Indonesian Journal of Digital Business

Journal homepage: https://ejournal.upi.edu/index.php/IJDB/index

Techno-Economic Analysis in The Production of Copper Nanoparticles with Chemical Reduction Methods using L-Ascorbic Acid

Rahmahani Alfathia Fadhilah[1], Febrian Khoirul Insan[1], Lewi Stefanus Anggiat[1], Gabriela Chelvina Santiuly Girsang[1], Asep Bayu Dani Nandiyanto[1], Muhammad Roil Bilad[2]*

[1]Departemen Pendidikan Kimia, Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alam, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi no.229, Bandung 40154, Jawa Barat, Indonesia

[2]Faculty of Integrated Technologies, Universiti Brunei Darussalam, Jalan Tungku Link, Gadong BE1410, Brunei

Correspondence: E-mail:
[1] rahmahanialfathia@upi.edu

A B S T R A K

Copper nanoparticles (Cu-NPs) are a type of nanoparticles with various industrial applications. The synthesis of copper nanoparticles by the chemical reduction method is environmentally friendly, simple, and produces better nanoparticles compared to other methods. This study aims to determine the feasibility of a Cu nanoparticle manufacturing project through a chemical reduction method using L-ascorbic acid on an industrial scale and evaluate it from an engineering and economic perspective. Technical analysis is carried out using a simple balance sheet analysis while the economic evaluation is carried out using several economic parameters, such as Payback Period (PBP), Break-even Point (BEP), and Cumulative Net Present Value (CNPV). The carried-out analysis is supported by using data taken based on the availability of tools on online shopping websites. The results of the study show that this project is profitable and feasible to run with the anticipation of taxes and sales. This research is expected to provide an industrial scale representation of the economic evaluation and plan of the production of Cu nanoparticles by chemical reduction method using L-Ascorbic Acid.

Informasi Artikel

Diterima 28 Sep 2022
Direvisi 1 Okt2022
Diterbitkan 26 Okt2022
Tersedia online 26 Okt 2022

Kata Kunci:
Copper nanoparticles,
Chemical reduction,
Economic evaluation,

1. Pendahuluan

Copper nanoparticles (Cu-NPs) are a type of nanoparticles with various industrial applications (Giuffrida, *et al*., 2008; Lee, *et al*., 2008). Cu-NPs and their alloys have been used as superior disinfectants in the water treatment, food processing, optical nanodevices (Tanabe, 2007), catalyst (Isomura, *et al*., 2012), and medical industries due to their mutation-resistant antibacterial and antiviral properties (Varshney, *et al*., 2012; Ramyadevi, *et al*., 2012). In addition, the optical, structural, electrical, sensor and thermal properties of copper nanoparticles have an important role in the technology field (Moniri, *et al*., 2017; Sedighi, *et al*., 2014; Wen, *et al*., 2011).

Numerous methods have been developed to synthesize Cu nanoparticles, including chemical reduction methods with sodium hypophosphite (Lee, *et al*., 2018) and L-ascorbic acid (Xiong, *et al*., 2011), electrochemistry (Theivasanthi & Alagar., 2011), microemulsion (Solanki, *et al*., 2010), and photochemistry (Giuffrida, *et al*., 2008). Synthesis of Cu nanoparticles can also be carried out by physical methods such as laser ablation (Moniri, *et al*., 2017), pulsed wire discharge (Das, *et al*. 2012), mechanical milling (Amrollahi, *et al*., 2014), and vapor phase synthesis (Nasibulin, *et al*., 2001). Biological methods such as biosynthesis using plants (Shende, *et al*., 2015). However, both methods have their drawbacks, namely requiring special equipment. The method that is considered the most appropriate for the economic evaluation analysis is the chemical reduction method using L-ascorbic acid. This method was chosen because it is environmentally friendly, simple, and produces better nanoparticles than other methods.

