Urecol Journal. Part G:
Multidisciplinary Research
Vol. 1 No. 2 (2021) pp. 57-66
eISSN: 2797-1813

Published by:
KONSORSIUM LPPM PTMA
KOORDINATOR WILAYAH JATENG & DIY

Techno-Economic Analysis on the Production of Copper Oxide (CuO) Nanoparticles by Hydrothermal Method on an Industrial Scale

Rahmi Sabila Sidqi, Rian Febriyana Putra, Clarysa Satari, Silmi Ridwan Putri, Asep Bayu Dani Nandiyanto
Department of Chemistry Education, Universitas Pendidikan Indonesia, Indonesia
nandiyanto@upi.edu

https://doi.org/10.53017/ujmr.107

Received: 13/08/2021 Revised: 22/09/2021 Accepted: 27/09/2021

Abstract
The purpose of this study was to evaluate the economic and technical layout carried out on industrial scale CuO production using the hydrothermal method. The evaluation method used is economic evaluation by calculating gross profit margin (GPM), payback period (PBP), break even point (BEP), internal rate return (IRR), cumulative net present value (CNPV), and profitability index (PI). CuO was synthesized using Cu(CH3COO)2.H2O dissolved in water and then 1M sodium hydroxide solution was added. The solution was put in an autoclave at 110□C for 2 hours. Distilled water and ethanol were used to wash the black precipitate obtained and dried at 90□C in air. The results of the calculation of GPM and CNPV from the manufacture of industrial scale CuO show that the payback period (PBP) has increased in the third year because the project has been running well. CuO applications on an industrial scale can be used as photocatalysts and lithium battery anodes. This research is expected to provide an industrial scale overview of the economic evaluation and layout of the production of CuO through the hydrothermal method used as a photocatalyst and anode of lithium-ion batteries.

Keywords: *Economic Evaluation; Hydrothermal Method Synthesis; Photocatalyst; Lithium-ion Battery Anode*

Analisis Tekno-Ekonomi dalam Produksi Nanopartikel Tembaga Oksida (CuO) dengan Metode Hidrotermal pada Skala Industri

Abstrak
Tujuan dari penelitian ini adalah untuk mengevaluasi tata letak ekonomi dan teknik yang dilakukan pada produksi CuO skala pabrik menggunakan metode hidrotermal. Metode evaluasi yang digunakan adalah evaluasi ekonomi dengan menghitung *gross profit margin* (GPM), *payback period* (PBP), *break even point* (BEP), internal rate return (IRR), *cumulative net present value* (CNPV), dan *profitability index* (PI). CuO disintesis menggunakan $Cu(CH_3COO)_2.H_2O$ yang dilarutkan dalam air kemudian ditambahkan larutan natrium hidroksida 1M. Larutan dimasukkan ke dalam autoclave pada temperatur 110°C selama 2 jam. Air suling dan etanol digunakan untuk mencuci endapan hitam yang diperoleh dan dikeringkan pada 90°C di udara. Hasil perhitungan GPM dan CNPV dari pembuatan CuO skala industri menunjukkan bahwa payback period (PBP) telah meningkat pada tahun ketiga karena proyek telah berjalan dengan baik. Aplikasi CuO pada skala industri dapat digunakan sebagai fotokatalis dan anoda baterai lithium. Penelitian ini diharapkan dapat memberikan gambaran skala industri tentang evaluasi ekonomi dan tata letak pada produksi CuO melalui metode hidrotermal yang digunakan sebagai fotokatalis dan anoda baterai lithium ion.

Kata kunci: Evaluasi Ekonomi; Sintesis Metode Hidrotermal; Fotokatalis; Anoda Baterai Lithium-ion

1. Introduction

CuO is one of the materials that is widely used in the field of catalysis [1]. CuO nanoparticles are used as excellent photocatalysts for the degradation of different organic dyes under sunlight irradiation. Copper oxide nanoparticles have been chosen as photocatalysts because of their low cost, high catalytic efficiency, and narrow band gap [2]. Lithium-ion batteries (LIB) have been widely used in everyday life such as in electronic equipment. Copper oxide (CuO) is one of the promising anode materials for LIB because of its high theoretical capacity, high safety, environmental friendliness, and low cost [3],[4]. Although excess is dominant, CuO usually undergoes large volume changes (about 174%) and severe aggregation during charge-discharge, which can lead to rapid capacity fading and electrode destruction [4].

There are several CuO synthesis methods that can be considered to minimize the shortcomings of CuO synthesis. Has been reported by several researchers, namely electrochemical [5]-[8], sonochemical [9]-[11], sol-gel [12]-[15], green synthesis [16]-[18], biogenic [19]-[21], and hydrothermal methods [22]-[24]. The most appropriate method used in economic evaluation is hydrothermal. Because this method is simple (without using any surfactant template), easy to vary the variables of temperature, reactant concentration and time on the growth of nanostructures [22].

