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Engineering and Economic Study on the Production of Silicon Dioxide Nanoparticles using a Sol-gel Method

Hafizh Arsytari Wahyudi[1] and Asep Bayu Dani Nandiyanto [1]*

[1] *Departemen Pendidikan Kimia, Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alam, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudhi No. 229, Bandung, 40154*

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Abstract

The purpose of the research carried out is to evaluate the economic viability of the production of silicon dioxide (SiO2) nanoparticles using the sol-gel method on a factory scale. The evaluation is carried out from a technical and economic perspective, where some of the parameters are the cumulative net present value (CNPV), breakeven point (BEP) and Payback Period (PBP) which are calculated based on mathematical calculations using the Microsoft Excel Application. Parameters can indicate the potential benefits of the project. Project estimates are also complemented by calculations from ideal conditions to the worst conditions that might occur such as changes in tax material, utilities, labor that must be completed until an increase in selling prices occurs. From the analysis of techniques obtained from the synthesis of SiO2 nanoparticles can be done with available equipment at low prices. From the economic evaluation, the results obtained from the production of silicon dioxide nanoparticles give a profit of up to 51%. This project can be approved to have potential benefits because under ideal conditions PBP can be achieved in the 2.98 year and CNPV until the 30th year gives a positive value. Thus, the production of SiO2 nanoparticles can be a promising project in the future in developing countries, studio must still be done to further improve the efficiency of re-action and to increase profits so, that it can be more attractive to investors.

Keywords: Silicon dioxide, nanoparticles, Economic evaluation, feasibility study

*Corresponding author.
E-mail address: nandiyanto@upi.edu

1. Introduction

Nanoparticles have been developed at this time, one of which is silicon dioxide nanoparticles (SiO_2). Silica has high stability, chemical flexibility and biocompatibility properties that play an important role in various scopes. In addition, the abundance of silica is quite a lot and the price is relatively cheap [1]. SiO2 nanoparticles can be used as an ideal support material for magnetic nanoparticles, prevent anisotropic dipolar magnetic pull when given an external magnetic field [2] increase corrosion resistance of plastic and rubber to increase magnetic particles, additives in elastomeric mechanical properties, in systems liquid to improve the suspension properties of solution [3] and is also useful in various industrial processes related to the production of cement, pigments, pharmaceuticals, ceramics and catalysts and in the scope of biotechnology and the environment [4,5]

Synthesis of SiO_2 nanoparticles can be performed using the sol-gel method [6,7], flame spray pyrolysis [5], Co-condensation [2], micro-emulsion processing, chemical vapor deposition, combustion, hydrothermal, and plasma [8], But, the synthesis method the most widely used SiO_2 nanoparticles are the sol-gel method [9]. The most efficient method for economic evaluation analysis is the sol-gel method because the materials used are somewhat less, are cheap and easy to obtain, and the process does not require too much energy because the regulation can take place at room temperature.

At present, there is no paper that discusses in detail the perspective of economic evaluation from the synthesis of sol-gel method SiO_2 nanoparticles, so it is necessary to do an economic evaluation analysis from the engineering and economic sides. Specifically, the research conducted is to determine the possible benefits that can be obtained and evaluate the economic viability of the SiO2 nanomaterial sales industry. To facilitate our research, we changed the quantity of raw materials and laboratory scale equipment in journals [6] to industrial scale.

Figure 1 shows the flowchart synthesis process of SiO_2 nanoparticles. Based on Literature [6] synthesis of SiO2 nanoparticles was carried out by reacting water, with tetraethyl ortho silicate using acetic acid as catalyst at room temperature with the aid of stirring. The mixture is stirred until thickened, then washed using ethanol and calcined at 7000C. Then SiO_2 was mashed using a mechanical powder refiner to obtain nanoparticles sized SiO2.

