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Techno-Economic Evaluation of the Production of Dysprosium-Doped Cobalt Ferrites Nanoparticles by Sol-Gel Auto-Combustion Method

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ABSTRACT

The purpose of this study was to examine two models of the economic feasibility of producing nanoparticle of dysprosium-doped cobalt ferrites by sol-gel auto-combustion method, from a laboratory scale to an industrial scale, including technical analysis and economic evaluation. Various economic evaluation parameters were analyzed to report the fabrication potential of dysprosium-doped cobalt ferrites nanoparticles in the case of the time required for a speculation to recover its total initial expenditure (PBP), the conditions of a generating project in the production function in years (CNPV), undertaking profits, etc. The results of the economic feasibility study on the production of dysprosium-doped cobalt ferrites nanoparticles showed that all parameter changes gave positive values, demonstrating that this project might have been practical to run commercially and on a large scale. Technical analysis to produce 26.4 tons of dysprosium-doped cobalt ferrites nanoparticles per year reveals that investment will be gainful then afterward more than three years. This project emulates PBP capital market guidelines due to the crisp return on investment. Estimates range from ideal to worst-case states in production to ensure project feasibility, including labor, sales, crude materials, utilities, external factors, and taxes.

1. INTRODUCTION

In the current era of globalization, the development of science is very rapid, especially in nanotechnology, which has enormous potential for various fields. Nanotechnology is a technology that involves precursors as a source of nanomaterials. The particle size and shape of the nanometer-scaled material are altered to achieve unique properties [1]. Nanomaterials in the form of particles are called nanomaterials. One of the magnetic nanoparticle materials that have been widely studied is cobalt ferrite ($CoFe_2O_4$) nanoparticles. $CoFe_2O_4$ nanoparticles were chosen because of their excellent electrical and magnetic properties. $CoFe_2O_4$ nanoparticles have potential in various applications, such as, in biomedicine as a fine magnetic material in drug delivery that acts as a target carrier [2], magnetic fluids [3], catalysts [4], antibacterial [5], etc. In the compound formula AB_2O_4 to Co_2Fe_4, cobalt ferrite belongs to the spinel ferrite oxide structure. The octahedral site (B) is governed by the Co^{2+} ion, while the octahedral and tetrahedral sites are governed by the Fe^{3+} ion [6]. Several research groups have studied the changes in physical and chemical characteristics of cobalt ferrite nanoparticles produced by substitution with different trivalent rare-earth cations. In cobalt ferrite nanoparticles, thulium substitution enhances optimization and tunability in conductivity, dielectric constant, loss, and dissipation factor [7]. Cobalt ferrite has been developed by several synthesis methods such as sol-gel, microemulsion, auto-combustion [8], and co-precipitation [9]. The standard ceramic method in the synthesis of nano ferrite powder was initially common, involving milling for hours at a high temperature of ~1000°C, and producing relatively large particles with irregular shapes. The nano ferrite powder product cannot be produced [10]. A detailed comparison of the synthesis of dysprosium-doped cobalt ferrites nanoparticles is shown in Table 1.

Sol-gel synthesis is a technique that can synthesize nanoparticles, where the chemical and crystallographic combination of this material has a finer particle size compared to metal alloys synthesized through traditional methods such as solid-state reactions. Another advantage of this method is that it can develop a crystallization method when the colloid phase is at a relatively low temperature, which is around 100°C [11]. Because of its low-temperature heat treatment and ease of use in comparison to other methods, sol-gel auto-combustion is a well-used method for synthesizing nano-scale ferrite powder [12]. Nanoparticles of doping spinel ferrite with a few rare-earth ions have freshly appeared as a guaranteeing technique for enhancing their physical properties [13]. The substitution of Fe^{3+} ions in spinel ferrite by rare-earth ions with an extensive ionic radius causes structural distortion, that significantly impacts the electrical and magnetic properties.

