International Journal of Sustainable Transportation Technology
Vol. 4, No. 1, April 2021, 29-34

Techno-Economic Analysis of the $NiFe_2O_4$ Nanoparticles for Vehicle Battery Application Using the Hydrothermal Synthesis Method

Muhammad Aldin Nur Zen[1], Fatih Izzul Haq[1], Rachel Gabriella[1], Silmi Ridwan Putri[1], Asep Bayu Dani Nandiyanto[1*], Tedi Kurniawan[2]

[1]Department of Chemistry, Faculty of Mathematics and Natural Sciences Education, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi no. 229, Bandung 40154, Jawa Barat, Indonesia
[2]Community College of Qatar, Qatar
**Email: nandiyanto@upi.edu*

Abstract

The purpose of this paper is to evaluate the economic and industrial scale of the production of $NiFe_2O_4$ for vehicle batteries using the hydrothermal synthesis method. 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). $NiFe_2O_4$ nanoparticles were synthesized with the main raw materials being $NiCl_2 \cdot 6H_2O$, $FeCl_3 \cdot 6H_2O$, and NaOH (1:2:8). Calculation results from GPM and CNPV/TIC from the $NiFe_2O_4$ industry using the hydrothermal 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. It is expected that $NiFe_2O_4$ can be applied on an industrial scale for Li-ion battery anodes.

Keywords

Economic evaluation; Hydrothermal; $NiFe_2O_4$; Li-Ion

1 Introduction

At present, Li-ion batteries are very widely used, especially for rechargeable batteries of electronic devices, such as laptops, computers, telephones, and vehicles [1-4]. Therefore, there is a huge demand for Li-ion battery consumption. The electrode material having high capacity and high magnification performance are the main properties for the next generation of lithium-ion batteries. More and more researchers are starting to pay attention to those materials which have a high specific capacity and abundant resources for superior performance [4]. Carbon and metal oxides can be combined into one electrode to improve the electrochemical properties of electrodes such as RuO_2, MnO_2, Fe_2O_3, ZnO, In_2O_3 [5]. However, the transition metal ferrite, $NiFe_2O_4$, 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 the tetrahedral [4]. Such structures are beneficial for electron transport and can provide the necessary surface redox-active sites for the storage of larger amounts of lithium ions [6,7]. $NiFe_2O_4$ is an attractive candidate for energy storage applications due to its good chemical stability, good catalytic properties as well as inexpensive and abundant storage on earth. However, $NiFe_2O_4$ has poor electrical conductivity, but this problem can be solved by adding a conducting material to $NiFe_2O_4$ [5].

There are several methods of $NiFe_2O_4$ synthesis reported by researchers, including the hydrothermal method [8-18], coprecipitation [19-23], citrate precursor [24-26], mechanical alloy [27-29], sonochemical [30-35], reverse micelle [36-40], sol-gel [41-43], and pulsed wire discharge [44-46]. The most appropriate method used in economic evaluation is hydrothermal because the reaction process is simple, the raw materials are easy to obtain, and are environmentally friendly, and do not require high temperatures in the calcination process. Therefore, this study aimed 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, such as increases in tax prices, decreases and increases in product prices, and the effect of raw material prices.

2 Experiment

2.1 Theoretical synthesis of $NiFe_2O_4$ nanoparticles

The chemicals used are "AR grade" and are purchased at various online stores such as www.alibaba.com, www.amazon.com, www.tokopedia.com, and www.merck.com. The synthesis method used is the hydrothermal method by dissolving $NiCl_2 \cdot 6H_2O$, $FeCl_3 \cdot 6H_2O$ and NaOH (1:2:8) in 70 mL of deionized

Received April 5, 2021, Revised April 19, 2021, Accepted for publication April 26, 2021

water, while NaOH is dissolved separately in 30 mL of water and added slowly to the previous solution. The solution was stirred with a magnetic stirrer for 30 minutes so that all the ingredients reacted perfectly. Next, the stirred solution was poured into a Teflon-coated stainless steel autoclave at a temperature of about 220°C for 15 hours. After the reaction was completed, the mixture was naturally cooled to room temperature, the brown precipitate was collected with a magnet and washed with water. Finally, the resulting $NiFe_2O_4$ nanoparticles were then dried overnight at 90. The schematic of the $NiFe_2O_4$ synthesis process is shown in Figure 1.

