Engineering and Economic Evaluation of Production of SnO_2 Nanoparticles by Microwave-Assisted Green Synthesis

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Abstract – *The synthesis of nanoparticles from noble metals such as tin (IV) oxide (SnO_2) is a research in progress with a very wide application in various fields, such as environmental improvement, gas sensors, catalysis, and lithium-ion batteries. The purpose of this study was to evaluate the economic feasibility of producing tin (IV) oxide (SnO_2) nanoparticles using the microwave-assisted green synthesis method on an industrial scale for 10 years by evaluating from an engineering and economic perspective. Various economic parameters are used to analyze economic viability, including Gross Profit Margin (GPM), Payback period (PBP), Cumulative Net Present Value (CNPV), as well as economic variations in sales, taxes, raw materials, labor wages, and utilities to ascertain project viability. Technical analysis to produce 8.54 kg of SnO_2 nanoparticles per day shows a total production cost of 1,982,243,613.12 IDR and a total investment cost of 1,732,590,765.12 IDR. The resulting gross profit margin is 39,231,578,268 IDR/year, the profit is relatively economical, so this project can be run for 10 years under ideal conditions. This research is expected to be a reference for technical and economic analysis of industrial scale production of SnO_2 nanoparticles.*

Keywords: *SnO_2 nanoparticles, microwave-assisted green synthesis, economic evaluation, feasibility study.*

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I. Introduction

Tin (IV) oxide nanoparticles (SnO_2 NPs) are a group of metal oxides that have semiconductor properties. SnO_2 NPs can be used as transparent electrodes for solar cells, liquid crystal displays, catalysts for methanol conversion, antistatic coatings, gas sensors, anodes for lithium-ion batteries, transistors, catalyst supports, nano and ultrafiltration membranes, and anti-corrosion coatings [1].

SnO_2 NPs can be synthesized by various methods, including the sol-gel method [1,2], hydrothermal [3-5], coprecipitation [6-9], microwave-assisted [10-12], mechanochemical [13,14], green synthesis [15]. Among these methods, the microwave-assisted green synthesis method is considered to have the highest efficiency, because the method is simple and more economical than other methods, produces minimum waste and is easy to handle, and does not use harmful oxidizing and reducing agents. The synthesized particles size of 27 nm, pure, and have spherical morphology. To evaluate the increase in production from small to large scale (industry), this study adopted the SnO_2 NPs synthesis method with the microwave-assisted green synthesis method and changing the quantity of materials on a lab scale to an industrial scale [16]. There are also advantages of using a microwave, namely, the reaction takes place quickly [17] and the controlled high temperature in the microwave can increase the nucleation process during the synthesis of nanoparticles [18]. Many raw materials for tin oxide also have been reported, such as tin chloride (e.g., $SnCl_2$ and $SnCl_4$) and tin fluoride [19].

An Economic evaluation of the chemical industry is a form of a quantitative assessment of what is expected and desired by the community to carry out the process of investing in a project. This evaluation analysis uses several parameters such as the number of SnO_2 NPs produced per day, total equipment costs, total production cost, total investment cost, calculating Gross Profit Margin (GPM) as the first analysis to determine the level of profitability of a project; calculating Payback Period (PBP) to predict the length of time it takes for an investment to be able to return the initial total expenditure; Cumulative Net Present Value (CNPV) to predict the condition of the project as a function of the production year or it can be obtained as the number of cumulative financial flows each year [20] also as well as several economic variations on sales, taxes, raw materials, salary labor, and utilities will be discussed and analyzed to support the economics analysis. The purpose of this study was to determine the feasibility of the project for making SnO_2 nanoparticles using the microwave-assisted green synthesis method by conducting technical and economic evaluations. This is because there are no articles that discuss the technical and economic evaluation of the synthesis of SnO_2 NPs.