Table 1. Comparison preparation methods of dysprosium-doped cobalt ferrites nanoparticles

Method	Result	Advantage	Disadvantage	Ref.
Sol-gel auto-combustion route	Formation of face-centered cubic spinel ferrite and a narrower grain size distribution	Low-temperature condition	Conduct research on a lab scale	[14]
Sol-gel auto-combustion	Single phase cubic spinel structure and particle size in the range of 20-30 nm	Lower impurities result	Not producing on an industrial scale	[15]
Ultrasonication	Crystallite size of nanoparticles was around 7.8 nm and uniform dispersion of nanoparticles	Stability of nanocomposite	There is no analysis of economic evaluation	[16]
Citrate-gel auto-combustion	Spinel cubic structure	Slight agglomeration without any impurity pickup	Conduct research on a lab scale	[17]
Sol-gel	Spinel structure and homogeneity phase	The optimal calcination temperature could be determined	There is no analysis of economic evaluation	[18]

Table 2. Current literature on techno-economic analysis

Objective	Parameter	Result	Ref.
The feasibility of the production of zinc sulfide from zinc nitrate hexahydrate and thioacetamide by microwave irradiation method	GPM, CNPV, IRR, PBP, BEP, and PI	The profits increased over 20 years and the payback period was achieved within two years.	[19]
The feasibility of a hyaluronic acid fabrication project by extraction and isolation of the fish eyeball	GPM, PP, and PI	The investment will be profitable after more than four years and compete with the capital market standard.	[20]
Analysis of whether a project to manufacture clay polymer nanocomposites is feasible or not	PI and total profit earned	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.	[21]
The feasibility of producing zinc sulfide from zinc acetate and sodium sulfide using the precipitation-assisted ultrasonic radiation method	GPM, CNPV, IRR, PBP, BEP, and PI	The production of zinc sulfide nanoparticles by the 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.	[22]
The economic feasibility of producing copper oxide (CuO) nanoparticles using the green synthesis method on an industrial scale for 10 years	GPM, CNPV, and PBP	PBP analysis shows that the investment will be profitable after more than three years.	[23]
The feasibility of an industrial project to manufacture Cu nanoparticles through a biosynthetic method using *Citrus medica Linn*	PB), BEP, and CNPV	PBP occurred in the 3rd year with the CNPV/TIC value reaching 3.746% in the 9th year. Based on the economic evaluation, the project is concluded to be feasible to run with the anticipated tax and percentage of sales.	[24]
The economic feasibility of manufacturing hydroxyapatite nanoparticles from eggshell waste	GPM, PBP, BEP, IRR, CNPV, RI) and PI	The production of hydroxyapatite nanoparticles from eggshell waste is prospective. This project can compete with PBP capital market standards due to the short return on investment of around 3 years.	[25]
The feasibility of a project for the production of magnesium oxide nanoparticles using precipitation methods on a large scale	PBP, GPM, and CNPV	The production of magnesium oxide nanoparticles using the precipitation method can be carried out on an industrial scale. Payback Period analysis shows that the investment will be profitable after more than three years.	[26]
Computation in the techno-economic analysis of the production of aluminum oxide (Al_2O_3) using the precipitation method on an industrial scale	GPM, PBP, and CNPV	The manufacture of Al_2O_3 nanoparticles using the precipitation method could be done industrially.	[27]
The feasibility of a project for the manufacture of magnesium oxide nanoparticles using the sol-gel method by evaluating both technically and economically	GPM, IRR, BEP, PBP, and CNPV	Payback period analysis shows that the investment will be profitable after more than three years.	[28]

Several studies of economic evaluation about scaling up material production from laboratory scale to industrial scale have been published in many papers. Table 2 shows the current literature on techno-economic evaluation with objectives, parameters, and results [19-28].

There have been many studies related to the addition of materials or doping in the production of cobalt ferrite nanoparticles. In general, metal-based materials can be used as doping materials, such as nickel, aluminum, magnesium, strontium, and lanthanum. Substitution of doping is carried out on metal materials belonging to rare earth elements such as Nd, Sm, and Gd [29]. In this way far, investigations on Dy^{3+} substituted nano-sized cobalt ferrites have infrequently been published. This research aims to test the feasibility of fabricating nanoparticles of dysprosium-doped cobalt ferrite with the sol-gel auto-combustion method from a laboratory scale to an industrial scale, including technical analysis and economic evaluation.

