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Economic evaluation in industrial scale Co_3O_4 nanoparticle synthesis

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Abstract

Co_3O_4 nanoparticles are useful as heterogeneous catalysts, electrochromic devices, and solid-state sensors. The purpose of this research was to evaluate the production of Co_3O_4 nanoparticles from the laboratory scale to the industrial scale from the engineering and economic side. From a technical point of view, the results demonstrated the production of Co_3O_4 nanoparticles could be done using simple technology and methods. From an economic perspective, the results showed that the production of Co_3O_4 nanoparticles is favorable under certain conditions of raw materials, sales, and production capacity. All evaluation parameters gave a positive value. Project development needed to be added especially regarding strategies to increase profits and attract investors. This study was quite promising to be realized in developing countries.

Keywords: Co_3O_4, nanoparticle, industry, economic evaluation.

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1. Introduction

Cobalt (Co) is a chemical element in Period 4, Group 9, the block D element, with an atomic mass of 58.933195. The cobalt atom has a radius of 125 pm and a Van Der Waals radius of 192 pm. In its elemental form, cobalt is shiny gray. Cobalt produces brilliant blue pigments which have been used since ancient times to color paint and glass. Cobalt is a ferromagnetic metal and is used primarily in the production of magnetic and high-strength super-alloys [1]. Cobalt oxide has found use in applications in many fields, such as heterogeneous catalysts, electrochromic devices, and solid-state sensors [2].

Several researchers have conducted research on the synthesis of cobalt oxide nanoparticles. Cobalt synthesis research has a variety of synthesis methods such as solution phase synthesis [3], synthesis under hydrothermal conditions [4], mechanochemical synthesis [5], foam-based synthesis [6], and synthesis of microemulsion techniques [7]. Although many studies confirm prospective methods of producing Co3O4 nanoparticles, research on feasibility studies on an industrial scale is still rare. From the various methods mentioned, mechanochemical synthesis was the most efficient method. It could be seen from the many synthesis processes and raw materials used.

This study aims to evaluate in terms of engineering and economics. Several parameters are calculated to support economic evaluation such as payback period (PBP), break-even point (BEP), and cumulative net present value (CPNV) [8]. Some information from commercial websites was adopted to support economic techniques and analysis, such as prices for raw materials and production equipment. To get a feasibility study, data calculation was needed to get the maximum results of Co_3O_4 nanoparticle fabrication that is applied to small scale industries. In addition, this research is important to help consider the benefits obtained from the fabrication of Co_3O_4 nanoparticles. This study was also used to suggest project optimization, to benefit economic growth. All calculations of this study were carried out under specific conditions [9]. The variables used are variations in prices of raw materials, sales, and production capacity.

2. Materials and methods

2.1. Theory of Co_3O_4 nanoparticle synthesis

Cobalt oxide nanoparticles were synthesized based on literature [5]. The starting materials were AR-grade $Co(NO_3)_2•6H_2O$ and NH_4HCO_3. Five grams of starting materials were put in an agate mortar with $Co(NO_3)_2•6H_2O$ to NH_4HCO_3 molar ratio of 2:5. The starting materials were mixed and milled at room temperature until the color of the as-milled powder kept unchanged, then the as-milled powder was thoroughly washed with distilled water and dried at 100°C in air to obtain the nanoparticle precursor. The precursor was calcined at 300°C in air in a porcelain crucible for 2 h to prepare the Co_3O_4 nanoparticles.

2.2. Economic evaluation

The method in this study was based on analysis of marerial prices and equipment, and equipment prices obtained from online stores such as alibaba.com. Data processing was calculated using simple mathematical calculations in the Microsoft Excel application to get economic evaluation parameters:

PBP and CPNV.

Calculation of these parameters was based on literature [8], which shows a formula like the following:

- PBP is a calculation to predict the length of time required to recover initial costs. PBP is determined from the CPNV curve by looking at the time when CPNV reaches zero.
- CNPV (Cumulative net present value) is a calculation of the total NPV from the onset of manufacturing to the end of the planned operation. In other words, CPNV is derived from cumulative financial flows every year.