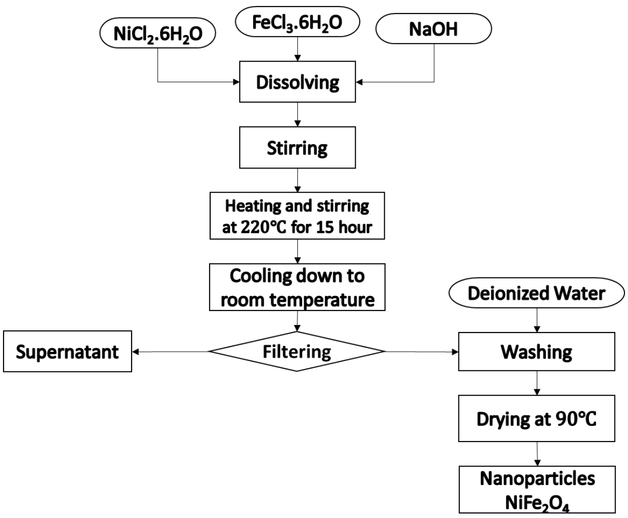

Figure 1 Flowchart of the synthesis $NiFe_2O_4$ nanoparticles

2.2 Energy and mass balance

The materials needed for the synthesis of $NiFe_2O_4$ are 4,1595 g $NiCl_2.6H_2O$, 9,4601 g $FeCl_3$. $6H_2O$, 2,4 g NaOH, and 170 mL H_2O. The solution was prepared by dissolving 4,1595 g $NiCl_2.6H_2O$ and 9,4601 g $FeCl_3$. $6H_2O$ into 70 mL H_2O, while 2,4 g NaOH was dissolved in 30 mL H_2O separately and drop by drop. Then, the solution was stirred for 30 minutes with a magnetic stirrer. The synthesis process was carried out in an autoclave of Teflon-coated stainless steel at a temperature of about 220°C for 15 hours. After the reaction was completed, the mixture was naturally cooled to room temperature, the brown precipitate was collected with magnets and washed with water. Finally, the resulting $NiFe_2O_4$ nanoparticles were then dried overnight at 90°C. The reaction is as follows:

1. $NiCl_2.6H_2O_{(s)} + H_2O_{(l)} \longrightarrow Ni^{2+}{}_{(aq)} + 2Cl^{-}{}_{(aq)} + 7H_2O_{(l)}$
1. $FeCl_3.6H_2O_{(s)} + H_2O_{(l)} \longrightarrow Fe^{3+}{}_{(aq)} + 3Cl^{-}{}_{(aq)} + 7H_2O_{(l)}$
2. $Ni^{2+}{}_{(aq)} + 2Fe^{3+}{}_{(aq)} + 8Cl^{-}{}_{(aq)} + H_2O_{(l)} + 8NaOH_{(aq)} \longrightarrow NiFe_2O_{4(s)} + 8NaCl_{(s)} + 5H_2O_{(l)}$

From a technical point of view, the production of $NiFe_2O_4$ nanoparticles allows it to be increased because the capacity and quantity of tools and materials used can be enlarged. To produce about 100 kg of $NiFe_2O_4$ nanoparticles in one day, it takes one reaction cycle using about 100 kg of $NiCl_2.6H_2O$, 225 kg of $FeCl_3$. $6H_2O$, 150 kg NaOH, and 5106 L H_2O. With a total cost of raw materials of IDR 57,945,125.00 and a one-year profit of $4,500,000 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 the hydrothermal method.