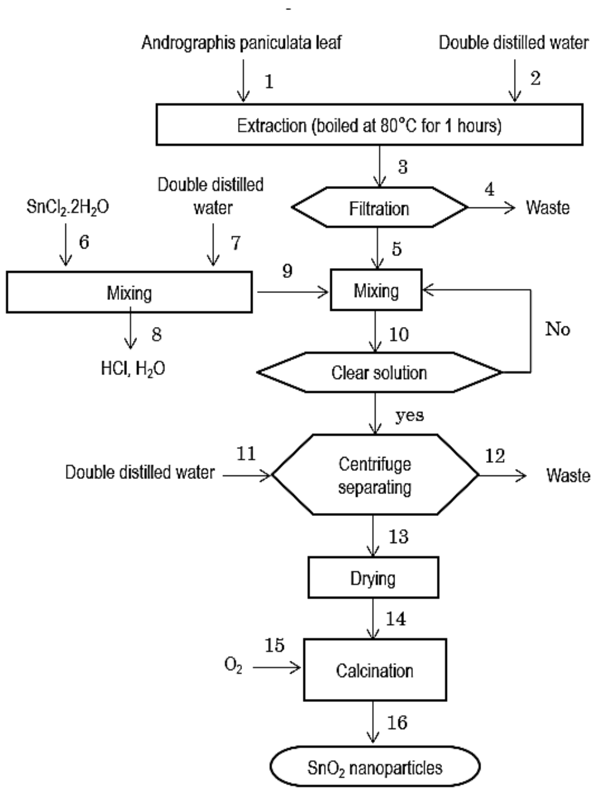

Figure 1. Synthesis scheme of SnO_2 NPs

II. Research Method

II.1. Theoretical Synthesis of SnO_2 Nanoparticles

Figure 1 shows the stages of the SnO_2 NPs synthesis scheme using microwave-assisted green synthesis and *Andrographis paniculata* leaf extract as a chelating agent. The method of synthesis of SnO_2 NPs was adopted from research conducted by [16]. The synthesis of SnO_2 NPs was initiated by dissolving 14.10 kg of $SnCl_2.2H_2O$ with 68 L of water. *Andrographis paniculata* leaf extract was prepared by heating 2.50 kg of leaves with 50 L of water at 80°C for 2 hours. The result of heating the leaf extract is filtered to separate the extract from the residue. The leaf extract is then mixed with $SnCl_2$ solution and stirred for 2 hours until a clear solution is formed which indicates the formation of SnO NPs. The formed SnO NPs were separated and washed with deionized water by centrifugation method. The final product was microwave-dried at 180°C for 3 hours. Calcination was carried out at 673 K for 6 hours to obtain SnO_2 NPs.

II.2. Technical Perspective

The engineering perspective is based on the synthesis process of SnO_2 NPs as shown in Figure 1. The flow diagram of the process for making SnO_2 NPs is shown in Figure 2. Several assumptions are made to synthesize SnO_2 NPs on a large scale (industry) and are based on stoichiometric calculations and mass balance.

- The synthesis process is carried out using the microwave-assisted green synthesis method.
- All materials used in the synthesis reaction of SnO_2 NPs such as double distilled water, $SnCl_2.2H_2O$, *Andrographis paniculata* leaves have high purity and are enlarged 500 times as calculated based on the literature from [16].
- The formation of SnO_2 is assumed to be a complete reaction.
- The residence time of the substance in the filter is 1.5 hours.
- The stirring temperature for leaf extraction is 90°C while for mixing it is 25°C with a residence time of 2 hours.
- The centrifugation process is carried out for 1.5 hours.
- The microwave temperature used is 180°C with a residence time of 3 hours.

- The furnace temperature used is 674 K with a residence time of 6 hours.
- Assuming a loss of 5% in any mechanical process.

