Engineering and Economic Evaluation of Production of Copper Nanoparticle By Chemically Controlled Reduction

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ABSTRACT

The purpose of this study was to evaluate economic feasibility of industrial scale production of copper (Cu) nanoparticles for 20 years. Several economic evaluation parameters are analyzed, including payback period, Cumulative Net Present Value, and gross profit marigin of the project. Engineering perspective is based on the synthesis of Cu nanoparticles by the chemical reduction method with stoichiometric calculations and mass balance. The Engineering perspective analysis of Cu nanoparticle production shows the resulting product is 1563,862 kg/year, with a total manufacturing cost of 8,231,547,131 IDR/year, resulting in sales of 22,675,854,000 IDR/year, so the profit is 14,444,306,868 IDR/year. Profit value is relatively economical, so this project can be run for 20 years under ideal conditions. Economic evaluation analysis shows the production of Cu nanoparticles is prospective. The payback period for initial investment capital in this project is quite short in 2.5 years. Tax cost, raw material costs, sallary labor, and sales greatly affect the profitability of the project. Therefore, this influence needs to be estimated, so that project profitability remains good and is feasible to run. This research can be used as a reference to analyze economically in the manufacture of industrial scale Cu nanoparticles.

Keywords: Cu Nanoparticle; Economis Evaluation; Feasibility Study

1. INTRODUCTION

Copper (Cu) is a metal group. Copper has quite good conductive and electrical properties. Because of its properties, Cu nanoparticles are widely used in many potential applications in the industrial field. One such exploitable use is as the main element of conductive ink and paste used to print various electronic components. To synthesize Cu nanoparticles can be done by several methods.

Many methods of synthesis of Cu nanoparticles have been developed including, Cu nanoparticles have been prepared using methods such as thermal reduction [1], vacuum vapor deposition [2], chemical reduction [3, 6], polyols [4] and ablation laser [5]. Among these methods, the chemical reduction method is the most effective, because this method is simple and economical compared to other methods. This method can create better particle size by optimizing experimental parameters, such as the molar ratio of the covering material to the precursor salt and the ratio of the reducing agent to the precursor salt. So that it can create a good dispersion stability. Chemical reduction methods usually involve the reduction of metal salts in several types of solvents and separate reducing agents. However, this method does not yet have an economic evaluation of existing research.

To evaluate the increase in production from small scale to large scale (industry), this study adopted the method of synthesis of Cu nanoparticles from the literature [7]. Therefore the purpose of this study is to evaluate the engineering perspective and economic evaluation. To support economic evaluation analysis, several economic evaluation parameters are analyzed and discussed.

2. METODOLOGY

A. Theoretical Synthesis of Cu Nanoparticles

Figure 1 shows the schematic stages of synthesis Cu nanoparticle using the chemical reduction method. The synthesis method of Cu nanoparticles was adopted from the literature [6]. The stage of synthesis are by mixing 1.11 kg of PVP and 400 g of $NaH_2PO_2 \cdot H_2O$ mixed in 4 L of ethylene glycol. The mixture is heated to 90 °C at 5 °C min^{-1}. Then, 1 L of 1 M solution of copper sulfate in ethylene glycol at 90 °C was rapidly added into the PVP/sodium hypophosphite solution while stirring. When the reduction occurs, the color of the suspension changes from green to henna, indicating the formation of Cu nanoparticles. Then, the reaction was stopped and the suspension is cooled down. Cu nanoparticles formed are separated and washed with deionized water by centrifugation, while using acetone as a non-solvent to remove excess PVT and side products. Then, the resulting precipitate were then dried.