1. $CNPV = \sum NPV$

- NPV (Net Cumulative Value) is the value obtained from income and expenditure. NPV calculations must consider the value of the discount rate (i). In addition, the NPV can be used to estimate the following year's Cash Flow (CF). NPV calculation requires data of TIC, depreciation, operational costs, and expected profits.

2. NPV is obtained from $NPV = CF.i$

- TIC (Total Investment Cost), is the initial capital that must be prepared at the beginning of production. TIC must be predicted based on the Lang Factor.

The above values needed assumptions to facilitate the calculation of economic evaluation. The assumptions used were as follows:

- Project operations last for 10 years.
- Raw material prices were obtained from (www.alibaba.com). In short, the prices of cobalt nitrate hexahydrate and ammonium bicarbonate were 174,000 IDR/kg and 2,755 IDR/kg, respectively.
- The total investment cost (TIC) was calculated based on the Lang Factor (8).
- This production was carried out on owned land. Therefore, land included the initial cost of industrial development.
- Direct-type depreciation was used to calculate depreciation [10].
- The production process was carried out two cycles per day.
- All reactant compositions, such as cobalt nitrate and ammonium bicarbonate were scaled up two thousand times and calculated based on literature. [5] The reaction conversion rate was assumed to be 100%.
- There was a mass loss of the chemical compound transferred by 5% of the initial mass in each transfer process.
- Co_3O_4 nanoparticles as the main product and NH_4NO_3 solution as a byproduct
- Minimum of product purchase was one pack (5 grams for Co_3O_4 nanoparticles and 1 liter for NH_4NO_3 solution).

- The water used in the production process was purified, deionized water obtained from the water treatment plant.
- Water treatment was carried out at night.
- The work day in a year was 300 days and the rest of the day was used to clean and prepare the process.
- Electricity costs were estimated at 1,467 IDR / kWh.
- The salary of employees were assumed to be 451,522 IDR/day.

The feasibility test for economic evaluation was now carried out by making variations in the prices of raw materials, variations in selling prices, and variations in production capacity.
Figure 1 describe the synthesis of cobalt oxide nanoparticle modified from literature [5]. The starting materials were put in the ball-mill for an hour. Then the as-milled powder were washed. Washing process were using water from water treatment then using wash water until ammonium nitrate were concentrated (about 4-5 times). Then the washed powder were put in furnace for drying and calcined to obtain Co_3O_4 nanoparticles.