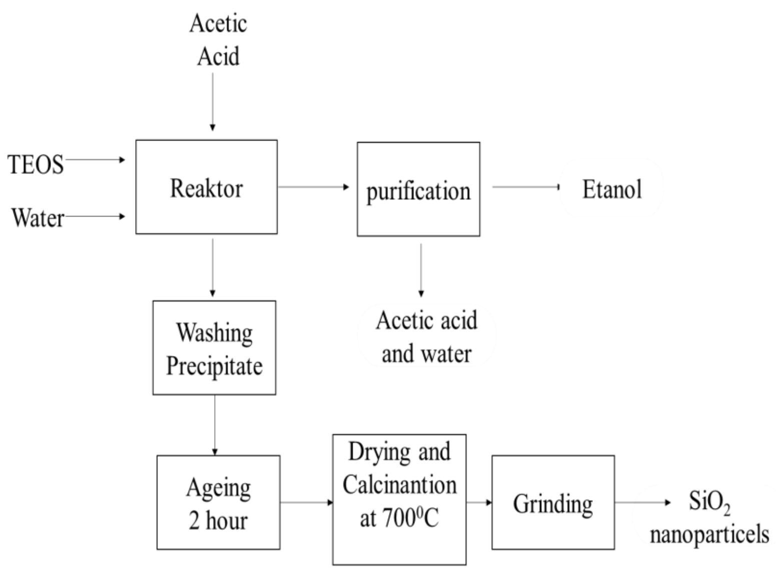

Fig 1. Flowchart of the SiO_2 nanoparticle synthesis process

2. Materials and methods

The method used in this research is based on analysis of material prices, equipment prices, and equipment specifications sourced from online websites such as Alibaba.com. Data processing is calculated based on simple mathematical calculations using the Microsoft Excel application to obtain economic evaluation parameters: GPM, PBP, and CNPV with various price variables. Economic evaluation parameters are calculated based on literature [10]:

1. Gross Profit Margin (GPM) value can describe the business that is running a loss or profit, if the GPM value is positive then the business is profitable and vice versa if the GPM value is negative then the business is losing money. GPM can be calculated by reducing sales results and raw material costs
2. PBP is a calculation carried out to predict the length of time required to return the initial capital. The simplest way to get the PBP value is from the CNPV/TIC curve with respect to time (years) by looking at the intersection point on the x-axis (time).
3. Cumulative net present value (CNPV) is a value that predicts the condition of a production project in the form of a production function in years. CPNV value is obtained from the net present value (NPV) at a certain time. NPV is the value that represents the expenses and income of a business. In brief, CNPV is obtained by adding the NPV value from the first until project to the end of the NPV mill operation calculated by adding a discount factor to the calculation of multiplying cash flows.
4. Breakeven point value (BEP) describes the minimum production capacity requirements, BEP value is calculated by dividing fixed costs with profits.
5. Profitability index (PI) is an index used to identify the relationship between project costs and impacts. PI can be calculated by dividing the CNPV with the total investment cost (TIC). If the PI is less than 1, then the project can be classified as a non-use project and if the PI is more than 1, then the project can be classified as a good project.

Based on Figure 1 to calculate energy and mass balance based on the process of making SiO2 nanoparticles the synthesis requires several assumptions:

1. All chemical compositions in the reaction, such as tetraethyl orthosilicate (TEOS), acetic acid, ethanol, and distilled water used for the production of SiO2 nanoparticles are increased up to 1000 times, the materials used have high purity, and are calculated based on literature [6].
2. Water and tetraethyl orthosilicate (TEOS) are reacted in a ratio of 4:1 and it is assumed that both of them have reacted to produce silicon dioxide with 99% purity and ethanol.
3. The conversion rate for all reactions is 100% with a loss in each process of moving from the reactor to purification (filtration), purification (distillation), drying, and refinement of the product, each resulting in a mass reduction of 2.5%

Analysis of the economic point of view is based on the following assumptions:

1. The exchange rate of USD (American currency) against IDR (Indonesian currency) has been set at 1 USD = IDR 14000 [11].
2. Projects a year are 300 days and the rest are days used to clean and manage the process.
3. The price of raw materials obtained from the online market chemical price catalog, for tetraethyl orthosilicate, acetic acid and ethanol water respectively is 128.57 USD / kg, 0.5 USD / L, 25.00 USD / L, and 32.50 USD / L.
4. The amount of material used in production refers to stoichiometric calculations
5. Total investment cost (TIC) is calculated based on the lang factor [12].
6. The TIC is prepared in at least two steps. The first step is 40% in the first year and the second step is the rest (during project construction).
7. Land purchased. As such, land costs are added at the beginning of the factory construction year and recovered at the end of the project.
8. Depreciation is estimated using direct calculations [14].
9. Land purchased. As such, land costs are added at the beginning of the factory construction year and recovered at the end of the project
10. Within 1 day the production of SiO2 nanoparticles takes 12 hours of production and produces 4.9052 kg of SiO2 nanoparticles, 42.6891 L ethanol and 40.4644 L 80% acetic acid.
11. The postage costs are borne by the buyer.
12. The packaging fee is borne by the buyer for 5 gram packaging and is charged 0.07 USD and for 250 mL bottle packaging 0.5 USD
13. SiO2 nanoparticles are sold at a price of 5.07 USD per pack (5 grams)
14. 80% acetic acid is sold at 2.56 USD per pack (250 mL)
15. Ethanol is sold at 3.68 USD per pac (250 mL)
16. The electricity fee charged is 0.11 USD / kWh, in one day the electricity fee to be paid is 49.11 USD
17. Total wages / labor is assumed with a fixed value of 40 USD / day.
18. The discount rate is 15% and income tax is 10% every year.
19. The project is carried out for 30 years.

