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Techno-economic Analysis on the Production of Zinc Sulfide Nanoparticles by Microwave Irradiation Method

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ABSTRACT

Zinc sulfide is a semiconductor that is widely used in various fields. Synthesis of zinc sulfide nanoparticles by microwave irradiation method has promising prospects because of its advantages, such as commercially available precursors, short reaction times, low operating temperatures, and produced high quantity and high-quality products. The purpose of this study was to evaluate the feasibility of the production of zinc sulfide from zinc nitrate hexahydrate and thioacetamide by microwave irradiation method. The evaluation was done from the engineering and economic perspectives. The feasibility analysis method from the engineering perspective was done by designing the initial production design on a large scale, whereas the analysis from an economic perspective was done by calculating various economic parameters (i.e., Gross Profit Margin, Cumulative Net Present Value, Internal Rate Return, Payback Period, Break Event Point, and Profitability Index). The engineering perspective showed that the production of zinc sulfide nanoparticles can be done on a large scale due to the commercial availability of materials and tools. Based on the economic evaluation, this project is ideal for an industrial scale. The profits increased over 20 years and the payback period was achieved within two years. We hope this study can provide references to readers, industry, and researchers regarding the feasibility analysis of the production of zinc sulfide nanoparticles by microwave irradiation method on a large scale.

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1. INTRODUCTION

The utilization of semiconductor nanostructures has attracted a lot of interest, especially its application as optoelectric materials (Saenger *et al.*, 1998). Zinc sulfide is the first semiconductor nanostructure to be discovered and widely used in various fields such as for optical devices, sensors, and the environment (Fang *et al.*, 2011; Jiang *et al., 2007)*. Applications of zinc sulfide can also be found in light-emitting diodes (Ma *et al.*, 2011), electroluminescence (Krysthab *et al.*, 2009), flat panel solar cells (Lin *et al.*, 2014), infrared windows, sensors (Mehta and Umar, 2011), wastewater treatment (Maji *et al.*, 2011), photocatalysis, and biological sensors (Xue *et al.*, 2011).

Zinc sulfide has two allotropes, namely zinc blende (sphalerite) and wurtzite with a cube structure. It has high stability at low temperatures and forms polymorphs at 1296K (Yeh *et al.*, 1992). Zinc sulfide was found to be more thermodynamically stable in the form of cubic sphalerite (Schaefer and Gokeen, 1982). Sphalerite is a metallic mineral that can be found in the earth because of the inactive hydrothermal system (Hedenquist *et al.*, 2000). Madi conducted the mineral analysis of eight samples from Maluku Utara, Indonesia. As a result, there are several types of metallic minerals shown in **Table 1** (Madi, 2020).

Table 1. Results of the mineral analysis. The research was taken with eight samples from Maluku Utara, Indonesia. This table was adopted from Madi, 2020.

Sample Number	Mineral Quantity			
	Pyrite	Chalcopyrite	Sphalerite	Magnetite
1	-	-	-	Abundant
2	Abundant	-	Medium	-
3	-	Abundant	Medium	-
4	Abundant	-	-	-
5	-	-	-	Abundant
6	-	-	-	Abundant
7	Abundant	-	Abundant	-
8	Abundant	-	-	-

Sphalerite contains several elements such as zinc and sulfur. **Table 2** provides the information on sphalerite composition.

Table 2. Sphalerite Composition. This table adopted from Benedetto *et al.*, 2020.

Element	Quantity (%)
Zinc (Zn)	32.49
Sulfur (S)	64.00
Iron (Fe)	0.29
Manganese (Mn)	1.34
Cadmium (Cd)	0.35
Other elements	1.53

The continuous use of sphalerite can cause its amount to be depleted, so a promising method for the production of zinc sulfide from sphalerite is needed. There are various methods for the production of zinc sulfide, namely hydrothermal, sonochemical, spray pyrolysis, sol-gel, precipitation reaction, and microwave irradiation. The microwave irradiation method is considered more proper than other methods. This is motivated by the interaction of microwaves with reactants at the molecular level. Electromagnetic energy is transferred and turned into heat by rapid kinetic collisions between molecules, thus caused an explosion followed by the evolution of gases to form nanostructures (Abraham *et al.*, 2016). The microwave irradiation method uses commercially available precursors, short reaction times with low operating temperatures, produced products with high quantity and purity (Roy *et al.*, 2008), is environmentally friendly, and reduces the risk during the production process (Savalia *et al.*, 2013).

The zinc source from sphalerite can be made into salt such as zinc chloride which is reacted with thiourea to obtain ZnS (Rashad *et al.*, 2010). Several studies have reported the successful processes in the production of zinc sulfide nanoparticles (Sabaghi *et al.*, 2018; Salavati-Niasari *et al.*, 2012; Soltani *et al.*, 2012; Zhu *et al.*, 2000). Although reports have been well documented (Sabaghi *et al.*, 2018), the production of zinc sulfide nanoparticles is only presented on the laboratory scale. Meanwhile, the production of zinc sulfide nanoparticles has the opportunity to be carried out on a large or industrial scale (Roy *et al.*, 2008).

