International Journal of Research and Applied Technology

1(1)(2021) 162-172
Journal homepage: https://ojs.unikom.ac.id/index.php/injuratech

Economic Evaluation on the Production of Poly-DADMAC and Sepiolite Nanocomposite

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Abstract. Some agricultural wastes are not suitable for direct disposal to standard sewage treatment plants and pre-treatment is required to avoid clogging by colloidal materials. One of the pre-treatment stages is coagulation and flocculation. In several studies, the mixture of polymer and clay fulfills the properties of coagulant and flocculant materials. A mixture of poly-DADMAC polymer and sepiolite clay can be used as a coagoflocculant at the same time. This study aims to analyze whether a project to manufacture clay polymer nanocomposites is feasible or not. By taking into account various perspectives including engineering and economic perspectives, this project is considered prospective to be carried out. This is indicated by the increase in the Profitability Index (PI) value of 5.33658 in the third year from -0.00975 which was the PI value the previous year. In twenty-four hours, the project can produce approximately 8.25 tonnes of adsorbent. The total profit earned in one year reaches 719,738.04 USD when run under ideal conditions. Apart from the results of the economic analysis mentioned, this project is also very effective in terms of time because it is simple and the raw materials needed are abundant.

1. Introduction

Nanocomposite is defined as a multi-phase material derived from a combination of two or more components, first is a matrix component as a continuous phase and second is a nano-dimensional phase as a discontinuous phase with one dimension of nano size with a diameter of less than 100 nm. Several types of composites have been developed by strengthening these composite compounds to polymers to increase their resistance to heat, mechanical and other barriers [1-2].

Water from some agricultural effluents (such as olive mills, wineries, pig farms, soybeans, or the coffee bean industry) is not suitable for discharge to standard sewage treatment plants, due to the large amount of organic and suspended matter. Annual production of black olive mill wastewater and highly toxic in Mediterranean olive-producing countries is estimated to be around 10–30 million m^3. Disposal of such waste without treatment is known to cause serious environmental problems [3].

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Coagulation and flocculation are processes that are often used in the primary purification of industrial wastewater (in some cases for secondary and tertiary treatment) [4-5]. Coagulation using chemical coagulants involves the incorporation of insoluble particles and dissolved organic matter into large aggregates to facilitate their transfer at subsequent stages of deposition, flotation and filtration [6]. Flocculation refers to the process by which unstable particles actually change into larger aggregates so that they can be separated from the wastewater. To achieve this effect, a series of industrial measures are used. In most cases, the process carried out is based on two separate stages, and in two separate tanks:

1. Neutralization of the charges to overcome electrostatic repulsion (yielding "coagulation")
2. Bridging between several relatively small particles to form larger aggregates that, due to their size and density, sink to the bottom of the vessel, leaving a clarified effluent (leading to "flocculation") [7].

Several studies have been reported on the examination of coagulation–flocculation aiming at performance optimization, that is selection of the most appropriate coagulant, determination of experimental conditions, assessment of pH effect and investigation of flocculant addition [8]. Aluminum sulfate (alum), ferrous sulfate, ferric chloride and ferric chloro-sulfate were commonly used as coagulants [9-10]. Iron salts were proved to be more efficient than aluminum ones, resulting in sufficient chemical oxygen demand (COD) reductions (up to 56%), whereas the corresponding values in case of alum or lime addition were lower (39 or 18%), respectively [11]. Additionally, high COD removal capacities have been observed during the combined action of alum and lime for the treatment of stabilized leachates [12]. Furthermore, the addition of flocculants together with coagulants can increase the rate of floc deposition [10].

Addition of "coagulants" and "flocculants" at the same time usually yields in the destabilization of the colloidal suspension, followed by flocculation of large amounts of suspended matter, lowering total suspended solids (TSS), turbidity, and even chemical oxygen demand (COD). This, in turn, increases the following water treatment efficiency, thereby reducing environmental hazards [13].