Economic evaluation is carried out by testing various conditions such as if there is a change in the tax burden paid in the range of 10% -100%, sales prices in the range of 70%-120% and variations in variable costs such as prices for materials, utilities and employee salaries in the range of 80% -140 %. This economic evaluation is carried out with the aim of knowing the feasibility test of the project being carried out.

3. Results and discussion

3.1. Engineering Perspective

Figure 2 shows the process of making silicon oxide nanoparticles (SiO2) synthesized by the sol gel method based on literature [6] and Table 1 presents the code descriptions in Figure 2. SiO2 is synthesized by mixing water, TEOS and catalyst in a ratio of 4:1:2. The reaction process is carried out by inserting materials into the reactor with a minimum capacity of 70 L, the mixture is stirred until become a coagulate, then washed using ethanol as much as TEOS volume used with a filter press and calcined at 7000C using a furnace with a minimum capacity of 50 L. SiO2 is mashed using a tool mechanical smoothing powder to obtain nanoparticles sized SiO2. The reaction that occurs in the SiO2 synthesis process can be seen in the following reaction equation (1,2):

$$Si(OC_2H_5)_4 + 4H_2O \rightarrow Si(OH)_4 + 4C_2H_5OH \quad (1)$$

$$Si(OH_4) \rightarrow SiO_2 + 2H_2O \quad (2)$$

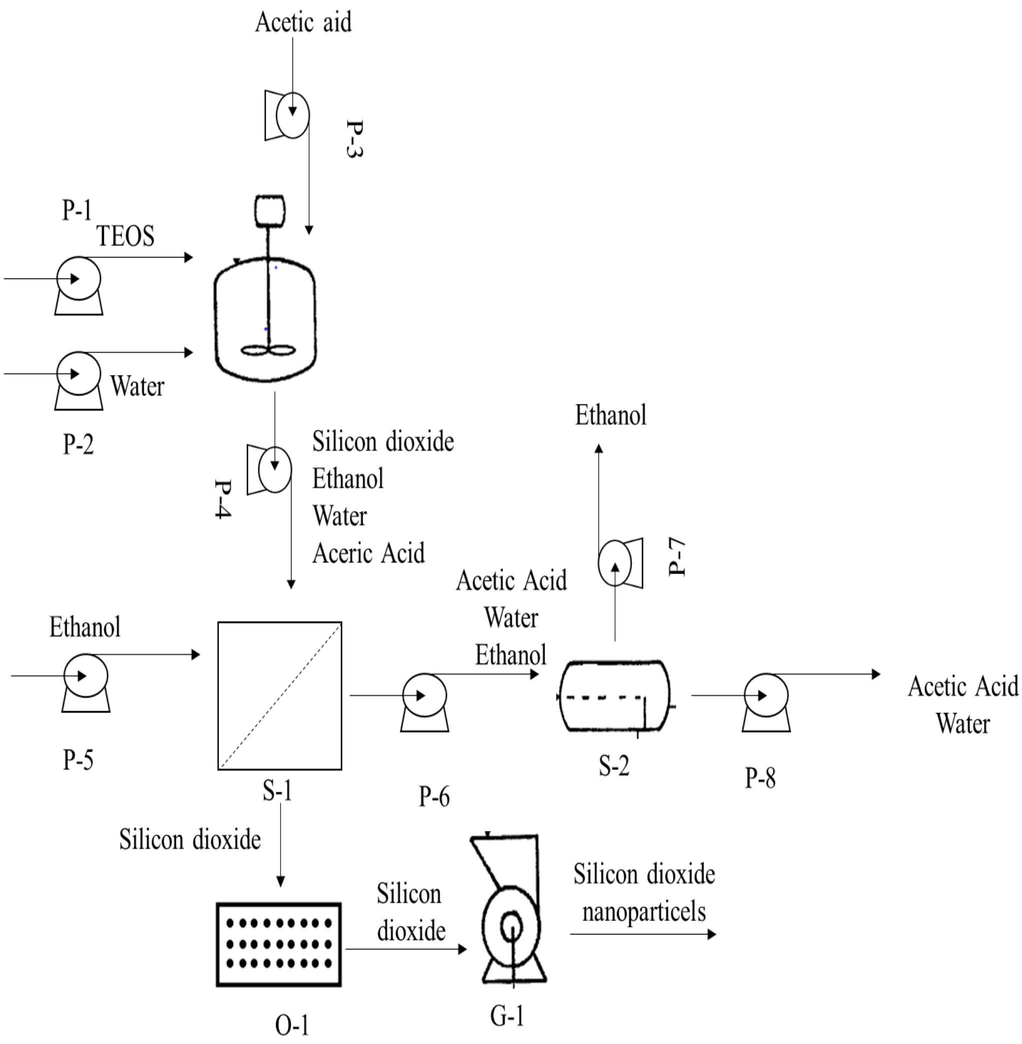

Fig 1: Flowchart diagram of the SiO_2 nanoparticle synthesis process

Table 1: Code description in figure 2

Code	Description
P-1	Centrifugal type pumps, for running water
P-2	Centrifugal type pumps, for running TEOS
P-3	Centrifugal type pumps, for running acetic acid
P-4	Centrifugal type pumps, for running water, ethanol, acetic acid and silicon dioxide
P-5	Centrifugal type pumps, for running ethanol
P-6	Centrifugal type pumps, for running water, ethanol, and acetic acid
P-7	Centrifugal type pumps, for running ethanol
P-8	Centrifugal type pumps, for running acetic acid and water
R-1	Stirred tank , in this case the reaction between air and TEOS is carried out at room temperature using an acetic acid catalyst, while stirring
S-1	Centrifuge (solid and liquid separation). In this case to separate SiO2 from impurities (water, acetic acid and ethanol) by washing using ethanol
S-2	Setler/Decanter (liquid and liquid separation) in this case separation is carried out between water, ethanol and acetic acid.
O-1	Dry Oven, In this case it is used to calcination SiO_2 at 700^0C.
G-1	Hammer mill type grinder, used to smooth SiO2 so that its size becomes nanoparticles.

