Economic Evaluation of Different Fuels in the Production of La_2NiO_4 Particles using A Sol-Gel Combustion

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ABSTRACT

Lanthanum nickelate (La_2NiO_4) is a precursor for producing lanthanum pentanickel ($LaNi_5$) alloys for nickel-metal hydride battery (NiMH; a type of rechargeable battery), which has been developed quite rapidly for many applications, such as Hybrid Electric Vehicles. The purpose of this study was to evaluate the economic feasibility of the production of La_2NiO_4 with different fuels (i.e., glycine fuel (F-G) and citric acid fuel (F-CA)) using a sol-gel combustion method. Several economic evaluation parameters were analyzed, such as gross profit margin, internal rate of return, payback period, cumulative net present value, and so on. The project was evaluated from the ideal condition to the worst-case conditions, including labor, sales, raw material, utility, as well as external conditions (e.g., tax). The results showed that the production of La_2NiO_4 is prospective from engineering and economic perspectives. The engineering analysis for both production steps using F-G and F-CA is feasible, and the production can be done even in small-scale production using commercially available apparatus. The economic analysis showed that the process using F-CA is better than that using F-G. From this economic evaluation analysis, the project is profitable and the recovery of the investment is less than seven years for F-G and four years for F-CA. Although this project is feasible to run and profitable, it is not attractive to industrial investors due to the fewer values in some parameters. Thus, since this material is very important to reduce dependence on imports, additional further technologies for improving processes and support from Corporate Social Responsibility (CSR) and government are important for maintaining this project.

Key words: La_2NiO_4 material, sol-gel combustion, engineering process design, economic evaluation, feasibility study

INTRODUCTION

Several methods have been suggested for the synthesis of Lanthanum Nickelate (La_2NiO_4) (as an intermediate compound for the preparation of lanthanum pentanickel alloys ($LaNi_5$) that can be used as a negative electrode for nickel-metal hydride (NiMH) batteries), such as the hydrothermal method (Wei et al., 2016), the Pechini method (Niwa et al., 2014), the sol-gel combustion method (Efimov et al 2009; Boumaza et al., 2020; Hao et al, 2018; & Liu et al, 2016), the citrate-nitrate synthesis (Tarutin et al., 2019), the conventional solid-state synthesis method (Cetin et al., 2017), the citric acid complexation method (Guo et al., 2007), the solid-state reaction, the nitrate freeze-drying (Adachi et al., 2019), and the polyaminocarboxylate complex method (Kim & Yoo, 2010). Although their methods have successfully synthesized La_2NiO_4, the production is feasible for the laboratory scale and there is no information for the large scale fabrication. Based on our previous studies (Nandiyanto et al., 2018; Nandiyanto et al., 2017; Nandiyanto & Ragadhita, 2019; Nandiyanto et al. 2020a; Nandiyanto et al., 2020b; Miftahurrahman et al., 2019; Ragadhita et al., 2019) on the techno-economic analysis of several materials, the purpose of this study was to evaluate the economic feasibility of the production of La_2NiO_4 by the sol-gel combustion method. The sol-gel combustion method was selected because of several reasons: scalability and feasibility, versatility from the raw materials that can be set from the use of largely available and inexpensive raw materials, and simple design of apparatus for the production that can be done even in the small scale industry. These benefits cannot be obtained using other methods. For example, the hydrothermal method has issues in expensive apparatuses, safety handling when applying in large-scale production, and difficulties in controlling the chemical stoichiometry during the reaction (Liu et al, 2016). The solid-state reaction method has problems in the stoichiometry calculation and the existence of the impurity phase, requiring additional purification steps (Rizaldy et al, 2018). In this study, we focused and compared the analysis of the production of La_2NiO_4 using two types of fuels, i.e., glycine fuel (F-G) and citric acid fuel (F-CA). The analysis was done by putting stoichiometry into the energy and mass balance calculation for the large-scale production, in which this was estimated based on the commercially available apparatuses. To support the feasibility study, several economic evaluation parameters (i.e., gross profit margin (GPM), internal rate of return (IRR), payback period (PBP), cumulative net present value (CNPV), breakeven point (BEP), breakeven capacity (BEC), return investment (ROI), and profitability index (PI)) were used and put into the calculation from ideal condition to change in various economic conditions, such as labor, sales, raw materials, utilities, and external conditions (tax). In addition, since this material is very important to reduce dependence on imports, understanding this feasibility study is important, especially generating and growing economic conditions. Indeed, by creating this industry, the economic conditions in the surrounding chemical plant will grow (Kurniati et al., 2019).

