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Techno-economic Analysis on the Production of Zinc Sulfide Nanoparticles by Precipitation Assisted Ultrasonic Radiation Method

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Abstract. Zinc sulfide is a material that has many uses in various fields. Zinc sulfide is deriving from the mineral sphalerite. The purpose of this study was to evaluate the feasibility of producing zinc sulfide from zinc acetate and sodium sulfide using the precipitation-assisted ultrasonic radiation method. This method is the most efficient method for the synthesis of zinc sulfide nanoparticles, because it does not take much time and the resulting product is high. 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, that is 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, the production of zinc sulfide nanoparticles by precipitation-assisted ultrasonic method is ideal for an industrial scale. Earned increased profits over 20 years, the payback on investment costs lasted only two years. We hope that this study can provide references to readers, industry, and researchers regarding the feasibility analysis of the production of zinc sulfide nanoparticles using the precipitation-assisted ultrasonic radiation method.

1. Introduction

Zinc sulfide is an important inorganic material for light-emitting applications. Zinc Sulfide is doped with various transition metal ions such as manganese. This combination is an efficient material to be used as a light-emitting material [1]. Applications of zinc sulfide can also be found in light-emitting diode [2], electroluminescence [3], flat panel solar cells [4], infrared windows, sensors [5], wastewater treatment [6], photocatalysis, and biological sensors [7]. Zinc sulfide consists of two allotropes, that is sphalerite and wurtzite. [8]. Zinc sulfide in the form of cube sphalerite has high thermodynamic stability [9]. Sphalerite can be found from the inactive hydrothermal system in the earth [10]. Table 1 shown the information on sphalerite composition.

Tabel 1. Sphalerite Composition. This table adopted from reference [11].

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 it's amount to be depleted, so an efficient zinc sulfide synthesis method is needed. Synthesis of zinc sulfide nanoparticles has several methods including, one-pot process, sol-gel, hydrothermal, coprecipitation, microwave irradiation, and ultrasonic radiation. In a previous study, the synthesis of zinc sulfide nanoparticles was done by precipitation method. This precipitation method is a method that is simple, inexpensive, and produces a large number of products. However, the precipitation process has a weakness. It is take a long time to manufacture the products [12]. So we need a method that has a short time and has quite high product, namely the ultrasonic radiation method.

This ultrasonic radiation method is better to use than other traditional methods because the reaction in this method gets higher yields, shorter reaction times, and lighter conditions under ultrasonic radiation [13]. The use of ultrasonic irradiation (USI) for the production of nanomaterials has become a very interesting research topic. This is due to the simplicity of the chemical method, the low cost of the equipment, and in most cases the material obtained in the crystalline phase. The chemical effect of USI comes from non-linear acoustic phenomena, especially the acoustic cavity which is divided into three different stages namely formation, growth, and bursting of bubbles [14]. The advantages of this method are, it does not take much time because of the large temperature, pressure, and extreme cooling. The resulting product was also high [15].

This research was conducted to evaluate the feasibility on the production of zinc sulfide from zinc acetate and sodium sulfide by precipitation-assisted ultrasonic radiation method on an industrial scale. The evaluation was done from an engineering and economic perspective. The feasibility analysis from an 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.

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There are several steps on the production of ZnS nanoparticles using the precipitation-assisted ultrasonic radiation method shown in (See Figure 1).