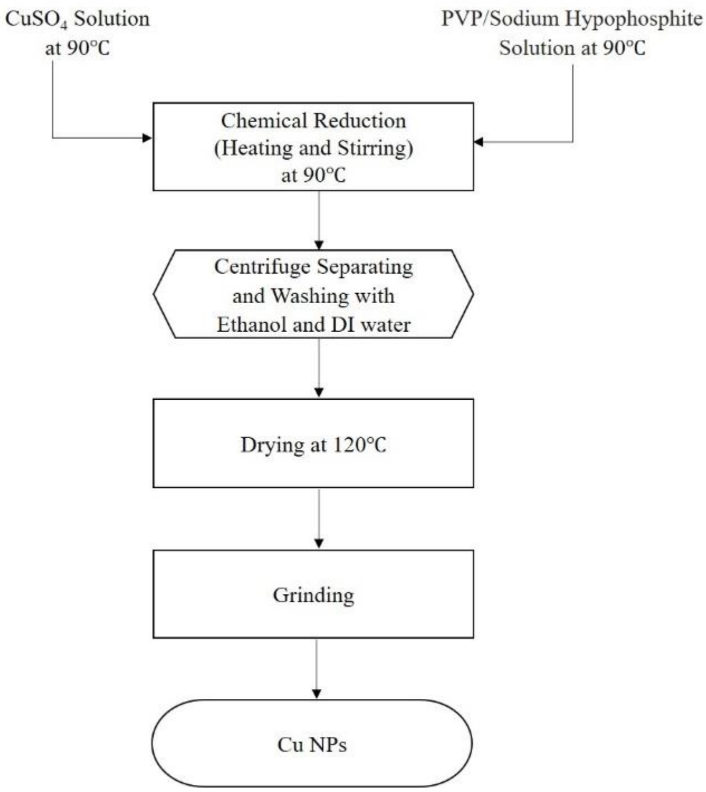

Figure 1. Schematic Synthesis Cu Nanoparticle

B. Engineering Perspective

Engineering Perspective is based on the process of Cu nanoparticle synthesis as shown in Figure 1. The process flow diagram of making Cu nanoparticles is shown in Figure 2. Several assumptions are made to synthesize Cu nanoparticles on a large scale and are based on stoichiometric calculations and mass balance.

- The synthesis process is carried out using a chemical reduction method
- All ingredients used in the synthesis reaction of Cu nanoparticles such as $CuSO_4.5H_2O$, ethanol, PVP, $NaH_2PO_2H_2O$, deionized

water, and acetone were enlarged 100 times which were calculated based on the literature [6]

- The reaction of Cu nanoparticle formation is assumed to be a complete reaction.
- The temperature of the mixer is 90℃ with a residence time of 1 hour
- The temperature at the reactor when the reaction is 90℃, then the temperature is lowered at room temperature when the reaction is stopped. The residence time of the substance in the reactor is 2 hours.
- The residence time of the substance in the separator reactor is 30 minutes
- The oven temperature is 120℃ with 30 minutes of residence time in the oven
- Grinding process is carried out for 30 minutes
- Loss of mechanical processes is assumed to be 5%.