The economic evaluation of the chemical industry is a form of quantitative research on what people expect and want to invest in a project. Economic evaluation in the field of synthesis of CuO nanoparticles on an industrial scale has not been widely carried out.

Therefore, the aim of this study was to evaluate the technical and economic feasibility in the production of CuO nanoparticles through hydrothermal methods on an industrial scale. In this study, we vary several factors to see their effect on the economic evaluation under study, such as the increase in tax prices, the decrease and increase in product prices, and variable costs (raw materials, labor, and utilities).

2. Materials and Methods

2.1. Theoretical synthesis of CuO materials

The process of forming CuO nanoparticles is shown in the flow diagram in Figure 1. All chemicals used were analytical grade and purchased at Foshan City Qiruide Additives Co., Ltd and Anhui Huakai Light Industry S&t Co., Ltd [22]. The synthesis method used is the hydrothermal method by dissolving $Cu(CH_3COO)_2.H_2O$ into water and stirring until dissolved. Then 1M sodium hydroxide solution was added to the $Cu(CH_3COO)_2.H_2O$ solution with continuous stirring. The total solution was transferred to a sealed Teflon-coated stainless-steel autoclave at 110°C for 2 hours. Finally, the autoclave is opened and naturally cooled to room temperature. After the termination reaction, distilled water and ethanol were used to wash the black precipitate obtained and dried at 90°C in air.

2.2. Energy and mass balance

The materials needed for the synthesis of CuO are 4 g $Cu(CH_3COO)_2.H_2O$, 40 mL 1M sodium hydroxide, and 50 mL H_2O. Ethanol is also used as a wash. The formation of CuO follows the following reaction equation:

$$Cu(CH_3COO)_2.H_2O_{(s)} + H_2O_{(l)} \rightarrow Cu^{2+}_{(aq)} + 2CH_3COO^-_{(aq)} + 2H_2O_{(l)} \quad (1)$$

$$NaOH_{(s)} + H_2O \rightarrow NaOH_{(aq)} + H_2O_{(l)} \quad (2)$$

$$Cu^{2+}_{(aq)} + 2CH_3COO^-_{(aq)} + 3H_2O_{(l)} + 2NaOH_{(aq)} \rightarrow CuO_{(s)} + 2CH_3COONa_{(aq)} + 2H_2O_{(l)} + 3OH^-_{(aq)} \quad (3)$$

From a technical point of view, it is possible to increase the production of CuO nanoparticles because the capacity and quantity of tools and materials used can be enlarged.

To produce 144 kg CuO nanoparticles in one day, it takes 1 reaction cycle of about 400 kg $Cu(CH_3COO)_2.H_2O$, 4160 kg sodium hydroxide, and 7000 L H_2O.

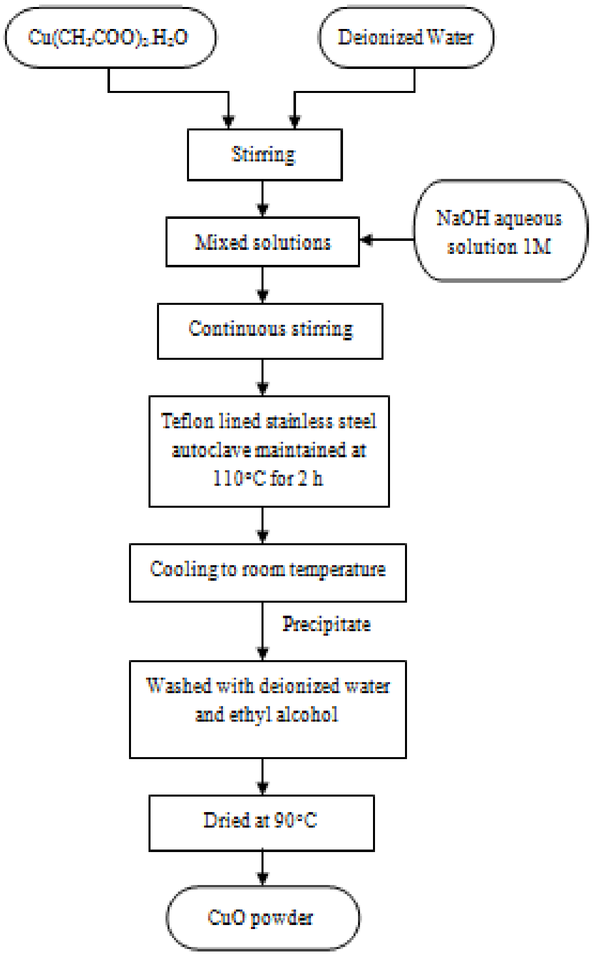

Figure 1. Flow chart of the synthesis of CuO nanoparticles

2.3. Economic evaluation

The synthesis of CuO through the hydrothermal method was carried out by analyzing some raw data. Then the data is calculated to obtain various evaluation parameters. All data is calculated based on mathematical calculations using the Microsoft Excel application. To get the economic evaluation parameters, several calculations can be used such as:

