processes. These difficulties are reduced in ferrite materials [4]. This means that among the many types of humidity sensors such as polymer based, optical type, metal oxide based and ferrite based sensors used, mesoporous ferrite based sensors are preferred due to their versatile microstructural properties such as nano size, large surface area, uniform particle size. so that they readily respond to surface phenomena such as adsorption which are favorable for moisture sensing [1]. In addition, the main advantage of spinel-type ferrite over traditional sensor materials based on single metal oxide semiconductors is the ability to adjust the conductivity type and resistance value by changing the cation composition, stoichiometry or annealing condition. Conduction in spinel ferrites occurs through the transfer of charge carriers (electrons or holes) between the same cations located in octahedral locations. [5]. $NiFe_2O_4$, has an inverted spinel structure from Fe^{3+} [Ni^{2+}, Fe^{3+}]O_4, where Ni^{2+} and half of Fe^{3+} are located at octahedral sites, and the other Fe^{3+} occupies a tetrahedral [6]. Nickel ferrite has great potential in electronic device applications, its electrical and magnetic properties are based on its distribution between tetrahedral and octahedral sites. Nickel ferrite exhibits ferromagnetic properties stemming from the antiparallel spin between Ni^{2+} ions at the octahedral site and Fe^{3+} ions at the tetrahedral site. [4]. Nickel ferrite is also considered the most promising among high-sensing properties due to its temperature-dependent surface morphology and photocatalytic activity [7].

There are several methods of $NiFe_2O_4$ synthesis reported by researchers, including sonochemical methods [8-13], hydrothermal [14-16], coprecipitation [17-20], citrate precursors [21-23], mechanical alloys [24-26], reverse micelle [27-30], sol-gel [31-33], and pulsed wire discharge [34-36]. The method used in the economic evaluation in this paper is the sonochemical method. Therefore, the aim of this study was to evaluate the technical and economic feasibility of manufacturing $NiFe_2O_4$ nanoparticles on an industrial scale. In this study, we vary several factors to see their effect on the economic evaluation under study, such as increases in tax prices, decreases and increases in product prices, and the effect of raw material prices.

2. Method

2.1 Theoretical Synthesis of NiFe2O4 nanoparticles

The chemicals used Fe(NO3)3.9H2O, Ni(NO3)2.6H2O, and "AR grade" NaOH which were in www.alibaba.com, www.tokopedia.com, and www.merck.com. The synthesis method of NiFe2O4 nanoparticles used is the sonochemical method. First, Fe(NO3)3.9H2O and Ni(NO3)2.6H2O were mixed in the required molar ratio and added to the 6M NaOH solution in an ultrasonic bath at room temperature. The pH of the solution was maintained at 11-13 by adding excess NaOH. The total allowable reaction period is 5 hours accompanied by centrifugation at 15,000 revolutions per minute for 15 minutes. The precipitate was cleaned ten times with distilled water to remove additional products, which were formed during ferritization. The washed precipitate was collected and heated on a hot plate at 363 K for 36 hours. Then, NiFe2O4 nanoparticles were formed into pellets which were made by hydraulic press using several molds for various applications, especially in gas sensors. Finally, the samples were annealed in a temperature range of 1273 K–1673 K in a programmable furnace by controlling the heating rate to about 3°C/min to prevent sample cracking accompanied by furnace cooling. The schematic of the NiFe2O4 synthesis process is shown in Figure 1.

