Research Article

Production and Economic Evaluation of Biobased Detergent from Waste Cooking Oil

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Abstract
Waste cooking oil is an abundant food waste resource. Converting waste cooking oil into high-value products, such as methyl ester sulfonate (MES) surfactants, is one approach to improving its economic value. MES can be used as a bio-based detergent due to its biodegradability compared to synthetic surfactants. This study investigated the production of a biobased detergent derived from MES surfactant using waste cooking oil as the raw material. MES was produced through two stages: transesterification of waste cooking oil to produce methyl esters, followed by sulfonation of the methyl esters to produce MES. Additional supporting materials were then incorporated into the MES to formulate the biobased detergent. The results showed that the MES-based detergent had a pH range of 10–12. A formulation consisting of 20 g of MES and 15 g of sodium silicate was identified as the optimal composition, as it provided good oil emulsification and foam stability. An economic analysis indicated that producing biobased detergent within a biorefinery framework—where waste cooking oil is processed into both biodiesel and MES as co-products—is more profitable than producing biobased detergent alone. The standalone production of bio-based detergent was not economically viable, yielding a negative net present value (NPV) of 65,060,382 USD. In contrast, the biorefinery approach, with a processing capacity of 4,000 kg of waste cooking oil per hour, achieved a return on investment (ROI) of 58.72%, a payback period (PBP) of 1.24 years, a net present value (NPV) of 37,386,064 USD, and an internal rate of return (IRR) of 59.67%.

Keywords: Biobased detergent, Biorefinery, Economic evaluation, Methyl ester sulfonate, Waste cooking oil

1 Introduction

Cooking oil is an important commodity in the food industry. Repeated use of cooking oil can cause oil decomposition at high temperatures to become waste cooking oil [1]. Waste cooking oil has characteristics such as darkening, thickening, foaming, and odor, which make it a waste in the food industry [2]. Waste cooking oil can be converted into various high–value products, such as bioactive components in medicines, food supplements, soaps, and surfactants. Research in surfactant production from waste cooking oil has increased in the past 10 years, with the surfactant products being used as additives in food, cosmetics, pharmaceuticals, and bioremediation [3]. The main characteristic of surfactants is their hydrophilic and hydrophobic groups, making them widely used in various chemical industries, particularly in cleaning and pharmaceuticals [4]. One of the most widely used surfactants is methyl ester sulfonate (MES).

MES surfactant can be produced through the sulfonation process of methyl esters using oils and fats as raw materials. Methyl ester or biodiesel can be produced through a two-step reaction, namely esterification and transesterification from oil with high free fatty acids [5]. MES production can be integrated into methyl ester or biodiesel production using waste cooking oil as a feedstock [6]. The challenge in MES production from waste cooking oil was the need for a purification stage to remove impurities, free fatty acids and clarify the color of the oil [7]. MES demand continues to increase, which is predicted to reach 1.5 million metric tons by 2026 [8]. MES has characteristics such as biodegradability, good stability in water, good cleaning properties, and low cost [9] [4]. Therefore, MES surfactants have great potential for application in the cleaning industry, such as detergents.

Detergents are one of the household products for removing stains on clothing [10]. Detergents can modify the surface tension and pH of water, making them widely used for cleaning and degreasing [11]. Detergent waste from synthetic surfactants creates environmental damage because detergent waste is difficult to degrade in water. Because of that, it is important to search for natural substitutes for synthetic surfactants [12]. Currently, the detergent industry is dominated by anionic petrochemical–based surfactants such as linear alkyl benzene sulfonate (LABS), which have the potential to damage the environment [13]. MES is a surfactant with potential as a biobased detergent to replace LABS [14], [15]. MES, as a biobased detergent to replace LABS, has attracted attention in the cleaning industry due to its renewable and ecologically friendly [16]. The advantage of using MES over LABS at the same concentration was its detergency. In detergents that used enzymes, MES had the ability to maintain enzyme activity compared to LABS [17].

Economic evaluation of biobased detergent production has not been widely conducted. Dewi and Danaryanti studied the economic feasibility analysis of a bio–enzymatic detergent product with a capacity of 1,000 liters/month, which was a combination of MES surfactants and enzymes. Based on the research, it was shown that the IRR, NPV, PBP and ROI values were 57.57%, Indonesian Rupiah (IDR) 1,117,448,350.97, 3 years and 54% [17]. In this study, the production of bio–based detergent based on MES surfactant from waste cooking oil and the evaluation of its economic production on plant scale using SuperPro Designer 10 software will be studied. This study aims to utilize waste cooking oil and apply it as a bio–based detergent and evaluate the economic production.

2 Materials and Method

2.1 *Materials*

The materials used in this study were waste cooking oil that had been used for three frying cycles, bleaching earth, NaOH, phenolphthalein indicator, methanol, KOH, distilled water, sodium bisulfite, sodium sulfate, sodium silicate, and hydroxypropyl methylcellulose (HPMC). The equipment used in this study were oil filter, burette, beaker, measuring cylinder, oven, pH paper indicator, separating funnel, spatula, erlenmeyer flask, and sulfonation apparatus.

2.2 *Methods*

2.2.1 Waste cooking oil purification

Waste cooking oil purification was carried out by mixing 100 mL of waste cooking oil with 9 grams of bleaching earth adsorbent at 80 °C with stirring for 60 minutes. After the adsorption process, the adsorbed waste cooking oil was separated from the bleaching earth by filtration. The adsorbed waste cooking oil was used as raw material for methyl ester production.

2.2.2 Methyl ester production

Operating conditions in methyl ester production were based on Monika *et al*. [18]. Methyl ester production was carried out by reacting 400 ml of waste cooking oil with potassium methoxide containing a mixture of 100 mL of methanol and 0.5% KOH catalyst. The methyl ester production process was carried out at 60 °C for 1 h. The reaction product was then transferred to a separating funnel and allowed to settle for 24 hours until two layers formed. The upper layer, which was methyl ester, was then separated for further purification.

2.2.3 Methyl ester purification

In the methyl ester purification process, the separated methyl ester was then mixed with warm water at 80 °C in a 1:1 ratio. The mixture was stirred for 30 min using a magnetic stirrer. The mixture was then left for 24 hours to separate into two layers. The upper layer, which was methyl, was then separated.

2.2.4 Methyl ester sulfonate (MES) production

The production of methyl ester sulfonate was based on Permadani and Slamet [19]. MES was prepared by mixing methyl ester and sodium bisulfite in a 1:1 molar ratio at 100 °C for 4.5 h. After that, the mixture was cooled and separated by centrifugation for 30 min at 1500 rpm. The MES was then purified with 40% methanol solution at 50 °C for 1.5 h. The remaining methanol was evaporated using a hot plate. Next, neutralization of MES was carried out by mixing it with 20% NaOH solution at 55 °C for 30 min. The resulting MES was then analyzed.