This research was conducted to evaluate the feasibility of the production of zinc sulfide from zinc nitrate hexahydrate and thioacetamide by microwave irradiation method on an industrial scale. The evaluation was done from an engineering and economic perspective. The feasibility analysis from the engineering perspective was done by stoichiometric calculations and designing the initial production on a large scale, while the analysis from an economic perspective was done by calculating various economic parameters, namely Gross Profit Margin, Cumulative Net Present Value, Internal Rate Return, Payback Period, Break Event Point, and Profitability Index.

The schematic process on the production of ZnS nanoparticles using the microwave irradiation method is shown in **Figure 1**.

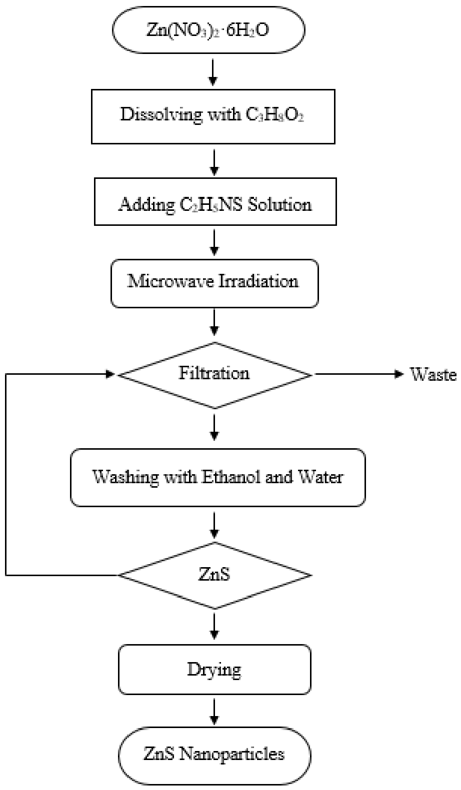

Figure 1. A schematic process on the production of ZnS nanoparticles.

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2. METHOD

This study examines the synthesis of ZnS nanoparticles using the microwave irradiation method from the engineering perspective and the economic evaluation. We performed the analysis with zinc nitrate hexahydrate as the zinc source and thioacetamide as the sulfur source. The engineering perspective was done to evaluate the production of ZnS nanoparticles by microwave irradiation method on a large scale and its production simulated by commercially available tools. The precursors used in the production of zinc sulfide nanoparticles are zinc nitrate hexahydrate, ethylene glycol, and thioacetamide which are analytical grade reagents with high purity (Salavati-Niasari *et al*., 2009).

The economic evaluation was done with several assumptions regarding equipment specifications, raw material prices, and equipment maintenance costs adopted from online stores. These data are used as a reference for economic feasibility analysis. The parameters used in the economic evaluation are Gross Profit Margin, Cumulative Net Present Value, Internal Rate Return, Payback Period, Break Event Point, and Profitability Index (Nandiyanto *et al*., 2020).

- Gross Profit Margin (GPM) is profit calculated from the ratio of gross profit to net sales.
- Cumulative Net Present Value (CNPV) is a value to predict the condition of the production of a product as a function within one year. CNVP is calculated from the Net Present Value (NPV) at any given time. NVP is the cash value of a business, including expenses and income.
- Internal Rate Return (IRR) is a method that calculates the interest rate of an investment and then equating it with the current investment value based on the calculation of net cash in the future. IRR is calculated to determine the level of efficiency of an investment.
- Payback period (PBP) is calculated to determine the period required to return capital through profits. PBP is calculated when the CNPV reaches zero.
- Break-Even Point (BEP) is the point when income equals capital. In that case, there is no gain or loss. BEV is calculated by dividing capital by profit.
- The profitability index (PI) is the estimation result by dividing CNPV by sales (PI for sales) or total investment cost (PI for investment).

The economic evaluation was done with the following assumptions:

- Analysis in US Dollars ($1 = Rp14.500).
- Based on commercially available prices, the prices for zinc nitrate hexahydrate are 0.8 USD/kg, thioacetamide 256 USD/kg, and propylene glycol 4.49 USD/liter.
- The total investment cost (TIC) was calculated based on the Lang Factor.
- It is estimated that one day can produce one cycle.
- Shipping costs are borne by the buyer.
- Production in a year includes 264 working days and the remaining days are used for tool maintenance.
- Utilities are described in units of electricity such as kWh, so the units of electricity are assumed to be costs. Utility costs are assumed to be 0.1 USD/kWh.
- Synthesis of ZnS nanoparticles is estimated to take place every day.
- The selling price of ZnS nanoparticles is 55 USD/150 g.
- The workforce is assumed to be 15 people with a salary per person of 6.9 USD/day.
- Discount rate 15% per year.
- The annual income tax rate is 10%.
- The project operation duration is 20 years.

