

Economic Analysis of the Preliminary Design of a Chemical Mini plant to produce Palm Oil Based Estolide Calcium Sulfo-Ole Heavy-duty Bio grease with a Capacity of 36 Tons/Year

Muhammad Luthfi *, Sukirno

Department of Chemical Engineering, Faculty of Engineering, Universitas Indonesia
Jl. Dr. Indro S, Kukusan, Beji, Depok City, West Java, Indonesia, 16424

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Abstract

[Economic Analysis of the Preliminary Design of a Chemical Mini Plant to produce Palm Oil Based Estolide Calcium Sulfo-Ole Heavy-duty Bio grease with a Capacity of 36 Tons/Year] The rapid growth of the automotive, manufacturing, and heavy-duty industries has increased lubricant demand, particularly lithium-based grease. However, due to supply constraints and rising costs, calcium is a more sustainable substitute for lithium in lubricants. This study develops heavy-duty bio grease based on palm oil estolide with calcium sulfo-oleate as a more economical and eco-friendlier alternative. The research adopts a pilot-scale approach with a 36 tons/year production capacity, aligned with Micro, Small, and Medium Enterprises (MSMEs). The product, heavy-duty bio grease Calcium Sulfo-Ole, uses Estolide Base Oil SAE 40 as the primary component. The process includes epoxidation, esterification, saponification, and formulation. Testing confirms that the ester-based oil has high viscosity and oxidative stability, making it suitable for NLGI 2 standard applications in heavy machinery. Economic analysis indicates strong viability, with a positive Net Present Value (NPV) of Rp1.3 billion over 10 years, Internal Rate of Return (IRR) of 13%, and Return on Investment (ROI) of 206%. The Break-Even Point (BEP) reached 83% capacity, proving feasibility. This bio grease reduces reliance on lithium-based lubricants while promoting sustainable, plant-based lubricants.

Keywords: calcium sulfo-oleate; economic analysis; estolide, heavy-duty bio grease; MSMEs

1. Introduction

The rapid growth of various industries, including automotive, manufacturing, and heavy equipment, has led to an increasing demand for lubricants, particularly in Asia, which accounts for 49% of global lubricant demand by region (Sazzad et al., 2024). One widely used type of lubricant is grease, a semi-solid lubricant composed of base oil, a thickening agent, and additives (Pirro & Daschner, 2001). Grease plays a crucial role in reducing friction, preventing wear, and improving machine component efficiency.

Various types of grease are used depending on specific application needs, each offering unique performance characteristics. Lithium grease, for example, is widely used for its excellent thermal stability,

mechanical load capacity, and water resistance. Calcium grease is known for its biodegradability and good water resistance, making it suitable for environmentally sensitive applications. Aluminum complex grease provides superior rust protection and is commonly used in the food industry due to its non-toxic properties. Polyurea grease is preferred in electric motor bearings because of its oxidative stability and high-temperature performance. Clay-based (bentonite) grease is suitable for high-temperature operations due to its non-melting nature, and sodium-based grease offers good oxidation resistance, though with limited water resistance. These diverse types of grease underscore the importance of selecting the appropriate formulation to ensure optimal equipment performance under various conditions.

One of the most popular types of grease is lithium complex grease, classified as National Lubricating Grease Institute (NLGI) 2, which is commonly used for vehicle wheel bearings (Japar et al., 2018). The classification of this grease is based on its stiffness level

*) Corresponding Author.

E-mail: muhammad.luthfi310@ui.ac.id

according to NLGI standards, where NLGI 2 grease maintains a balance between softness and hardness, making it suitable for various operating conditions. Its primary components include mineral oil as the base oil and lithium complex as the thickener, which provides thermal stability and high mechanical load resistance.

Although lithium complex grease has been widely used, its production faces significant challenges (Barriga et al., 2005), particularly regarding lithium availability and cost. Lithium hydroxide (LiOH), the key ingredient in lithium complex thickeners, has become increasingly expensive and scarce due to the rising demand for electric vehicle batteries (Niu & Qu, 2018). This has led to competition for raw materials between the lubricant and battery industries, prompting researchers to explore more economical and sustainable grease thickener alternatives. One promising alternative is calcium complex-based thickeners, produced through the saponification reaction between calcium hydroxide (Ca(OH)_2) and various fatty acids, such as 12-hydroxystearic acid (12-HSA) and acetic acid (Wagiman et al., 2011). Calcium-based grease offers several advantages over lithium complex grease, including better water resistance, higher biodegradability, and lower raw material costs (Sukirno et al., 2010). Therefore, substituting lithium thickeners with calcium complex thickeners presents a promising solution to reduce lithium dependence and create more environmentally friendly products.

The use of calcium-based grease has been explored in several previous studies, including the development of complex calcium bio grease and over based calcium sulfonate bio grease. Zahir (2012) developed complex calcium bio grease using Ca(OH)_2 , stearic acid, epoxidized oleic acid, and acetic acid as complexing agents, with epoxidized refined bleached deodorized palm oil (RBDPO) as the base oil. The study found that the resulting grease had a high dropping point, making it suitable for heavy-duty applications. Dewi (2012) also studied over based calcium sulfonate bio grease, formulated using Ca(OH)_2 , LABSA (Linear Alkyl Benzene Sulfonic Acid), and CaCO_3 . This grease exhibited better anti-wear properties than complex calcium oleate grease due to its micellar structure, which effectively neutralized acidic oxidation by-products (Prasannakumar et al., 2025). Susilowati (2023) later combined these two types of thickeners to create calcium sulfo-ole grease, which demonstrated a higher dropping point and improved wear resistance. With its high thermal stability and ability to withstand extreme pressure, this grease is well-suited for heavy equipment such as bulldozers, cranes, excavators, tractors, and dump trucks (Castañeiras et al., 2017), which operated in extreme conditions in the construction, mining, and forestry sectors (Siswanto, 2008; Ministry of Industry of the Republic of Indonesia, 2017).

