International Journal of Research and Applied Technology

1(1)(2021) 211-226
Journal homepage: https://ojs.unikom.ac.id/index.php/injuratech

Cost Analysis and Economic Evaluation for Manufacturing Hydroxyapatite Nanoparticles from Eggshell Waste

T Annisa[1*], A Azkiya[1], R N Fauzi[1], A B D Nandiyanto[1], S N Hofifah[2]
[1]Departemen Pendidikan Kimia, Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alam, Universitas Pendidikan Indonesia, Jl. Dr Setiabudi no.229, Bandung 40154, Jawa Barat, Indonesia

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

Email:*tiaraan1807@upi.edu

Abstract. The aim of this study is to evaluate the economic feasibility of manufacturing hydroxyapatite nanoparticles from eggshell waste. The economic analysis perspective is carried out by calculating various economic parameters, namely gross profit margin (GPM), payback period (PBP), break event point (BEP), internal rate return (IRR), creating net present value (CNPV), return on investment (ROI) and profitability index (PI). The results show that the production of hydroxyapatite nanoparticles from eggshell waste is prospective. Technical analysis to produce 30,150 Kg of hydroxyapatite per year shows the total cost of equipment purchased is Rp. 230,580,000.00, and the total cost of raw materials is Rp. 890,235,720.00. The profit obtained from the sale of the product is Rp. 4,520,803,500.00/year. Within 20 years of the construction of this project, using eggshells as a raw material for production can reduce the accumulation of eggshell waste. This project can compete with PBP capital market standards due to the short return on investment of around 3 years. To ensure feasibility, the project is estimated from ideal to worst case conditions in production, including labor, sales, raw materials, utilities, as well as external conditions (taxes and subsidiaries). The benefits of this research are that it can provide information on the economic feasibility of manufacturing hydroxyapatite nanoparticles on a large scale, and can optimize/develop projects for further investigation.

1. Introduction

Hydroxyapatite is a form of calcium phosphate with the chemical formula $Ca_{10}(PO_4)_6(OH)_2$ and a hexagonal crystal structure [1]. Hydroxyapatite (HA) is one of the most widely used biomaterials and can be found in tooth enamel, dentin and bone tissue in the human body [2]. This material has been commonly and successfully used in regenerative medicine and in drug delivery systems [1]. This material is also used as a bone substitute, anti-wrinkle cream, and sun cream [1,2]. In fact, this material was developed by scientists in Poland into patches and ointments. In addition, it is used in the production of toothpaste formulations and to accelerate wound healing [1].

The commercial availability of hydroxyapatite in the market is quite expensive due to the use of high-purity reagents [3]. Hydroxyapatite (HA) powder can be derived using eggshell waste to reduce costs. Moreover, it is an economical way to synthesize nanocrystalline hydroxyapatite [4]. The conversion of hydroxyapatite from this waste is not only considered economical but also environmentally friendly. Therefore, it is very important to use substitute materials that are easily accessible, renewable and cost-effective [5]. Eggshells represent 11% of the total egg weight and consist mostly of calcium carbonate (94%), calcium phosphate (1%), organic matter (4%) and magnesium carbonate (1%) [3]. In addition, according to Ramesh et al. [6], eggshell contains several trace elements such as sodium, magnesium, silicon, and strontium which make it a biocompatible material for human bones when used as implant material [6].

Previous studies reported several different methods in the synthesis of hydroxyapatite nanoparticles, namely the sol-gel method [7, 8], the precipitation process [9, 10], microwave-assisted method [11], green synthesis method [12], hydrothermal method [2, 5], and mechanochemical method [13, 14]. The hydrothermal method of synthesizing hydroxyapatite nanoparticles offers unique advantages because the materials used are more economical, non-toxic, and the process is simple. In addition, the resulting biocompatible product can be used on human bones with controlled size and shape of hydroxyapatite [15–17]. The prospective method for producing hydroxyapatite nanoparticles has been confirmed by many published reports, but few have reported on the analysis for feasibility studies in the large-scale production of hydroxyapatite nanoparticles. With this study, it is hoped that it can provide information to prospective industrial practitioners in applying the method in realistic applications.

The aim of this study is to evaluate the economic feasibility and cost analysis in manufacturing hydroxyapatite nanoparticles on a large scale. This feasibility study is important because it helps in making a decision whether a process of this scale is prospective or not. In addition, another goal is to provide advice in optimizing projects to build prosperity for economic growth. Building and developing this project can create job opportunities that have a direct impact on reducing unemployment and poverty [18].

In this study, all the calculation of economic analysis parameters were carried out under certain conditions. There are variables added to the calculation, such as PI (Profitability Index) variables, product sales prices, tax costs, labor salaries, utility costs, raw material prices, and variable costs. However for the scaling process, further analysis should be carried out to predict realistic conditions for project development. We believe that this analysis will encourage further investigations for the large-scale production of hydroxyapatite nanoparticle materials.

2. Method

2.1 Theoritical Synthesis of Hydroxyapatite

According to Toibah et al. [5] and Rivera et al. [19], hydroxyapatite production was adopted and improved from the literature. Hydroxyapatite nanoparticles were manufactured using a hydrothermal method based on the use of calcium oxide with calcium phosphate. Calcium oxide (CaO) is obtained from eggshell waste which is further processed.

Calcium phosphate reagent and several other reagents are purchased on the online market with industrial grade quality.

Eggshell waste is collected and cleaned with distilled water and/or hexane to remove impurities and organic components contained. Then, the clean eggshells were dried in a dryer at a temperature of 450°C for 2 hours at a heating rate of 5°C/min; At this temperature, any organic residue is expected to disintegrate. After that, it was ground before calcining at 900°C for 2 hours. At this temperature, the eggshell (source of $CaCO_3$) turns into calcium oxide (CaO) by liberating carbon dioxide (CO_2) according to the following equation:

$$CaCO_3 \rightarrow CO_2 + CaO$$

The resulting CaO powder was used as a calcium precursor for the production of hydroxyapatite by hydrothermal synthesis. After that, the resulting powdered calcium oxide (CaO) is mixed with calcium phosphate (a phosphate precursor) for the production of hydroxyapatite. Both are prepared by dispersing in distilled water and stirring in an autoclave. The temperature of the mixed solution was maintained at ~90°C.