1. Gross Profit Margin (GPM) or gross profit is a type of profit which is calculated by subtracting income for one period from the cost of goods sold. The calculation of gross profit margin is the first step to determine the level of profitability of this project [25].
2. Break Even Point (BEP) is the point where the income is equal to the invested capital, there is no profit or loss. BEP can be calculated by calculating the value of fixed costs divided by value (total selling price minus total variable price). The calculation of BEP can be in the form of a projection or an estimate of the minimum number of goods that must be sold during a certain period [25].
3. Total Investment Cost (TIC) is the cost to build the factory and the initial cost (the cost of equipment and related service equipment for the installation of equipment in the factory) [26].
4. Cumulative Net Present Value (CNPV) is the value obtained by the net present value (NPV) at a certain time. In short, CNPV is obtained by adding up the NPV value from the start of the project. NPV is calculated by multiplying cash flows by a discount factor [27]. CNPV is calculated through equation (4) below:

$$CNPV = \sum NPV = \sum \frac{(B_t - C_t)}{(1+i)^t} \quad (4)$$

where:

B_t = profit

C_t = cost

i = one-period social discount rate in period t

t = time (year)

5. Internal Rate Return (IRR) is calculated through equation (5) as follows:

$$IRR = \sum_{t-1}^{t} \frac{C_t}{(1+r)^t} - C_o \quad (5)$$

where:

Ct = net cash inflows during period t

Co = total investment cost

r = discount rate

t = time (year)

6. Profitability Index (PI) is estimated by dividing the CNPV and the total cost of investment or sales, according to the PI type of profit for each investment or profit for sales [27].
7. Payback Period (PBP) is the time required to recover the cost of an investment. The easiest way to get PBP is obtained from the CNPV curve. The value of PBP is determined by understanding the time when the CNPV/TIC value reaches zero for the first time [27].

After calculating, there are several assumptions in this study, including:

1. Calculation of 1 USD is equivalent to Rp. 15,000.00.
2. All material prices are based on online market prices.
3. The chemical composition in the reaction to form CuO nanoparticles is increased by 1000 times.
4. The purity of CuO nanoparticles is assumed to be 95%, while 5% is a side product.
5. The cycle of making CuO nanoparticles per day is 12 hours.
6. Total Investment Cost (TIC) is calculated based on the Lang Factor.
7. Total salary per worker is assumed to be 3,000.00 USD/month for 20 workers.
8. 10% income tax.
9. The operation duration of the project is 10 years.
10. The project lasts 300 days/year.

3. Results and Discussion

3.1. Engineering perspective

Figure 2 shows the production process of CuO nanoparticles using the hydrothermal method. From an engineering point of view, the total raw material cost per year is 6,578,799.00 USD and one-year profit is 540,688.16 USD. The selling price in one year is 7,732,800.00 USD. The purchase price of the tools is 8,801.15 USD. TIC must be less than 39,077.11 USD. This project has been operating for 10 years and PBP has been achieved in the 3rd year because the project has been running well.

3.2. Ideal condition

Figure 3 shows the relationship between the CNPV/TIC value and the year of production. The x-axis is the year of production while the y-axis is the CNPV/TIC value. The curve shows a negative CNPV/TIV value, where the value is below 0 in the first year to the second year. This indicates a decrease in earnings during the year due to the initial capital costs for the production of CuO nanoparticles. The lowest CNPV/TIC value occurred in the second year, -0.8432. There is no profit in the first year to the second year because of the initial capital costs such as the tools needed during the production process of CuO nanoparticles. The third year is the initial return on capital or is called the payback period

[27]. The increase in profit is then earned every year until the 10th year and the income earned can cover the initial capital or capital reversal.