This paper was made to determine the feasibility of a Cu nanoparticle manufacturing project through a chemical reduction method using L-ascorbic acid and evaluate it from an engineering and economic perspective. This paper was written because there are limited papers that were published and discusses which provide a detailed economic evaluation of the synthesis of Cu nanoparticles using the chemical reduction method by L-ascorbic acid on an industrial scale. The change from lab scale to industrial scale on the quantities of raw materials and equipment was carried out for this research. We perform several economic variations on taxes, sales, raw materials, labor, and utilities. The results of this study are expected to encourage further research on the synthesis of Cu nanoparticles.

2. Metode

2.1. Theory of Cu Nanoparticles Synthesis

Cu nanoparticles can be synthesized using the L-ascorbic acid chemical reduction method. **Figure 1** shows the schematic stages of the synthesis of Cu nanoparticles using the chemical reduction method of L-ascorbic acid. The Cu nanoparticle synthesis method was adopted from the research conducted by Xiong, *et al*., 2011. The first step is the synthesis of Cu nanoparticles that dissolve $CuCl_2.2H_2O$ in deionized water (10 mmol). Furthermore, the solution is heated to a temperature of 80°C and stirred up. Moreover, a solution of L-ascorbic acid with a concentration of 1 M was added slowly to the precursor salt solution while stirring. The mixture was allowed to stand at a temperature of 80°C to form a dark brown solution. The suspension formed was centrifuged for 15 minutes at a power of 8000 rpm. Lastly, the resulting solid is dried.

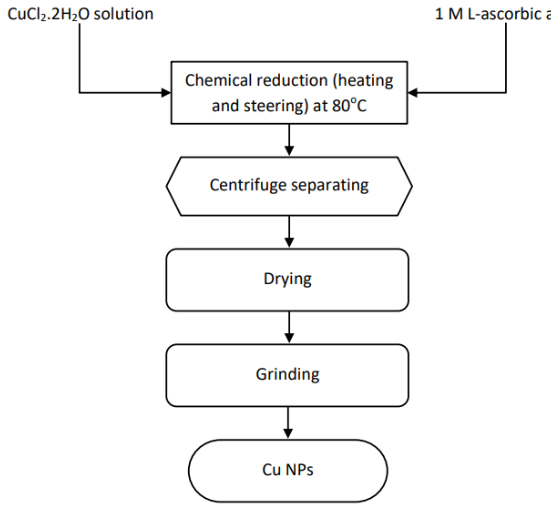

Figure 1. Schematic synthesis of copper nanoparticles.

Economic Evaluation

This study used a method based on the analysis of the prices of materials, equipment, and equipment specifications found available commercially on online shopping websites. The entire data is calculated based on simple mathematical calculations using Microsoft® Excel application and economic parameters are evaluated to confirm this project. Several economic evaluation parameters were obtained from the literature study and presented in the following formula (Mubarok & Nandiyanto, 2019; Nandiyanto et al., 2018):

1) Gross profit margin (GPM) is the first analysis conducted to determine the profitability level of a project by subtracting the cost of goods sold by the price of raw materials.

2) The 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.

3) Break-even point (BEP) is the minimum amount of product that must be sold at a certain price to cover the total cost of production.

4) Cumulative net present value (CNPV) is a value that predicts the condition of a production project in the form of a production function in several years. NPV is a value that expresses the expenses and income of a business.

5) The profitability index (PI) is an index used to identify the relationship between project costs and impacts. PI can be calculated by dividing the CNPV by the total investment cost (TIC). If the PI is less than one, then the project can be classified as an unprofitable project and if the PI is more than one then the project can be classified as a good/profitable project.

Several process-based assumptions in the industrial-scale synthesis of Cu nanoparticles are based on stoichiometric and mass balance calculations. The assumptions were: (1) All materials used in the synthesis of Cu nanoparticles such as copper (II) chloride dihydrate ($CuCl_2.2H_2O$), L-ascorbic acid, and deionized water were enlarged 30000 times which is calculated based on the literature. (2) The reaction for the formation of Cu nanoparticles is assumed to be a complete reaction. (3) Copper (II) chloride dihydrate ($CuCl_2.2H_2O$) and L-ascorbic acid react in a 1:5 ratio. (4) The percentage of the nanoparticle formation process is 100%.

Several assumptions are used to support the calculation of the economic evaluation. In this study, some of the assumptions used are as follows.