During the synthesis, the pH of the solution was adjusted to pH 9 to produce a basic solution by adding an ammonia solution (NH_4OH, Fisher Scientific). The expected reaction is:

$$3\ Ca_3(PO_4)_2 + CaO + H_2O \rightarrow Ca_{10}(PO_4)_6(OH)_2$$

After the reaction was completed, the solution was filtered and the resulting material was dried at 80°C for 24 hours in a dryer. After that, it was ground with a grinder and then calcined at 400°C to form a white hydroxyapatite powder. The experimental procedure for synthesizing hydroxyapatite from eggshell waste at certain pH conditions is presented in Figure 1.

2.2 Theoritical Synthesis of Hydroxyapatite

The engineering perspective is carried out by simulating the production process on a large scale using commercially available equipment. Each process is simulated based on the mass balance involved. Based on energy and mass balance calculations hydroxyapatite can be synthesized or produced on a larger scale than the laboratory scale. Process engineering design can be achieved on a large scale. The process is based on assumptions and stoichiometric calculations. The following are the assumptions used in the design of this project:

(i) Cost of equipment and raw materials based on online market prices, such as alibaba, tokopedia etc. Commercially obtained;
(ii) There are no by-products/secondary produced in the hydroxyapatite synthesis process;
(iii) The temperature in each process is based on reference [5, 19];
(iv) The conversion rate of hydroxyapatite production is 100%;
(v) In one day processing, the total processing cycle is 1 cycle, 5 cycles/week, and 25 cycles/month;
(vi) This method yields 100.5 kg of hydroxyapatite in one cycle. Under ideal conditions, this project can be scaled up to 300 cycles in a year. As a result, the project's production capacity is 24,110.9 kg/year or 24.1 tons/year.

2.3 Theoritical Synthesis of Hydroxyapatite

In this study, in addition to using a feasibility study method from the perspective of technical evaluation, a feasibility study from an economic evaluation perspective is also used. Several parameters used for the economic feasibility analysis were adopted from the literature [20], [21], which is explained as follows:

(i) Gross Profit Margin (GPM) is the determination of the level of profit of a project obtained from reducing the selling price with raw materials.
(ii) Payback Period (PBP) is a calculation performed to predict the length of time required to return the initial capital. PBP can be determined from the CNPV curve when the CNPV reaches zero for the first time.
(iii) Break Event Point (BEP) is the minimum number of products sold to cover the total production costs. BEP calculation is formulated by dividing the value of fixed costs (total selling price minus total variable costs).
(iv) IRR or Internal Rate of Return (%) is the percentage of return each year so that no initial capital is used.
(v) NPV is the value obtained as state revenues and expenditures. The calculation of NPV must consider the value of the discount rate (i). In addition, NPV can also be used to estimate future Cash Flows (CF). The data needed to calculate NPV includes TIC, depreciation, operating costs, and expected benefits.
(vi) Cumulative net present value (CNPV) is the calculation of the total NPV value from the beginning of factory construction to the end of plant operation. In short, CNPV can be obtained from the sum of the cumulative financial flows each year.
(vii) ROI (%) is obtained by dividing the increase in total profit by the investment cost. Profitability Index (PI) is estimated by dividing CNPV by sales and total investment cost depending on the type of PI whether PI is for sales or PI is for investment.
(viii) TIC (Total Investment Cost), is the initial capital cost that must be provided at the beginning of production.

The feasibility test for the current economic evaluation is carried out by varying the Profitability Index (PI), selling price, worker wages, utilities and raw materials in five conditions of decreasing and increasing costs, namely, 50, 75, 100, 125, and 150%. The tax variations used are 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100%.

3. Results and Discussion

3.1 Energy and Mass Balance

Based on the literature, the manufacturing process of hydroxyapatite nanoparticles using the hydrothermal method is shown in **Figure 2**. At one time cycle production of 100.5 kg of hydroxyapatite, it takes 5.608 kg of CaO (obtained from eggshell waste extract), 93.054 kg of $Ca_3(PO_4)_2$, and 1.802 L distilled water. Ammonia solution is also used to adjust and maintain the pH of the reaction in an alkaline state (pH 9). In the one year production span, there are 300 production cycles of hydroxyapatite nanoparticles. Through 300 cycles for one year, it is estimated that hydroxyapatite under ideal conditions is obtained at 3,0150 kg/year. Assuming that the percentage of CaO preparation from eggshell waste is 90%, in order to obtain about 2 tons of eggshell waste required for one year of production. With this project, about 2 tons of eggshell waste in one year can be minimized. Therefore, the total cost to be paid for raw materials for one year is Rp. 890,235,720.00. The total cost to pay for the

International Journal of Research and Applied Technology
1(1)(2021) 211-226
Journal homepage: https://ojs.unikom.ac.id/index.php/injuratech

equipment for one year is Rp. 230,580,000. The results of product sales in one year amounted to Rp. 4,520,803,500.00 and the profit earned per year is Rp. 1,433,764,791.