In addition, several parameters of economic evaluation were utilized in light of the literature [30]. The evaluation used several economic parameters is:

a The payback Period (PBP) is the time required to recover the cost of an investment. The easiest way to get PBP is obtained from the CNPV curve. The value of PBP is determined by understanding the time when the CNPV/TIC value reaches zero for the first time [31].

b Gross Profit Margin (GPM) or gross profit is a type of profit that is calculated by subtracting income for one period from the cost of goods sold. The calculation of gross profit margin is the first step to determining the level of profitability of this project [32].

c Cumulative Net Present Value (CNPV) is the value obtained by the net present value (NPV) at a certain time. In short, CNPV is obtained by adding up the NPV value from the start of the project [31].

d Break Even Point (BEP) is the point where the income is equal to the invested capital, there is no profit or loss. BEP can be calculated by calculating the value of fixed costs divided by the value (total selling price minus total variable price). The calculation of BEP can be in the form of a projection or an estimate of the minimum number of goods that must be sold during a certain period [32].

e Internal Rate Return (IRR) is a calculation used to find the interest rate that equates the present value of expected future cash flows, or cash receipts, with the initial investment expenditure [32].

f Profitability Index (PI) is estimated by dividing the CNPV and the total cost of investment or sales, according to the PI type of profit for each investment or profit for sales [31].

g Return on Investment (ROI) is a ratio that shows the results (return) on the number of assets used in the company or a measure of management efficiency [31].

2. MATERIALS AND METHOD

2.1 Synthesis of dysprosium-doped cobalt ferrites nanoparticle using sol-gel auto-combustion method

Figure 1 depicts the sol-gel auto-combustion method for producing nanoparticles of dysprosium-doped cobalt ferrites. To guarantee every last one of the preparation steps is covered, the transform flow diagram is exhibited in Figure 2. Because of these figures, at least eight processing steps are involved in producing dysprosium-doped cobalt ferrites nanoparticles by the sol-gel auto-combustion method. The materials needed are metal nitrates (ferric nitrates $Fe(NO_2)_3.9H_2O$, cobalt nitrate $Co(NO_3)_2.6H_2O$, dysprosium nitrate $Dy(NO_3)_3.5H_2O$), and nitric acid. Detailed steps and additional information for producing dysprosium-doped cobalt ferrites nanoparticles by the method of sol-gel auto-combustion were reported elsewhere [33].

The production process is presented in the following steps (see Figures 1 and 2). Initially, all three metal nitrates act as oxidizing agents when mixed with citric acid, which affairs as a reducing agent (steps 1-5) to achieve the dark brown gel. Metal nitrates and citric acid are dissolved in deionized water separately in their tanks. The obtained gel was dried (step 6) to produce a powder. The dried powder was grinned using a commercial grinder (step 7), and the nanopowder as a product was then put on the burner for calcination (step 8). The final products, as dysprosium-doped cobalt ferrites nanoparticles, are put into the packaging step.

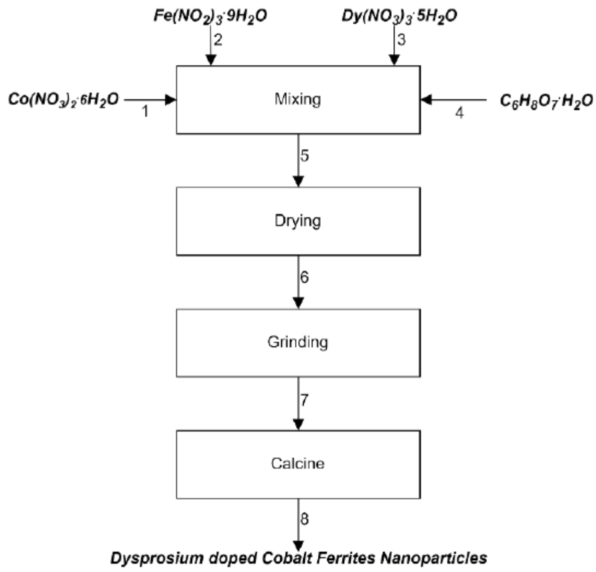

Figure 1. Scheme for production nanoparticles of dysprosium-doped cobalt ferrites using sol-gel route

