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Temperature Effect on Oil Solubilization Kinetics and Activation Energy of *Moringa oleifera* Biosurfactant Detergent

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ABSTRACT

The environmental impact of synthetic surfactants in detergents has encouraged the development of eco-friendly alternatives from natural sources, such as Moringa oleifera leaves. This study aimed to determine the activation energy and evaluate the oil solubilization performance of a Moringa oleifera-based biosurfactant detergent compared with a synthetic detergent at various temperatures. The biosurfactant was prepared through maceration followed by acid activation using HCl. Product evaluation included organoleptic analysis, pH and density measurements, and kinetic analysis based on the Arrhenius equation. The results showed that the formulated biosurfactant met SNI quality standards, with pH values ranging from 8 to 10 and density between 1.176 and 1.199 g/mL. Arrhenius analysis revealed a lower activation energy for the Moringa oleifera detergent (4.16 kJ/mol) compared to the synthetic detergent (6.92 kJ/mol). These findings indicate enhanced oil solubilization efficiency and support its potential as a sustainable detergent alternative.

Keywords: biosurfactant, *moringa oleifera*, oil solubilization, activation energy, reaction kinetics

1. INTRODUCTION

Detergents generally contain various chemical components, including active ingredients, fillers, builders, additives, fragrances, and antifoaming agents. The primary active ingredients responsible for their cleaning performance are surfactants, such as Alkylbenzene Sulfonate (ABS) and Linear Alkylbenzene Sulfonate (LAS). The widespread use of these synthetic surfactants has become a significant source of environmental pollution. Certain surfactants, particularly ABS, exhibit low biodegradability and are resistant to microbial decomposition. As a result, these chemicals can pollute water and soil sources, endangering the ecosystem.[1]

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An alternative strategy to mitigate this environmental concern involves the development of natural, biodegradable surfactants derived from renewable resources.

In recent decades, increasing public awareness of environmentally friendly products has driven significant growth in research on biosurfactants as alternatives to synthetic surfactants. One potential natural source of biosurfactants is *Moringa oleifera* leaves. These leaves contain saponin compounds, which exhibit natural surfactant properties due to their amphiphilic structure.[2] The high saponin content in *Moringa oleifera* leaves indicates their potential for producing environmentally friendly foam, as these compounds are readily biodegradable. In addition, saponins function as natural surfactants by reducing surface tension, thereby enhancing their ability to remove stains. However, their cleaning effectiveness may also be influenced by various factors, such as temperature and concentration.[3]

Temperature is one of the key factors influencing the rate of stain solubilization in detergent systems. Oil stains are among the most commonly encountered types of stains in daily life. Previous studies on soap production using kapok fruit peel have shown that higher temperatures can increase the rate of saponification reactions[4]. Furthermore, studies on surfactants derived from the sulfonation of methyl esters have demonstrated that temperature significantly influences product characteristics, including density and acid number. Higher reaction temperatures were reported to accelerate the sulfonation process and increase product density.[5] Other studies have also shown that higher temperatures increase surfactant yield.[6]

Previous studies have identified temperature as a key factor influencing reaction rates in saponification and surfactant formation processes. Increasing temperature accelerates the reaction by enhancing the kinetic energy of the reactants, thereby increasing the frequency of effective molecular collisions that overcome the activation energy barrier.[7] Therefore, it is hypothesized that increasing temperature will accelerate the rate of oil solubilization.

The preparation of biosurfactant liquid detergent from *Moringa oleifera* leaves requires appropriate extraction methods. Maceration is one of the widely applied techniques for obtaining bioactive compounds from plant materials.[2] Maceration is an extraction technique that involves immersing plant material in a solvent at room temperature for a defined duration to facilitate the diffusion of bioactive compounds. This method is particularly suitable for heat-sensitive compounds, as it avoids thermal degradation during the extraction process.

In addition to developing a biosurfactant-based liquid detergent, this study investigates the effect of temperature on the rate of oil solubilization using *Moringa oleifera*-derived biosurfactant. The activation energy of the solubilization process was determined to better understand the reaction kinetics and support process optimization in eco-friendly detergent production. The findings of this study contribute to the development of more effective and sustainable detergent formulations.