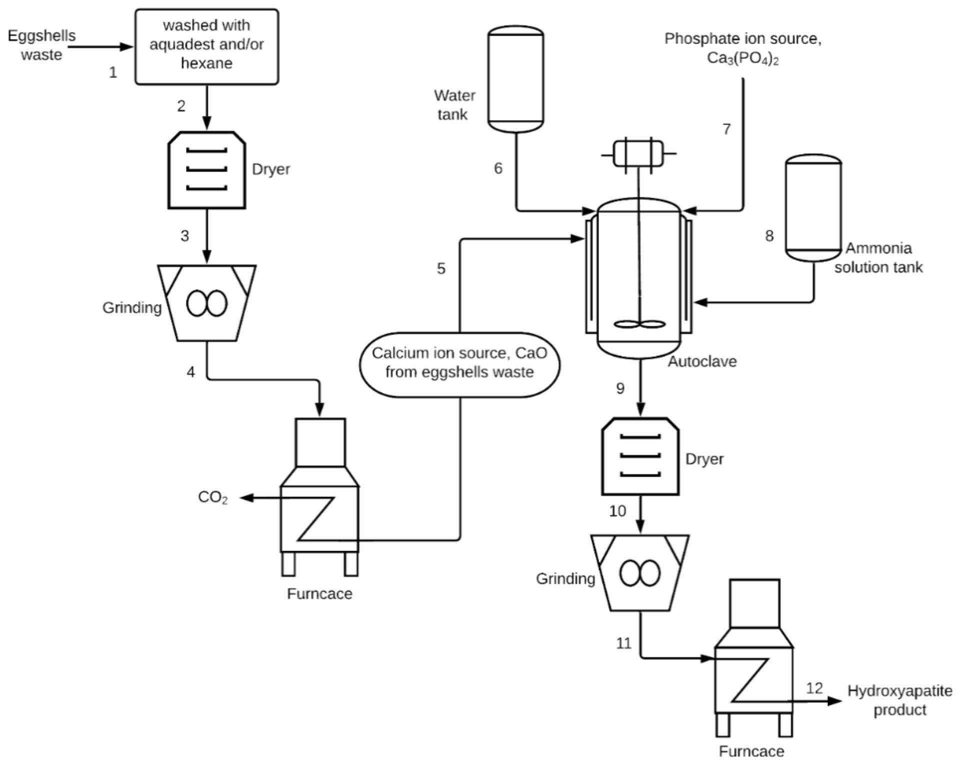

Figure 2. Process flow diagram of the hydroxyapatite production process from eggshell waste.

From an engineering point of view, this project makes it possible to increase the production volume. This is because the scaling up process (company development) can be implemented using commercially and economically available equipment.

3.2 Economic Evaluation

In the economic evaluation, several assumptions are used based on the specifications of all equipment, raw material prices, utility systems, and equipment costs, which are taken from online market such as: Alibaba, Bukalapak, Tokopedia, etc. The data is then used and included in the calculations for the economic feasibility analysis. The following are the assumptions needed to analyze and predict some of the possibilities that occur during the project as follows:

1). In the calculation using Indonesian currency (IDR) which is based on economic conditions in Indonesia for all purchases of project needs. Then the value is converted to USD with a fixed currency of 1 USD = 15,000 IDR.
2). All prices used are based on commercially available materials obtained in available online markets. In short, the price of hexane, calcium phosphate, and ammonia solution is Rp. 14,800.00/kg; Rp. 38,050.00/kg; and Rp. 400.00/kg each;
3). All materials used in production are estimated based on stoichiometric calculations;
4). The production percentage of calcium ion source (CaO) from eggshell waste is 90% purity.

5). The process ignores other supporting costs (eg, instrumentation, factory start-up, electrical related components);
6). Total investment cost (TIC) is calculated based on the Lang Factor. The results from the Lang Factor show that TIC is about four times the total cost of equipment;
7). The project is carried out/built on the land/land purchased. Therefore, land is calculated as initial cost (at the beginning of the factory construction) and recovered/acquired after the project (at the end of the project);
8). One cycle in production to convert eggshell waste into hydroxyapatite nanoparticles requires 6.5 kg of eggshell waste assuming 90% purity is converted to a source of calcium ions (CaO);
9). One year project is 300 days and the remaining days are used for holidays, cleaning and process management;
10). The basic electricity cost is 1,380 IDR/kWh;
11). Total wages/labor is assumed to be at a fixed value of 8 USD/day;
12). Discount rate and income tax are 15% and 10% per annum, respectively;
13). The duration of the project operation is 20 years.

Based on the economic analysis conducted, this project is very feasible in both ideal and non-ideal conditions. A detailed description of the specific conditions based on the analysis is described as follows:

- The project can still be profitable if the increase in raw material costs is below 100% of the estimated raw material costs.
- Sales of products must be made in quantities of at least 100.5 kg per day to sustain the project. When the price of capital is lowered, the total selling price increases. On the other hand, the project will give you a loss.
- In addition to the economic prospects, a feasibility analysis of the project also needs to be carried out. In this project, GPM and CNPV for variable costs show promising results under ideal conditions. This perspective is based on Indonesian capital market standards with PBP analysis showing that this investment will be profitable in the third to fourth year.

3.2.1 Ideal Condition

CNPV with various economic evaluation parameters (eg, GPM, PBP, BEP, BEC, IRR, ROI, and PI) under normal conditions is shown in **Figure 3**. Technical analysis confirms that manufacturing can be improved using currently available technology and inexpensive equipment. The analysis shows that the conversion of eggshell waste into hydroxyapatite nanoparticles is prospective, indicated by the excellent and promising economic evaluation analysis. Payback period (PBP) occurs at 3 years because product sales have generated a profit. After the payback period, profits will continue to increase until the 20th year. The economic evaluation analysis is presented in **Table 1.**

