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Economic Evaluation of Cobalt Ferrite ($CoFe_2O_4$) Nanoparticles Using Thermal Decomposition Synthesis Method

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Abstract

The purpose of this study was to determine the technical and economic feasibility of a project to manufacture CoFe2O4 nanoparticles using the thermal decomposition synthesis method on an industrial scale. The method used in economic evaluation is to compare several parameters such as gross profile margin (GPM), payback period (PBP), breakeven points (BEP), internal rate return (IRR), cumulative net present value (CNPV), return on investment (ROI), and profitability index (PI). The results show that the production of CoFe2O4 nanoparticles is profitable on an industrial scale with a relatively lower selling price than the market price and a relatively small size. This project can run within nine years and the investment will be profitable within 2 years according to PBP results.

Keywords: *Cobalt Ferrite nanoparticles; Economic Evaluation; Thermal Decomposition Synthesis Method*

1. Introduction

Spinel ferrite belongs to an important class of magnetic materials [1]. Cobalt ferrite is a subset of spinel ferrite which has an inverted spinel structure. Under ideal conditions of cobalt ferrite, all Co^{2+} ions are at site B and Fe^{3+} ions are evenly distributing at site A and B [2]. Ferrite has many technological applications due to its combination of magnetic and electrical properties [1]. Cobalt ferrite has several properties such as relatively high coercivity, large enough magnetocrystalline anisotropy, and moderate saturation magnetization [3]. Recently, cobalt ferrite has attracted much attention because it has many applications in technological fields such as microwave devices, high density magnetic fields, and ferrous fluids [4]. Cobalt ferrite can be applied in the medical field of crystals because it has a high magneto-crystal anisotropy derived from spin-orbit coupling (L-S) on the lattice [5].

Several uses of cobalt ferrite in the medical field are in hyperthermia applications [6], genomic DNA isolation and purification [7], great potential for use as MRI contrast agents and drug carriers for diagnostic and therapeutic applications, therapeutic [8]. Various methods have been developed to synthesize cobalt ferrite nanoparticles such as sol-gel auto combustion [9-11], coprecipitation [12-14], reverse micelle [3,15,16], hydrothermal [17-19], microwave-assisted decomposition [20-22], and thermal decomposition [23-25]. The most appropriate method for economic evaluation analysis is the thermal decomposition method. This synthesis method is environmentally friendly because it can use non-toxic materials, tools and materials are commercially available, and produce products with a narrow diameter distribution [25].

The purpose of this study was to determine the technical and economic feasibility of a project to manufacture $CoFe_2O_4$ nanoparticles using the thermal decomposition synthesis method on an industrial scale. This study was carried out because there is no articles are describing the economic evaluation of the synthesis of $CoFe_2O_4$ nanoparticles in detail. In this study we vary several factors to see the effect on the economic evaluation, such as taxes, raw materials, sales, labor and utilities.

2. Method

2.1. Theoritical Synthesis of $CoFe_2O_4$ Nanoparticles

Synthesis of $CoFe_2O_4$ nanoparticles using thermal decomposition method begins with dissolving 5.464 g anhydrous $FeCl_3$ 25.2 mmol and 4.608 g $CoCl_2 \cdot 6H_2O$ 12.6 mmol in 240 ml ethylene glycol at room temperature. After 4 gram of sodium acetate was added to the mixture, the reddish black color solution was obtained. Then, the obtained solution stirred for 30 min at 110 °C along with the addition of 93 ml of ethanol amine. Afterwards, the temperature was increased to 160 °C and stayed at that temperature for 6 hours. The solution was refluxed during this heating process using a condenser and fine black colloidal particles appeared. Then it naturally cooled down. Ethanol was added to the mixture and magnet was used to separate the $CoFe_2O_4$ colloidal from the supernatant solution. The obtained products were then washed with ethanol for several times and were dried in rotary vacuum for 2 h at 50 °C. The heating process at a temperature of 160 °C carried out in this method can produce cobalt ferrite nanoparticles with a relatively small size, which is 4-14 nm [25]. The overall synthesis process of $CoFe_2O_4$ shown in Figure 1.