The nanocomposite used in this study uses the mineral sepiolite clay and cationic polymer poly-DADMAC. The nanocomposites are also used as "coagoflocculants" to incorporate colloid neutralization (coagulation), achieved by the polymer-charged parts and bridging of the neutralized particles (flocculation), achieved by the fact that polymer chains are linked to denser and heavier anchoring particles; this may result in highly efficient wastewater pre-treatment and reduction of TSS in a single treatment step [7]. Needle-like clay mineral sepiolite as anchoring particles and poly-DADMAC linear cationic polymer as bridging ribbon.

For efficient coagoflocculation, the anchoring particles should have the following properties :

1. A size or diameter of less than 0.5 μm in at least one dimension, resulting in a large specific surface area
2. The ability to adsorb cationic polymers in strong interactions
3. The bulk density of the particles should be larger than the density of the effluents.

Therefore, anchoring particles might be acicular (needlelike) clay minerals such as sepiolite and palygorskite or clay smectites such as montmorillonite, hectorite, laponite, and

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saponite. However, similar results might be obtained with non clay minerals such as zeolites or even powdered activated carbon [14].

The stability of the dispersion is related to its particle size, density and charge. Other than that, in organic waste colloids usually have a negative charge, cationic polymers must be used to neutralize the colloidal charge. In addition, the polymer must have medium to long chains with charges spread throughout to allow a bridging effect. The polymer must also be relatively water soluble to allow efficient distribution in the effluent. Therefore, suitable polymers might be :

1. Water-soluble linear polymers such as poly-DADMAC or cationic polyacrylamide;
2. Polyquaternium molecules such as quaternary hydroxyethylcellulose ethoxylate;
3. Cationic biopolymers such as cationic guar gum or chitosan;
4. Polymers with aromatic rings such as poly-4-vinylpyridine-costyrene and additional styrene-based cationic copolymers. The latter might even yield in additional π-π interactions with organic colloids, enabling more efficient coagoflocculation [13].

The purpose of this study was to evaluate the economic feasibility of production clay polymer nanocomposites using DADMAC polymer and sepiolite. Several economic evaluation parameters used, such as GPM, IRR, ARR, NPV, CNPV, BEP, PBP, and PI were analyzed to determine the potential production of valuable materials from fishery waste. Then, the economic parameters are tested by changing various economic conditions, such as labor, sales, raw materials, utilities, and external conditions.

2. Method

2.1. Polymer Clay Nanocomposite Synthesis Method

Materials used in the manufacture of polymer clay nanocomposites are **Sepiolite S9 clay** with a size of <200 mesh (the authors obtained it from TOLSA SA (Madrid, Spain)), with 99% pure mineral content, and **poly (diallyldimethylammoniumchloride)** (poly-DADMAC; molecular weight medium, 200,000-350,000 g/mol) (the author got it from Sigma-Aldrich). All ingredients are used without further treatment or purification.

The nanocomposites were prepared from sepiolite and poly-DADMAC at masses ranging between 3 and 2400 mg polymer/g clay. A concentrate batch containing 100 g clay/kg (10%) suspension was prepared. To produce nanocomposites, a solution containing the desired amount of polymer was prepared per gram of clay.

For example, the procedure for making a 10% stock suspension is as follows. The concentrated polymer (poly-DADMAC, usually 40% w/w) is dissolved in a suitable amount of warm water to obtain a final volume of 500 mL containing 5 g of polymer. The solution was placed in a sonication bath to obtain a homogeneous solution. After that, the polymer solution is poured into a container with 50 g of sepiolite and stirred vigorously for 2 hours. The preparation is completed when the clay aggregate is no longer observed, and the viscosity of the suspension is relatively low. An increased viscosity indicates that the polymer is not dissolving well or the process has not been completed, because a 10% suspension of most clay minerals in water (without polymer) produces a paste that cannot be used efficiently [13].