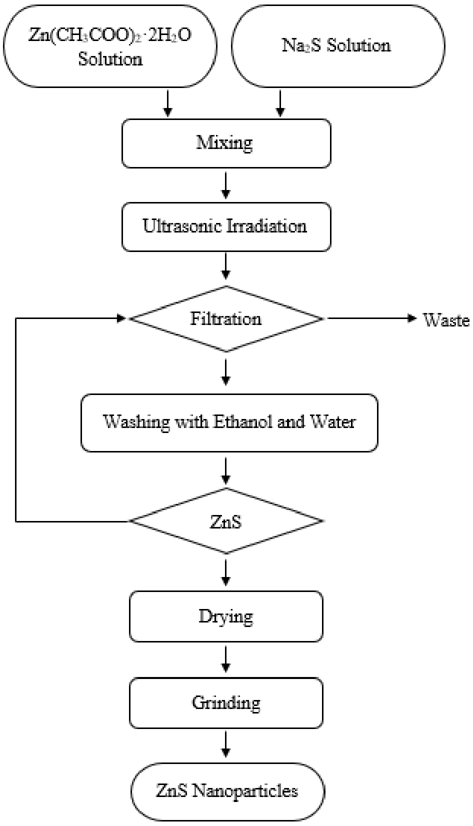

Figure 1. Schematic process on the production of ZnS nanoparticles

2. Method

This research aims to study the synthesis of ZnS nanoparticles using the precipitation-assisted ultrasonic radiation method from the engineering and economic perspective. The analysis was carried out using sodium sulfide (Na_2S) as a source of sulfur and zinc acetate dihydrate [$(CH_3COO)_2Zn.2H_2O$] as a source of zinc. The evaluation was carried out in a large-scale production simulation with commercially available tools [16].

In determining the economic evaluation, several assumptions regarding the specifications of the equipment, the cost of maintaining the equipment, and the price of the materials used. All price assumptions are adopted from online stores. The reference used in the economic feasibility analysis is adopted from these data. In conducting an economic evaluation, appropriate parameters are needed, such as Gross Profit Margin, Cumulative Net Present Value, Internal Rate Return, Payback Period, Break Event Point, and Profitability Index [17].

- Gross Profit Margin (GPM) is profit calculated from the ratio of gross to net sales.
- Cumulative Net Percent Value (CNPV) is a value to predict the condition of the production as a function within one year. The CNVP value is calculated from the Net Percent Value (NPV) at any given time. NVP is the cash value of the business, including expenses and income.
- Internal Rate Return (IRR) is a method used to calculates the interest rate of an investment then equating it with the current investment value based on the calculation of net cash in the future. The purpose of calculating the IRR is to determine the level of efficiency of an investment.

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- 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. There is no profit or loss when BEP was reach. BEP is known for dividing capital by profit.
- Profitability Index (PI), the estimated result known when dividing CNPV by sales (PI for sales) or total investment cost (PI required for investment).

The economic evaluation was done to test the feasibility of the project. This is done by applying variations in tax values of 10, 25, 50, 75, and 100%, sales variations of -100, -50, 0, 50, 100, 150, and 200%. Variations applied to labor and utilities are 50, 100, 125, 150, 175, 200, and 500%. Meanwhile, the variation of raw materials applied is 50, 100, 125, 150, 175, and 200%.

3. Results and Discussion

3.1 Engineering Perspective

In this study, the production of zinc sulfide nanoparticles was done by precipitation-assisted ultrasonic radiation method. The materials used are zinc acetate dihydrate as a zinc source, sodium sulfide as a sulfur source, and water as a solvent. The washing process use some water and ethanol. In the precipitation step, zinc acetate dihydrate solid and sodium sulfide solid are dissolved in water, respectively. Next, the zinc acetate dihydrate solution and the sodium sulfide solution were mixed until a white precipitate was formed in the solution [16]. The solution was then exposed to ultrasonic radiation (90°C) for 2 hours and cooled until reached room temperature. Subsequently, it washes with distilled water and ethanol to clean the unreacted sodium sulfide. The solid obtained was then dried in an oven for 7 hours and milled to obtain zinc sulfide nanoparticles [18]. The production of zinc sulfide nanoparticles on a large scale is formed in several processes (See Figure 2).