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The economic evaluation was conducted to test the feasibility of the project. This economic evaluation is carried out by varying the value of taxes by 10, 30, 50, 70, and 100%, sales variations by -100, -50, 0, 50, 100, 150, 200%, labor and utilities at 50, 75, 100, 125, 150, 175, 200, and 500 %. While the variation of raw materials using variations of 50, 75, 100, 125, 150, 175, and 200%.

3. RESULTS AND DISCUSSION

3.1. Engineering Perspective

The production process of ZnS nanoparticles by microwave irradiation method uses zinc nitrate hexahydrate as a zinc source and thioacetamide as a sulfur source. 0.01 mole of zinc nitrate hexahydrate ($Zn(NO_3)_2 \bullet 6H_2O$) mixed with propylene glycol ($C_3H_8O_2$). Then, a solution of thioacetamide (C_2H_5NS) was added into the solution, drop by drop for 10 minutes (Sabaghi *et al*., 2018). After that, the solution was exposed to irradiation in a microwave oven with a working cycle of 50 seconds on and 100 seconds off at 50°C. After the reaction was completed, the mixture cooled slowly until reached room temperature. The precipitate was filtered and washed with deionized water (5 × 50 ml) and absolute ethanol (3 × 10 ml). Then, the precipitate dried in the oven at vacuum and room temperature for 7 hours (Salavati-Niasari *et al*., 2012). Heating and radiation in the microwave oven make thioacetamide produce methane and react with H from water to form H_2S molecules. The water molecules in zinc nitrate hexahydrate will be released when in the microwave oven. Heat and radiation exposure also cause zinc nitrate to break down into its ions. Zn^{2+} ions from zinc nitrate hexahydrate bind to S^{2-} from H_2S to form ZnS precipitates (Prabowo, 2019). The reactions that occur in this process are shown in **Figure 2**.

$$C_2H_5NS \longrightarrow CH_2NS + CH_3$$

$$2H + S \longrightarrow H_2S$$

$$Zn(NO_3)_2 \longrightarrow Zn^{2+} + 2NO_3^-$$

$$Zn^{2+} + 2NO_3^- + H_2S \longrightarrow ZnS + 2HNO_3$$

Figure 2. Reaction in production of ZnS nanoparticles. Adopted from Sabah *et al*., 2015.

The process flow diagram of the production of ZnS nanoparticles by the microwave irradiation method is shown in **Figure 3**. In one cycle on a laboratory scale, 0.97 g ZnS nanoparticles were produced from 10 mL thioacetamide, 25 mL propylene glycol, and 2.97 g zinc nitrate hexahydrate. On an industrial scale, it is assumed that the amount of production in one day is 200 kg. The production process of 200 kg of ZnS nanoparticles requires 612.4 kg of zinc nitrate hexahydrate; 2,061.86 liters of thioacetamide solution; 6,185 liters of propylene glycol; 53,608.3 liters of water; and 6,815.6 liters of ethanol. The side products of this project are methanol and nitric acid. Side products are not used.

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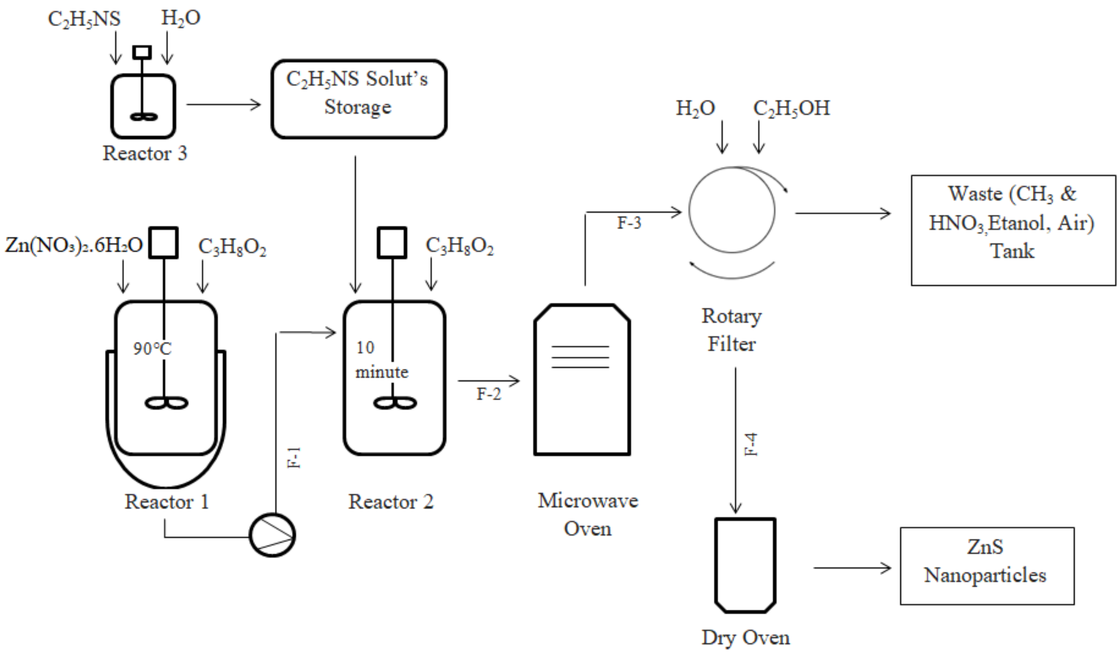