1) Calculation is based on conversion of 1 USD = 15,000 IDR;

2) Based on commercially available prices, the prices of $CuCl_2.2H_2O$ and L-ascorbic acid in kg are 4.13 USD/kg; and 5.00 USD/kg. Deionized water is obtained from the treatment of water developed inside the industry or factory, assuming the location of the factory is located near natural water sources;

3) Labor wages are 75,000 USD/year for 50 workers;

4) The project generates production twice a day;

5) The number of Cu nanoparticles obtained in one production is 20 kg;

6) Cu nanoparticles are priced at 20 USD/pack (50 g);

7) The project will operate for nine (9) years;

8) The project runs for five working days a week for a total of 240 days a year;

9) To simplify utility, utility units can be described and converted as electrical units, such as kWh. Utility costs (kWh) are assumed to be 391.92 USD/year;

10) Discount rate 15% per year (Nandiyanto et al, 2018);

11) Income tax rate 10% (Nandiyanto et al, 2018);

12) The total investment cost (TIC) is calculated based on the Lang Factor;

13) Direct type depreciation is used to calculate the depreciation value;

14) There is a mass loss of chemical compounds transferred by 5% of the initial mass in each transfer process.

The above economic evaluation parameters will be calculated for the manufacture of Cu nanoparticles with L-ascorbic acid and deionized water as solvent. Furthermore, the results of these calculations are treated with a number of conditions such as varying the prices of variable costs, sales, fixed costs, and labor to evaluate feasibility.

3. Hasil dan Pembahasan

3.1. Engineering Prospective

Figure 2 shows the Cu nanoparticles manufacturing process is an environmentally friendly and effective method of chemical reduction by L-ascorbic acid based on the literature (Xiong et al., 2011). From an engineering perspective, the synthesis of Cu nanoparticles can be carried out on an industrial scale. The total cost of raw materials used in one year is 328,831.12 USD.

This cost is required to produce Cu nanoparticles as much as ± 9600 kg/year. Sales in one year resulted in a profit of 565,524.50 USD. The cost for equipment requirements is 41,490 USD. The project life span is 9 years, producing Cu nanoparticles with CNPV/TIC reaching 9.41% in 9 years, and PBP being achieved in year 2 of the project

