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TECHO-ECONOMIC ANALYSIS FOR THE PRODUCTION OF TITANIUM DIOXIDE NANOPARTICLE PRODUCED BY LIQUID-PHASE SYNTHESIS METHOD

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Abstract

Titanium dioxide (TiO_2) is one of the most used and popular materials due to its excellent performance. This makes the demands for the production of TiO_2 increasing recently. Therefore, there is a need for the feasibility study for generating industries for the production of TiO_2 especially in the developing countries. This study aimed to evaluate the prospect for the production of TiO_2 nanoparticles in practical uses. This study was done to confirm whether the large-scale production of TiO_2 is profitable or not. As a model of the synthesis method for fabricating TiO_2, the liquid-phase synthesis involving the hydrolysis of titanium isopropoxide with nitric acid was used. The evaluation was done using two types of feasibility studies: engineering analysis and economic evaluation. The estimation of the project was also completed with the calculation from ideal conditions to the worst cases of production by adding several parameters: raw materials, sales, utilities, labor, and external conditions (i.e., taxes and subsidiaries). The engineering analysis gave information the potential large-scale production since the process can be done using current available technology and inexpensive apparatuses. The economic evaluation based on various economic evaluation parameters (such as gross profit margin, break-even point, payback period, etc.) showed the potential profitability for the project. The project also used relatively inexpensive total cost of purchased equipment. Although further developments must be also added especially regarding the additional strategies to boost the profit to attract the investors, this study provides a great promise for the possible fabrication of TiO_2 in developing countries.

Keywords: Economic evaluation, Feasibility study, Titanium dioxide nanoparticles.

1. Introduction

Titanium Dioxide (TiO_2) is one of the most important transition metals that have been widely studied and recently used for many technologies and applications. The wide applications of TiO_2 are used to for pigment, paint, toothpaste, cosmetics, electronics, and also photocatalyst at present [1-3]. TiO_2 exists in three crystal structure that include are anatase, rutile, and brookite. Anatase-phased TiO_2 has a crystalline structure that establishes in the tetragonal system with bypiramidal system. This material is applied for cosmetics, especially for sun protection. Rutile-phased TiO_2 also has a crystalline structure that corresponds to the tetragonal system with prismatic system. Rutile is used for paint, plastics, coating, and also cosmetics. The brookite-phased TiO_2 has a crystalline structure with orthorombic system. Rahman et al. [4] explained that its crystalline polymorphic forms make it suitable for several technological applications due to its chemical stability and low toxicity.

Macwan et al. [5] and Grubb and Bakshi [6] reported on TiO_2 nanoparticles production. TiO_2 nanoparticles have been synthesized by various methods such as aerosol process, sol-gel method, inert gas condensation, and hydrotermal process [7-14]. In the aerosol process, high-purity TiO_2 nanoparticles are produced using a simple process. However, the high temperature setting when applying this process leads to the problems in the cost of production. Sol-gel method involves many steps of processes. For some cases, it also uses expensive chemicals. In the case of the inert gas condensation process, the process needs expensive cost of production due to the use of sophisticated apparatuses such as ultrahigh vacuum. Hydrothermal process can produce particles in the relatively low-temperature range (less than 300 °C). However, to get better materials, the additional processes and safety for handling the system are still required. Among the types of processes, the liquid-phase synthesis is the best. The liquid-phase synthesis method can allow the obtainment of high surface area and highly crystalline of product. Cushing et al. [14] mentioned that the process is simple, uses fast reaction with relatively simple apparatuses, and is prospective to form high purity of products by additional simple treatments.

To evaluate the production of TiO_2 nanoparticles, the present study adopted a synthesis method from literature [14]. This method was evaluated from two perspectives: engineering and economic evaluation. To support the economic evaluation in this study, several economic evaluation parameters were calculated:

- gross profit margin (GPM; to predict the rough analysis of the economic condition).
- internal rate return (IRR; to ensure the condition of economic).
- payback period (PBP; to estimate the possibility for the year of profit).
- cumulative net present value (CNPV; to predict the condition of the project as a function of year of production).
- break-even point (BEP; to get the minimum requirement of the production capacity) and
- profitability index (PI, to obtain information about the profit).

