JOURNAL OF ADVANCED MECHANICAL ENGINEERING APPLICATIONS
e-ISSN: 2716-6201

Vol. 6 No. 2 (2025) 49-57
https://publisher.uthm.edu.my/ojs/index.php/jamea

JAMEA

Optimization of NaOH Concentration for Sustainable Soap Production Using Waste Cooking Oil

Mohd Nur Izzuddin Rosman[1], Siti Aida Ibrahim[1]*, Muhammad Yusuf Rosman[2,3]

[1] *Faculty of Mechanical and Manufacturing Engineering,*
Universiti Tun Hussein Onn Malaysia, Persiaran Tun Dr. Ismail, 86400 Parit Raja, Johor, MALAYSIA
[2] *Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (Pagoh Campus),*
Pagoh Higher Education Hub, 84600 Pagoh, Muar, Johor, MALAYSIA
[3] *Wajan Cater & Canopy*
No. 23, Jalan Dato' Jalal, Parit Besar, Jalan Kluang, 83000 Batu Pahat, Johor, MALAYSIA

*Corresponding Author: saida@uthm.edu.my
DOI: https://doi.org/10.30880/jamea.2025.06.02.005

Article Info

Received: 9 July 2025
Accepted: 18 November 2025
Available online: 31 December 2025

Keywords

Waste cooking oil, soap production, saponification, free fatty acid (FFA), foam stability, sustainable synthesis

Abstract

This study presents a sustainable approach for synthesizing soap bars from WCO. The process involves collecting and filtering WCO, followed by an optimized saponification reaction using alkaline, resulting in soap bars with desirable properties. Comparative analysis reveals that WCO appears darker, with higher free fatty acid content (4.00%) and slightly increased viscosity (79.13 cP) compared to new cooking oil. The study highlights the significant impact of NaOH concentration on soap consistency, where 10% NaOH concentration (sample BS3) has achieved the most stable foam formation. BS3 has no appearance of a gel phase upon cutting and shows 1.78% moisture content. This research emphasizes the utilization of waste cooking oil as a valuable resource for soap production, contributing to waste reduction and supporting sustainable practices within the circular economy framework.

1. Introduction

Palm oil is a widely used cooking oil that comes from the oil palm tree. It is used in many products, from food to personal care items to industrial by-products, because of its low price and high yield [1-4]. However, deforestation, habitat deterioration, and environmental contamination are significant ecological consequences of palm oil production and consumption. Malaysia is one of the world's leading producers and exporters of palm oil. It can produce a significant surplus of waste cooking oil (WCO), which primarily comes from the food service industry.

In Malaysia, approximately 30,000 tons of WCO are produced, highlighting the substantial quantity of used oil created from food preparation and cooking throughout the country [5]. Inadequate WCO management could exacerbate environmental issues and endanger human health. Thus, WCO generation must be reduced and waste management improved by strategic planning. As a step towards the use of sustainable resources and environmental preservation, soap production is a proactive measure for WCO management [6-7].

Soap fabrication requires the transformation of WCO into useful goods. The composition of WCO varies significantly based on the duration of frying and the type of food being cooked, which will affect the free fatty acid (FFA) and peroxide values. However, few studies have established standardized pretreatment procedures, such as filtration, neutralization, or bleaching treatment, which control these variations [8-9]. In this complex procedure, triglycerides, which are rich in oils and fats, are expertly combined with an alkaline substance to cause the chemical reaction known as saponification [6], [10-11].

In a process called saponification, lye solution combines with a mixture of oils to produce soap [12]. This saponification process is complete once the soap has been cured for at least 4 weeks. Saponification takes place when triglycerides are mixed with an alkaline, resulting in the formation of metal salts from fatty acid [12]. High levels of FFA in waste cooking oil led to increased alkali consumption during the saponification process, which resulted in inconsistencies in soap hardness and residual oil content [13].

The reaction involves breaking the ester bonds in triglycerides. Glycerin and soap molecules (carboxylate salts) are the products of this saponification process. The amount of sodium hydroxide (NaOH) can be influenced by the completeness of the reaction and the quality of the soap produced. This can be supported by the Azme *et al.* (2023) study, where the required amount of NaOH is determined by the saponification value of the oil used, which shows the quantity of alkali needed to fully convert the fat into soap [6]. Insufficient NaOH in soap formulation can lead to unreacted oil, which results in greasy soap. While an excess of NaOH may cause high alkalinity, which leads to skin irritation [14].

In general, soap can be manufactured using either a hot process method or a cold process method [15]. Soaps made from NaOH are used for bar soap, while potassium hydroxide (KOH) is suitable for making liquid soap [16]. The advantage of cold processed method is that it is free from synthetic or harsh ingredients [12]. This method entails allowing the ingredients to react at room temperature, which results in a soap that is typically more hydrating and milder. It also gives greater control over the materials and the product due to the ability to incorporate value added compounds [17-18].