International Journal of Research and Applied Technology

1(1)(2021) 211-226

Journal homepage: https://ojs.unikom.ac.id/index.php/injuratech

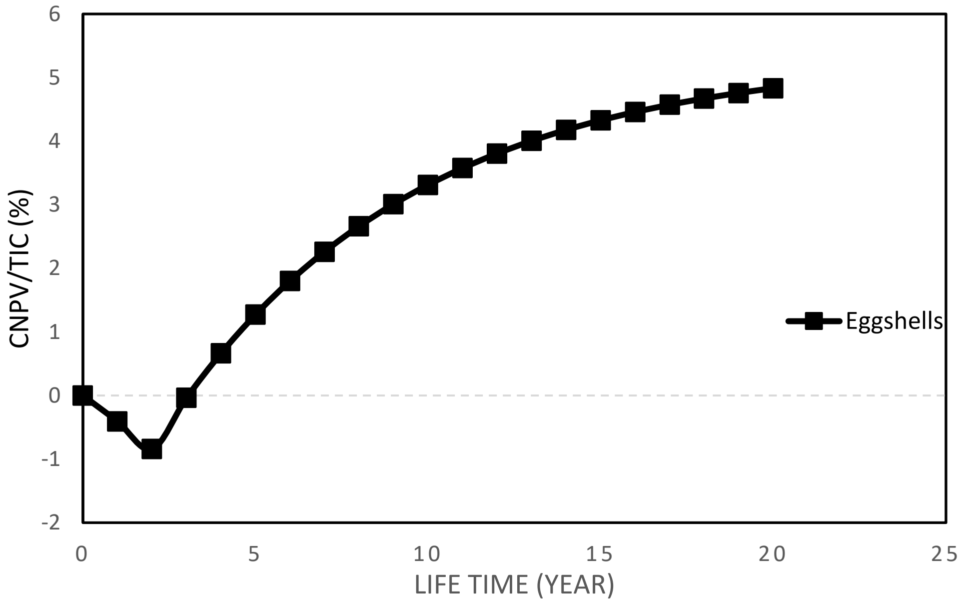

Figure 3. Analysis of CNPV/TIC ideal conditions for the production of hydroxyapatite nanoparticles

Table 1. Parameters of economic evaluation under ideal conditions

Economic Evaluation Parameter	*Values*
PBP	*3,1 years*
BEP (pack)	4.525
GPM/tahun (IDR/pack)	Rp 3.630.567.780
TIC (IDR)	Rp 1.023.775.200,00
IRR (%)	*84,93*
ROI (% per year)	7,78
Total ROI	140,04
PI provit to sale	*32%*
Pi provit to TIC	*140%*

3.2.2 Variable PI value

In the profit-to-sales PI analysis of equipment, raw materials and labor, the decline is accompanied by fluctuations in sales as shown in **Figure 4.** The sales curve has a polynomial value with the highest PI at a reduction of 50%, namely 2.37 or 237%. The addition of labor will reduce the value of PI or profits. Likewise with the addition of raw materials and utilities. Changes in utility have a significant impact on the PI value. Changes in raw materials and wages of workers have the opposite rate of reduction and addition of ideal

International Journal of Research and Applied Technology

1(1)(2021) 211-226

Journal homepage: https://ojs.unikom.ac.id/index.php/injuratech

conditions. At a sensitivity of less than 100%, the PI value for changes in raw materials has a lower value than changes in workers' wages. However, sensitivity of more than 100% the PI value on changes in raw materials has a higher value than changes in worker wages. an increase in the selling price will result in a decrease in the value of PI.

In the case of profit-to-investment PI, all factors are linear curves. Changes in utilities, raw materials and labor costs of up to 200% can still achieve a positive PI. Changes in the profit-to-investment PI on sales increased from -100% to 100% sensitivity as shown in **Figure 5**. However, in the same large variation (-50%), the profit-to-investment value decreased dramatically from profit-to-investment. sale. If the amount of raw materials, utilities and workers is doubled, the project will have a small PI value. This can result in losses and even the worst possible occurrence for a company. Investment limit will decrease if sales are less than 50% and vice versa. However, an increase in the selling price has a good impact on the success of the project. Based on the analysis results, changes in wages and selling prices provide significant changes.