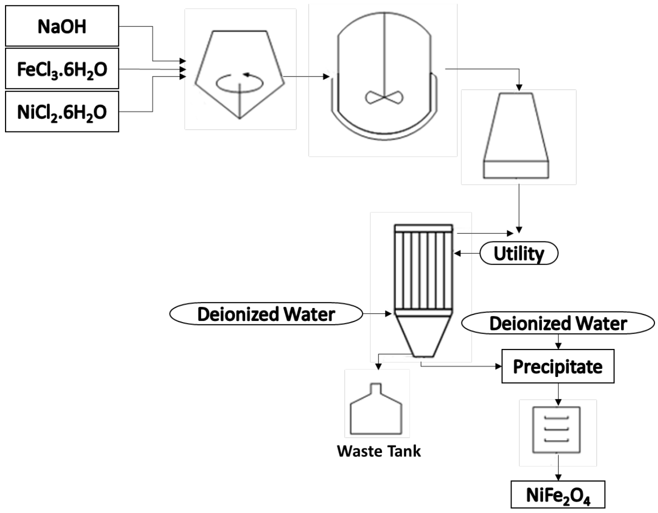

Figure 2 Flow diagram of the production process of $NiFe_2O_4$ nanoparticles using the hydrothermal method

2.3 Economic evaluation

In this economic evaluation, the existing price data are obtained from several sources such as www.alibaba.com, www.amazon.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 capital or initial cost that must be present at the beginning of production. TIC is usually calculated based on the total cost of the plant [47].
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 [48].
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 the CNPV is at zero for the first time [49].

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 [50].
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 [49].
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 [49].

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:

1. The exchange rate used is 1 USD = Rp. 15.000,00.
2. Based on commercially available prices against raw material prices: 1 kg $NiCl_2.6H_2O$ is Rp. 100.280; 1 kg $FeCl_3$. $6H_2O$ is Rp. 176.965; 1 kg of NaOH is Rp. 54.000. All materials were calculated stoichiometrically.
3. One production cycle is for 15 hours.
4. The tax issued is 10%.
5. Based on the commercial price available for the equipment used, the total cost of the equipment is Rp. 85.384.097,-.
6. The production process lasts for 300 days in one year.
7. To simplify the utility calculation, we assume about 9,425 kWh in one day of production. The price for 1 kWh is Rp. 1.380,-.
8. The total salary/employee is 266.8 USD/day for 40 people.
9. 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 Result and Discussion

3.1 CNVP in ideal circumstances

Figure 3 shows the relationship between Profit Investment or Cumulative Net Present Value (CNPV) per Total Investment Cost (TIC) with the year of production. The figure shows constant income in the first year of production. In the second year, the factory's income decreased. However, in the second year, the income began to increase so that it reached the point where the total initial expenditure returned. The lowest CNPV/TIC was in the second year of production, namely -0.82759.

The third year is the point of increasing income or known as the Payback Period (PBP). From the third year to the tenth year, production profits are seen increasing due to the achievement of the Payback Period (PBP), ie the value of CNPV/TIC is positive. It can be concluded that the $NiFe_2O_4$ production project using the hydrothermal method is a possible project because there are benefits, although in the first two years of production there is a decrease in the value of CNPV/TIV, in the third year and so on, there is an increase.

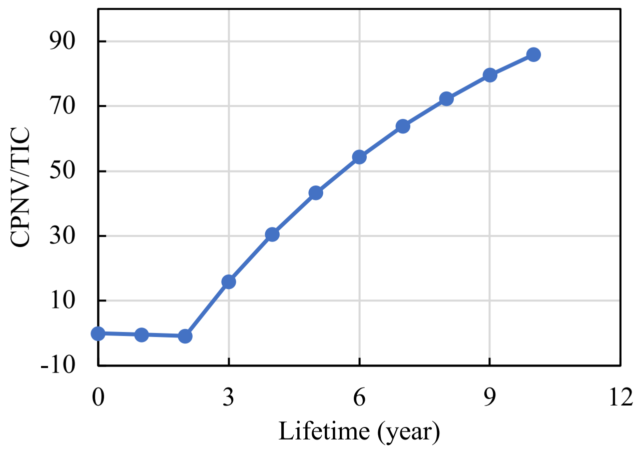

Figure 3 Flow diagram of the production process of $NiFe_2O_4$ nanoparticles using the hydrothermal method

3.2 Variation of tax increase

Figure 4 shows 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 curve shows that the higher the tax rate, the less profit is received. Therefore, the PBP value for each variation of the tax increase is different. The higher the tax rate, the longer the PBP.