To support the analysis, several information was adopted, such as data for chemical price, utilising components, and specifications for apparatuses. The data is then calculated to get the feasibility study for generating industry for the fabricating of TiO_2 in developing countries such as Indonesia. In addition, this feasibility study is important because this helps the decision whether the scaling up process is prospective or not. This study also gives suggestion how to optimize the project to give benefit to the economic growth. The successful production can create several aspects relating to the socio-economic condition, including reducing poverty [15, 16]. In short, building and developing this project can create employment opportunities that has direct impact to reducing poverty. Additional opportunities obtained from the presence of this project are also found in the cash flow generation. The cash flow can be generated from workers, distributors, sellers, and even the surrounding community (e.g., housing, restaurant, etc.).

Since the present study is the first analysis in the feasibility study, all calculations were done in the specific conditions. The additional variables were added to the calculation, such as labor condition [17], raw materials, product (sales), utility, [18] as well as the external condition including environmental uncertainty (e.g., such as competition in the production and sales, tax from the government, and subsidiary from the government) [19]. However, for scaling up process, further analyses must be done to predict the realistic condition for the development of the project. We believe that the present analysis will drive further investigation for the large-scale production of the TiO_2 material in developing countries.

2. Theoretical Synthesis of TiO_2 Nanoparticles

According to Cushing et al. [14] and Cargnello et al. [20], the production of TiO_2 was adopted and improved from literature. In short, the synthesis procedure in this project was done using the liquid-phase synthesis method based on the use of titanyl nitrate and glycine. Titanyl nitrate was prepared by reaction of titanyl hydroxide ($TiO(OH)_2$) obtained by hydrolysis of titanyl isopropoxide with nitric acid. Systematic process used in this study is shown in Fig. 1. The process is described as follows: initially, the titanylnitrate [$TiO(NO_3)_2$] precursor is synthesized by reaction of titanyl hydroxide [$TiO(OH)_2$]. Titanyl hydroxide is obtained from the hydrolysis of titanium isopropoxide [$Ti(i\text{-}OPr)_4$] with nitric acid. Hydrolysis was controlled under ice-cold condition (4 °C) with stirring for 2 hours until a white titanyl hydroxide precipitate was produced. The precipitate was mixed with distilled water and then dissolved in nitric acid to obtain a titanyl nitrate solution. This mixed solution was used as a precursor for the synthesis of TiO_2 nanoparticles. The precursor was then mixed with glycine in water and heated in a furnace to 550 °C under stirring condition. The solution was dehydrated to produce titania [7, 14, 20]. During the process, the following reactions occur [14, 20]:

- Hydrolysis

$$Ti(C_3H_7O)_4\,(s) + 3H_2O\ (aq) \rightarrow TiO(OH)_2\,(s) + 4C_3H_7OH\ (aq) \tag{1}$$

- Nitration

$$TiO(OH)_2\,(s) + 2HNO_3\,(aq) \rightarrow TiO(NO3)_2\,(aq) + 2H_2O\ (aq) \tag{2}$$