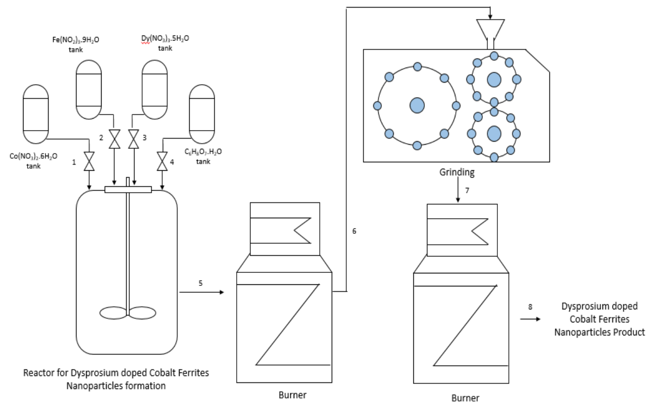

Figure 2. Process flow diagram for the sol-gel auto-combustion method to produce nanoparticles of dysprosium-doped cobalt ferrites

2.2 Method

This research utilized a method based on analyzing the cost of equipment and materials. The greatest data was computed in light of basic scientific calculations using the Microsoft Excel application. Economic parameters were conveyed to affirm the economic evaluation in this study. Several parameters of economic evaluation were utilized in light of the literature [30, 34-37]. Several bases were used to examine and predict a few possibilities throughout the project. The following basis is:

a) All examinations may be to USD. 1 USD = 15,000 rupiah

b) In light of commercially accessible costs for ferric nitrates (1.2 \$/kg), cobalt nitrate (8 \$/kg), dysprosium nitrate (20 \$/kg) and nitric acid (2 \$/kg). All materials are calculated from lab scale to industrial scale based on stoichiometric calculations.

c) The absolute investment cost (TIC) may be ascertained given the Lang Factor.

d) A year's worth of work equals 264 days (the remaining times were utilized to clear up and construct the process).

e) Area bought. Furthermore, area costs were included at the start of the plant project year and recuperated toward the end.
f) Devaluation was evaluated utilizing immediate measurement [38].
g) Dysprosium-doped cobalt ferrites nanoparticles are sold for 18 USD/pack.
h) A year project is equal to 264 days (and the remaining times were utilized to clear up and construct the process).
i) To clarify utility, utility units, such as kWh [20], can be explained and transformed into electrical units. The power unit can then be switched to charge. The cost of power raises the unit of power (kWh). The accepted utility rate is 0.0925 USD/kWh.
j) Absolute wages/labor would expect to be fixed at 400 USD/day (8 USD/day each).
k) The markdown rate will be 15% every year.
l) Salary charge will be 10% yearly.
m) The project's operational lifespan is 20 years.

Evaluation economy is conveyed to assess the project possibility. It is carried out by fluctuating the quality of sales, taxes, crude materials, work, and utilities under a few states. Tax varieties were conveyed out at 10, 25, 50, 75, and 100%. Varieties previously, sales, crude materials, work, and utilities were conveyed out at 80, 90, 100, 110, and 120%.

3. RESULTS AND DISCUSSION

3.1 Technical analysis

Based on the process shown in Figures 1 and 2, there is some additional information to facilitate the estimate calculation. The following information is:

a. The greatest chemical compositions in the reaction, for example, ferric nitrates, cobalt nitrate, dysprosium nitrate, and nitric acid used for the production of dysprosium-doped cobalt ferrites nanoparticles were expended up to 1000 times. The constituents are of great purity. The constituents are calculated [38].
b. Metal nitrate is a mixture with the respective mole ratio of ferric nitrates, cobalt nitrate, and dysprosium nitrate of 1.96 mol: 1 mol: 0.04 mol.
c. Metal nitrate and citric acid are reacted at a mole ratio of 3 mol: 2.22 mol. Both are assumed to have completely reacted to produce dysprosium-doped cobalt ferrites nanoparticles.
d. The conversion rate for the dysprosium-doped cobalt ferrites formation process is assumed to be 100%.
e. One production cycle produces 100 kg nanoparticles of dysprosium-doped cobalt ferrites. In a month, the production can reach 2,200 kg Nanoparticles of dysprosium-doped cobalt ferrites, while in one year, as much as 26,400 kg of product is produced. The by-products produced will be discarded and not used or utilized.