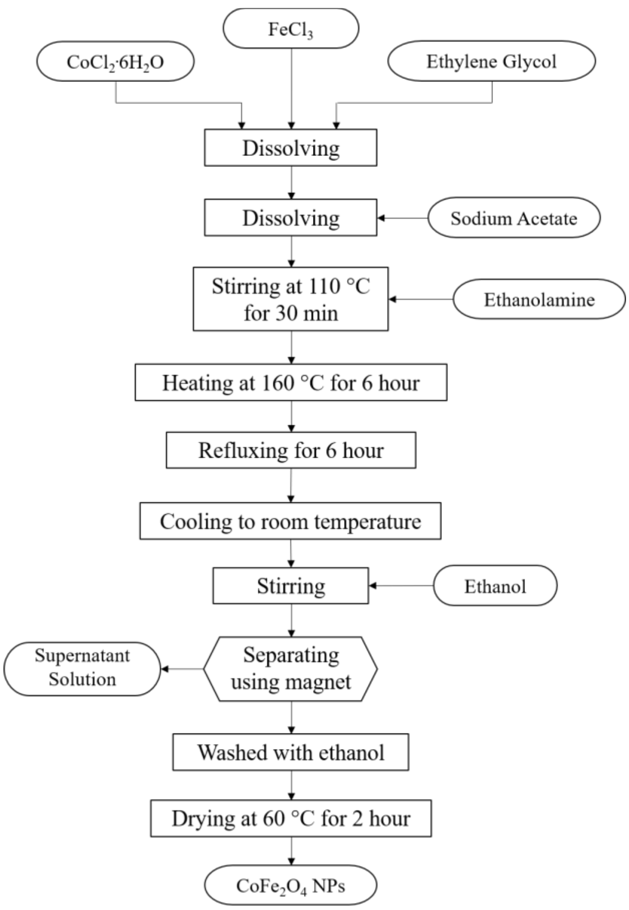

Figure 1. Synthesis of $CoFe_2O_4$ nanoparticles using thermal decomposition method

2.2. Economic Evaluation

The method used in this study derives from an analysis of the average price of commercially available products on the online shopping web to guarantee the current prices of materials and equipment. All data is calculated based on simple mathematical calculations using Microsoft Excel. Based on the literature [26], several parameters are using in economic evaluation, such as GPM, BEP, CNPV, PBP, IRR, and PI. The parameters in economic evaluation are explained in the following:

a. Gross Profit Margin (GPM) is an analysis that determines the level of profitability in a project. Deciding the GPM on a project can be calculated by subtracting the income from product sales with the price of raw materials.
b. Break-Even Point (BEP) is the minimum number of products that must sell at a specific price to cover production costs. BEP can be calculated by dividing the fixed cost (sales cost-variable cost) times the complete unit.
c. Cumulative Net Present Value (CNPV) calculates the total NPV from the start of factory construction to the end of factory operation. CNPV can be obtained as the sum of the cumulative financial flows in each year.
d. The payback period (PBP) calculates how long it will take to return the initial contest total. PBP can be calculated when CPNV reaches zero value for the first time.
e. The Internal Rate of Return (IRR) describes the average interest profit per year from all expenses and income of the same amount. Suppose the IRR is less than the prevailing genuine interest (current bank loan interest) the factory is considered a loss, the factory will profit when the IRR is greater than the overall genuine interest.
f. The profitability index (PI) is using to determine the relationship between project impact and costs. PI can be calculated by dividing the CNPV by the total investment cost (TIC). If the PI value is more than 1, then the project can be categorized as good, but if the PI value is less than 1, then the project can be classified as an unprofitable project.

Several assumptions are used to analyze and predict the possibilities that will occur during the project and this aims to confirm the economic analysis of this project. The assumptions are:

a. Calculation of 1 USD = IDR 15.000,00.
b. All item prices are based on online market prices.
c. The project lasts for 300 days/year
d. Synthesis of $CoFe_2O_4$ nanoparticles carried out two cycles/day.
e. Shipping costs are borne by the buyer.
f. $CoFe_2O_4$ nanoparticles are priced at 150 USD/Kg.
g. Total wages/labor is assumed to be fixed at 125 USD/day for 25 workers.
h. The duration of the project operation is nine years.

3. Result and discussion

3.1. Technical perspective

The making process is nanoparticles $CoFe_2O_4$ shown in Figure 2 with symbol information listed in Table 1. Based on the engineer perspective, the total cost for purchasing raw materials for one year is 1,960,860.00 USD. Sales in one year are 3,150,000.00 USD. The profit earned is 883,900.04 USD. The price of the equipment cost is 20,969.00 USD. From the total calculation analysis, a project requires substantial investment. The project went on for nine years. CNPV/TIC value in the 9th year reached 27.1915 and PBP achieved in year 3.