- Synthesis

$$9TiO(NO_3)_2\,(aq) + 10C_2H_5O_2N\ (aq)$$

$$9TiO_2(s) + 14N_2\,(g) + 20CO_2\,(g) + 25H_2O\ (g) \tag{3}$$

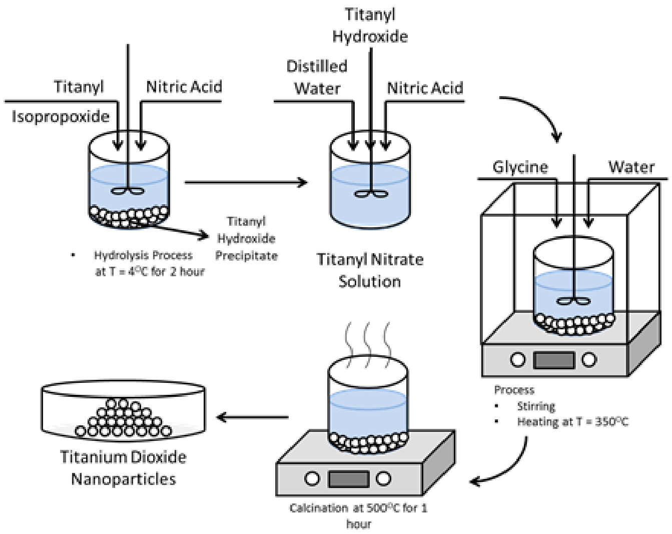

Fig. 1. Schematic representation of the liquid-phase process.

3. Method

The present method used for the analysis data of price, utilising components, and specifications for apparatuses that were taken based on available online shopping web such as alibaba. All data are then calculated by a simple mathematical analysis to get several economic evaluation parameters, including GPM, IRR, PBP, CNPV, BEP, and PI sales to investment. The economic evaluation parameters were calculated based on the literature [18]. In short, the calculation was obtained using the following formulas:

- GPM was calculated by substracting sales and raw material cost
- IRR was from the following equations: $NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} - C_o$ where C_t and C_o are the net cash inflow during the t period and the total investment costs, respectively. r is the discount rate. t is the project time (as year).
- PBP is the length of time required to recover the cost of an investment. The simplest way to obtain PBP is gained from the CNPV curve. The value of PBP was determined by understanding the time when value of CNPV/TIC reaches zero for the first time.
- CNPV is the values gained from the net present value (NPV) at a specific time. In short, the CNPV was obtained by adding the value of NPV from the beginning of the project. The NPV was calculated by multiplying cash flow with discount factor.
- BEP was calculated by dividing fixed cost and profit.
  - PI was estimated by dividing CNPV and total investment cost or sales, corresponding the PI types of profit to investment or profit to sales, respectively.

Then, when evaluating economic feasibility, various conditions are tested, such as changes in raw material, sales capacity, labor, interest rates, etc.

4. Results and Discussion

4.1. Energy and mass balance analysis

Based on the process as shown in Fig. 1, the amount of product was calculated stoichiometrically based on 40 L of titanyl tetra isopropoxide (TTIP). Several assumptions were made:

- All compositions of chemicals, such as titanium isopropoxide, nitric acid, titanyl nitrite and glycine used for the produce TiO_2 nanoparticle were calculated based on literature [14, 21].
- Conversion rate for the titanium hidroxide formation process was 90%.
- Conversion rate for the TiO_2 nanoparticle formation process was 90%.
- All products are anatase-typed TiO_2 nanoparticles.
- Losses obtained due to the mechanical process, including purification, drying, calcination, and product collection were 10%.

Based on the above assumptions, to produce 38 kg of TiO_2, the process needs 40 L of titanyl tetraisopropoxide, 48 L of nitric acid, and 16 kg of glycine. And, water required for the process was at least 4 L. This calculation was then used for further analysis for the scaling up process.

4.2. Economic evaluation

To analyse the economic perspective in this study, assumptions were made:

- The calculation was based on the economic condition in Indonesia, which used IDR (Indonesian currency) for purchasing equipment. Then, the value was then converted to USD with a fix currency of 1 USD = 10,000 IDR.
- All prices used based on commercially available materials gained in the available online markets. In short, the price of titanyl isopropoxide, nitric acid, glycine, and TiO_2 nanoparticles were 5 USD/L; 4 USD/L; 1 USD/kg; and 16 USD/kg respectively.
- All materials used in the production were estimated based on the stoichiometrical calculation.
- The process neglected other supporting fees (e.g., instrumentation, plant start-up, electrical-related component).
- The total investment cost (TIC) was calculated based on the Lang Factor [18]. The result from the Lang Factor showed that the TIC was about four times of the total equipment cost.
- The process was done under purchased land. Therefore, the land was calculated as the initial cost (at the beginning of the plant construction) and recovered/regained after the project (at the end of the project).
- For calculating depreciation, direct-typed depreciation was used [18].
- One cycle in the production to convert titanium isopropoxide into TiO_2 nanoparticles needs 2 hours of production
- One-year project is 300 days and the rest of the days are used for cleaning and setting up the process.