2. EXPERIMENTAL

2.1. Chemicals, Equipment and Instrumentation

The materials used in this study included *Moringa oleifera* leaves, 70% methanol as the extraction solvent, 5 M hydrochloric acid (HCl), methyl ester sulfonate (MES) as a secondary surfactant, sodium sulfate (Na_2SO_4), sodium carbonate (Na_2CO_3), and distilled water. The equipment utilized in this study consisted of standard laboratory glassware, an analytical balance, a thermometer, and pH paper for acidity measurement.

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2.2. Research Procedure

2.2.1 Manufacture of Biosurfactant

Moringa leaf powder was extracted using 70% methanol at a ratio of 1:10 (w/v) using the maceration method.[2] The maceration process produced a concentrated macerate, which was subsequently filtered to remove solid residues. The filtered extract was then diluted with distilled water and acidified by the addition of HCl solution. After being allowed to stand for a specified period, the biosurfactant extract was obtained.

2.2.2 Manufacture of Liquid Detergent

During the detergent formulation stage, the activated biosurfactant solution was mixed with melted methyl ester sulfonate (MES) until a homogeneous mixture was obtained (Solution 1). Separately, Na_2CO_3 and Na_2SO_4 were dissolved in distilled water at a ratio of 1:1 to form a homogeneous mixture (Solution 2). Solution 1 and Solution 2 were subsequently combined and homogenized to produce Solution 3. The resulting mixture was heated and stirred until a liquid detergent was obtained.

2.2.3 Organoleptic Test

Organoleptic evaluation was performed by visually observing the sample to assess its appearance, color, and odor.[8]

2.2.4 Hedonic Test

This examination was carried out by means of a questionnaire addressed to 30 panelists with the three best samples produced.

2.2.5 Liquid Detergent Quality Test

The pH of the samples was determined using universal pH paper. A small amount of the sample was applied to the pH paper, and the resulting color change was compared with the standard color scale (pH 0–14) provided by the manufacturer.

In addition to pH analysis, the density of the liquid detergent was determined using the gravimetric method. A clean and dry beaker was weighed using an analytical balance to obtain the mass of the empty beaker. The liquid sample was then added to the beaker, and the total mass was recorded. The mass of the liquid was calculated by subtracting the mass of the empty beaker from the combined mass of the beaker and the liquid. The volume of the liquid was measured using a graduated cylinder. Density was calculated by dividing the mass of the liquid by its volume.

2.2.6 Determination of Activation Energy

Solutions of *Moringa oleifera* biosurfactant detergent and synthetic detergent were prepared at concentrations of 10%, 20%, and 30%. Equal volumes of oil samples were used for each experiment. The biosurfactant detergent solution was placed in a beaker and heated to the desired temperatures (30°C, 60°C, and 90°C). After reaching the target temperature, a fixed volume of oil was added to the solution, and the mixture was stirred continuously. The time required for complete oil solubilization was recorded using a stopwatch. The same procedure was applied to the synthetic detergent for comparison.

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3. RESULTS AND DISCUSSION

3.1. Organoleptic Test

Organoleptic testing is also known as sensory evaluation.[8] Organoleptic testing was conducted to evaluate the physical characteristics of the liquid detergent, including appearance, odor, and color[9] as shown in Table 1.

Table 1. Organoleptic Analysis of Liquid Detergent Formulations

Deterjent Concentration (%)	Shape	Color	Scent
10	Homogeneous	Yellowish-brown	Non-pungent odor
20	Homogeneous	Greenish-brown	Slightly pungent odor
30	Homogeneous	Dark greenish-brown	Pungent odor

The organoleptic characteristics of the liquid detergent, including color and aroma, complied with SNI 4075-1:2017 standards. The product exhibited a distinctive color and aroma of *Moringa oleifera* and showed a homogeneous appearance, as required by the standard.

3.2. Hedonic Test

In this study, preference level was evaluated using a five-point hedonic scale to assess panelists' acceptance of the *Moringa oleifera* biosurfactant detergent. The scale ranged from 1 (dislike very much) to 3 (like very much). A total of 30 panelists evaluated three detergent samples based on this scale.