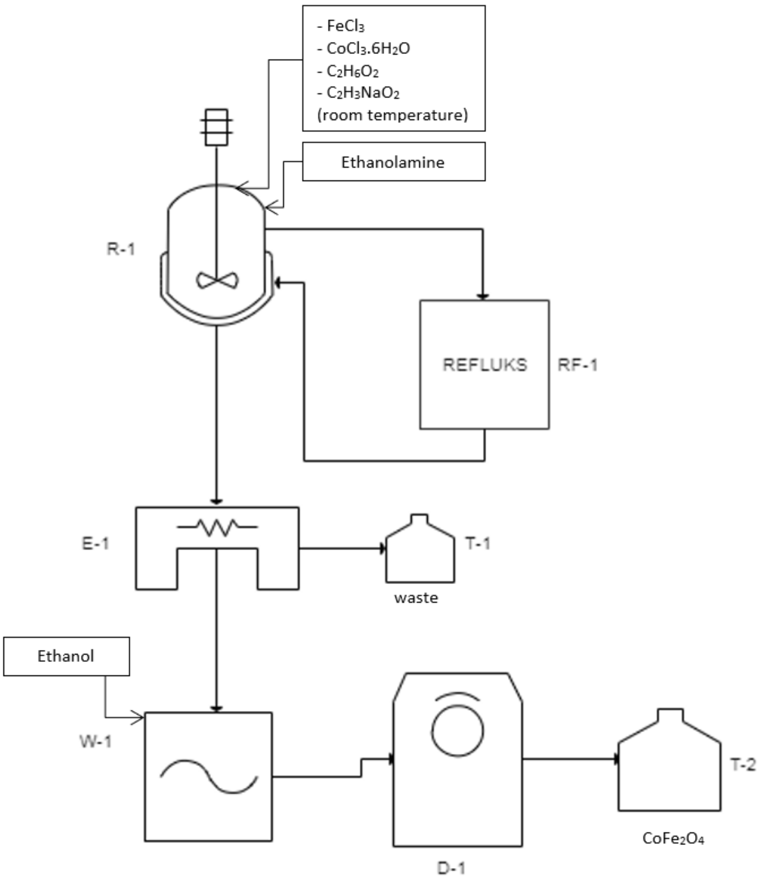

Figure 2. Process flow chart for $CoFe_2O_4$

Table 1. Process Flow Chart $CoFe_2O_4$ Nanoparticles

No	Symbol	Information
1	R-1	Reactor-1
2	RF-1	Reflux-1
3	E-1	Electromagnetic-1
4	T-1	Tank-1
5	T-2	Tank-2
6	W-1	Washer-1
7	D-1	Drayer

3.2. Economic Evaluation

3.2.1. Ideal conditions

Figure 3 shows a graph of the relationship between CNPV/TIC on the y-axis and lifetime (year) on the x-axis. The curve shows a decrease in income from the 1st year to the 2^{nd} year, and this is due to the initial capital cost for the production of $CoFe_2O_4$ nanoparticles. In year 3, the curve shows an increase in initial income or return on capital. This condition is called the payback period (PBP) [26]. The increase in revenue from the 3^{th} year to the 9^{th} year can cover the initial capital or capital reversal.

Based on Table 2 the lowest CNPV/TIC value is in the 2^{nd} year with a value of -0.8452, and then the curve shows an increase for the first time in the 3^{th} year to the 9^{th} year with the highest CNPV/TIC value in the 9^{th} year amounted to 27.1915. Thus, the production of $CoFe_2O_4$ nanoparticles can be considered profitable with a short time to recover investment costs.

3.2.2. The effects of external conditions

The economic condition of a country is an external factor that can affect a project. This factor can be in the form of tax provisions provided by a country. Taxes need to be considered in a project because they can affect profits. In this study, CNVP calculations were carried out with several variations of taxes for 9 years as can be seen in Figure 4. The x-axis shows the year the project was run (lifetime) and the y-axis shows the CNPV/TIC value. In this study, several variations of taxes were used, namely 10, 25, 50, 75, and 90%.