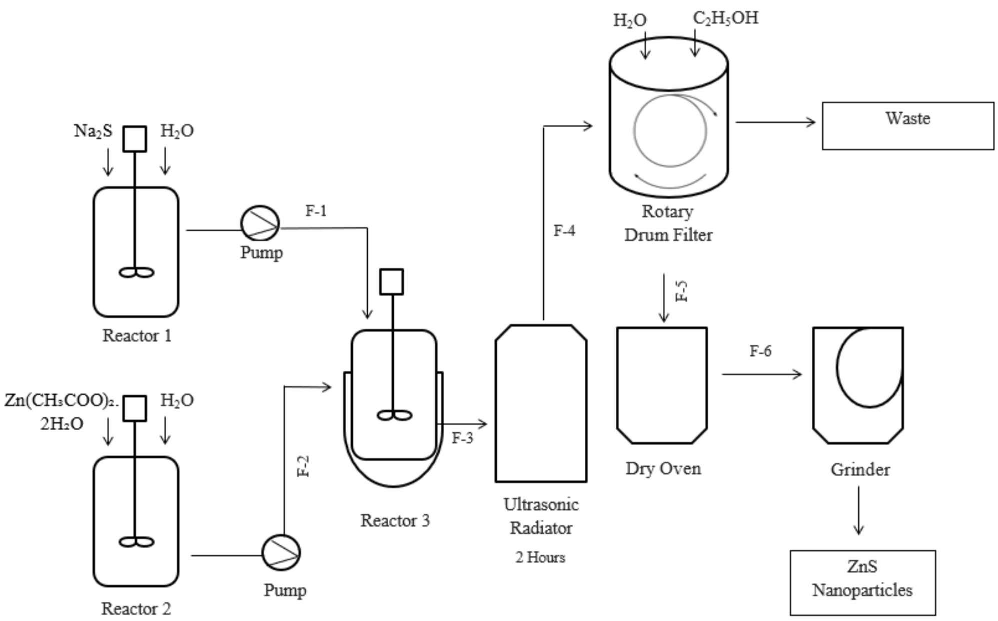

Figure 2. Process flow diagram on the production of zinc sulfide nanoparticles.

Production of ZnS nanoparticles on a laboratory scale requires 12.331 g Na_2S; 17.56 g $Zn(CH_3COO)_2 \cdot 2H_2O$; 200 mL H_2O, and 8 mL ethanol. In large scale production, it is assumed that the amount of raw material needed to make 400 kg/day of ZnS is shown in Table 2.

Table 2. Composition of Raw Materials and Zinc Sulfide Yielded

Raw Material	Quantity	Result	Quantity (kg)
Na_2S	635,62 kg	ZnS	400
$Zn(CH_3COO)_2 \cdot 2H_2O$	905,16 kg		
H_2O	10.309,28 L		
C_2H_5OH	150 L		

Based on the assumption, 105.600 tons of zinc sulfide nanoparticles are produced in one year (264 working days). The production process consumes 167.804 tons of Na_2S; 238.962 tons $Zn(CH_3COO)_2 \cdot 2H_2O$; 2,721,649.92 L H_2O; and 39,600 L C_2H_5OH in a year.

3.2 Economic Evaluation

Economic evaluation was done based on various economic parameters such as Gross Profit Margin, Internal Rate Return, Break Event Point, Payback Period, Cumulative Net Present Value, and Profitability Index. The following assumptions are used as a reference in conducting economic evaluations:

- The analysis is carried out in US Dollars ($1 = Rp14,500).
- Material prices are based on prices listed on web online shops, such as Alibaba, Tokopedia, and Shopee. The price of sodium sulfide is 17.24 USD/kg, zinc acetate dihydrate 20 USD/kg, and ethanol 1.28 USD/L.
- Stoichiometric calculations were carried out to design the production of zinc sulfide nanoparticles on a large scale.
- Utility costs are calculated based on kWh electricity units assuming 0.1 USD/kWh.
- The cost of water as a solvent is assumed to be 0 USD because the project location is close to a water source.
- Zinc sulfide nanoparticles are priced at 25 USD/200 g.
- The cost of shipping the product is borne by the buyer.
- The discount rate is 15%/year while the annual income tax rate is 10%.
- The Lang factor used to analyze the total investment cost is shown in Table 3.
- Manufacturing costs are predicted from the start of the project. Factors for predicting manufacturing costs are shown in Table 4.
- The production of zinc sulfide nanoparticles is estimated that one day can complete one cycle. The processing time is 10 hours.
- One year there are 264 working days and the remaining days are used for equipment maintenance.
- The number of workers is assumed to be 20 people with a salary of 7 USD/day for a person.
- The project operates for 20 years.

Table 3. Lang Factor in Total Investment Cost Analysis.

Component	Factor
Purchased Equipment	1
Piping	0,5
Electrical	0,1
Instrumentation	0,2
Utilities	0,5
Foundations	0,1
Insulations	0,06
Painting, fireprofing, safety	0,05
Yard Improvement	0,08
Environmental	0,2
Building	0,08
Land	0,5
Contructions, engineering	0,6
Contractors fee	0,3
Contingency	0,2

Table 4. Factors for Manufacturing Cost Estimation.