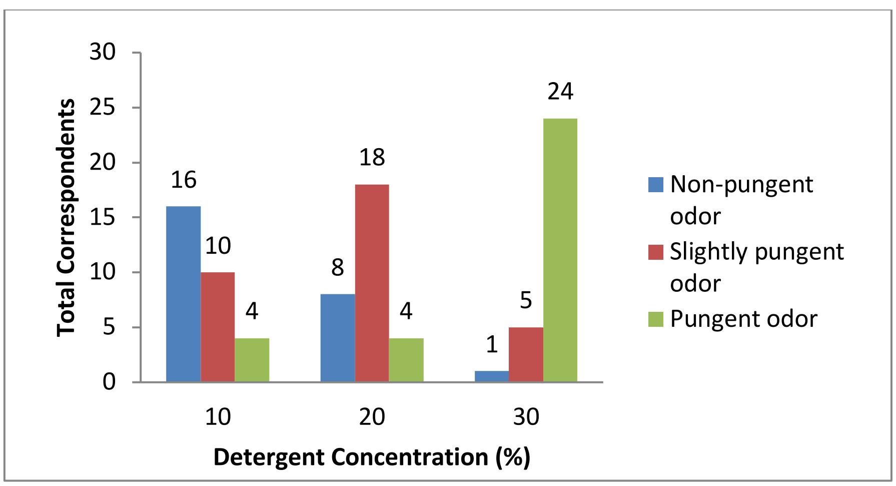

Figure 1. Hedonic Test on Aroma

Aroma sensitivity testing was conducted as part of the sensory evaluation. Panelists were asked to assess the aroma of the detergent formulated with *Moringa oleifera* leaf extract. The characteristic scent of the formulation originated from the added leaf extract. As the extract concentration increased, the intensity of the aroma became more pronounced.The highest average selection of panelists' liking was F2 with 17 out of 30

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panelists, while the one that tended to be close to the rating scale was F1 with 8 out of 30 panelists. This is because the distinctive odor of moringa leaves in the detergent in F2 is more pronounced than F1. On the scale of likes with the lowest average in F3 of 5 out of 30 panelists, this is because the odor of the detergent is too strong.

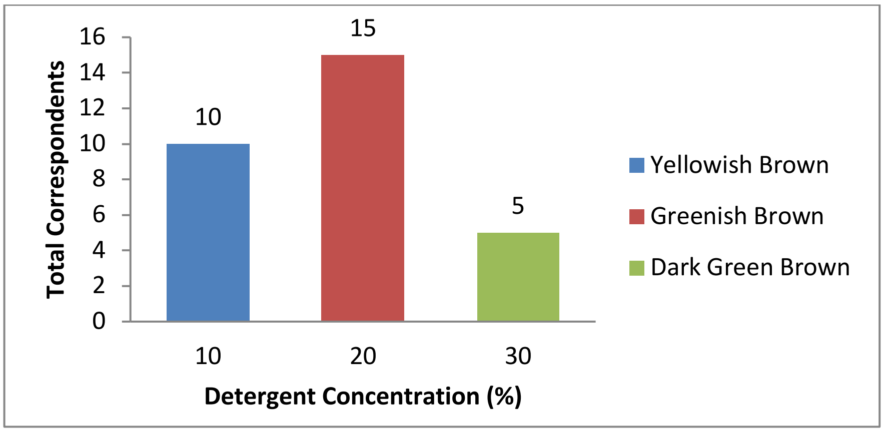

Figure 2. Hedonic Test on Color

Panelists were presented with samples of *Moringa oleifera* leaf extract liquid detergent and asked to evaluate the color based on their level of preference. The natural extract exhibits a dark green color, which influenced the final appearance of the detergent formulation. Increasing the concentration of the extract resulted in a darker color intensity. This variation in color significantly affected the level of consumer preference.

The highest level of preference was observed in formulation F2, which was selected by 15 out of 30 panelists. Formulation F1 was preferred by 10 panelists, indicating moderate acceptance. In contrast, F3 received the lowest preference score, with 5 panelists expressing dislike. These results suggest that panelists tended to prefer detergent formulations with a moderately green color rather than those with a darker green appearance.

3.3. Liquid Detergent Quality Test

Feasibility testing was conducted to evaluate the quality and safety of the formulated liquid detergent prior to potential application. Two key parameters assessed in this study were pH and density. The results of these measurements are presented in Figures 3 and 4.