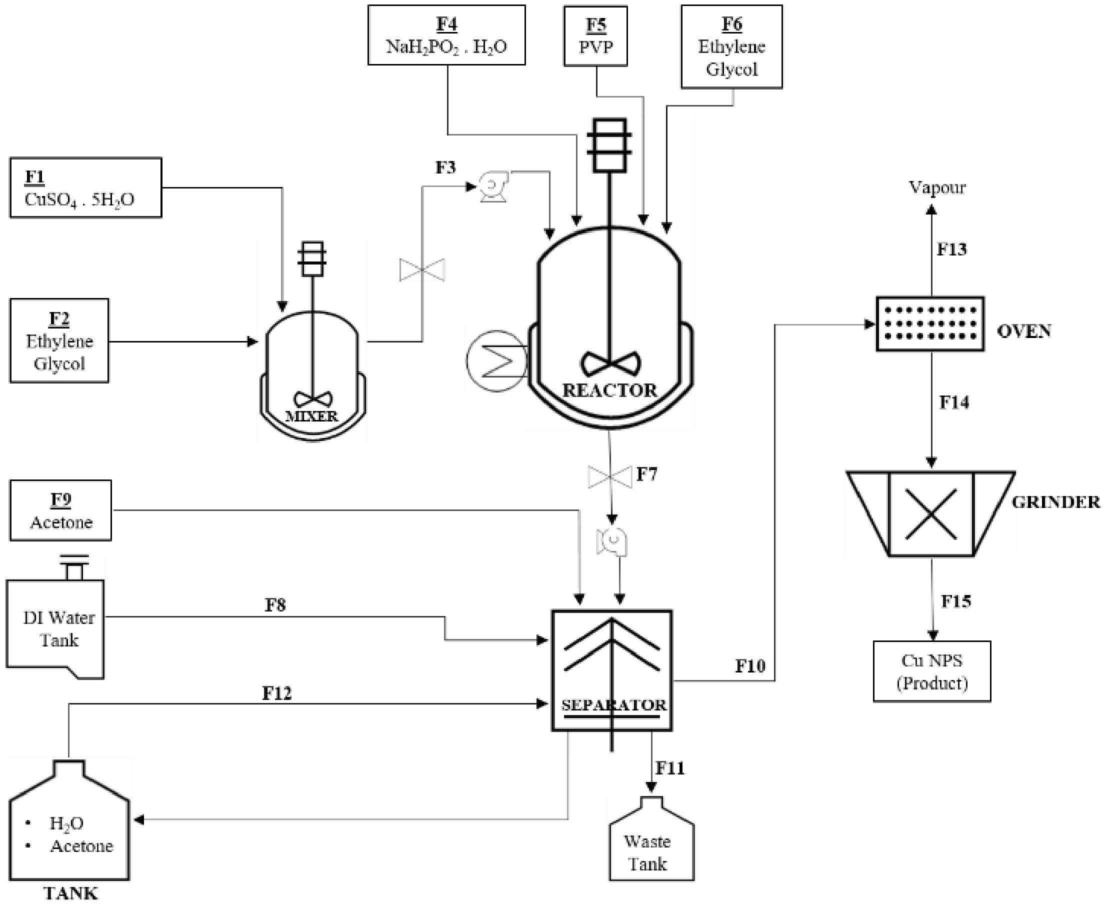

Figure 2. Process Flow Diagram of Cu NPs Production

C. Economic Evaluation

The data we use in the synthesis of Cu nanoparticles is based on literature [6]. The data is scale up that can be applied as an industry. The data of price in the economic evaluation analysis was obtained from an online shop called www.alibaba.com. Data processing in economic evaluation analysis is processed using the Microsoft Exel application with standard mathematical calculations. To support a project, an economic evaluation process is carried out. The economic evaluation parameters measured are as follows:

- Gross Profit Marigin (GPM) is an analysis to determine the level of profitability of a project. This analysis is estimated by reducing the cost of product sales with the cost of raw materials

- Payback Period (PBP) is a calculation used to predict the amount of time required for an investment to be able to return the total initial expenditure. PBP is calculated based on when CNPV reaches zero point for the first time
- Net Present Value (NPV) is the value obtained from a project that states expenditure and income
- Cumulative Net Present Value (CNPV) is the total NPV from the beginning of factory construction to the end of factory operations
- Total Investment Cost (TIC) is capital or initial costs that must be provided at the beginning of production. TIC is usually predicted using the lang factor [7].

To ensure economic analysis, several assumptions are used to predict and analyze possibilities that occur during the project. Some of the assumptions are:

- Calculations on economic evaluation analyzes using the IDR currency. 1 USD = 14,500 IDR
- Based on prices sold commercially, the prices of $CuSO_4.5H_2O$, $Na_2H_2PO_2.H_2O$, PVP, ethylene glycol, and acetone are 29,000 IDR/Kg; 14,500 IDR/Kg; 72,500 IDR/Kg; 12,325 IDR/Kg; and 14,500 IDR/Kg. The deionized water needs are obtained from water treatment that is treated at the factory, assuming the factory is located near natural water sources
- Equipment prices are determined based on commercially available prices with total equipment purchase costs of 1,179,405,600 IDR
- Land is bought to be a factory
- Electricity costs are assumed to be 1,500 IDR/KWH
- One cycle of the synthesis process of Cu nanoparticles takes 9 hours
- The project runs 300 days/year
- The total workforce during processing is 10 people with a salary per worker of 3,500,000 IDR/month
- Income tax of 10%
- Sales discount rate of 15%
- The project duration is 20 years

3. Result And Discussion

A. Theoretical Synthesis of Cu Nanoparticles

Based on engineering perspective assumptions, synthesis of Cu nanoparticles is possible to be produced on a large scale using adequate and commercially available equipment. Furthermore, by calculating the project with 300 processing cycles per year, the suggested scheme is prospective to produce 1563,862 Kg of Cu nanoparticles per year in ideal conditions, by consuming raw materials per year ie, 7500 Kg $CuSO_4.5H_2O$; 12000 Kg $Na_2H_2PO_2.H_2O$; 33300 kg PVP; 166500 Kg ethylene glycol; 1740 kg of acetone. Then, the costs incurred for total manufacturing costs are 8,231,547,131 IDR/year. With sales totaling 22,675,854,000 IDR/year, so the profit of 14,444,306,868 IDR/year is obtained. Profit value is relatively economical, so this project can be run for 20 years under ideal conditions.