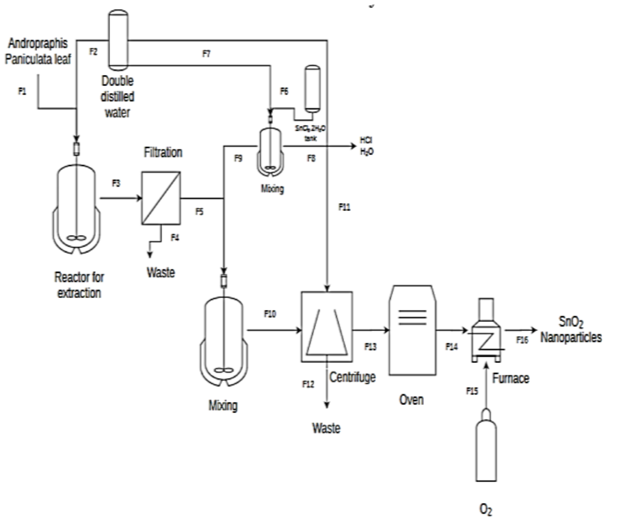

Figure 1. Flowchart of the synthesis process for the production of SnO_2 NPs

II.3. Economic Evaluation

In this economic evaluation, the data of price in the analysis were obtained from an online shop called www.tokopedia.com, www.alibaba.com, and www.sigmaaldrich.com. The data processing in this economic evaluation analysis is processed mathematically using the Microsoft Excel application. The economic evaluation process in a factory is carried out based on the following parameters:

- Total Investment Cost (TIC)

Total Investment Cost (TIC) is capital or initial cost that must be provided at the beginning of production. TIC is usually calculated based on the total factory cost (Total Purchasement Cost (TPC)) [21]. Simply put, TIC is the cost to build a factory and initial costs (equipment and service costs related to equipment for equipment agencies in the factory) [22].

- Gross Profit Margin (GPM)

Gross Profit Margin (GPM) is the first analysis to determine the level of profitability of a project. This analysis is estimated by subtracting the cost of products sold (revenue) from the cost of raw materials [23]. GPM is also used to measure the efficiency of companies using materials and labor to produce and sell products so that they can make a profit [21].

- Payback period (PBP)

Payback period (PBP) or fund back is a calculation done to predict the length of time it will take for an investment to return the total initial outlay. PBP is calculated when CNPV is at zero for the first time [23].

- Net Present Value (NPV)

Net Present Value (NPV) is the value obtained from a project which represents expenses and income. The NPV calculation must consider the opportunity cost of social capital (as a discount rate) [21]. On the other hand, NPV can also be used to estimate the expected financial flows in the future [24].

- Cumulative Net Present Value (CNPV)

Cumulative Net Present Value (CNPV) is the calculation of the total NPV value from the beginning of factory construction to the end of factory operations. CNPV can be obtained as the amount of cumulative financial flows each year [21]. In addition, CNPV also calculates land and final depreciation, as well as the value of the savings (final depreciation value) [24].

In determining the economic analysis, there are several assumptions that may occur during the project, including:

- Calculations on economic evaluation analyse using the IDR currency.
- Based on prices sold commercially, the price of *Andrographis paniculata* leaves is 53,000.00 IDR/ kg and the $SnCl_2.2H_2O$ price is 142,148.40 IDR/ kg. As for deionized water, it is obtained from water treatment that is processed in a factory using a water purifier and assumes that the factory is close to a water source.
- Equipment prices are determined based on commercially available prices with a total equipment purchase cost of 499,305,696.00 IDR.
- Electricity costs are assumed to be 1,444.70 IDR/ KWh.
- One cycle of the synthesis process of SnO_2 takes four hours.
- The project runs 25 days / month or in one year is 300 days.
- The total labor during processing is 50 people with a per worker of 3,100,000.00 IDR/month.
- Income tax 10%.
- Sales discount rate of 15%.
- The project duration is 10 years.

III. Result and Discussion

III.1. Theoretical Synthesis of SnO_2 Nanoparticles

The synthesis of SnO_2 NPs based on the assumptions of an engineering perspective, allows them to be produced on a large scale with the help of commercially available equipment. The reaction mechanism that occurs is as follows [25].

$$SnCl_2.2H_2O(s) + H_2O(l) \rightarrow Sn(OH)_2(s) + 2HCl(aq)$$
$$Sn_6O_4(OH)_4(s) \rightarrow 6SnO(s) + 2H_2O(l)$$
$$2SnO(s) + O_2(g) \rightarrow 2SnO_2(s)$$

Furthermore, by calculating the processing cycle/year, the suggested scheme is prospective to produces 8.54 kg of SnO_2 NPs per day. Meanwhile, the raw materials used were as follows: 2.50 kg of *Andrographis paniculata* leaves and 14.10 kg of $SnCl_2.2H_2O$. The total cost incurred by the production process/year is 641,037,732.00 IDR. Total sales/year were obtained for 39,872,616,000.00 IDR, gross profit margin/year for 32,768,518,317 IDR.