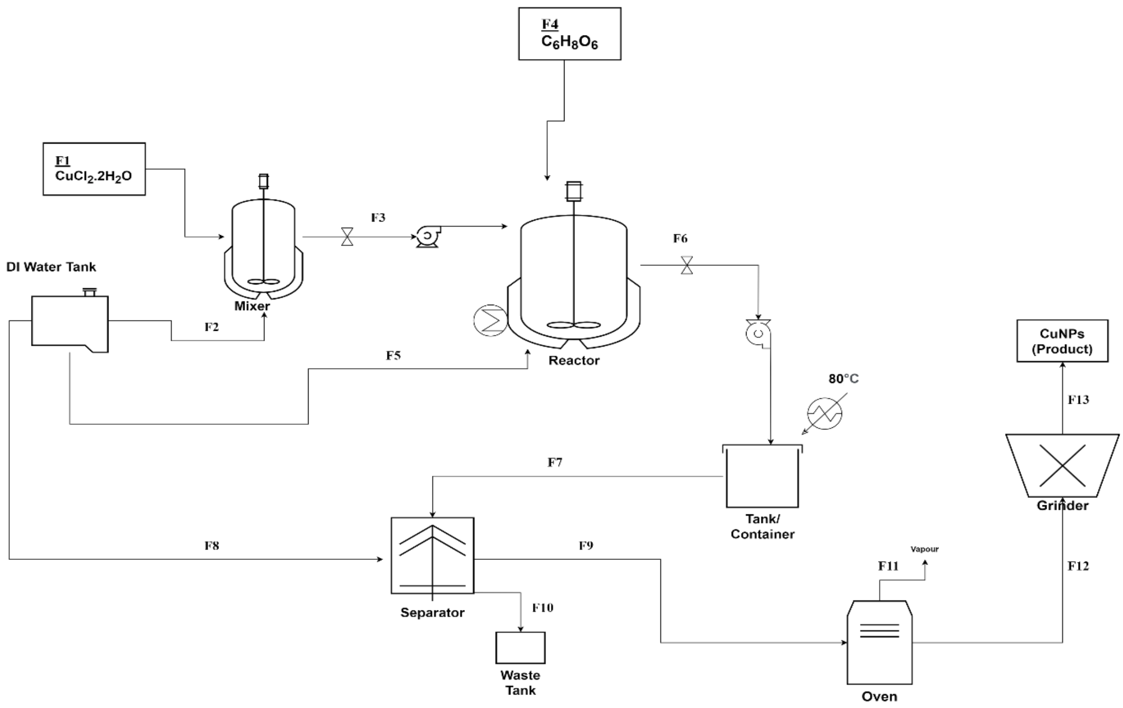

Figure 2. Process flow diagram for the production of Cu nanoparticles.

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 the life span (years) of the project on the x-axis. The graph is made using economic evaluation parameters under ideal conditions. In the first year to the second year, it is found that the CNVP/TIC will be negative (in %). This indicates a decrease in income due to the initial investment costs for the production of Cu nanoparticles such as the purchase of land, equipment, and building construction. In the 3rd year of the project, the curve begins to rise with the emergence of the Payback Period (PBP) or when the initial investment costs have returned. In this year and beyond, there has been an increase in revenue that results in a profit. The increase in income continues to occur every year. **Table 1** shows the negative CNPV/TIC value in the 1st year to the 2nd year, with the lowest value being -0.845204551. Meanwhile, in the 3rd year and onwards, the CNPV/TIC value increased to positive with the highest value in the 9th year, namely 9.406624142. A project can be said to be profitable if the CNPV/TIC or PI value is more than 1. Thus, the production of Cu nanoparticles can be considered a profitable project because it requires a short time to recover the investment costs. This is in line with previous research, where the CNPV/TIC value fell below 0 in the first 2 years, and there was an increase in the CNPV/TIC value to a positive value on economic parameters (Mubarok & Nandiyanto, 2019).

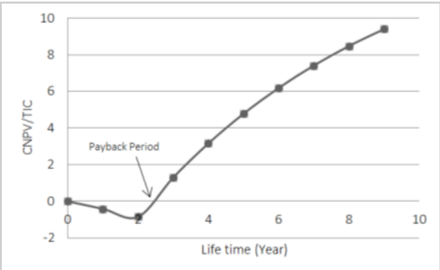

Figure 3. CNPV/TIC graph for lifetime year under ideal conditions.

Table 1. CNPV/TIC value in ideal conditions.

CNPV/TIC	Year
0	0
-0.409351928	1
-0.845204551	2
1.297520033	3
3,160758803	4
4,780966428	5
6,189842624	6
7,41495236	7
8,480265173	8
9,406624142	9

3.2.2. Impact of External Conditions

An economic evaluation of external factors can affect the success of a project. One of these external factors is taxes. These taxes usually come from countries that fund various public expenditures. **Figure 4** shows a graph of CNPV/TIC for 9 years with various tax variations. In the graph, the y-axis is the CNPV/TIC (%) and the x-axis is the life of the project (years).

The tax variations shown on the graph are 10%, 25%, 75%, and 100% of total income. In the graph, the conditions at the beginning of the year until the second year show the same results as the ideal conditions, which is negative because of the initial investment cost of the project. The increase in taxes occurs after the second year. Taxes that increase after two years lead to lower profits.

In addition to affecting profits, variations in the amount of tax also affect the Payback Period (PBP). **Figure 4** shows that the higher the tax issue, the PBP for initial investment costs will be longer than ideal conditions. At 10, 25, 50, 75, and 100% tax variation, PBP for initial investment costs will occur in year 2.2; 2.5; 3.0; 3.5; and at 100% no PBP is achieved. In the tax variation of 10, 25, 50, and 75%, the CNPV/TIC value is positive or above 0. However, at the 100% tax variation, the CNPV/TIC value remains negative or below 0. This indicates that the project not making a profit until the 9th year. Therefore, the maximum tax earned to achieve PBP on initial investment cost recovery is 75%. If the tax change obtained is more than 75%, the project will be declared a failure.