B. Ideal Condition

Figure 3. shows the CNPV graph for time (years) with some economic evaluation parameters in ideal conditions. The curve shows a decrease in income (GPM) in the 1st and 2nd year, this is because that year is the year where the factory has not yet operated to produce Cu

nanoparticles. But in that year, there were costs incurred for initial investment capital such as the purchase of land, the purchase of equipment needed when producing Cu nano particles, and the cost of building a factory. In the 3rd to 20th year, there was an increase in income because in that year there was an income obtained from the sale of the product due to the Cu nanoparticle production process. Economic evaluation results show that the synthesis of Cu nanoparticles is very beneficial. And the payback period for initial investment capital in this project is quite short in 2.5 years. And in the following years until the 20th year shows an increase in income each year. Therefore, this project is ideal to run in industrial scale production because of its very good profitability. The graph of ideal condition is the same as the study conducted in the literature [8]. Where on the CNPV/TIC chart in the year of factory formation has decreased and in the year after the production process has increased

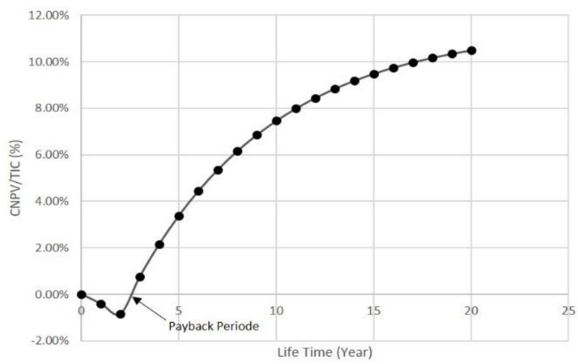

Figure 3. Graph of Ideal Condition for CNPV/TIC as Log as Twenty Years

C. Variation of Tax

Figure 4. shows the CNPV graph of time over 20 years with variations in tax increases. The 1st and 2nd years of each graph shows the same result, decrease of the graph because in that year there was no income tax expense incurred and in that year the construction of the factory occurred, so the graph was decreased the same as the ideal condition graph. An increase in tax can affect the value of CNPV. The higher of tax that must be issued, the payback period (PBP) for initial investment capital will be longer than in ideal conditions and also affects the income from a production (GPM).The higher the tax issued, the profitability of Cu nanoparticle production is getting smaller or not very profitable. The CNPV/TIC chart with the tax variations we analyzed is the same as the study conducted in the literature [8]. Where the higher the tax that must be issued each year, the profitability will decrease.

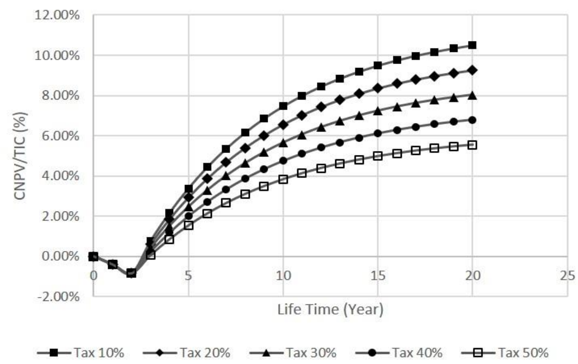

Figure 4. Graph of CNPV/TIC as Long as Twenty Years with Various Increasing of Tax

D. Variation of Raw Maetrial

Figure 5. shows a CNPV graph of time over 20 years with variations in price increases for raw materials. From this graph, it is known that in the 3rd to 20th years there was a difference in CNPV increase in each variation of the increase in raw material prices. The higher the raw material price increases, the lower the CNPV value and the lower the GPM value. This means that the increase in raw material prices can affect the decline in GPM. In addition, the increase in raw material prices causes PBP to exceed the minimum limit of PBP in ideal conditions, which can reduce the profitability of Cu nanoparticle production.

In a project, raw material is included in the variable cost, where the variable cost plays an important role in determining the profitability of a project. Based on the literature [8], a decrease in variable costs can increase the final CNPV value, and cause PBP values to decrease which means the payback period (PBP) for initial investment capital will be faster and profitability will be higher. Conversely, increasing raw material can cause PBP to be slower and cause profitability to decrease.