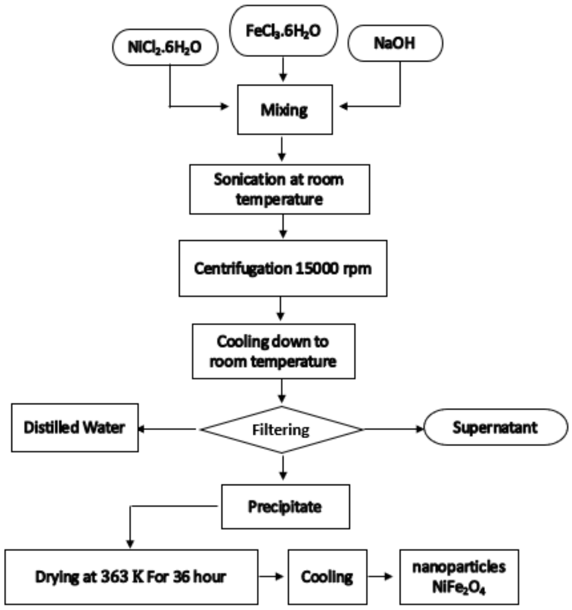

Figure 1. Flowchart of the synthesis $NiFe_2O_4$ nanoparticles

2.2 Energy and mass balance

The materials needed for the synthesis of $NiFe_2O_4$ are 6.54277 g $Ni(NO_3)_2.6H_2O$, 18.1798 g $Fe(NO_3)_3.9H_2O$, 7.2 g NaOH, and 90 mL H_2O. The solution was prepared by dissolving 6.54277 g of $Ni(NO_3)_2.6H_2O$ and 18.1798 g of $Fe(NO_3)_3.9H_2O$, respectively, into 30 mL of H_2O, while 7.2 g of NaOH was dissolved in 30 mL of H_2O separately. The solution is put into an ultrasonic bath. The pH of the solution was maintained at 11-13 by adding excess NaOH. The total allowable reaction period is 5 hours and is accompanied by centrifugation at 15,000 revolutions per minute for 15 minutes. The precipitate formed was cleaned ten times with distilled water to remove additional products, which were formed during ferritization. The precipitates were washed, collected and heated on a hot plate at 363 K for 36 hours. Then, the precipitate is formed into pellets with the help of a hydraulic press and using several molds for various applications, especially in gas sensors. Finally, the samples were annealed in a temperature range of 1273 K–1673 K in a programmable furnace by controlling the heating rate to about 3°C/min to prevent sample cracking accompanied by furnace cooling. The reaction is as follows:

(1) $Ni(NO_3)_2.6H_2O_{(s)} + H_2O_{(l)} \longrightarrow Ni^{2+}_{(aq)} + 2NO_3^-{}_{(aq)} + 7H_2O_{(l)}$

(2) $Fe(NO_3)_3.9H_2O_{(s)} + H_2O_{(l)} \longrightarrow Fe^{3+}_{(aq)} + 3NO_3^-{}_{(aq)} + 9H_2O_{(l)}$

(3) $Ni^{2+}_{(aq)} + 2Fe^{3+}_{(aq)} + 8NO_3^-{}_{(aq)} + H_2O_{(l)} + 8NaOH_{(aq)} \longrightarrow NiFe_2O_{4(s)} + 8NaNO_{3(s)} + 5H_2O_{(l)}$

From a technical point of view, it is possible to increase the production of $NiFe_2O_4$ nanoparticles, because the capacity and quantity of tools and materials used can be enlarged. To produce about 50 kg $NiFe_2O_4$ nanoparticles, it takes 1 reaction cycle for two days using about 62 kg $Ni(NO_3)_2.6H_2O$, 171 kg $Fe(NO_3)_3$. $9H_2O$, 68 kg NaOH, and 852.85 L H_2O. With a total raw material cost of IDR 51,518,000.00 and a one year profit of $864,891.06 in ideal conditions with a project life of 10 years. Figure 2 shows a flow diagram of the production process of $NiFe_2O_4$ nanoparticles using sonochemical methods.

International Journal of Research and Applied Technology

1(2)(2021) 289-299

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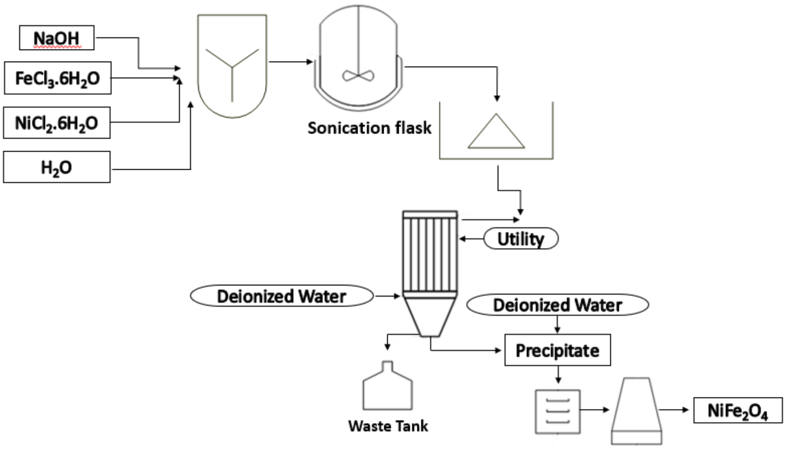

Figure 2. Flowchart of the synthesis of $NiFe_2O_4$ nanoparticles

2.3 Economic Evaluation

In this economic evaluation, the existing price data is obtained from several sources such as www.alibaba.com, www.tokopedia.com and www.merck.com. This economic evaluation analysis was carried out with the help of the Microsoft Excel application to perform some of the calculations needed. The parameters used in this economic evaluation analysis are as follows:

1. Total Investment Cost (TIC) is the initial capital or cost that must be present at the beginning of production. TIC is usually calculated based on the total cost of the plant [37].
2. Gross Profit Margin (GPM) is the first analysis to determine the level of profitability of a project by reducing the cost of selling the product with the cost of raw materials [38].
3. Payback Period (PBP) is a calculation performed to predict the length of time it will take for an investment to return the total initial expenditure. PBP is calculated when CNPV is at zero for the first time [39].
4. Cumulative Net Present Value (CNVP) is obtained by adding up the Net Present Value (NPV) at a certain time since the start of the project [40].
5. Net Present Value (NPV) is a value that expresses the expenses and income of a business. In short, CNPV is obtained by adding the NPV value from the first project to the end of the plant operation [39].
6. Investment Profitability (PI) is an index to identify the relationship between project costs and impacts. PI can be calculated by dividing the CNPV by the total investment cost (TIC). Profitability Index (PI) is estimated by dividing CNPV by sales and total investment costs depending on the type of PI whether PI is for sales or PI is for investment [39].

Several assumptions are needed to carry out this economic evaluation analysis. This assumption is needed to perform calculations and predict several possibilities that occur during the production process. The following are some of the assumptions used:

- The exchange rate used is 1 USD = IDR 15,000.00.
- Based on commercially available prices against raw material prices:
  1 kg $Ni(NO_3)_2.6H_2O$ is IDR 187,000.00; 1 kg $Fe(NO_3)_3$. $6H_2O$ is IDR 212,000.00; 1 kg NaOH is IDR 54,000.00.
  All materials were calculated stoichiometrically.
- All materials were calculated stoichiometrically.
- The tax issued is 10%.

- Based on the commercial price available for the equipment used, the total cost of the equipment is IDR 599,018,096.00.
- The production process lasts for 300 days in one year.
- To simplify the utility calculation, we assume about 9,425 kWh in one day of production. Price for 1 kWh is IDR 1,380.00.
- Total salary/employee is 266.8 USD/day for 40 people.
- The production process lasts for 10 years.

This economic evaluation analysis aims to test the feasibility of the production process. This economic evaluation varies several variables, namely, selling prices, prices of raw materials and utilities with variants of 80%, 90%, 100%, 110% and 120%. While the large variations of taxes are 10%, 25%, 50%, 75% and 100%.

3. Results and Discussion

3.1 CNVP in Ideal Circumstances

Figure 3 shows a graph of the relationship between Profit Investment or Cumulative Net Present Value (CNPV) per Total Investment Cost (TIC) with the year of production. The graph shows a decrease in revenue in the 1st to 2nd years due to initial capital expenditures for the purchase of equipment and building a plant needed during the production process of NiFe2O4 nanoparticles as well as for the cost of purchasing land. In that year the factory did not produce nanoparticles. However, in the 3rd year there is an increase in income, this condition is called the Payback Period (PBP). This means that in the 3rd year, the factory is able to produce NiFe2O4 nanoparticles and is starting to make a profit.

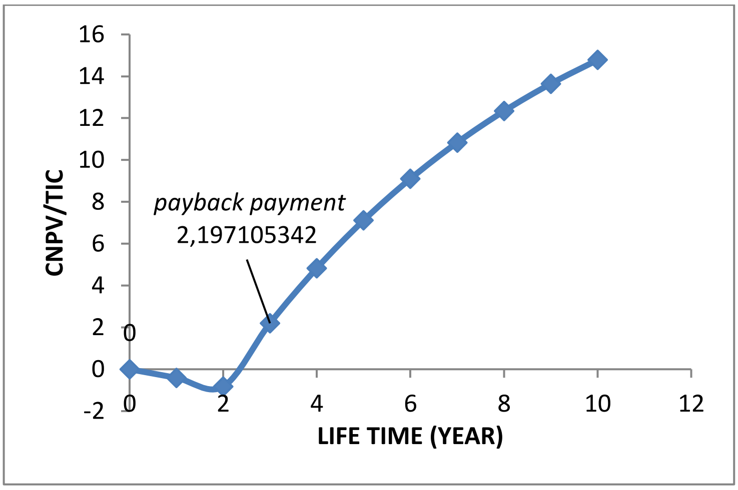

Figure 3. Graph of CNPV/TIC against the year of production under ideal conditions

In Table 1 it can be observed that the first two years of production decreased marked by a negative CNPV/TIC value. This means that in 2 years the production has not been able to generate profits. Until the third year onwards, the value of CNPV/TIC has increased which is indicated by a positive value. That is, in the third year and so on, there will be profits from the production. In the third year is the point of increasing income or known as the payback period (PBP). Therefore, in the 3rd to the 10th year, there is an increasing production profit due to the achievement. The payback period is the positive CNPV/TIBC value. So it can be concluded that the production of $NiFe_2O_4$ using this sonochemical method under ideal conditions is a profitable project.