2.2.5 Fourier Transform Infrared (FTIR) analysis of MES

FTIR spectrophotometer analysis aims to identify the chemical groups of MES. In this study, FTIR was used as an analytical tool to identify MES. The spectrum produced by the FTIR was used to detect the presence of sulfonate groups that react with methyl esters.

2.2.6 Bio–based detergent production

The biobased detergent preparation begins with the preparation of detergent mixture ingredients such as 10 g of sodium sulfate, 5 g of hydroxypropyl methylcellulose (HPMC), and 10 g of sodium silicate. These ingredients were mixed sequentially. In the first stage, sodium sulfate and various variations of MES surfactants 15, 20, and 25 g were mixed and produced mixture 1. Distilled water was then added to mixture 1 to form mixture 2. Other ingredients, such as HPMC and sodium silicate, were then added to mixture 2 to form mixture 3. The variations of sodium silicate used in this study were 5, 10, and 15 g. Mixture 3 was then poured onto aluminum foil to be dried in an oven for 3 h at 80 ºC. The dried product of mixture 3 was a dry biobased detergent which was then cooled for 5–15 min, weighed, and separated from the aluminum foil to be ground with a mortar. The resulting bio-based detergent was then analyzed for its characteristics, such as pH analysis, oil emulsification test, and foamability test.

2.2.7 Biobased detergent analysis

pH Analysis
The pH analysis of biobased detergents was performed using universal pH test paper.

Oil emulsification test
The oil emulsification test was performed by mixing cooking oil and biobased detergent in an analysis tube. The tube was then shaken and allowed to stand for 2 minutes and 10 minutes. The resulting foam height was compared and analysed in three repetitions.

Foamability test
Foamability test was a foam measurement by mixing biobased detergent and distilled water to produce a measurable foam height. Besides that, the foam stability percentage can be calculated using the formula Equation (1):

$$Foam\ Stability\ (\%) = \frac{x_1}{x_{10}}\ x\ 100\% \quad (1)$$

Where x_1 was the height of the foam at 1 min and x_{10} was the height of the foam at 10 min.

Economic evaluation method
The economic simulation of biobased detergent production was conducted using SuperPro Designer 10 simulation software. The stages of biobased detergent production in this study can be summarized in a block flow diagram based on Figure 1. The dependent variables generated in this simulation included the return on investment (ROI), payback period (PBP), net present value (NPV), and internal rate of return (IRR). In addition, several constant variables used in calculating the economic simulation include:

- The currency used in the economic simulation is United States dollars.
- The factory will be constructed over two years and will operate for 20 years.
- The total investment cost will be obtained through a loan with compound interest of 10% per year.
- The year for the cost analysis is 2025.
- The factory's raw material capacity is 400 kg of used cooking oil hour^{-1}.
- The depreciation method used is the MACRS method with a depreciation period of 15 years.
- The minimum acceptable rate of return is 11%.
- The tax rate is 25%.
- The price of bio–based detergent products is 500 USD/ton.

Total capital investment (TCI) and total operating cost (TOC) can be calculated using formulas Equations (2) to (5):

Total capital investment = fixed capital investment + startup cost + working capital (2)

Fixed capital investment (FCI) = 1.2 x equipment cost (3)

Startup cost = 5% x fixed capital investment (4)

Total operating cost = raw material cost + labor-dependent cost + facility-dependent cost + laboratory/quality control cost + waste treatment cost (5) where equipment cost, working capital, total operating cost, and total revenue were calculated from SuperPro Designer 10 simulation.

Profitability analysis, such as return on investment (ROI), payback period (PBP), net present value (NPV), and internal rate of return (IRR), was calculated. Return on investment (ROI) was defined as the percent ratio of average profit (Np) to total capital investment (TCI). Payback period (PBP) is identified as the project time required for payback, and defined as the ratio of fixed capital investment (FCI) to annual cash flow (Aj). Net present value (NPV) is the total of the present worth of all cash flows minus the present worth of all capital investments, and internal rate of return (IRR) is the discount rate that makes NPV zero. The formula and calculation method of NPV and IRR were based on Peters *et al*. [20].

3 Results and Discussion

3.1 *MES analysis using FTIR*

The FTIR results of the MES surfactant were shown in Figure 2. The presence of methyl ester sulfonate (MES) was confirmed by the absorption bands obtained from the test. The absorption range of 3000–2800 cm^{-1} indicated the aliphatic C–H stretching vibrations of the methyl ($–CH_3$) and methylene ($–CH_2$-) groups originating from the long hydrocarbon chains in the MES structure [14]. The absorption range of 1200–1000 cm^{-1} indicated the vibrations of the sulfonate (S=O) groups, which were produced in the sulfonation process of the ester group. The success of the sulfonation reaction was indicated by the appearance of a strong absorption band in the range of 1200–1040 cm^{-1}, which was an indicator of the presence of a sulfonate group ($–SO_3H$) [14], [21]. All absorption bands from the FTIR analysis indicated that the compound contains ester and sulfonate functional groups that match the chemical structure of methyl ester sulfonate as a product of the methyl ester sulfonation process. The presence of sulfonate groups in MES improves the cleaning performance and better hardness tolerance. The ability of MES as an anionic surfactant was shown by binding ions under water hardness conditions [22].

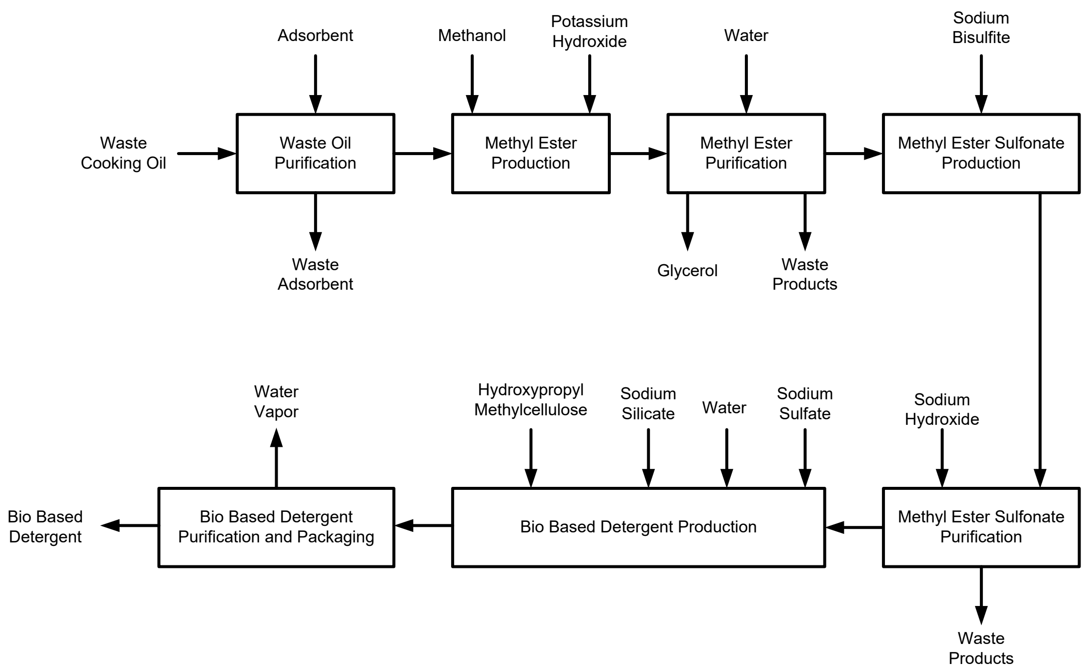

Figure 1: Biobased detergent block flow diagram.