Concentration of NaOH solutions is essential in the saponification process. Higher concentrations of NaOH generally increase the saponification rate and conversion efficiency. For example, a study on soap stock processing revealed that a 45% NaOH solution is ideal for achieving high yields and quality in fatty acids [19]. Additionally, higher concentrations of NaOH can create a more alkaline environment, which may improve foam stability by lowering the surface tension of the soap solution. [20]. By optimizing NaOH concentration along with other reaction rates, conversion efficiency and product quality can be maximized.

However, in previous studies, there were fewer findings on optimized NaOH concentrations in formulations for soap production. Therefore, the aim of the study was to investigate the method applied by the cold process to synthesize a range of WCO bar soaps. Diverse NaOH concentrations were investigated for their impact on the synthesis procedure. The physiochemistry of the WCO and produced samples was analyzed, including viscosity measurement, free fatty acid analysis, moisture content, color observation, and Fourier Transform Infrared Spectroscopy (FTIR). The bar soap performance will be evaluated based on the stability of its foam.

2. Experimental Method

2.1 Chemicals and Reagents

Analytical standard chemicals and reagents such as sodium hydroxide (NaOH, Merck), isopropanol (70%, Sigma-Aldrich), and the filtered WCO were collected from Wajan Caterer Sdn. Bhd. For comparison, new cooking oil (NCO) from a similar brand (Buruh) was used.

2.2 Analysis of Constituent of Waste Cooking Oil

2.2.1 Determination of Free Fatty Acid (FFA) and Acid Value (AV)

The oil was tested for FFA using the American Oil Chemists' Society (AOCS-CA 5a-40) method [21-22]. The oil sample weighed 5 grams and was treated with 50 mL of neutralized isopropanol in a dry conical flask. Following this, 500 mL of a 1% phenolphthalein indicator was added to the mixture, which was then heated on a hot plate until it reached a temperature of 40°C. The mixture was then titrated with NaOH solution (0.1 M) for at least 30 seconds or until it turns into a pink color. The free fatty acid was determined by using Eq. (1):

$$FFA\% = \frac{25.6 \times N \times V}{W} \tag{1}$$

In this context, V represents the volume of NaOH in mL, N denotes the normality of the NaOH standard, W indicates the weight of samples in grams, and 25.6 serves as both the formula for determining free fatty acid content and the equivalence factor for palmitic acid, which is the predominant fatty acid in palm oil.

The acid value was determined using the Eq. (2) as follows:

$$AV = FFA\% \times 2.19 \quad (2)$$

where FFA is the value of free fatty acid and 2.19 is the conversion factor for palmitic acid.

2.2.2 Determination of Viscosity

Viscosity of oil was determined by using the Brookfield model DV-I (USA) equipped with the LV-2 (62) spindle. At ambient temperature, the cooking oil was stirred for 1 minute at a speed of 100 rpm. Then, the spindle was rotated in the oil until the reading on the meter monitor was stable. The substance is placed in the viscometer, and its resistance to flow is measured in centipoise (cP).

2.2.3 Color Observation

The color of WCO and NCO was compared to find any differences between the two cooking oils. The visual assessment was conducted by pouring 1 L of each oil sample into a beaker for observation. The waste cooking oil samples were filtered before use, whereas the new cooking oil was utilized in its original state.

2.2.4 Soap Preparation

Producing soap from waste cooking oil by experimenting with different weight ratios of sodium hydroxide (NaOH), water, and waste cooking oil [3]. The percentage of NaOH varied from 5%, 7%, 10%, 13%, and 15% of the total water and waste cooking oil. The process involved mixing all the ingredients in a container until the batter became homogenous. Then the mixture was placed in a mold and cured for 6 weeks at room temperature. The properties of the resulting soap were evaluated, and the study aimed to find the best ratio of ingredients and conditions for sustainable soap production.

2.3 Characterization of Soap

2.3.1 Determination of Moisture Content

The moisture content of soap samples was determined using the official AOCS Db 1- 48 method. Approximately 5 g of the soap sample was placed into a tared moisture dish, which had been dried for 1 hour at 105°C ± 2 and then cooled to room temperature in a desiccator. The samples maintained a constant weight or lost no more than 0.1% after 1 hour of heating. The following Eq. (3) was utilized to compute the moisture content from the recorded data.

$$m\ (\%) = \frac{m_1 - m_2}{m_1 - m_0} \times 100 \quad (3)$$

Where, m_0 represents the dish's mass in grams, m_1 represents the dish and the test part before heating, and m_2 represents the dish and the test portion after heating.