Table 1. CNPV/TIV development every year

Year	CNPV/TIC
0	0
1	**-0.4099**
2	-0.8276
3	2.19711
4	4.82727
5	7.11437
6	9.10316
7	10.8325
8	12.3363
9	13.644
10	14.7811

3.2 Variation of Tax Increase

Figure 4 shows a graph of the effect of the tax increase on CNPV/TIC. The x-axis is the year of production, while the y-axis is the CNPV/TIC value which is affected by the tax rate. Variations in tax rates used are 10, 25, 50, 75, and 100%. The graph shows that the higher the tax rate, the less profit you make. Therefore, the PBP value for each variation of the tax increase is different. The higher the tax rate, the longer the PBP is achieved.

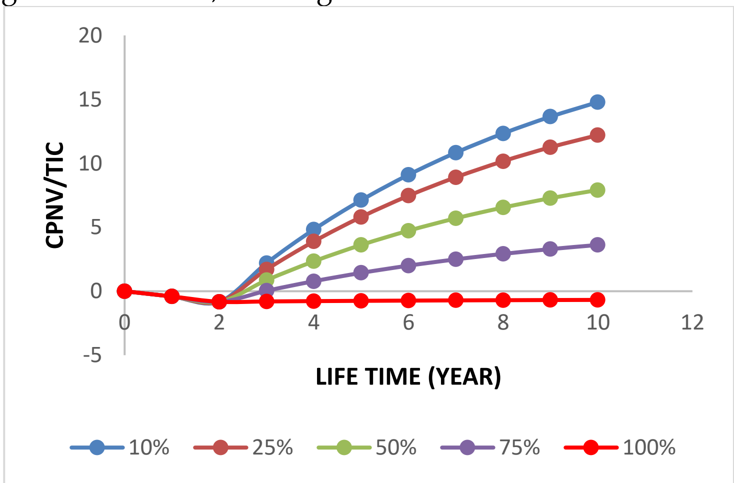

Figure 4. Variation tax increase against the CNPV/TIC

3.3 Variation in Raw Material Price Increase

Figure 5 shows the effect of various variations in raw material prices on CNPV/TIC in each year of production. The x-axis shows the year of production while the y-axis shows the CNPV/TIC value which is influenced by the increase in raw material prices. Based on Figure 5, if there is an increase in the price of raw materials, the CNPV/TIC graph will change. If the increase is 10-20%, then the payback period (PBP) and profits are reduced. This shows that the higher the price of raw materials, the smaller the profit and payback period (PBP). Vice versa,

International Journal of Research and Applied Technology

1(2)(2021) 289-299
Journal homepage: https://ojs.unikom.ac.id/index.php/injuratech

if the price of raw materials is low, i.e. 10-20% below the normal price, the profit and payback period (PBP) will increase.

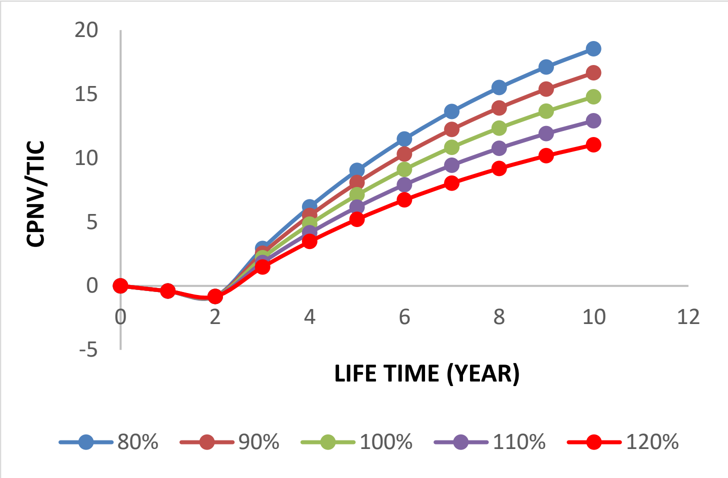

Figure 5. Variations in the increase in raw material prices against CNPV/TIC

3.4 Variation of Selling Price Increase

Figure 6 shows a graph of the effect of selling price variations on CNPV/TIC. The x-axis is the year of production, while the y-axis is the CNPV/TIC value which is affected by the selling price. The variations of increasing and decreasing selling prices used are 80, 90, 100, 110, and 120%. The graph shows that the higher the selling price, the greater the profit, while the lower the selling price, the smaller the profit. Based on the graph, the 120% selling price variance indicates the fastest payback period (PBP), while the 80% selling price variance indicates the late PBP. The payback period (PBP) is faster if the selling price is increased, whereas if the selling price is lowered, the PBP will be slower.