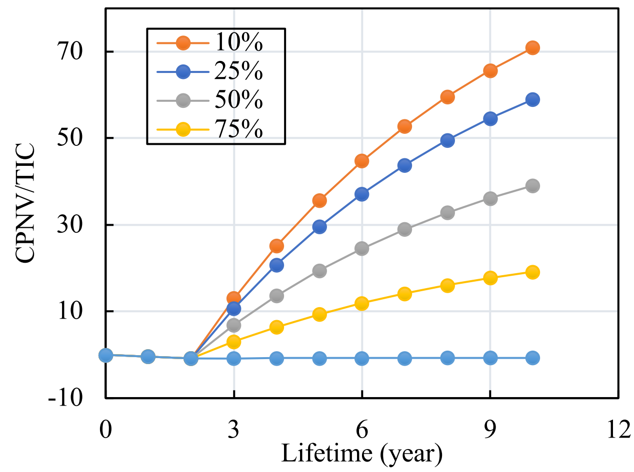

Figure 4 Variation of tax increase CNPV/TIC

3.3 Variations in raw material price increase

Figure 5 shows the variation in the price of CNPV/TIC raw materials against the year of production. The x-axis shows the year of production, while the y-axis is the CNPV/TIC value which is affected 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 curves will change. If the increase is 0%, the payback period (PBP) and profits are reduced. This shows that the smaller the material, the smaller the profit and payback period (PBP) [51].

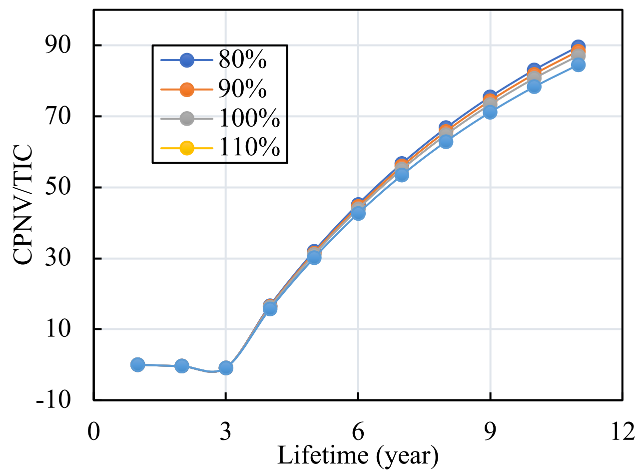

Figure 5 Variations of increase in raw material prices against CNPV/TIC

3.4 Variation of selling price increase

Figure 6 shows 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 figure shows that the higher the selling price, the greater the profit, while the lower the selling price, the smaller the profit. Based on the figure, 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, while if the selling price is lowered, the PBP will be slower.

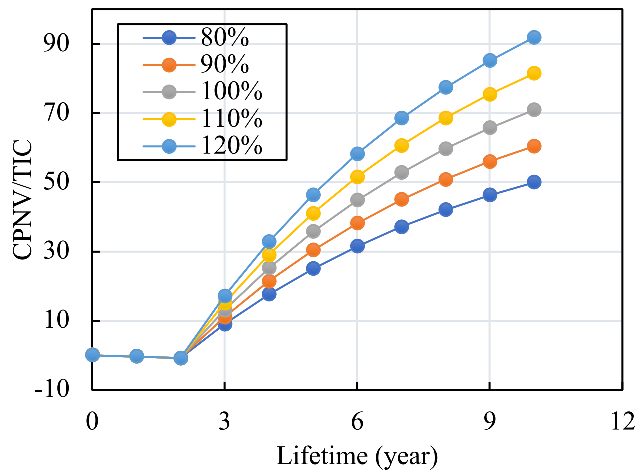

Figure 6 Variation of selling price increase against CNPV/TIC

3.5 Utilities price increase variation

Figure 7 shows the effect of CNPV/TIC under 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 110 and 120%. There is no significant change of utility variation on the CNPV/TIC. However, the value of CNPV/TIC experienced a large difference in the 10th year in each variation. The difference in the value of CNPV/TIC for each variation of 80,90,100,110,120% is 3.5; 3.3; 3.1; 3 and 2.8.