2.2. Energy and Mass Balance

To make the engineering process and calculate the mass balance in the production of clay polymer nanocomposites, several stoichiometric assumptions are used, including :

a. The cost of all equipment is based on a commercially available online marketplace;

b. The composition of DADMAC polymer with sepiolite clay is a ratio of 1:10 [13];
c. All reactants react perfectly, there are no by-products, the final product is just a polymer clay nanocomposite coagoflocculant.
d. In a one-day process, the total processing cycles are 3 cycles and 15 cycles/week.

From an engineering point of view, it is possible to increase the production of sepiolite poly-DADMAC nanocomposite because the capacity and quantity of the tools and materials used can be increased. To produce 110 kg of nanocomposite requires 1 reaction cycle of about 1000 L of water, 10 kg of DADMAC polymer, and 100 kg of sepiolite clay.

2.3. Economic Evaluation

The method used in this research is the method of economic feasibility analysis, which is calculated through a simple mathematical analysis. This method uses data obtained based on the average price of commercially available products in online shopping media (such as Bukalapak, Alibaba, Tokopedia, etc.). Some of the parameters used to assess the economic feasibility are described as follows :

a. **Gross Profit Margin (GPM)**
An analysis that estimates by subtracting the cost of goods sold from the cost of raw materials.
b. **Break Even Point (BEP)**
The minimum number of products that must be sold at a certain price to cover the total cost of production.
c. **Average Rate of Return (ARR)**
Total inflows during the investment period divided by the number of years in the investment period. This value is important for predicting the state of the project.
d. **Net Present Value (NPV)**
The value obtained from the project, takes into account expenses and income and uses discount rate considerations.
e. **Cumulative Net Present Value (CNPV)**
Calculate the total NPV value from the beginning of the construction of the plant to the end of the operation of the plant, which can be obtained as the sum of accumulated capital flows each year.
f. **Internal Rate of Return (IRR)**
IRR is a percentage that describes the average annual interest gain of all expenses and income of the same amount.
g. **Profitability index (PI)**
The index is used to determine the relationship between project costs and impacts.
h. **Payback Period (PBP)**
PBP is a calculation used to predict the length of time required for an investment to return to the total initial expenditure. PBP is calculated based on the time when the CNPV first reaches zero.
[15]

2.4. Parameters in Economic Evaluation

The feasibility test for the manufacture of clay polymer nanocomposites using sepiolite and DADMAC polymer was carried out by changing the ideal conditions to the worst conditions. Several variations of internal problems such as raw materials, utilities, labor salaries, and production quantities were applied, as well as external problems such as taxes. The basic points of the variety of internal and external problems are:

a. Variations in raw materials, utilities, and labor salaries are from 80% to 120%.
b. Variations in the number of sales, namely from 80% to 120%
c. The tax variation is from 10% to 100%.

3. Result and Discussion

3.1. Engineering Perspective

The process of making poly-DADMAC nanocomposite with sepiolite is shown in **Figure 1.** The process carried out is dissolving the DADMAC polymer using warm water from a water heater and then homogenizing it in a sonicator bath. To this solution was added sepiolite clay solids measuring <200 mesh. The mixture was then homogenized for 2 hours until it was evenly mixed and shaped like a paste [13].

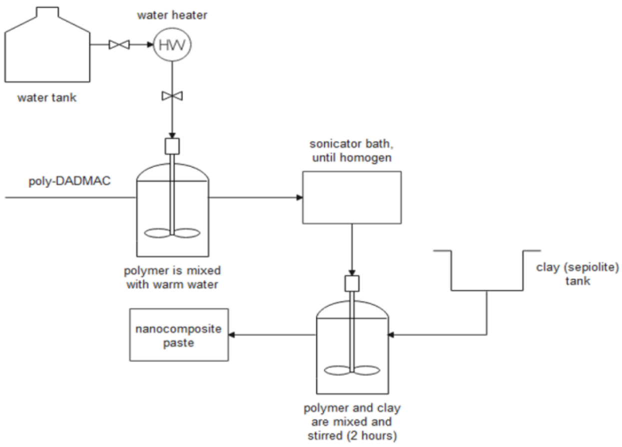

Figure 1. Process Flow Diagram (PFD) for production of nanocomposite from poly-DADMAC and sepiolite

