Preliminary Economic Study on the Production of ZnO Nanoparticles Using a Sol-Gel Synthesis Method

Fikri Aziz Shalahuddin¹, Sera Serinda Almekahdinah¹, Asep Bayu Dani Nandiyanto¹

1) Departemen Pendidikan Kimia, Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alam, Universitas Pendidikan Indonesia

*Corresponding author: nandiyanto@student.upi.edu

I. INTRODUCTION

In recent years, a nano semiconductor particle has attracted more interests due to their optical, electrical and also mechanical properties. Among these various semiconductor nanoparticles, zinc oxide (ZnO) has been attracted tremendous attention. This is confirmed by the fact in the wide range of applications, for example energy conversion, luminescence, photo-catalysis, electrostatic dissipative coating, transparent UV protection films, and chemical sensors [1-4].

Previous researches reported the different approaches in the synthesis of ZnO nanoparticles, i.e., the vapor phase, the solution, and the solid [5]. In the vapor phase, synthesis methods can be found in chemical vapor condensation, hydrogen plasma-metal reaction, and laser pyrolysis. In the liquid phase, the methods are hydrothermal, sol-gel, microemulsion, sonochemical, and microbial processes. The process in the solid phase can be found in the ball milling [6,7]. Sol-gel method of metal oxide synthesis offers unique advantages due to the possibility in obtaining metastable materials, achieving superior purity and compositional homogeneity of the products at moderate temperatures with simple laboratory equipment [8], and gaining good crystallinity of the product resulted [9]. Although there are many reports confirmed the prospective methods for producing ZnO nanoparticles, there is almost no report on the analysis for the feasibility study in the large scale production. In fact, this information is important for giving better prospective for industrial practitioners to apply the method in realistic application[10-14].

Here, the purpose of this study was to evaluate the possibility in the large-scale production of ZnO nanoparticles using the sol-gel method. This method was evaluated using two main perspectives of ZnO nanoparticles production: engineering and economic evaluation. Several parameters were calculated to support the economic evaluation[14]:

- Gross profit margin (GPM; to predict the economic condition in rough calculation).
- Payback period (PBP; to assume the possibility for annual profit).

Abstract

The economic evaluation is one of the key points in building chemical industries. This paper presented a preliminary economic evaluation of the large-scale production of zinc oxide (ZnO) nanoparticles using the sol-gel method, which is very useful for helping decision whether the fabrication of this material profitable or not. Particularly, the study was done by changing the cost of raw material, which was compared to several economic parameters such as GPM, PBP, and CNPV. The result showed that the project was profitable by increasing raw material cost below 100% from the estimated raw material cost, informing the fact for the prospective fabrication for fulfilling the demand of ZnO nanoparticles.

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Cumulative net present value (CNPV; to predict the project condition as a function of annual production).

Several informations from commercial website was adopted to support both engineering and economic analysis, such as chemical price, components for utilization, and specification of the apparatuses. To get the feasibility study, the data was calculated for getting the maximum yield of ZnO fabrication that can be applied on the small enterprise industry. In addition, this study is important to help in making decision whether the ZnO nanoparticle fabrication is profitable or not. Also, this study can be used for suggesting ways to optimize the project, indeed, to give benefit for economic growth. All the calculations of this study were done in the specific conditions [13]. Additional variables used was raw materials [15].

1.1. Synthesis of ZnO Nanoparticles Using Sol-Gel Method

The synthesis of ZnO nanoparticle in this project was adopted and improved from the literature [9, 16, 17]. In short, the solution containing sodium hydroxide were mixed with zinc acetate dihydrate solution and stirred continuously. Then, ethanol was filled up into a burette for titration of those mixed solutions. After the reaction, a white precipitate was formed [1], this white precipitate was then dried, washed, and annealed at 500°C for two hours to obtain the ZnO nanoparticles. This study was reported in literature [9, 18, 19]. The schematic process of sol-gel method shown in Figure 1.