This study will further explore the production of heavy-duty bio grease, which has yet to be available in Indonesia, based on RBDPO estolide with SAE-40 specifications and a thickener combination of Ca(OH)_2 and CaCO_3 . The SAE-40 base oil, produced through epoxidation and esterification, has a high viscosity index, making it suitable for heavy-duty applications that require optimal lubrication and extreme pressure resistance (Kurre & Yadav, 2023).

Additionally, to enhance its performance, this bio grease will be formulated with additives that provide surface protection against wear and improve load-bearing capacity (Abouelkasem et al., 2024). This research develops high-performance, environmentally friendly bio grease using SAE-40-quality estolide as its primary raw material. Additionally, this study will conduct an economic analysis and evaluate production on a pilot scale with a capacity of 36 tons/year to assess the feasibility and commercialization potential of heavy-duty bio grease based on palm oil. The findings are expected to provide a more economical, environmentally friendly, and high-performance lubricant alternative for the heavy equipment industry.

2. Research Methods

2.1 Design and Production Scale of Heavy-duty Bio grease

This study is a pilot-scale continuation of the research conducted by Susilowati (2023) at the laboratory scale. The difference between the pilot scale and the laboratory scale lies in production capacity, while the process flow remains the same. The developed product is heavy-duty Bio grease Calcium Sulfo-Ole, based on palm oil estolide, with Estolide Base Oil SAE 40 as the primary raw material for grease production. The manufacturing process consists of several key stages, including raw material preparation, epoxidation reaction, esterification reaction, saponification, and the product collection stage, as outlined in Table 1.

Table 1. Gantt Chart of Tasks in a Single Batch

Types of Work	Hour to-
Raw Material Preparation	1
Epoxidation	2 – 4
Cleaning	5
Esterification Reaction	5 – 9
Cleaning	10
Saponification	11– 13
Product Collection	14
Cleaning	14

The time required to reach optimal output is approximately 14 hours per batch, with a total annual production of around 36 tons/year. The production

capacity of 109 kg per day was selected to meet the annual production target of approximately 36 tons of bio grease. This target is based on an assumed 330 operational days per year. This study adopts a mini plant concept suitable for Micro, Small, and Medium Enterprises (MSMEs), allowing for more flexible and cost-effective implementation. The production site is planned to be located in West Java, with a designated area of approximately 200 m².

The planned workforce consists of a total of 14 employees, including 10 technical operators, 1 security guard, and 3 staff members with bachelor's degrees. To ensure smooth and continuous operations across all process units from raw material preparation to final cleaning the workforce is organized into a hybrid two-shift system.

The morning shift (06:00-13:00) includes 1 Supervisor Process Engineer, 2 Process Operators, 1 Mechanical Operator, 1 Quality Control staff, and 1 Logistic Support staff. The afternoon shift (13:00-20:00) follows the same composition, ensuring consistent operational coverage. One of the S1-level employees works as an administrative officer from 06:00 to 15:00, handling tasks such as logistics management, batch documentation, and preparation of production reports. Additionally, 1 security guard (with a high school diploma) is scheduled to work from 06:00 to 20:00 to ensure site safety. This staffing arrangement allows for effective management of all production processes using the available human resources.

Operational planning, as reflected in the Gantt chart, shows that the process can run continuously without interruption. Furthermore, this study includes an economic analysis to assess the feasibility of heavy-duty bio-grease production. The analysis covers capital investment, production costs, and profitability, helping to determine future prospects for the industry in terms of operational efficiency, cost-effectiveness, and potential for growth.

The production of bio grease begins with raw material preparation, followed by epoxidation, esterification, saponification, and product collection. Epoxidation is a key functionalization reaction that converts double bonds into more stable functional groups, enhancing the oxidative stability of vegetable oils (Salimon et al., 2011), providing plasticizing properties (Joseph et al., 2014), coating applications (Derawi & Salimon, 2016), and suitability for high-temperature lubricants (Lathi et al., 2007). The process produces more reactive epoxidized oil (Danov et al., 2017), with improved oxidative stability (Nor & Salimon, 2022) and the addition of epoxide groups to the compound (Jalil et al., 2014). This reaction lasts approximately three hours (Nor & Salimon, 2022).

The esterification process, or palm oil hydroxy oleate (POHO), involves reacting epoxidized oil with organic acids or alcohols to form esters (Ob-eye et al., 2021), enhancing lubrication properties and viscosity (Cohen et al., 1953).

This esterification process produces esters that possess crucial lubrication properties such as improved viscosity, which enables the formation of a stable lubricating film on metal surfaces. This strong lubricating film reduces direct metal-to-metal contact, thereby minimizing wear and extending the lifespan of machine components. Additionally, these esters enhance thermal stability and oxidation resistance, allowing the lubricant to perform effectively at high temperatures and slowing degradation caused by oxidation. These properties also contribute to reduced friction between moving surfaces, which can improve energy efficiency and decrease heat generation during machine operation.