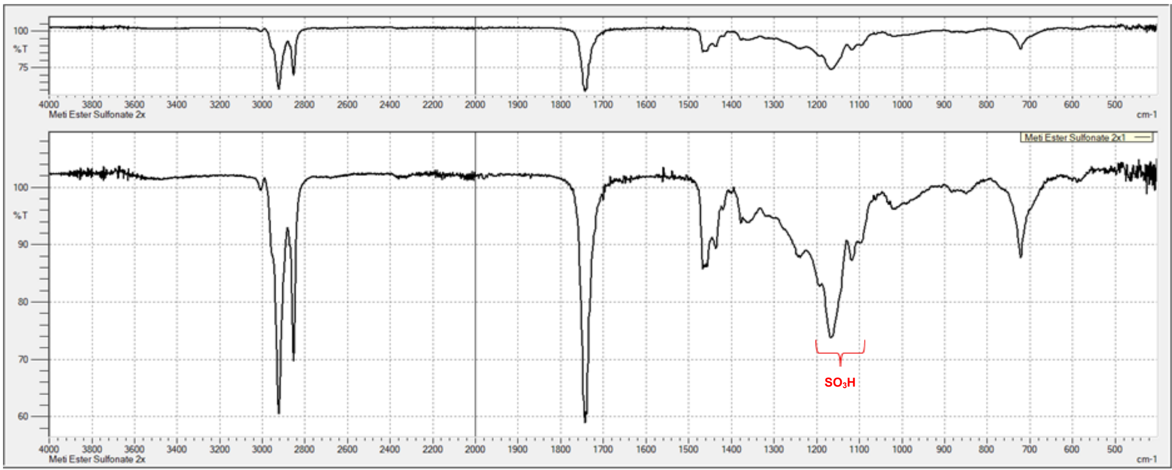

Figure 2: FTIR analysis of MES.

3.2 *Biobased detergent analysis*

3.2.1 pH analysis

This research consisted of several steps, including waste cooking oil purification, methyl esters production, methyl ester sulfonate (MES) production, and biobased detergent production. The purification of waste cooking oil using bleaching earth yielded 0.28% FFA content, which can be used as raw material for methyl esters production. Based on the biobased detergent pH analysis, the pH range obtained was between 10 and 12. A higher pH range was necessary to create optimal alkaline conditions for the cleaning process [23]. Surfactant in biobased detergents can increase the pH of detergents and reduce surface tension [24]. The high pH range of biobased detergents facilitates the saponification process of fats and oils, a hydrolysis reaction that converts oily dirt into water–soluble soap and glycerol, which makes it easier to remove oily dirt from the cloth surface. Furthermore, higher pH of biobased detergents helps dissolve and remove acidic dirt and prevents the re–adhesion of loosened dirt on the cleaned surface [25].

3.2.2 Oil emulsification test

The oil emulsification test aims to assess how well bio-based detergents emulsify oil or oily dirt. Emulsification using a detergent is a process in which an immiscible solution is dispersed into another immiscible solution. This property is crucial for dissolving water–insoluble compounds such as oil, which surfactants stabilize the emulsions [26], [27]. Emulsification test was conducted at 2–minute and 10–minute intervals to evaluate the initial stability of the emulsion during the oil emulsification process using a detergent. The 2–minute oil emulsification test was designed to observe the initial rate of emulsion formation. The 10–minute oil emulsification test was designed to evaluate the short–term stability of the emulsion. The 10–minute oil emulsification test can provide an overview of the detergent's ability to stabilize oil droplets through the mechanism of reducing interfacial tension and forming a protective layer around the oil particles [28].

Figure 3 shows an oil emulsification test using a mixture of 5 g of detergent, 100 ml of distilled water, and 5 g of cooking oil. The foam heights produced by the oil emulsification test using the combination of MES and sodium silicate showed significant differences. The 15–15–2 biobased detergent formulation (15 grams of MES, 15 grams of sodium silicate, and 2 min of emulsification time) in Figure 3 produced the highest foam height, which was 3.6 cm, indicating good foam formation and stability. Furthermore, the 15–15–10 and 20–15–2 biobased detergent formulations also produced high foam heights. Conversely, several formulations produced lower foam heights, with an average foam height below 2.5 cm, indicating lower surfactant effectiveness in these formulations. The significant standard deviations at several points indicated variation between samples, particularly in the formulation with the highest foam.

These differences in foam height results may be due to differences in the composition of MES and sodium silicate in the detergent. Surfactants mixed with sodium silicate improved the solution structure and made the surfactant more efficient in lowering the surface tension of water, thus facilitating foam formation. The resulting foam height indicated the surfactant's efficiency in forming and stabilizing oil in water. When sodium silicate was added and produced higher foam, it indicated in higher emulsification efficiency. Higher foam indicated that oil was more easily dispersed and formed a stable emulsion, resulting in better cleaning action [23].

3.2.3 Foamability test

Two important foam properties in the cleaning process and related to detergent quality are foamability and foam stability [26], [29]. Foamability is the ease of foam formation, while foam stability is the ease of foam to collapse. Foamability depends on surface tension and critical micelle concentration. Foam stability was influenced by molecular packing in the adsorbed surfactant and the surface viscosity of the film. Foam collapse can be caused by liquid drainage, bubble disproportion, and coalescence [30]. To protect clothing fibers, stable foam was needed to reduce agitation pressure during the cleaning process [23]. Surfactants can be used to reduce surface tension and prevent foam from collapsing [30], [23].