By witnessing 19.2030 L TEOS and 6.1920 L water using 38.4060 L acetic acid as catalyst, 4.9052 kg of SiO2 nanoparticles, 14.8350 L ethanol as a by-product, with ethanol used for washing are 19.030 L. The by products produced can be further purified to increase sales, from the resulting refining 42.66891 L of ethanol and 80.4644 L of acetic acid 80% can be produced. Thus, in one cycle of production 1006 products (per 5 grams) of SiO_2 nanoparticles, 170 products (per 250 mL) of ethanol and 162 products of acetic acid 80% will produce 30.800 products (per 5 grams) of SiO_2 nanoparticles, 5.100 products (per 250 mL) of ethanol and 48.600 products (per 250 mL) of acetic acid 80% in one year.

From a engineering analysis, it is possible to make improvements, because the scaling process can be implemented using commercially available and inexpensive equipment. In addition, with a project with 300 processing cycles per year, the suggested scheme is to produce perspective of about 1.47 tons of SiO2, 12.8067 tons of ethanol and 12.1393 tons of 80% acetic acid using 5.7609 tons of L TEOS, 1.8576 tons of L water, 11.5218 tons of acetic acid and 5.7609 tons of ethanol per year in ideal conditions. With a total cost that must be paid for raw materials for 1 year is 1,216,888.9034 USD with sales in 1 year 1,842,566.40 USD to obtain a profit of 625.677,50 USD or equivalent to 51%. Analysis of the total equipment cost requires a total cost of 6,307.43 USD. Adding the Lang Factor to the calculation, the TIC must be less than USD 28,037.14 USD. This value is relatively economical, and this project requires less investment funds. With a project life span of 30 years, it produces 44.1470 tons of SiO2 nanoparticles, 384.2022 tons of L ethanol and 364.1797 tons of acetic acid 80%.

3.2 Economic Evaluation

3.2.1 Ideal Conditions

Figure 3 is a CNPV graph showing the relationship between CNPV/TIC and life time (year) with various economic evaluation parameters under ideal conditions, namely a 15% discount rate and 10% income tax each year. From the graph it can be seen that economic evaluation shows promising results as a positive value. In the 1st to 2nd year there was a decrease but in the 2nd to 3rd year there was a sharp increase, in the 2.98 year there was an intersection of the curve with the x axis where the point is known as the Payback Period (PBP), thus, PBP is reached in the 2.98 year, and profits will continue to increase until the 30th year. In the 3rd to 15th years it can be seen from the graph that the increase continues to increase quite sharply and the increase starts to stabilize in the 16th to the 30th years.