The resulting ester-based oil exhibits improved lubricant characteristics (Annisa & Widayat, 2018), producing SAE-40 estolide base oil through epoxidation and esterification (Kurre & Yadav, 2023). This process takes approximately five hours, as shown in Nor & Salimon (2022), which recorded a reaction time of 4.96 hours.

Saponification follows, reacting fatty acids with alkali to form thickening agents or soap (Saleem et al., 2024). The previously obtained ester undergoes a reaction with strong bases to produce soap (Agrawal et al., 2022), serving as a thickener in bio grease (Boner, 1937). This process takes approximately three hours.

In the product collection stage, the thickener is mixed with estolide-based SAE-40 oil, modified to achieve the desired consistency and stability. The resulting heavy-duty Bio grease Calcium Sulfo-Ole is a high-performance, environmentally friendly, and biodegradable lubricant.

2.1 Economic Analysis

In the economic analysis, the initial investment represents the costs incurred at the establishment of the plant or business. Capital investment consists of two components: fixed capital and working capital (Peters et al., 1991; Turton et al., 2009). Fixed capital refers to the initial costs of setting up the production layout, including the purchase and installation of equipment. Meanwhile, working capital is required on an ongoing basis to support production, covering expenses such as raw materials, electricity, and water. Fixed capital includes the procurement and installation of equipment, construction of production facilities, laboratory space for storage and sample testing, and a safe waste disposal site. Direct costs cover these components, while indirect costs include reserves for equipment maintenance. Electricity costs for the pilot-scale operation (categorized as a business) are

assumed MSMEs standards. According to government regulations, business electricity tariffs require a power supply of > 200 kVA, with a rate of Rp1,035.78 per kWh (Ministry of Energy and Mineral Resources of the Republic of Indonesia, 2016).

Next, the production costs in this study consist of manufacturing costs and general costs. Manufacturing costs include all operational expenses in the production process, such as raw materials, electricity, water, employee salaries, packaging costs, equipment maintenance, and patent fees. Meanwhile, general costs cover non-production expenses, including administration, marketing, legal consulting, and occupational safety and health (OSH) expenses for employees.

In profitability analysis, according to Abouelkasem et al., (2024), it is used to assess the financial feasibility of the bio grease production plant. Several key indicators used include:

a. Net Present Value (NPV)

NPV measures the difference between the present value of cash inflows and outflows over a specific period. A positive NPV indicates that the plant is profitable and feasible to operate. The formula used to calculate NPV is shown in Equation (1).

$$NPV = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} \quad (1)$$

where B_t represents the benefit per year, C_t also denotes the cost per year, t refers to the time period (1,2,3,...), n is the total number of years, and i represents the interest rate.

b. Internal Rate of Return (IRR)

IRR is the discount rate that makes the NPV equal to zero. An IRR higher than the cost of capital indicates that the plant is profitable. The formula used to calculate IRR is shown in Equation (2), with the interest rate determined in Equation (3).

$$IRR = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} = 0 \quad (2)$$

$$i = DF_1 \left(\frac{NPV_1}{NPV_1 - NPV_2} \right) (DF_2 - DF_1) \quad (3)$$

where DF_1 is the discount factor that results in a positive NPV, DF_2 is the discount factor that results in a negative NPV, NPV_1 is the NPV at DF_1 , and NPV_2 is the NPV at DF_2 .

c. Return On Investment (ROI)

ROI can be calculated by dividing the annual profit from sales by the initial capital. The formula used in Equation (4).

$$ROI = \frac{P}{TCI} \quad (4)$$

where P represents gross profit and TCI stands for Total Capital Investment

d. Payback Period (PP)

PP is the time required to recover the capital of a plant, which can be calculated by dividing the capital by the after-tax cash flow. The formula used in Equation (5).

$$PP = \frac{TCI}{P + D} \quad (5)$$

where TCI is Total Capital Investment, P is gross profit, and D is depreciation.

e. Break Even Point (BEP)

BEP is the point where total revenue equals total production costs, resulting in neither profit nor loss. BEP indicates the minimum production or sales volume required to avoid losses. The formula used to calculate BEP is shown in Equation (6).

$$\begin{aligned} R &= TC \\ rQ &= FC + vQ \end{aligned} \quad (6)$$

where R represents revenue, TC is the total cost or total production cost, FC is the fixed cost, r is the price per unit, and v is the variable cost per unit.

The BEP percentage is determined by the intersection point of the total cost and revenue graph.

3. Results and Discussion

3.1 Heavy-duty Bio grease Manufacturing Process

In the raw material preparation stage, refined bleached deodorized palm oil (RBDPO) with 100% purity is used as the main feedstock. Technical-grade formic acid (90% purity) and hydrogen peroxide solution (50% purity) are prepared as oxidizing agents. Oleic acid (epoxidized) with high reactivity, p-Toluenesulfonic acid (p-TSA, 97% purity) as a catalyst, and other reagents such as technical-grade acetic acid (96%), LABSA (100% purity), calcium hydroxide (96% purity, pH 12.6), calcium carbonate (98% purity), and Butylated Hydroxytoluene (BHT, food-grade antioxidant) are also prepared and verified for specification compliance prior to the reaction steps. All reactions are conducted under ambient pressure.