Labor related cost	Factor	
a. Payroll overhead	30%	of labor
b. Supervisory, misc. labor	25%	of labor
c. Laboratory charges	12%	of labor
Capital related cost		
a. maintenance	6%	of (TPC-land)
b. Operating supplies	1,75%	of (TPC-land)
c. Enviromental	2,25%	of (TPC-land)
d. Depreciation	5,00%	of (TPC-land)
e. Local taxes, insurance	4%	of (TPC-land)
f. Plant overhead cost	3%	of (TPC-land)
Sales related cost		
a. Packaging	1%	of sale
b. Administration	2%	of sale
c. Distribution and marketing	2%	of sale
d. Research and development	1%	of sale
e. Patents and royalties	1%	of sale

3.3 Ideal Condition

The production of zinc sulfide nanoparticles based on an engineering perspective is considered to be able to operate well, can be developed according to technological developments, and produce large-scale products in a short time. Economic evaluation requires ideal conditions as a benchmark in project analysis. The relationship between CNPV/TIC (y-axis) and time (x-axis) shown in a graph (See Figure 3). The declining graph condition in the first year was caused by investment costs. But from 2nd year, the value of CNPV/TIC has increased. This means that the Payback Period (PBP) can be achieved just two years. This shows that the project has promising prospects.

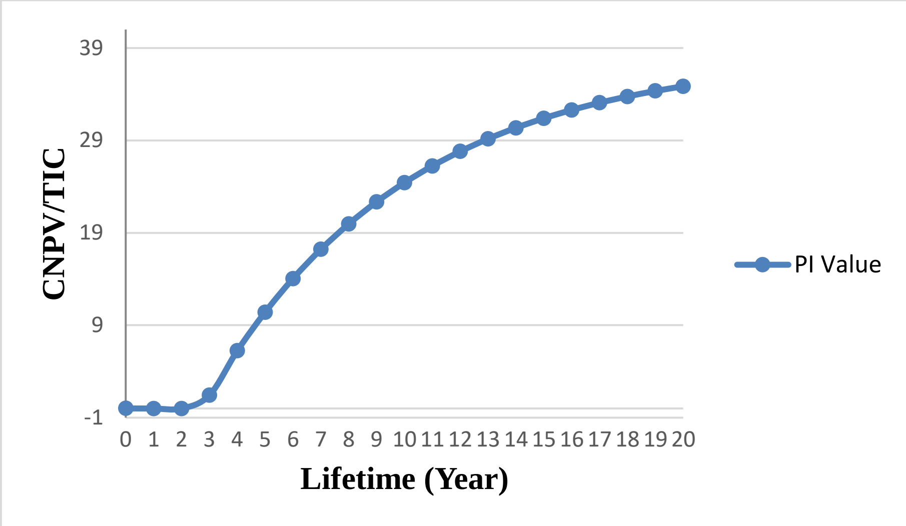

Figure 3. Analysis of CNVP/TIC on the production of zinc sulfide nanoparticles

In addition to the CNPV analysis, other economic parameters also show that the project has promising prospects. It can be seen in Table 5 which shows that all economic parameters have positive results.

Table 5. Economic Parameters.

Economic Parameters	Value
TIC (USD)	18,605.89
GPM/Year (USD)	5,493,940
IRR (%)	18.32
PI to Sales (%)	34
BEP/year (Pack)	313.52

The value of GPM is influenced by the quantity of the product, the greater quantity of the product, the greater final CNPV value. BEP is a condition when income is equal to capital issued. BEP value is influenced by profit, the greater profit influenced the greater BEP value.

3.4 The Effect of External Condition

The project is not only influenced by internal conditions. There are external conditions that can affect the progress of the project. Therefore, it is necessary to analyze the external conditions as a parameter to determine their effect on the project. One of the external factors is taxes. The higher tax, the less profit is earned. In addition, if the tax value is too high, the project may suffer losses. The results of the tax effect analysis carried out with tax variations of 10, 25, 50, 75, and 100% (See Figure 4). From the beginning of the working year until the 2nd year, the tax does not affect the project because it is still in the construction stage. In subsequent years, the tax increase has affected the project. This can be seen from the smaller CNPV value when the tax percentage is increased. This means that the profit of the project is reduced. The results of the analysis show that the maximum tax percentage for project sustainability is 75%. If the tax exceeds 75%, the project will suffer a loss.