III.2. Ideal Condition

Figure 3 shows a graph of the relationship between CNPV/TIC and time. The X axis is the year and the Y axis is CPNV/TIC. The graph shows a decrease in income, namely in 1st to 2nd year, caused by initial capital expenditures for the purchase of equipment needed during the nanoparticle production process as well as for land purchase costs. In that year the factory had not yet produced nanoparticles. In the 3rd year, there is an increase in income, this condition is called the Payback Period (PBP). This increase in revenue because the factory has produced nanoparticles and is sold, it can cover the initial capital used for equipment purchases and land purchase costs. The profit earned continues to increase until the 10th year. Thus, the production of nanoparticles is a very profitable project because this project takes only 2 years for initial capital.

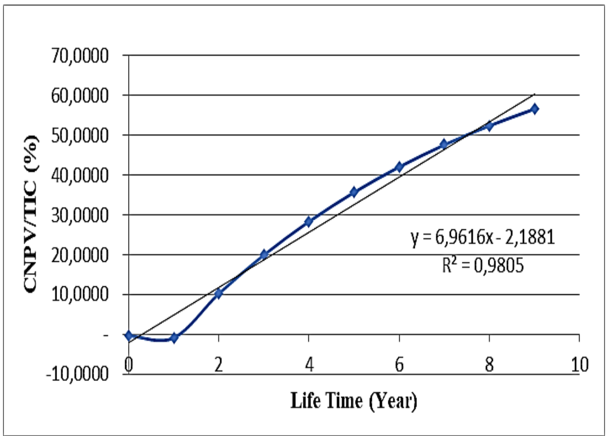

Figure 3. Graph of Ideal Condition of CNPV/TIC as long as ten years

III.3. Variation of Sales

Figure 4 shows a CNPV chart with various sales variations over 10th years. The analysis was carried out by increasing and decreasing sales by 10 and 20%. The ideal sale is 100%, when sales are decreased by 10 and 20%, the sales are 90 and 80%, respectively. When sales are increased by 10 and 20%, sales are 110 and 120%. From Figure 4, sales with various variations have the same value at the beginning of the project development (from 1st to 2nd year). After the project was created (in 3rd year) there was a sales effect on CNPV. The greater the sales value, the higher the profit for the project being undertaken. But if there are conditions that cause product sales to decline, then the project profits are reduced from the ideal state. Profits continue to increase after reaching the PBP point until the 10th year. When sales are reduced by 20% from ideal conditions, the gap in profits generated for each year will be less. Conversely, the distance between the profits generated from each year increases with an increase in sales from ideal conditions. The CNPV/TIC values in the 10th year for each variation of 80, 90, 100, 110 and 120% were 42.575; 49,602; 56,630; 63,658 and 70,685%. From the variation of sales, the project can still run and make a profit.