RESEARCH METHOD

Engineering evaluation

For engineering evaluation, we used data, based on the prices of material, equipment, and specification of equipment that are commercially available in the market in Indonesia. These data were then put into mathematical calculations for gaining the energy and mass balance. Detailed information for the production is shown in Fig. 1. Several assumptions were added:

(i) The stoichiometric calculation is done using the same amounts of mole of fuels based on the available reactor used. We obtained that the production of La_2NiO_4 using F-G and F-CA was 3.22 and 4.81 kg per day, respectively.

(ii) All chemicals were consumed and reacted to form La_2NiO_4, which using only lanthanum nitrate hexahydrate ($La(NO_3)_3.6H_2O$), nickel nitrate hexahydrate ($Ni(NO_3)_2.6H_2O$), fuel glycine ($C_2H_5NO_2$), citric acid ($C_6H_8O_7$), and water. All chemicals have high purity (used without additional purification processes).

(iii) The mixing reactor has a capacity of 500 L; the furnace capacity (for calcination) is 198 L operated at 400-1400°C. Tthe process is scaled up 7000 times of the lab scale.

(iv) The chemical composition and ingredients are calculated based on literature (Liu et al, 2016; Hao et al, 2018). The ratio of $La(NO_3)_2.6H_2O$, $Ni(NO_3)_2.6H_2O$, and F-G is 1:5:7.22, and the ratio of $La(NO_3)_2.6H_2O$, $Ni(NO_3)_2.6H_2O$, and F-CA is 4: 2 : 3.

(v) The final purities of the La_2NiO_4 product fabricated using F-G and F-CA are 37 and 100%, respectively, based on literature (Liu et al, 2016 & Hao et al, 2018).

(vi) The conversion rate for the La_2NiO_4 formation process is 80%.

(vii) Losses in the reactor, drying, calcining, and grinding are 10% from each process.

Economic evaluation

Several economic evaluation parameters based on literature (Nandiyanto, 2018) include:

(i) GPM, determining the level of profitability on the project by reducing the cost of sales with the cost of raw materials.

(ii) PBP, calculated to predict the length of time investment to be returned for getting the total initial expenditure. PBP was calculated when CNPV is zero for the first time.

(iii) BEP, defined as the minimum number of products that must be sold at a certain price to cover the total production cost. BEP was calculated by calculating the value of fixed cost divided by (total sales price less total variable cost).

(iv) BEC, calculated by dividing BEP with production capacity in units over a period of time.

(v) IRR, defined as the method for estimating investment from the interest rate,

(vi) CNPV value, defined as the value for predicting the project in the production function in a specific year. CPNV value was obtained from the net present value (NPV) at a certain time. NPV is the value representing the expenditure and income of a business. In short, CNPV was obtained by adding NPV value from the first project to the end of factory operation.

(vii) ROI, calculated by dividing gained total profits by investment.

(viii) PI, defined as the index to identify the relationship between project cost and impact. PI can be calculated by dividing CNPV with total investment costs (TIC). If the PI is less than one, the project can be classified as a non-profitable project. If the PI is more than one, the project is good.

Several assumptions were in the following:

(i) All analyses used currency of 1 USD = 14,000 IDR. Based on commercially available prices, prices of $La(NO_3)_3.6H_2O$, $Ni(NO_3)2.6.H_2O$, glycine, citric acid, and H_2O were 21, 7, 10, 3.57, and 0.39 USD/kg, respectively.

(ii) All materials were estimated based on literature (Liu et al, 2016; Hao et al, 2018).

(iii) The total investment cost (TIC) is calculated based on the Lang Factor (Nandiyanto, 2018), in which TIC was prepared at least into two steps. The first step is 40% in the first year and the second step is the rest (during the development of the project).

(iv) The cost of land was added at the beginning of the construction and re-recovered at the end of the project. Depreciation was from direct calculation (Nandiyanto, 2018).

(v) The project was worked in 5 cycles of production per week (5 working days). A one-year project is 240 days (holiday is an off-day production) and the rest is a day used to clean and manage the process. La_2NiO_4 products are sold at 21.43 USD/50 grams.

(vi) To simplify the calculation, the unit of utility can be explained and converted as an electricity unit, such as kWh (Nandiyanto, 2018). Then, the electricity unit kWh is converted into the cost. The electricity unit (kWh) is multiplied by the electrical cost. Assuming utility cost was 0.986 USD/kWh.

(vii) Total labor was assumed to be at a fixed value of 2,400 USD/year.

(viii) The discount rate is 15% per year. Income tax is 10% every year.

(ix) The length of the project operation is 20 years.