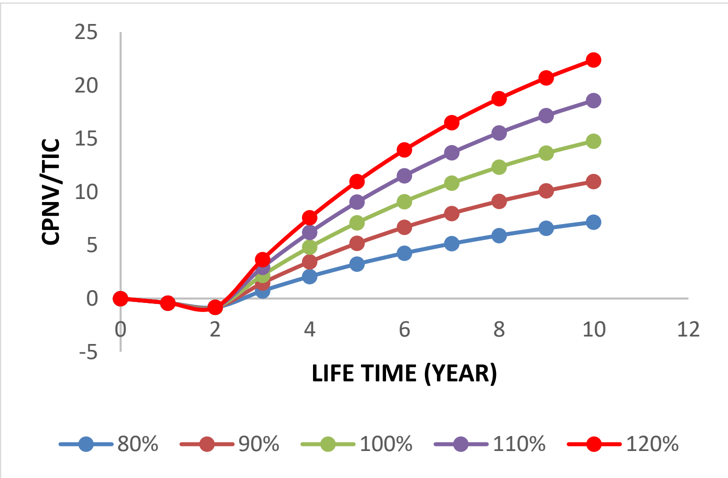

Figure 6. Variation of selling price increase against CNPV/TIC

3.5 Utilities Price Increase Variation

Figure 7 shows a graph of CNPV/TIC with various utility variations. The y-axis is CNPV/TIC and the x-axis is the year of production. The analysis is carried out by increasing and decreasing utility prices by 10 and 20%. The ideal utility cost is 100%, when the utility is reduced by 10 and 20% then the utility becomes 90 and 80% respectively. Meanwhile, when the utility is increased by 10 and 20%, the utility becomes 100 and 120%. The graph shows that there is no significant change of utility variation on the CNPV/TIC graph. Even from year 0 – 3 there is almost no change. The difference in CNPV/TIC values for variations of 80, 90, 100, 110, and 120% is 3.5; 3.3; 3.2; 3 and 2.7.

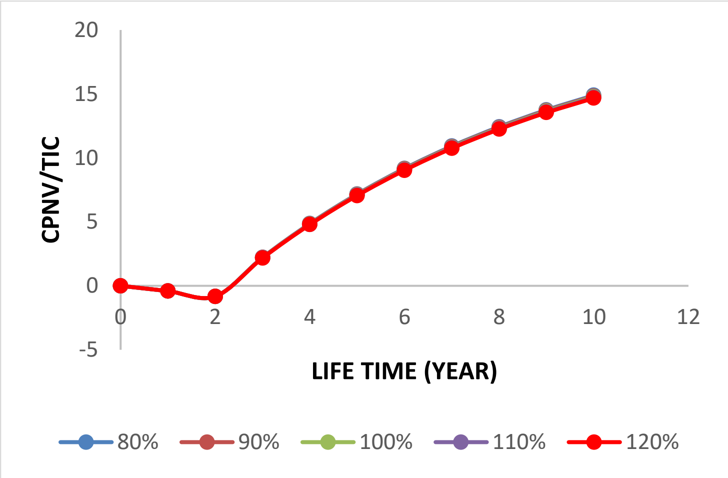

Figure 7. Variation of increase in utility prices to CNPV/TIC

4. Conclusion

In the study that has been carried out on the economic evaluation and layout of $NiFe_2O_4$ production using sonochemical methods. The results obtained in the economic evaluation are positive. Based on the Payback Period (PBP) it occurs in the third year of production and will increase for the next 10 years. Based on the tax rate, the higher the tax rate, the less profit will be made. Analysis of the value of CNPV/TIC and PBP is influenced by several factors such as the increase in tax prices, the decrease and increase in product prices, as well as the influence of raw material prices. The results of our research regarding the economic evaluation and layout of $NiFe_2O_4$ production using the sonochemical method are expected to provide an overview of the industrial scale of economic evaluation and layout, especially in the production of $NiFe_2O_4$ which is used as a humidity.

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International Journal of Research and Applied Technology

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