Figure 3. Process flow diagram of zinc sulfide nanoparticles fabrication.

From an engineering perspective, the project produces 52,800 kg of ZnS nanoparticles in a year by consuming 161.67 tons of zinc nitrate hexahydrate; 45,361 liters of thioacetamide solution; 1,632,990 liters of propylene glycol; 14,152,578 liters of water; and 1,632,990 liters of ethanol for washing per year under ideal conditions. The total cost to be paid for raw materials for a year is 10,958,498.69 USD. While sales in one year are 19,369,680.00 USD. The profit earned in one year is 7,004,965.54 USD or equivalent to 36%. The Lang Factor added to the calculation indicates the TIC must be less than 37,156.65 USD. The value of this investment is relatively economical, so less investment is needed. The project life span is 20 years, yielding 1,056 tons of ZnS nanoparticles. The economic parameter in this project has a CNPV/TIC up to 27,73 in the 20th year; PBP achieved in the 2nd year; GPM each year of 8,411,181.31 USD; BEP up to 285,52 packages; IRR up to 28,81%; PI to sales up to 0.36%; and PI to investment up to 188,53%.

3.2 Ideal Condition

The engineering perspective shows that this project is profitable. In the economic evaluation, it is necessary to have ideal conditions, so it can be used as a benchmark for this project. Ideal conditions were analyzed from the graph between CNPV/TIC against time. The relationship between CNPV/TIC and time is shown in **Figure 4**. The y-axis is CNPV/TIC and the x-axis is a lifetime (years). This graph shows that there is a decrease in income during the first year, due to the initial capital cost. While in the second year, the graph shows an increase in income. This condition is called the Payback Period (PBP) which shows that the initial capital has been covered with the profits. The PBP that is achieved in only a short time and the income that tends to increase until the 20th year indicates the project will be profitable.

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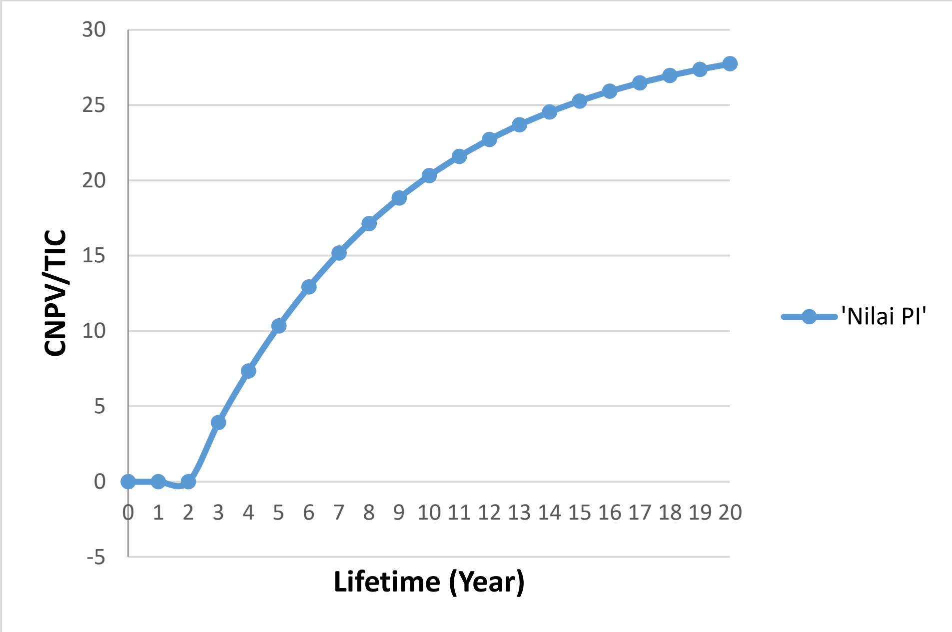

Figure 4. Ideal conditions for CNPV/TIC to a lifetime (years).