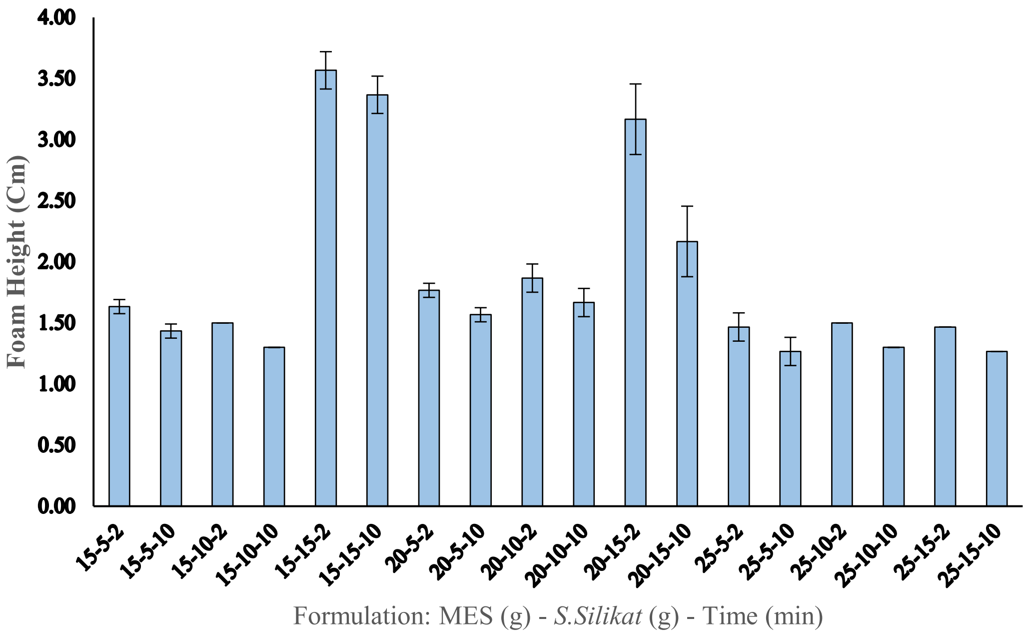

Figure 3: Oil emulsification test.

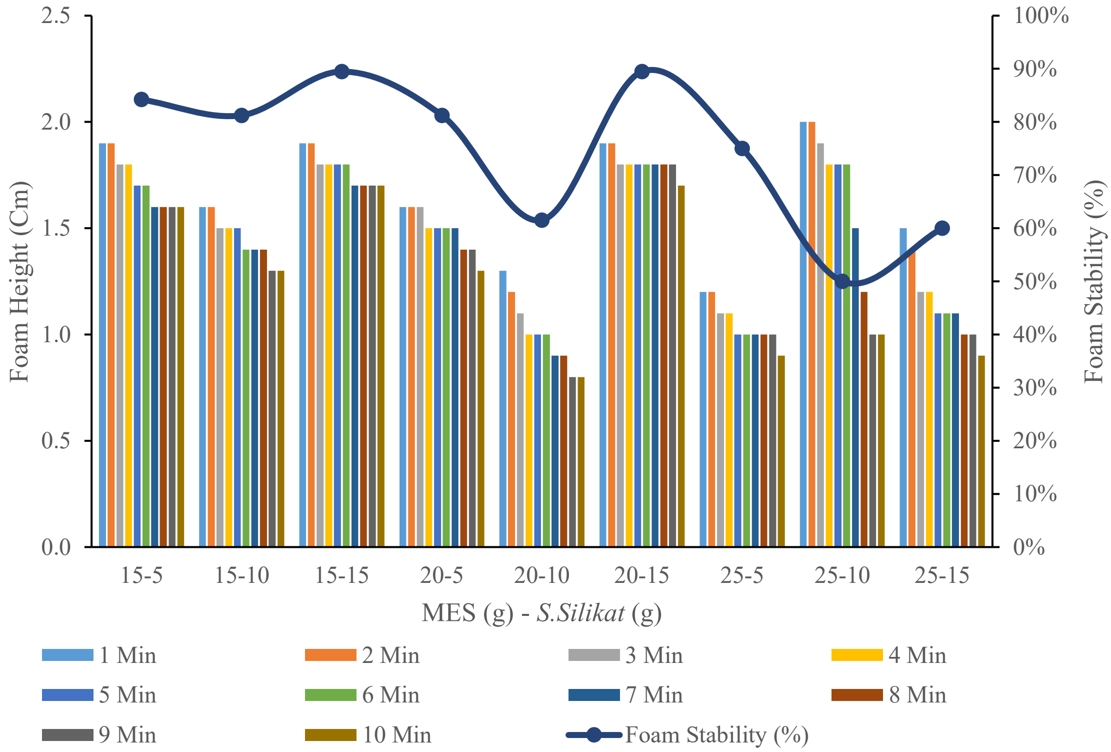

Figure 4: Foamability test.

The samples tested for foamability were methyl ester sulfonate (MES) and sodium silicate–based detergent formulations with 5 g of detergent and 100 mL of distilled water. Figure 4 shows the foamability testing of various MES and sodium silicate mixture formulations and variations in stirring time. At 1 minute, the initial foam height in most formulations was higher than in subsequent minutes, especially at minutes 7–10, which showed a tendency for the foam height to decrease drastically. This indicated that foam forms quickly, but tends to decrease over time [23]. Formulation 25–10 (25 g MES and 10 g sodium silicate) at minutes 1 and 2 showed the highest foam height, reaching almost 2 cm, indicating that this formulation was the best initial foam–forming. Meanwhile, formulation 20–15 showed a more stable foam height, reaching 1.9 cm in the initial minute and after 10 minutes, only decreasing to 1.7 cm.

The gradual decrease in foam height over the following minutes indicated the limit of foam stability, which may be caused by the surfactant composition and its interaction with sodium silicate. While initial foam formation was crucial for cleaning product applications, foam stability was also a crucial indicator of detergent effectiveness, as it can create a strong interfacial film [31]. The foaming process required surfactants to reduce surface tension in the solution, facilitating the formation of stable foam lamellae [32]. Furthermore, foam stability over time indicated sustained cleaning ability, especially when used in longer washing processes [23]. Sodium silicate, as a builder, not only improves foam stability but also helps bind metal ions in hard water, thereby enhancing the effectiveness of surfactants such as MES. Increasing the MES surfactant composition in detergents can produce higher foam yield [33]. However, a balanced concentration of sodium silicate builder was essential to maintain foam stability.

3.2.4 Economic evaluation of bio–based detergent production

The economic evaluation of biobased detergent production was conducted at a factory scale with 400 kg of waste cooking oil/hour as a raw material using SuperPro Designer 10. Operating conditions data that were used in SuperPro Designer 10 simulation were based on the biobased detergent laboratory–scale production in this paper. The reactor simulation data used methyl ester and MES production yield data, which were 80% for methyl ester yield and 84% for MES yield. The process flow diagram for biobased detergent production was shown in Figure 5.

Based on Figure 5, the biobased detergent production process begins with the purification of waste cooking oil using bleaching earth in a mixer (MX–101), which was then separated by filtration in a plate and frame filtration (PFF–101). The methyl ester production process was then produced in a reactor (R–101) by reacting bleached waste cooking oil with methanol as a reactant and potassium hydroxide as a catalyst. The methyl ester was then separated through decantation and purified by washing with water. The methyl ester was then reacted with sodium bisulfite in a reactor (R–102) to produce methyl ester sulfonate (MES). The MES product from the reactor was then separated from its impurities using a centrifuge process (DC–101) and mixed with methanol and sodium hydroxide to neutralize the MES. A distillation column (C–101) was needed to separate the MES from the methanol. The separated MES was then mixed with various additives such as sodium sulfate, water, hydroxypropyl methylcellulose, and sodium silicate to produce a biobased detergent. The final product, a mixture of MES and various additives, was produced as a biobased detergent and then heated on a drying tray (TDR–101).