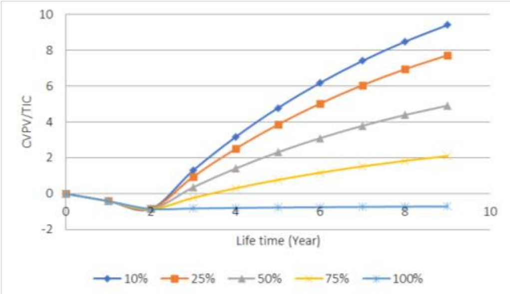

Figure 4. Graph of CNPV/TIC on tax variation.

3.2.3. Changes in Sales

Product sales factors are very influential on the success of a project. This factor is the main factor that can determine the sustainability and continuity of the project. **Figure 5** shows a graph of CNPV for 9 years on the variation of the decline percentage in sales. The y-axis in the graph represents the CNPV/TIC (%) and the x-axis represents the life span (in years) of the project. The analysis is done by reducing the number of sales by 20%, 40%, 60%, and 80% while also being compared with normal sales (ideal conditions). The graph shows that the lower the number of sales, the CNPV/TIC value will be lower than the ideal situation.

Based on the PBP analysis, the initial investment cost will return in the 3rd year for a 20% decrease in sales variation. Meanwhile, in the variation of a 40% decrease in sales, the initial investment cost will return in the 4.5 year. However, the initial investment cost will not return at the 60% and 80% variations of the decline percentage in sales. Therefore, the maximum sales drop for earning PBP is 40%. Changes in declining sales above 40% will lead to project failure. On the graph, sales declining of 20% and 40% have positive CNPV/TIC values in the 9th year. While the sales decline of 60% and 80%, did not increase the CNPV/TIC value and remained negative.

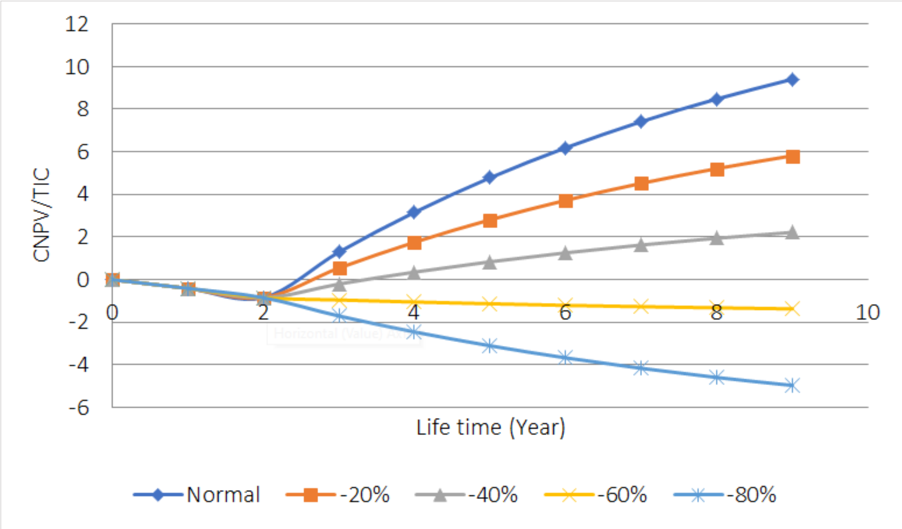

Figure 5. Graph of CNPV/TIC on sales variation.

3.2.4. Changes in Variable Costs (Raw Materials, Labor, Utilities)

Factors such as the price of raw materials, utilities, and labor can affect the success of a project. **Figure 6** shows a graph of CNPV for 9 years with variations in raw material prices. Analysis of the variation in the price of raw materials is done by lowering the price of raw materials by 25% and increasing the price of raw materials by 25, 50, and 100%. The graph of the variation in the price of raw materials is compared with the graph under ideal (normal) conditions.

