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# Valorization of Cacao Pod Husk for the Development and Performance Evaluation of an Eco-Friendly Alkaline Degreaser for Oil and Grease Removal in Petroleum Industry Equipment

**Dr. Julie Pearl M. Andal[1], Gemmel Mae C. Amul[2], Jezreel John O. Dela Cruz [2], Katrina C. Dolor [2], Marianne Dimple M. Macatangay [2], Geraldine A. Ruiz [2]**

[1]Program Chairperson Bachelor of Science in Petroleum Engineering, College of Engineering, Batangas State University-The National Engineering University, Alangilan Campus, Batangas City 4200, Philippines

[2]Bachelor of Science in Petroleum Engineering, College of Engineering, Batangas State University- The National Engineering University, Alangilan Campus, Batangas City 4200, Philippines

Email: juliepearl.marasigan@g.batstate-u.edu.ph

**ABSTRACT**

This study aimed to evaluate potassium hydroxide (KOH) derived from cacao pod husk (CPH) as an alkaline agent for industrial degreaser formulation. An experimental research design was employed in which CPH was converted into ash, leached to extract potassium carbonate, and subjected to causticization to produce KOH. Formulations containing 10%, 15%, and 20% KOH were prepared at mixing temperatures of 25°C, 40°C, and 55°C and mixing times of 30, 45, and 60 minutes. Their physicochemical properties, foaming capacity, and physical stability were evaluated, followed by oil removal and surface cleanliness testing of the optimized formulation against a commercial degreaser. The formulation containing 15% KOH, mixed at 40°C for 45 minutes, demonstrated the most favorable overall performance, with a pH of 12.43, density of 1.085 g/mL, viscosity of 14.26 mPa·s, and foaming capacity of 52%. After seven days, it exhibited no phase separation or sedimentation, with only a 1.8% viscosity change and a 0.03% pH change. Its oil removal efficiency reached 92.20%, compared with 94.10% for the commercial degreaser, while both formulations passed the water-break test. The findings establish CPH-derived KOH as a promising alkaline agent for industrial degreaser production. Further testing of biodegradability, volatile organic compound content, corrosion behavior, and extended storage stability is recommended. The study was limited by its seven-day stability assessment and the absence of validated environmental and corrosion data. Nevertheless, it demonstrates an approach to agricultural waste valorization by converting cacao pod husk into a value-added industrial cleaning product, contributing to resource recovery and the development of potentially more sustainable chemical formulations.

**Keywords:** *Cacao pod husk, Potassium Hydroxide, Industrial Degreaser, Oil Removal Efficiency, Physical Stability, Agricultural Waste Valorization*

## 1. INTRODUCTION

Agricultural waste valorization has gained importance as a strategy for improving resource efficiency, reducing environmental burdens, and developing value-added products from locally available biomass. In the Philippines, cacao production presents an opportunity to recover useful materials from agricultural residues. Cacao pod husk (CPH), which accounts for approximately 70–75% of the total cacao fruit weight, represents a substantial by-product that may remain underutilized after harvesting and bean extraction (Meza-Sepulveda et al., 2024). Although initiatives have encouraged the conversion of cacao by-products into beverages, vinegar, ethanol, and fuel briquettes, opportunities for recovering industrially useful chemical constituents warrant further investigation (Sotelo-Coronado et al., 2025; Morales et al., 2025).

One promising approach is the recovery of potassium-containing compounds from CPH. Previous studies have reported substantial potassium content in cacao husk ash, with the mineral composition varying according to the material and its production conditions (Kone et al., 2020; Soares & Oliveira, 2022). The water-soluble fraction of potassium provides a basis for extracting potassium compounds through leaching. Following appropriate chemical processing, potassium carbonate can undergo causticization to produce potassium hydroxide (KOH), an alkaline chemical with applications in industrial cleaning formulations.

Industrial degreasers use alkaline agents to facilitate the removal of oils and grease from equipment and other hard surfaces. KOH can promote the breakdown of susceptible fatty materials through alkaline reactions, including saponification. Its incorporation into a degreaser derived partly from agricultural waste may therefore provide a practical application for recovered potassium compounds while reducing dependence on conventional raw materials. However, the usefulness of a waste-derived alkaline agent depends on the resulting formulation's physicochemical properties, stability, and cleaning performance. Accordingly, evaluating CPH-derived KOH in degreaser production provides a relevant intersection of agricultural resource recovery, chemical engineering, and sustainable industrial product development.