- Basic electricity cost is 0.15 USD / kWh.
- The total wage/labor was assumed with a fixed value of 8 USD/day.
- The discounted rate and the income tax were 15, and 10% annually, respectively.
- The length of the project operation was 20 years.

4.2.1. Ideal condition

Figure 2 presents the CNPV curve with various economic evaluation parameters under ideal conditions. The result confirmed that the conversion of titanyl isopropoxide to TiO_2 nanoparticles are promising. The engineering analysis confirmed that the preparation can be scaled up using current available technologies and inexpensive apparatuses. The economic evaluation also showed the prospective results since the values of economic parameters are positive (see the insert table in Fig. 2). However, regarding the PBP, the project needs about more than 10 years.

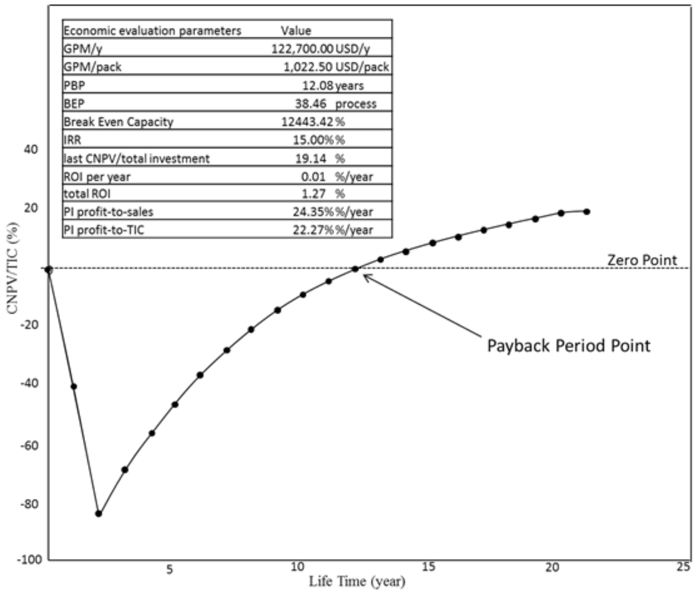

Fig. 2. Ideal condition for CNPV under various economic evaluation parameters.

4.2.2. Effects of raw material (i.e., titanyl isopropoxide, nitric acid, and glysine), product sales, labor, and utility

Initially, the analysis was to evaluate the effect of raw material prices and sales on GPM (see Fig. 3). The calculation result was obtained by subtracting the cost of the product sales (revenue; how many product can be sold) with the initial cost of the raw materials [17]. Sales had a positive impact with GPM values, while raw material has opposite correlations. It means that generating more sales will be profitable on the project, while the increase in raw material prices had a negative impact on the project. Based on the analysis in the raw materials, the impacts of nitric acid and glycine on the GPM were almost similar. The most influential parameters in the raw materials is titanyl isopropoxide.