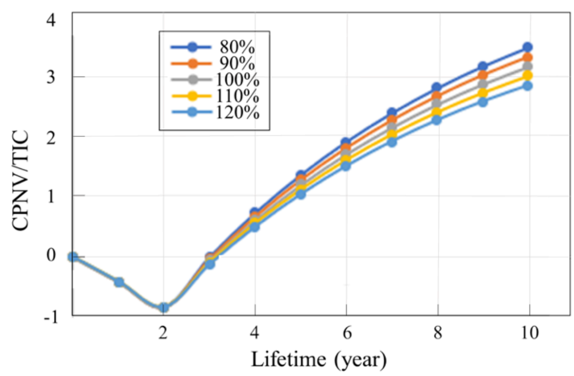

Figure 7 Variation of increase in utility prices against CNPV/TIC

4 Conclusion

In a study that has been carried out on the economic evaluation and layout of $NiFe_2O_4$ production using the hydrothermal method. The results obtained in the economic evaluation are good. 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 price variations, sales tax, and selling price. The results of our research regarding the economic evaluation and layout of $NiFe_2O_4$ production using the hydrothermal method are expected to provide an industrial-scale overview of economic evaluation and layout, especially in the production of $NiFe_2O_4$, which is used as an anode of lithium-ion batteries.

Acknowledgment

We acknowledged *Pengembangan Dosen dan Kapasitas Institusi* program from Universitas Pendidikan Indonesia.

References

[1] Z. Zhang, D.-H. Wu, Z. Zhou, G.-R. Li, S. Liu dan X.-P. Gao, "Sulfur/nickel ferrite composite as cathode with high-volumetric-capacity for lithium-sulfur battery," *Sci. China Mater*, vol. 62, no. 1, pp. 74-86, 2019.

[2] H. Zhao, Z. Zheng, K. W. Wong, S. Wang, B. Huang dan D. Li, "Fabrication and electrochemical performance of nickel ferrite nanoparticles as anode material in lithium ion batteries," *Electrochem. commun.*, vol. 9, no. 10, pp. 2606-2610, 2007.

[3] A. Chairunnisa, S. A. Wulandari, S. Salsabila, S. R. Putri, W. Maryam dan A. B. D. Nandiyanto, "Economic and Technical Evaluation of LifePO4 Production using Hydrothermal Method," *Int. J. Energetica*, vol. 5, no. 2, pp. 07-11, 2020.

[4] X. Tong, L. Zhao, X. Lin, X. Pan, J. Zhang, X. Duan dan Q. L, "High-index faceted nickel ferrite nanocrystals encapsulated by graphene with high performance for lithium-ion batteries," *Electrochim. Acta*, vol. 257, pp. 99-108, 2017.

[5] A. Soam, R. Kumar, D. Thatoi dan M. Singh, "Electrochemical performance and working voltage optimization of nickel ferrite/graphene composite based supercapacitor," *J. Inorg. Organomet. Polym. Mater.*, vol. 30, no. 9, pp. 3325-3331, 2020.

[6] M. Li, Y. Xiong, X. Liu, X. Bo, Y. Zhang, C. Han dan L. Guo, "Facile synthesis of electrospun MFe 2 O 4 (M= Co, Ni, Cu, Mn) spinel nanofibers with excellent electrocatalytic properties for oxygen evolution and hydrogen peroxide reduction," *Nanoscale*, vol. 7, no. 19, pp. 8920-8930, 2015.

[7] J. Wang, G. Yang, L. Wang dan W. Yan, "Synthesis of one-dimensional NiFe2O4 nanostructures: tunable morphology and high-performance anode materials for Li ion batteries," *J. Mater. Chem. A*, vol. 4, no. 22, pp. 8620-8629, 2016.

[8] K. Byrappa dan T. Adschiri, "Hydrothermal technology for nanotechnology," *Prog. Cryst. Growth Charact.*, vol. 53, no. 2, pp. 117-166, 2007.

[9] L. Chen, H. Dai, Y. Shen dan J. Bai, "Size-controlled synthesis and magnetic properties of NiFe2O4 hollow nanospheres via a gel-assistant hydrothermal route," *J. Alloys Compd.*, vol. 491, no. 1-2, pp. 33-38, 2010.

[10] D. K. Dinkar, B. Das, R. Gopalan dan B. S. Dehiya, "Effects of surfactant on the structural and magnetic properties of hydrothermally synthesized NiFe2O4 nanoparticles," *Mater. Chem. Phys.*, vol. 218, pp. 70-76, 2018.