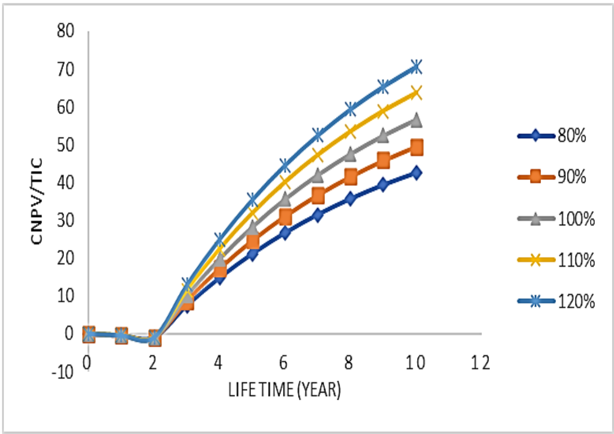

Figure 4. Graph of CNPV/TIC as long as ten years with Variation of Sales

III.4. Variation of Tax

Tax is another levy imposed on projects by the state and is an external factor that can affect the success of a project. Figure 5. In 1st and 2nd year shows the initial conditions of the project. The initial condition of the project in the graph has decreased because in the first and second years there was no income tax expense and in that year there was a factory construction, so the graph was the same as the ideal graphic conditions. The variation of taxes in the 3rd to 10th year is increasing, this is very influential on this project. The CNPV/TIC values obtained in the 10th year with tax variations of 80, 90, 100, 110, and 120% were 56,630; 47.0623; 31,116; 28,0260; 24.9359%. The higher the tax that must be issued, the return on the initial investment will be longer than ideal conditions. The higher the tax issued, the smaller or less profitable the profitability of nanoparticle production is. From the graph of CNPV/TIC, the higher the tax that must be issued each year, the lower the profitability will be.

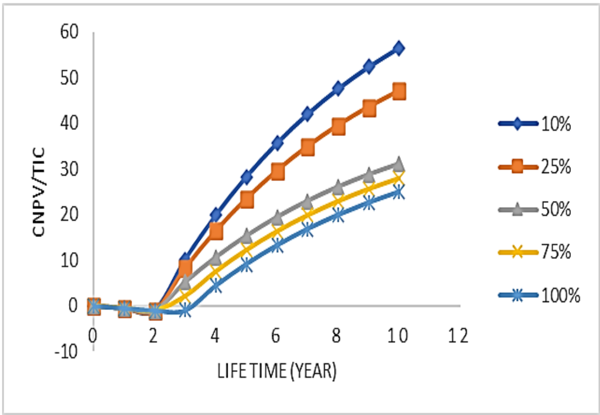

Figure 5. Graph of CNPV/TIC as long as ten years with Variation of Tax

III.5. Variation of Raw Material

The success factor of a project can be influenced by the condition of the raw materials. Graph of CNPV against time with variations in the raw material is shown in Figure 6. The analysis was carried out by decreasing and increasing the ideal raw material (represented by 100%) by 10 and 20%. When the raw material is reduced by 10 and 20%, the raw material becomes 90 and 80%, respectively. When the raw material is increased by 10 and 20% the raw material becomes 100 and 120%, respectively. In the 1st to 2nd year indicate the initial conditions of the project. The initial conditions of the project on the CPNV chart under the variation of raw materials have the same CNPV/TIC (%) value and have decreased due to project development. Variations in raw materials will affect the project in 3rd to 10th year, this is indicated by the value of CNPV/TIC (%) which will increase starting in 3rd year for each variation. The CNPV/TIC (%) values obtained did not show any significant difference except for the 120% variation which had very different values and had curves under ideal conditions. From Figure 6, it can be concluded that the higher the conditions for the variation of raw materials, the lower the CNPV/TIC value will be and it will lead to the formation of curves under ideal conditions. In the 10th year with variations of 80, 90, 100, 110, and 120% the CNPV/TIC values were 56.856; 56.743; 56.630; 56.517; 56.517%. From the variety of raw materials, the project can still run and get profit. Furthermore, the profit will continue to increase after reaching the PBP point until the 10th year.