Fig 3. Ideal condition for CNPV/TIC to Life Time (year)

The decrease that occurred at the beginning of the year until the second year was due to the costs that had to be paid at the beginning, namely for equipment, raw materials and land purchased. In the 2nd to 2.98 years there was a sharp increase because this year began the return of initial capital from the sale so that it reached the point of 0% in the 2.98 year which is referred to as the PBP point. The time needed to return the initial capital is quite short because in only 2.98 years can return the initial capital of the business, and profits will continue to be obtained until the 30th year. To achieve this ideal condition the minimum production capacity or break event point (BEP) that must be achieved in 1 year is 7,405.654 products. Thus, the production of SiO2 nanoparticles can be considered a profitable project and is an ideal project to run in industrial products. This result is comparable with research conducted by [14] who stated that the project was carried out although PBP was achieved in the 5th year.

3.2.2 Effects of External Factors

3.2.2.1 Tax

External factors greatly affect the success of a project. One of them is another levy imposed on projects by the state to finance various public expenses or taxes. The analysis is done by increasing the tax that must be paid by 25%, 50%, 75% and 100%.

Figure 4 is a CNPV graph showing the relationship between CNPV/TIC and life time (year) and the effect of changes in taxes that must be paid. From the graph it can be seen that at the beginning of the year up to 2 years the current project CNPV/TIC value with the change in tax costs paid is the same. Because this year is still related to the construction of the project and the function of the tool the effect of changes in tax costs to be paid to the value of CNPV/TIC began to be seen in the 2nd year. From the chart, it can be seen that PBP is achieved in different years, where the higher tax burden paid by PBP is achieved in a longer time, with taxes to be paid in the amount of 10%, 25%, 50%, 75% and 100% respectively PBP was achieved in the years 2.98, 3, 4.5, 5.5 and PBP was not achieved. In addition to PB, it can be seen in the graph that the profits obtained are getting smaller with increasing tax costs that must be paid, it is seen from the CNPV/TIC value on each curve which is decreasing in the 30th year. The CNPV/TIC value in the 30th year with tax costs to be paid at 10%, 25%, 50%, 75% and 100% respectively is 6.27%, 5.12%, 3.20%, 1.27% and -0.65%. Thus the profit is still ideally obtained if the tax paid reaches 75% because PBP is still in 5.5 years and the curve obtained is still positive. If the tax to be paid more than 75% profitability is not achieved because PBP is not reached and negative curve. The results obtained are in accordance with the literature [15] which states that if the tax costs to be paid are too high, ie exceeding the value of 50%, the resulting profits will be smaller and even reach a negative value when the tax reaches 100%.

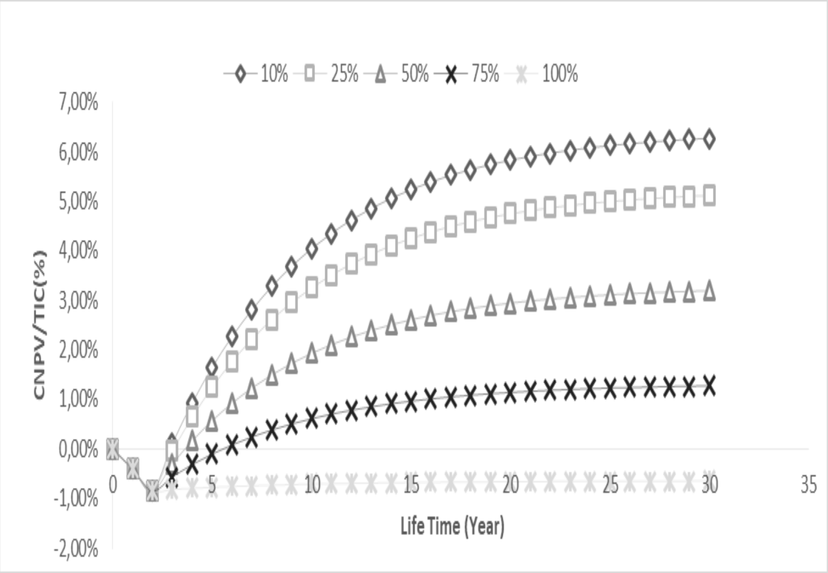

Fig 4. CNPV curves under various tax

3.2.2.2 Changes in Selling Prices

Besides tax, another external factor that influences the success of a project is the selling price of the product. Analysis of the effect of selling prices on profits is done by changing the selling price to 70%, 80%, 90%, 110% and 120%.

