International Journal of Energetica (IJECA)
https://www.ijeca.info
ISSN: 2543-3717 Volume 5. Issue 2. 2020
Page 07-11

Economic and Technical Evaluation of LifePO$_4$ Production using Hydrothermal Method

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Abstract – *The aim of this study is to evaluate the economic and engineering layout carried out on a factory scale LiFePO4 production using the hydrothermal synthesis method. The method used is economic evaluation by calculating gross profit margin (GPM), payback period (PBP), break-even point (BEP), internal rate return (IRR), cumulative net present value (CNPV), return on investment (ROI). , and the profitability index (PI). LiFePO$_4$ was synthesized using precursors FeSO$_4$.H$_2$O, ascorbic acid and H$_3$PO$_4$ and then reacted with LiOH$_2$.2H$_2$O by maintaining the Li: Fe: P molar ratio of 3: 1: 1. The results of GPM and CNPV calculations from the manufacture of industrial scale LiFePO4 show that the payback period (PBP) has increased in the fourth year. LiFePO4 applications on an industrial scale can be used for lithium ion batteries.*

***Keywords**: Evaluate the Economic, Hydrothermal Synthesis Method, lithium, batteries.*
Received: 28/10/2020 – Accepted: 01/12/2020

I. Introduction

Lithium ion batteries are very widely used, especially for rechargeable batteries [1,2]. LiFePO$_4$ is very likely to be used as a cathode in lithium ion batteries [3,[4] because it is cheap, has a good specific capacity (170 mAh/g), the battery life cycle is good [1,2], safe, the structure is stable [2], a Li/Li+ charge-discharge curve at a voltage of ~3.45V [2], and the properties of the phosphate are excellent [3]. However, the disadvantage of LiFePO4 as a lithium ion battery cathode is its low electrical conductivity [1-4] which limits the extraction of lithium ions and can reduce the charge/discharge capacity [2,4]. The cause of this electrical conductivity is the large band gap of pure LiFePO4.

There are several LiFePO$_4$ synthesis methods reported by researchers, including hydrothermal method [5-13], solid state reaction [14-18], freeze drying [14-16,19], and co-precipitation [19-25]. The most appropriate method used in economic evaluation is hydrothermal because the reaction process is simple and the raw materials are easy to obtain. Therefore, the aim of this study is to evaluate the technical feasibility and economics of manufacturing LiFePO$_4$ nanoparticles on an industrial scale. In this study, we vary several factors to see their effect on the economic evaluation under study, such as increases in tax prices, decreases and increases in product prices, and the effect of raw material prices.

II. Experiment

II.1. Theoretical Synthesis of LiFePO$_4$ nanoparticles

All chemicals used are "AR grade" and purchased at Sinopharm Chemical Reagent. The synthesis method used is the hydrothermal method by reacting precursors made of FeSO$_4$.7H$_2$O, H$_3$PO$_4$ (85 wt.%), And ascorbic acid. The three materials were dissolved in 50 mL of deionized water using magnetic stirring so that all the materials reacted completely. LiOH that has been dissolved in deionized water is also needed and slowly added to the previous solution to maintain the Li:Fe:P molar ratio of 3:1:1. The resulting mixture was transferred to a stainless steel autoclave and then tightly closed to prevent oxidation of the precursors. The autoclave was stored in a silicone oil bath and heated to 100-180 ° C for 0-180 minutes with magnetic stirring. Furthermore, the autoclave is cooled to room temperature in an oil bath. The precipitate formed was separated from the supernatant by steam filtration and then washed several times with deionized water to produce pure $LiFePO_4$ nanoparticles. The supernatant is measured to measure its pH. The process of forming $LiFePO_4$ nanoparticles according to the flowchart in Figure 1.