The decrease in GPM due to the increase in raw material prices can be overcome by increasing the product sales price. By increasing product sales prices, the value of GPM will increase again. That is, when the price of raw material rises, the step that must be taken is to increase the sales price of Cu nanoparticle products.

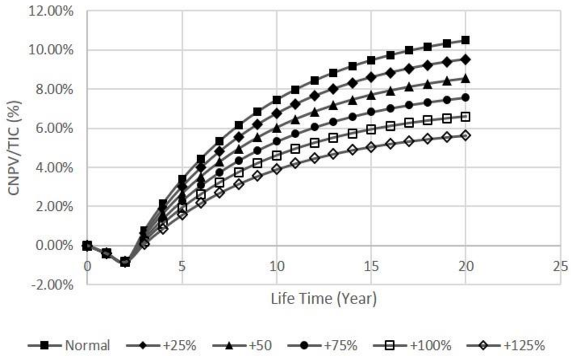

Figure 5. Graph of CNPV/TIC as Long as Twenty Years with Various Increasing of Cost Raw Material

E. Variation of Sallary Labor

Figure 6. shows a CNPV graph of time over 20 years with variations in labor wages. The number of labor assumed in this study is 10 people with a salary of 3,500,000.00 IDR/month. Increase in labor salaries by up to 100% only slightly decreased CNPV. With an increase in labor wages of up to 100%, the profitability of the Cu nanoparticle project is still in good condition and has no loss.

Labor salary is also included in the variable cost, as explained in the literature [8], decreasing the variable cost can increase the final CNPV value, so that the PBP value decreases or the initial capital investment becomes faster and profitability is higher. Conversely, an increase in raw material can cause PBP to be slow and cause profitability to decrease.

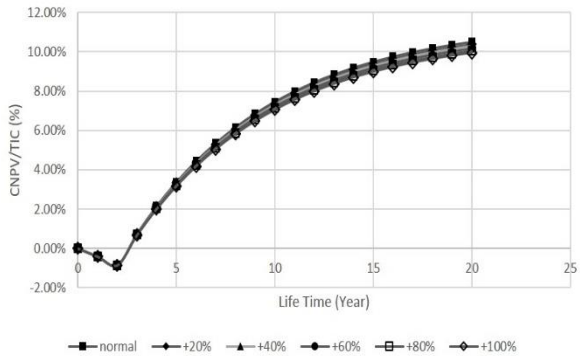

Figure 6. Graph of CNPV/TIC as Long as Twenty Years with Various Increasing of Sallary Labor

F. Variation of Sales

Figure 7. shows a CNPV graph of time over 20 years with variations in sales price decrease. The decline in sales prices can affect CNPV. When sales prices is decrease, CNPV will go down as well as GPM will go down and suffer losses. A decrease in sales price of more than 50% will result in losses in Cu nanoparticle production. This condition is very unfavorable for continuing the Cu nanoparticle production project. Based on the literature [8], the increases in sales relate to the change in variable cost does not affect project profitability. Therefore the sales price must be optimized so that the profitability of a project is optimum. Based on these results, the effect of decrease in sales prices can affect the profitability of a project.

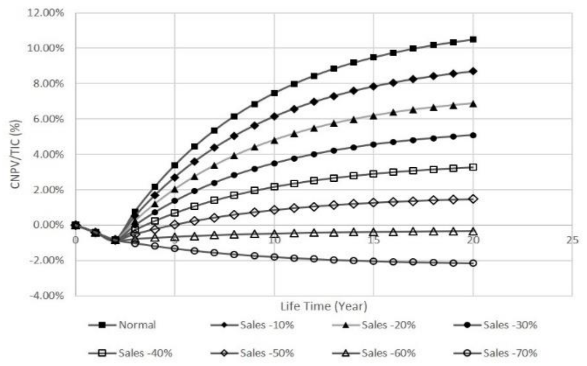

Figure 7. Graph of CNPV/TIC as Long as Twenty Years with Various Decrease of Sales

4. CONCLUSIONS

Based on the results of analysis above, the manufacture of Cu nanoparticles by chemical reduction methods on a large scale is very prospective from the results of the engineering perspective. This analysis was supported by an economic evaluation using several parameters which stated that the project of making Cu nanoparticles was very profitable and a short payback period for initial investment. Income tax, raw material costs, labor costs, and sales greatly affect the profitability of the project. In order to maintain optimum profitability and keep the project feasible to run, then this influence needs to be estimated, so that the project profitability remains good and feasible to run.

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