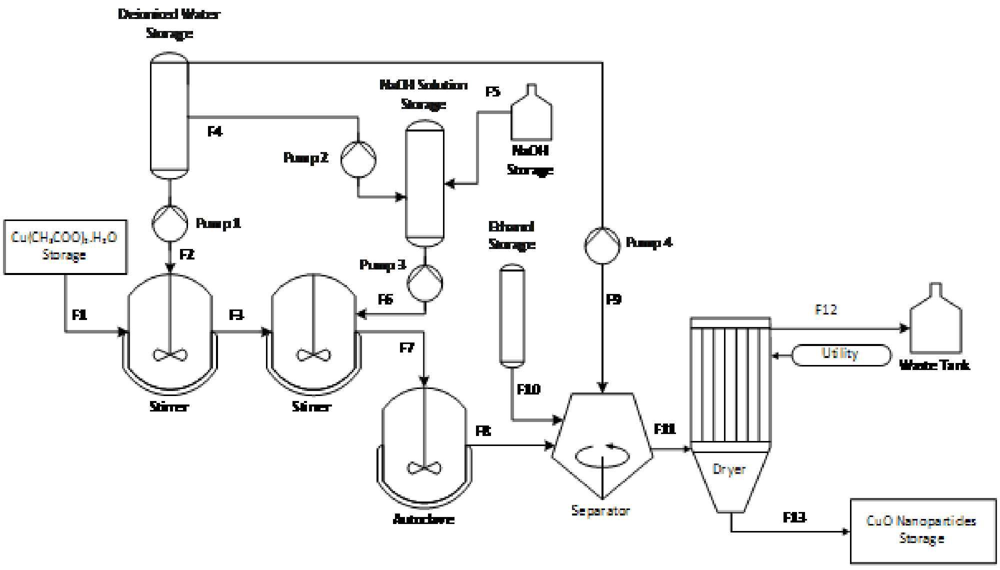

Figure 2. Process Flow Diagram of the Synthesis of CuO Nanoparticles

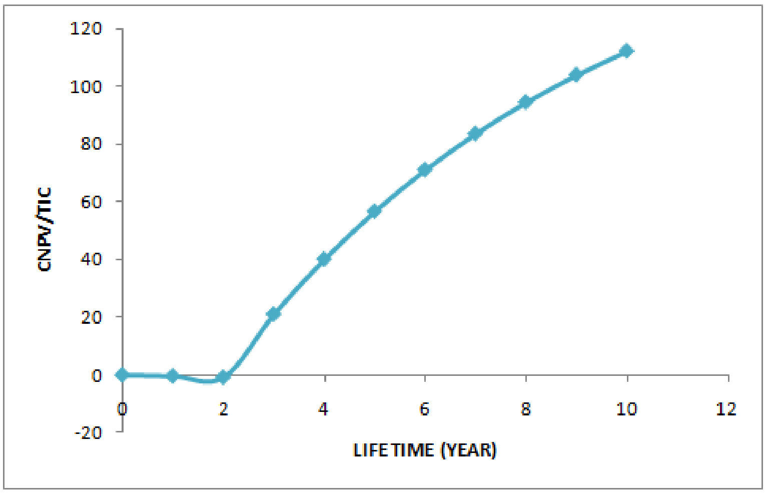

Figure 3. CNPV in ideal conditions per year

In Table 1, the value of CNPV/TIC is negative from first 2 year. Then the CNPV/TIC value began to return to positive in the 3rd year with a value of 21.1019 which continued to increase until the 10th year with a value of 112.4029. Thus, the production of CuO nanoparticles can be considered as a profitable project because the production of CuO nanoparticles requires a short time to recover the investment costs. This is because the CNPV/TIC value falls below 0 in the first 2 years to recover the total initial expenditure for the project. However, after that there was an increase in the value of CNPV/TIC to a positive value after the second year [28].

3.3. The effect of external conditions

Economic evaluation of external factors can actually affect the success of a project. One factor is the tax imposed on projects by the state to finance various public expenditures [28]. 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 changes in tax prices. Tax rates are varied by 10, 20, 30, 40, and 50%.

Based on Figure 4, the conditions in the first year and the second year show the same results because CNPV is under tax variations and there is project development. In addition, in that year there was no income and there was a reduction in accordance with the graph of ideal conditions. The PBP value for each variation of the tax increase is different. The higher the tax value, the longer the PBP [27]. The graph shows that the higher the tax value, the less profit will be received.

Table 1. Annual CNPV values in ideal conditions

CNPV/TIC	Year
0	0
-0.406580494	1
-0.843236345	2
21.1019082	3
40.18464508	4
56.77832932	5
71.20761996	6
83.75482922	7
94.66544596	8
104.1529388	9
112.4029325	10