Figure 5 is a CNPV graph showing the relationship between CNPV/TIC on life time (year) and the effect of changes in product selling prices. From the graph it can be seen that at the beginning of the year up to 2 years the current project value of CNPV/TIC with the change in selling price is the same. Because this year it is still related to project development and tool functions. The effect of changes in selling prices on the value of CNPV/TIC began to be seen in the 2nd year. From the chart, it can be seen that PBP is achieved in different years, where the lower selling price PBP achieved at a longer time and conversely the higher selling price of products PBP can be achieved at a shorter time. With a selling price of 80%, 90%, 100%, 110%, and 120% respectively PBP achieved in the 9.5, 4.5, 2.98, 2.62 and 2.49 years and PBP not achieved at a selling price of 70%. In addition to PBP, it can be seen in the graph that the profits obtained are getting smaller with decreasing product selling prices, it is seen from the CNPV/TIC value on each curve which is decreasing in the 30th year. The CNPV/TIC value in the 30th year with a selling price of 70, 80%, 90%, 100%, 110%, and 120% are respectively -2.48%, 0.437%, 3.355%, 6.273%, 9.191% and 12.106%. Therefore, if there is a decrease in the selling price of the project product, it is still possible to survive the 10% decrease in the selling price, but it will be a detrimental project if the sales price decreases more than 10%. This result is in accordance with the literature [16] where According to [16] the increase in company profits will be followed by an increase in selling prices and the decline in company profits will be followed by a decrease in selling prices.

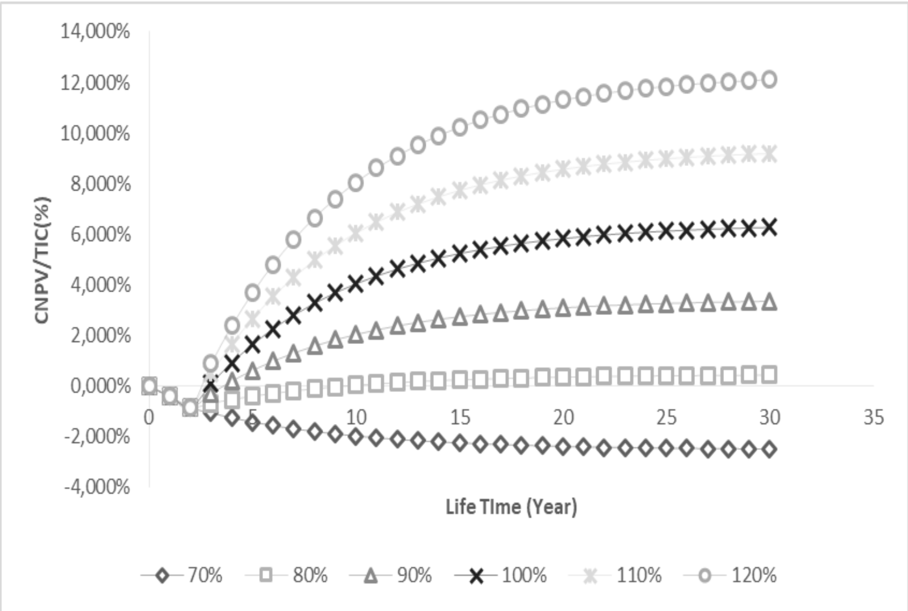

Fig 5. CNPV curves under various sales

3.2.3 Changes to variable costs (raw materials, labor and utilities)

In addition to external factors, there are other factors that can affect the success of a project, one of which is variable costs. Variable costs include the price of raw materials, labor and utilities. Analysis of the effect of changes in variable costs on profits is done by changing the value to 80%, 90%, 110%, 120%, 130% and 140%. According to [10] the value of variable cost has an important role in profitability, where, the decrease in variable cost will increase the final value of CNPV

3.2.3.1 Effect of changes in raw materials

Figure 6 is a CNPV graph showing the relationship between CNPV/TIC on life time (year) and the effect of changes in raw material prices. From the graph it can be seen that at the beginning of the year up to 2 years the current project value of CNPV/TIC with the change in selling price is the same. Because this year it is still related to project development and tool functions. The effect of changes in raw material prices on CNPV/TIC values began to be seen in the 2nd year. From the perspective, PBP can be seen in different years, where the higher the price of PBP raw materials is achieved in a longer time and vice versa the lower the price of PBP raw materials can be achieved in a shorter time. With raw material prices of 80%, 90%, 100%, 110%, 120% and 130%. PBP was achieved in the 2.57, 2.71, 2.98, 3.2, 3.98 and 8.8 years, and PBP was not reached at the raw material price of 140%.