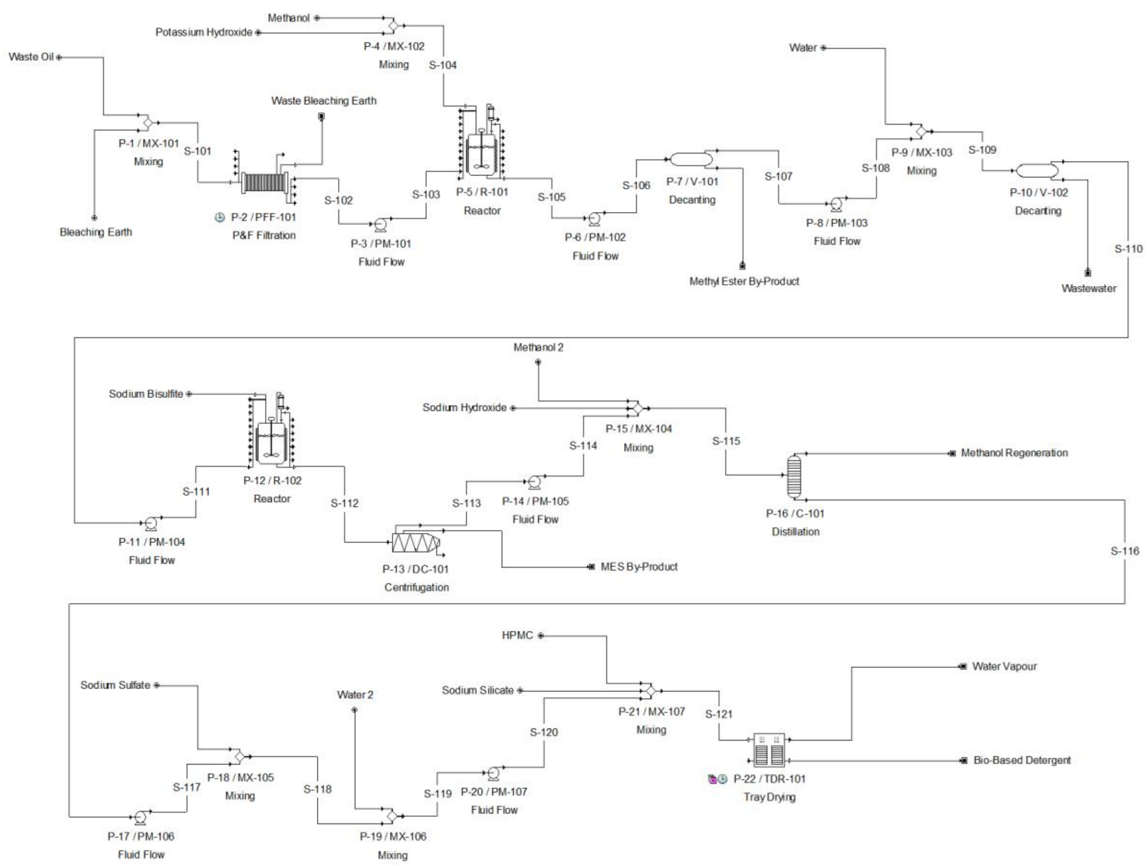

Figure 5: Biobased detergent process flow diagram.

Table 1: Economic parameters of biobased detergent plant.

Raw Material Costs	Cost (USD/Ton)	Reference
Bleaching Earth	685	[34]
Methanol	325	[35]
Potassium Hydroxide	244	[36]
Sodium Bisulfite	368.03	[37]
Sodium Hydroxide	433.68	[36]
Sodium Sulfate	95.33	[38]
Hydroxypropyl methylcellulose (HPMC)	1000	[39]
Sodium Silicate	343	[40]
Product Cost	**Cost (USD/Ton)**	**Reference**
Bio–Based Detergent	500	[41]
Profitability Analysis	**Value**	
Total Capital Investment (TCI) (USD)	4,991,060	
Total Revenue (USD/year)	3,153,268	
Raw Materials	3,163,000	
Labor–Dependent	4,763,000	
Facility–Dependent	3,819,000	
Quality Control	714,000	
Utilities	118,000	
Total Operating Cost (USD/year)	12,577,000	
ROI (%)	N.A.	
PBP (years)	N.A.	
NPV (USD)	-65,060,382	
IRR (%)	N.A.	

The raw material and product pricing parameters, as well as the profitability analysis of the bio–based detergent plant, can be seen in Table 1. Table 1 showed that a lot of raw materials were required to produce biobased detergent from waste cooking oil. This was due to the lengthy process stages that require significant amounts of chemicals, starting from waste cooking oil purification, methyl esters production, methyl ester sulfonate production, methyl esters and MES purification process, and the mixing of additional ingredients to produce biobased detergent, which was shown in Figure 5. The prices of some raw materials were quite high, even exceeding the price of the main product, such as potassium hydroxide and hydroxypropyl methylcellulose (HPMC). Therefore, the profitability analysis calculation in Table 1 indicated that the biobased detergent plant was not profitable.

The profitability analysis calculation in Table 1 indicated that producing a single biobased detergent product was unprofitable. Furthermore, Figure 5 suggests that several production schemes can be optimized to produce a more profitable plant. Therefore, the economic evaluation of the biobased detergent plant was repeated with several modifications, including:

1) Increasing the raw material capacity of waste cooking oil to 4,000 kg oil/hour.

2) The biobased detergent plant scheme will be modified to also sell high–value intermediate products such as methyl ester (biodiesel) and methyl ester sulfonate through a biorefinery concept. Biodiesel is a high–value alternative energy product, while methyl ester sulfonate (MES) is a high-demand surfactant.

3) Reusing process byproducts, such as the “MES By–Product” stream in Figure 5, which still contained significant amounts of sodium bisulfite and methyl ester, and the "Methanol Regeneration" stream in Figure 5, which was a methanol recycling stream.

The various modifications to the biobased detergent plant mentioned above were carried out using SuperPro Designer 10, resulting in the biorefinery biobased detergent plant (Figure 6).

The biorefinery biobased detergent plant in Figure 6 was a modification of the biobased detergent plant in Figure 5. The biorefinery biobased detergent plant used 4000 kg of waste cooking oil hour^{-1} capacity to produce biodiesel, methyl ester sulfonate, and bio–based detergent products. Several flow modifications were made to increase the economic value of the plant. The S–110 stream in Figure 6 was divided into two streams with a flow division of 50% each, namely the biodiesel product and the S–122 stream. The S–116 stream in Figure 6 will enter the centrifugation process, which was continued with 50% flow division each into the methyl ester sulfonate product and the S–127 stream. In addition, in Figure 6, the unreacted sodium bisulfite reactant was recycled according to the S–125 stream and the methanol was recycled according to the S–129 stream. This recycling flow scheme had the advantages of reducing the need for fresh feed in the 'sodium bisulfite' and 'methanol 2' streams, which had an impact on reducing the cost of sodium bisulfite and methanol raw materials.