The effect of variations in the price of raw materials is seen after 2 years of the project's life span. The decrease in raw material prices resulted in an increase in profits from ideal conditions. On the other hand, an increase in the price of raw materials results in a decrease in profits from ideal conditions. The value of CNPV/TIC in the 9th year for variations in raw material prices -25%, normal, +25, +50, +75, and +100% is 10.73; 9.41; 8.08; 6.76; and 4.11 respectively. PBP results from variations in raw material prices -25%, normal, +25, +50, +75, and +100% are achieved in the 2nd year to the 3rd year. Thus, this project will still be successful even though the price of raw materials rises to 100% of the normal price.

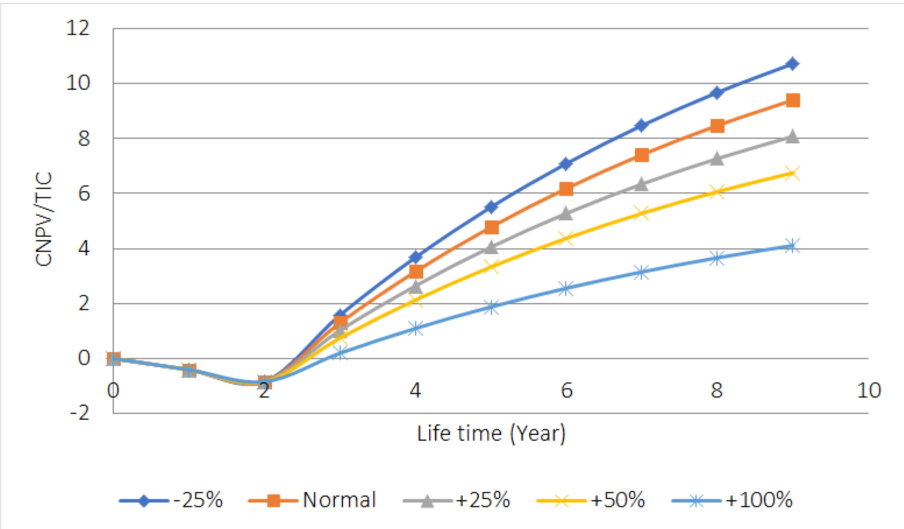

Figure 6. Graph of CNPV/TIC on variations in raw material prices.

Figure 7 shows a graph of CNPV for 9 years with utility variations. Analysis of utility variation is done by reducing utility costs by 25% and increasing utility costs by 25%, 50%, and 100%. The graph of the variation in the price of raw materials is compared with the graph under ideal (normal) conditions.

According to the graph presented in **Figure 7**, the decrease and increase in utility costs did not result in a significant change in the value of CNPV/TIC. The value of CNPV/TIC in the 9th year for variations in utility costs -25%, normal, +25%, +50%, +75%, and +100% is 9.41 in various ranges of variation. The curves for all variations in utility costs appear to coincide. This shows that the decrease and increase in utility costs does not have a significant effect even though utility costs increase by 100% from normal costs. Therefore, this project is considered to be successful and does not affect profits despite a doubling of utility costs.

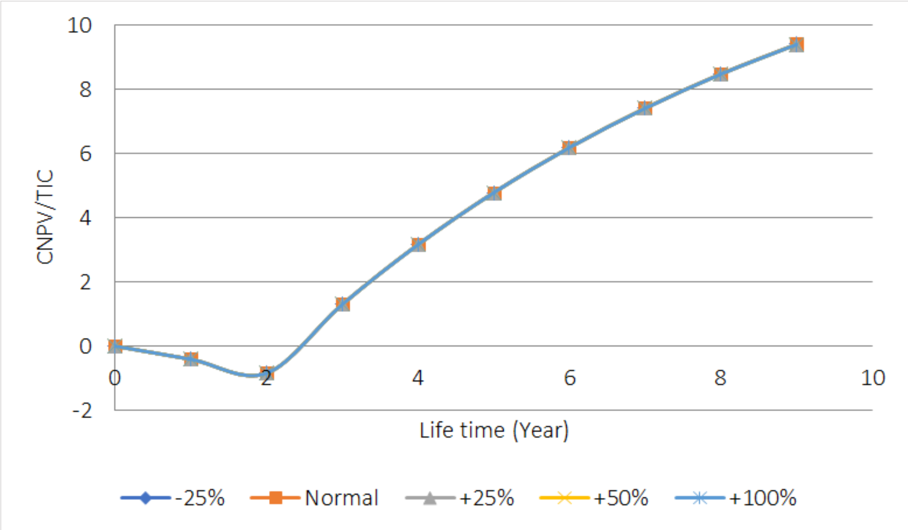

Figure 7. Graph of CNPV/TIC on variations in utility prices.