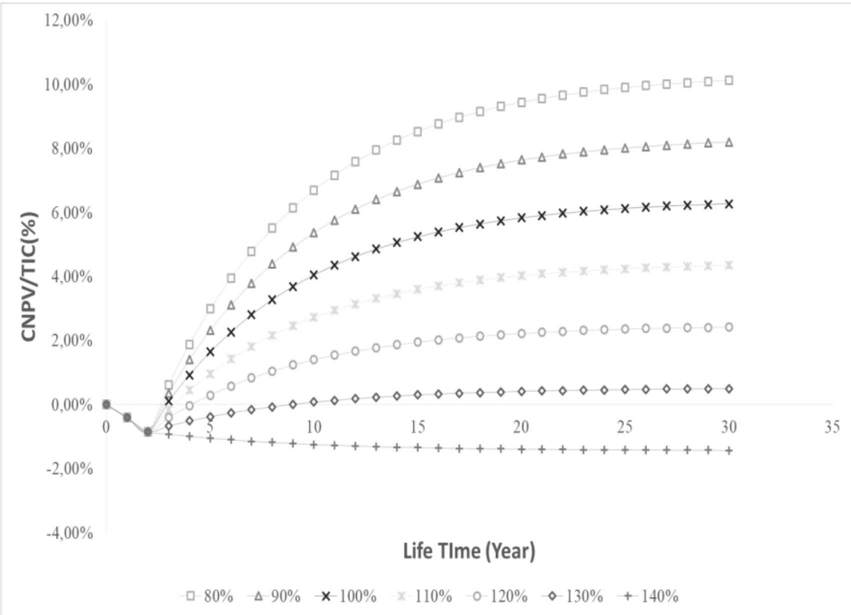

Fig 6. CNPV curves under various raw material prices

In addition to PBP, it can be seen in the graph that the profits obtained are getting smaller with increasing raw material prices, this is seen from the CNPV/TIC value on each curve which is decreasing in the 30th year. The value of CNPV/TIC in the 30th year with raw material prices is 80%, 90%, 100%, 110%, 120%, 130% and 140% respectively 10,12%, 8,20%, 6,27%, 4,35%, 2,42%, 0,50% and -1,43%. Thus, the profit is still ideally obtained if the increase in raw material prices by 20% because PBP is still reached in the 3,98 year and the curve obtained is still positive. If the price of raw materials to be paid more than 20% the profits obtained are very small and PBP obtained over a period of more than 4 years, even no profit is achieved if there is an increase in raw material prices up to 40% because PBP is not reached and the curve is negative. This result is in accordance with the literature [10]. The lower the raw material, the more effective it is to produce greater profitability. However, if there is an increase in the cost of raw material, it will cause a decrease in profits obtained.

3.2.3.2 Utility

Figure 7 is a CNPV graph showing the relationship between CNPV/TIC and life time (year) and the effect of changes in utility expenses to be paid. To simplify the utility factor, utility units can be explained and converted as electric units, such as kWh [15]. Then, the electricity unit is converted into a charge. Assuming utility costs is 0.1075 USD/kWh. From the graph it can be seen that at the beginning of the year up to 2 years the current project value of CNPV/TIC with the change in selling price is the same. Because this year is still related to project development and the function of tools. The effect of changes in raw material prices on the value of CNPV/TIC began to be seen in the 2nd year. There was no significant change in the CNPV curve due to changes in utility expenses to be paid, where PBP was achieved in the 2,93-3 year range, as well as the CPNV / TIC value in the 30th year of each curve in range 6,23-6.30%. So that, with an increase or decrease in the burden of utility payments paid does not significantly influence the benefits obtained. That is because the percentage of salary expenses paid to profit is around 0.03%, the figure is relatively small compared to 100%.