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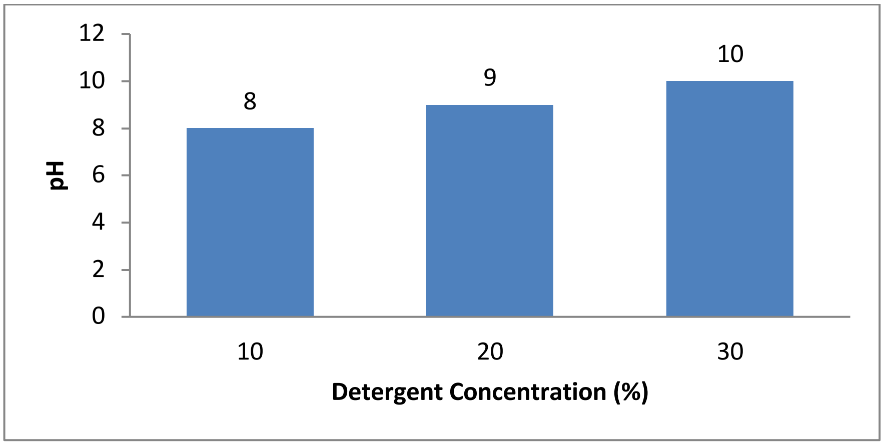

Figure 3. pH Analysis of Liquid Detergent

pH is an important parameter in evaluating whether the detergent formulation is acidic or alkaline. The pH value plays a crucial role in determining product safety and skin compatibility, as liquid detergents come into direct contact with the skin. An inappropriate pH level may cause irritation or other adverse effects.[10]

According to SNI 06-4075-1996, the acceptable pH range for liquid detergent is 8.0–11.0.[10] Alkaline conditions enhance detergent performance by promoting the emulsification and dispersion of oily contaminants, allowing dirt particles to remain suspended in solution. Based on the experimental results, all formulations exhibited pH values within the acceptable range specified by SNI standards.

In addition to pH analysis, density testing was also conducted, as density significantly influences the solubility of detergent in water and the stability of liquid detergent emulsions.[2]

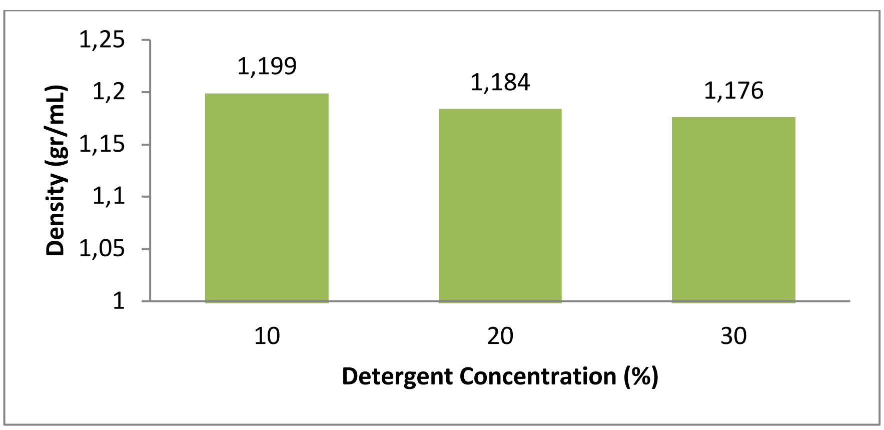

Figure 4. Density Analysis of Liquid Detergent

Density is an important physicochemical parameter that is influenced by the concentration and composition of the components in a formulation. Water has a density of approximately 1.0 g/cm³; therefore, compounds with lower densities, such as fats and methanol, can affect the overall density of the product. The incorporation of these lower-density components into the formulation may lead to a decrease in the final density of the liquid detergent.[11]

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According to SNI 4075-1:2017, the acceptable density range for liquid detergent products is 1.1–1.3 g/mL. The density values obtained in this study ranged from 1.176 to 1.199 g/mL, indicating that all formulations met the quality requirements specified by the standard.

3.4. Effect of Temperature on Oil Solubility in Detergents

In general, both synthetic detergents (DS) and natural detergents (DK), such as those derived from *Moringa oleifera* leaves, function by solubilizing and emulsifying fats and oils. However, their cleaning performance can be influenced by several factors, particularly temperature.