The bio grease manufacturing process involves a series of batch-operated equipment units specifically designed for pilot-scale production. The process begins with the epoxidation reactor, which consists of a stainless-steel vessel equipped with a gear motor, motor coupling joint connectors, insert bearing shaft supports, and a turbine-type agitator. Heat control during the exothermic reaction is managed using a 16 mm x 6 m helical tube heat exchanger, integrated externally. The reactor operates under ambient pressure and maintains a temperature range of 50–60°C for approximately 4.5 hours. A booster pump is used for circulation, and raw materials are initially prepared in an HDPE feed tank connected to the system.

In the epoxidation process (Ju et al., 2020), palm oil reacts with peracid to form epoxide groups at the double bonds of fatty acids. The raw material ratio is palm oil, formic acid, and hydrogen peroxide in a 1:3.6:3 molar ratio (Sukirno & Fajar, 2024). The reaction proceeds for approximately 4.5 hours, using external water cooling to manage exothermic heat in the reactor. The product is epoxidized palm oil, a functional intermediate for further reactions.

Following epoxidation, the product is transferred to the esterification reactor, which is structurally similar to the epoxidation unit but includes additional heating components, such as a tubular heater, thermocouple, and temperature controller to achieve higher temperatures between 100–120°C. This reactor is also equipped with a gear motor with speed control and a turbine agitator to ensure uniform mixing. The esterification reaction typically lasts about five hours under atmospheric pressure.

Several HDPE holding tanks are integrated between major process steps (labeled as Tanks 1, 2, 3, and 4), each fitted with ball valves for material flow control. These tanks are used for intermediate product storage, settling, or washing processes as needed.

The estolide is then reacted with two thickening agents: Complex Calcium Oleate (Ca-Oleate) and Over based Calcium Sulfonate (Ca-Sulfonate). The base oil to thickener ratio is 75:25, while the thickener ratio between Ca-Sulfonate and Ca-Oleate Complex is 10:90. According to Povkha et al. (2015), grease typically consists of 80–90% base oil and 10–20% thickening agent, with variations depending on the specific formulation and application.

For saponification, a separate stainless steel batch reactor is employed, specifically built for alkaline reactions. It is equipped with multiple motors and speed controllers to drive both turbine and anchor-type agitators, ensuring proper mixing of viscous soap-forming components. The reactor includes integrated heaters, thermocouples, a temperature control panel, and a dedicated control box. The reaction typically operates

at 70–90°C and lasts for about three hours under ambient pressure.

The final stage involves a cooling and homogenization batch reactor, which has a similar configuration to the saponification unit. It is designed for post-reaction blending and viscosity adjustment. This unit also includes multiple agitation systems and temperature controllers to ensure uniform consistency throughout the bio grease matrix. Cooling is carried out naturally or via external water circulation.

Altogether, the production system is arranged in a semi-continuous, serial layout, with each unit operating batch-wise but coordinated throughout the day to maintain efficient workflow. The equipment design ensures scalability, ease of control, and suitability for small-to-medium enterprises (SMEs) or pilot production environments.

3.2 Bio grease Production Reactor

The design and validation of the reactor are based on equipment developed by the National Research and Innovation Agency (BRIN) which is divided into two stages. The First stage involves epoxidation and esterification processes using modified reactor as illustrated in Figure 1.

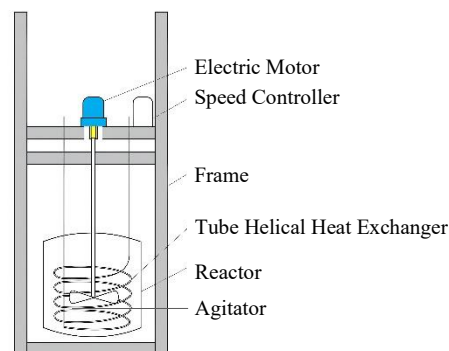


Figure 1. Modified reactor from BRIN for epoxidation and esterification.

The second stage is the saponification process, which produces bio grease. The reactor design is shown in Figure 2. These two reactors technically represent the equipment used in various stages of palm oil-based bio grease production.

3.3 Test Results

Based on testing conducted by the Chemistry Laboratory - LTMP under BRIN, the Base Oil Ester (Biolubricant) sample was analyzed to determine its kinematic viscosity and viscosity index. The test was performed using the ASTM D445 (Sentanuhady et al.,

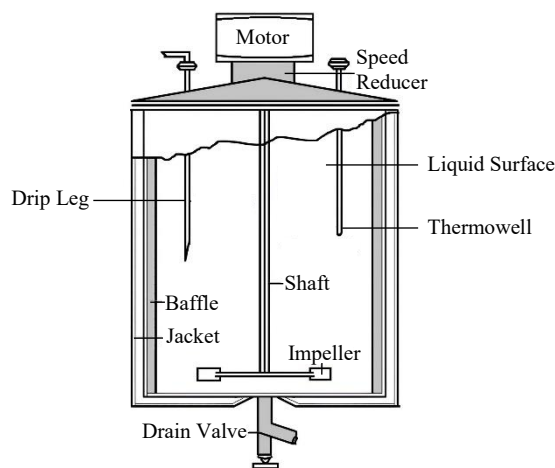


Figure 2. Reactor for saponification to produce bio grease.

2020) method with an SVM 3000 viscometer under environmental conditions of 69.5% relative humidity and a temperature of 23.3°C. The kinematic viscosity was measured at 40°C and 100°C. The viscosity of lubricating oil fractions is a crucial factor in lubricant manufacturing.