2.3.2 Foaming Ability Measurement

A 0.2 g portion of each soap sample was placed into a 100 mL measuring cylinder containing 10 mL of distilled water, and the mixture was shaken vigorously to generate foam. After shaking, the cylinder was allowed to stand for about 10 minutes, and the height of the foam was then measured and recorded. The observation took place over a 10 hour period, and the measurement was taken at 2 hour intervals. The measurement was calculated using Eq. (4) as described in detail by Abdul Rahman *et al.* [12].

$$foaming\ stability\ (\%) = \frac{foam\ volume\ after}{initial\ sample\ volume} \times 100 \quad (4)$$

3. Results and Discussion

3.1.1 Analysis of Physicochemical Properties for Cooking Oils

The experimental outcomes for determining the physicochemical properties of the cooking oils through the examination of free fatty acid, acid value, viscosity, and color are detailed in Table 1. The percentage value of free fatty acids in NCO was higher compared to WCO. Specifically, the free fatty acid percentage in NCO is 1.54%, while in WCO, it is 4.00%. WCO typically contains high levels of free fatty acid due to repeated use in frying, which can lead to soap formation during transesterification processes [23]. This difference in free fatty acid percentage contributes to the noticeable difference in color between the two cooking oils, as seen in Fig. 1. NCO appears yellow, while WCO turns darkish yellow due to repeated exposure to heat and oxidation.

In terms of viscosity, WCO shows a slight increase from 76.20 cP to 79.13 cP, likely due to the formation of polymerized compounds and accumulation of impurities during the frying process. A similar finding shows that the viscosity of palm oil increased after successive frying cycles, with the polymer formation identified as a primary cause [24]. WCO undergoes oxidation, during which oxygen interacts with the unsaturated fatty acids in the oil, which results in the formation of hydroperoxides [25]. The oxidation products can undergo polymerization, leading to the formation of larger molecular weight compounds. This process significantly increases the viscosity of the oil [25]. These changes highlight the chemical and physical alterations that occur in cooking oil after repeated use.

Table 1 *Characterization of cooking oil*

Sample	Color	FFA%	AV	Viscosity (cP)
New Cooking Oil (NCO)	Yellow	1.54	11.6	76.20
Waste Cooking Oil (WCO)	Darkish yellow	4.00	3.37	79.13

(a) **(b)**

Fig. 1 *Color observation: (a) New cooking oil; (b) Waste cooking oil*

Fig. 2 displays the FTIR analysis for NCO and WCO. The figure indicates that NCO and WCO exhibited no significant changes, as the materials utilized in the production of cooking oil are the same. The phase 1 area has a pronounced C-H bond indicative of alkanes at a wavelength of 2922 cm^{-1}. These peaks are characteristic of C–H bonding in long-chain fatty acids and triglycerides, the principal constituents of cooking oils. In phase 2, the region exhibits C=O bonding at 1743 cm^{-1}, corresponding to the second peak in the spectrum of bonding modes with significant intensity. A pronounced peak indicates a substantial presence of ester groups, aligning with conventional oil chemistry as illustrated in Table 2.

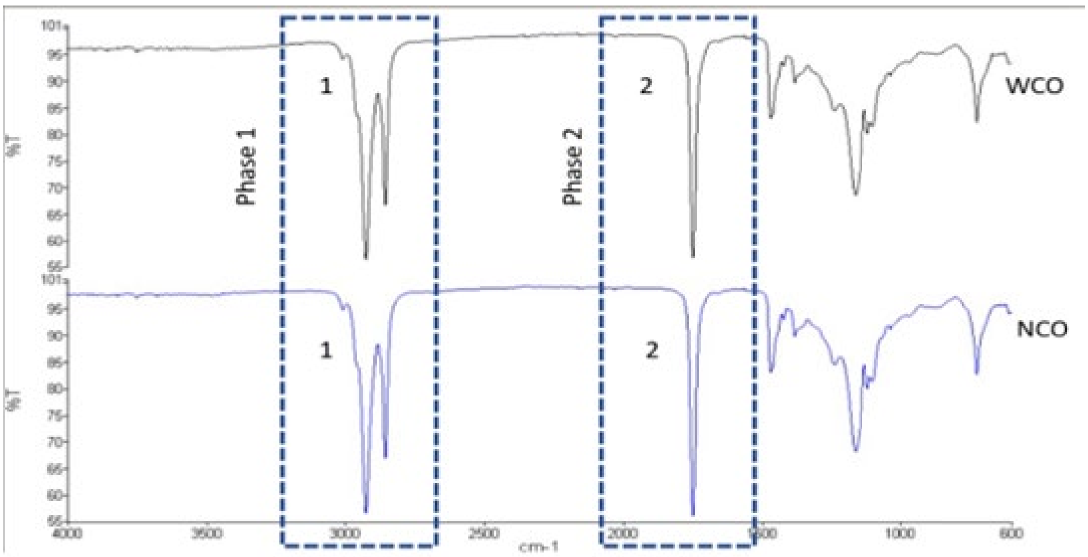


Fig. 2 *FTIR observations for WCO and NCO*

Table 2 *FTIR spectroscopic regions of cooking oils*

Frequency Range (cm^{-1})	Wavenumber (cm^{-1})	Functional group	Bond type	Mode of vibrations
1700-1750	1743	C=O (ester)	C=O	Stretching
2843 - 2936	2922	C-H (alkanes)	CH_2	Stretching