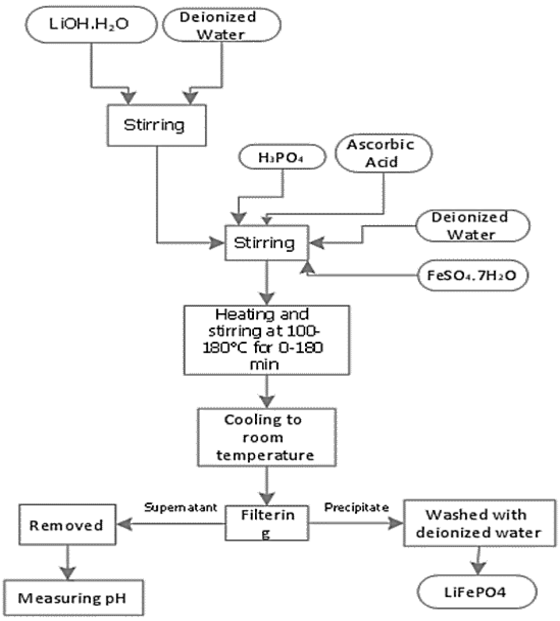

Figure 1. Flow diagram of the synthesis of $LiFePO_4$ nanoparticles

II.2. Energy and mass balance

The synthesis process of $LiFePO_4$ is shown in Figure 2. The materials needed for the synthesis of $LiFePO_4$ are 1.724 kg H_3PO_4, 0.2g ascorbic acid, 4.1703 g $FeSO_4.7H_2O$, and 49.85 mL H_2O. LiOH solution is also needed as a precursor. The solution was prepared by dissolving 1.8882 g $LiOH.H_2O$ in 29.91 mL H_2O. The synthesis process is carried out in a stainless steel autoclave stored in a silicone oil pen. The autoclave was heated to 100-180 ° C for 0-180 minutes with magnetic stirring. Then the autoclave is cooled to room temperature in an oil bath. The precipitate formed is separated from the supernatant by filtering. The precipitate is washed several times with deionized water to remove impurities. The work steps are made in the flow diagram in Figure 2. The formation of $LiFePO_4$ follows the chemical reaction equation as follows:

(1) $LiOH.H_2O_{(s)} + H_2O_{(l)} \rightarrow Li+_{(aq)} + OH\text{-}_{(aq)} + 2H_2O_{(l)}$

(2) $Li+_{(aq)} + OH\text{-}_{(aq)} + 3H_2O_{(l)} + H_3PO_{4(s)} + C_6H_8O_{6(s)} + FeSO_4.7H_2O_{(s)} \rightarrow LiFePO_{4(s)} + C_6H_8O_{6(s)} + H_2SO_{4(aq)} + 11H_2O_{(l)}$

From a technical point of view, the amount of $LiFePO_4$ nanoparticle production allows it to be increased because the capacity and quantity of tools and materials used can be enlarged. To produce about 16.2 kg of $LiFePO_4$ nanoparticles in one day, it takes 1 reaction cycle using about 188.82 kg of $LiOH.H_2O$, 172.4 kg H_3PO_4, 20 kg of ascorbic acid, 417.03 kg $FeSO_4,6H_2O$, and 7000 L H_2O. With a total raw material cost of Rp1.976.90.650.000,00 and a one-year profit of $ 536,679,789.24 in ideal conditions with a project life of 20 years.

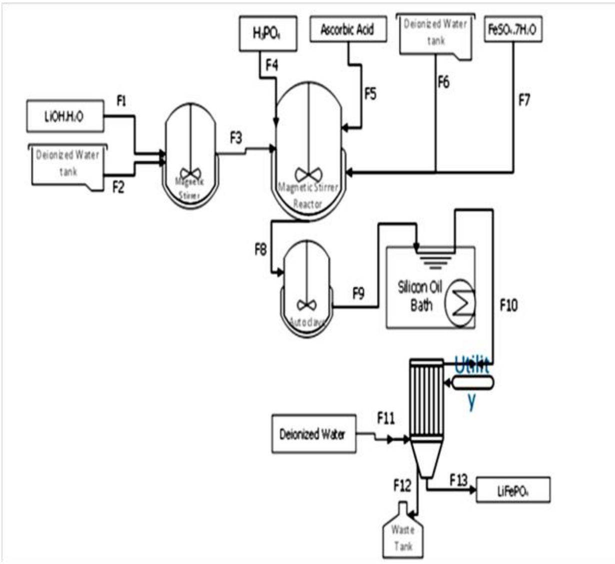

Figure 2. Flowchart of the $LiFePO_4$ nanoparticle synthesis process

II.3. Economic Evaluation

This method is done by analyzing some raw data. Then the data is calculated to obtain various evaluation meters. In short, to obtain economic evaluation parameters, several calculations can be used such as:

1. Break event point (BEP) is a value that describes the minimum production value to gain profit or loss. It has been calculated by dividing the fixed costs and profits [26].
2. CNPV (cumulative net present value) to predict and evaluate project conditions as a function of time (in years) [27].
3. Interval Rate of Return (IRR) is the rate of return on annual income so that the initial capital is reduced to zero during the project [28].