The biorefinery concept is a processing concept aimed at optimizing the sustainable use of biomass resources through various conversion methods. This concept produces various high–value commodities from specific raw materials [42]. The application of the biorefinery concept using waste cooking oil as raw material in a biorefinery biobased detergent plant can be seen in Table 2. The products from this scheme were biodiesel, methyl ester sulfonate, and biobased detergent, which can significantly increase the plant's economic value. Based on the profitability analysis in Table 2, the ROI, PBP, NPV, and IRR were 58.72%, 1.24 years, 37,386,064 USD, and 59,67%, respectively.

Based on Table 2, the economic value of the biorefinery biobased detergent plant was already profitable. However, several considerations regarding raw material substitutions can be made to improve plant costs for the next research. Hydroxypropyl methylcellulose (HPMC) was an expensive raw material (Table 2). Hydroxypropyl methylcellulose (HPMC) in this study was used as an anti–redeposition agent that prevents dirt from sticking back to clothes. Alternative anti–redeposition materials other than hydroxypropyl methylcellulose (HPMC) with a lower price can be used to reduce the production costs of bio–based detergents.

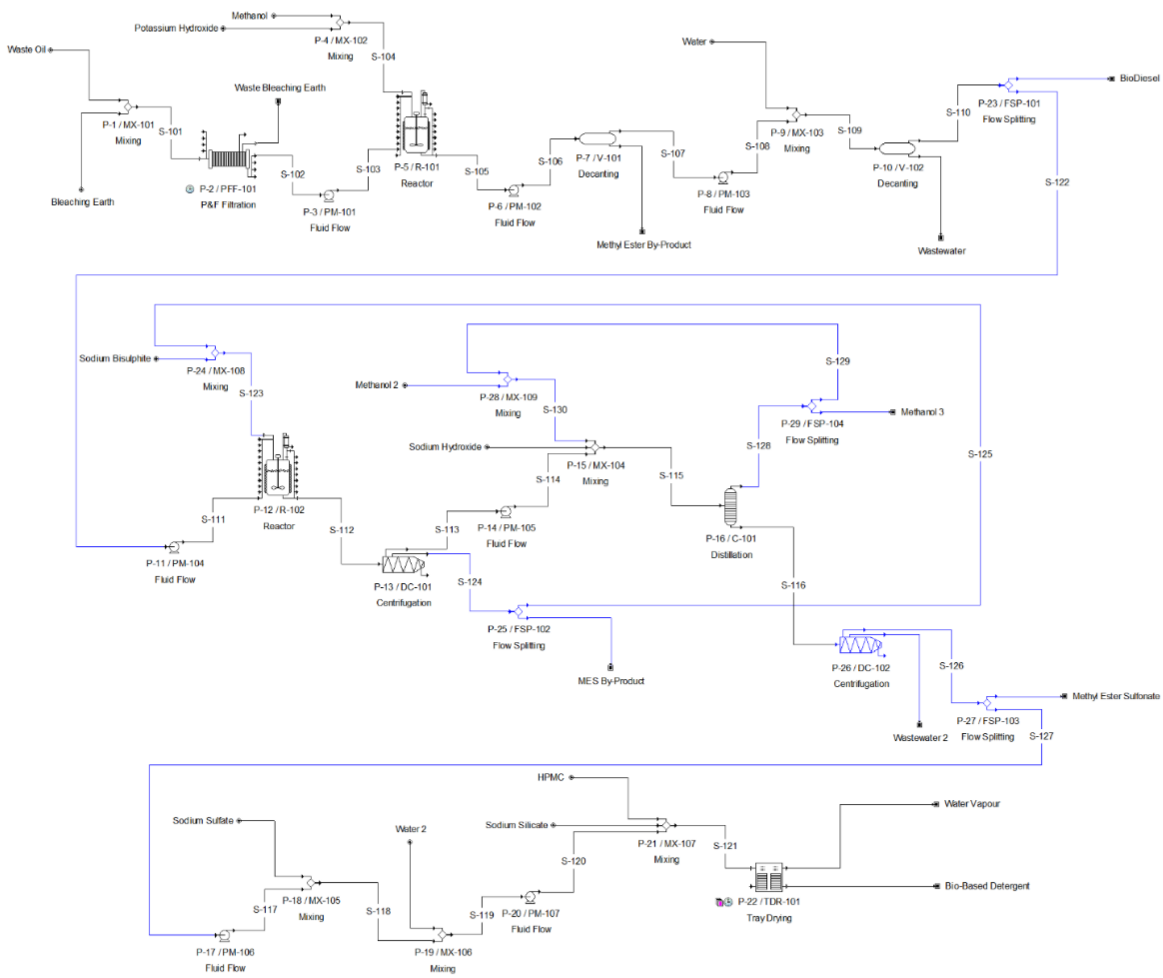

Figure 6: Biorefinery biobased detergent process flow diagram.

Table 2: Economic parameters of biorefinery biobased detergent plant.

Raw Material Costs	Cost (USD/Ton)	Reference
Bleaching Earth	685	[34]
Methanol	325	[35]
Potassium Hydroxide	244	[36]
Sodium Bisulfite	368.03	[37]
Sodium Hydroxide	433.68	[36]
Sodium Sulfate	95.33	[38]
Hydroxypropyl methylcellulose (HPMC)	1000	[39]
Sodium Silicate	343	[40]
Products Costs	**Cost (USD/Ton)**	**Reference**
BioBased Detergent	500	[41]
Biodiesel	1000	[43]
Methyl Ester Sulfonate	1800	[44]
Profitability Analysis	**Value**	
Total Capital Investment (TCI) (US$)	9,684,080	
Total Revenue (USD/year)	36,817,586	
Raw Materials	13,631,000	
Labor–Dependent	5,543,000	
Facility–Dependent	7,080,000	
Quality Control	831,000	
Utilities	613,000	
Total Operating Cost (USD/year)	27,698,000	
ROI (%)	58.72	
PBP (years)	1.24	
NPV (US$)	37,386,064	
IRR (%)	59.67	

4 Conclusions

This study investigated the production of a biobased detergent based on methyl ester sulfonate (MES) surfactant from waste cooking oil. MES can be produced from the sulfonation of waste cooking oil-based methyl esters that have the potential to be used as a bio-based detergent after being combined with various supporting raw materials. The bio-based detergent produced in this research had a pH range of about 10–12, which was an alkaline condition to aid the cleaning process. The best bio-based detergent formulation obtained in this study was a bio-based detergent with 20 g MES and 15 g sodium silicate composition due to its oil emulsification and foamability test. Economic analysis of single bio-based detergent production as a product from waste cooking oil showed unprofitable results. Therefore, other products such as methyl esters or biodiesel and MES surfactant can be produced as by-products to support the economic viability of biorefinery biobased detergent plant. Profitability analysis showed that biorefinery biobased detergent plant that produces bio-based detergent, biodiesel, and MES using 4,000 kg of waste cooking oil hour^{-1} capacity as raw materials had ROI, PBP, NPV, and IRR values which were 58.72%, 1.24 years, 37,386,064 USD, and 59,67%, respectively.

