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Cost Analysis and Economic Evaluation for TiO2 Synthesis using Sol-Gel Method

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Abstract

TiO2 nanoparticles as a photocatalyst system transition metal have many benefits in various application example for removal of toxic compound. To synthesis the TiO2 nanoparticle, we used sol-gel as the method. The goal of this paper is to determine whether the sol-gel method of generating TiO2 is economically and industrially viable. Numerous economic evaluation parameters had been analyzed such as gross profit margin (GPM), payback period (PBP), cumulative net present value (CNPV), and total investment cost (TIC). The result of GPM and CNVP/TIC on industrial-scale production of TiO2 nanoparticles showed payback period (PBP) in the 3 years. From the results, it shows that the engineering analysis for TiO2 nanoparticles production is feasible to run. Nevertheless, there are still several parameters that need to be studied further to ensure the feasibility of producing TiO2 nanoparticles on an industrial scale and to boost the profit to attract the investors.

Keywords: *Economic evaluation; sol-gel method; titanium dioxide nanoparticle*

1. Introduction

When compared to the conventional bulk state, nanoparticles have distinct properties. As a semiconductor material, titanium dioxide (TiO2) with the chemical formula TiO2 has numerous applications including bioanalysis, photocatalysis, pigments, sensors, cosmetics, and so on [1]. Titanium is a well-known material due to its chemical structure stability, optical properties, physical properties, electrical properties, and biocompatibility. TiO2 is one of the transition metals that has been widely utilized in a variety of applications [2]. TiO2 as a photocatalyst system has many applications, including the removal of toxic compounds, the removal of unwanted compounds, the treatment of polluted water and air, and the killing of bacteria [3]. Many methods for producing TiO2 nanoparticles had been suggested, which include the sol-gel method, microemulsion method, ultrasonic spray pyrolysis method, hydrothermal method, solvothermal method, and hydrolysis method [3–5]. One of the most suitable TiO_2 nanoparticle synthesis methods for economics evaluation compared to other methods is the sol-gel method because it does not require high temperatures and thus does not require a large amount of energy in processing. Some of the benefits of this method include its versatility, the ability to produce a high purity product, and the ability to fine-tune the microstructure of the final product [6]. Typically, the sol-gel derivative precipitate has amorphous properties in the sol-gel method. As a result, to induce crystallinity, it is necessary to add heat treatment. Temperatures greater than 300°C are usually required to induce the transition from the amorphous to the anatase phase. Titanium's photocatalytic activity, on the other hand, is dependent on particle size and crystallinity [7]. Ragadhita et al. [8] conducted a technology economic analysis for the liquid-phase method of producing TiO2 nanoparticles in previous research. In this study, there are two kinds of feasibility studies used for evaluation: economic evaluation and technical analysis. Because the procedure can be carried out using already available technology and low-cost equipment, the engineering analysis provides information on the potential large-scale production. The economic evaluation demonstrated the project's potential profitability. There are many reports on economic evaluation [9-24]. Although many reports on economic evaluation, the research on TiO2 synthesis using sol-gel method is still limited. Therefore, goal of this research is to assess the economic and technical feasibility of producing TiO2 nanoparticles on a large scale using the sol-gel method. This analysis incorporates stoichiometry calculations for large-scale production. Some parameters for economic evaluation studies, including the value of GPM, PBP, TIC, CNPV, and CNPV/TIC, were calculated to support the feasibility study.

2. Materials and Method

2.1. Theoretical and technical method of synthesis TiO2 nanoparticles

Mirjalili et al. did research on the synthesis of TiO2 nanoparticles using the sol-gel process [25]. TiO2 nanoparticle were prepared by sol-gel method i.e., strong stirring was carried out on a suspension mixture of 2.5 mL titanium (IV) isopropoxide (Ti(OC3H7)4) with 12.5 mL ethanol at 25℃. Then, To form a colloidal solution, slowly add 2 mL of distilled water to the solution that has been obtained. The resulting solution was stirred once more about 12 hours and the pH was adjusted to 3.5 using HCl. After that, the colloid solution was dried for 8 hours at 110°C in an oven, and the xerogel was calcined for 2 hours at 450°C. From a technological standpoint, the materials used and the production of TiO_2 nanoparticles can be increased due to the capacity of the tools available in the industry to process large quantities. To produce about 100 kg of TiO_2 nanoparticles in one day, it takes on reaction cycle the usage of approximately 15 kg of $Ti(OC_3H_7)_4$, 81 kg of C_2H_5OH, 18 kg distilled water, and 7.5 kg HCl. In ideal conditions, with a project length of 20 years, a total cost of raw materials of IDR848,400.00 and a one-year profit of $187,705.27. The flow diagram regarding the production of TiO_2 nanoparticles that using the sol-gel method (see figure 2).