From an engineering perspective, the result confirmed that the production project is promising. This is because all the apparatus needed throughout the production process is commercially available, and the scale-up for processing from a lab scale to an industrial scale can take place without a hitch. In addition, to calculate a project with 264 processing cycles every year, the recommended scheme produced 26.4 tons of dysprosium-doped cobalt ferrites nanoparticles, a total of 21.12 tons of ferric nitrate, 7.92 tons of cobalt nitrate, 0.528 tons of dysprosium nitrate, and 1,188 tons of citric acid. The total cost of crude materials for a single year is 88,704 USD. Sales in a single year are 1,320,000 USD. The profit earned is 874,008 USD. Then, the analysis of the total cost of equipment requires a total cost of 83,867 USD. The project life of one year producing 26.4 tons of dysprosium-doped cobalt ferrites nanoparticles with CNPV/TIC was attained in the 3rd year.

3.2 Economic evaluation

Ideal Conditions

Figure 3 reveals a curve of the correlation of CNPV/TIC against the project period and Table 3 shows the detail of CNPV value under ideal condition. The CNPV/TIC is shown on Y-axis, and the x-axis is the lifetime (year). The graph indicates a decrease in revenue in years 0 to 2, due to the first capital costs, for example, the apparatuses needed for the synthesis of dysprosium-doped cobalt ferrites nanoparticles. The graph indicates a rise in earnings in the third year. This situation is called the PBP. Benefits can cover the initial investment, and profits will be growing until the twentieth year. Thus, the production of dysprosium-doped cobalt ferrites nanoparticles can be recognized as gainful. Because PBP is only about 3 years, this study necessitates a short period to recoup the investment costs. This project is perfect for running in industrial production. The PBP analysis investigates the point at which the profit ahead is less than the planned life of the project, which is said to be profitable.

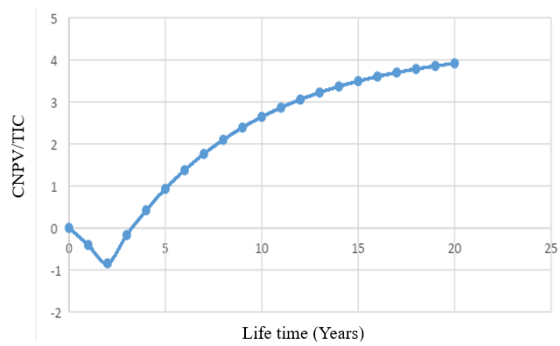

Figure 3. Ideal conditions for CNPV/TIC to a lifetime (year)

Table 3. CNPV values under ideal conditions

CNPV/TIC	Year	CNPV/TIC	Year
0	0	6.650377	11
-0.40658	1	7.038572	12
-0.84324	2	7.376133	13
0.522387	3	7.669665	14
1.709885	4	7.924909	15
2.742492	5	8.146861	16
3.640412	6	8.339863	17
4.421211	7	8.50769	18
5.100167	8	8.653627	19
5.690564	9	8.780529	20

The Influence of External Conditions in the Form of Taxes

A few external factors can have an impact on a project's completion. Other levies imposed by the state on projects to fund several public expenditures are the most influential external factor.

A curve of CNPV under tax conditions is described in Figure 4, where the y-axis is CNPV/TIC and the x-axis is the lifetime period (year). PBP is gained from several taxes. Figure 4 shows the beginning states (from 0 to 2 project years) under various tax has no chance of CVPV value. It might be caused by the project's growth. The tax effect on CNPV will be gained after the project is made (from 2 years). When it is combined, then the profits declined. Fortunately, this is related to the PBP project.

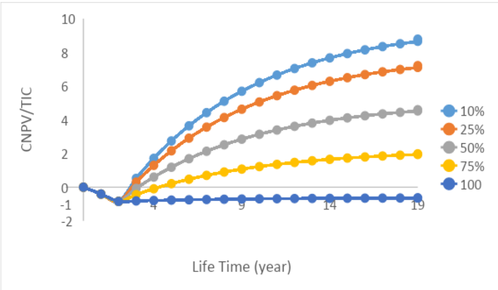

Figure 4. CNPV curve against tax variations

Based on the PBP evaluation, the funds are refunded when the taxes to be paid are 10, 25, 50, 75, and 100%, respectively, in the 3rd, 4th, and 5th year, and the PBP is not reached. After reaching the PBP, profits continue to rise until the 20th year. However, each year's profit margin is less and less as taxes and losses increase when the tax is waged at 100% of ideal conditions. The value of CNPV/TIC in the 20th year for each variation of 10, 25, 50, 75, and 100% is 8.78, 7.21, 4.59, 1.98, and -0.64%. So, the maximum tax on getting a BEP (the point at which gains and losses are in the project) is 75%. Tax changes of up to 75% lead to failure in the project. We carried out the CNPV/TIC graph analysis of tax variations. The evaluation effects display that the extra taxes are brought to the project (indicated with the aid of using clean dots; from zero to 65%), the fewer advantages are obtained.