The test results show that the kinematic viscosity at 40°C is 99.759 mm²/s, while at 100°C, it is 13.403 mm²/s. These values are compared with SAE 40 lubricants commercially available in the market (MTU, 2020), as shown in Table 2. The viscosity index of lubricating oil indicates how its viscosity changes with temperature variations (Mohammed & Al-Rubai, 2008). Lubricants exhibit an inverse relationship between viscosity and temperature, where kinematic viscosity decreases as temperature increases (Booser, 1983).

Table 2. Comparison of physical properties between Base Oil Ester and SAE 40 Lubricant.

Physical Properties	Base Oil	SAE 40 Lubricant
Viscosity @ 40°C (mm ² /s)	99.759	133.4
Viscosity @ 100°C (mm ² /s)	13.403	13.66
Viscosity Index	133.5	98

MTU (2020) states that SAE 40 viscosity at 40°C ranges from 12.5 to 16.3 mm²/s, while at 100°C, it ranges from 130 to 150 mm²/s. This viscosity index falls into the high category, as Siskayanti & Kosim (2017) define a viscosity index above 80 as a High Viscosity Index (HVI). A higher viscosity index indicates better lubricant quality (Sonjaya & Rahmasari, 2019). SAE 40 lubricants with a viscosity index above 85 are considered high-performance and suitable for extreme applications, such

as heavy-duty machinery and high-performance vehicles (Afrand et al., 2016; Totten, 2006).

A viscosity index of 133.5 confirms that Base Oil Ester exhibits excellent thermal stability, making it suitable for lubricant production and compliant with industry standards (Hu et al., 2021). In summary, lubricants with higher viscosity indices demonstrate greater viscosity stability across temperature variations (Center, 2011) and better shear stability (Stambaugh & Kinker, 2011; Mortier et al., 2011). The findings indicate that Base Oil Ester has a higher viscosity index than commercially available SAE 40 lubricants.

3.4 Product Composition

The main composition of this product formulation consists of 80% estolide, which serves as the primary base oil in bio grease. Additionally, calcium sulfonate and calcium oleate act as thickening agents to enhance grease stability. Other additives include LABSA, CaCO₃, and p-TSA as a catalyst in the esterification process. To improve grease performance, BHT is added as an antioxidant, while acetic acid and E-as oleate are used in the chemical reaction process.

The base oil-to-thickener ratio in the mini plant bio grease production is 80:20. This composition is based on various literature sources and laboratory test results. The optimal ratio of base oil to thickener is 80:20, as it provides consistency that meets NLGI grade 2 standards, comparable to most commercial greases (Sofi et al., 2019). The composition of base oil and thickener in grease production from various studies is presented in Table 3.

Table 3. Comparison of physical properties between Base Oil Ester and Thickener.

Literature	Base Oil (%)	Thickener (%)
Adhvaryu et al., 2004	75 – 80	20 – 25
Salomonsson et al., 2007	80 – 90	10 – 20
Sukimno et al., 2009	75 – 95	5 – 25
Gow, 2009	80	20
Ebisike et al., 2016	80	20
Abdulbari & Zuhan, 2018	70 – 80	20 – 30
Japar et al., 2018	70 – 90	10 – 30
Habib, 2018	80 – 85	15 – 20
Sofi et al., 2019	80	20
Rahman et al., 2019	70 – 80	20 – 30
Zhornik et al., 2021	80	20
Razak et al., 2023	79 – 84	16 – 21
Kozdrach, 2024	80 – 95	5 – 20

Based on the literature review, the composition of 80% base oil and 20% thickener is strongly supported by various previous studies. Research conducted by Gow

(2009), Ebisike et al. (2016), Sofi et al. (2019), and Zhornik et al. (2021) explicitly applied this 80:20 ratio, demonstrating that this formulation has been widely implemented in earlier studies. In those studies, the formulations were primarily based on mineral oil. However, in this research, a bio-based feedstock is used instead, which is considered non-toxic and biodegradable. The use of a bio-based base oil is expected to improve the environmental sustainability of the product without significantly compromising essential grease properties such as consistency, lubricity, and thermal stability. This makes the formulation not only effective but also environmentally responsible.

Therefore, it can be concluded that the 80% base oil and 20% thickener formulation is not only theoretically viable but also has strong justification based on prior research, making it a reliable foundation for bio grease development. With this composition, the production of palm oil estolide-based bio grease is expected to achieve high quality and stability, making it suitable for heavy-duty lubrication applications.

3.5 Production Cost of Heavy-duty Bio grease

The feasibility analysis of capital investment to produce heavy-duty bio grease based on palm oil estolides shows that this project is financially viable. Several economic analyses have been conducted to evaluate the capital investment required for establishing the bio grease production facility.

Economic analysis in the preliminary design of the plant is essential to assess the feasibility of capital investment in the production process. This includes evaluating investment requirements, profit potential, payback period, and the BEP, which indicates the threshold between profit and loss. Additionally, this analysis aims to determine whether the planned plant is viable and capable of generating profits. The results of the economic analysis calculations for the preliminary design of the heavy-duty bio grease calcium sulfo-ole plant are presented in Table 4.

Table 4. Production cost of Heavy-duty Bio grease.

No	Description	Total Cost (Rp)
1	Equipment Cost	111,336,706
2	Raw Material	3,206,477,922
3	Utility	773,944
4	Employee Salary	539,500,000
5	Product Sales	9,089,511,589
6	Total Capital Investment	
	Fixed Capital Investment	218,086,340
	Working Capital Investment	256,572,164
7	Total Production Cost	
	Direct Production Cost	3,783,437,458
	Fixed Charge	1,013,160,809

No	Description	Total Cost (Rp)
	Plant Overhead Cost	2,648,406,221
	General Expense	636,642,476

Equipment costs were estimated based on primary market data. The author initially determined the daily production target, followed by market surveys and benchmarking activities to evaluate suitable equipment types, designs, and pricing. After identifying the appropriate equipment, resizing was performed using the Sixth-Tenths Factor Rule to match the required production capacity. This method ensures that the estimated costs are both realistic and scalable for pilot-scale implementation.