RESULTS AND DISCUSSION

Engineering Perspective

The process flow diagram is shown in Fig. 1. Fig. 1(a) shows the process flow diagram of the production of La_2NiO_4 using F-G. The process was adopted from literature (Liu et al, 2016). La_2NiO_4 was synthesized by mixing $La(NO_3)_3.6H_2O$, $Ni(NO_3)_2.6H_2O$, glycine precursors, and water, having compositions of 3.03; 10.18; 3.78; 70 kg, respectively to produce 3.22 kg of La_2NiO_4 under room temperature. The formed products (a transparent green solution) were then put in the drying oven, heating at 100°C, and calcined at 500°C. Fig. 1(b) shows the process for the production of La_2NiO_4 using F-CA based on literature (Hao et al, 2018). La_2NiO_4 was synthesized by mixing $La(NO_3)_3.6H_2O$, $Ni(NO_3)_2.6H_2O$, and citric acid precursors. To produce 4.81 kg of La_2NiO_4, the process was done by mixing $La(NO_3)_3.6H_2O$, $Ni(NO_3)_2.6H_2O$, and water with compositions of 12.12; 4.07; and 210 kg, respectively, under a temperature of 60°C. The mixed solution was then added 1.58 kg of citric acid, mixed, heated to 80°C to form a gel, and calcined at 1000°C. High-temperature calcination would result in a calcined product with a relatively large surface area. The produced powder was mashed with a special mechanical powder to get finer products.

The mechanism of the synthesis reaction with F-G (see reaction (1)) and fuel F-CA (see reaction (2)) are:

$$La(NO_3)_3.6H_2O + Ni(NO_3)_2.6H_2O + \frac{65}{9}C_2H_5NO_2 \rightarrow \frac{1}{2}La_2NiO_4 + \frac{9}{2}NiO + \frac{130}{9}CO_2 + \left(36 + \frac{325}{18}\right)H_2O + \frac{13}{15}(5+9)N_2 \qquad (1)$$

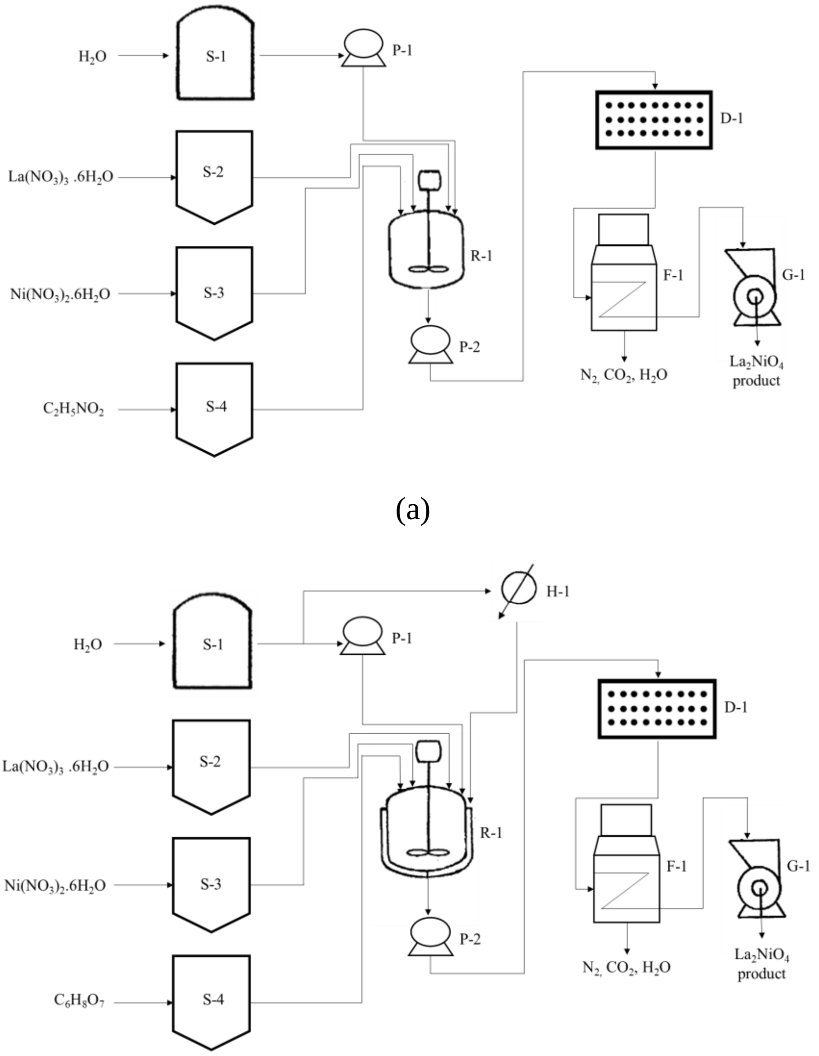
$$4La(NO_3)_3.6H_2O + 2Ni(NO_3)_2.6H_2O + 3C_6H_8O_7 \rightarrow 2La_2NiO_4 + 48H_2O + 18CO_2 + 8N_2 \qquad (2)$$