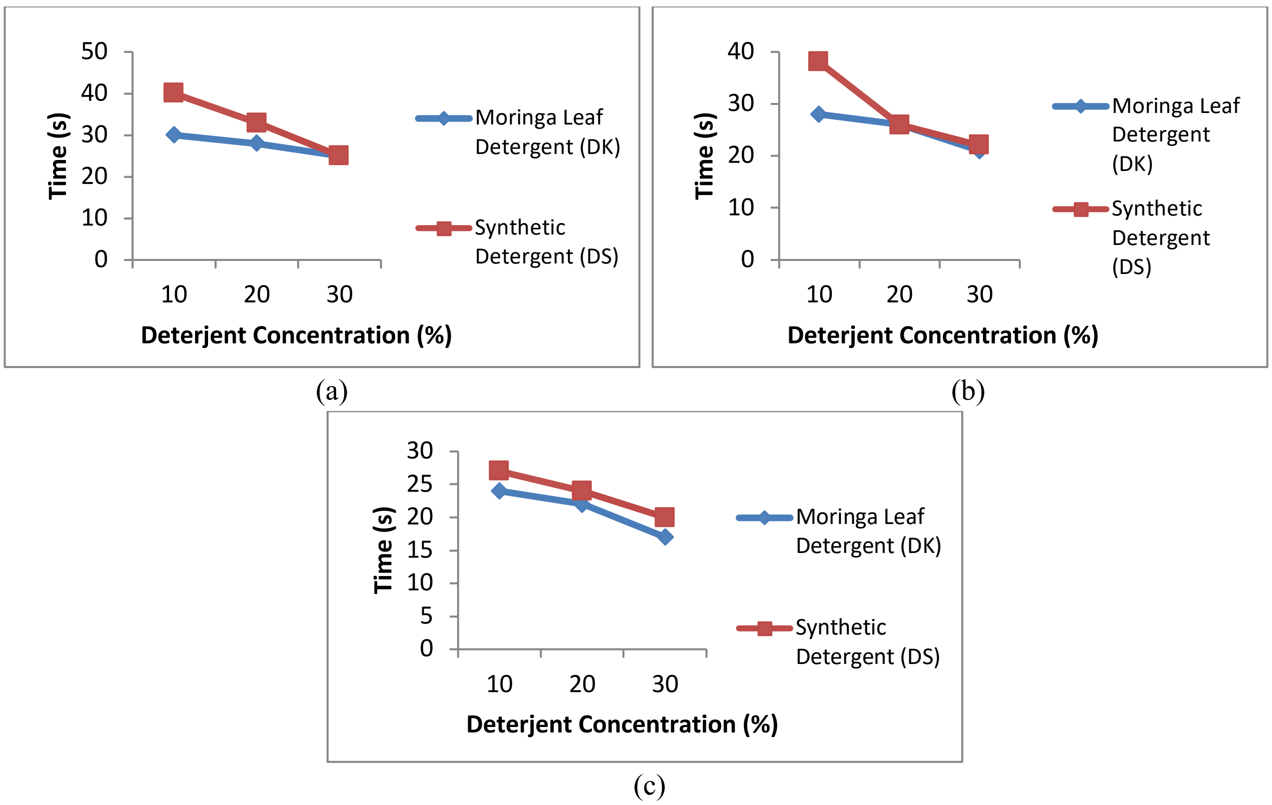

Figure 5. Effect of detergent concentration on solubilization time at different temperatures: (a) 30°C, (b) 60°C, and (c) 90°C.

Increasing the concentration of DK and the temperature significantly accelerated the oil solubilization process. At 30°C, higher DK concentrations (30%) reduced the solubilization time due to the greater availability of surfactant molecules interacting with oil droplets. Surfactants reduce interfacial tension between oil and water, thereby promoting emulsification. The saponin compounds present in *Moringa oleifera* leaves act as natural emulsifying agents, enhancing the dispersion and removal of oil. Furthermore, the maceration process used to extract these bioactive compounds likely contributed to the effectiveness of the biosurfactant formulation.[12]

As the temperature increased to 60°C and 90°C, the kinetic energy of the molecules also increased, enhancing molecular motion and promoting more frequent interactions between oil droplets and surfactant molecules. This resulted in a shorter oil solubilization time at higher temperatures. At a concentration of 30%, the fastest solubilization time was recorded at 90°C, reaching 17 seconds.