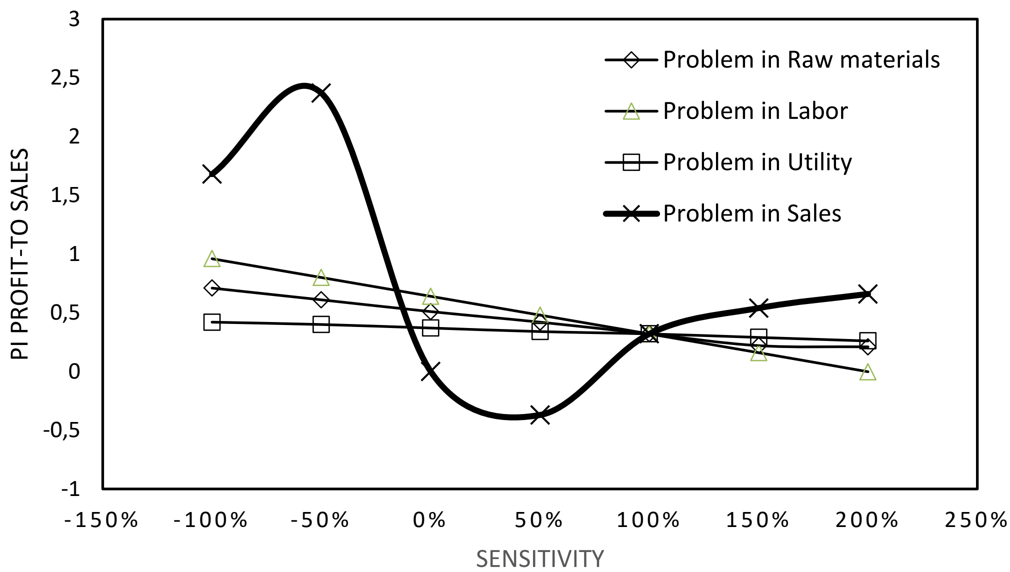

Figure 4. The effect of variable cost factors on sales profit

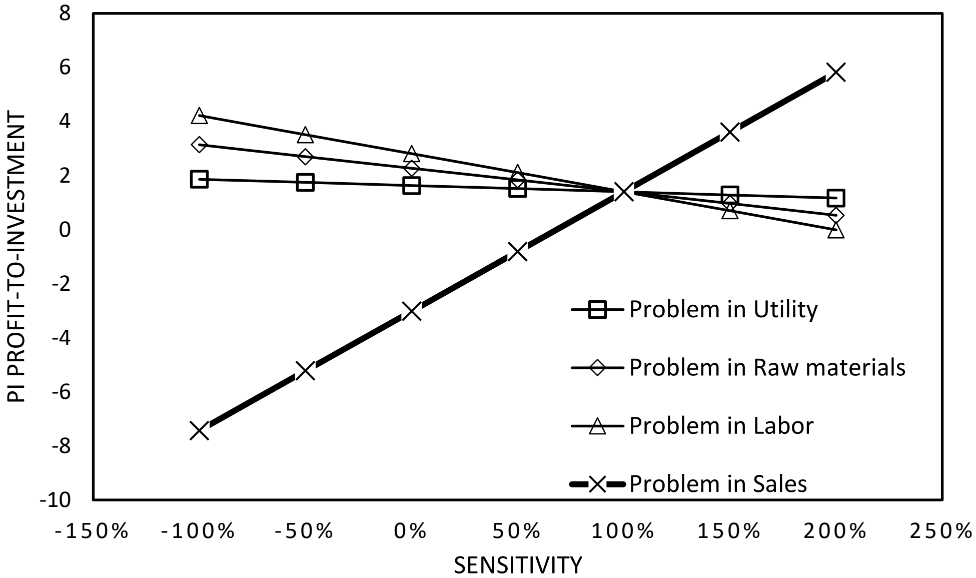

Figure 5. Effect of variable cost factors on investment profit

3.2.3 Selling Price Variable

Profitability index analysis (PI) is used to determine the effect of variable costs such as selling prices. The curve of the PI value (y axis) against time of year (x axis) of the selling price variations is shown in **Figure 6**. The selling price variations used are 50, 75, 100, 125, and 150%. The curve is decreasing for less than 2 years constantly as the company is still in development stage.

In the 20th year, the PI value for the variation of the selling price of 50, 75, 100, 125, and 150% is -4.37; 0.22; 4.83; 9.42; and 14.04. Variations in the selling price of 100 to 150% have increased because the profits obtained are greater. In general, the project is declared a failure if the selling price is less than 75% because it has a profit of 0 or even negative. An increase in the selling price of more than 100% resulted in an increase in the PI value as shown in **Figure 6.**

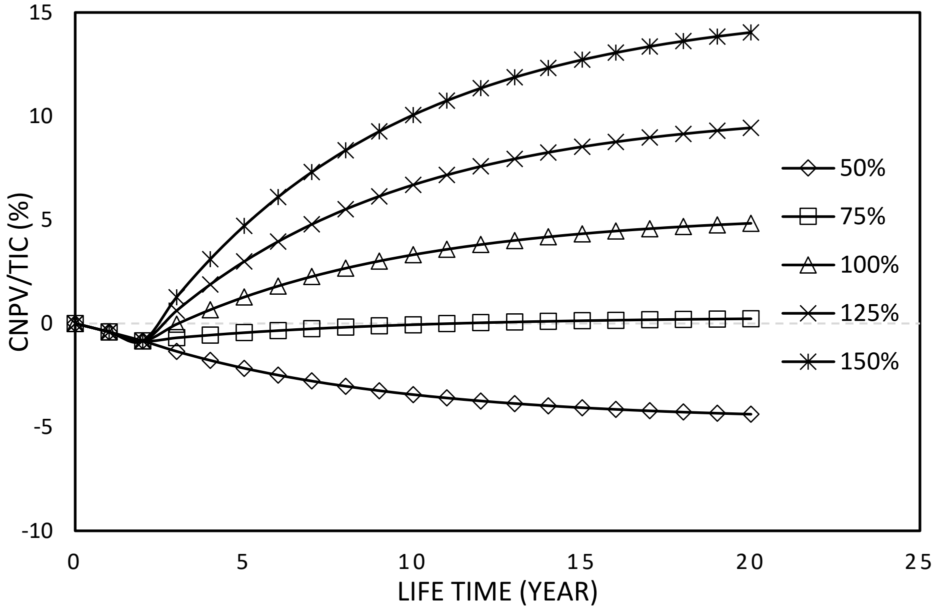

Figure 6. The effect of selling price variations on the value of CNPV/TIC during the processing time of 20 years

3.2.4 Tax Variable

Analysis of the evaluation of the tax economy can affect the amount of expenditure. The large variations of taxes used are 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% within 20 years since the establishment of the company as shown in **Figure 7.** A positive PI value was achieved in the third year due to the process company development.

Payment of tax costs for each variation has a significant difference. The 10% variation has the highest PI value because of the low tax expenditure. In addition, the tax rates of 20% and 10% have a small difference in the PI value.

In the 20th year, the highest PI value was achieved at the 10% tax rate, which was 4.83. In addition, the fastest payback period is achieved at 10% tax, which is 3.1 years. Large tax variations of more than 70% take more than 4 years to reach PBP. The maximum tax that must be met is 90%. If the tax paid is more than 90%, the project will suffer losses for more than 20 years. The lower the tax paid, the higher the profit.

International Journal of Research and Applied Technology

1(1)(2021) 211-226
Journal homepage: https://ojs.unikom.ac.id/index.php/injuratech

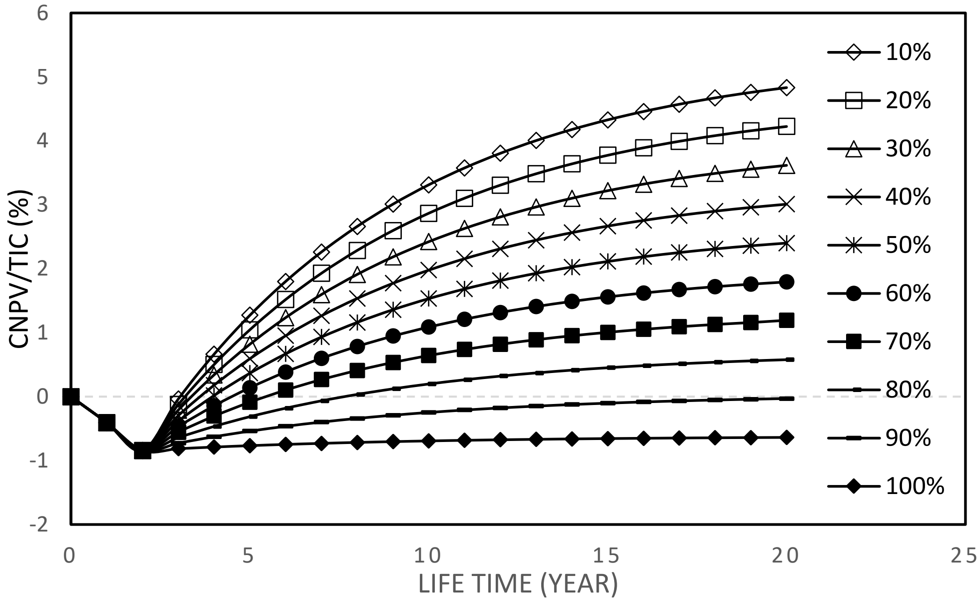

Figure 7. The effect of tax variations on the value of CNPV/TIC during the processing time of 20 years