From an engineering point of view, the total cost used to purchase raw materials for one year is 508,780.80 USD. Total annual sales is 3,049,200 USD with an annual profit of 719,738.04 USD. The cost analysis of the required equipment is 4,818.05 USD and the TIC should be less than 5,155.31 USD. This project requires a relatively low investment cost with a project life of 20 years to produce DADMAC sepiolite polymer nanocomposite with CNPV/TIC reaching 37.67% in year 20 and PBP achieved in third year.

3.2. Ideal Condition

Figure 2 shows a graph showing the relationship between lifetime (in years) plotted on the x-axis and the CNPV/TIC value (in %) plotted on the y-axis. The graph shows an analysis of the CNPV/TIC value carried out during the 20 years of the project. During the first two years, this project did not provide a profit because the CNPV/TIC value obtained showed a negative value below zero (0). This is because at the beginning of the project, the project was still under development. The lowest CNPV/TIC value was achieved in the second year with a value of -0.0098, then the CNPV/TIC value increased in the following year obtain reach 5.3366. In that year, the project experienced its first profit for three years of operation, this is called the Payback Period (PBP) where the project was able to recover the

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initial capital issued. In a period of 20 years, the CNPV/TIC value obtained reached 37,66668, which is the largest number that describes the highest profit that can be obtained by the project manager. With this analysis, the project of production nanocomposites based on poly-DADMAC polymer mixed with sepiolite is considered feasible.

Then in **Table 1**, the complete data for the CNPV/TIC value is presented for a period of 20 years.

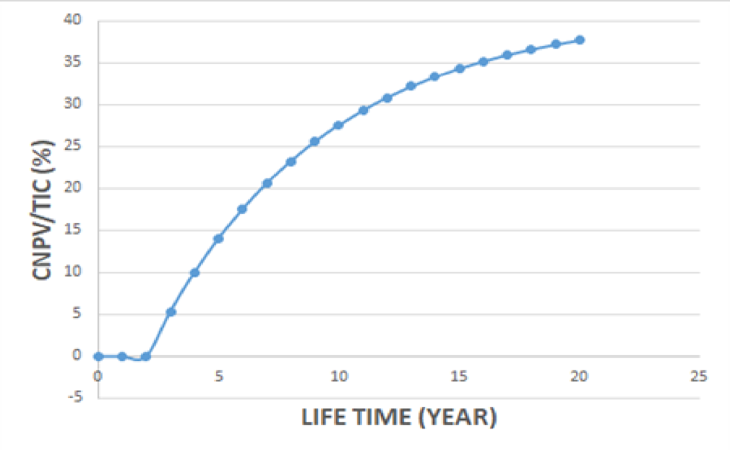

Figure 2. Graph of the value of CNPV/TIC under ideal conditions in a period of 20 years

Table 1. Annual CNPV values under ideal conditions

CPNV/TIC	YEARS
0	0
-0.00059	1
-0.00975	2
5.33658	3
9.98556	4
14.02815	5
17.54345	6
20.60023	7
23.25830	8
25.56966	9
27.57954	10
29.32727	11

30.84703	12
32.16856	13
33.31771	14
34.31698	15
35.18591	16
35.94150	17
36.59853	18
37.16986	19
37.66668	20

3.3. Changes in External Conditions (Taxes)

Economic evaluation of external factors might be one of the factors that can affect project success. One of the factors is the taxes to fund various public expenditures. **Figure 3** shows a 20 year CNPV value graph with various tax changes, where the y-axis is CNPV/TIC and the x-axis is lifetime (years).