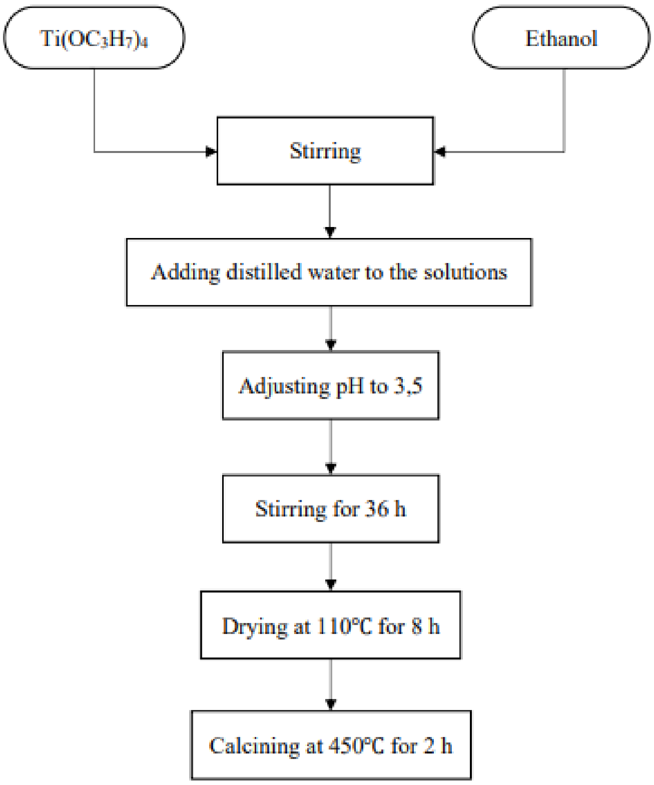

Figure 1. Schematic of TiO_2 nanoparticles synthesis by sol-gel method

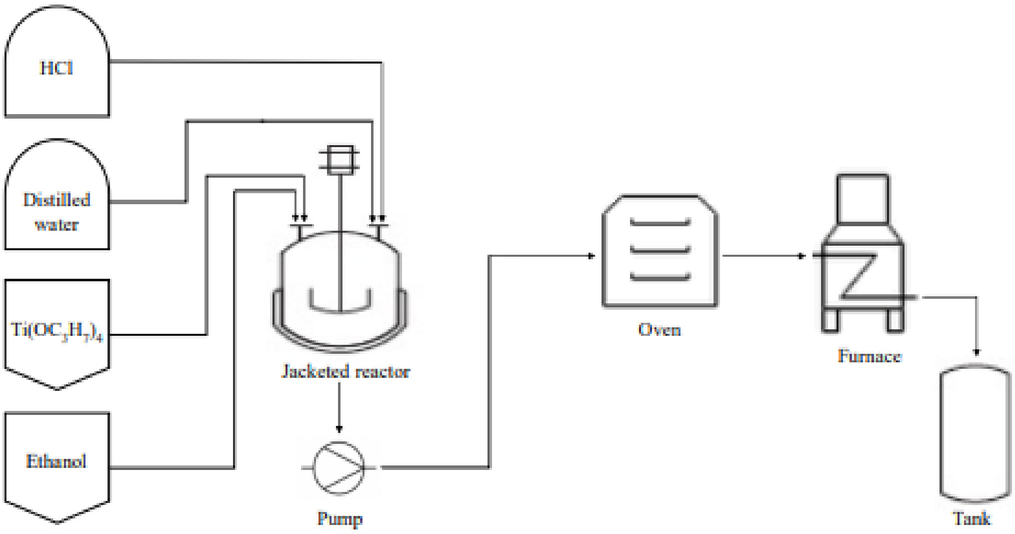

Figure 2. TiO_2 nanoparticles production flow diagram

2.2. Engineering evaluation

In the engineering evaluation process, data are used based on the prices of materials, equipment, and equipment specifications commercially to be had in the marketplace in Indonesia. This information is then fed into mathematical calculations to obtain mass balance and energy. Figure 2 shows the detail information to produce TiO_2 nanoparticles. Several assumptions were used to manufacture TiO_2 nanoparticles on a large scale, including:

(i) The stoichiometric calculations were carried out using the same amount of moles of fuel based on the availability of the reactor used. We found that the production of TiO_2 was 100 kg per day.

(ii) The chemicals were needed to form TiO_2 are titanium (IV) isopropoxide ($Ti(OC_3H_7)_4$), ethanol (C_2H_5OH), distilled water, and hydrochloric acid (HCl), with high purity so that no purification process is required.

(iii) The stirring reactor has a capacity of up to 100 L; the dryer oven operated at 110°C; and the capacity of the furnace (for calcination) was set at 450°C.

(iv) The chemical compositions are calculated based on Mirjalili et al. [25]. Comparison of $Ti(OC_3H_7)_4$, C_2H_5OH, and HCl is 1 : 5.5 : 0.5, and comparison of $Ti(OC_3H_7)_4$ with distilled water is 1 : 7.5.

(v) To generate TiO_2, the entire process employing both fuels was consumed.

(vi) The purity result of TiO_2 is 100%, and the conversion rate for TiO_2 formation process was 85%.

(vii) Losses in the reactor, drying, and calcining were 5% from each process.

2.3 Economic evaluation

Various economic assessment factors have been used to confirm the project's evaluation utilizing a variety of parameters including as:

(i) Gross Profit Margin (GPM) is obtained from reducing raw material costs with sales results [26].

(ii) Payback Period (PBP) is the result of a calculation that provides information about the predict time required for an investment to be able to recoup its whole initial investment [26].

(iii) The Cumulative Net Present Value (CNPV) is a value calculated from the net present value at a specific point in time [26].

(iv) The Profitability Index (PI) is a metric that attempts to establish a link between project costs and project outcomes. The PI is calculated by dividing the CNPV by the overall investment cost (TIC) [27].

(v) Table 1 shows the Lang Factor used for analyzing the Total Investment Cost (TIC).

To ensure the economic analysis, certain assumptions were applied. This assumption became necessary as the project progressed, as it was necessary to analyze and anticipate numerous possibilities.

(i) 1 USD = 14,000 IDR was utilized in all analyses.

(ii) Ti (OC3H7)4, C2H5OH, HCl, and distilled water have prices of 10, 1.15, 1.8, and 0.39 USD/kg, respectively, based on commercially available pricing. Stoichiometry was used to calculate all materials..

(iii) One production cycle was for 22 h.

(iv) The tax issues were 10%.

(v) Based on the commercial price available for the equipment used, the total cost of the equipment was 33,401USD.

(vi) The production processed lasts for 260 days in a year.

(vii) To simplify the calculation, it was assumed that in one day production requires 258.4 kWh.

(viii) The total salary per employee was 235.71USD/day for 35 people.

(ix) The production process lasted for 20 years.

An economic evaluation become finished for feasibility take a look at. This economic evaluation is carried out with numerous variations including, raw materials prices, selling prices, and taxes.

3. Results and Discussion

3.1. CNPV in ideal condition

The CNPV curves in normal condition to produce TiO_2 nanoparticles was shown in figure 3. The figure shows decreased income in the first year of production. This graph depicts the relationship between CNPV/TIC and the year of production. In terms of engineering analysis, it turned into confirmed that the manufacturing can be scaled up using to be had technologies and less expensive apparatuses

Table 1. Lang factor for estimating total investment cost [28]