3.2.5 Salary Variable

All human resources involved in the company are entitled to receive benefits in the form of salaries. The decrease or increase in salary issued affects the design of a company's economic evaluation. The curves of each variation in salary costs with variations ranging from 50, 75, 100, 125, to 150% are presented in **Figure 8.**

The value of PI or CNPV/TIC presented varies depending on the percentage of variation in salary costs. For the percentage of salary 50 and 75%, the PI value in the third year has shown positive, while for the percentage of salary 100 and 125% the PI value is positive in the fourth year, and for the percentage of 150% the PI value is positive in the fifth year. Although the data shows that the value of CNPV/TIC has increased every year until the 20th year, the salary increase for existing human resources should not exceed 25% of the ideal condition. If the salary increase exceeds 25% of the ideal conditions, the payback period (PBP) will be achieved in a longer time and the company is highly likely to suffer losses.

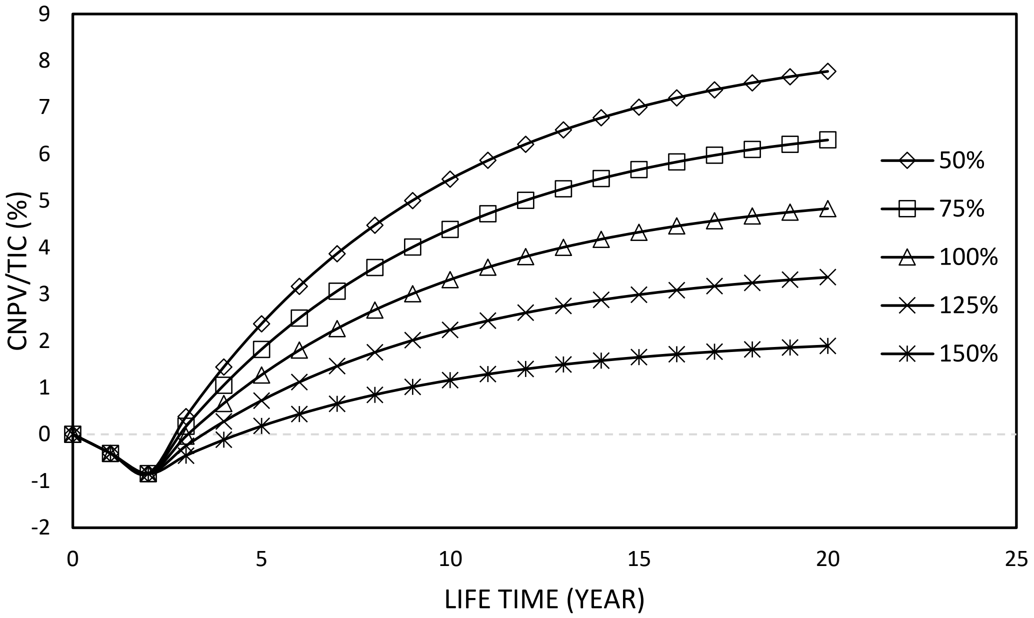

Figure 8. The effect of variations in salary on the value of CNPV/TIC during the processing time of 20 years

3.2.6 Utility Variable

Variations in utility costs can also affect the economic evaluation of hydroxyapatite production. The curve of the PI or CNPV/TIC value against the unit of time (years) with variations in utility costs is presented in **Figure 9.** Each multiple of the percentage decrease and increase in the variation in utility costs by 25% has a low difference in the value of profits starting from 50, 75, 100, 125, up to 150%. The average PI value is constant until the second year and is negative until the third year because the company is still in the development process. The payback period (PBP) will be reached in the third to fourth year at a utility cost variation of 50 to 150%. An increase in utility costs will result in lower profits and PBP will be achieved in a longer time. On the other hand, reduced utility costs will lead to higher profits and PBP is achieved in less time.

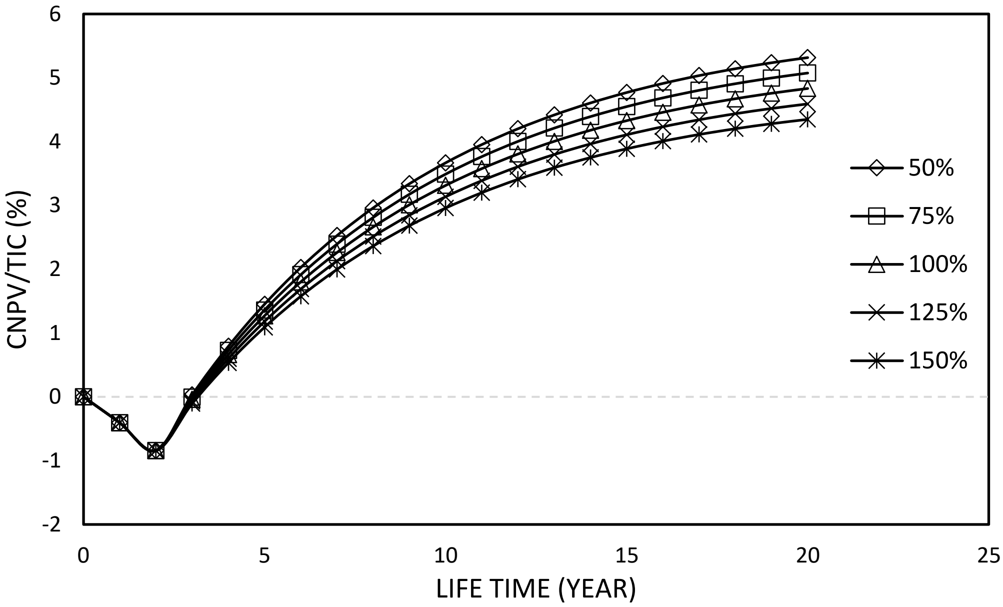

Figure 9. The effect of utility variations on the value of CNPV/TIC during the process time of 20 years

3.2.7 Raw Material Variable

The price of raw materials used for the manufacture of hydroxyapatite can be varied from the ideal conditions. Varied raw material prices certainly affect the value of the economic evaluation as shown in **Figure 10**. ideal conditions have a percentage of 100%. The decrease in raw material prices resulted in a percentage value that was less than ideal conditions, while the increase in raw material prices resulted in a percentage value that was more than ideal conditions. In the beginning until the second year, the PI value was constant and negative because the company was still in the development process so it had not yet made a profit. The distance between the curves of raw material price variations from each other has a small value, so that a decrease or increase in profits from variations in raw material prices in multiples of 25% gives a small value.