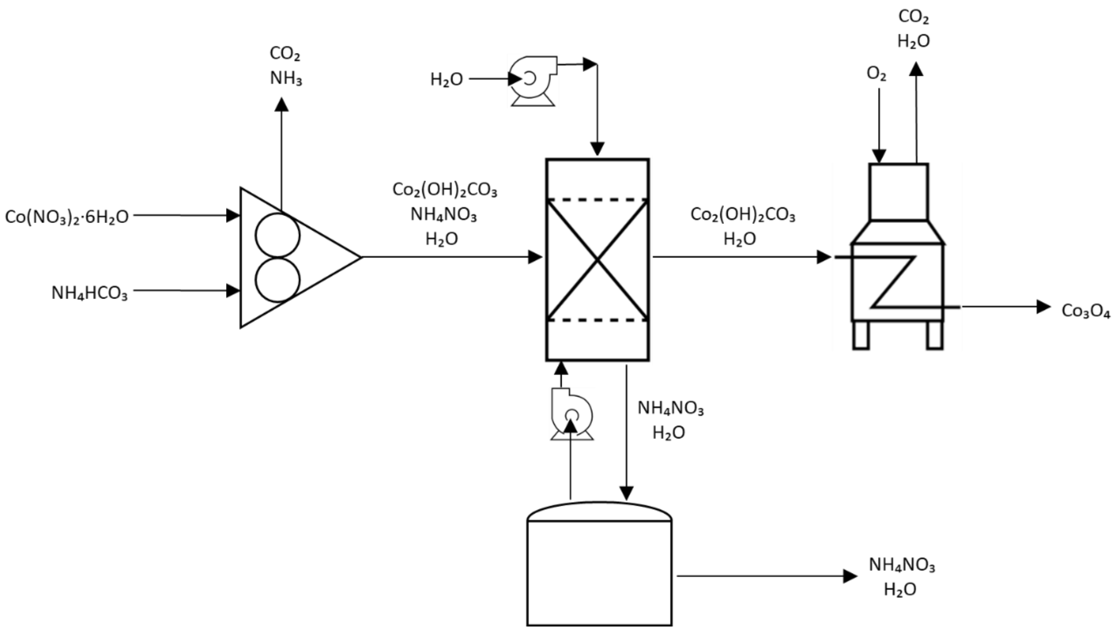

Fig 1. Process Flow Diagram of Co_3O_4 nanoparticles industrial scale

3. Results and discussion

3.1. Engineer perspective

Synthesis of Co_3O_4 nanoparticles based on engineering point of view was possible to do more improvement. This was because scale enlargement can be implemented using affordable equipment. By calculating projects with 600 cycles per year, the proposed scheme had a high prospective yield of 2,375 tons of Co_3O_4 nanoparticles and 3,325 liters of NH_4NO_3 solution from 6 tons of $Co(NO_3)_2 \cdot 6H_2O$ and 6,482 tons of NH_4HCO_3 per year. Then, analysis of total equipment costs required a total cost of 152,031,000 IDR. Adding Lang Factor to the calculation, TIC had a value of 675,017,640 IDR. If seen from the literature [8], the value was economical, and this project required low investment. With a project term of 10 years, the results showed that the entire project can produce 23.75 tons of Co_3O_4 nanoparticles and 33,250 liters of NH_4NO_3 solution under ideal conditions.

The data in Table 1 shows the amount of raw material used in the one-time synthesis of Co3O4 nanoparticles. Each raw material was scaled up by 2000 times, so that the amount of cobalt nitrate hexahydrate which was originally as much as 5 grams turns to 10 kg. Ammonium bicarbonate which was originally as much as 5.402 grams changed to 10.804 kg. Conversion of reactions in chemical reactions that occur by 100%.

Table 1. Usage of raw materials.

Cobalt nitrate hexahydrate (Kg)	Ammonium bicarbonate (Kg)	Reaction Conv. (%)
10	10,804	100%

Figure 2 shows the comparison of the prices of raw materials, utilities, and labor needed per day of the synthesis of Co_3O_4 nanoparticles. Where the price of raw materials is the highest compared to the price of utilities and labor, which is equal to 3,539,527 IDR per day. While the prices of utilities and labor respectively 319,806 IDR and 451,522 IDR. Based on data from Figure 1, it can be seen that the price of raw materials is very influential in increasing the production of Co_3O_4 nanoparticles.