[11] K. G, N. N, C. SM dan L. LH, "Hydrothermal synthesis of NiFe2O4 nanoparticles as an efficient electrocatalyst for the electrochemical detection of bisphenol," *New J. Chem.*, vol. 44, no. 19, pp. 7698-7707, 2020.

[12] L. X. Yang, Y. J. Zhu, H. Tong, Z. H. Liang, L. Li, L. Zhang, "Hydrothermal synthesis of nickel hydroxide nanostructures in mixed solvents of water and alcohol," *J. Solid State Chem.*, vol. 180, no. 7, pp. 2095-2101, 2007.

[13] F. Majid, J. Rauf, S. Ata, I. Bibi, A. Malik, S. Ibrahim dan M. Iqbal, "Synthesis and characterization of NiFe2O4 ferrite: Sol-gel and hydrothermal synthesis routes effect on magnetic, structural and dielectric characteristics," *Mater. Chem. Phys.*, vol. 258, p. 123888, 2020.

[14] B. Paul, D. D. Purkayastha dan S. S. Dhar, "Size-controlled synthesis of NiFe2O4 nanospheres via a PEG assisted hydrothermal route and their catalytic properties in oxidation of alcohols by periodic acid," *Appl. Surf. Sci.*, vol. 370, pp. 469-475, 2016.

[15] M. Safaei, H. Beitollahi dan M. R. Shishehbore, "Synthesis and characterization of NiFe2O4 nanoparticles using the hydrothermal method as magnetic catalysts for electrochemical detection of norepinephrine in the presence of folic acid," *J. Chinese Chem. Soc.*, vol. 66, no. 12, pp. 1597-1603, 2019.

[16] V. A. Samson, S. B. Bernadsha, R. Xavier, C. S. T. Rueshwin, S. Prathap, J. Madhavan dan M. V. A. Raj, "One pot hydrothermal synthesis and characterization of NiFe2O4," *Mater. Today: Proc.*, pp. 1-3, 2020.

[17] A.A.Sattar, H.M.EL-Sayed dan Ibrahim.ALsuqia, "Structural and magnetic properties of CoFe2O4/NiFe2O4 core/shell nanocomposite prepared by the hydrothermal method," *J. Magn. Magn. Mater.*, vol. 395, pp. 89-96, 2015.

[18] J. Zhou, J. Ma, C. Sun, L. Xie, Z. Zhao, H. Tian, Y. Wang, J. Tao dan X. Zhu, "Low-Temperature Synthesis of NiFe2O4 by a Hydrothermal Method," *J. Am. Ceram. Soc.*, vol. 88, no. 12, p. 3535–3537, 2005.

[19] S. Sagadevan, Z. Z. Chowdhury dan R. F. Rafique, "Preparation and Characterization of Nickel ferrite Nanoparticles via Co-precipitation Method," *Mater. Res.*, p. 21, 2018.

[20] P.Sivakumar, R.Ramesh, A.Ramanand, S.Ponnusamy dan C.Muthamizhchelvan, "Synthesis and characterization of NiFe2O4 nanosheet via polymer assisted co-precipitation method," *Mater. Lett.*, vol. 65, no. 3, pp. 483-485, 2011.

[21] E. Agouriane, A. Essoumhi, A. Razouk, M. Sahlaoui dan M. Sajieddine, " X-ray diffraction and Mössbauer studies of NiFe2O4 nanoparticles obtained by co-precipitation method," *J. Mater. Environ. Sci.*, vol. 7, no. 12, pp. 4614-4619, 2016.

[22] J. Li, Y. Lin, X. Liu, Q. Zhang, H. Miao, T. Zhang dan B. Wen, "The study of transition on NiFe2O4 nanoparticles prepared by co-precipitation/calcination," *Ph. Transit.*, vol. 84, no. 1, pp. 49-57, 2011.

[23] M. Aliahmad, M. Noori, N. Hatefi Kargan dan M. Sargazi, "Synthesis of Nickel Ferrite Nanoparticles by Co-precipitation Chemical Method," *Int. J. Phys. Sci.*, vol. 8, no. 18, pp. 854-858, 2012.