Profits continue to increase every year as shown in **Figure 10**. The amount of raw material prices is inversely proportional to the profits obtained by the company. Reducing the price of raw materials will increase the company's total profit because the value of the CNPV/TIC ratio increases from ideal conditions and vice versa. In the 20th year, the CNPV/TIC ratio of the percentage variations in raw material prices 50, 75, 100, 125, and 150% are 6.65; 5.74; 4.83; 3.92; and 3.02%.

International Journal of Research and Applied Technology
1(1)(2021) 211-226
Journal homepage: https://ojs.unikom.ac.id/index.php/injuratech

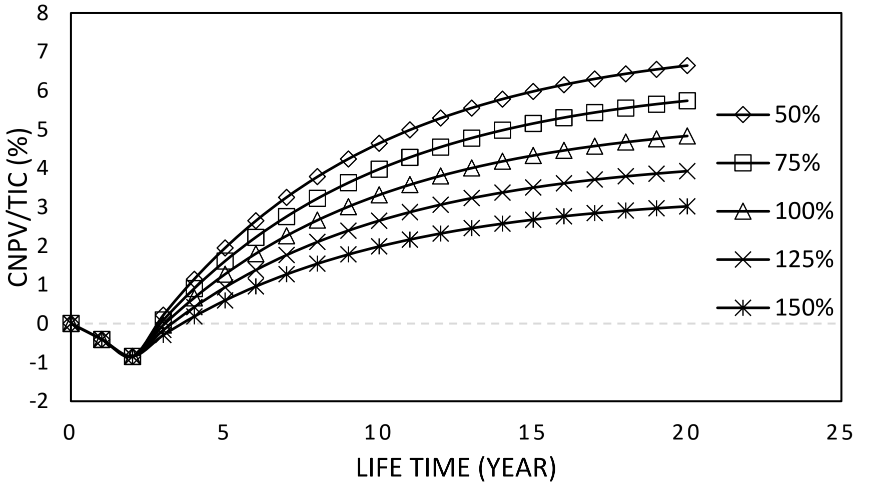

Figure 10. The effect of variations in raw material prices on the value of CNPV/TIC during the process time of 20 years

3.2.8 Variable Cost

Variable costs include the sum of the prices of raw materials, utilities, wages of workers and selling prices. Variable price variations are 50, 75, 100, 125, and 150% within 20 years since the establishment of the company. The diagram presented, namely the value of PI or CNPV/TIC (y axis) against time (x axis) is shown in **Figure 11**. At the beginning of the year until the second year, the PI value decreased constantly in each variation. This is because the company is still in the development stage.

At a variation of 50 to 125% PI is positive. However, the 150% variation has a significantly negative PI value. The payback period or PBP at variations of 50, 75, 100, and 125%, respectively, is 2.53; 2.71; 3.1; and 4.41 years. Variable cost variations of more than 125% have a long PBP that is more than 20 years. If the variable costs used are more than 25% of the ideal situation, the company will fail. An increase in variable costs results in a decrease in the value of PI so that the possibility of loss is higher.

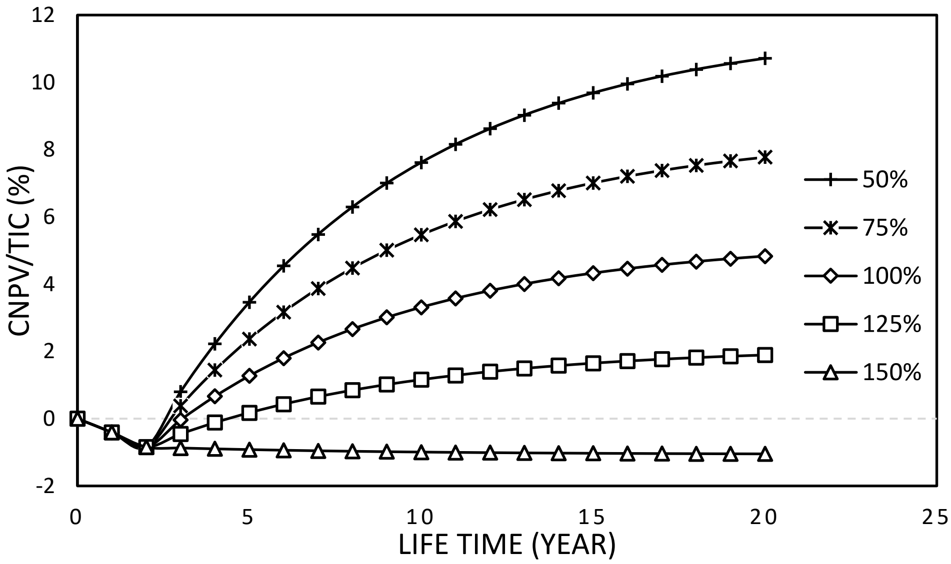

Figure 11. Variable cost analysis on hydroxyapatite project produced from eggshell

International Journal of Research and Applied Technology

1(1)(2021) 211-226
Journal homepage: https://ojs.unikom.ac.id/index.php/injuratech

4. Conclusion

Based on the analysis conducted, the conversion of eggshell and calcium phosphate into hydroxyapatite nanoparticles on an industrial scale by the hydrothermal method can be said to be of high profit and prospective from a technical and economic evaluation point of view. This is indicated by the number of products produced 100% pure hydroxyapatite every one production cycle. Then, it is also supported by the analysis of economic evaluation parameters which show positive results. Several production cost variables were varied to see the best condition of this project from an economic point of view within a period of 20 years of production. The results show that the Payback Period (PBP) will be achieved in 3.1 years and the PI value is positive in the 3rd year and continues to increase. So, the project is feasible for large-scale production for use in the biomedical field.