3.3 Effect of External Condition

A project can be influenced by several factors, one of them is external factors. The external condition of the country or the place where the business is conducted is a very important factor; one of the parameters is taxes. Taxes are important because they can affect a project. Taxes that are too high will make a project suffer losses. CNPV graph with various tax variations is shown in **Figure 5**. The y-axis is CNPV/TIC and the x-axis is a lifetime (years). In **Figure 5**, the initial conditions of various tax variations with the same CNPV/TIC value have decreased. Meanwhile, from the 2nd year to the 20th year, CNPV/TIC various tax variations have changed. The detailed tax variations of 10, 30, 50, 70, and 100% with CNPV/TIC prices are listed in **Table 3**.

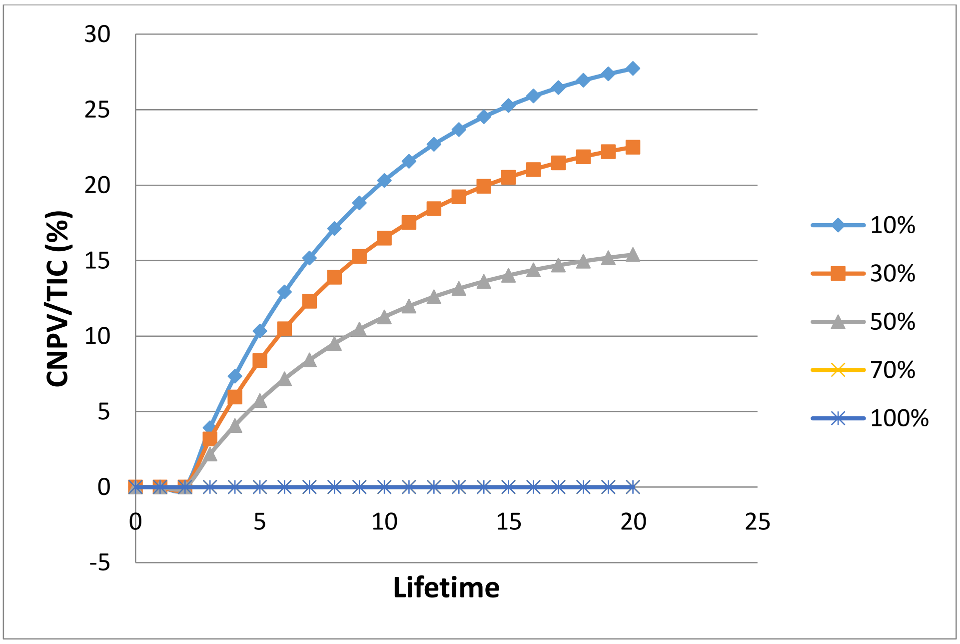

Figure 5. CNPV/TIC various tax variations on lifetime (years).

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Table 3. CNPV/TIC value with tax variations

Tax Variation	CNPV/TIC
10%	28.95510858
30%	22.51871516
50%	16.08232174
70%	9.645928316
100%	-0.00866182

Based on the results of the PBP analysis, various tax variations, namely 10, 30, 50, 70, and 100% can cover the capital in the second year. These various tax variations increase in income after going through the 2nd year, only the difference in the profit margins obtained. However, for 100% tax, there is no increase in income but rather a loss in the 20th year. This can be seen from the CNPV/TIC in the 20th year which has a negative value, meaning that it suffers a loss. **Figure 5** also shows the maximum tax for obtaining a BEP is 70%. The project can be carried out with a tax of less than 70%. If more, it will be a loss.

3.4 Sales Change

Sales is a very important factor in a project. The results showed that the increase in selling prices had a positive impact on profits (Yang, 2015). The influence of sales can be analyzed by Profitability Index (PI). The PI analysis is shown in **Figures 6** and **7**.

The analysis shows that higher sales allow more profit to be achieved. Based on the results of profitability analysis, in general, this study finds that the project fails if sales are less than 0% of the initial estimated condition. This is because the profit for the product sales less than 0%, the sales graph shows a reduction. **Figure 6** shows that the smaller number workforce will increase profits and vice versa, the more workers add, the more profits will be reduced.

The analysis was also carried out on investment profits. the graph in **Figure 7** shows the investment limit is when it decreases by 25%.

3.5 Variable Cost Changes (Raw materials, Utilities and Labor)

Variable costs consisting of raw materials, utilities, and labor can affect a project. **Figure 7** shows a graph of CNPV/TIC in percent (%) against lifetime in years. The analysis was carried out using the initial conditions, reducing the number of raw materials with variations of 50% and 75% with the results showing an increase in CNPV/TIC from the initial conditions when the raw materials were lowered. Meanwhile, when the amount of raw materials is increased with variations of 125, 150, 175, and 200%, there is an indication that the CNPV/TIC yield decreases from the initial condition when the raw material was increased.