3.1.2 Physicochemical Properties of the Prepared Soaps

Table 3 describes the comparison of the characteristics of the as-prepared soap. All samples underwent successful saponification, resulting in their transformation into bar soap. The effect of the NaOH concentration on the color and texture of soap has been determined. The first observation was the difference in outer color among the soap samples; as NaOH concentration increased, the color of the as-prepared soap got whiter. At lower NaOH levels (BS1 and BS2), the soap remains soft with higher moisture content, measuring 2.41% and 1.87%, respectively. The gelling phase color at BS1 is darker than the outer layer, while BS2 shows nearly similar coloration between layers. However, only BS3 has no appearance of a gel phase upon cutting. In contrast, other samples became clearer when the NaOH was increased (refer to Fig. 3).

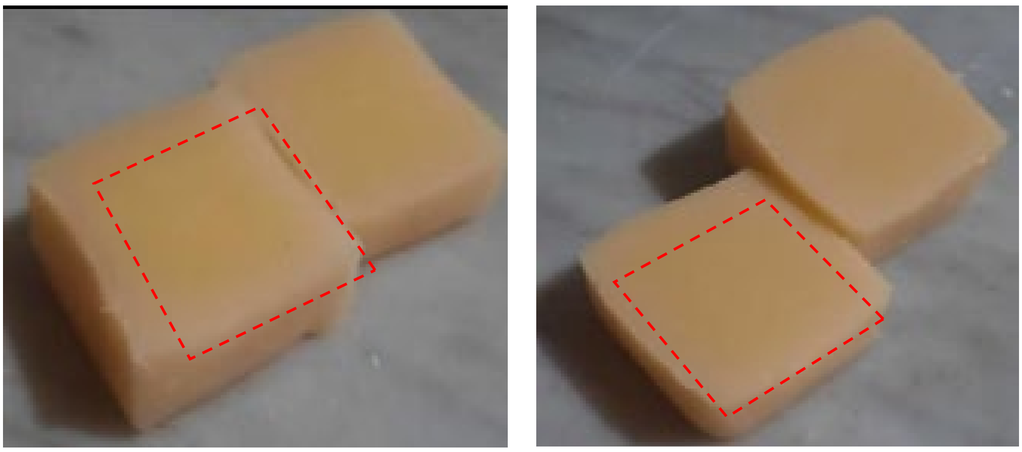
The gelling phase in soap production can be caused by several factors, such as the presence of glycerol and the structural changes that occur during the soap making process. During the process, the structure of the continuous phase can transition from a lamellar gel to a micellar aqueous solution with the addition of water. This transition is important for the foaming activity and cleansing properties of the soap [26].

Table 3 *Characteristic of the as-prepared soap*

Sample	NaOH (%)	Gelling Phase Color	Soap Texture	Moisture content (%)
BS1	5	Darker than the outer layer	Soft	2.41
BS2	7	Nearly similar	Soft	1.87
BS3	10	Non-gelling	Hard	1.78
BS4	13	Darker than the outer layer	Harder	0.90
BS5	15	Darker than the outer layer	Hardest	0.86

Further increases in NaOH to 13% (BS4) and 15% (BS5) result in even harder soap textures with moisture levels dropping to 0.90% and 0.86%, respectively. This shows the concentration of NaOH can influence properties of the soap and its moisture content. Higher NaOH concentration generally leads to increased conversion rates in saponification reactions. Another study shows similar results in which soap produced using a high concentration of NaOH (50%) resulted in a final product with a moisture content of about 8.5% [27]. This suggests that higher concentrations of NaOH may result in soaps with relatively lower moisture content.

Fig. 4 shows the appearance of several lye pockets on sample BS5, which is the sample with the highest NaOH presence. Lye pockets are areas within the soap where the lye has not fully reacted with the fats or oils. This indicates that a localized concentration of alkaline substances occurred during the saponification process. During saponification, thorough mixing is necessary for an even distribution of the lye throughout the fats and oils. Inadequate mixing can create areas where the lye has not fully reacted, leading to the formation of lye pockets [28]. Furthermore, the concentration of NaOH can affect the efficiency of this reaction, influencing the properties of the soap, such as its lather formation [29].