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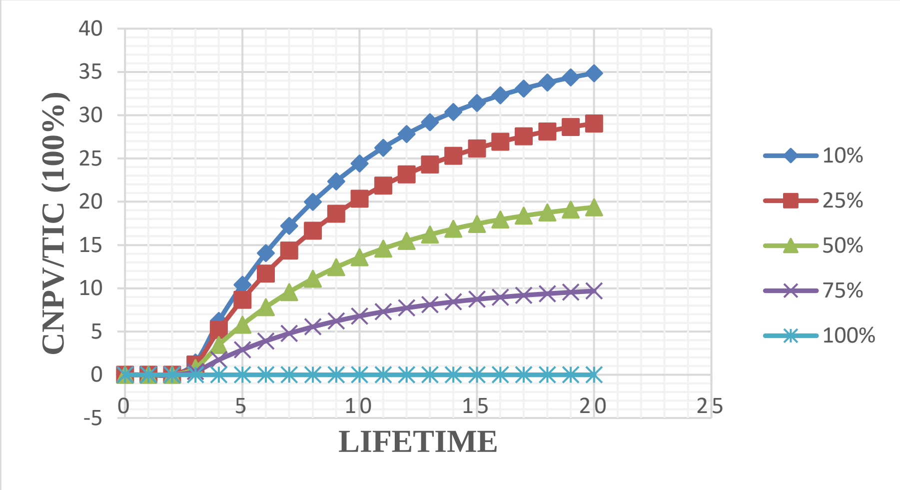
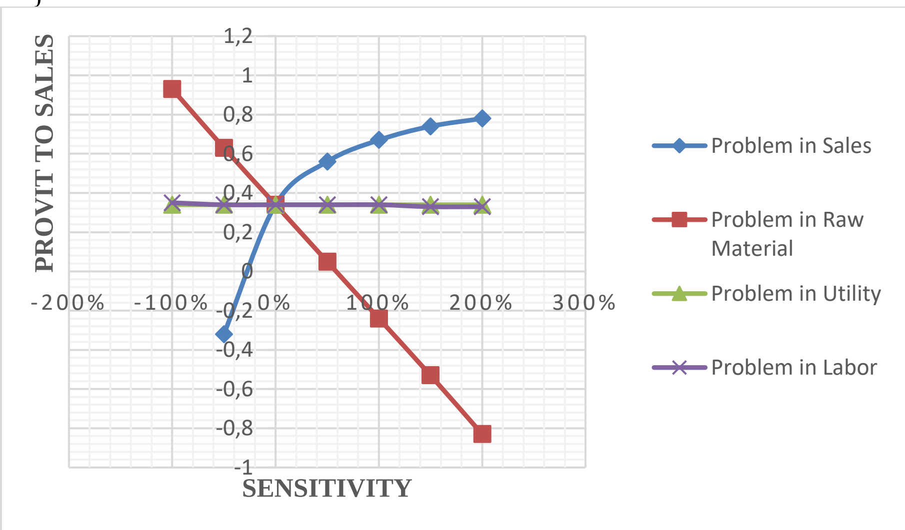


Figure 4. Tax analysis on the production of zinc sulfide nanoparticles. This analysis was done with variations of 10, 25, 50, 75, and 100% tax.

3.5 The Effect of Sales Change

Profitability Index (PI) can be used as a parameter to analyze the effect of changes in sales on the project. PI analysis was performed on sales, raw materials, utilities, and labor with sensitivity variations of -100, 50, 0, 50, 100, 150, and 200% for each parameters. The PI to sales and PI to investment analysis is shown in graph (See Figure 5). Based on the graphs in Figures 5a and 5b, utilities and labor do not significantly affect the value of PI to sales and PI to investment, indicated by the graph which tends to be flat. But if analyzed in more detail, the addition of utility and labor will decrease the PI value. This is because more costs incurred, the project's profits will be reduced. The increase in raw material prices also led to a decrease in the value of PI to sales and PI to investment, as shown by the graph that decreased from top right to bottom left. This is because the more costs incurred for raw materials, the more project profits will decrease. In contrast to utilities, labor, and raw materials, the increase in sales shows a positive value as shown in Figures 5a and 5b. In general, the project will incur a loss if sales are less than 0%.