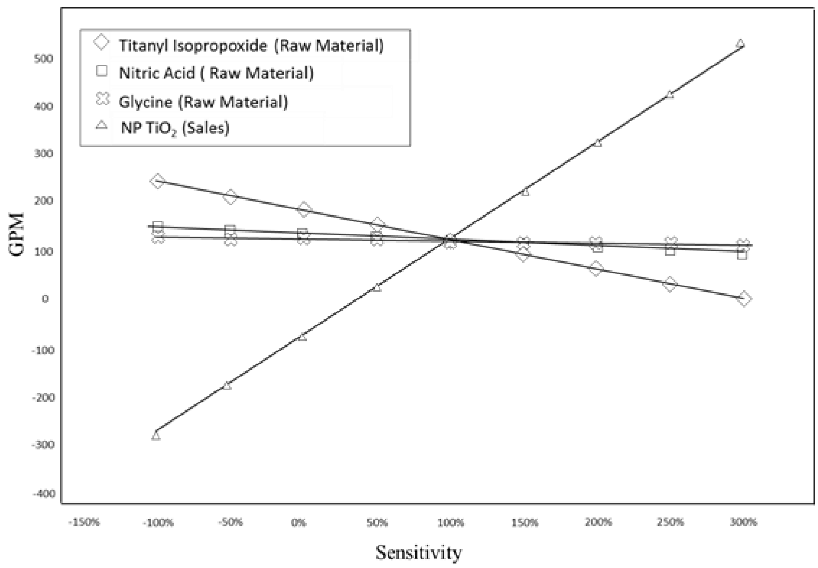

Fig. 3. Raw materials (i.e., titanyl isopropoxide, nitric acid, and glysine) and sales cost on the GPM.

To confirm other factors in addition to the raw materials and sales, analysis of PI was conducted (see Figs. 4 and 5). These figures combined the evaluation of PI based on sales, raw materials, labor and utilities. An exponential curve for the sales in the PI analysis was obtained. The change in the PI values was obtained, confirming that sales had a direct impact on the profit. However, a significant increase in sales prices did not give impacts to the obtainment of profit because an increase in sales will be followed to changes in variable costs. Therefore, the sales price must be optimized to get optimal value. In the case of raw material, the PI was a linier curve. This informs that the raw material has a direct impact to the change of PI. Regarding the labor and utility costs, increases in these parameters seem to give no significant effect on the PI in comparison with sales conditions and raw materials. In short, we can conclude that the higher production price has a direct impact on the more profit. However, this production cost must be optimized with raw materials, labor, and utilities for sustaining the project. Based on this analysis, the most dominant factor is sales and then followed by price of raw materials, labor parameter, and utility cost.

BEP analysis (see Fig. 6) was conducted to ascertain the effects of sales, labor costs, raw materials, and utilities on the profit. Analysis was carried out using variations of -100 to 300% of the predicted value. To provide a perception of project feasibility, the analysis was determined by the indication in the dotted and clear area for the infeasibility and feasibility of the project, respectively. The analysis results showed that the increases in sales have a good relation with the decreases in the BEP value. On the contrary, the labor condition, price of raw materials, and cost of utilities had the opposite correlations. To clarify the impact of these parameters on BEP, evaluations were also done in a certain range (between -100 and 300% of the predicted value).

CNPV analysis based on changes in variable costs is shown in Fig. 7. The analysis results showed that variable costs play an important role in project profitability, in which, a decrease in variable costs directly affects to the high value of the final CNPV. In short, when using lower variable costs, the project would be effective to generate more profits. However, regarding the cases in increasing variable costs, the project will be useless and the profit will reduce. The maximum value for varying the costs to sustain the project must be less than 100% of the predicted value. Then, when using production of more than 100% of variable costs, the minimum PBP cannot be gained. Indeed, this will create an unprofitable project.

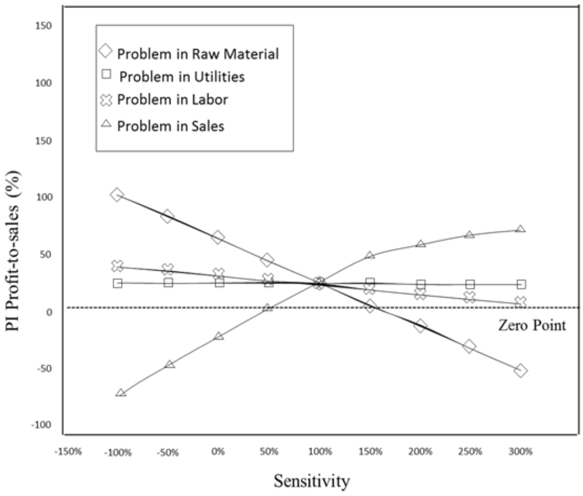

Fig. 4. PI profit to sales as a function of sales, raw materials, utility, and labor. Term problem in the figure is the variation of a specific parameter.