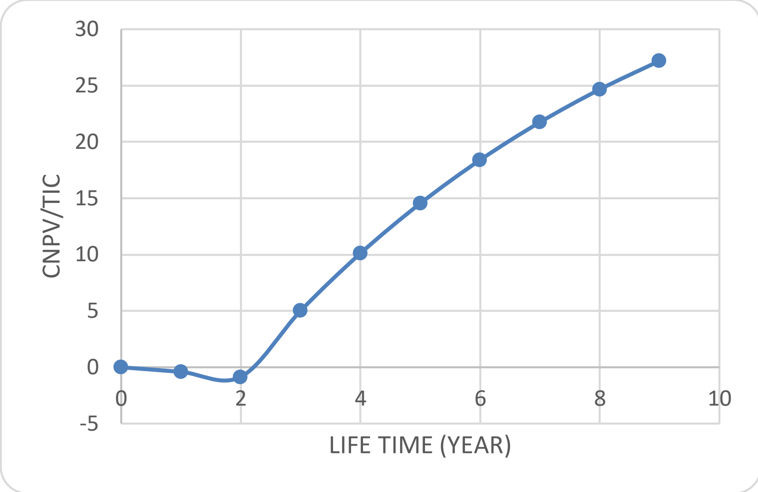

Figure 3. Graph of CNPV/TIC against lifetime (year) in ideal conditions.

Table 2. CNPV/TIC values under ideal conditions.

PI chart	
CNPV/TIC	**Year**
0	0
-0,4093	1
-0,8452	2
5,0147	3
10,1103	4
14,5412	5
18,3942	6
21,7447	7
24,6581	8
27,1915	9

Income is not obtained in the first and second years for all tax variations according to the PBP analysis, it is assumed because the project is still in development. Profits are obtained after the second year for tax variations of 10, 25, 50, and 75%. For the 90% tax variation, the profit is earned after the third year. These results indicate that the increase in taxes will affect the length of time the profits will be obtained. Variations in taxes also affect the amount of profit obtained. The bigger the tax increase, the lower the profit.

In the year when the curve decreases, the project capital cannot be covered and there is no income. The rising curve shows an increase in the project's profit on each tax variation but with a different amount of profit. The CNVP/TIC values in the third year for variations of 10, 25, 50, 75, and 90% respectively were 5.01; 4.04; 2.42; 0.8; and -0.16. Thus, in order to benefit from all tax variations in the third year, the maximum tax imposed should not be more than 75%. If above that, then the project does not get income in the 3rd year.

3.2.3. Change in sales

Figure 5 shows a graph of the relationship between CNPV and various sales variations, the y-axis is CNPV/TIC and lifetime (year) on the x-axis. The analysis is done by increasing and decreasing sales. Sales in ideal condition is 100%, and if reduced by 20 and 30%, sales will be 80 and 70% of ideal condition. The sales increase varied by 10 and 20% so that the sales became 110 and 120% from the ideal condition.

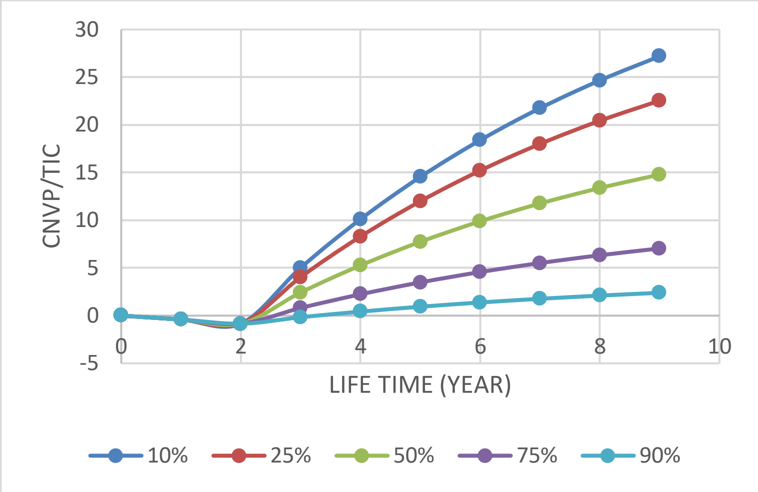

Figure 4. Graph of CNPV/TIC with tax variations against year

In Figure 5, it can be seen that the curve shows a decrease from year 1 to year 2 because there have been no sales but expenses for initial costs. The value of CNPV/TIC in year 3 for each variation of 120, 110, 100, 80, and 70% is 8.9144; 6.9645; 5.0147; 1.1150; and -0.8347%. With an increase in sales of 110 and 120%, it causes an increase marked by a curve that continues to increase and has a positive value. The cumulative Net Present Value/Total Investment Cost in the ninth year for each variation of 120, 110, 100, 80, and 70% is 45.8494; 36.5205; 27.1915; 8.5335; and -0.7953%. There is a constant decrease for the 70% sales variation, so a 30% decrease in sales will cause project losses. So, the minimum sales to get the BEP (the point at which the project's profit or loss) is 80%. Sales of $CoFe_2O_4$ nanoparticles will be more profitable if sales above 80% are indicated by a positive decent curve, so this project is worth doing [26].