PBP analysis of the results of this variation of raw materials shows the initial conditions until the 2nd year to achieve a return on capital. This condition is experienced by all variations in the number of raw materials.

After passing the 2nd year, all variations in the number of raw materials experienced an increase in CNPV/TIC. The difference is the CNPV/TIC distance each year. The larger the raw material, the less the project benefits from the ideal state, and vice versa, if there are fewer

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raw materials, the project's profits will increase (Astuty *et al*., 2020). Based on the variety of raw materials, this project is feasible with an increase in the number of raw materials by no more than 100%.

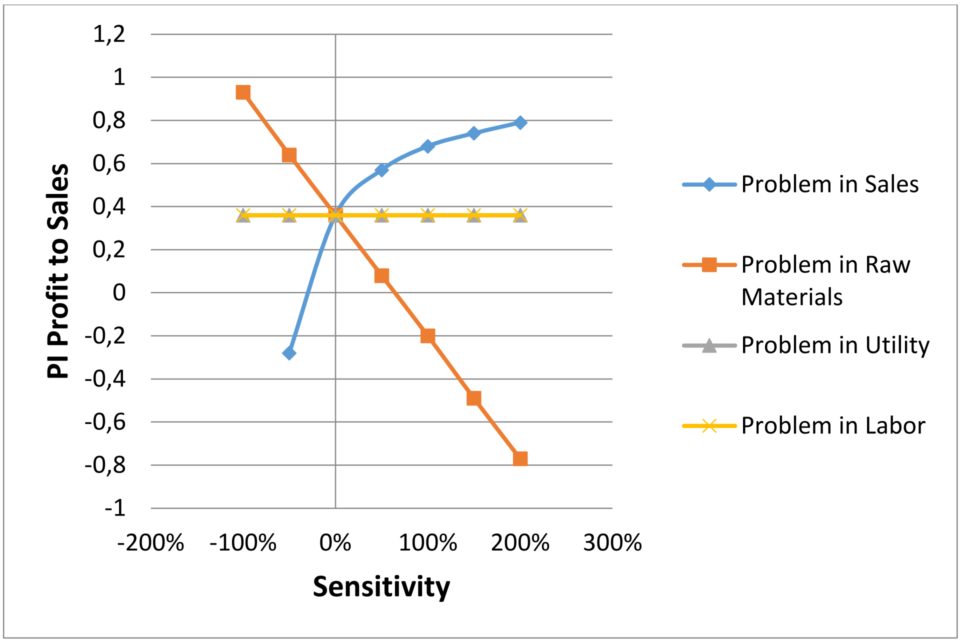

Figure 6. Effect of sales on sales profits.

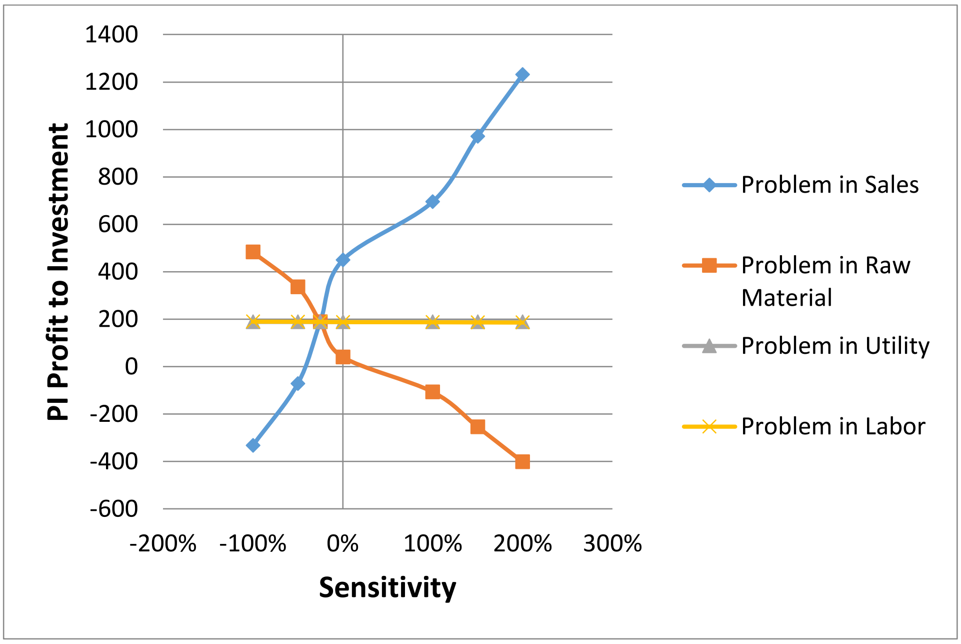

Figure 7. Effect of sales on investment profits.