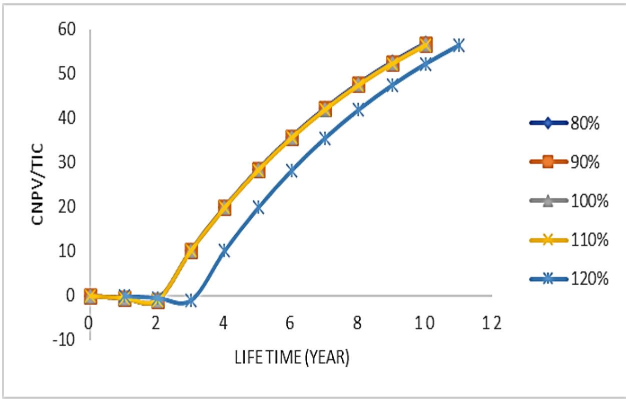

Figure 6. Graph of CNPV/TIC as long as ten years with Variation of Raw Material

III.6. Variation of Sales Labor

The labor factor can also affect the success of a project. Graph of CNPV against time with labor variation is shown in Figure 7. The analysis was carried out by reducing and increasing the salary of labor in ideal conditions (represented by 100%) by 10 and 20%. When the salary is reduced by 10 and 20%, it will be 90 and 80% respectively. When the salary is increased by 10 and 20%, it becomes 100 and 120% respectively. In the 1st to 2nd year indicate the initial conditions of the project. The initial project conditions on the CPNV chart under the labor variation have the same CNPV/TIC (%) value and have decreased due to project development. The labor variation will have an effect on the project in 3rd to 10th year, this is indicated by the value of CNPV / TIC (%) which will increase starting in 3rd year for each variation. In the 10th year with variations of 80, 90, 100, 110, and 120% the CNPV / TIC values were 57.286; 56.958; 56.630; 56.302; 55.974%. From the variation of labor, the project can take place and generate a profit. Furthermore, the profit will continue to increase after reaching the PBP point until the 10th year.

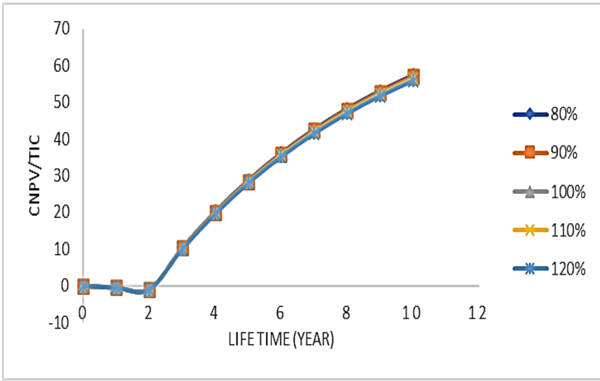

Figure 7. Graph of CNPV/TIC as long as ten years with Variation of Salary Labor

III.7. Variation of Utility

The success of a project can also be affected by the utility. The graph of CNPV against time with utility variations is shown in Figure 8. The analysis was carried out by decreasing and increasing the utility in an ideal state (represented by 100%) by 10 and 20%. When the utility is reduced by 10 and 20%, the utility becomes 90 and 80% respectively. When it is increased by 10 and 20% the utility becomes 100 and 120% respectively. In the 1st to 2nd year indicate the initial conditions of the project. The initial project conditions on the CPNV chart under the variation of utility have the same CNPV/TIC (%) value and have decreased due to project development. The variation in utility will affect the project in 3rd to 10th year, this is indicated by the value of CNPV/TIC (%) which will increase starting in the third year for each variation. The CNPV/TIC (%) values obtained did not have a significant change. In the 10th year with variations of 80, 90, 100, 110, and 120% the CNPV/TIC values were 56.692 respectively; 56.661; 56.630; 56.599; 56.568%. From the variation of utility, the project can take place and generate a profit. Furthermore, the profit will continue to increase after reaching the PBP point until the 10th year.

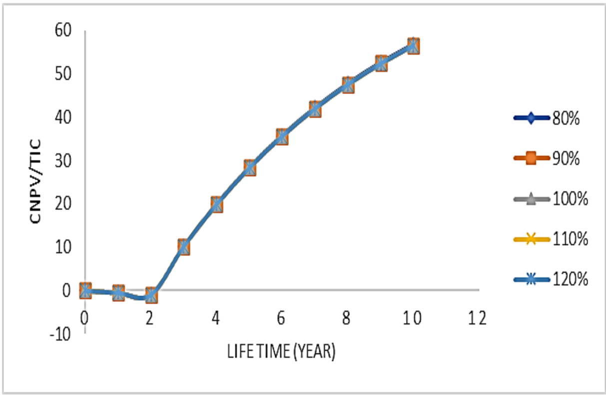

Figure 8. Graph of CNPV/TIC as long as ten years with Variation of Utility

IV. Conclusion

Based on the above analysis, the SnO_2 NPs production project using the microwave-assisted green synthesis method is a prospective production project from an engineering and economic perspective. This analysis is obtained from an economic evaluation using several parameters which state that the SnO_2 NPs manufacturing project is very profitable and the payback period is short for the initial investment. Income taxes, raw material costs, labor costs, and sales greatly affect project profitability. From this economic evaluation analysis, it can be concluded that this project is feasible to run.

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