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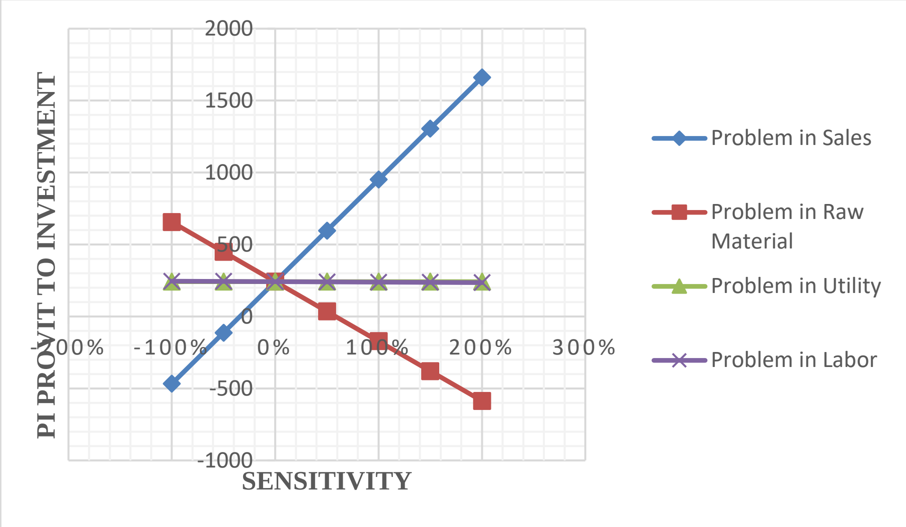

Figure 5. The effect of sales on PI to sales (a) and PI to investment (b).

3.6 The Effect of Changes in Cost of Raw Materials, Utilities, and Labor

A project can be affected by variable costs. The variable costs that affect a project consist of the variable costs of raw materials, utilities, and labor. That effect can be shown in **a** graph of CNPV/TIC (%) in the period of use (See Figure 6).

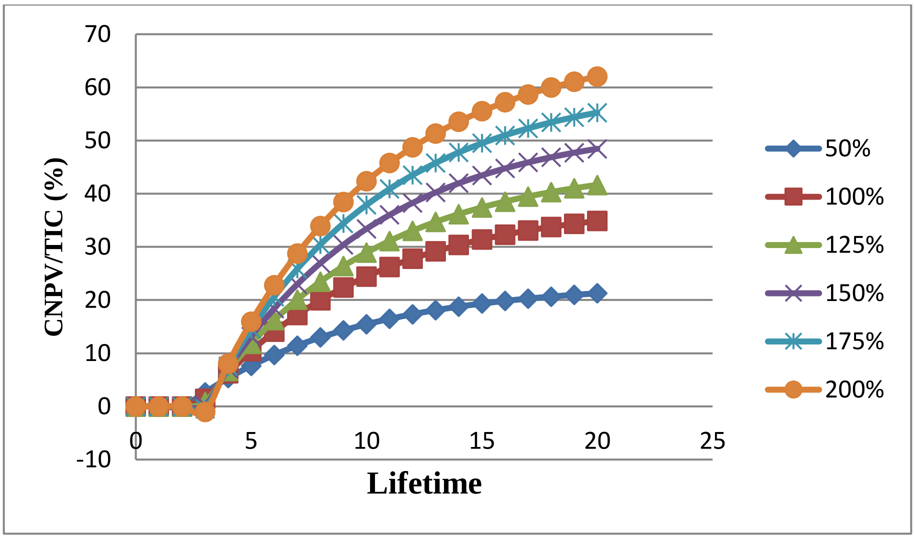

Figure 6. The effect of variations in raw materials on CNPV/TIC within 20 years.