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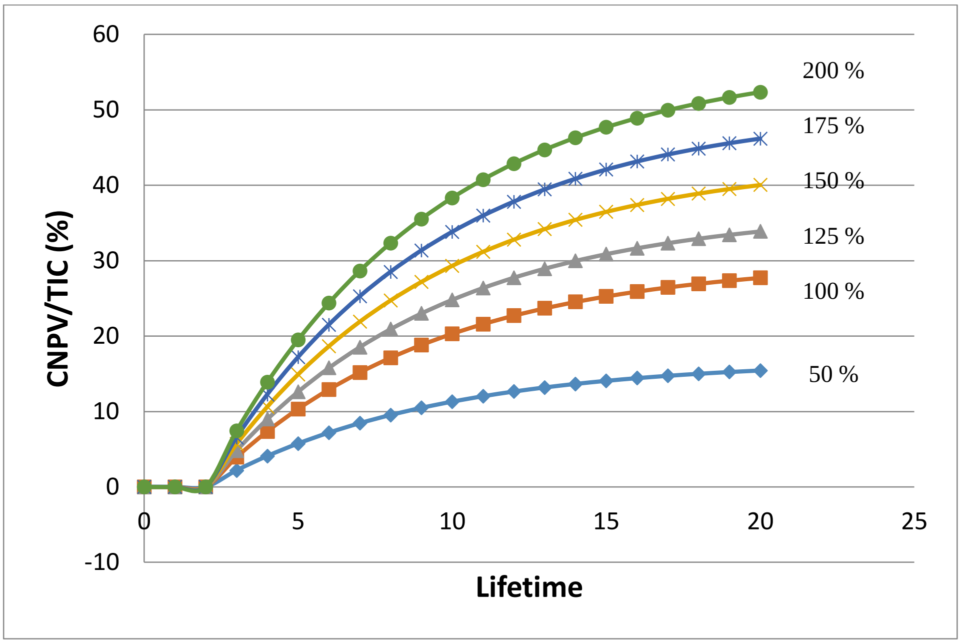

Figure 8. The effect of variations in raw materials on CNPV/TIC in 20 years lifetime.

Another variable cost is utility. The graph of the utility effect is shown in **Figure 9**. This graph consists of CNPV/TIC on the y-axis and lifetime on the x-axis. The analysis was carried out using the initial conditions, reducing the amount of utility by 50%. The results show that there is no significant increase in CNPV/TIC from the initial condition when the utility is lowered. Meanwhile, when the number of utilities with variations of 125, 150, 175, 200, and 500%, the results of CNPV/TIC did not get a significant decrease from the initial condition when the utility was increased. In the initial condition, PBP reached in the 2nd year, then all utility variations increase in CNPV/TIC. However, the effect of utility on CNPV/TIC did not change significantly. CNPV/TIC in year 20th for utility variations of 50, 100, 125, 150, 175, 200, and 500% respectively are 27.734; 27.734; 27.734; 27.735; 27.735; 27.735; and 27.737. Based on the utility that does not significantly affect the CNPV/TIC, this project is considered to be profitable.

Another variable cost is labor. The graph of the effect of labor is shown in **Figure 10**. The y-axis is the CNPV/TIC value and the x-axis is the lifetime (years). The analysis was carried out using the initial conditions, reducing the number of workers by 50%. The results showed that there was no significant increase in CNPV/TIC from the initial condition when the workforce was reduced. Meanwhile, when the number of utilities with variations of 125, 150, 175, 200, and 500%, CNPV/TIC did not decrease significantly from the initial condition when the workforce was increased. In the initial conditions, PBP reached in the second year. Then, all variations of the workforce increase in CNPV/TIC. However, the effect of labor on CNPV/TIC did not change significantly with CNPV/TIC in the 20th year for variations in labor that 50, 100, 125, 150, 175, 200, and 500 % are 27.68; 27.73; 27.76; 27.78; 27.80; 27.84; and 28.14, respectively. Based on labor that does not significantly affect CNPV/TIC, this project is considered to be profitable.