4. Profit investment (PI) is a ratio between the cumulative net present value and the total investment cost. PI corresponds to the type of return on investment or profit for each sale [26].

After doing the calculations, there are several assumptions in this study, including:

- Calculation of 1 USD is equivalent to IDR 15,000.00.
- All item prices are based on online market prices.
- The chemical composition in the reaction to form the $LiFePO_4$ nanoparticle product is increased by 1000 times.
- The purity of LiFePO4 nanoparticles is assumed to be 90%, while 10% is lost due to mechanical treatment.
- The cycle for making $LiFePO_4$ nanoparticles per day is 12 hours.
- Total salary per worker is assumed to be IDR 3,750,000 / month.
- 10% income tax.
- Value discount of 15%.
- The project operation duration is 15 years.
- The project lasts 300 days/year

III. Results and Discussion

III.1. CNPV in Ideal Condition

Figure 3 shows the relationship between the value of profit investment (PI) and the year of production. The curve shows constant income in the first and second years, and in the third year the return to the initial capital or called payback [26]. The increase in profit is then obtained every year until the 14th year.

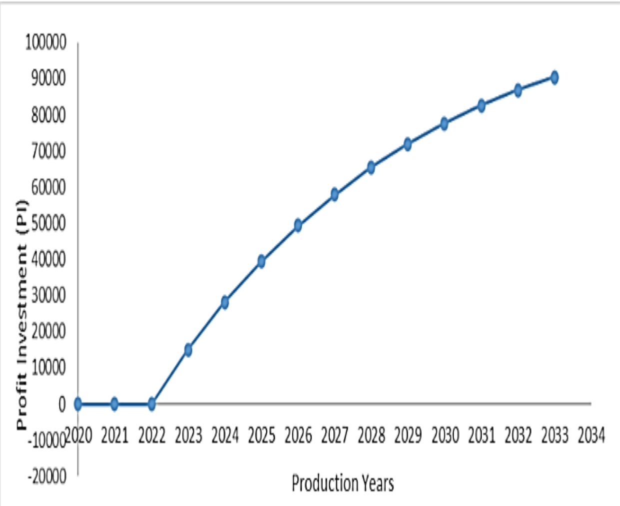

Figure 3. CNPV under ideal conditions per year

III.2. Tax Increase Variations

Figure 4 shows the effect of a tax increase on CNPV/TIC. The x-axis is the year of production while the y-axis is the CNPV/TIC value which is influenced by changes in tax prices. The tax rates vary from 10, 20, 30, 40, and 50%. The PBP value for each variation of tax increases is different. The greater the tax value, the longer the PBP is. The graph shows that the greater the tax value, the less profit will be received.