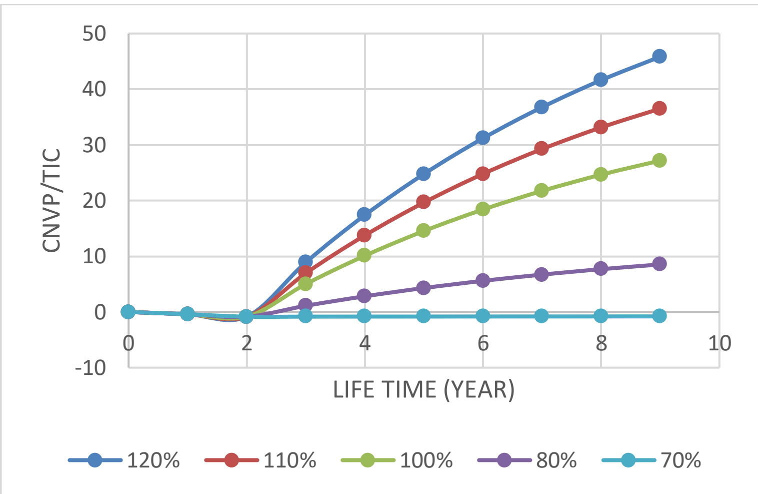

Figure 5. Graph of CNPV/TIC with sales variation against year.

3.2.4. Variable Cost Changes (Raw materials, Utilities, and Labor)

The conditions of raw materials, utility, and labor are among the factors that influence the success of a project. Figure 6 shows the CNVP/TIC graph with variations in raw materials price. Analysis of the variety of raw materials involves lowering and increasing the price of raw materials by 10 and 25% of the ideal conditions. The ideal raw material price is 100%. Variations of raw materials used in this analysis are 75, 90, 100, 110, and 125%.

The CPVN/TIC value is constant at the first 2 years of the project because the project is still running at the development stage. The decrease in the cost of raw materials leads to increased profits, and vice versa. The CPVN/TIC in the 9th year for variations in raw materials 75, 90, 100, 110, and 125% are 11.58; 20.95; 27.19; 33.43; and 42.80. The shortest time of payback period (3 years) with the biggest profit can obtained from the variation of raw materials 75% with the CPNV/TIC value of 8.28.

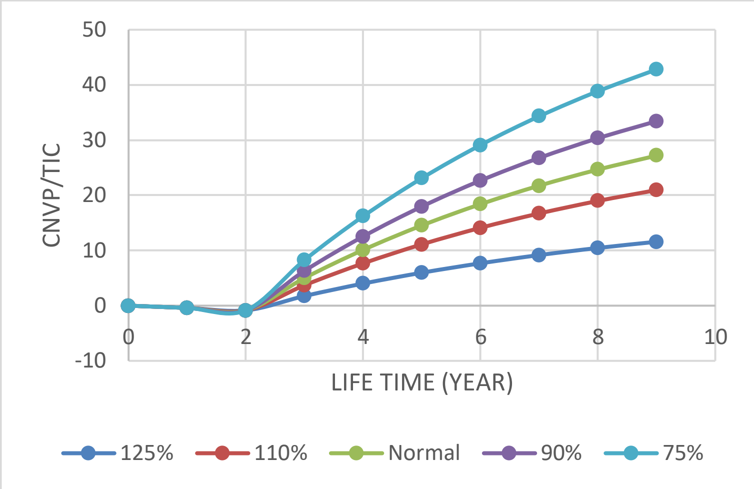

Figure 6. Graph of CPNV/TIC with variations in raw material prices against year

Analysis of the CNVP/TIC value against the year with various utility variations is shown in Figure 7. Variations are obtained by lowering and increasing the project utility price from ideal conditions. The utility variations used in this study are 130, 120, 100, 90, and 80%. Variation of 100% is the normal utility price. While variations above 100% indicate an increase in utility prices and variations below 100% indicate a decrease in utility prices.