[24] S. Prasad dan N. Gajbhiye, "Magnetic studies of nanosized nickel ferrite particles synthesized by the citrate precursor technique," *J. Alloys Compd.*, vol. 265, no. 1-2, pp. 87-92, 1998.

[25] L. Cerda dan S. M.Montemayor, "Synthesis of CoFe2O4 Nanoparticles Embedded in a Silica Matrix by The Citrate Precursor Technique," *J. Magn. Magn. Mater.*, vol. 294, no. 2, pp. 43-46, 2005.

[26] N. Yang, H. Yang, J. Jia dan X. Pang, "Formation and magnetic properties of nanosized PbFe12O19 particles synthesized by citrate precursor technique," *J. Alloys Compd.*, vol. 438, no. 1-2, pp. 263-267, 2007.

[27] A. Hajalilou, M. Hashim, R. Ebrahimi-Kahrizsangi, H. M. Kamari dan S. Kanagesan, "Parametric optimization of NiFe 2 O 4 nanoparticles synthesized by mechanical alloying," *Mater. Sci.-Pol*, vol. 32, no. 2, pp. 281-291, 2014.

[28] S. B. Waje, M. Hashim, W. D. W. Yusoff dan Z. Abbas, " X-ray Diffraction Studies on Crystallite Size Evolution of CoFe2O4 Nanoparticles Prepared Using Mechanical Alloying and Sintering," *Appl. Surf. Sci.*, vol. 256, no. 10, pp. 3122-3127, 2010.

[29] C. Suryanarayana, "Mechanical Alloying and Milling," *Prog. Mater. Sci.*, vol. 46, no. 1-2, pp. 1-184, 2001.

[30] M. S. Amulya, H. Nagaswarupa, M. A. Kumar, C. Ravikumar, S. Prashantha dan K. Kusuma, "Sonochemical synthesis of NiFe2O4 nanoparticles: Characterization and their photocatalytic and electrochemical applications," *Appl. Surf. Sci. Adv.*, vol. 1, p. 100023, 2020.

[31] S. I. Liba, M. Tariq, H. N. Das, A. Nahar dan S. M. Hoque, "Effect of sintering treatment on the microstructure of NiFe2O4 synthesized by the sonochemical method and the conventional method," *AIP Adv.*, vol. 10, no. 6, p. 065103, 2020.

[32] K. V. Shafi, Y. Koltypin, A. Gedanken, R. Prozorov, J. Balogh, J. Lendvai dan I. Felner, "Sonochemical preparation of nanosized amorphous NiFe2O4 particles," *J. Phys. Chem. B*, vol. 101, no. 33, pp. 6409-6414, 1997.

[33] Y.Slimani, B.Unal, M.A.Almessiere, A. D. Korkmaz, S. E.Shirsath, G. Yasin, A.V.Trukhanov dan A.Baykal, "Investigation of structural and physical properties of Eu3+ ions substituted Ni0. 4Cu0. 2Zn0. 4Fe2O4 spinel ferrite nanoparticles prepared via sonochemical approach," *Results Phys.*, vol. 17, p. 103061, 2020.

[34] H. Xu, B. W. Zeiger dan K. S. Suslick, "Sonochemical synthesis of nanomaterials," *Chem. Soc. Rev.*, vol. 42, no. 7, pp. 2555-2567, 2013.

[35] S. R. Yousefi, O. Amiri dan MasoudSalavati-Niasari, "Control sonochemical parameter to prepare pure Zn0. 35Fe2. 65O4 nanostructures and study their photocatalytic activity.," *Ultrason. Sonochem.*, vol. 58, p. 104619, 2019.

[36] A. Kale, S.Gubbala dan R. Misra, "Magnetic behavior of nanocrystalline nickel ferrite synthesized by the reverse micelle technique," *J. Magn. Magn. Mater.*, vol. 277, no. 3, pp. 350-358, 2004.

[37] R. D. K. Misra, S. Gubbala, A. Kale dan W. F. Egelhoff Jr, "A comparison of the magnetic characteristics of nanocrystalline nickel, zinc, and manganese ferrites synthesized by reverse micelle technique.," *Mater. Sci. Eng. B*, vol. 111, no. 2-3, pp. 164-174, 2004.