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In contrast, the synthetic detergent (DS) exhibited a longer solubilization time than DK at 30°C, although a reduction in time was observed with increasing concentration. DS contains synthetic surfactants formulated to enhance cleaning performance. However, at elevated temperatures, its performance improved significantly, indicating that while DS may be less efficient at lower temperatures, it becomes increasingly competitive under higher-temperature conditions.

This explanation is supported by Wei et al., who reported that increasing temperature and surfactant concentration enhances the rate of emulsification and oil removal from surfaces.[14] Increasing temperature significantly enhances oil solubilization in both natural and synthetic detergents. However, the natural detergent (DK) exhibited greater efficiency than the synthetic detergent (DS) at all tested temperatures. This effect can be attributed to increased molecular kinetic energy and reduced interfacial tension at elevated temperatures.

3.5. Activation Energy in Detergents

The activation energy (Ea) provides insight into the temperature dependence of the solubilization process. Lower Ea values indicate that the interaction between the detergent and oil occurs more readily, resulting in faster cleaning performance.

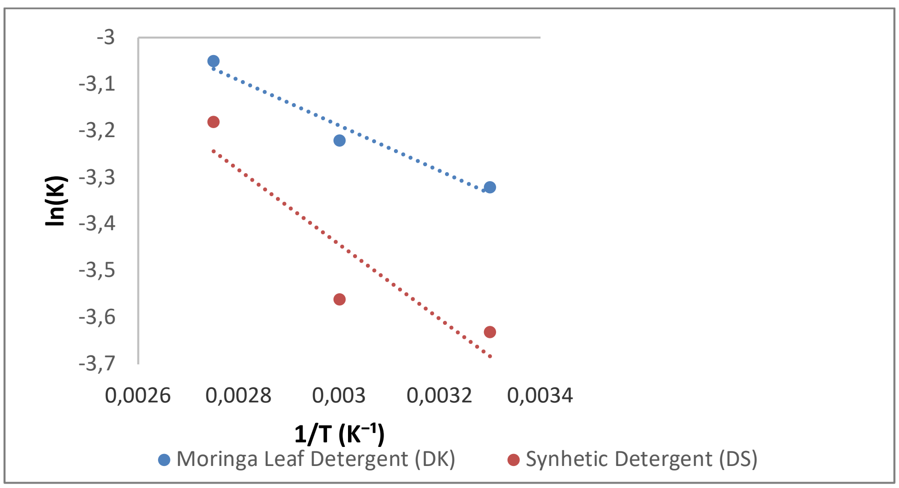

Figure 6. Arrhenius plot showing the relationship between ln(k) and 1/T (K^{-1}) for natural and synthetic detergents.

Activation energy (Ea) is defined as the minimum energy required for reactant molecules to undergo a chemical reaction.[15] Activation energy represents the energy barrier that must be overcome for the oil removal process to occur. As temperature increases, the kinetic energy of the molecules also increases, resulting in a greater fraction of surfactant molecules possessing sufficient energy to overcome the activation barrier and form micelles with the oil.[5]

Based on the data presented in Figure 6, a linear relationship was observed between ln(k) and 1/T, consistent with the Arrhenius equation. The slope of the regression line corresponds to –Ea/R, from which the activation energy (Ea) of the reaction was determined.[16] In an Arrhenius plot, a steeper slope corresponds to a higher activation energy. The synthetic detergent (DS) exhibited a steeper slope than the natural detergent

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(DK), indicating that DS has a higher activation energy. Furthermore, at the same temperature, DK showed higher ln(k) values compared to DS, suggesting a greater reaction rate constant and faster oil solubilization performance.