Figure 8 shows a graph of CNPV for 9 years with variations in the increase in labor wages. The analysis of variations in the increase in labor wages was carried out by increasing the wages of workers by 20%, 40%, 50%, 60%, 80%, and 100%. The graph of wage variation is compared with the graph under ideal (normal) conditions.

The effect of variations in the increase in labor wages is considered to exist after 2 years of the project life. In the previous year, the CNPV/TIC value was constant because the project was still under development. An increase in labor wages results in a decrease in profits from ideal conditions. The value of CNPV/TIC in the 9th year for variations in the increase in labor wages by 20%, 40%, 60%, 80%, and 100% is 9.41; 9.00; 8.60; 8.20; 7.79; and 7.39 respectively. PBP results from variations in raw material prices -25%, normal, +25, +50, +75, and +100% are achieved in 2 to 2.5 years. Thus, this project will still be successful even if the wages of workers increase to 100% of normal conditions.

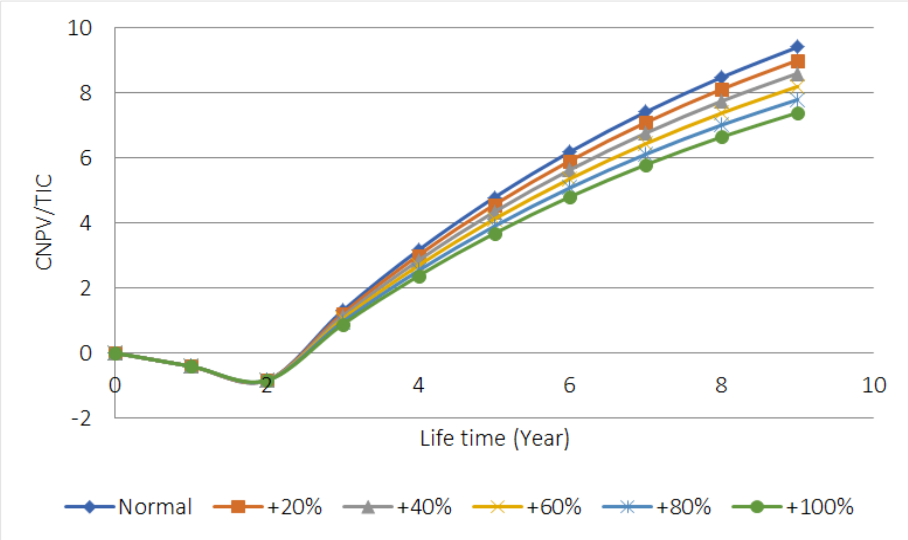

Figure 8. CNPV/TIC graph on labor wage.

4. Kesimpulan

Based on the analysis that has been carried out, the project for the production of Cu nanoparticles by chemical reduction method by L-ascorbic acid is prospective from an engineering point of view and holds promise in economic evaluation. PBP analysis shows that profitable investment occurs after the project has been running for more than 2 years. The project can compete with PBP capital market standards, due to the short initial investment costs recovery. The chosen method also has the advantages of being environmentally friendly, simple, cheap raw materials, and produces excellent Cu nanoparticles products. From this economic evaluation analysis, it can be concluded that this project is feasible and attainable to run with anticipated tax changes and sales variations.

5. REFERENCE

Amrollahi, P., Ataie, A., Nozari, A., & Sheibani, S. (2014). Synthesis and characterization of CuNi magnetic nanoparticles by mechano-thermal route. *Journal of Superconductivity and Novel Magnetism*, *27*(2), 481-485.

