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ARTICLE

Techno-Economics of Al_2O_3 (Aluminum Oxide) Nanopowder Production Using Mechanochemical Methods

*Yuni Kartika Suryana1, Yusrianti Sabrina Kurniadianti1, Adzra Zahra Ziva1, Risti Ragadhit1, Asep Bayu Dani Nadiyanto1**

[1]Departemen Kimia, Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alam, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi no. 229, Bandung 40154, Jawa Barat, Indonesia

Correspondence: E-mail: nadiyanto@upi.edu

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A B S T R A K

Penelitian ini bertujuan untuk mengkaji keekonomian produksi aluminium oksida (Al_2O_3) dalam skala besar dengan memanfaatkan proses mekanokimia. Penilaian ini dibuat dari sudut pandang teknis dan keuangan. Berdasarkan margin laba kotor, durasi pengembalian, dan nilai sekarang bersih kumulatif, beberapa faktor penilaian ekonomi diperiksa untuk memperoleh informasi potensial dari pembuatan nanopowder Al_2O_3. Temuan penelitian ini mengungkapkan bahwa metode mekanokimia dapat digunakan untuk menghasilkan nanopowder Al_2O_3 dalam skala komersial. Menurut perhitungan teknik, nanopowder Al_2O_3 dapat dihasilkan dalam jumlah hingga 146,88 ton per tahun dengan keuntungan 715.216,75 USD selama 20 tahun. Tinjauan ekonomi dilakukan untuk memastikan bahwa proyek ini dapat diselesaikan berdasarkan proyeksi situasi ideal dan non-ideal, seperti kenaikan pajak, perubahan penjualan, harga bahan baku, harga utilitas, dan upah tenaga kerja. Penelitian ini diharapkan dapat membantu produksi nanopowder Al_2O_3 dalam skala besar dengan memanfaatkan proses mekanokimia.

Kata Kunci: Evaluasi ekonomis; nanopowder alumina; metode mekanokimia, Al_2O_3.

A B S T R A C T

This research aims to assess the economics of producing aluminum oxide (Al_2O_3) on a large scale utilizing mechanochemical processes. This assessment is made from both a technical and a financial standpoint. Based on gross profit margin, payback duration, and cumulative net present value, several economic assessment factors were examined to acquire potential information from the manufacturing of Al_2O_3 nanopowder. The findings of this study revealed that mechanochemical methods might be used to produce Al_2O_3 nanopowder in a commercial setting. According to engineering calculations, Al_2O_3 nanopowder can be generated in quantities of up to 146.88 tons per year for a profit of 715,216.75 USD over 20 years. An economic review is conducted to ensure that this project can be completed based on projections of ideal and non-ideal situations, such as tax increases, sales changes, raw material prices, utility prices, and labour pay. This research should help with the production of Al_2O_3 nanopowder on a large scale utilizing the mechanochemical process.

Keyword: Economic evaluation; Alumina nanopowder; Mechanochemical methods; Al_2O_3

INTRODUCTION

Nanopowder materials are 1-100 nm and exhibit different chemical, optical, electrical, mechanical, or magnetic properties from their bulk form [1,2]. Nanopowder materials can be used as adsorbents or catalysts because they provide a larger surface area than micro and macro-sized materials [2].

Alumina is a chemical compound consisting of aluminum and oxygen with the formula Al_2O_3. Alumina is used in various applications such as biomedical implants, catalysts, adsorbents, flame retardants, insulators, ceramics manufacture, optics, and wear protection [3,4]. That's because alumina has the properties of chemical and thermal stability, wear resistance, high hardness, good electrical and chemical resistance, high melting point, resistance to bases and acids, non-volatility, and resistance to oxidation and corrosion [2]-[5]. Alumina can be synthesized into several different phases depending on the temperature during the synthesis process [3]. Alpha alumina phase is the most stable structure because it has high hardness, high stability, high insulation, and transparency, so it is often used in ceramics [3-5].

Synthesis of Al_2O_3 nanopowder can be carried out by various methods such as mechanochemical [6,7]; combustion [8,9]; precipitation [5,10]; microwaves [11]; sol-gel [3,4]; wet chemical [6,12]; hydrolysis [13]; and synthesis under supercritical water conditions [14]. Compared to some of these methods, the mechanochemical method has good prospects for development and is more suitable for commercial production. Mechanochemical has several advantages, such as a simpler and more efficient method, environmentally friendly, very short synthesis time, low energy consumption, without applying external heat, low nanopowder agglomeration, and relatively low production costs for large amounts of nanocrystalline phase. Therefore, this synthesized product has high purity, a large specific surface area, and high surface energy [6,15].