Capital investment in this study includes costs for procuring processing equipment and raw materials such as tanks, chemicals, pumps, reactors, processing and separation equipment, and valves. The calculation of processing equipment costs includes an additional 27% of the total equipment price as a safety factor, as recommended by Turton et al. (2009) and Peters et al. (1991). They also mention that a contingency or safety factor of 20–30% is commonly applied during the early design phase. The projected price for 2030 results in a tools price of Rp111,336,706.

The calculation of raw material costs, utilities, and product sales involves estimating the costs of primary raw materials such as RBDPO, H₂O₂, formic acid, oleic acid, LABSA, and other additives, as well as operational costs such as water and electricity. The total raw material cost per year reaches Rp3,206,477,922.

Regarding other utility costs, electricity is primarily consumed to power the agitator and heater in the Continuous Stirred Tank Reactor (CSTR). Waste treatment expenses are not included in the current cost structure because the process involves temporary waste storage followed by disposal through third-party treatment services. Laboratory expenses have been accounted for following Turton et al. (2009) method, where laboratory costs are estimated as 15% of the operating labor costs.

In this study, the Capital Expenditure, or CapEx, consists of two main components: Fixed Capital Investment and Working Capital Investment. The Fixed Capital Investment amounts to Rp126,582,770 and includes the procurement and installation of main process equipment such as reactors, tanks, pumps, valves, as well as construction and infrastructure components. To account for potential uncertainties, a safety factor of 27 percent is applied to the total equipment cost. The Working Capital Investment totals Rp148,920,907 and is allocated for operational needs such as initial raw material supply, utility expenses, and buffer inventory.

Accordingly, the total CapEx for the project reaches Rp275,503,677.

Employee salaries for one year, based on the regional minimum wage (UMK) in West Java, are estimated at Rp539,500,000. The total capital investment amounts to Rp474,658,504. With the selling price of the produced bio grease set at Rp251,000/kg, the total product price is Rp9,089,511,589, while the total production cost is Rp8,081,646,963.

The Micro, Small, and Medium Enterprise (MSME) operations are managed by a dedicated production team to ensure efficient and quality-controlled production. The team consists of two Process Supervisors, both graduates in Chemical and Mechanical Engineering, who oversee daily operations, maintain ISO-compliant quality control, and manage batch processing and formulation. They lead eight vocational-trained operators organized into functional units: three Process Operators responsible for raw material preparation (vegetable base oils, thickeners, and additives), reactor operation, and homogenization; three Equipment Technicians who maintain reactors, grease pumps, and filling lines; and four QC/Logistics Operators who conduct in-process quality checks, perform laboratory analyses, coordinate packaging into pails/drums, and manage inventory.

This management system was chosen for its balance between technical expertise and operational efficiency, ensuring strict adherence to quality and safety standards while enabling flexible production scaling. The production system yields approximately 100 kg of product daily through three batches per day, each requiring 3-5 hours of processing followed by 3 hours of cleaning.

Strict safety protocols are implemented, including staggered breaks, mandatory personal protective equipment (heat-resistant gear and respirators), hazardous chemical handling compliant with regulations, and environmental controls such as VOC (Volatile Organic Compound) capture systems. These measures guarantee workplace safety and sustainable operations while maintaining consistent product quality.

The salaries of the Process Supervisors are included in the operating costs, reflecting competitive compensation aligned with industry standards for technical management roles in MSME manufacturing settings. This consideration ensures motivation and retention of qualified personnel critical for plant operation success.

3.6 Profitability Analysis of Heavy-duty Bio grease

Profitability analysis consists of gross profit, NPV, IRR, ROI, PP, and BEP. The results of the profitability analysis can be seen in Table 5.

Table 5. Profitability Analysis of Heavy-duty Bio grease.

No	Description	Value
1	Gross Profit	Rp. 977,264,626
2	Net Present Value	Rp.1,256,154,781
3	Internal Rate Return	13%
4	Return on Investment	206%
5	Payout Time	2 years
6	Break Even Point	83%

The calculated gross revenue obtained is Rp. 977,264,626 on a pilot scale for an area of 200 m². According to Soekartawi (1995), net income is revenue minus Total Production Cost (TPC), including variable and fixed costs. Based on Law Number 36 of 1983 on Income Tax and Law Number 16 of 2009 on General Provisions and Tax Procedures, the income tax calculation is 22% of taxable income, not directly of gross profit.

The NPV value is calculated by discounting cash flows over 10 years using an inflation rate of 4% and an interest rate of 6% per year. Were based on historical data from Bank Indonesia, representing conservative estimates that reflect a “bad case” or lower-bound scenario of Indonesia’s macroeconomic conditions. The NPV value is Rp. 1,256,154,781, meaning this plant is feasible because the NPV is positive. According to Hendra et al. (2024), an NPV greater than zero indicates that the plant is feasible for operation. The IRR value obtained from the calculation is 13%, which is higher than the bank interest rate of 6%. Therefore, in terms of the IRR indicator, this plant is feasible to establish. According to Rani et al. (2024), if the IRR is greater than the bank interest rate, the business or plant is viable for continuation and development.