Based on the engineering evaluation, the process from the laboratory scale can be scaled up, which was implemented using commercially available and inexpensive apparatuses. As explained in the above assumptions that the largest reactor is 500 L, one cycle produced La_2NiO_4 as much as 3.22 and 4.81 kg when using F-G and F-CA, respectively. In one year, the project can produce La_2NiO_4 of 773 and 1154 kg for F-G and F-CA, respectively. By-products such as nitrogen, carbon dioxide, and water vapor were neglected and removed directly to the environment. The consumptions of reactants can be predicted:

(i) The F-G process consumed 730 kg of $La(NO_3)_3.6H_2O$, 2440 kg of $Ni(NO_3)_2.6H_2O$, and 910 kg of glycine.

(ii) The F-CA process consumed 2910 kg of $La(NO_3)_3.6H_2O$, 980 kg of $Ni(NO_3)_2.6H_2O$, and 380 kg of citric acid.

The total costs of raw materials for one year are 47,937 USD for F-G and 79,013 USD for F-CA. Sales in one year were 331,153 USD for F-G and 494,465 USD for F-CA. Then, analysis of total equipment cost was required a total cost of 90,537 USD. By adding the Lang Factor into the calculation results, TIC must be less than 401,984 USD, informing the project required less investment fund.



(a)

(b)

Fig. 1 Process flow diagram of La_2NiO_4 production using: (a) F-G and (b) F-CA. Note: S-1 = Storage-1; S-2 =Storage-2; S-3 = Storage-3; S-4 = Storage-4; P-1 = Pump-1; P-2 = Pump-2; R-1 = Reactor-1; H-1 = Heater-1; D-1 = Drying oven-1; F-1 = Furnace-1; G-1 = Grinding-1.

Evaluation Economic in Ideal Condition

Fig. 2 shows CNPV curves in the ideal condition for the production using different fuels, and the detailed comparison of the use of F-G and F-CA using the economic evaluation parameters (GPM, BEP, BEC, IRR, CNPV, ROI, and PI) is shown in Table 1. The curves were a correlation between CNPV/TIC and the project lifetime. The curves showed decreases in income at 1st and 2nd year, which were due to the consumption of initial capital costs such as the tools needed during the La_2NiO_4 production process, the land purchasing, as well as incomplete production process. In the 3rd year of the production process, the curves begun to increase with different trends in each fuel, in which this is because of difference in the cost of raw materials as well as the number of product fabricated. The costs of raw materials for F-G are more expensive than those for the F-CA. In addition, the differences in the compositions of $La(NO_3)_3.6H_2O$, $Ni(NO_3)_2.6H_2O$, and fuel affected the La_2NiO_4 product produced (see reactions (1) and (2)). La_2NiO_4 production using F-G resulted in lower quantity and quality than that using F-CA, making the F-G curve have a longer time to get the return point (zero points in the CNPV curve, known as PBP). PBP was obtained, in which it is about 7-8 years for F-G and about 4-5 years for F-CA. The return rate from the production using F-G is slower than that using F-CA, although profit can be recovered from the initial capital spent and profits continue to increase until the 20th year. Both project types can be considered as profitable projects because this project required a short time to recover investment costs (Sudaryanto et al., 2006).