The analysis was carried out using the initial conditions, the reduction of the raw materials used at a variation of 50% showed an increase from the initial conditions when the raw materials were lowered. However, when the number of raw materials is increased in variations of 125, 150, 175, and 200%, it is obtained an indication that the yield of CNPV/TIC has decreased from the initial condition when the raw materials were increased.

Based on the PBP analysis obtained from the results of variations in raw materials, it can be seen that the initial condition until the 2nd year is a period to achieve a return on capital. All variations in the number of raw materials experience this period. However, after passing

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the 2nd year, all variations in the number of raw materials simultaneously experienced an increase in CNPV/TIC and only had differences in the CNPV/TIC distance each year. The greater raw material used, the less profit will be obtained in the project from its ideal state. And vice versa, the fewer raw materials used, the project will experience an increase in profits [19]. So based on the variation in the number of raw materials used, this project is feasible to use an increase in raw materials whose amount does not exceed 100%.

In addition to raw material variables, there are other variables, namely utility variables. The analysis of the utility effect on CNPV/TIC in a 20-year lifetime shown in a graph (See Figure 7). There are two axes on the graph, the x-axis and the y-axis. The x-axis serves to show the period of use while the y-axis shows the CNPV/TIC. The analysis is carried out using the initial condition, which reduces the total utility by 50% from the initial condition.

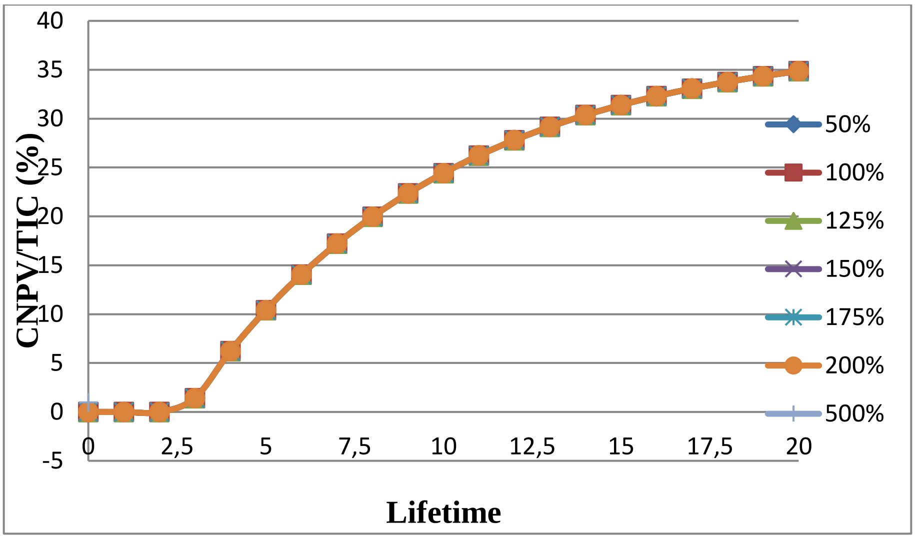

Figure 7. Effect of utility variation on CNPV/TIC with 20 years of service life.

The graph shows that there is no significant increase in CNPV/TIC from the initial condition when the utility was reduced by 50%. However, when the number of utilities was varied to 125, 150, 175, 200, and 500%, the CNPV/TIC did not decrease significantly from the initial condition when the utility was increased. From the initial condition until the 2nd year, PBP was only reached in the 2nd year and an increase in all utility variations occurred in CNPV/TIC later. There is no significant change in the effect of utility on CNPV/TIC. In the 20th year, the CNPV/TIC for utility variations of 50, 100, 125, 150, 175, and 200% were 34.85845; 34.86073; 34.86187; 34.86301; 34.86416; 34.8653; and 34.87898. Based on the utility that does not have a significant effect on CNPV/TIC, this project is considered profitable.

The next variable cost is the variable cost of labor. The effect of labor on CNPV/TIC for 20 years shown in a graph (See Figure 8). In the graph, there are two axes, the x-axis for the period of use (years) and the y-axis for the CNPV/TIC value.