Component	Factor
Total Plant Cost (equipment)	
Purchased Equipment	1.00
Piping	0.50
Electrical	0.10
Instrumentation	0.20
Utilities	0.50
Foundations	0.10
Insulations	0.06
Painting, fireproofing, safety	0.05
Environmental	0.20
Building	0.08
Land	0.50
Total Plant cost (management services)	
Construction, engineering	0.60
Contractors fee	0.30
Contingency	0.20
Starting-up fee	
Off-site Facilities	0.20
Plant start-up	0.07
Working capital	0.20

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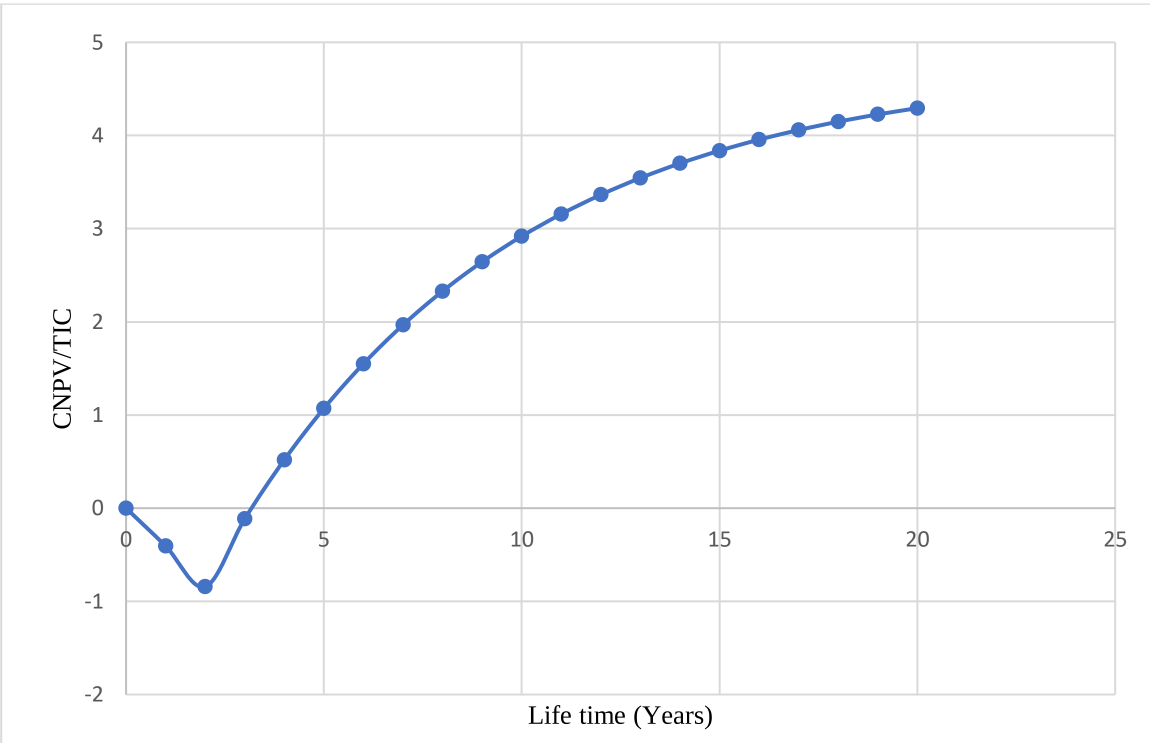

Figure 3. CNPV curves in ideal condition

The economic evaluation also showed prospective results. In the first year, the figure shows constant income. The factory's income starts to decrease in two years of production, and the lowest CNPV/TIC was in third year of production namely -0.11433. However, after 3 years, the income began to increase until it starts to reach the point where the initial total expenditure returned. From figure 3, information about the PBP (Payback Period) point can also be obtained, in which it is about 3-4 years. From the third year of the twenty-year, production profits have increased due to the achievement of PBP, namely the CNPV/TIC value is positive.

3.2. Variation of raw materials prices

Figure 4 depicts the impact of changes in raw material prices on the CNPV/TIC value when raw material prices rise. The variations were selected if there is an increase of 30, 50, 70, and 90% of the initial raw material price. The year of production was indicated by the x-axis, while the value of CNPV/TIC which was affected by the increase in raw material prices was indicated by the y-axis. Based on figure 4, an increase in raw material prices can cause a decrease in the value of GPM, which has a negative impact on the sustainability of the project. By reducing the cost of product sales (revenue; how many items can be sold) from the cost of raw materials, the calculation result was reached [28, 8].