Few studies discuss the economic evaluation of Al_2O_3 and there is no economic evaluation based on mechanochemical methods. Thus, this study aims to demonstrate the economic evaluation of the synthesis of Al_2O_3 nanopowder using mechanochemical methods on an industrial scale. This study has several variations of raw materials, taxes, utilities, labor, and sales.

METHODS

2.1 Synthesis of Al_2O_3 Nanopowder using Mechanochemical Method

The synthesis of Al_2O_3 nanopowder can be selected and improvised based on the literature [6,7]. The materials used for the mechanochemical method are $AlCl_3{\cdot}6H_2O$, NH_4HCO_3, NH_4OH, anhydrous ethanol, and starch. First, $AlCl_3{\cdot}6H_2O$ was mixed with NH_4HCO_3 in a grinding machine for 15 minutes at room temperature. Then, 25% ammonium was added and crushed for 5 minutes. The addition of ammonium is done to maintain the pH in the range of 9-10. The precipitate was then filtered and washed with deionized water and ethanol. Then, add starch with starch scale and ammonium aluminum carbonate hydroxide (AACH) 1:1 and dissolve in ethanol. The resulting mixture was sonicated for 30 minutes, filtered, and dried at 60 °C for 30 minutes. After drying, it was calcined at 1100 °C for 1.5 hours at normal pressure. The schematic of the Al_2O_3 synthesis process from this mechanochemical method is shown in Figure 1.

2.2 Analysis Method

This research investigates the possibility of constructing a factory from both a technical and economic perspective. Using Gao et al. [6] as a reference, engineering and economic perspectives were used to analyze the production of Al2O3 nanopowder via the mechanochemical method on an industrial scale. The procedure is carried out through large- scale simulation of the production process utilizing commercially accessible equipment and raw materials from the engineering perspective. The mass balance that occurs during the manufacturing process then simulates this process. Furthermore, we analyze the usage of raw materials and equipment to support and reduce investment expenses. Economic data evaluation includes all specifications of equipment, equipment costs, raw material prices, and utility systems. The information has been collected from online web stores like Alibaba.com. The data is then processed in the Microsoft Excel application, where simple mathematical computations are performed. Several economic feasibility parameters based on Ragadhita et al. [16] literature was used to compute the economic evaluation. The parameters of the economic evaluation are concisely explained as:

- The first analysis, Gross Profit Margin (GPM), predicts an approximate estimate of this project's profitability level. GPM is obtained by deducting the cost of the product from the cost of raw ingredients.
- The Break-Even Point (BEP) is the smallest quantity of product required to cover the total cost of production at a given price. BEP is calculated by dividing fixed costs value and profits (total selling price minus total variable costs).
- The Cumulative Net Present Value (CNPV), estimates project outcomes in years based on production. CNPV is calculated by adding the Net Present Value (NPV) at a specific time since the project's beginning. The net present value (NPV) is a number that represents the sum of a company's expenses and profits. The cash flow is multiplied by the discount factor to obtain the NPV.
- The Payback period (PBP), 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.

The Profitability Index (PI), identifies the link between project investment expenses and the influence on the continuity or the profitability of the business. PI is calculated by dividing the CNPV by the total investment cost (TIC). The project is unprofitable if the PI is less than one. However, the project can be considered an excellent project if PI is more than one.

Engineering assumptions are based on the manufacturing method of Al_2O_3 nanopowder, as shown in Figure 2. Table 1 will list all of the symbols that are featured in Figure 2. These assumptions show the stoichiometric calculations that produce 12 kg of α- Al_2O_3 nanopowder per cycle, after scaling up the project. Several assumptions were made:

1. All chemical ingredients are counted from the literature.
2. All chemical compositions in the reaction consist of high purity ingredients.

3 The chemical composition scale is increased up to 8,000 times

4 Aluminum chloride is reacted with ammonium bicarbonate in a 1:5 ratio.

Conversion rate for the α-Al_2O_3 nanopowder formation process was 100%.