Author Contributions

J.R.H.P.: conceptualization, investigation, funding acquisition, project administration, reviewing and editing; D.Y.S.: investigation, methodology, data curation, writing an original draft; E.S.T.: investigation, methodology, data curation, writing an original draft. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] C. G. Lopresto, M. G. De Paola, and V. Calabrò, "Importance of the properties, collection, and storage of waste cooking oils to produce high-quality biodiesel – An overview," *Biomass and Bioenergy*, vol. 189, 2024, Art. no. 107363, doi: 10.1016/j.biombioe.2024.107363.

[2] B. Haryanto, R. Tambun, O. M. Sitohang, S. Y. Sidauruk, G. E. Naomi, and V. Alexander, "Competence of corncob (*Zea mays* L.) powder with HCl activation as adsorbent to purify waste cooking oil: Reference in the batch adsorption process," *South African Journal of Chemical Engineering*, vol. 52, pp. 48–60, 2025, doi:

10.1016/j.sajce.2025.01.006.
[3] A. Caporusso, M. Radice, A. Biundo, R. Gorgoglione, G. Agrimi, and I. Pisano, "Waste cooking oils as a sustainable feedstock for bio-based application: A systematic review," *Journal of Biotechnology*, vol. 400, no. February, pp. 48–65, 2025, doi: 10.1016/j.jbiotec.2025.02.003.
[4] L. Qadariyah, S. Sahila, and M. Mahfud, "The effect of reaction time and temperature on the synthesis of methyl ester sulfonate surfactant from palm oil as a feedstock using microwave-assisted heating," *ASEAN Journal of Chemical Engineering*, vol. 21, no. 1, pp. 104–112, 2021, doi: 10.22146/ajche.63786.
[5] E. Kurniasih, R. Rahmi, M. D. Supardan, and D. Darusman, "Two-step reaction for biodiesel synthesized from a high-free fatty acid crude palm kernel oil," *Applied Science and Engineering Progress*, vol. 18, no. 2, 2025, Art. no. 7570, doi: 10.14416/j.asep.2024.09.009.
[6] L. Qadariyah, D. S. Ryvalda, N. Y. Aditama, V. Aswie, and M. Mahfud, "Methyl ester sulfonate (mes) surfactant production from waste cooking oil (WCO) with microwave technology," *Science and Technoogy Indonesia*, vol. 9, no. 4, pp. 929–940, 2024, doi: 10.26554/sti.2024.9.4.929-940.
[7] R. L. Permadani, M. Ibadurrohman, and Slamet, "Utilization of waste cooking oil as raw material for synthesis of methyl sster sulfonates (MES) surfactant," in *2nd International Tropical Renewable Energy Conference (i-TREC)*, 2017, pp. 1–7.
[8] V. I. Yavrukova et al., "Enhanced solubility of methyl ester sulfonates below their krafft points in mixed micellar solutions," *Journal of Colloid and Interface Science*, vol. 660, 2023, pp. 896–906, 2024, doi: 10.1016/j.jcis.2024.01.127.
[9] E. S. Basheva et al., "Properties of the micelles of sulfonated methyl esters determined from the stepwise thinning of foam films and by rheological measurements," *Journal of Colloid and Interface Science*, vol. 538, pp. 660–670, 2019, doi: 10.1016/j.jcis.2018.12.034.
[10] S. N. Ilmiah, N. R. Mubarik, and B. Wahyuntari, "Characterization of protease from *Bacillus licheniformis F11.1* as a bio-detergent agent," *Makara Journal of Science*, vol. 22, no. 3, 2018, doi: 10.7454/mss.v22i3.8809.
[11] J. A. S. Miranda et al., "Ultrasound and eco-detergents for sustainable cleaning," *Processes*, vol. 11, no. 7, 2023, doi: 10.3390/pr11072082.
[12] S. Dinurrohmah, U. H. Fauki, M. Jiana Bahi, L. Subagiyo, and A. Nuryadin, "Efektivitas pemanfaatan daun kelor sebagai alternatif biosurfaktan detergen dengan metode PRES (Prinsip Rotary Evaporator Sederhana)," *Envirotek*, vol. 14, no. 2, pp. 192–196, 2022, doi: 10.33005/envirotek.v14i2.257.
[13] V. M. L. Nguyen, A. Ndao, E. C. Peterson, J. F. Blais, and K. Adjallé, "*Bacillus* species: Evolving roles in bio-based detergents," *Processes*, vol. 13, no. 6, pp. 1–28, 2025, doi: 10.3390/pr13061885.
[14] P. P. Wulandari, M. T. Adiwibowo, A. S. Redjeki, M. Ibadurrohman, and Slamet, "Synthesis of eco-friendly detergent based on crude palm oil and titania nanoparticles," *Asian Journal of Chemistry*, vol. 31, no. 10, pp. 2394–2396, 2019.
[15] Q. Helmy, S. Gustiani, and A. T. Mustikawati, "Application of rhamnolipid biosurfactant for bio-detergent formulation," *IOP Conference Series: Materials Science and Engineering*, vol. 823, no. 1, 2020, doi: 10.1088/1757-899X/823/1/012014.
[16] S. Nurdin, N. H. Kamin, M. V. Sivaguru, N. S. Ghazali, M. Z. Sahad, and S. F. Haron, "Future prospects of biobased detergent derived from *Jatropha* c. seeds oil (JSO)," *Australian Journal Of Basic And Applied Sciences*, vol. 11, no. 3, pp. 79–84, 2017.
[17] D. M. Dewi and A. Danaryanti, "Financial analysis of green detergent as a water-friendly solution in Indonesia," *Journal Research of Social Science, Economics, and Management*, vol. 2, no. 3, pp. 382–390, 2022, doi: 10.59141/jrssem.v2i03.290.
[18] Monika, S. Banga, and V. V. Pathak, "Biodiesel production from waste cooking oil : A comprehensive review on the application of heterogenous catalysts," *Energy Nexus*, vol. 10, p. 100209, 2023, doi: 10.1016/j.nexus.2023.100209.
[19] R. L. Permadani and Slamet, "Development of nanofluid detergent based on methyl ester sulfonates surfactant from waste cooking oil and titanium dioxide nanoparticles," *IOP Conference Series: Materials Science and Engineering*, vol. 509, no. 1, 2019, doi: 10.1088/1757-899X/509/1/012120.
[20] M. S. Peters, K. D. Timmerhaus, and R. E. West, *Plant Design and Economics for Chemical Engineers*, 5th Eds. OH: McGraw-Hill, 2003.
[21] G. D. Junior, M. Ibadurrohman, and Slamet,