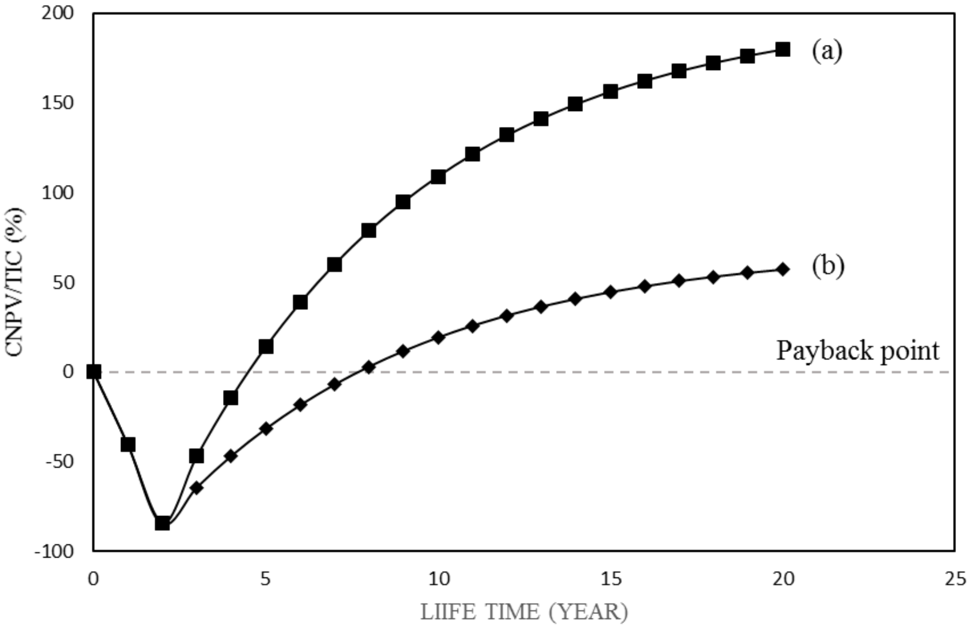


Fig. 2 Ideal condition of different fuels on La_2NiO_4 production

Table 1 The economic evaluation parameters of different fuels in an ideal condition

Economic evaluation parameters	**Fuel glycine**	**Fuel citric acid**
	Value	
GPM (IDR/pack)	256.573	252.061

PBP (years)	7.69	4.51
BEP (packs)	6.452	6.371
BEC (%)	41.74	26.87
IRR (%)	25.77	45.28
Final CNPV/TIC (%)	57.13	179.69
ROI (% per year)	2.10	3.74
Total ROI (%)	37.86	67.25
PI profit-to-sales (%)	45.96	54.67

As shown in Table 1, GPM analysis can determine profitability, which is used to calculate project efficiency in the raw materials to get products. The projects can get big profits, especially when selling products using F-CA rather than F-G process. Assuming the price of La_2NiO_4 is 21.43 USD per pack (50 g) for each fuel, GPM shows good results for project revenue with a profit of more than 50%. However, to confirm the economic feasibility, GPM must be supported other analyses that are involving various evaluation parameters and production costs.

BEP is the minimum number of products that must be sold to cover the total cost of production. BEP analysis results, as the minimum products that must be sold to cover the total cost of production, showed that La_2NiO_4 production must be able to sell 6,000-6,500 packs per year. In this ideal condition, the number of products ready for sale is 15,454 packs per year for F-G and 23,075 packs per year for F-CA. This means that 41.75% of the products available (15,454 packs) and 26.87% of the products available (23,075 packs) must be sold for products with F-G and F-CA. Comparing the BEC, the minimum percentage of products compared to products produced per year, this project is relatively good.

IRR values, as the indicator of the level of investment efficiency, were 25.77 and 45.28% for products with F-G and F-CA for 20 years in the ideal condition, respectively. This value calculation gives a very low rate for each year, which is only 1-2%. This value is not promising, creating a conflict with local Indonesian bank interest (which is 5-6%)

(Nandiyanto, 2018).

The final CNPV/TIC analysis resulted in the fact that the process using F-CA is more prospective than that using F-G. The final CNPV/TIC value using F-CA is higher (around 179%) than that using F-G (around 57%).

ROI analysis yielded a value of around 2-4%, showing negative results since it implies that investing funds of 100 USD generates an additional benefit of 2-4 USD. Indeed, this profit is relatively unattractive, compared to the bank's interest and capital market. The local capital market in Indonesia should be at least 10% of profit per year, in which 2.50% of it was usually for social responsibility or charity (known as zakat) (Nandiyanto, 2018).

PI values are used as a way to identify the relationship between project cost and impact. The profit-to-sales PI values for F-G and F-CA were 45.96 and 54.67%, respectively. The profit-to-TIC PI values for F-G and F-CA were 37.86 and 67.25%, respectively. The product with F-CA shows the best result to create a good impact on the project compared to that with F-G. The results indicated that the project is a quite perspective based on sales and investment cost.

Although engineering results showed that the project is quite prospective, it is not interesting from economic analysis for Indonesian industrial investors. Other perspectives must be considered and negative economic evaluation parameters need to be further improved.

CONCLUSION

Feasibility analysis for the production of La_2NiO_4 is successfully done and presented in this report. This study compared the use of F-G and F-CA in the production. The engineering analysis showed that both processes can be done even in the small-scale production. The economic analysis showed that the process using F-CA is better than that using F-G. From this economic evaluation analysis, this project is feasible to run and profitable, but it is not attractive to industrial investors due to the fewer values in some parameters. Thus, additional further technologies for improving processes and support from Corporate Social Responsibility (CSR) and government are important for maintaining this project.

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