[38] K. M. Reddy, L. Satyanarayana, S. V. Manorama dan R. Misra, "comparative study of the gas sensing behavior of nanostructured nickel ferrite synthesized by hydrothermal and reverse micelle techniques," *Mater. Res. Bull.*, vol. 39, no. 10, pp. 1491-1498, 2004.

[39] H. Nathani, S. Gubbala dan R. Misra, "Magnetic behavior of nanocrystalline nickel ferrite: Part I. The effect of surface roughness," *Mater. Sci. Eng. B*, vol. 121, no. 1-2, pp. 126-136, 2005.

[40] S. Thakur, S. C. Katyal dan M. Singh, "Structural and magnetic properties of nano nickel–zinc ferrite synthesized by reverse micelle technique," *J. Magn. Magn. Mater.*, vol. 321, no. 1, pp. 1-7, 2009.

[41] F. Majid, J. Rauf, S. Ata, I. Bibi, A. Malik, S. M.Ibrahim, A. Alif dan M. Iqbal, "Synthesis and Characterization of NiFe2O4 ferrite: Sol-Gel and Hydrothermal Synthesis Routes Effect on Magnetic, Structural and Dielectric Characteristics," *Mater. Chem. Phys.*, vol. 258, pp. 1-28, 2021.

[42] D.-H. Chen dan Xin-RongHe, "Synthesis of nickel ferrite nanoparticles by sol-gel method," *Mater. Res. Bull.*, vol. 36, no. 7-8, pp. 1369-1377, 2001.

[43] M. George, A. M. John, S. S.Nair, P. Joy dan M. Anantharaman, "Finite size effects on the structural and magnetic properties of sol–gel synthesized NiFe2O4 powders," *J. Magn. Magn. Mater.*, vol. 302, no. 1, pp. 190-195, 2006.

[44] W. Jiang dan K. Yatsui, "Pulsed wire discharge for nanosize powder synthesis," *IEEE Trans. Plasma Sci.*, vol. 26, no. 5, pp. 1498-1501, 1998.

[45] S. Ishihara, HisayukiSuematsu, T. Nakayama, T. Suzuki dan K. Niihara, "Nano-sized particles formed by pulsed discharge of powders," *Mater. Lett.*, vol. 67, no. 1, pp. 289-292, 2012.

[46] Y. Tokoi, H. B. Cho, T. Suzuki, T. Nakayama, H. Suematsu dan K. Niihara, "Particle size determining equation in metallic nanopowder preparation by pulsed wire discharge.," *Jpn. J. Appl. Phys*, vol. 52, no. 5R, p. 055001, 2013.

[47] F. Nantamandini, S. Karina, A. B. D. Nandiyanto dan R. Ragaditha, "Feasibility study based on economic perspective of cobalt nanoparticle synthesis with chemical reduction method," *Cakra Kimia (Indones. J. Chem.)*, vol. 7, no. 1, pp. 61-68, 2019.

[48] K. Hayat, M. Gondal, M. M. Khaled, S. Ahmed dan A. M. Shemsi, "Nano ZnO synthesis by modified sol gel method and its application in heterogeneous photocatalytic removal of phenol from water," *Appl. Catal. A: Gen*, vol. 393, no. 1-2, pp. 122-129, 2011.

[49] F. Zahra, F. A. Utami, G. C. S. Girsang, S. Z. M. S. Mulya, V. D. Fentiana, Y. K. Putri dan A. B. D. Nandiyanto, "Economic evaluation of zinc oxide nanoparticle production through green synthesis method using Cassia fistula plant extract," *Int. J. Energetica*, vol. 5, no. 2, pp. 18-24, 2020.

[50] A. B. D. Nandiyanto, R. Ragadhital dan I. Istadi, "Techno-economic Analysis for the Production of Silica Particles from Agricultural Wastes," *Moroc. J. Chem.*, vol. 8, no. 4, pp. 8-4, 2020.

[51] G. Miftahurrahman, H. Setiarahayu dan A. B. Nandiyanto, "An Economic Evaluation on Scaling-up Production of Nano Gold from Laboratory to Industrial Scale," *Indones. J. Sci. Technol.*, vol. 1, no. 1, pp. 29-36, 2019.