Table 1. Symbol on process diagram flow alumina of alumina nanopowder

No.	Symbol	Information
1	G-1	Grinding-1
2	P-1	Pump-1
3	S-1	Separator-1
4	T-1	Tank-1
5	P-2	Pump 2
6	S-2	Separator-2
7	O-1	Oven-1
8	F-1	Furnace-1

To ensure the economic analysis, several assumptions were used. This assumption is required to analyse and predict several possibilities happening during the project. The assumptions are:

1 The calculation used fixed currency on the conversion of 1 USD = 14,500 IDR.

2 All prices of raw materials used, and prices of products follow market prices at online webshops (Alibaba.com). The cost of aluminium chloride hexahydrate, ammonium bicarbonate, ammonium hydroxide, anhydrous ethanol, and starch are 0.40 USD/kg, 0.15 USD/kg, 1.50 USD/kg, 0.60 USD/kg, and 1.00 USD/kg, respectively.

3 The price of α-Al_2O_3 nanopowder (as product sales) is 100 USD/kg.

4 The source of water is free because the project is constructed next to a river.

5 Stoichiometry calculations are used to calculate all raw materials used during the α-Al_2O_3 nanopowder fabrication process.

6 The Lang Factor [17] is used to compute the total investment cost (TIC).

7 The project is not being financed with a bank loan.

8 The process of running under purchased land. Therefore, the land is calculated as the initial cost of project construction and will then be recovered after the project is finished (at the end of the project).

9 One cycle in the production of α-Al_2O_3 nanopowder needs 5 hours.

10 The projected total processing cycle is 12 cycles in a single day, provided all tools are utilized continuously. Al_2O_3 nanopowder can be produced up to 146 kilograms each day.

11 All products are sold completely. There is no product loss as a result of poor product quality or damaged/destroyed raw materials.

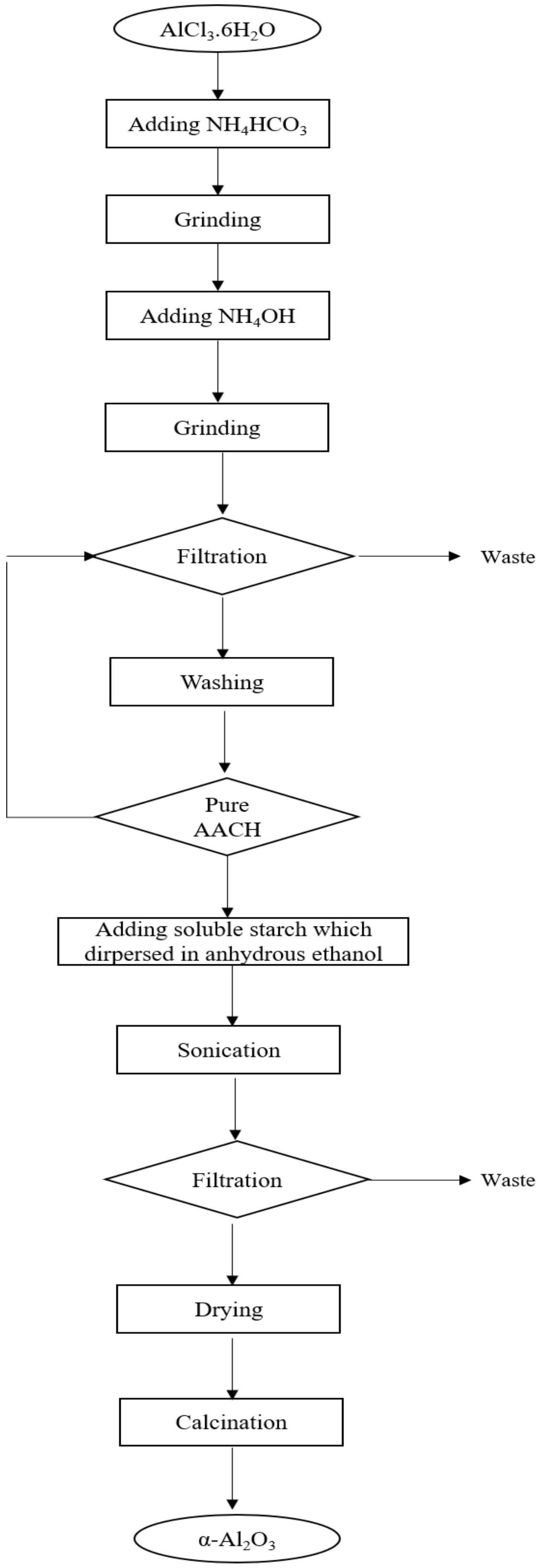

Figure 1. Schematic synthesis of Al_2O_3 nanopowder using the mechanochemical method