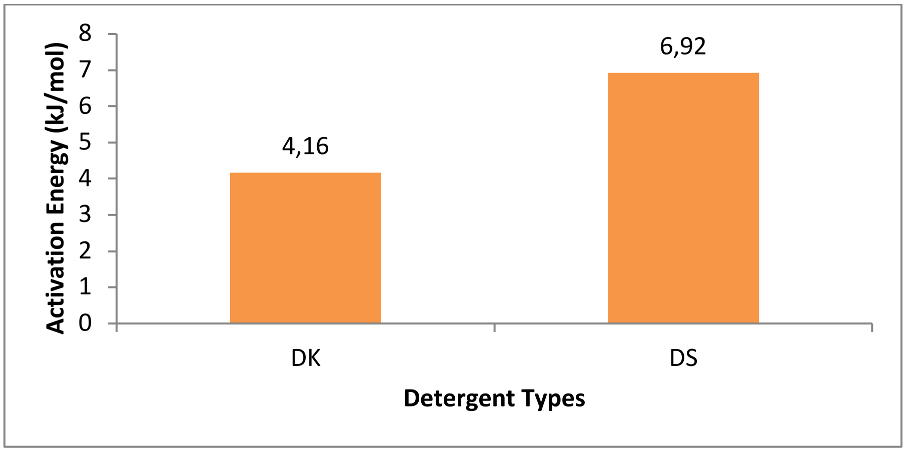

Figure 7. Activation energy (Ea) of natural and synthetic detergents

Based on the data presented in Figure 7, the activation energy (Ea) of DK was 4.16 kJ/mol, whereas that of DS was 6.92 kJ/mol. According to the Arrhenius relationship, a lower activation energy corresponds to a higher reaction rate constant at the same temperature. Therefore, the lower Ea value of DK indicates a faster oil solubilization rate compared to DS under identical thermal conditions. The lower activation energy observed for DK may be attributed to differences in surfactant characteristics, including molecular structure and micelle formation behavior. In contrast, the higher Ea value of DS suggests that greater energy is required to initiate effective oil–surfactant interactions during the cleaning process.

DK contains saponins, which are natural surfactant compounds. Saponins possess amphiphilic structures that enable them to reduce the surface and interfacial tension between water and oil. This property enhances oil solubilization and promotes the emulsification of hydrophobic impurities.[17] The synthetic detergent (DS) may exhibit different molecular characteristics that influence its interfacial behavior, potentially reducing emulsification efficiency at lower temperatures. Consequently, DK demonstrates a higher reaction rate constant at the same temperature, consistent with its lower activation energy. The observed difference in activation energy between DK and DS is likely associated with variations in molecular structure, surfactant composition, and micelle formation mechanisms rather than temperature alone.

4. CONCLUSION

This study demonstrates that biosurfactants extracted from *Moringa oleifera* leaves have strong potential as environmentally friendly detergent ingredients. The maceration-derived biosurfactant exhibited enhanced oil solubilization performance, particularly at elevated temperatures, and showed higher efficiency compared to the synthetic detergent. Kinetic analysis revealed that the biosurfactant had a lower activation energy (4.16 kJ/mol) than the synthetic detergent (6.92 kJ/mol), indicating that the oil solubilization process occurs more readily. The linear Arrhenius relationship further confirms that the process follows temperature-dependent kinetic behavior. Overall, the lower activation energy and improved performance at higher temperatures

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highlight the effectiveness of *Moringa oleifera*-based biosurfactants as sustainable alternatives to synthetic detergents.