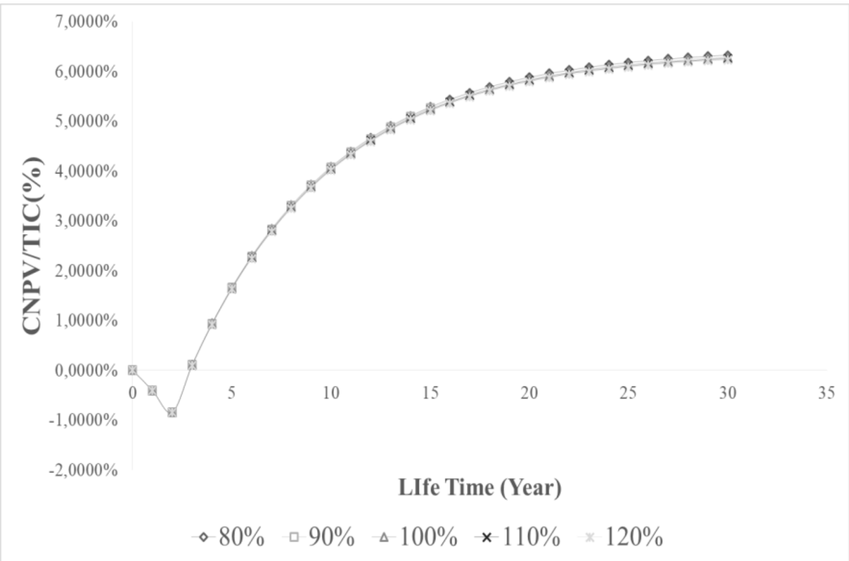

Fig 7. CNPV curves under various utility

3.2.3.3 Labor

Figure 8 is a CNPV graph showing the relationship between CNPV/TIC and life time (year) with the effect of changes in salary expense that must be paid. From the graph it can be seen that at the beginning of the year up to 2 years the current project value of CNPV/TIC with the change in selling price is the same. Because this year is still related to project development and the function of tools the effect of changes in raw material prices on the value of CNPV/TIC began to be seen in the 2nd year. There was no significant change in the CNPV curve due to changes in utility expenses to be paid, where PBP was achieved in the 2.93-3 year range, as well as the CPNV / TIC value in the 30th year of each curve in range 6.23-6.30%. Thus, with an increase or decrease in the burden of salaries paid does not significantly influence the benefits obtained. That is because the percentage of salary expenses paid to profit is around 0.026%, the figure is relatively small hen compared to 100%.

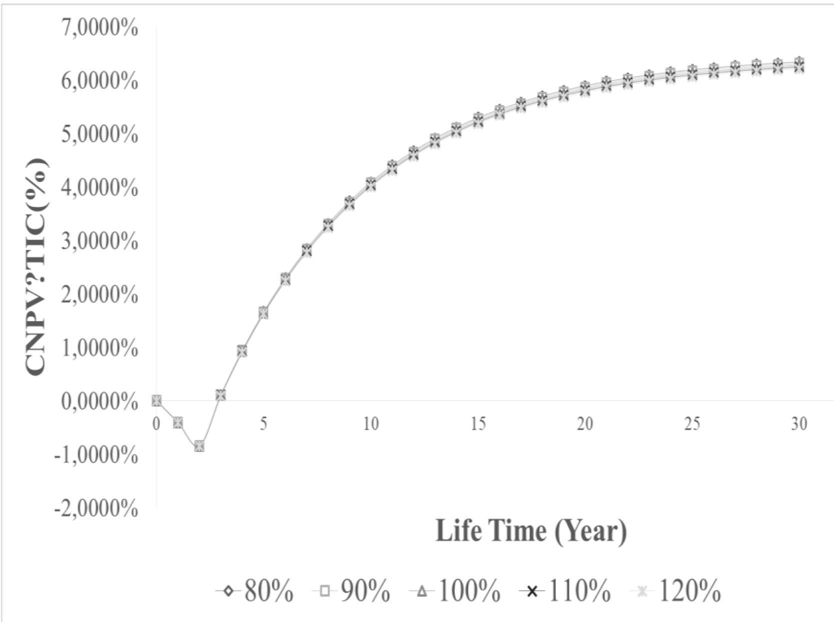

Fig 8. CNPV curves under various Labor

Conclusion

Based on the above analysis, the SiO2 nanoparticle synthesis project can be said to be a profitable project from a engineering evaluation because the process requires existing equipment at a low price, as well as from an economic evaluation that gives positive results. PBP was achieved quite quickly, namely in years 2-98, as well as CNPV which gave positive results until the 30th year, GPM in ideal conditions reached 51%. Analysis of some sensitivity parameters is also carried out and some boundary conditions are displayed so that the project continues to benefit. Further research is needed to improve the efficiency of re-action as well as to increase profits so that they can attract more investors. This study shows that this industry will be a promising project in the future in developing countries.

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