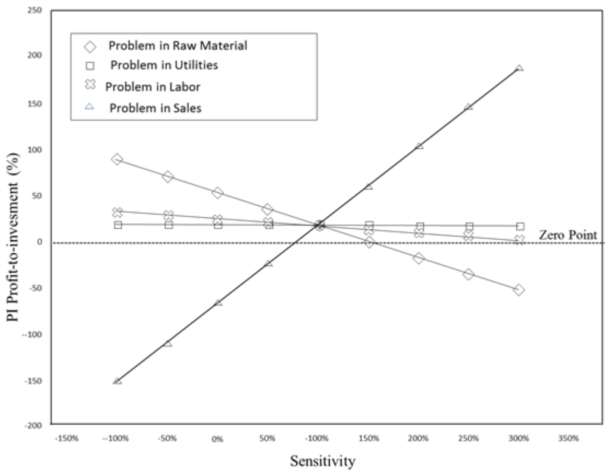

Fig. 5. PI profit to investment as a function of sales, raw materials, utility, and labor. Term problem in the figure is the variation of a specific parameter.

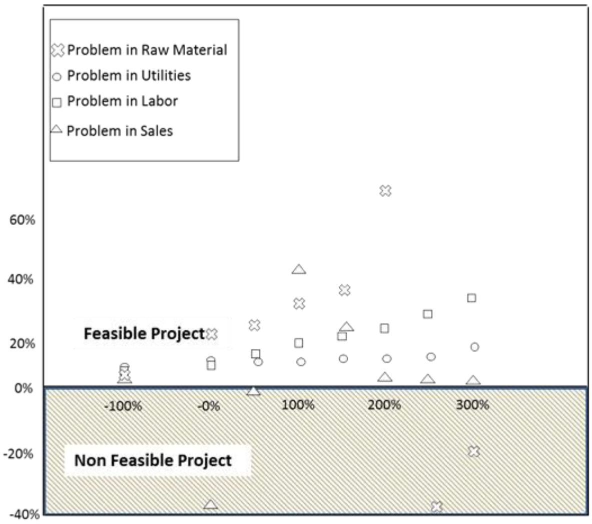

Fig. 6. BEP as a function of sales, labor, raw materials, and utility. Term problem in the figure is the variation of a specific parameter.

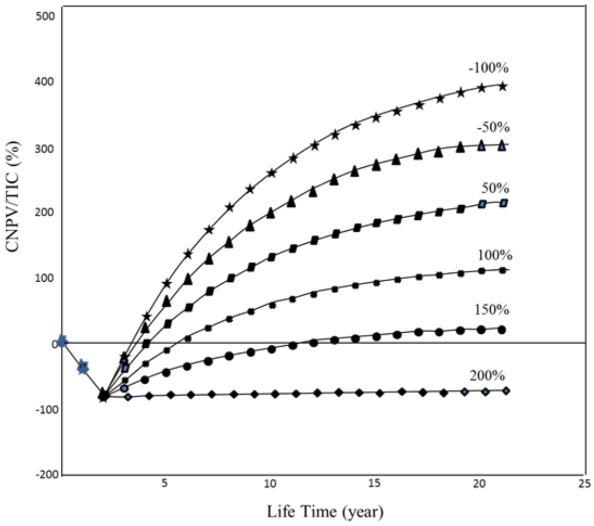

Fig. 7. CNPV curve under various variable costs.

4.2.3. Effect of production capacity

To get the minimum production capacity requirements, the calculation must be done through the CNPV analysis as presented in Fig. 8. CNPV analysis is used to predict in detail whether the project starts to get benefit or not. This also estimates PBP of the projects. The results showed that capacity plays an important role in project profitability. Reducing the production capacity will directly affect the final CNPV value and also affect PBP values. The minimum production capacity to maintain the project must be more than 50% of the predicted value. If the production capacity is less than the minimum production capacity (less than 50%of the predicted value), it will create the unprofitable project.