Das, R., Das, B. K., Shukla, R., Prabaharan, T., & Shyam, A. (2012). Analysis of electrical explosion of wire systems for the production of nanopowder. *Sadhana*, *37*(5), 629-635.

Giuffrida, S., Costanzo, L. L., Ventimiglia, G., & Bongiorno, C. (2008). Photochemical synthesis of copper nanoparticles incorporated in poly (vinyl pyrrolidone). *Journal of Nanoparticle Research*, 10(7), 1183-1192.

Isomura, Y., Narushima, T., Kawasaki, H., Yonezawa, T., & Obora, Y. (2012). Surfactant-free single-nano-sized colloidal Cu nanoparticles for use as an active catalyst in Ullmann-coupling reaction. *Chemical Communications*, *48*(31), 3784-3786.

Lee, Y., Choi, J. R., Lee, K. J., Stott, N. E., & Kim, D. (2008). Large-scale synthesis of copper nanoparticles by chemically controlled reduction for applications of inkjet-printed electronics. *Nanotechnology*, 19(41), 415604.

Moniri, S., Ghoranneviss, M., Hantehzadeh, M. R., & Asadabad, M. A. (2017). Synthesis and optical characterization of copper nanoparticles prepared by laser ablation. *Bulletin of Materials Science*, 40(1), 37-43.

Mubarok, F. A., & Nandiyanto, A. D. (2019). Engineering and Economic Evaluation of Production of Copper Nanoparticle by Chemically Controlled Reduction. *International Journal of Engineering and Science Applications*, 6(2), 85-91.

Nandiyanto, A. B. D., Maulana, A. C., Ragadhita, R., & Abdullah, A. G. (2018). Economic evaluation of the production ethanol from cassava roots. In IOP Conference Series: *Materials Science and Engineering*, 288(1), 012023.

Nasibulin, A. G., Ahonen, P. P., Richard, O., Kauppinen, E. I., & Altman, I. S. (2001). Copper and copper oxide nanoparticle formation by chemical vapor nucleation from copper (II) acetylacetonate. *Journal of Nanoparticle Research*, *3*(5), 383-398.

Ramyadevi, J., Jeyasubramanian, K., Marikani, A., Rajakumar, G., & Rahuman, A. A. (2012). Synthesis and antimicrobial activity of copper nanoparticles. *Materials letters*, *71*, 114-116.

Sedighi, A., Montazer, M., & Hemmatinejad, N. (2014). Copper nanoparticles on bleached cotton fabric: in situ synthesis and characterization. *Cellulose*, 21(3), 2119-2132.

Shende, S., Ingle, A. P., Gade, A., & Rai, M. (2015). Green synthesis of copper nanoparticles by Citrus medica Linn.(Idilimbu) juice and its antimicrobial activity. *World Journal of Microbiology and Biotechnology*, 31(6), 865-873.

Solanki, J. N., Sengupta, R., & Murthy, Z. V. P. (2010). Synthesis of copper sulphide and copper nanoparticles with microemulsion method. *Solid State Sciences*, 12(9), 1560-1566.

Tanabe, K. (2007). Optical radiation efficiencies of metal nanoparticles for optoelectronic applications. *Materials Letters*, *61*(23-24), 4573-4575.

Theivasanthi, T., & Alagar, M. (2011). Nano sized copper particles by electrolytic synthesis and characterizations. *International Journal of Physical Sciences*, 6(15), 3662-3671.

Varshney, R., Bhadauria, S., & Gaur, M. S. (2012). A review: biological synthesis of silver and copper nanoparticles. *Nano Biomedicine & Engineering*, 4(2).

Wen, J., Li, J., Liu, S., & Chen, Q. Y. (2011). Preparation of copper nanoparticles in a water/oleic acid mixed solvent via two-step reduction method. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 373(1-3), 29-35.

Xiong, J., Wang, Y., Xue, Q., & Wu, X. (2011). Synthesis of highly stable dispersions of nanosized copper particles using L-ascorbic acid. *Green Chemistry*, 13(4), 900-904.