During the process, the following reactions occur [9, 19]:

- Hydrolysis of Zinc Acetate Dihydrate
\[
\text{Zn(CH}_3\text{COO)}_2\cdot2\text{H}_2\text{O} + 2\text{NaOH} \rightarrow \text{Zn(OH)}_2 + 2\text{CH}_3\text{COONa} + 2\text{H}_2\text{O}
\] (1)

- Condensation of Zinc Hydroxide
\[
\text{Zn(OH)}_2 + 2\text{H}_2\text{O} \rightarrow \text{Zn(OH)}_4^{2+} + 2\text{H}^+
\] (2)

\[
\text{Zn(OH)}_4^{2+} \rightarrow \text{ZnO} + \text{H}_2\text{O} + 2\text{OH}^-
\] (3)

- Synthesis of ZnO NP
\[
\text{Zn(CH}_3\text{COO)}_2\cdot2\text{H}_2\text{O} + 2\text{NaOH} \rightarrow \text{ZnO} + 2\text{CH}_3\text{COONa} + 3\text{H}_2\text{O}
\] (4)

2. EXPERIMENTAL

2.1. Methods

The method used in this study based on an analysis of the prices of materials and equipment, as well as the specifications of the equipment sourced from the online web such as alibaba.com. Data processing is calculated based on simple mathematical calculations using Microsoft Excel applications to obtain economic evaluation parameters: GPM, PBP, and CNPV. The calculation of these parameters based on the literature [14, 16, 17], which presented in the following formula.

- The GPM parameter is obtained by reducing sales (S) with raw materials (R).
\[
GPM = S - R
\] (5)

- PBP is a calculation conducted to predict the length of time needed to return the total initial cost. The simplest way to get PBP was determined from the CNPV curve by seeing when CNPV reaches zero points for the first time.

- CNPV (Cumulative net present value) is the calculation of the total NPV value from the onset of the factory construction to the end of the plant operation. In short, CNPV can be obtained from the amount of cumulative financial flows each year.
\[
\text{CNPV} = \sum \text{NPV}
\] (6)
• NPV is the value obtained as state income and spending. NPV calculation should consider the value of discount rate ($i$). Besides, NPV also can be used to estimate future Cash Flow ($CF$). Data needed to calculate NPV are included TIC, depreciation, operational cost, and expected benefits.

NPV is obtained by

$$NPV = CF.i$$ (7)

• TIC (Total Investment Cost), is the initial cost of capital that must be provided at the beginning of production. TIC must be predicted based on the Lang Factor [16].

Then the feasibility test for the present economic evaluation was done by varying the value of raw materials in five conditions (i.e., 100%, 50%, 0%, -50%, -100%).

3. RESULT AND DISCUSSION

3.1. Engineering Perspective

Some assumptions based on the process are shown in Fig. 1. It shows the stoichiometric calculation after scaling up project which produced about 3 kg of ZnO nanoparticles.

• All chemical compositions in the reaction, such as zinc acetate dihydrate, sodium hydroxide, ethanol, and distilled water used for the production of ZnO nanoparticles were scaled up 4000 times and calculated based on literature [9]. Several raw materials used in this production are listed in Table 1.

• Conversion rate for all reaction was 100% [20].

• ZnO nanoparticles obtained have 100% purity at pH 12 [21]

• The level of production is carried out based on the small industry scale

• The cost of raw material, utility, and labor are shown in Fig. 2.

Table 2. Several raw material used

<table>
<thead>
<tr>
<th>NaOH (Kg)</th>
<th>Zinc Acetate (Kg)</th>
<th>Ethanol (L)</th>
<th>Reaction Conv. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>32</td>
<td>400</td>
<td>100</td>
</tr>
</tbody>
</table>

Fig. 2. The Cost of Raw material, Utility, and Labor

3.2. Economic Evaluation

Several factors were assumed to analyze the economic perspective:

• The USD (American currency) exchange rate against IDR (Indonesian currency) has been set at 1 USD = 14000 IDR [22].

• Prices of all raw materials and components were based on prices (www.alibaba.com). In short, the price of zinc acetate dihydrate, sodium hydroxide, ethanol and ZnO nanoparticles were 2,5 USD/kg; 0,6 USD/kg; 1,02 USD/L; and 0,5 USD/g respectively.

• The total investment cost (TIC) was calculated based on the Lang Factor [10, 14].

• This production process was carried out under the purchased soil. Therefore, the land was calculated as the initial cost of industrial development and is recovered after the project (at the end of the project).

• Direct-type depreciation was used for calculating depreciation [17].

• The process needed 5 hours to produce 3 kg of ZnO nanoparticles in one cycle [19].

• In one day, only one cycle production process of ZnO nanoparticles was carried out.

• Minimum product purchase is one pack (100 grams).