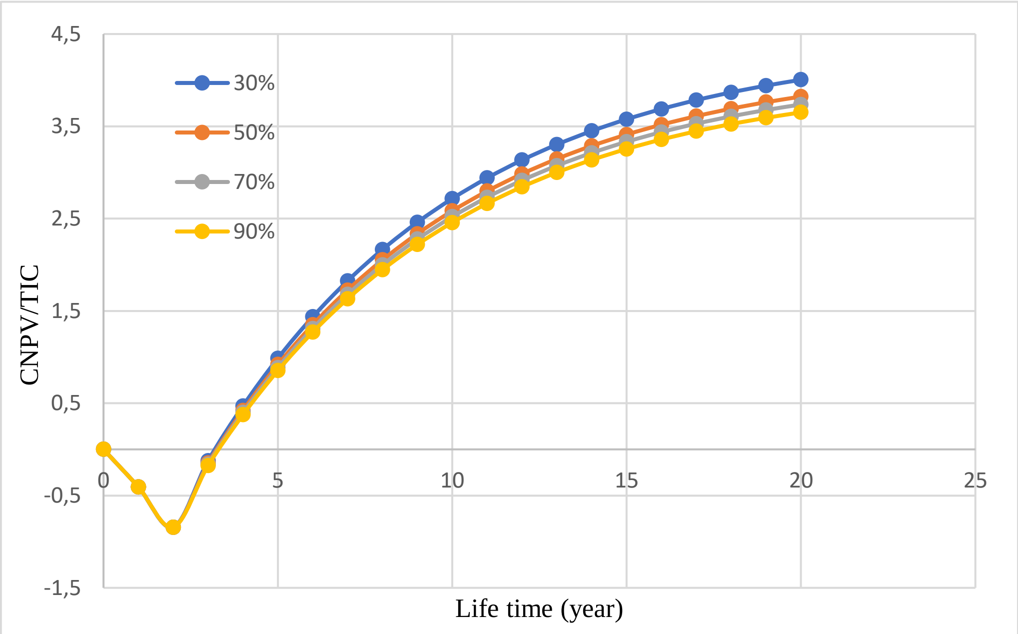

Figure 4. Variation of raw materials increase against CNPV/TIC

3.3. Variation of selling prices

Figure 5 depicts the impact of changes in product selling prices on the CNPV/TIC value. The x-axis represented the production year, while the y-axis represented the CNPV/TIC value that was affected by the increase in selling prices. The variation of increasing selling prices used were 40, 60, 80, and 100%. The figure shows that the lowest selling price

was the smaller profit, while higher selling price was the greater profit. The PBP is lowest if the selling prices is lowered, while PBP is faster if the selling price is increased.