The same results are shown at the initial one to three years due to variation in tax and CNPV project development. In addition, there was no income that year. The tax increase occurs two years later and will affect the CNPV value. When tax costs are added to the project, it will result in lower project profits. This is related to PBP, because the higher the tax, PBP for initial capital participation will be longer than ideal.

According to the PBP analysis, the funds required to pay the 10%, 25%, 50%, 75%, and 100% tax will be realized in the third year, which means the business is feasible, because when the project reaches the payback period (PBP), the project profit will continued to increase until the 20th year. The value of CNPV/TIC 10%, 25%, 50%, 75%, 100% in the 20th year is 3.77; 9.41; 18.83; 28.25; and 37.67%. Therefore, the highest point for obtaining BEP or project profit or loss is 100%.

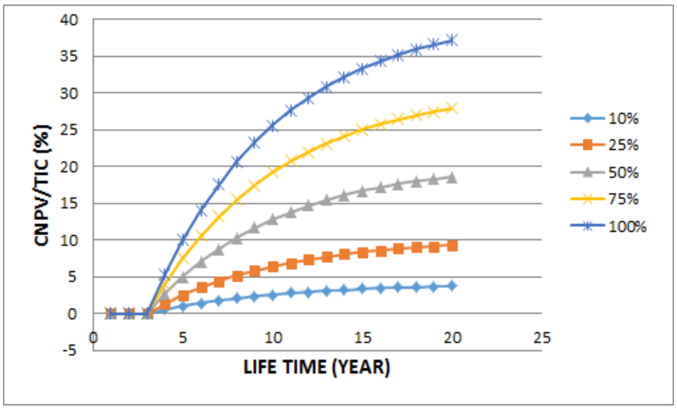

Figure 3. Graph of CNPV/TIC value on tax variations over a period of 20 years

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3.4. Changes in Sales Amount Variations

The analysis is carried out by varying the amount of the sales to 10% and 20%. The ideal sales are 100%, when the sales amount is decreased by 10% and 20%, the sales are 90% and 80%, but when the sales amounts are increased by 10% and 20%, the sales are 110% and 120%. The results of the PBP are shown in **Figure 4.** At the initial conditions of 0 to 2 years project with various variations showing the same CNPV/TIC value, this is because the project is still in the construction and development stage. The higher amount of sales, the profit will be increased. However, if there are conditions that cause a decrease in the number of product sales, the project's profits will fall from the ideal state.

Profits continue to increase after reaching the Payback Period (PBP) until the 20th year. From the PBP analysis, the funds will return on the third year sales in every variation in the number of sales. The profit increased every year as sales increased from ideal conditions. The value of CNPV/TIC in the 20th year for each variation of 80%, 90%, 100%, 110%, and 120% is 36.98; 37.32; 37.67; 38.01 and 38.36%. So sales will still yield a profit if the amount of sales is more than 100% or less than 100% because it can be seen on the graph that it still shows a positive CNPV/TIC value.

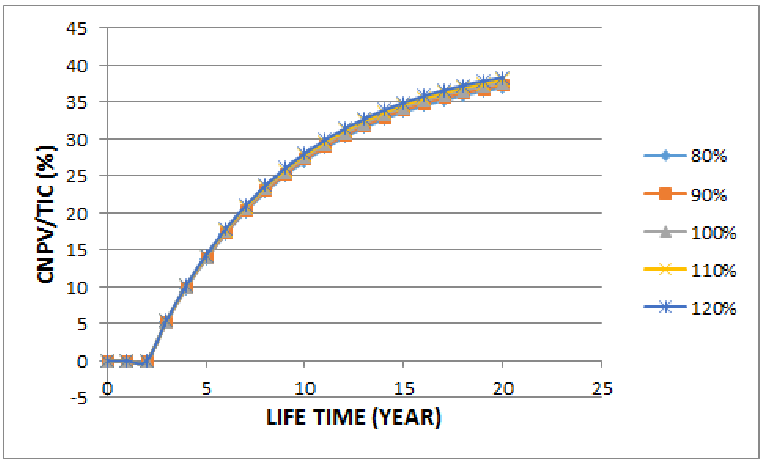

Figure 4. Graph of the value of CNPV/TIC on variations in the number of sales over a period of 20 years