The ROI value is calculated by comparing net income to TCI. The ROI value is 206%, making this project highly profitable as it is well above the minimum ROI for a low-risk chemical industry, which is only 11% (Aries & Newton, 1995), thus making the plant feasible to establish. The ROI value is high because the total revenue is higher than the CapEx.

Next, Payout Time measures the time required to recover the investment capital. The calculated Payout Time value is 2 years. Aries & Newton (1995) explain that the maximum Payout Time for the low-risk chemical industry category is 5 years, and Kusnarjo (2010) states that the fastest Payout Time is 2 years and the longest is 5 years. The calculated PP value remains below the maximum limit, confirming the plant's feasibility.

The BEP is calculated as the point where total revenue equals total cost. The BEP value determines the minimum working capacity required for the plant to avoid losses (Ekawati et al., 2020). The Break-Even Point occurs at a capacity of 36 tons/year. Based on

calculations, the BEP is reached at 83% of production capacity as shown in Figure 3. In other words, at this production level, total revenue equals total production cost, meaning the company neither gains nor loses money. If the plant operates above 83% of its installed production capacity, it begins to generate profit. The higher the utilization above this break-even point, the greater the potential profit. Therefore, this relatively low BEP value (83% of capacity utilization) indicates substantial profit potential, assuming that market demand supports higher output and production costs remain controlled.

Moreover, the shutdown point is calculated at 35% of the installed production capacity. This means that if the plant operates below this threshold, the revenue generated would not even be sufficient to cover the variable costs, leading to greater financial losses the longer it continues operating. Hence, production should only be sustained if capacity utilization remains above this shutdown level.

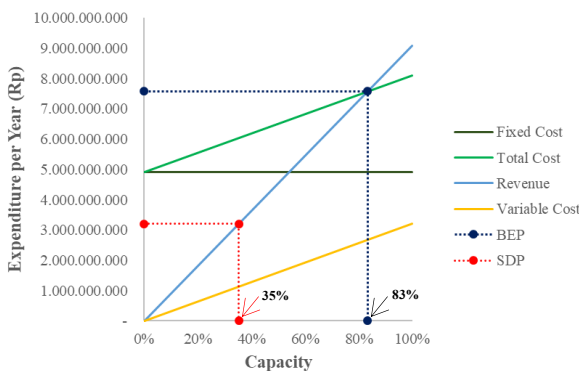


Figure 3. BEP Chart of capacity 36 tons/year.

3.7 Cost and Benefit

The production of heavy-duty Bio grease based on palm oil estolides involves various cost and benefit aspects that need consideration. From the cost perspective, the Total Production Cost reaches Rp8.1 billion, covering all operational production expenses. Although it requires significant capital, this project offers a rapid return on investment, with a PP of only 2 years, which is still within the feasibility limit for the industry.

From the benefit perspective, this project provides substantial economic benefits. The NPV indicates that this investment is profitable in the long term. The IRR value is significantly higher than the bank interest rate of 6%, indicating considerable profit potential. Additionally, a ROI of 206% demonstrates that the project has high profitability.

From a sustainability aspect, palm oil-based bio grease is more environmentally friendly as it is biodegradable and reduces dependency on petroleum-based lubricants. Furthermore, the project supports the

downstream palm oil industry, creates economic opportunities for MSMEs, and promotes the lubricant industry towards more sustainable products. With the BEP reaching 83% of production capacity, this project remains within the feasible category. Therefore, despite its high initial costs, the economic, environmental, and industrial benefits make heavy-duty Bio grease production a promising and strategic option for development.

3.8 Comparison of Heavy-duty Bio grease with Grease Products in the Market

This mini plant tends to use alternative grease as a substitute for lithium-based grease. One of the substitute materials that has been researched is calcium, as studied by Amin et al. (2023). Calcium is considered an innovation that can replace lithium in grease formulations and even has the advantage of higher energy density compared to lithium (Hosein, 2021). Additionally, the use of calcium as a base material for grease is more environmentally friendly and has a more abundant availability than lithium, making it a potentially more sustainable alternative solution.

The selling price of heavy-duty Bio grease, which is calcium-based, is recorded at Rp251,000/kg. Compared to the price of lithium-based grease available on several e-commerce platforms in Indonesia, there is a significant price difference. Figure 4 presents the price comparison data of grease per kilogram from various e-commerce platforms.

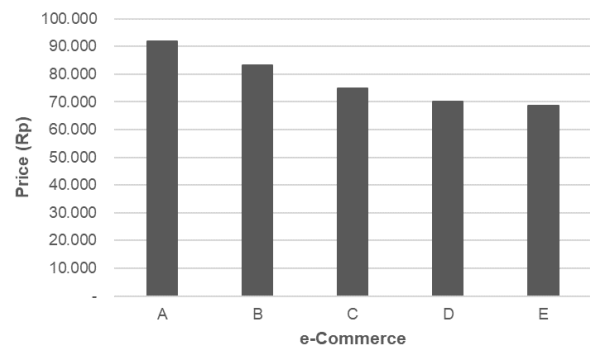


Figure 4. Price Comparison of Grease on Indonesian E-commerce Platforms.

According to the data, the average price of lithium-based grease on e-commerce platforms is Rp77,809/kg. Thus, the price of heavy-duty Bio grease is higher than that of lithium-based grease available in the market. Heavy-duty Bio grease is often designed with more environmentally friendly base materials, such as synthetic lubricants that have better degradation compared to conventional grease. Therefore, although the

initial price of heavy-duty Bio grease is higher, it offers several advantages.