Based on the PBP analysis, all variations indicate that income is obtained after the second year. In years 0 to 2 there is no income because the project is still in the development stage. Figure 7 shows that the curves of all utility variations look like they are stacked. This is because there is no significant effect of changes in utility prices on the CNVP/TIC value. The CNVP/TIC values in the third year for variations of 130, 120, 100, 90, and 80% were 5.0058; 5.0088; 5.0147; 5.0177; and 5.0206, respectively. The greatest profit will be obtained by the project at 80% utility variation or a 20% reduction in utility prices.

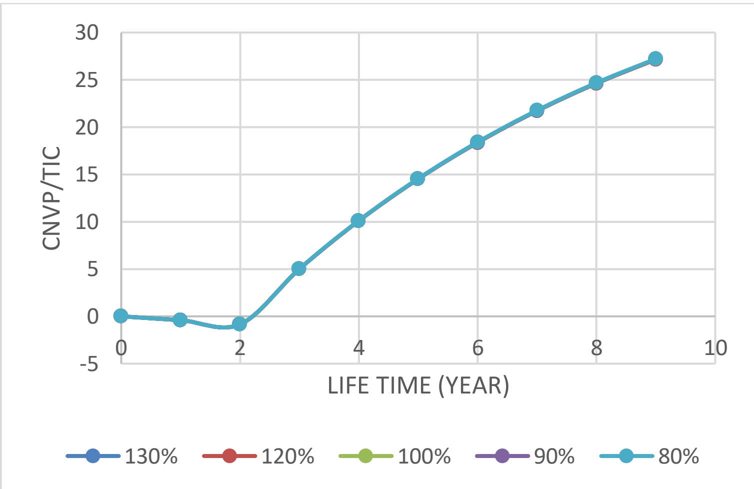

Figure 7. Graph of CNPV/TIC with utility variations against year

Figure 8 shows the CNPV/TIC graphics analyzed with various salary labor. The analysis is done by lowering and raising the salary labor by 10, 25, 40, and 80% from the ideal conditions. The variety of salary labor used in this analysis is 80, 100, 110, 125, and 140%, with the 100% as the ideal condition. The CPVN/TIC value constant at the beginning of the project (0-2 years) because the project is at the development stage. The increase in salary labor affects the decrease in project's profit. The biggest profit come from lower salary labor. The CPVN/TIC value in the 9th year for the variety of salary labor of 80, 100, 110, 125, and 140% each one is 26.40; 26.70; 27.00; 27.20; and 27.60. Based on the PBP analysis, the biggest profit obtained from the variation of salary labor 80% with CPNV/TIC value of 5.10.

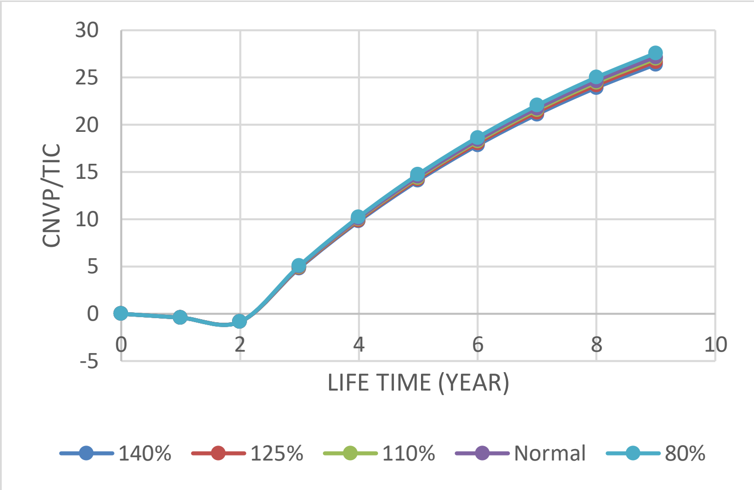

Figure 8. Graph of CPNV/TIC with salary labor variations against year

4. Conclusion

Based on the perspective of engineering and economic analysis, the production of cobalt ferrite nanoparticles by the thermal decomposition synthesis method can be carried out on a large scale. This project has promising advantages with a selling price that is relatively lower than the market price for cobalt ferrite nanoparticles and a relatively small size compared with the market size. This project can run within nine years and the investment will be profitable within 2 years according to PBP results. Changes in utility prices and salary labor have little effect on income. Other factors such as changes in taxes, sales, and raw materials have an effect on revenue but the project remain profitable within 2 - 3 years.