Acknowledgement

Thanks to Prof. Dr. Ir. Eddy Soeryanto Soegoto, Lecturer in Entrepreneurship and Universitas Komputer Indonesia.

References

[1] Kuśnieruk, S., Wojnarowicz, J., Chodara, A., Chudoba, T., Gierlotka, S., and Lojkowski W. 2016. Influence of hydrothermal synthesis parameters on the properties of hydroxyapatite nanoparticles. *Beilstein Journal of Nanotechnology*, vol. 7, no. 1, pp. 1586–1601

[2] Ibrahim, W. M. A., & Kasim, A. S. M. 2011. Evaluation of compressive strength of eggshell hydroxyapatite. *Advanced Materials Research*, vol. 264–265, pp. 571–575

[3] Siva Rama Krishna D., Siddharthan A., Seshadri, S. K., and Sampath, K. T. S. 2007. A novel route for synthesis of nanocrystalline hydroxyapatite from eggshell waste. *Journal of Materials Science: Materials in Medicine*, vol. 18, no. 9, pp. 1735–1743

[4] Sasikumar, S., & Vijayaraghavan, R. 2006. Low temperature synthesis of nanocrystalline hydroxyapatite from egg shells by combustion method. *Trends in Biomaterials and Artificial Organs*, vol. 19, no. 2, pp. 70–73

[5] Toibah, A. R., Misran, A. F., Shaaban, and Mustafa, Z. 2019. Effect of pH condition during hydrothermal synthesis on the properties of hydroxyapatite from eggshell waste. *Journal of Mechanical Engineering and Sciences*, vol. 13, no. 2, pp. 4958–4969

[6] Ramesh, S., *et al.* 2016. Direct conversion of eggshell to hydroxyapatite ceramic by a sintering method. *Ceramics International*, vol. 42, no. 6, pp. 7824–7829

[7] Chen, J. *et al.* 2011. A simple sol-gel technique for synthesis of nanostructured hydroxyapatite, tricalcium phosphate and biphasic powders. *Materials Letters*, vol. 65, no. 12, pp. 1923–1926

[8] Chung, V. H. K., Wongso., Sambudi., and Isnaeni. 2019. Biowaste-derived carbon dots/hydroxyapatite nanocomposite as drug delivery vehicle for acetaminophen," *Journal of Sol-Gel Science and Technology 2019 93:1*, vol. 93, no. 1, pp. 214–223

[9] Kamalanathan, P., *et al.* 2014. Synthesis and sintering of hydroxyapatite derived from eggshells as a calcium precursor. *Ceramics International*, vol. 40, no. PB, pp. 16349–16359

[10] Cengiz, B., Gokce, Y., Yildiz, N., Aktas, Z., and Calimli, A. 2008. Synthesis and characterization of hydroxyapatite nanoparticles. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, vol. 322, no. 1–3, pp. 29–33

[11] Hamzah, S., Yatim, N. I., Alias, M., Ali, A., N. Rasit, and Abuhabib, A. 2019. Extraction of hydroxyapatite from fish scales and its integration with rice husk for ammonia removal in aquaculture wastewater. *Indonesian Journal of Chemistry*, vol. 19, no. 4, pp. 1019–1030

[12] Sabry, A. A., & Salih, N. A. 2020. Synthetic properties of hydroxyapatite powder prepared from natural eggs shell. *Journal of Green Engineering*, vol. 10, no. 7, pp. 3498–3507

[13] Gergely G. *et al.* 2010. Preparation and characterization of hydroxyapatite from eggshell. *Ceramics International*, vol. 36, no. 2, pp. 803–806

[14] Ferro A. C., & Guedes M. 2019. Mechanochemical synthesis of hydroxyapatite using cuttlefish bone and chicken eggshell as calcium precursors. *Materials Science and Engineering: C*, vol. 97, pp. 124–140

[15] Fujishiro, H. Y., Yabuki, K., Kawamura, T., Sato, and A. Okuwaki,. 1993. Preparation of needle-like hydroxyapatite by homogeneous precipitation under hydrothermal conditions. *Journal of Chemical Technology & Biotechnology*, vol. 57, no. 4, pp. 349–353

[16] Chen, P. Y., *et al.* 2019. Evolution of the microstructural and mechanical properties of hydroxyapatite bioceramics with varying sintering temperature. *Ceramics International*, vol. 45, no. 13, pp. 16226–16233

[17] Alif, M. F., Aprillia, W., and Arief, S. 2018. A hydrothermal synthesis of natural hydroxyapatite obtained from Corbicula moltkiana freshwater clams shell biowaste. *Materials Letters*, vol. 230, pp. 40–43

[18] Ragadhita, R., *et al.* 2019. Techo-economic analysis for the production of titanium dioxide nanoparticle produced by liquid-phase synthesis method. *Journal of Engineering Science and Technology*, vol. 14, no. 3, pp. 1639–1652

[19] Rivera, E. M., *et al.* 1999. Synthesis of hydroxyapatite from eggshells. *Materials Letters*, vol. 41, no. 3, pp. 128–134

[20] Nandiyanto, A. B. D., Ragadhita R., and Istadi I. 2020. Techno-economic analysis for the production of silica particles from agricultural wastes. *Moroccan Journal of Chemistry*, vol. 8, no. 4, pp. 801–818

[21] Shalahuddin, F. A., Almekahdinah. S. S., and Nandiyanto A. B. D. 2019. Preliminary Economic Study on the Production of ZnO Nanoparticles, Using a Sol-Gel Synthesis Method. *Jurnal Kimia Terapan Indonesia*, vol. 21, no. 1, pp. 1–6