(a) **(b)**

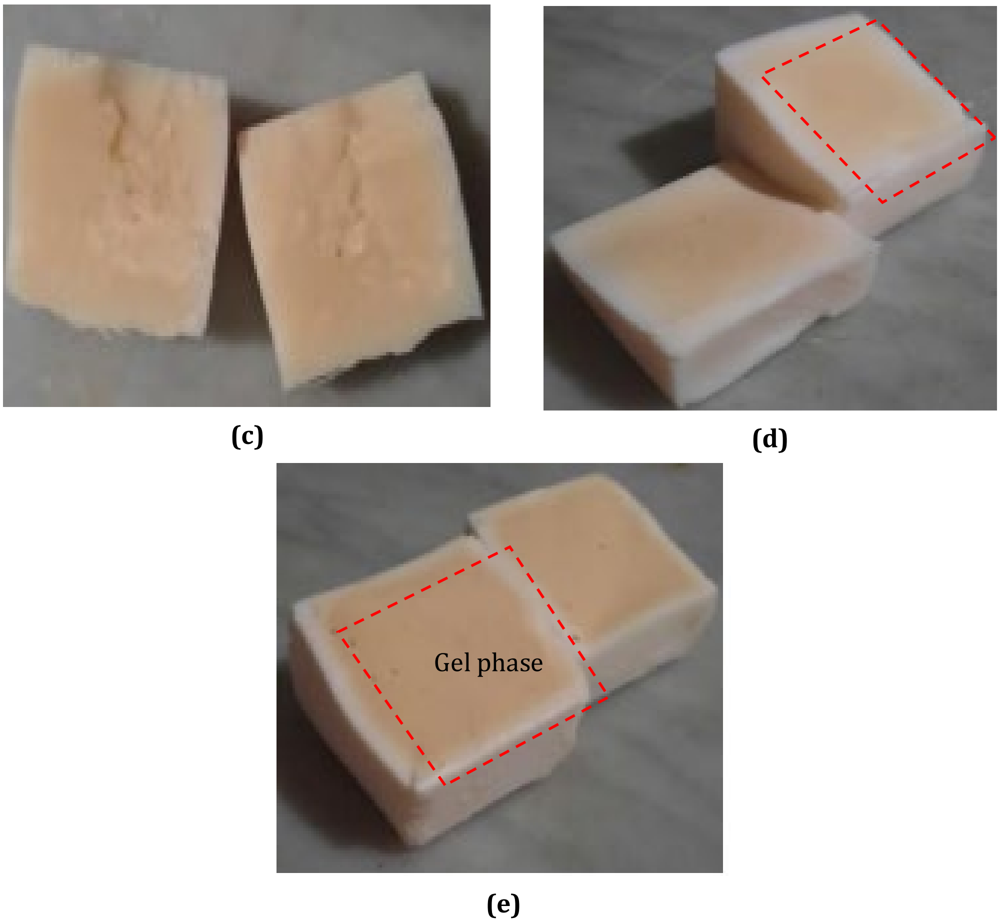


Fig. 3 *Soap bars prepared by various NaOH percentages: (a) 5%; (b) 7%; (c) 10%; (d) 13%; and (e) 15%*

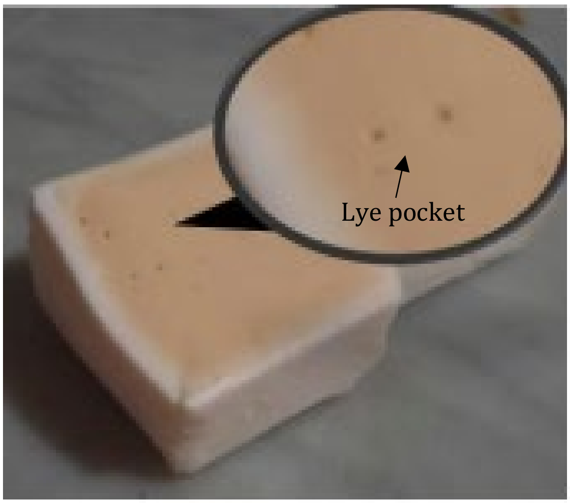


Fig. 4 *Lye pocket appearance of BS5*

Fig. 5 presents the foam stability of bar soap samples (BS1 to BS5) over a 10-hour period. Foam stability refers to the ability of the soap to maintain its foam and is a measure of its performance. The vertical axis shows the foam stability, and the horizontal axis shows the time in hours. The results indicated that the decline in foam stability over time implies that the soap is unable to maintain the foam it produces. BS3 was the most stable in terms of foam stability; BS2 and BS4 had zero foam stability by the 10th hour. The foam stability of all soap samples decreased over the 10-hour period, with BS5 experiencing a drastic decrease from 2 to 4 hours. The difference in NaOH concentration can be a factor of foam stability. This is because NaOH increases the viscosity of the foaming solution, which in turn enhances foam density and stability [30]. Higher surface viscosity can enhance foam stability by slowing down the flow of liquid from the foam films [31]. As an example, the higher sodium content in

NaOH, compared to other sodium-based admixtures such as sodium chloride (NaCl) and sodium carbonate (Na_2CO_3), makes it more effective at achieving the desired foam density with a relatively lower dosage [32]. NaOH plays a crucial role in enhancing and improving foam stability in various applications by increasing the viscosity and density of the foaming solution.