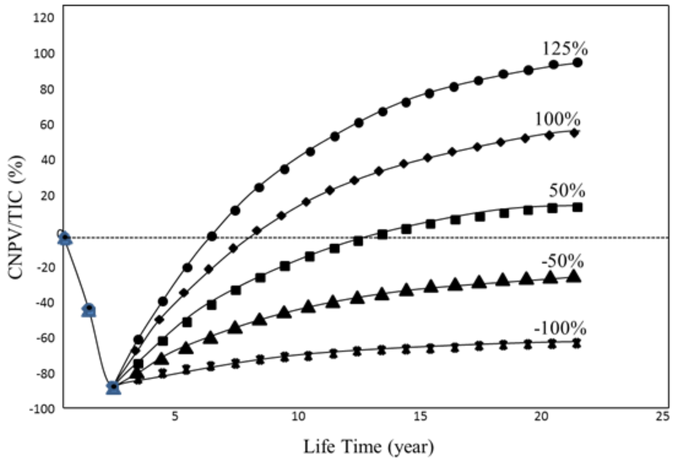

Fig. 8. CNPV curve under various production capacities.

4.2.4. Impact of external condition

In addition, internal factors (conditions of raw materials, utilities, labor, and sales costs) can affect the success of a project, there are external factors that can affect a project. One of the most influential external factors is the economic condition of a country where the project is implemented. This is related to the financial costs or other imposed factor on the project. The impact of domestic economic conditions can also take the form of taxes from the government itself. To get the correlation of the external condition, the present study used the most speculative values between -100% and +150% of the predicted value based on literature [22] for the worst case in Indonesia. The negative value shows the subsidiary from the government, whether positive is the information for the change in the tax.

Figure 9 presents the curve of CNPV under various tax costs. PBP was obtained with tax variations. As shown in the picture, the initial conditions (calculated from beginning (0 year) to the end of the project (2 years)) of the CNPV curve under various tax costs were identical. This is because these years of productions is related to the construction of a project. No tax can be applied. Indeed, the effect of tax on CNPV can be obtained after the project is established (from two years). When the tax costs added to the project increase, the project profits would decrease. This is related to the PBP. Based on the analysis of PBP, the maximum tax cost for obtaining BEP (the position at which, either a profit or a loss on the project) was 50% of the predicted value. Changes in taxes to more than 50% create a failure in the project.

Investigation about the governmental subsidiary cash for the project was also done. For example, when the government provides an additional fee of 50% of the predicted value (displayed as -50% in the graph), it will create more profit in the project. It was found that the additional subsidiary gave to the additional cash flow in the company. However, we found that the subsidiary did not give too much impact on the project because PBP was around 5 years.

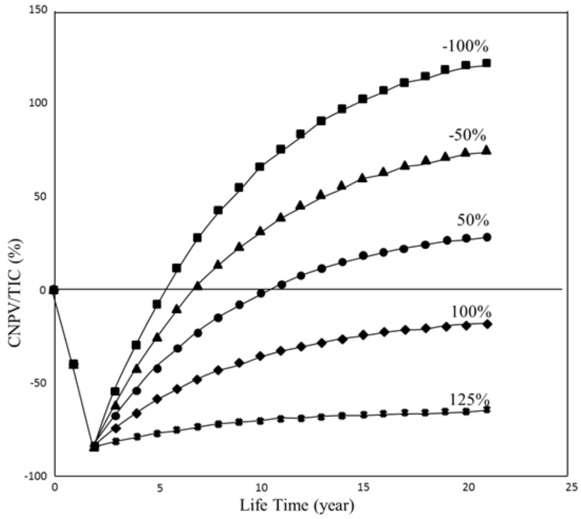

Fig. 9. CNPV curve as a function of project lifetime of the project with various taxes.