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Referensi

[1] A.B. Shinde, "Structural and Electrical Properties of Cobalt Ferrite Nanoparticles," *Int J Innov Technol Explor Eng*, vol. 3(4), 2013.

[2] M. Naseri, E. B. Saion, H. A. Ahangar, A. H. Shaari, and M. Hashim, M, "Simple Synthesis and Characterization of Cobalt Ferrite Nanoparticles by a Thermal Treatment Method," *Journal of Nanomaterials*, 2010.

[3] T. Sodaee, A. Ghasemi, E. Paimozd, A. Paesano, and A. Morisako, "An Approach For Enhancement of Saturation Magnetization in Cobalt Ferrite Nanoparticles by Incorporation of Terbium Cation," *Journal of Electronic Materials*, vol. 42(9), pp. 2771-2783, 2013.

[4] E. Pervaiz, I. H. Gul, and H. Anwar, "Hydrothermal Synthesis and Characterization of CoFe2O4 Nanoparticles and Nanorods," *Journal of Superconductivity and Novel Magnetism*, vol. 26(2), pp. 415-424, 2013.

[5] S. Amiri and H. H Shokrollahi, "The Role of Cobalt Ferrite Magnetic Nanoparticles in Medical Science," *Materials Science and Engineering: C*, vol. 33(1), pp. 1-8, 2013.

[6] S. W. Lee, S. Bae, Y. Takemura, I. B Shim, T. M. Kim, J. Kim, H. J. Lee, S. Zurn, and C. S. Kim, "Self-heating Characteristics of Cobalt Ferrite Nanoparticles for

Hyperthermia Application," *Journal of Magnetism and Magnetic Materials*, vol. 310(2), pp. 2868-2870, 2007.

[7] J. Prodělalová, B. Rittich, A. Španová, K. Petrová, and M. J. Beneš, "Isolation of genomic DNA Using Magnetic Cobalt Ferrite and Silica Particles," *Journal of Chromatography A*, vol. 1056(1-2), pp. 43-48, 2004.

[8] H. Wu, G. Liu, X. Wang, J. Zhang, Y. Chen, J. Shi, H. Yang, H. Hu, and S. Yang, "Solvothermal Synthesis of Cobalt Ferrite Nanoparticles Loaded on Multiwalled Carbon Nanotubes for Magnetic Resonance Imaging and Drug Delivery," *Acta Biomaterialia*, vol. 7(9), pp. 3496-3504, 2011.

[9] R. S. Yadav, I. Kuřitka, J. Vilcakova, J. Havlica, J. Masilko, L. Kalina, J. Tkacz, J. Švec, V. Enev, and M. Hajdúchová, "Impact of Grain Size and Structural Changes on Magnetic, Dielectric, Electrical, Impedance and Modulus Spectroscopic Characteristics of CoFe2O4 Nanoparticles Synthesized by Honey Mediated Sol-Gel Combustion Method," Advances in Natural Sciences: *Nanoscience and Nanotechnology*, vol. 8(4), 045002, 2017.

[10] V. P. Senthil, J. Gajendiran, S. G. Raj, T. Shanmugavel, G. R. Kumar, and C. P. Reddy, "Study of Structural and Magnetic Properties of Cobalt Ferrite (CoFe2O4) Nanostructures," *Chemical Physics Letters*, vol. 695, pp. 19-23, 2018.

[11] K. L. Routray, S. Saha, and D. Behera, "Green Synthesis Approach for Nano Sized CoFe2O4 Through Aloe Vera Mediated Sol-gel Auto Combustion Method for High Frequency Devices," *Materials Chemistry and Physics*, vol. 224, pp. 29-35, 2019

[12] M. Houshiar, F. Zebhi, Z. J. Razi, A. Alidoust, and Z. Askari, "Synthesis of Cobalt Cerrite (CoFe2O4) Nanoparticles Using Combustion, Coprecipitation, and Precipitation Methods: a Comparison Study of Size, Structural, and Magnetic properties," *Journal of Magnetism and Magnetic Materials*, vol. 371, pp. 43-48, 2014.