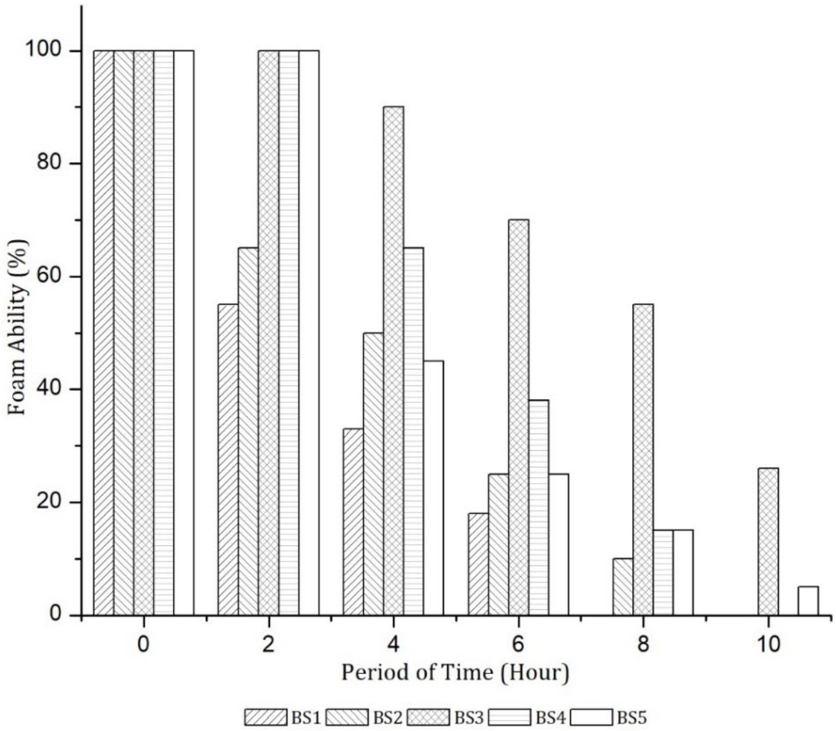


Fig. 5 *Foam stability of as-prepared soap for a duration of 10 hours*

4. Conclusion

A soap made from different concentrations of NaOH has been produced successfully from WCO in this study. The physicochemical properties of five soap samples were evaluated by focusing on foaming ability and moisture content. The result revealed that 10% NaOH concentration (sample BS3) has achieved the most stable foam formation. This formulation not only exhibited excellent foaming properties but also resulted in a soap with a hard texture, characterized by a moisture content of 1.78%, which presents an optimized solution for sustainable soap production. The concentration of NaOH affects the efficiency of the reaction and influences soap properties of other samples. This highlights that the ratio of NaOH is an important ingredient in the saponification process, which can affect the final properties of soap. Careful selection of NaOH concentration can significantly influence the characteristics of soap.

Acknowledgement

The authors wish to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, which has supported the accomplishment of research activity.

Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper, as follows: ***study conception and design:*** *Muhammad Yusuf Rosman;* ***data collection:*** *Muhammad Yusuf Rosman;* ***analysis and interpretation of results:*** *Muhammad Yusuf Rosman, Mohd Nur Izzuddin Rosman, Siti Aida Ibrahim;* ***draft manuscript preparation:*** *Mohd Nur Izzuddin Rosman, Siti Aida Ibrahim. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Durango-Giraldo, G., Zapata-Hernandez, C., Santa, J. F., & Buitrago-Sierra, R., (2022). Palm oil as a biolubricant: Literature review of processing parameters and tribological performance, *Korean Society of Industrial Engineering Chemistry*, https://doi.org/10.1016/j.jiec.2021.12.018

[2] Hor, C. J., Tan, Y. H., Mubarak, N. M., Tan, I. S., Mohd Lokman Ibrahim, Yek, P. N. Y., Karri, R. R., & Mohd Khalid (2023). Techno-economic assessment of hydrotreated vegetable oil as a renewable fuel from waste sludge palm oil, *Environ Res*, vol. 220, https://doi.org/10.1016/j.envres.2022.115169

[3] Ilyas, R. A., Sapuan, S. M., Ibrahim, M. S., Wondi, M. H., Norrrahim, M. N. F., Harussani, M. M., Aisyah, H. A., Jenol, M. A., Nahrul Hayawin, Z., Atikah, M. S. N., Ibrahim, R., SaifulAzry, S. O. A., Hassan, C. S., & Haris, N. I. N. (2022). Classification and application of composite panel products from oil palm biomass, in *Oil Palm Biomass for Composite Panels: Fundamentals, Processing, and Applications*, 217-240. https://doi.org/10.1016/B978-0-12-823852-3.00012-X

[4] Savarese M., Castellini G., Paleologo M., & Graffigna G. (2022). Determinants of palm oil consumption in food products: A systematic review, *Journal of Functional Foods,* 96, 105207, https://doi.org/10.1016/j.jff.2022.105207