3.5. Changes in varying needs (raw materials, utilities and labor salaries)

Many factors can affect the success of a project such as the raw materials, utilities such as electricity and water, as well as the salary for the labor to ensure the project goes well. **Figure 5** shows the graph of the relationship between the value of CNPV/TIC with lifetime in various raw material prices. This analysis is carried out by varying the price of raw materials to 10-20% from the initial price. The price variations used in this analysis are 80%, 90%, 100%, 110%, and 120%.

After being varied, the graph shows a similar trend. In the first two years, the project did not provide a profit, but in the following year there was a spike in the value of CNPV/TIC so that the project could earn a profit and experience PBP.

The value of CPNV/TIC in the 20th year for variations in raw material prices 80%, 90%, 100%, 110%, and 120% respectively was 36.0204; 36.8436; 37.6667; 38.4898; 39.3129. This value proves that the lower the price of raw materials, the higher profit will be generated.

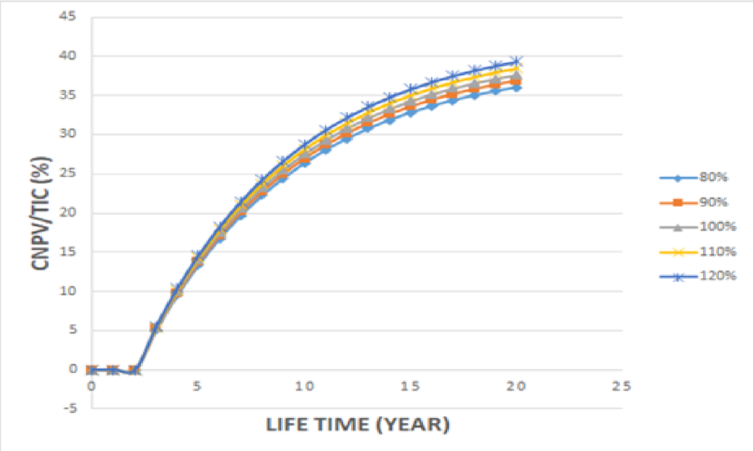

Figure 5. Graph of CNPV/TIC value on variations in raw material prices over a period of 20 years

The next factor is utility that the additional crucial requirements that need to be considered. The ideal sales are 100%, when sales are decreased by 10% and 20%, the sales are 90% and 80%, but when sales are increased by 10% and 20%, the sales are 110% and 120%. The results of the PBP are shown in **Figure 6**. At the initial conditions of 0 to 2 years with various variations shows the same CNPV/TIC value because the project is still in the construction and development stage. The effect of utility prices on the value of CNPV/TIC can be seen after third years. The results of the analysis show that the variation in utility prices affects the value of CNPV/TIC, but the project can still run and generate profits. The value of CNPV/TIC in the 20th year on the variation of utility prices 80%, 90%, 100%, 110%, and 120% is 32.62%; 35.14%; 37.67%; 40.19% and 42.72% . The closest PBP is achieved in the second year with the largest profit of 32.62% can be obtained from the 80% utility variation.