The Influence of External Conditions in the Form of Sales

Figure 5 shows the initial conditions (from 0 to 2 years into the undertaking) of CNPV in several profits variations are not different. It is because of the undertaking's development. The profits effect on CNPV can be acquired after it is made (from 2 years). The more the profits fee, the higher profits will boom. Nonetheless, if the conditions worsen, the undertaking's income will be dropped from the proper situation.

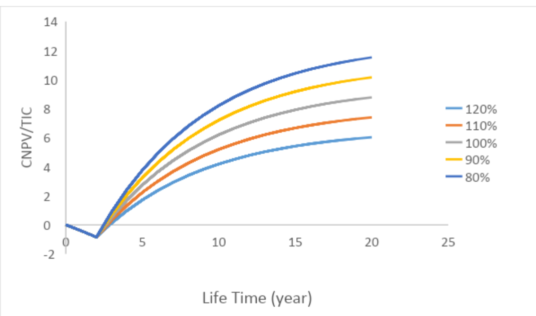

Figure 5. Sales variation CNPV curve

According to PBP evaluation, funds are reduced while income versions of 120, 110, 100, 90, and 80% are accomplished in the third year, and PBP is not accomplished. Profits will grow after it reaches the PBP until the 20th year. However, each year's profit margin is getting smaller as income is lower and losses are decreased with the aid of using 20% from best conditions. On the opposite hand, the income margin generated every 12 months will increase with growing income in best conditions. CNPV/TIC value in the 20th year for each variation of 120, 110, 100, 90, and 80% is 11.53; 10.15; 8.78; 7.41; and 6.03. Therefore, the minimum sales to get the BEP (at which profits, as well as losses, are in the project) is 90%. Less than 90% of changes will lead to failure. As in the sale of dysprosium-doped cobalt ferrites nanoparticles, it's far worthwhile if income is multiplied with the aid of using extra than 100% purpose the graph indicates a high-quality CNPV/TIC fee, because of this that the undertaking is viable to run.

The influence of External Conditions in the Form of Variable Cost

There are inner factors, which include the situation of uncooked substances, labor, and utilities which could affect the achievement of an undertaking. Figure 6 shows the CNPV curve with several raw materials. The CNPV/TIC is shown on the y-axis and the lifetime is shown on the x-axis. The analysis is done by lowering and increasing some factors such as the raw materials by 10 and 20%, respectively. Ideally, the raw material is 100%. When reducing the raw materials by 10 and 20%, it changes to 90 and 80%, respectively. When raw materials are increased by 10 and 20%, they reach 110 and 120%, respectively.

PBP is produced as a result of varying raw materials. Figure 6 depicts the PBP results. The initial conditions of CNPV under various raw material variations are the same (from 0 to 2 years into the project). This is due to the project's progress. After completing the project, the impact of raw materials on CNPV can be calculated (from 2 years). The less cost of raw materials, the project profits will be higher. But, if there are instances that purpose the fee of uncooked substances to grow, the undertaking income will lower at the right time.

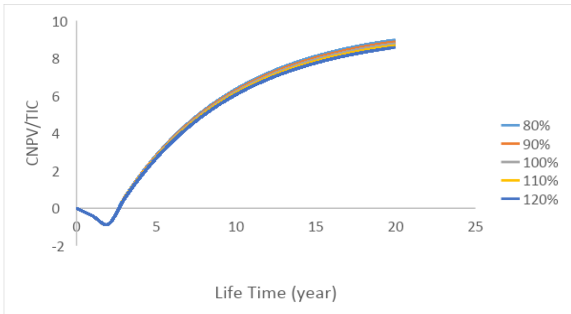

Figure 6. CNPV curve for variations in raw materials

According to PBP evaluation, finances are returned, while varying crude materials of 80, 90, 100, 110, and 120% are achieved in the third year. Profits increase until the twentieth year after completing the payback period (PBP). However, the earnings margin received each year becomes smaller with the increase in crude materials from ideal states. In contrast, the yearly profit margin rises when the cost of raw materials falls below optimal levels. The value of CNPV/TIC in the 20th year for each variation of 80, 90, 100, 110, and 120% is 8.98; 8.88; 8.78; 8.68; and 858. From the version of crude materials, the project will nevertheless run and make a profit.