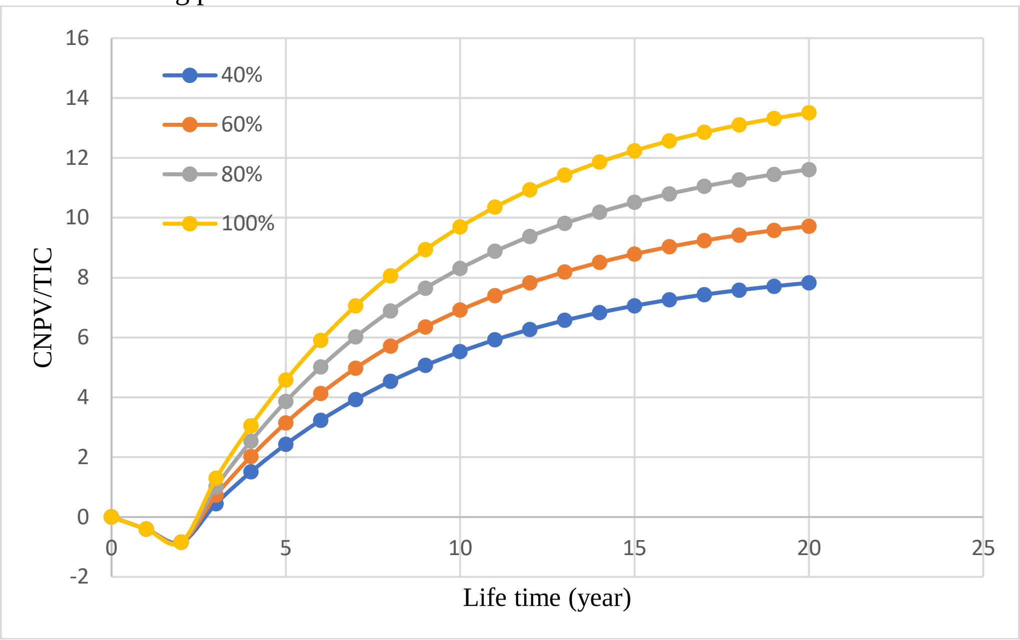

Figure 5. Variation of selling prices increase against CNPV/TIC

3.4. Variation of tax increase

Figure 6 shows the effect of taxes increase if the tax increases by 25, 50, 75, and 100%. The bigger tax increase, the lower CNPV/TIC value. This is because the more taxes added to the project, the less income can be earned. According to PBP study, the greatest tax to obtain BEP (the point at which the project has no profit or loss) is 65 percent. The failure of a project is caused by a tax rise of more than 65 percent [28].

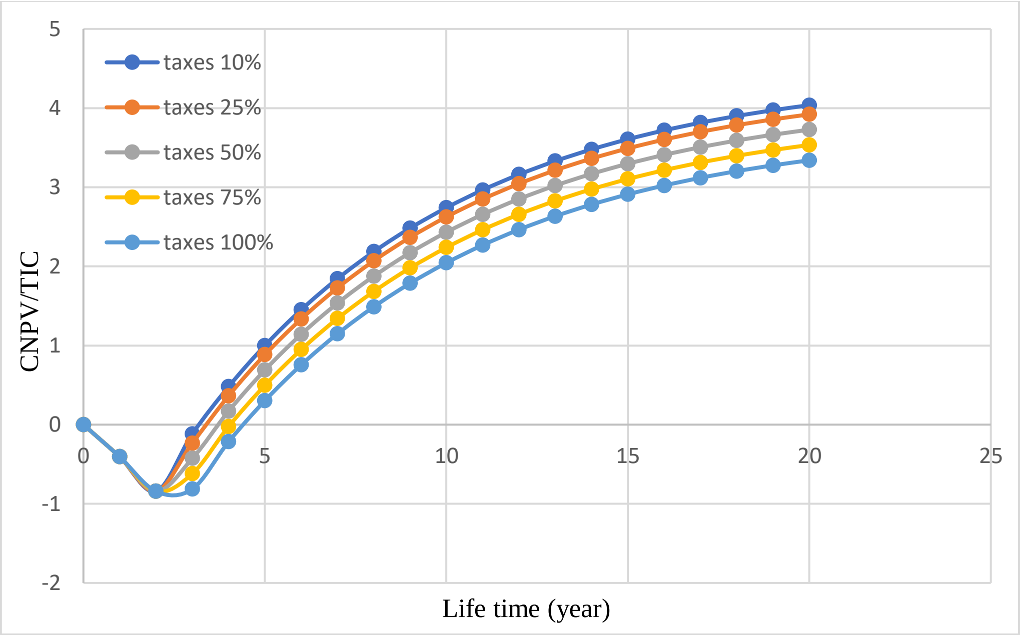

Figure 6. Variation of tax increases against CNPV/TIC

Conclusion

This study carried out the cost analysis and economic evaluation of TiO2 nanoparticles production using the sol-gel method. The result obtained in engineering analysis and economic evaluation were good. PBP occurs after 3-4 years of

production and continues to increase until the 20th year. Analysis of the value of CNPV/TIC and PBP is stimulated with the aid of numerous factors such as the increase inside the rate of raw materials, the increase in the selling price, and the increase in taxes that ought to be paid. The findings of the study on the economic and commercial viability of generating TiO_2 nanoparticles show that there are numerous conditions under which the industry can be profitable. This study is expected to provide an overview of industrial and economic evaluation, particularly in the field of TiO2 nanoparticle production..

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