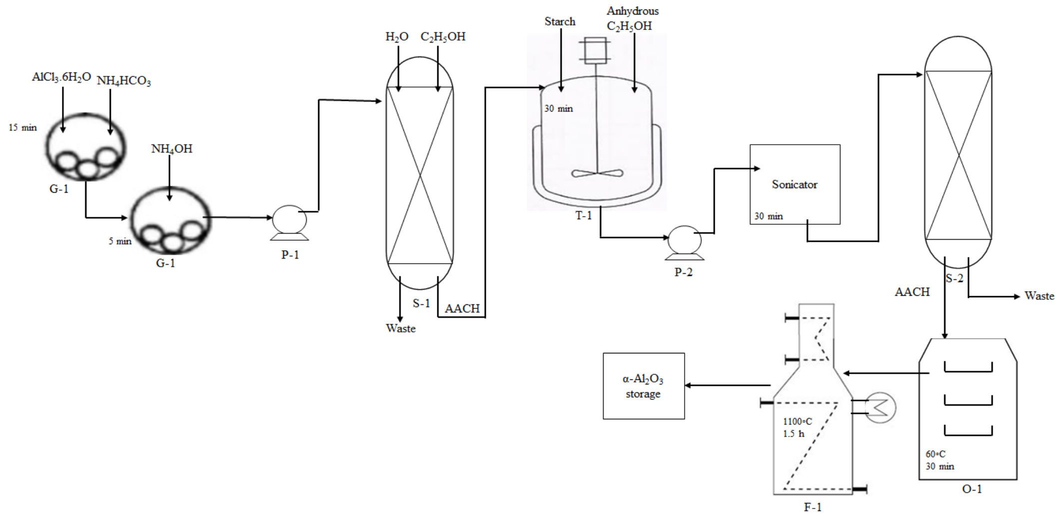

Figure 2. Process flow diagram of alumina nanopowder.

12 Shipping fees are charged to the customer.

13 The total fixed-rate salary is 6 USD/day, with 30 workers in this project.

14 Working days for one year are 300 days (the remaining days are used to clean and repair tools).

15 Electric utility costs are 0.099 USD/kWh.

16 Discount rate and income tax are, respectively, 15% and 10% per year.

17 The project operates for 20 years.

Economic evaluation is conducted for project feasibility tests. This economic evaluation is carried out by varying the tax value at 10, 25, 50, 75, and 100%, while the variations in sales, raw materials, labour, and utility are carried out at 85, 90, 100,110, and 115%.

RESULTS AND DISCUSSION

3.1. Engineering Perspective

The process of Al_2O_3 nanopowder using mechanochemical methods is carried out with several instruments using an industrial scale which can be obtained commercially and economically. If the production is carried out 3,600 times a year, it will get the Al_2O_3 nanopowder with a total of 146.88 tons. Al_2O_3 nanopowder requires 454.76 tons of aluminum chloride hexahydrate, 743.815 tons of NH_4HCO_3, 1,689.6 tons of ammonium hydroxide, 13,404 tons of ethanol, and 261.75 tons of starch. The total price required in a year for production is 2,582,630 USD, with annual sales of 4,406,400 USD, resulting in a profit of 715,216.75 USD per year. These benefits will be shown in an economic evaluation and the value of the project will be shown over 20 years.

3.2. Economic Evaluation

3.2.1. Ideal Condition

The ideal condition is shown by analysing the relationship of CNPV/TIC to a lifetime (year). The CNPV/TIC graph analysis results from the calculation of several economical evaluation parameters in the Al_2O_3 nanopowder industry from time to time (years) under ideal conditions can be seen in Figure 3. The Y-axis is CNPV/TIC and the x-axis is a lifetime (year). As shown in the curve, the initial time shows a negative CNPV/TIC value, and its value increases with the time of the project. There is a negative CNPV/TIC value, which is below 0 in the first to second year. This shows a decrease in income in that year due to the initial expenditure for the production of Al_2O_3 nanopowder. The lowest CNPV/TIC value was in the second year, namely -0.9746. However, in the third year, the value rose to 16,1868. This point is referred to as the payback point, then the increase shown on the graph is called the Payback Period (PBP). The profit to cover the initial expenses increased up to year 20 to a value of 119.96. Moreover, making Al_2O_3 nanopowder with this mechanochemical method can be considered profitable because it requires a short time to recover the investment cost, which is only three years.