REFERENCES

1. Handayani, L. **(2020)**. Pengaruh kandungan deterjen pada limbah rumah tangga terhadap kelangsungan hidup udang galah (Macrobracium rosenbergii). *Sebatik*, *24*(1), 75-80.
2. Maranggi, I. U., Rahmasari, B., Kania, F. D., & Sari, I. P. **(2020)**. Aplikasi Biosurfaktan Dari Daun Sengon (Albizia Falcataria) Dan Kulit Buah Pepaya (Carica Papaya L.) Sebagai Detergen Ramah Lingkungan. In *Prosiding Seminar Mahasiswa Teknik Kimia*, *1*(1), 1-5.
3. Nurkhasanah, T. A., & Dhurhania, C. E. **(2023)**. Analisis Kadar Saponin Pada Ekstrak Daun Kelor (Moringa oleifera Lam.) Secara Gravimetri. *Jurnal Insan Farmasi Indonesia*, *6*(2), 300-309.
4. Sukeksi, L., Sitorus, A., & Sidabutar, C. **(2017)**. C, waktu pengadukan 60 menit, 90 menit, 120 menit. Respon yang diamati adalah densitas, Keasaman (pH), bilangan penyabunan dan alkali bebas. Hasil yang terbaik diperoleh pada suhu 80. *Jurnal Teknik Kimia*, *6*(3), 8-13.
5. Amin, J. M., Manggala, A., Ningsih, A. S., Hilmasari, J., Aliza, S. N., & Al Kusari, W. **(2020)**. Pengaruh Variasi Suhu, Rasio Mol Reaktan Dan Persen Katalis Terhadap Metil Ester Sulfonat Menggunakan Reaktor Sulfonasi. *KINETIKA*, *11*(1), 18-26.
6. Sukmawati. **(2017)**. Pengaruh Temperatur dan Rasio Bahan Baku pada Pembuatan Surfaktan dari Pelepah Sawit. *J Anim Sci Agron Panca Budi*, *2*(2):37-44.
7. Fiyani A, Nanda Saridewi, Siti Suryaningsih. **(2021)**. Analisis Konsep Kimia Terkait dengan Pembuatan Surfaktan dari Ampas Tebu. *JRPK J Ris Pendidik Kim*, *10*(2), 94-101.
8. Suryono C, Ningrum L, Dewi TR. **(2018)**. Uji Kesukaan dan Organoleptik Terhadap 5 Kemasan Dan Produk Kepulauan Seribu Secara Deskriptif. *J Pariwisata*, *5*(2), 95-106
9. Jannah Z R, Bahri S, Muhammad M, Ibrahim I, Ginting Z. **(2023)**. Pembuatan Deterjen Cair Dari Minyak Kelapa Virgin Coconut Oil (Vco). *Chem Eng J Storage*, *3*(5):608-6011.
10. Nurrosyidah IH, Putri EN, Satria BA. **(2023)**. Formulasi Deterjen Ramah Lingkungan Dengan Serbuk Simplisia Daun Waru (*Hibiscus tilliaceus* L.) Dan Buah Lerak (*Sapindus rarak* DC.) Sebagai Surfaktan. *J Ris Kefarmasian Indones*, *5*(1):146-155.
11. Yuliyanti M, Husada VMS, Fahrudi HAA, Setyowati WAE. **(2019)**. Quality and Detergency Optimization, Liquid Detergent Preparation, Mahogany Seed Extract (Swietenia mahagoni). *JKPK (Jurnal Kim dan Pendidik Kim*, *4*(2):65.
12. Sulfa DM, Susanto H, Hasanah SM. **(2024)**. The Exploration of Moringa Leaves' Antibacterial in Biodegradable Detergent Production Through Application of Eco-enzyme Synthesis. *E3S Web Conf*., 481(1), 06003.
13. Helmy Q, Gustiani S, Mustikawati AT. **(2020)**. Application of rhamnolipid biosurfactant for bio-detergent formulation. *IOP Conf Ser Mater Sci Eng*, *823*(1), 1-8.
14. Wei Y, Xiong Y, Guo B, Yang H. **(2020)**. Study on the influencing factors of the emulsion stability of a polymeric surfactant based on a new emulsification device. *Energies*, *3*(18),4794.
15. Putri QU, Augustin D, Hasanudin H. **(2022)**. Kinetika Esterifikasi Asam Lemak Bebas dari Sludge Industri Crude Palm Oil (CPO) Menggunakan Katalis Komposit Montmorillonite/Karbon Tersulfonasi dari Tetes Tebu. *ALCHEMY J Penelit Kim*, *18*(1), 48-57.
16. Ulya, I. N., Jumaeri, J., Wawan, W., Rahayu, E. F., & Wijayati, N. **(2020)**. Uji Aktivitas Katalitik Hidrodesulfurisasi Campuran Light Gas Oil (LGO) dan Light Diesel Oil (LDO) dengan Katalis CoMo/Î³-Al2O3. *Indonesian Journal of Chemical Science*, *9*(2), 117-124.
17. Ria EMDB, Kartika Sari E, Eka Rosita M. **(2023)**. Analisis Flavonoid Daun Kelor serta Aplikasinya dalam Sediaan Sabun. *Indones J Pharm Sci Clin Res*, *1*(2):58-64.

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