"Synthesis of eco-friendly liquid detergent from waste cooking oil and ZnO nanoparticles," *AIP Conference Proceedings*, vol. 2085, 2019, doi: 10.1063/1.5095053.
[22] Y. S. Lim, N. B. Baharudin, and Y. W. Ung, "Methyl ester sulfonate: A high-performance surfactant capable of reducing builders dosage in detergents," *Journal of Surfactants and Detergents*, 2018, doi: 10.1002/jsde.12230.
[23] S. Nurdin, R. M. Yunus, A. H. Nour, J. Gimbun, N. A. N. Azman, and M. V. Sivaguru, "Restoration of waste cooking oil (WCO) using alkaline hydrolysis technique (ALHYT) for future biodetergent," *ARPN Journal of Engineering and Applied Sciences*, vol. 11, no. 10, pp. 6405–6410, 2016.
[24] I. Sailah, E. Hambali, and F. E. Aulyana, "Formulation of biodegreaser made from palm oil methyl ester sulfonate surfactant with oxalic acid additive," *International Journal of Oil Palm*, vol. 4, no. 2, pp. 39–45, 2021, doi: 10.35876/ijop.v4i2.62.
[25] J. R. H. Panjaitan, "Reaction kinetics of soap making and glycerol purification from soap alkaline waste: review," *Rekayasa*, vol. 14, no. 2, pp. 200–206, 2021.
[26] D. F. Mekonen, M. B. Regasa, and F. G. Ejigu, "Sustainable biosurfactants obtained from phytolacca dodecadra berries in the formulation of liquid laundry detergents and its performance evaluation," *Results in Chemistry*, vol. 18, p. 102645, 2025, doi: 10.1016/j.rechem.2025.102645.
[27] D. Langevin, "Recent advances on emulsion and foam stability," *Langmuir*, vol. 39, no. 11, pp. 3821–3828, 2024.
[28] D. Tania and R. Kuswahyuning, "Water-in-oil-in water (W/O/W) double emulsion formulations using variation concentration of carboxymethyl cellulose sodium," *Journal of Food and Pharmaceutical Sciences*, vol. 2020, no. 2, pp. 284–293, 2020.
[29] T. Sakai and Y. Kaneko, "The effect of some foam boosters on the foamability and foam stability of anionic systems," *Journal of Surfactants and Detergents*, vol. 7, no. 3, pp. 291–295, 2004, doi: 10.1007/s11743-004-0314-x.
[30] M. H. Amaral, J. Das Neves, M. Oliveira, and M. F. Bahia, "Foamability of detergent solutions prepared with different types of surfactants and waters," *Journal of Surfactants and Detergents*, vol. 11, no. 4, pp. 275–278, 2008, doi: 10.1007/s11743-008-1088-0.
[31] E. G. Ates, G. Tonyali Karsli, O. D. Ozcan, E. B. Ozvural, and M. H. Oztop, "Foaming and emulsifying properties of aquafaba powders as affected by saponin and amino acid content," *LWT*, vol. 226, p. 117975, 2025, doi: 10.1016/j.lwt.2025.117975.
[32] A. Bello et al., "An experimental study of foam-oil interactions for nonionic-based binary surfactant systems under high salinity conditions," *Scientific Reports*, vol. 14, no. 1, pp. 1–17, 2024, doi: 10.1038/s41598-024-62610-1.
[33] R. C. Soy, P. K. Kipkemboi, and K. Rop, "Synthesis, Characterization, and Evaluation of Solution Properties of Sesame Fatty Methyl Ester Sulfonate Surfactant," ACS Omega, vol. 5, no. 44, pp. 28643–28655, 2020, doi: 10.1021/acsomega.0c03698.
[34] A. Adiarso, E. Hermawan, and A. Nelly, "Optimized utilization of spent bleaching earth to enhance economic performance of integrated biodiesel-cooking oil plants," *Case Studies in Chemical and Environmental Engineering*, vol. 10, p. 100784, 2024, doi: 10.1016/j.cscee.2024.100784.
[35] Echemi. "Methanol international price." echemi.com. Accessed: Sep. 19, 2025. [Online.] Available: https://www.echemi.com/pip/methanol-reagent-pd20150901274.html
[36] S. Lee, W. Choi, H. Kim, S. Park, and J. Hwang, "Techno-economic analysis and life-cycle assessment of the electrochemical conversion process with captured CO_2 in amine-based solvent," *Green Chemistry*, vol. 24, pp. 1–31, 2023.
[37] Echemi. "Sodium bisulfite price." echemi.com. Accessed: Dec. 10, 2025. [Online.] Available: https://www.echemi.com/productsInformation/pd20160302191550321-sodium-bisulfite.html
[38] Chemanalyst. "Sodium sulphate price trend and forecast." chemanalyst.com. Accessed: Dec. 10, 2025. [Online.] Available: https://www.chemanalyst.com/Pricing-data/sodium-sulphate-1480
[39] Alibaba. "Hydroxypropyl methyl cellulose." alibaba.com. Accessed: Sep. 19, 2025. [Online.] Available: https://www.alibaba.com/showroom/hydroxypropyl-methyl-cellulose-price.html
[40] Chemanalyst. "Sodium silicate price trend and

forecast.” chemanalyst.com. Accessed: Dec. 10, 2025. [Online.] Available: https://www.chemanalyst.com/Pricing-data/sodium-silicate-1340

[41] Alibaba. “Bio detergent.” alibaba.com. Accessed: Sep. 19, 2025. [Online.] Available: https://www.alibaba.com/countrysearch/CN/bio-detergent.html

[42] D. C. Makepa and C. H. Chihobo, “Barriers to commercial deployment of biorefineries: A multi-faceted review of obstacles across the innovation chain,” *Heliyon*, vol. 10, no. 12, p. e32649, 2024, doi: 10.1016/j.heliyon.2024.e32649.

[43] ESDM, “Besaran harga indeks pasar bahan bakar nabati jenis biodiesel bulan september 2025.” ebtke.esdm.go.id. Accessed: Dec. 10, 2025. [Online.] Available: https://ebtke.esdm.go.id/artikel/pengumuman/hip-bbn-jenis-biodiesel-bulan-september-2025

[44] C. Charoentanaworakun, S. Assabumrungrat, and A. Soottitantawat, “Techno-economic-environmental analysis of sustainable anionic biosurfactant production from palm fatty acid distillate,” *ACS Omega*, vol. 8, pp. 45045–45055, 2023, doi: 10.1021/acsomega.3c06777.