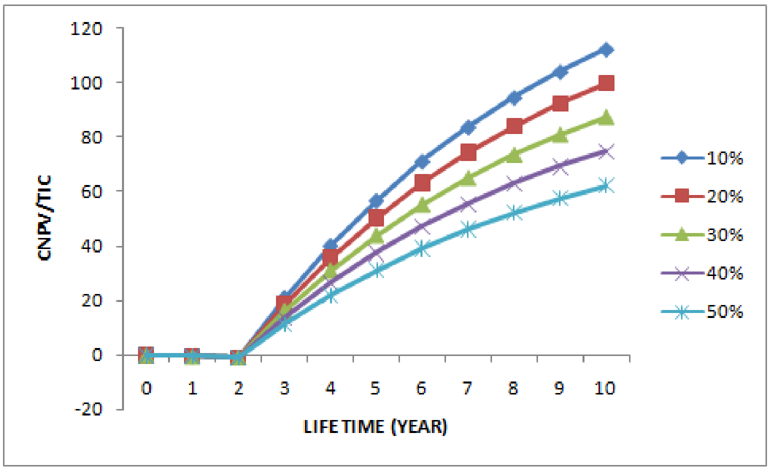

Figure 4. Variation of tax increase on CNPV/TIC

3.4. Change in sales

Figure 5 shows the effect of selling price on the value of CNPV/TIC. The x-axis is the year of production and the y-axis is the CNPV/TIC with the effect of selling price. To determine the effect of the selling price, a variation of the selling price is carried out. Variations in selling prices are lowered and increased from the normal selling price (100%), namely 80, 90, 100, 110, and 120%. Based on Figure 5, the closest payback period with the largest profit is obtained from the 80% selling price variation. The payback period (PBP) is faster if the selling price goes up, and longer if the selling price is lowered [27].

The closest payback period with the greatest profit can be obtained from the 80% variation in worker salaries. The profit obtained with a production time of 10 years shows that the higher the selling price, the greater the profit, and vice versa if the selling price decreases, the profit obtained will be smaller.

3.5. Change in variable cost

Factors such as the condition of raw materials, labor salaries, and utilities can affect the success of a project. Figure 6 shows a graph between CNPV/TIC with the effect of variations in raw materials and year of production. The x-axis is the year of production and the y-axis is CNPV/TIC with the influence of variations in raw materials. The ideal raw material price is assumed to be 100%. Analysis of variations in raw materials is done by lowering and increasing the price of raw materials. The variation of raw materials used in this analysis is 80, 90, 100, 110, and 120%.

The value of CNPV/TIC decreases in the initial conditions of the project (0-2 years) because the project is still in the construction stage. Variations in raw material prices begin to affect the value of CNPV/TIC after 2 years of the project. The decrease in raw material costs resulted in an increase in profit [27]. However, if there is a situation that causes the price of raw materials to increase, then profits will decrease. The closest payback period (3rd year) with the largest profit occurs from the 80% variation in raw material prices.