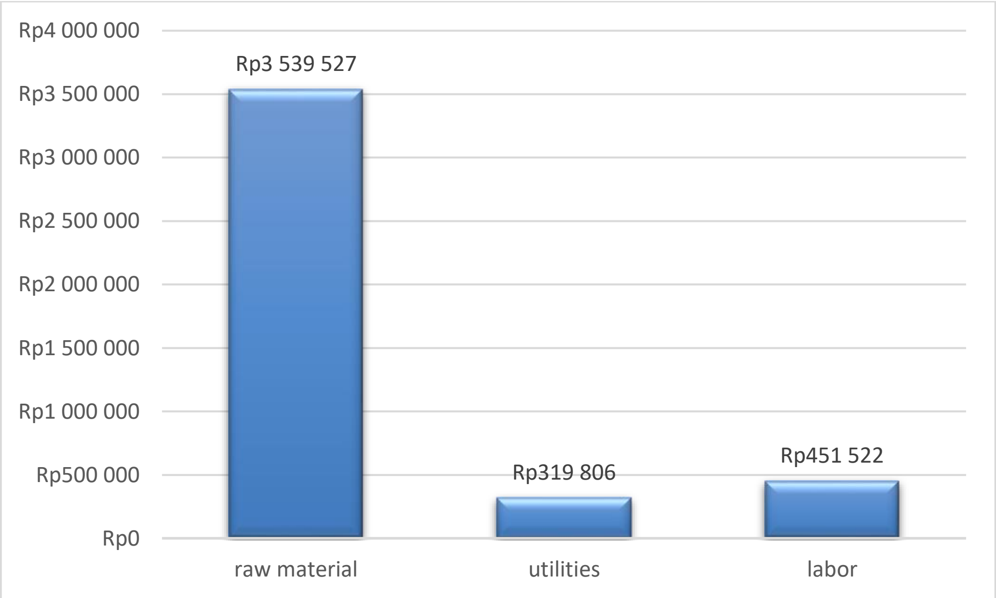

Fig 2. Costs of Raw material, Utilities, and Labor

3.2. Economic evaluation at ideal condition

Figure 3 shows the curve of the CPNV/TIC relationship to lifetime under ideal conditions for the production of Co_3O_4 nanoparticles. From this figure, there was a change in CPNV/TIC from year to year for ten years of production. In the first and second year, the CPNV/TIC value had decreased. This decrease occurred in the first and second year due to the initial cost of the project. In the 3rd year, there was an investment cost recovery or a payback period and profits will continue to increase until the 10th year. If the data in Figure 3 was compared with the literature [8], the production of Co_3O_4 nanoparticles could be said to be a profitable project.

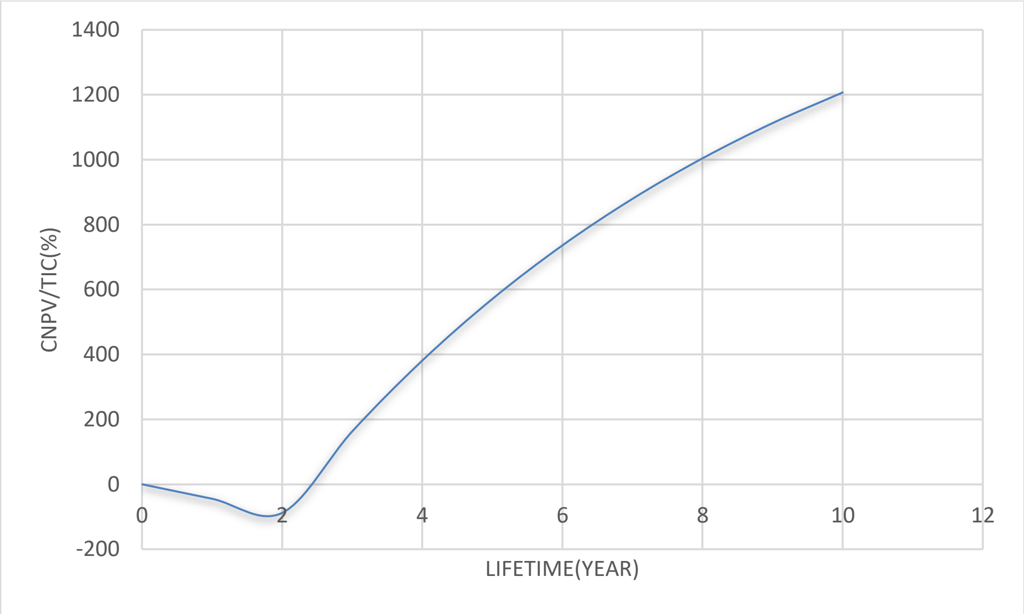

Fig 3. Ideal condition of CPNV in various economic evaluation parameter

3.3. Evaluation on raw material price change

Figure 4 shows the change in raw material prices affecting CPNV. The price of raw materials varied was the price of $Co(NO_3)_2{\bullet}6H_2O$ and NH_4HCO_3. The 100% RM curve is a curve under ideal conditions. RM 0% means the price of raw materials needed for the free production process, while RM 200% means the price of raw materials is double the ideal price. This means that raw material prices also affect project profits. A decrease in raw material prices results in an increase in final CPNV. However, with rising raw material prices, CPNV is declining. So, the effectiveness of projects that get high profits when the price of raw materials is low. However, if the price of raw materials increases, the project's profits will decrease. If the CPNV curve in Figure 4 is compared with the literature [8], the project still benefits even though the price of raw materials has doubled.