[5] Irawan, A., Mochamad Adha Firdaus, Kurniawan, T., Steven, S., Pandit Hernowo, Reni Yuniarti, & Yazid Bindar. (2024). Unlocking the potential of waste cooking oil pyrolysis for chemicals purposes: Review, challenges, and prospects, *Journal of Analytical and Applied Pyrolysis,* 181, 106567-106567, https://doi.org/10.1016/j.jaap.2024.106567

[6] Siti Nurdiyanah Kamarul Azme, Nur Sofea Insyirah Mohd Yusoff, Lim Ying Chin, Yusairie Mohd, Rossuriati Dol Hamid, Muhammad Noor Jalil, Hamizah Mohd Zaki, Sabiha Hanim Saleh, Norizan Ahmat, Mohd Abdul Fatah Abdul Manan, Nurjanah Yury, Nurul Nadiah Firdaus Hum, Famiza Abd Latif & Zainiharyati Mohd Zain. (2023). Recycling waste cooking oil into soap: Knowledge transfer through community service learning, *Cleaner Waste Systems,* 4, 100084, https://doi.org/10.1016/j.clwas.2023.100084

[7] Zhu, X., Lyu, X., Wang, Q., Qiu, J., Wang, S., Liu, X., & Li, L. (2019). Clean utilization of waste oil: Soap collectors prepared by alkaline hydrolysis for fluorite flotation. *Journal of Cleaner Production,* 240, 118179*,* https://doi.org/10.1016/j.jclepro.2019.118179

[8] Bhran, A. A. (2025). A Comparative Techno-Economic Analysis of Waste Cooking Oils and Chlorella Microalgae for Sustainable Biodiesel Production, *Processes*, 13(11), 3526, https://doi.org/10.3390/pr13113526

[9] Luo, S., Ye, Z., Lv, Y., Xiong, Y., & Liu, Y. (2024). Composition analysis and health risk assessment of the hazardous compounds in cooking fumes emitted from heated soybean oils with different refining levels, *Environmental Pollution*, vol. 343, https://doi.org/10.1016/j.envpol.2023.123215

[10] Cheng, G., Zhang, M., Lu, Y., Zhang, Y., Lin, B., & Von Lau, E. (2024). A novel method for the green utilization of waste fried oil. *Particuology*, 84, 1-11, https://doi.org/10.1016/j.partic.2023.02.019

[11] Atolani, O., Olabiyi, E. T., Issa, A. A., Azeez, H. T., Onoja, E. G., Ibrahim, S. O., Zubair, M. F., Oguntoye, O. S., & Olatunji, G. A. (2016). Green synthesis and characterisation of natural antiseptic soaps from the oils of underutilised tropical seed. *Sustainable Chemistry and Pharmacy*, 4, 32-39, https://doi.org/10.1016/j.scp.2016.07.006

[12] S. S. Abdul Rahman, S. A. Ibrahim, R. Hussin, A. R. Ainuddin, & Z. Kamdi (2024). Eco-friendly Detergent Powder from Waste Cooking Oil using Cold Process: Characterisation and Comparative Evaluation, *International Journal of Nanoelectronics and Materials (IJNeaM)*, 17 (December), 89-93, https://doi.org/10.58915/ijneam.v17iDecember.1611

[13] Caporusso, A., Radice, M., Biundo, A., Ruggiero Gorgoglione, Gennaro Agrimi, & Pisano, I. (2025). Waste cooking oils as a sustainable feedstock for bio-based application: A systematic review, *Journal of Biotechnology*, 400, 48-65, https://doi.org/10.1016/j.jbiotec.2025.02.003

[14] Soni, H., Bhattu, M., Verma, M., Kaur, M., Al-Kahtani, A. A., Hussain Lone, I., Nath Yadav, A., & Ubaidullah, M. (2024). From kitchen to cosmetics: Study on the physicochemical and antioxidant properties of waste cooking oil-derived soap. *Journal of King Saud University - Science*, 36(10), 103483, https://doi.org/10.1016/j.jksus.2024.103483

[15] Maotsela, T., Danha, G., & Muzenda, E. (2019). Utilization of Waste Cooking Oil and Tallow for Production of Toilet "Bath" Soap, *Procedia Manufacturing*, 35, 541-545, https://doi.org/10.1016/j.promfg.2019.07.008

[16] Nova, J. F., Smrity, S. Z., Hasan, M., Tariquzzaman, M., Hossain, M. A. A., Islam, M. T., Islam, M. R., Akter, S., Rahi, M. S., Joy, M. T. R., & Kowser, K. (2025). Comprehensive evaluation of physico-chemical, antioxidant, and antimicrobial properties in commercial soaps: A study on bar soaps and liquid hand wash, *Heliyon*, 11(4), 41614, https://doi.org/10.1016/j.heliyon.2024.e41614

[17] Adjei, F., Amponsah, E., Ebo-Donkor, P., Smith, J. B., & Tulashie, S. K. (2021). Formulation of mosquito repellent soap using neem extract, and covers as a substitute source of alkalis. *Case Studies in Chemical and Environmental Engineering*, 5, 100171, https://doi.org/10.1016/j.cscee.2021.100171