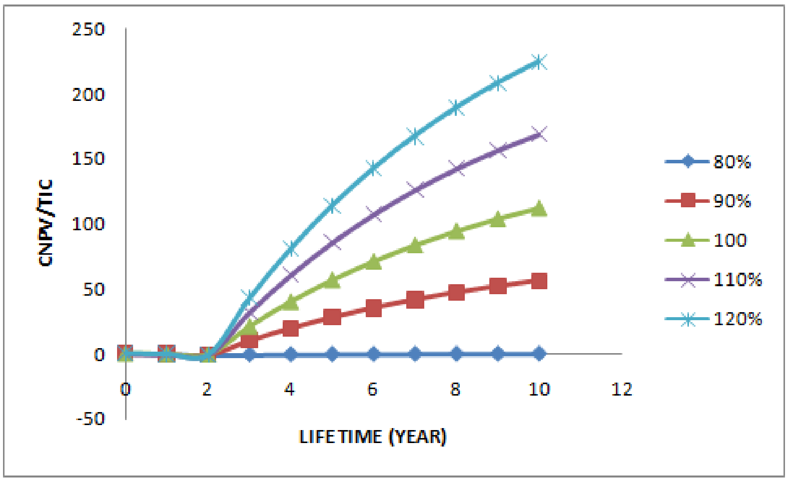

Figure 5. CNPV/TIC with variations in selling price

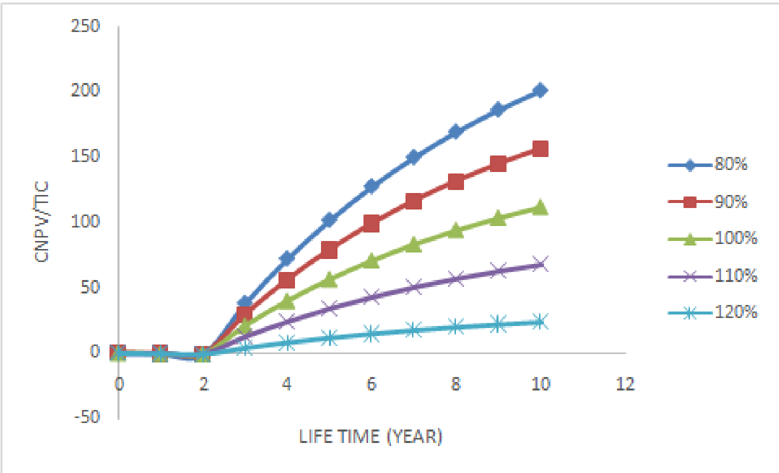

Figure 6. CNPV/TIC with variatons in raw materials

Figure7 shows CNPV/TIC with the effect of utility price and year of production. The x-axis is the year of production and the y-axis is the CNPV/TIC with the effect of utility prices. Figure 7 shows the CNPV/TIC chart is analyzed with various utility prices. The analysis is done by lowering and increasing utility prices. The ideal utility price is assumed to be 100%. The utility price variations used in this analysis are 80, 90, 100, 110, and 120%.

The value of CPNV/TIC from the first year to the second year after the project was created was constant and even decreased. This is due to the project development stage. Utility prices begin to affect the value of CPNV/TIC obtainable 2 years after the project is created. Variations in utility prices have no significant effect on the CPNV/TIC chart [28]. This is because utility prices are relatively constant every year. Projects can still run and generate profits. The closest payback period (PBP) (3rd year) with the largest profit can be obtained from the 80% utility variation.

The CNPV/TIC graph is analyzed with various labor salaries as shown in Figure 8. The analysis is done by lowering and increasing the wages of workers. The ideal salary of workers is 100%. Variations in the wages of workers used in this analysis are 80, 90, 100, 110, and 120%. Figure 8 shows the effect of variations in workers' salaries on CNPV/TIC. The x-axis shows the year of production while the y-axis is the CNPV/TIC value which is affected by the increase in workers' salaries.

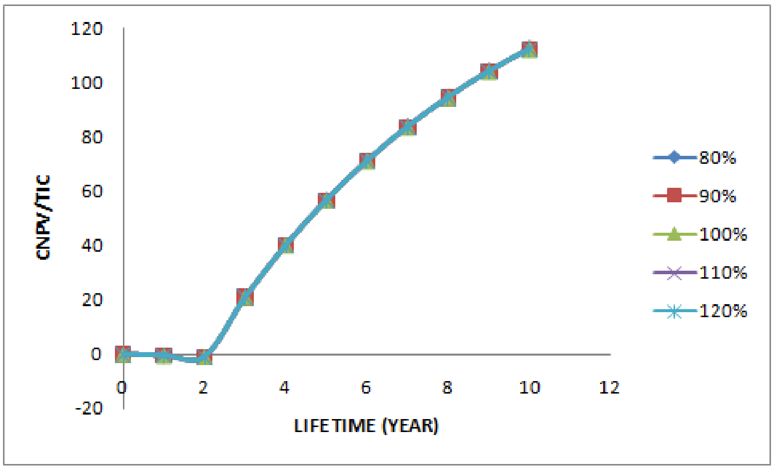

Figure 7. CNPV/TIC with variations in utility prices

Based on Figure 8, at the beginning of the project (years 1-2) the value of CNPV/TIC is decreasing because the project is still under construction. Variations in workers' salaries affect the CNPV/TIC graph after the second year since the project was established but variations in the price of workers' salaries have no significant effect on the CPNV/TIC graph. Projects can still run and generate profits. The higher the salary of the workers, the lower the profit of the project [28]. The greatest project profits come from the lowest worker salaries. The closest payback period with the greatest profit can be obtained from the 80% variation in worker salaries.