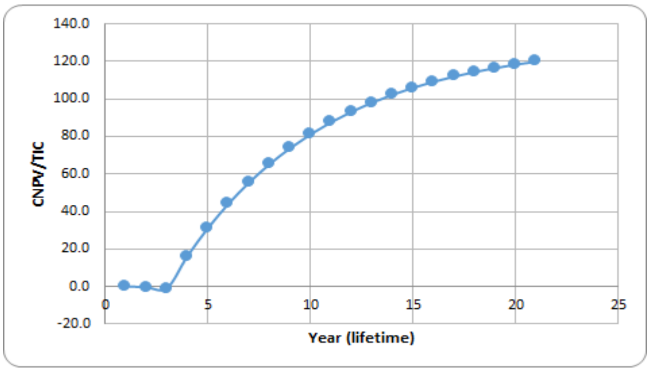

Figure 3. Graph of CNPV/TIC against lifetime (year) under ideal conditions.

3.2.2. Effect of External Condition

The external conditions of the economic evaluation influence the success of a project. The most influential external factor on the success of a project is the country's economic condition where the project is established. These factors, such as taxes levied on projects by the state to finance public spending. The graph of CNPV/TIC against lifetime with tax variations will be shown in Figure 4. The tax variations carried out are 10, 25, 50, 75, and 100%. The y-axis is the CNPV/TIC value, and the x-axis is the lifetime (year). The results obtained in the first and second years for various variations are still the same and have negative values because this year is the project's initial year, and the project is still in the construction stage. The effect of variations in taxes imposed by the government on the project can be analysed starting from the second year to the last year. The CNPV/TIC values obtained, in the third year, for the tax variations of 10, 25, 50, 75, and 100%, respectively, are 16.19, 13.33, 25.77, 16.86, 7.96, and -0.94. The analysis results show that the greater the tax imposed on a project, the greater the decrease in profit. Furthermore, the possibility of achieving PBP will take longer than ideal conditions. On the other hand, the smaller the tax variation imposed on a project, the greater the profit.

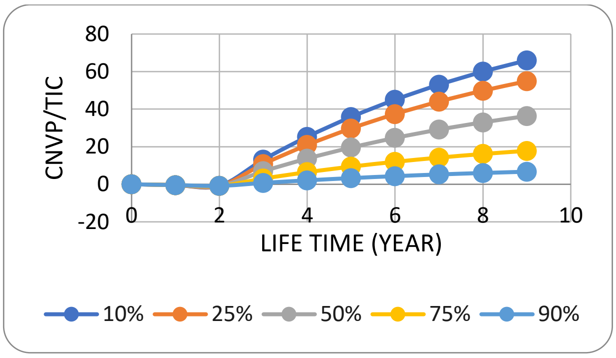

Figure 4. Graph CNPV/TIC with tax variation against year

3.2.3. Change in Sales

The results of CNPV/TIC on lifetime with variations in sales are shown in Figure 5. The CNPV/TIC value is on the y-axis, and the lifetime (year) is on the x-axis. The sales variations made were 85, 90, 100, 110, and 115%. In the first and second years, there is no difference in the variation in sales. This is because the project is still in the development phase. As the third year progressed, different values were obtained, namely 1.42, 6.34, 16.18, 26.02, and 30.94 for 85, 90, 100, 110, and 115% variations. Based on these results, it can be concluded that the more sales made, the greater the profit obtained. While fewer sales are made, the profits will be less.

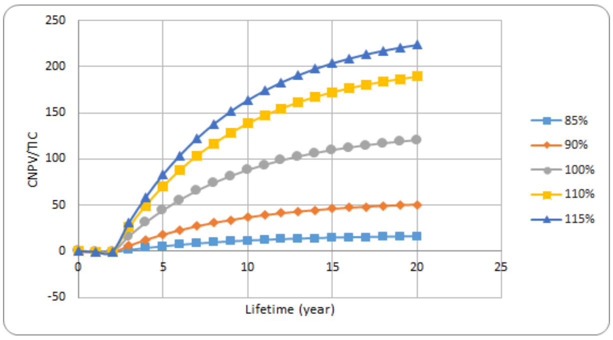

Figure 5. CNPV/TIC against lifetime for sales variations.

3.2.4. Changes in variable costs (raw materials, utilities, and labor)

The pricing of raw materials, utilities, and labor salaries also affect variable costs. The variation in raw material prices is shown in Figure 6. The CNPV/TIC value is on the y-axis, and the lifetime (year) is on the x-axis. This analysis varies the price of raw materials, namely 85, 90, 100, 110, and 115%, with the ideal condition of 100%. In the first and second years, the results obtained for all variations are still the same and have negative values. This is because the project is still in the development phase. In the third year, you can see the difference in each variation. The payback points obtained in the third year are 28.21, 24.20, 16.18, and 4.15 for 85, 90, 100, 110, and 115% variations in raw material prices. Based on Figure 6, it can be concluded that the lower the cost of raw materials, the greater the profits. The higher the cost of raw materials, the smaller the profit obtained.