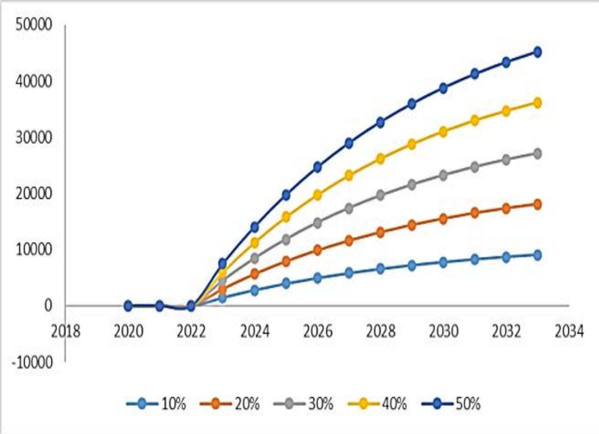

Figure 4. Variations in tax increases against CNPV/TIC

III.3. Selling Price Variations

Figure 5 shows the effect of the selling price on the CNPV/TIC value where the x-axis is the year of production and the y-axis is CNPV/TIC with the effect of the selling price. The variation of the selling price is the range if it is lowered or increased, namely 70, 80, 90, 100, 110, 120, and 130%. Based on Figure 5, the 130% selling price variant shows the fastest payback period or PBP while the 70% selling price shows the longest PBP. The payback period (PBP) is faster if the selling price increases, and longer if the selling price is lowered. The profit obtained with the same production time, which is 14 years, shows that the higher the selling price, the greater the profit, and if the selling price decreases, the profits will be smaller.

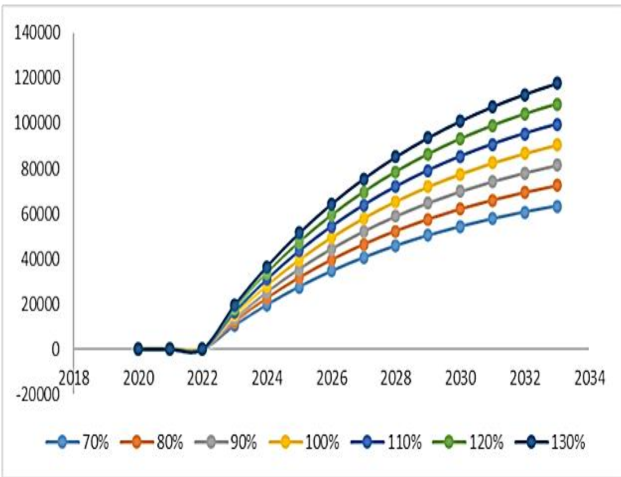

Figure 5. Variations in selling price increases against CNPV/TIC

III.4. Variations in Raw Material Prices

Figure 6 shows the variation in the price of CNPV/TIC raw materials against the year of production. The x-axis shows the year of production while the y-axis is the CNPV/TIC value which is influenced by the increase in raw material prices. Based on Figure 6, if there is an increase in raw material prices, the CNPV/TIC chart changes. If the increase is at 0%, the payback period (PBP) and profits decrease. This shows that the smaller the material, the smaller the profit and payback period (PBP) [29].

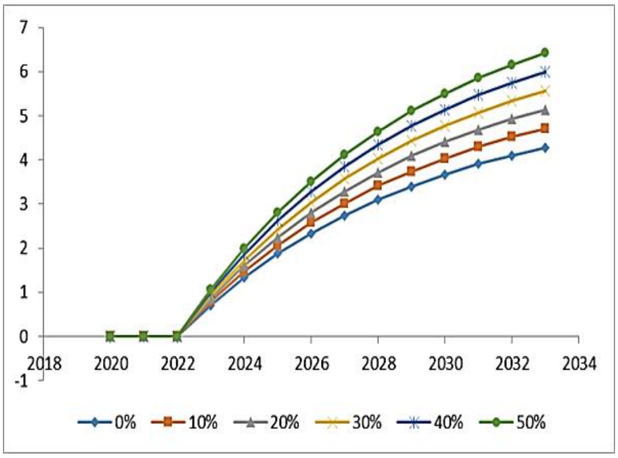

Figure 6. Variations in raw material prices against CNPV/TIC

IV. Conclusion

In the study, you have conducted regarding the economic evaluation and production layout of $LiFePO_4$ using the hydrothermal method. The results obtained in the economic evaluation are good. Based on the payback period (PBP) occurs in the fourth year of production and will increase until 2034. based on the tax price, the greater the tax price, the less profit is earned. The CNPV/TIC and PBP value analysis is mostly influenced by several factors such as price variations, sales tax and selling price. The results of our research regarding the economic evaluation and production layout of $LiFePO_4$ using the hydrothermal method are expected to provide an industrial scale depiction of economic and layout evaluation, especially in the production of $LiFePO_4$ which is used as a lithium ion battery.

Acknowledgements

Thanks to the course of industrial chemistry and Universitas Pendidikan Indonesia who have supported the preparation of this paper.

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