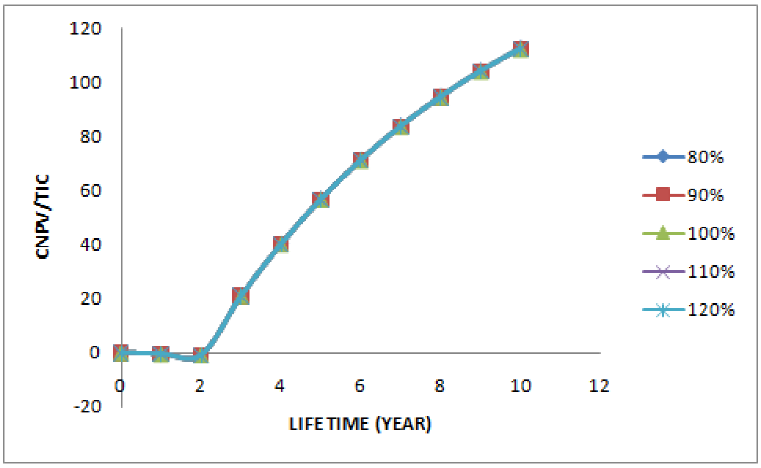

Figure 8. CNPV/TIC with variations in workers' salaries

4. Conclusion

Based on the above analysis, the industrial-scale production of CuO nanoparticles using the hydrothermal method is prospective and promising from a technical point of view in economic evaluation. PBP analysis shows that investment is profitable after more than 3 years. The project can compete with PBP's capital market standards due to its short return on investment. Based on the tax rate, the higher the tax rate, the less profit will be made. Analysis of CNPV/TIC and PBP values is influenced by several factors such as price variations, sales taxes, and variable costs (raw materials, labor, and utilities). The results of the research on the economic evaluation and layout of industrial-scale CuO production using the hydrothermal method are expected to provide an industrial-scale overview of the economic evaluation and layout. Especially in the production of CuO which is used as a photocatalyst and lithium ion battery anode.

Acknowledgements

We would like to thank to Bangdos, Universitas Pendidikan Indonesia for supporting the preparation of this paper.

References

[1] J.Singh, G. Kaur, M. Rawat, "A brief review on synthesis and characterization of copper oxide nanoparticles and its applications", Journal of Bioelectron Nanotechnology, Vol 1, Issue 9, 2016, pp. 1-9.

[2] R. Katwal, H. Kaur, G. Sharma, M, Naushad, D. Pathania, "Electrochemical synthesized copper oxide nanoparticles for enhanced photocatalytic and antimicrobial activity", Journal of Industrial and Engineering Chemistry, Vol 31, Issue 12, November 2015, pp. 173-184.

[3] B. Wang, X. L. Wu, C. Y. Shu, Y. G. Guo, C. R. Wang, "Synthesis of CuO/graphene nanocomposite as a high-performance anode material for lithium-ion batteries", Journal of Materials Chemistry, Vol 20, Issue 47, 2010, pp. 10661-10664.

[4] M. Kundu, G. Karunakaran, E. Kolesnikov, M. V. Gorshenkov, D. Kuznetsov, "Negative electrode comprised of nanostructured CuO for advanced lithium ion batteries", Journal of Cluster Science, Vol 28, Issue 3, May 2017, pp. 1596-1604.

[5] S. Jadhav, S. Gaikwadm M. Nimse, A. Rajbhoj, "Copper oxide nanoparticles: synthesis, characterization and their antibacterial activity", Journal of Cluster Science, Vol 22, Issue 2, June 2011, pp. 121-129.

[6] N. Dighore, S. Jadhav, S. Gaikwad, A. Rajbhoj, "Copper oxide nanoparticles synthesis by electrochemical method", Materials Science, Vol 22, Issue 2, June 2016, pp. 170-173.

[7] S. M. Pourmortazavi, M. Rahimi-Nasrabadi, A. Sobhani-Nasab, M. S. Karimi, M. R. Ganjali, S. Mirsadeghi, "Electrochemical synthesis of copper carbonates nanoparticles through experimental design and the subsequent thermal decomposition to copper oxide", Materials Research Express, Vol 6, Issue 4, 2019, pp. 045065.

[8] Mousali, M. A. Zanjachi, "Electrochemical synthesis of copper (II) oxide nanorods and their application in photocatalytic reactions", Journal of Solid State Electrochemical, Vol 23, Issue 3, March 2019, pp. 925-935.

[9] N. Wongpisutpaisan, P. Charoonsuk, N. Vittayakorn, W. Pecharapa, "Sonochemical synthesis and characterization of copper oxide nanoparticles", Energy Procedia, Vol 9, January 2011, pp. 404-409.

[10] N. A. Neto, P. M. Oliveira, R. M. Nascimento, C. A. Paskocimas, M. R. D. Bomio, F. V. Motta, "Influence of pH on the morphology and photocatalytic activity of CuO obtained by the sonochemical method using different surfactants", Ceramics International, Vol 45, Issue 1, January 2019, pp. 651-658.

[11] J. Zhang, J. Wang, Y. Fu, B. Zhang, Z. Xie, "Sonochemistry-synthesized CuO nanoparticles as an anode interfacial material for efficient and stable polymer solar cells" Rsc Advances, Vol 5, Issue 36, 2015, pp. 28786-28793.

[12] N. Zayyoun, L. Bahmad, L. Laânab, B. Jaber, "The effect of pH on the synthesis of stable Cu 2 O/CuO nanoparticles by sol–gel method in a glycolic medium", Applied Physics A, Vol 122, Issue 5, May 2016, pp. 488.

[13] B. Arunkumar, S. J. Jeyakumar, M. Jothibas, M, "A sol-gel approach to the synthesis of CuO nanoparticles using Lantana camara leaf extract and their photo catalytic activity", Optik, Vol 183, April 2019, pp. 698-705.