5. Discussion

5.1. Results from engineering perspective

The engineering point of view showed the possibility in the scaling up process. This is because the scaling up process can be implemented using commercially available and inexpensive apparatuses. Further, by calculating projects with 1200 processing cycles per year, the suggested scheme is prospective to produce about 12 tons of TiO_2 by consuming consume 12 tons of titanyl nitrate per year. Furthermore, an analysis of the total cost of equipment per batch of reactor that can consume 40 L of titanyl nitrate requires a total equipment purchase cost of USD 4.9350. Adding Lang Factor to the calculation, TIC must be less than USD 244000. This value is relatively economical and the project requires less investment funds. In the ideal condition, projects can reach 1200 processing cycles per year, which can allow the production of TiO_2 products of about 12 tons per year. Adding calculation for 20 years of project life time, the results showed that the whole project can generate 240 tons of product in the ideal condition.

5.2. Results from economic analysis

Based on the above analysis, the project under ideal conditions is feasible. However, when there are changes in economic conditions, the project is only beneficial in certain economic conditions. Based on studies by Nandiyanto [23], all analyses were compared with the condition of Indonesian bank and currency.

In short, if the project is carried out in a specific situation that is beyond the certain economic conditions, the project will be lost. Detailed descriptions of specific conditions based on the above analysis are described as follows:

- The project can still be profitable if the increases in the cost of raw material is less than 150% of the estimated raw material cost. Based on the analysis in the raw materials, the impacts of nitric acid and glycine on the GPM were almost similar. The most influential parameters in the raw materials is titanyl isopropoxide.

- To sustain the project, product sales must be done as higher as possible. However, the increasing sales must be still optimized due to its correlation to the other costs. When there is a condition for reducing the sales, the sales must be still higher than 50% of the estimated value. Otherwise, the project will be failure. This is because the minimum cost for production cannot be fulfilled if the sales is too low.
- Regarding labor cost, the increases in this value will create less profit. Labor has less impact to the profit. This is confirmed by the stability of the project although the maximum labor cost reaches the value of 300% of the estimated labor cost. However, for some cases, the labor cost can be lowered by applying automation technology as alternative to use of labor.
- There is no problem with the utility cost since it gives less impact to the project. In general, even there is an increase in the utility cost of up to 300% of the estimated utility cost, the project can be still profitable.
- Tax has a great effect on the project profitability. The tax must be less than 50% of the estimated tax value.
- Subsidiary from government gives improvement in the sustainability of the project. But, the subsidiary has less impact compared to tax.

In addition to economic prospect, a project feasibility analysis also needs to be carried out. In this project, GPM and BEP showed the positive value. However, other economic parameters such as PBP, ROI, IRR, PI, and CNPV final showed the opposite value giving a negative perspective from the investors. This perspective is based on Indonesian capital market standards. PBP analysis showed that investment will be profitable after more than 12 years. When compared with PBP's capital market standard, the results show an uncompetitive condition.

In the analysis of other economic parameters, it is found that ROI analysis showed around 0.01%. It seemed that the analysis has a negative impact on the sustainability of the project. This ROI analysis implies that 100 USD investment funds generate additional benefits that are not attractive compared to bank and capital market interest of 0.01 USD. So, long-term investment is not attractive to investors. Based on the ROI analysis, the results showed that the cost for sustaining the project is relatively high. For this reason, further analyses must be done for confirming the present results.

Regarding the final CNPV, the value is high enough for the project with 20 years of life time. But, when adding annual calculation, the CNPV value is relatively low. This result is also strengthened by the fact for the condition with relatively less value for PI. Certainly, this typical long-term investment will give unattractive perspective for investors. Another parameter that is considered is IRR. This value shows 15% for 20 years of life time of the project. This value provides a relatively low yield of 0.75% per year. This IRR value shows that this project is not promising.

6. Conclusion

Based on the results of the analysis, the TiO_2 nanoparticles project is prospective if we viewed from a technical point of view. The economic perspective shows unattractive results for investors. As a consequence, to sustain the project, financial supports must be considered. This can come from government or industrial social responsibility. In addition to the need of this project especially for giving socio-economic impact to the country, there is an additional concern regarding the environmental issue. The process to produce TiO_2 involves the non-biodegradable materials, creating the requirements for the additional careful waste treatments.

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