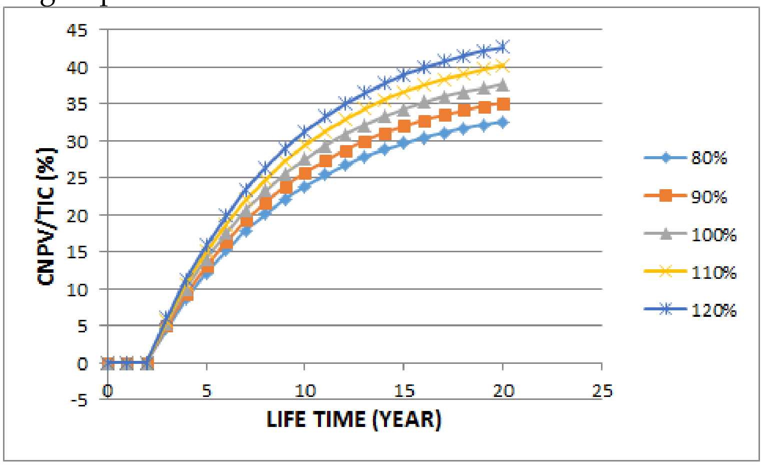

Figure 6. Graph of CNPV/TIC value on utility price variations over a period of 20 years

In addition, **Figure 7** shows a similar graph but with varying labor salaries. The analysis is carried out by varying the salaries of workers by 10% and 20% from ideal conditions. The variations used to analyze changes in workers' salary are 80%, 90%, 100%, 110%, and 120%. At the initial conditions of the project (0-3 years), the CNPV/TIC value obtained is in the area below zero (0). This is because in that year, the project was undergoing development.

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Changes in worker's salary will certainly affect the CNPV/TIC curve because the profits to be obtained from the project depend on the worker's salary. The higher worker's salary, the lower the profit of the project. Variations of changes in salary changes analyzed were 80%, 90%, 100%, 110%, and 120%. PBP is obtained in the third year the project is run, after the third year, the profit earned will continue to increase over time.

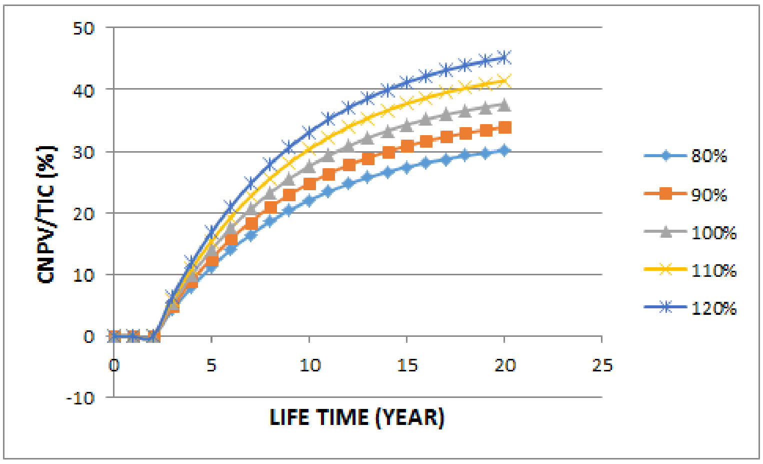

Figure 7. Graph of the value of CNPV/TIC on variations in labor salaries over a period of 20 years

4. Conclusion

Based on the results of the economic analysis carried out for various parameters, the project to produce clay polymer nanocomposites made from a mixture of poly-DADMAC with sepiolite is considered prospective when considering engineering and economic perspectives. This is indicated by the increase in the Profitability Index (PI) value of 5.33658 in the third year from -0.00975 which was the PI value the previous year. PBP analysis shows that the project can make a profit in the third year when the project is run, this is a good thing because PBP is obtained in a fairly short period of time. Thus, this project is considered to be able to compete in the market. In twenty-four hours, the project can produce approximately 8.25 tonnes of nanocomposite. The total profit earned in one year reaches 719,738.04 USD when run under ideal conditions. Apart from the results of the economic analysis mentioned, this project is also considered very effective in terms of time because it is simple and the raw materials needed are abundant. From the results of the economic evaluation analysis, it can be concluded that this project prospective to be carried out.

Acknowledgement

We would like to thank all those who have participated in helping us complete this research, especially our supervisor, Mr. Asep Bayu Dani Nandiyanto, so that our research can be written as information for further research.

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