[14] Y. Aparna, K. E. Rao, P. S. Subbarao, "Synthesis and characterization of CuO nano particles by novel sol-gel method", In Proceedings of the 2nd International Conference on Environment Science and Biotechnology, Vol 48, 2012, pp. 156-160.

[15] J. Jayaprakash, N. Srinivasan, P. Chandrasekaran, E. K. Girija, "Synthesis and characterization of cluster of grapes like pure and Zinc-doped CuO nanoparticles by sol-gel method", Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, Vol 136, February 2015. pp. 1803-1806.

[16] K. Vishveshvar, M. A. Krishnan, K. Haribabu, S. Vishnuprasad, "Green synthesis of copper oxide nanoparticles using Ixiro coccinea plant leaves and its characterization", BioNanoScience, Vol 8, Issue 2, June 2018, pp. 554-558.

[17] V. V. T. Padil and M. Černík, "Green synthesis of copper oxide nanoparticles using gum karaya as a biotemplate and their antibacterial application". International journal of nanomedicine, Vol 8, February 2013, pp. 889-898.
[18] S.A. Akintelu, A.S. Folorunso, F.A. Folorunso, A.K. Oyebamiji, "Green synthesis of copper oxide nanoparticles for biomedical application and environmental remediation", Heliyon, Vol 6, Issue 7, July 2020, pp. e04508.
[19] J. Singh, V. Kumar, K. H. Kim, M. Rawat, M, "Biogenic synthesis of copper oxide nanoparticles using plant extract and its prodigious potential for photocatalytic degradation of dyes", Environmental research, Vol 177, October 2019, pp. 108569.
[20] D. Vinu, K. Govindaraju, R. Vasantharaja, S.A. Nisa, M. Kannan, K.V. Anand, "Biogenic zinc oxide, copper oxide and selenium nanoparticles: preparation, characterization and their anti-bacterial activity against Vibrio parahaemolyticus", Journal of Nanostructure in Chemistry, Vol 11, Issue 2, June 2021, pp. 271-286.
[21] N. C. Joshi, Y. A. S. H. W. A. N. I. Prakash, "Leaves extract-based biogenic synthesis of cupric oxide nanoparticles, characterizations, and antimicrobial activity", Asian J Pharm Clin Res, Vol 12, Issue 8, 2019, pp. 288-291.
[22] T. Jiang, Y. Wang, D. Meng, X. Wu, J. Wang, J. Chen, "Controllable fabrication of CuO nanostructure by hydrothermal method and its properties", Applied Surface Science, Vol 3, Issue 11, August 2014, pp. 602-608.
[23] B. Dutta, E. Kar, N. Bose, S. Mukherjee, "Significant enhancement of the electroactive β-phase of PVDF by incorporating hydrothermally synthesized copper oxide nanoparticles", RSC advances, Vol 5, Issues 127, November 2015, pp. 105422-105434.
[24] M.P. Neupane,Y.K. Kim, I.S. Park, K.A. Kim, M.H. Lee, T.S. Bae , "Temperature driven morphological changes of hydrothermally prepared copper oxide nanoparticles", Surface and Interface Analysis: An International Journal devoted to the development and application of techniques for the analysis of surfaces, interfaces and thin films, Vol 41, Issues 3, January 2009, pp. 259-263.
[25] A. N. Astuty, A. R. M. Salsabila, D. Roslina, F. N. Aulia, N. Shafira, S. Rahayu, A. B. D. Nandiyanto, "Economic Evaluation of Carbon Nanoparticles Production through Non-Thermal Plasma Method", Journal of Materials and Environmental Science, Vol 11, Issue 12, 2020, pp. 1966-1975.
[26] F. Apriliana, A. B. D. Nandiyanto, "Engineering and Economic Evaluation Perspective in the Production of NiO Nanoparticles" , CHEMICA: Jurnal Teknik Kimia, Vol 6, Issue 2, December 2019, pp. 63-70.
[27] B. Prabowo, T. Khairunnisa, A. B. D. Nandiyanto, "Economic Perspective in the Production of Magnetite (Fe3O4) Nanoparticles by Co-precipitation Method", World Chemical Engineering Journal, Vol 2, Issue 2, December 2018, pp. 1-4.
[28] F. Zahra, F. A. Utami, G. C. S. Girsang, S. Z. M. S. Mulya, V. D. Fentiana, Y. K. Putri, A. B. D. Nandiyanto, "Economic evaluation of zinc oxide nanoparticle production through green synthesis method using Cassia fistula plant extract", International Journal of Energetica, Vol 5, Issue 2, December 2020, pp. 18-24.