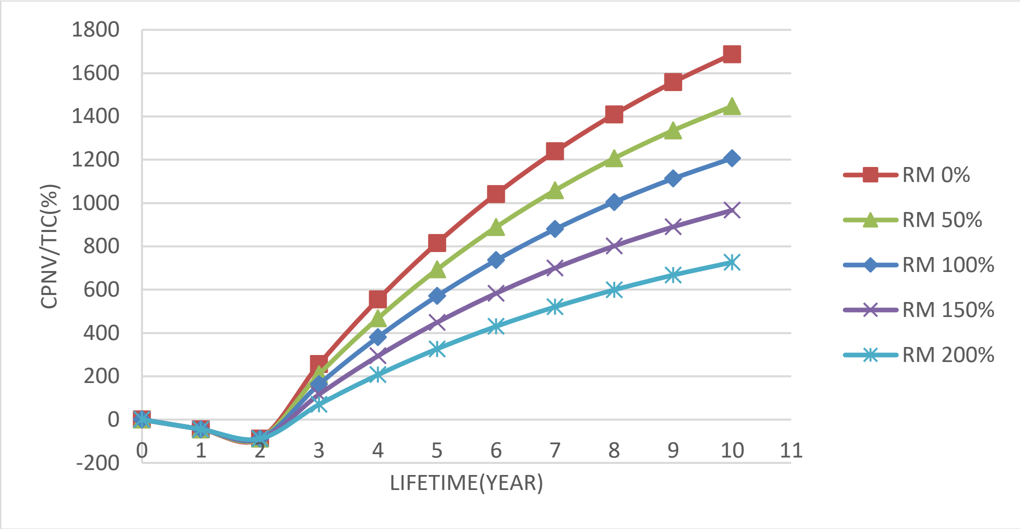

Fig 4. CPNV in raw material price variation

Figure 5 shows changes in product sales affecting CPNV. The sales of the varied product was the selling price of Co_3O_4 nanoparticles, while the price of NH_4NO_3 solution is fixed. The 100% Sales Curve is a curve in an ideal state. Sales of 120% means that the selling price of Co_3O_4 nanoparticles increases by 20% from the ideal price, while sales of 40% means that the selling price of Co_3O_4 nanoparticles is reduced by 60%. The increasing selling price of Co_3O_4 nanoparticles increases CPNV, whereas CPNV will decrease when the selling price of Co_3O_4 nanoparticles decreases. So, the profit will increase along with the increasing selling price of Co_3O_4 nanoparticles. If the CPNV curve in Figure 5 is compared with the literature [8], the project still benefits up to Sales 60%. At Sales 40, the profits almost not obtained.