Figure 7 shows the CNPV curve under variation in the workforce. The Y-axis is shown the CNPV/TIC and the x-axis is a lifetime. The investigation is carried out by decreasing and increasing the workforce by 10 and 20%. Ideally, the salary for workers is 100%. When reducing workers' salaries by 10 and 20%, they make 90 and 80%, respectively. When workers' salaries are raised by 10 and 20%, the workers' salaries become 110 and 120%, respectively. PBP is got from the results of varying workers' salaries. The results of the PBP are presented in Figure 7. The early situations (from 0 to 2 years of the project) of CNPV under various labor salaries are not different. It is because of the project's development. Labour influence on CNPV can be gained after creating the project (from 2 years). No significant change is found from the labor variation curve to the CNPV graph. The PBP value in each variation of the workforce is still gained in the 3rd year. But, the CNPV/TIC have different values in the 20th year in every variation. The main difference in values for every variation of 80, 90, 100, 110, and 120% is 9.18; 8.98; 8.78; 8.58; and 8.39. From the staff variant, the task nevertheless runs and gives profitability.

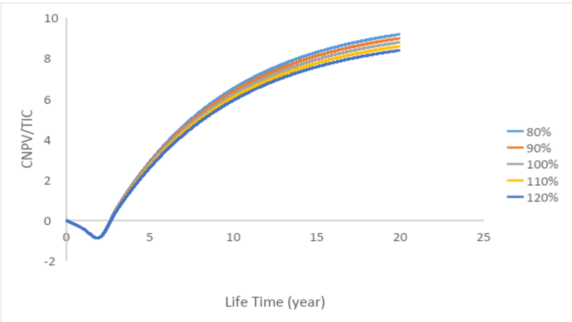

Figure 7. CNPV curve of labor variation

Figure 8 suggests a CNPV graph with diverse software variations. The y-axis is the CNPV/TIC, and the x-axis is the lifetime (year). The evaluation is done via way of means of growing and lowering software costs via way of means of 10 and 20%. The perfect software value is 100%. When the software is decreased via way of means of 10 and 20%, the software is ninety and 80%, respectively. When the software is improved via way of means of 10 and 20%, then the software is one hundred ten and 120%.

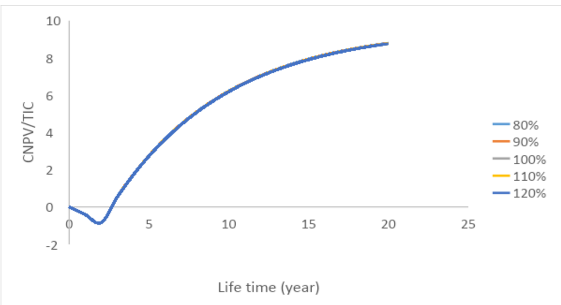

Figure 8. CNPV curve of labor variation

PBP is received from the outcomes of application versions. The PBP outcomes are proven in Figure 8. The preliminary conditions (from zero to two challenge years) of CNPV in diverse application versions are the same. This is because of the challenge's development. The application impact on CNPV may be received after the challenge is created (from 2 years). There is no any full-size alternate from the application variant to the CNPV graph. However, the CNPV/TIC price differs withinside the twentieth 12 months in every variant. The distinction in values for every variant of 90, 100, 110, and 120% is 8.80; 8.79; 8.78; 8.77; and 8.76. In PBP, every variant of application remains accomplished withinside the third 12 months. With the application variant, the project can nevertheless run and profit.

4. CONCLUSION

In light of the above analysis, the project for the sol-gel auto-combustion method to produce dysprosium-doped cobalt ferrites nanoparticles is prospective from an engineering angle and more truly guaranteeing in economic evaluation. The PBP analysis reveals the gainfulness of the investment after more than 3 years. This project can attempt with the PBP capital market guidelines due to the short profit looking into investment. Several factors influence this profit to incorporate utilizing the sol-gel combustion method a result this method is less complicated and inexpensive. From this economic evaluation analysis, we could finish up that this project is achievable to run.

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