First, this bio grease is more environmentally friendly because it uses palm oil-based estolides as its base material, which is a renewable and biodegradable source (Goyan et al., 1987). The use of these raw materials contributes to reducing environmental pollution and enhances sustainability in the lubricant industry (Diphare et al., 2013).

Second, this bio grease has excellent thermal stability and oxidation resistance (Sharma et al., 2006), making it capable of withstanding extreme working conditions, including high temperatures and heavy pressures (Honary & Richter, 2011). This advantage makes it an ideal choice for heavy industrial applications that require reliable and durable lubrication (Gow, 2011; Mortier et al., 2011). Moreover, this bio grease also has superior anti-wear and corrosion protection properties (Ren et al., 2021). This is due to the presence of calcium sulfo-oleate, which helps form a protective layer on metal surfaces, thereby reducing friction and preventing degradation caused by environmental exposure (Sultana et al., 2022; Shah et al., 2021).

Another benefit is long-term cost efficiency. With a longer lifespan compared to conventional grease (Allmaier, 2022), this bio grease can reduce the frequency of lubricant replacement (Lugt, 2016), ultimately lowering operational and machine maintenance costs (Shah & Precilla, 2024). With a mini plant (SME)-based production approach, this bio grease also creates business opportunities for the industry and supports the development of industries based on local raw materials.

3.9 Potential Development of MSMEs in the Grease Sector

In this preliminary design of the mini plant, the main material used is palm oil estolide. Estolide is a modified palm oil compound with oxidation stability (Khan et al., 2022), biodegradability (Hamnas & Unnikrishnan, 2023), and environmental friendliness (Hoong et al., 2019), making it suitable as a base material for bio grease. Currently, palm oil production in Indonesia reaches 50 million tons per year. The potential for a heavy-duty Bio grease Calcium Sulfo-Ole plant based on palm oil estolide is significant due to the sustainable availability of raw materials, projected to reach 80 million tons by 2030 (Rahman et al., 2024) and between 130–176 million tons by 2050. This ensures a stable supply of palm oil (Afriyanti et al., 2016). With the increasing global regulations on environmentally friendly lubricants, the demand for bio grease continues to grow, especially in the industrial, automotive, and heavy equipment sectors (Sharma & Singh, 2019).

The mini plant concept on an SME scale offers production flexibility with lower investment compared to

large-scale plants. According to the Ministry of Industry (2023), there are 52 companies registered as lubricant producers in the National Industrial Information System, with an installed production capacity of up to 2 million kiloliters per year. Of this capacity, the recorded actual production is 1.2 million KL per year. As of 2023, this industry employed 4,898 workers. The SME-based mini plant aligns with the minimum annual bio grease production standard of only 36 tons/year.

With the right production and marketing strategies, this mini plant has the potential to become an innovative and highly competitive SME model. The mini plant concept refers to PM KUKM 11 of 2022 concerning net asset value, business turnover, and the number of employees. Additionally, it complies with Article 36 paragraph (2) of Government Regulation (PP) Number 36 of 2021 on Wages, which stipulates that the minimum wage for MSMEs must be at least 50% of the average provincial household consumption and at least 25% above the poverty line in Indonesia. According to Statistics Indonesia (BPS) 2024, the number of workers in 2023 increased by 4% from 2022, as shown in Figure 5.

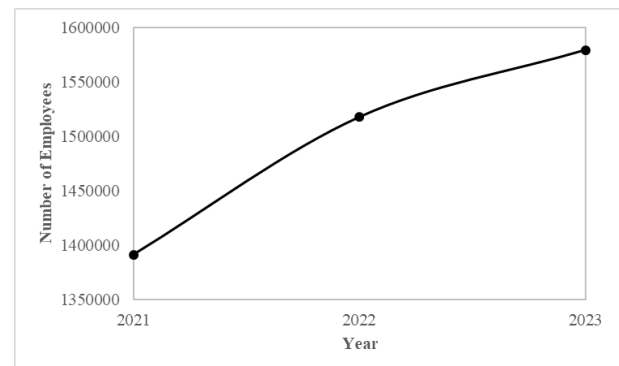


Figure 5. Number of MSMEs employees in West Java in 2021-2023 (BPS, 2024).

With the 4% increase in the number of MSMEs in Indonesia, the establishment of a heavy-duty bio grease mini plant based on palm oil estolides presents a strategic opportunity to enhance the added value of the environmentally friendly lubricant industry. This mini plant not only supports the diversification of palm oil-based products but also strengthens the local industrial supply chain, creates employment opportunities, and reduces dependence on imported conventional grease. Moreover, the production of more sustainable bio grease can enhance the competitiveness of MSMEs in the global market in line with the growing demand for environmentally friendly products.

4. Conclusion

Based on the economic analysis, the mini plant designed for producing palm oil estolide-based heavy-duty bio grease with a capacity of 36 tons/year is financially feasible. The project demonstrates a Net Present Value (NPV) of approximately Rp1.3 billion over a 10-year period, an Internal Rate of Return (IRR) of 13%, and a Return on Investment (ROI) of 206%. The Break-Even Point (BEP) reached 83% of production capacity, indicating that the business can operate profitably even before reaching full utilization. Despite requiring relatively high initial capital, the strong financial indicators confirm the economic viability of the mini plant.

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