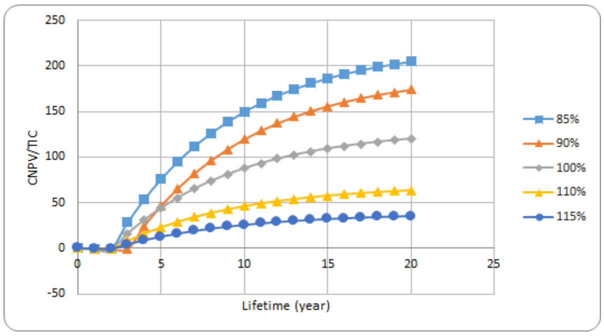

Figure 6. Graph of CPNV/TIC against lifetime (year) for variations in raw material prices.

Figure 7 shows the relationship between CPNV/TIC and lifetime (year) if the utility price is varied. The CNPV/TIC value is on the y-axis, and the lifetime (year) is on the x-axis. Variations are made by increasing and decreasing utility costs so that they become 85, 90, 100, 110, and 115%. Based on Figure 7, this variation in utility prices does not show a significant effect. This is because the CNPV/TIC values obtained in this variation are the same every year.

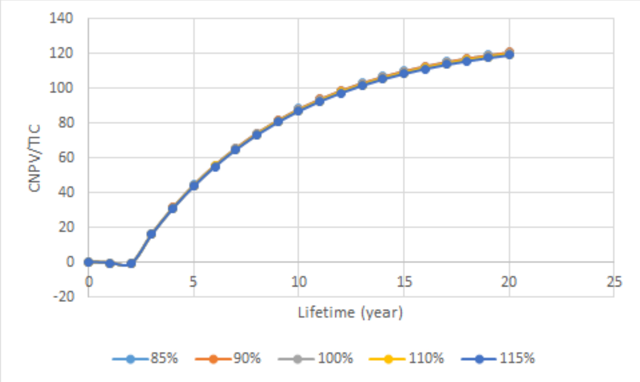

Figure 7. Graph of CPNV/TIC against lifetime (year) for variations in utility prices.

Figure 8 shows the relationship between CPNV/TIC and lifetime (year) if there is a variation in the labour salary. Variations are made by adding and subtracting salaries so that the percentages are 85, 90, 100, 110, and 115%. This variation does not have much effect on profits because the results obtained in each variation per year are the same.

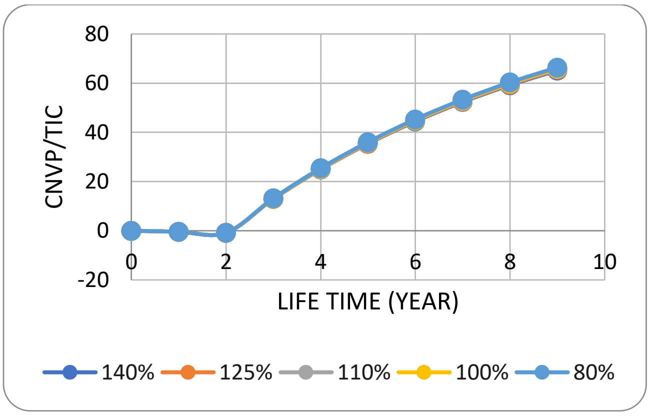

Figure 8. Graph of CNPV/TIC with utility variation against year

CONCLUSION

Based on the analysis results, the Al_2O_3 nanopowder production project using mechanochemical methods with aluminum chloride as the main raw material shows a prospective project from an engineering and economic perspective. Mechanochemical has several advantages, such as a simpler and more efficient method, environmentally friendly, very short synthesis time, low energy consumption, without applying external heat, low nanopowder agglomeration, and relatively low production costs for large amounts of nanocrystalline phase. In addition, this synthesized product has high purity, a large specific surface area, and high surface energy. The project can compete with the conventional market, according to PBP analysis, because the return on investment is profitable in a short period of time, around three years. The results of the economic evaluation analysis indicate that this project is possible to carry out.

AUTHOR CONTRIBUTION

YKS, YSK, AZZ, RR, and ABDN all contributed on the experimentation and the writing. All authors have read the manuscript and agreed on the final version."

DAFTAR PUSTAKA

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