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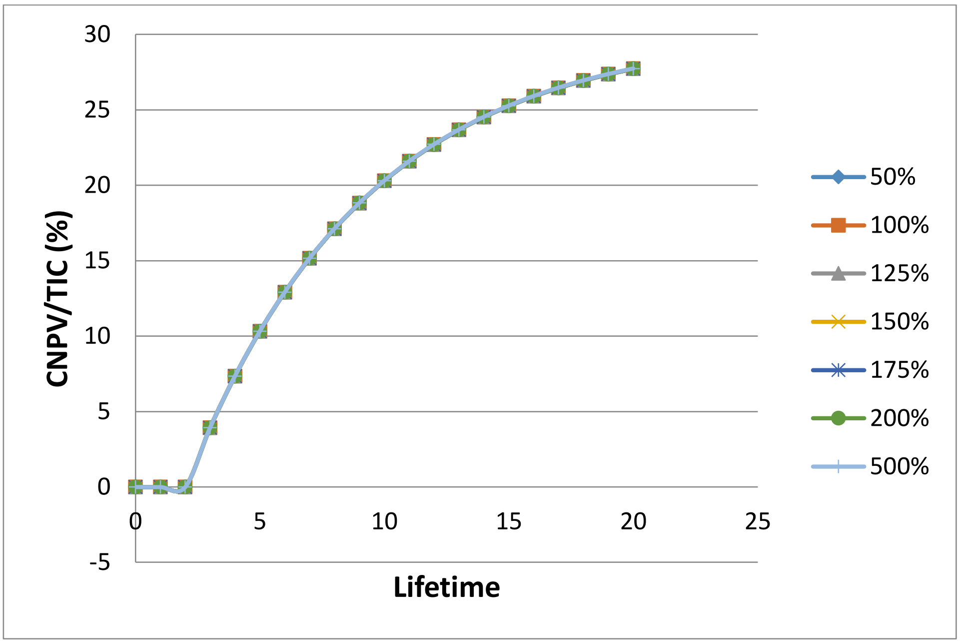

Figure 9. The effect of utility on CNPV/TIC in 20 years lifetime.

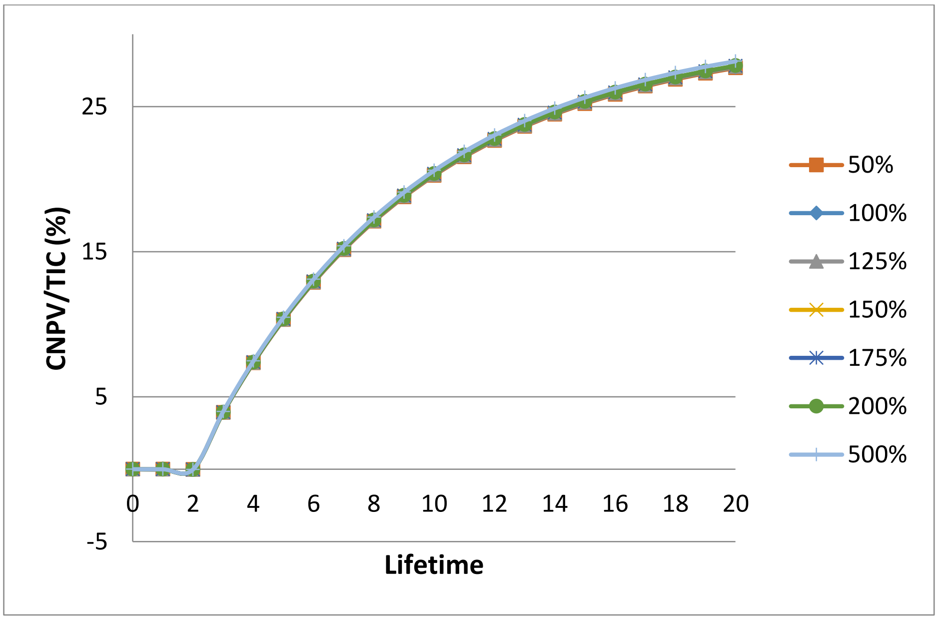

Figure 10. The effect of the number of workers on CNPV/TIC in 20 years lifetime.

Based on the above analysis, this project is ideal to be carried out on an industrial scale. This project has increased profits over 20 years and it only takes 2 years to recover investment costs since PBP in the second year. The changes that may occur do not make this project suffer the losses that make this project fail. The explanation of the specific conditions are listed below:

1) Taxes can affect project profits. The maximum tax for this project is 70%. So the tax should be estimated at no more than 70%.
2) Sales are maintained at not less than 0% of products sold.
3) Changes in raw materials with variations of 50, 75, 100, 125, 150, 175, and 200% affect the profit range each year. Larger raw materials will decrease in profits, and vice versa.

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4) Changes in utility with variations of 50, 75, 100, 125, 150, 175, 200, and 500% did not significantly affect the profitability of this project. This is because utility costs are only 0.0018% of sales.
5) Changes in labor costs with variations of 50, 75, 100, 125, 150, 175, 200, and 500% did not significantly affect the profit of this project. This is because labor costs are only 0.14% of profits.

4. CONCLUSION

The results of the feasibility analysis in the production of zinc sulfide nanoparticles by microwave irradiation method from an engineering perspective indicate that production can be carried out on a large scale with commercially available materials and equipment. Economic evaluation with parameters Gross Profit Margin, Cumulative Net Present Value, Internal Rate Return, Payback Period, Break Event Point, and Profitability Index shows that the project has a promising profit and potential to be carried out in a long period. Changes in utility and labor costs do not affect profits significantly, while tax rates, sales, and changes in raw materials can affect profits. This project can be carried out with initial capital or raise investors for the sustainability of the industry.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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