• Water distillation process was done at night.

• Working days in one year were 300 days and the rest of the days are used to clean and prepare the process.

• Basic electricity cost was 0.65 USD / kWh.
• The total labor was assumed with a fixed value of 7 USD/day.
• The discounted rate and the income tax were 15 and 10% annually, respectively.
• The length of the project operation was 20 years.

3.2.1. Ideal Condition

Fig. 3. shows the payback period occurred after the third year of production, and the profit will continuously increase afterwards until the year of 20th. Thus, the production of ZnO nanoparticles can be considered as profitable project.

3.2.2. Effects of raw material (i.e., Zinc Acetate Dihydrate, Sodium Hydroxide, and Ethanol)

The calculation was carried out by subtracting the sales cost of the product (revenue of products that can be sold) with initial cost of raw materials [14] to analyze the effect of raw materials on GPM. The result shows that changing raw materials gave a negative impact on the values of GPM, as shown in Fig. 4. Therefore, by increasing the prices of the raw materials, it brought a negative effect on the project. The significant impact occurred when changing the prices of ethanol, while Zinc Acetate Dihydrate and Sodium Hydroxide gave a similar impact.

Based on calculation data, changing variable costs affected the CNPV value, as shown in Fig. 5. Variable cost is the cost of maintaining the production process at the factory [14]. Changing the variable cost to -100% means that all costs required to process at the factory are free, but changing the variable cost to 50%, meaning that all costs needed for the production process are half of the original price. It means that variable costs also affect the profitability of the project. Decreases in variable costs resulted in the high value of final CNPV. However, by increasing the costs of the variable, the CNPV value decreased. Thus, when the variable costs are lower, the effectiveness of the project to generate profits would be high. However, if variable costs were increased, the project profitability would probably decrease. The best time for each variable cost that could provide benefits was started from the third year of production and so on.

3.3. Production Capacity

The production capacity specified in this industry is the minimum capacity. Therefore, this
industry provides benefits. According to Figure 2, the specified production capacity was as many as 29 packs per day, with a net/pack of 100 grams.

3.4. The result from Engineering Perspective

Based on the engineering point of view, it is possible to do more scaling up. It was because the scaling process can be implemented using commercially available and inexpensive equipment. Furthermore, by calculating projects with 300 processing cycles per year, the suggested scheme is prospective to produce around 0.9 tons of ZnO by consuming 2.4 tons of zinc acetate dihydrate and 9.6 tons of sodium hydroxide per year. Then, an analysis of total equipment costs requires a total cost of 11480 USD. Adding the Lang Factor to the calculation, TIC must be less than USD 50980. This value is relatively economical, and the project requires fewer investment funds. With a project life span of 20 years, the results showed that the entire project can produce 18 tons of products in ideal conditions.

3.5. The result from Preliminary Economic Analysis

Based on the economic analysis carried out, the project is very feasible both under ideal or non-ideal conditions. However, this is considered only based on changes in the prices of raw materials. The result would be different when there is a change in other parameters of economic evaluation. All analysis were compared to the condition of the bank and the Indonesian currency [13]. A detailed description of the specific conditions based on the analysis is explained as follows:

- Projects can still be profitable if the increase in raw material costs is below 100% of the estimated raw materials’ costs. The significant decrement occurred due to the changes in the amount of ethanol. Zinc acetate dihydrate and Sodium hydroxide did not cause significant changes.
- Product sales must be carried out in a minimum amount of around 2.9 kg per day to maintain the project. When sales prices are reduced, the number of sales product increased. On the contrary, the project will give a loss. Based on the technical analysis, the product from the reaction was not so high.
- Labor costs, utility costs, taxes, and other economic parameter are kept in ideal conditions. It was due to in this analysis, only the effect of changes in raw materials is considered.

In addition to the economic outlook, a project feasibility analysis also needs to be carried out. In this project, GPM and CNPV for cost variables showed promising results in ideal conditions. This perspective based on the Indonesian capital market standards with PBP's analysis showing that this investment will benefit from the third year.

4. CONCLUSION

Based on the results of the analysis, the ZnO nanoparticles project is prospective from both engineering point of view and preliminary economic analysis. Projects are considered profitable if the increase in raw material costs is below than 100% of the estimated raw materials’ costs. Also, product sales must be carried out in a minimum amount of around 2.9 kg per day.

REFERENCES