[18] B. H. Abera, A. Diro, & T. T. Beyene (2023). The synergistic effect of waste cooking oil and endod (Phytolacca dodecandra) on the production of high-grade laundry soap, *Heliyon*, 9(6), https://doi.org/10.1016/j.heliyon.2023.e16889

[19] Kalyna, V., Koshulko, V., Ilinska, O., Tverdokhliebova, N., Tolstousova, O., Bliznjuk, O., Gavrish, T., Stankevych, S., Zabrodina, I., & Zhulinska, O. (2021). Development of soapstock processing technology to ensure waste-free and safe production. *Eastern-European Journal of Enterprise Technologies*, 6 (6(114), 23-29, https://doi.org/10.15587/1729-4061.2021.245094

[20] H. Emami, A. Ayatizadeh Tanha, A. Khaksar Manshad, & A. H. Mohammadi (2022). Experimental Investigation of Foam Flooding Using Anionic and Nonionic Surfactants: A Screening Scenario to Assess the Effects of Salinity and pH on Foam Stability and Foam Height, *ACS Omega*, 7(17), 14832-14847, https://doi.org/10.1021/acsomega.2c00314

[21] Prasanth Kumar, P. K., & Gopala Krishna, A. G. (2015). Physicochemical characteristics of commercial coconut oils produced in India. *Grasas Y Aceites*, 66(1), 062, https://doi.org/10.3989/gya.0228141

[22] A. A. W. Japir, J. Salimon, D. Derawi, M. Bahadi, S. Al-Shuja'A, & M. R. Yusop (2017). Physicochemical characteristics of high free fatty acid crude palm oil, *Oilseeds and fats, Crops and Lipids*, 24(5), https://doi.org/10.1051/ocl/2017033

[23] Estrada, R., Alon-alon, K., Jesel Simbajon, Paňares, J., Pagalan, E., Ido, A., & Arazo, R. (2024). Reduction of Acid Value of Waste Cooking Oil through Optimized Esterification via Central Composite Design. *Circular Economy and Sustainability*, 4(3), 1819-1834, https://doi.org/10.1007/s43615-024-00363-9

[24] Sadawarte, P. D. & Annapure, U. S. (2023). Study of the behavior and properties of frying oil on repetitive deep frying, *Journal of Food Science and Technology*, 60 (10) 2549-2556, https://doi.org/10.1007/s13197-023-05774-4

[25] Meghwal, M., Desai, H., Sanchita Baisya, Das, A., Gade, S., Rani, R., Das, K., & Kadeppagari, R. K. (2022). Valorization of Waste Cooking Oil into Biodiesel, Biolubricants, and Other Products, *In Biotechnology for Zero Waste* (eds C.M. Hussain and R.K. Kadeppagari), 507-520, https://doi.org/10.1002/9783527832064.ch33

[26] Sagitani, H. (2014). Stability Conditions and Mechanism of Cream Soaps: Role of Glycerol. *Journal of Oleo Science*, 63(4), 365-372, https://doi.org/10.5650/jos.ess13174

[27] Alhassanil, N. A., Badday, A. S., & Esam, A. A. (2015). Biodiesel production from soapstock of palm oil refining. IREC2015 The Sixth International Renewable Energy Congress, 1-5, https://doi.org/10.1109/IREC.2015.7110960

[28] Esonye, C. (2019). The Development of Standard Agitator Conditions for Effective Performance of a Batch Crutcher in the Frame of Semi-Boiled Process. *International Journal of Chemical Reactor Engineering*, 17(9), 20180248, https://doi.org/10.1515/ijcre-2018-0248

[29] Zayed, L., Gablo, N., Kalcakova, L., Dordevic, S., Kushkevych, I., Dordevic, D., & Tremlova, B. (2024). Utilizing Used Cooking Oil and Organic Waste: A Sustainable Approach to Soap Production. *Processes*, 12(6), 1279, https://doi.org/10.3390/pr12061279

[30] Raj, S., Krishnan, J. M., & Ramamurthy, K. (2022). Influence of admixtures on the characteristics of aqueous foam produced using a synthetic surfactant. *Colloids and Surfaces A: Physicochemical and Engineering*, 643, 128770, https://doi.org/10.1016/j.colsurfa.2022.128770

[31] Imura, T. (2019). Surface Viscosity. In: Abe, M. (eds) *Measurement Techniques and Practices of Colloid and Interface Phenomena* (pp. 35-38). Springer, https://doi.org/10.1007/978-981-13-5931-6_5

[32] Siva, M., Ramamurthy, K., & Dhamodharan, R. (2015). Sodium salt admixtures for enhancing the foaming characteristics of sodium lauryl sulphate. *Cement and Concrete Composites*, 57, 133-141, https://doi.org/10.1016/j.cemconcomp.2014.12.011