[13] M. K. Surendra, D. Kannan, and M. R. Rao, "Magnetic and Dielectric Properties Study of Cobalt Ferrite Nanoparticles Synthesized by Co-Precipitation Method," *MRS Online Proceedings Library (opl)*, vol 1368, 2011.

[14] E. Suharyadi, E. A. Setiadi, N. Shabrina, T. Kato, and S. Iwata, "Magnetic Properties and Microstructures of Polyethylene Glycol (Peg)-Coated Cobalt Ferrite (CoFe2O4) Nanoparticles Synthesized by Coprecipitation Method," *Advanced Materials Research*, vol. 896, pp. 126-133, 2014.

[15] S. Li, L. Liu, V. T John, C. J. O'Connor, and V. G Harris, "Cobalt-ferrite Nanoparticles: Correlations Between Synthesis Procedures, Structural Characteristics and Magnetic Properties," *IEEE Transactions on Magnetics*, vol. 37(4), pp. 2350-2352, 2001.

[16] S. Rana, J. Philip, and B. Raj, "Micelle Based Synthesis of Cobalt Ferrite Nanoparticles and Its Characterization Using Fourier Transform Infrared Transmission Spectrometry and Thermogravimetry," *Materials Chemistry and Physics*, vol. 124(1), pp. 264-269, 2010.

[17] H. Zhang, L. C Nengzi, B. Li, Q. Cheng, J. Gou, and X. Cheng, "Successfully Aynthesis of FeSe2/CoFe2O4 Heterojunction with High Performance for Hydrogen Evolution Reaction," Renewable Energy, vol. 155, pp. 717-724, 2020. [18] Zhao, L., Zhang, H., Xing, Y., Song, S., Yu, S., Shi, W., Guo, X., Yang, J., Lei, Y. and Cao, F. (2008). Studies on the magnetism of cobalt ferrite nanocrystals synthesized by hydrothermal method. *Journal of Solid State Chemistry,* 181(2), 245-252.

[19] N. T. Hien, N. X. Truong, V. T. K. Oanh, P. V. Hai, N. X. Ca, H. T. Van, and N. V. Vuong, "Preparation of Exchange Coupled CoFe2O4/CoFe2 Nanopowders," *Journal of Magnetism and Magnetic Materials*, vol. 511, 166984, 2020.

[20] P. T. Phong, N. X. Phuc, P. H. Nam, N. V. Chien, D. D. Dung, and P. H. Linh, "Size-controlled heating ability of CoFe2O4 nanoparticles for hyperthermia applications," *Physica B: Condensed Matter*, vol. 531, pp. 30–34, 2018.

[21] K. Maaz, A. Mumtaz, S. K. Hasanain, and A. Ceylan, "Synthesis and magnetic properties of cobalt ferrite (CoFe2O4) nanoparticles prepared by wet chemical route," *Journal of Magnetism and Magnetic Materials*, vol. 308(2), pp. 289–295, 2007

[22] S. Golchinvafa, S. Masoudpanah, and M. Jazirehpour, "Magnetic and Microwave Absorption Properties of FeCo/CoFe2O4 Composite Powders," *Journal of Alloys and Compounds*, vol. 809, 151746, 2019.

[23] Y. Eom, M. Abbas, H. Noh, and C. Kim, "Morphology-controlled Synthesis of Highly Crystalline Fe3O4 and CoFe2O4 Nanoparticles Using a Facile Thermal Decomposition Method," *RSC Advances*, vol. 6(19), pp. 15861–15867, 2016.

[24] S. Gyergyek, D. Makovec, A. Kodre, I. Arčon, M. Jagodič, and M. Drofenik, "Influence of Synthesis Method on Structural and Magnetic Properties of Cobalt Ferrite Nanoparticles," *Journal of Nanoparticle Research*, vol. 12(4), pp. 1263–1273, 2009.
[25] D. Soundararajan, and K. H. Kim, "Synthesis of CoFe2O4 Magnetic Nanoparticles by Thermal Decomposition," *Journal of Magnetics*, vol. 19(1), pp. 5-9, 2014.
[26] F. Nandatamadini, S. Karina, A. B. D Nandiyanto, and R. Ragadhita, "Feasibility Study Based on Economic Perspective of Cobalt Nanoparticle Synthesis with Chemical Reduction Method," *Cakra Kimia (Indonesian E-Journal of Applied Chemistry)*, vol. 7(1), pp. 61-68, 2019.