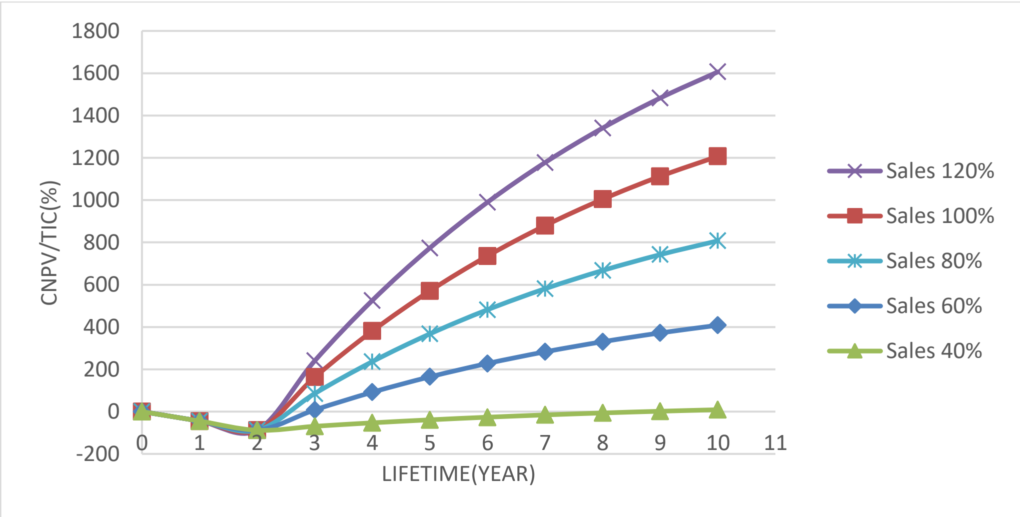

Fig 5. CPNV in Co3O4 nanoparticle sales variation

Figure 6 shows changes in production capacity affecting CPNV. The 100% PC curve is the ideal state curve. PC 60% means the production capacity of Co_3O_4 nanoparticles to 60% of the ideal production capacity, and 80% PC means the production capacity of Co_3O_4 nanoparticles to 80% of the ideal production capacity. Increased production capacity of Co_3O_4 nanoparticles increases CPNV, whereas CPNV will decrease when the production capacity of Co_3O_4 nanoparticles decreases. So, profits will increase along with the increased production capacity of Co_3O_4 nanoparticles. If the CPNV curve in Figure 6 is compared with the literature [8], the project still benefits even though the production capacity is set at 60%.

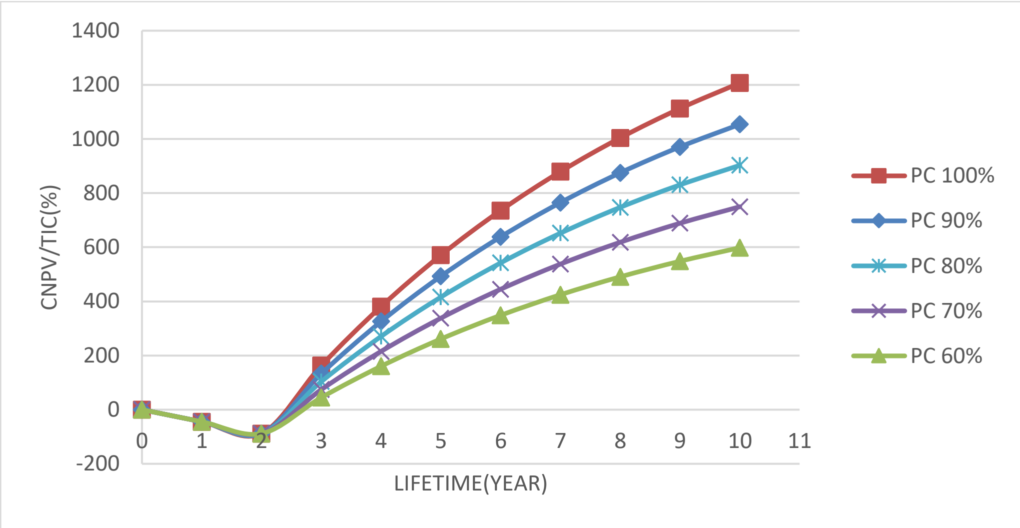

Fig 6. CPNV in production capacity variation

Judging from the economic analysis raised, this project was very feasible in both ideal and non-ideal conditions. However, this consideration was only based on changes in raw material prices, selling prices, or production capacity. Results would be different when there were changes to other economic evaluation parameters. All analyzes were compared with the condition of banks and Indonesian currencies [8]. Detailed descriptions of certain conditions based on analysis are explained in the following:

- The project continues to experience profits if the price of raw materials becomes 200% of the estimated raw material prices. With a 50% difference in raw material prices, changes in CPNV in the 10th year experienced a significant change.
- The project experienced a profit until the selling price became 60% of the estimated selling price. At a 40% selling price, the project did not show significant profits. With a difference in selling price of 20%, the change in CPNV in the 10th year experienced a very significant change.

- Profits can still be obtained at a production capacity of 60% of the estimated production capacity. With a 10% difference in production capacity, the change in CPNV in the 10th year experienced a significant change.
- Employee costs, utility costs, taxes, and other economic parameters remain in ideal conditions. This is because this analysis only reviews the effects of changes in raw materials, selling prices, or production capacity.

On the other side of the economy, a project feasibility analysis also needed to be raised. In this project, CPNV on the three proposed variations shows promising results under ideal conditions. This perspective is based on Indonesia's capital market standards with PBP analysis which shows this investment will experience profits in the 3rd year [8].

Conclusion

From a technical point of view, the production of Co_3O_4 nanoparticles could be done using mechanochemical methods. From an economic perspective, all evaluation parameters gave a positive value. So the results showed that the production of Co_3O_4 nanoparticles is favorable under certain conditions of raw materials, sales, and production capacity. Project development needed to be added especially regarding strategies to increase profits and attract investors. This study was quite promising to be realized in developing countries.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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