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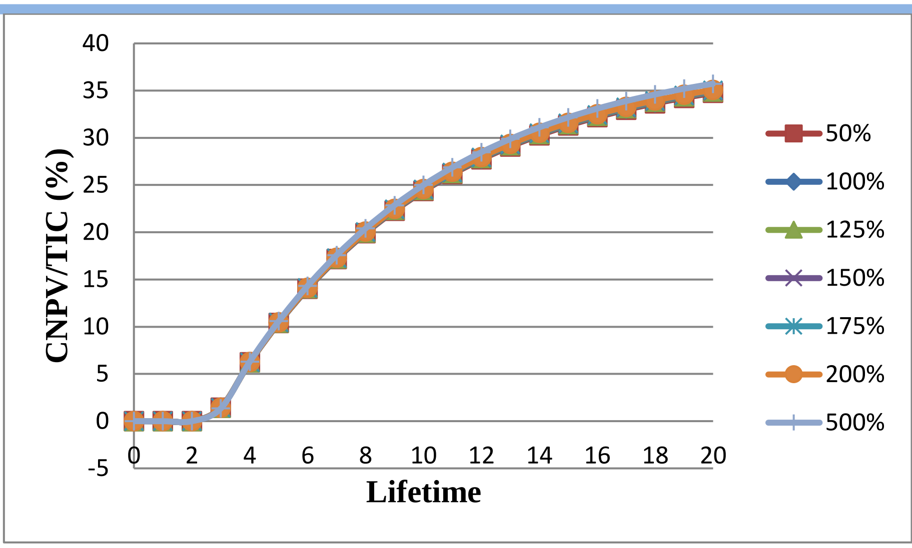

Figure 8. The effect of the number of workers on CNPV/TIC for 20 years.

This analysis is carried out using the initial conditions, reducing the number of workers by 50%. Based on the results of the study, it was found that there was no significant increase in the value of CNPV/TIC compared to the initial condition when the number of workers was reduced. However, if the number of utilities varies with 125, 150, 175, 200, and 500%, there is no significant decrease in the CNPV/TIC from the initial condition when the workforce was added. In the initial condition, PBP was reached in year 2 and all variations of labor experienced an increase in CNPV/TIC later. However, the effect of labor on CNPV/TIC did not change significantly with CNPV/TIC in the 20th year. The CNPV/TIC of the workforce variation of 50, 100, 125, 150, 175, 200% are 34.75184; 34.86073; 34.91518; 34.96963; 35.02408; 35.07853; and 35.73191. Therefore, based on the absence of a significant labor effect on CNPV/TIC, this project has a favorable value.

Based on the analysis that has been presented above, this project is considered very ideal to be realized on an industrial scale. The project has increased profits during its 20 years of operation. And this project only takes 2 years to return the investment costs since the PBP is in the 2nd year. Changes that may occur do not make the project suffer losses that result in project failure. Here are the specific circumstances that need to be considered in the project. First, taxes affect the profits earned by the project. 75% is the maximum tax for this project. So that, the tax should be estimated below 75% to avoid losses. Second, sales are maintained at not less than 0% of the products sold. Third, variations of 50, 100, 125, 150, 175, and 200% on the variation of raw materials can affect the profit every year. But if the raw material is smaller, the profit is increased and vice versa. Fourth, variations of 50, 100, 125, 150, 175, and 200% in utility variations do not result in any significant effect on project profits and finally, changes in labor costs with variations of 50, 100, 125, 150, 175, 200%, and 500% did not have a significant effect on the profits obtained in the project.

4. Conclusion

The feasibility analysis on the production of zinc sulfide nanoparticles using the precipitation-assisted ultrasonic radiation method was reviewed based on engineering and economic perspectives. According to the economic perspective in terms of the various parameters that have been mentioned, the project is said to have promising advantages. PBP can be achieved in a short period, two years. And the value of CNPV continues to increase during the 20 year of the project's operation. Taxes, sales volume, and raw materials are known to have a significant effect on project sustainability, while utilities and labor do not have a significant effect. From an engineering perspective, the project is said to have promising prospects for the production of zinc sulfide nanoparticles. This is in terms of the availability of commercial tools and materials and the relatively short processing time. One production cycle can be completed in one day and is capable of producing 400 kg of zinc sulfide nanoparticles. Projects can be done by raising funds or looking for investors to get initial capital and the sustainability of the industry in the future.

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