**Research Problem**

The Philippines faces the challenge of managing agricultural residues while maximizing locally available resources for value-added industrial applications. Cacao pod husk (CPH), which accounts for approximately 70–75% of the total cacao fruit weight, represents a substantial by-product of cacao harvesting and bean processing. Although CPH contains valuable minerals, particularly potassium, its industrial utilization remains limited, warranting further investigation into its recovery and valorization (Anoraga et al., 2024). Previous research has demonstrated the feasibility of recovering potassium carbonate from CPH ash, indicating its potential as an alternative source of alkaline compounds (Konan et al., 2025). However, the application of these recovered compounds in industrial degreaser formulations has not been sufficiently established. Developing an effective degreaser requires appropriate formulation conditions and evaluation of physicochemical properties, storage stability, and oil-removal efficiency. Its performance must also be compared with a commercially available product to determine its practical effectiveness. Despite existing research on CPH valorization and potassium recovery, experimental evidence on the formulation, stability, and degreasing performance of CPH-derived alkaline products remains limited. This unresolved issue warrants investigation into their suitability as alternative raw materials for industrial cleaning applications.

**Assumptions of the Study**

The study assumes that cacao pod husk ash contains recoverable potassium compounds that can be extracted and converted into a potassium-based alkaline agent suitable for degreaser formulation. It further assumes that the concentration of CPH-derived KOH, mixing temperature, and mixing duration influence the physicochemical properties, stability, and cleaning performance of the formulated product. The developed degreaser is expected to exhibit acceptable pH, density, viscosity, foaming capacity, and physical stability while achieving oil removal efficiency comparable to a commercially available industrial degreaser. It is also assumed that its biodegradability, volatile organic compound (VOC) content, and carbon steel corrosion rate can be reliably evaluated through appropriate laboratory procedures to determine its environmental and material compatibility. The laboratory results are assumed to provide a reasonable basis for assessing the potential application of the developed formulation as an alternative industrial cleaning product.

**Objectives of the Study**

This study aimed to evaluate potassium hydroxide (KOH) derived from cacao pod husk (CPH) as an alkaline agent for industrial degreaser formulation and determine its effectiveness in removing oil and grease from contaminated metal surfaces. Specifically, it sought to characterize CPH ash, extracted potassium carbonate, and the resulting KOH through physicochemical and chemical tests. It also aimed to formulate degreasers using varying KOH concentrations, evaluate their pH, density, viscosity, foaming capacity, and physical stability, and assess cleaning performance through gravimetric oil removal efficiency and the water-break test. The selected formulation was compared with a commercially available degreaser to determine its relative cleaning performance and potential for industrial application.

**Conceptual and Theoretical Framework**

This study adopts the Input–Process–Output (IPO) Model to illustrate the development and evaluation of a cacao pod husk (CPH)-derived alkaline industrial degreaser. The input includes dried cacao pod husk, extracted potassium compounds, calcium hydroxide, surfactants, xanthan gum, and other formulation ingredients, as well as the experimental variables: KOH concentration, mixing temperature, and mixing duration. The process involves CPH preparation, ashing, potassium extraction, causticization, and degreaser formulation. The resulting formulations undergo physicochemical characterization, stability testing, and performance evaluation, including oil removal efficiency, water break test, biodegradability, VOC content, and carbon steel corrosion testing. The optimized formulation is then compared with a commercial industrial degreaser. The output is an optimized CPH-derived alkaline industrial degreaser with established formulation conditions and evaluated physicochemical properties, cleaning performance, environmental characteristics, and material compatibility, demonstrating its potential as an alternative industrial cleaning product.

**Sustainable Development Goal and Multidisciplinary Sustainability Relevance**

The research is relevant to the United Nations Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production), through its investigation of agricultural waste recovery and the conversion of biomass residues into a potentially useful industrial product. It also relates to SDG 9 (Industry, Innovation and Infrastructure) by exploring an alternative source of an alkaline ingredient for industrial cleaning applications. Furthermore, the study may contribute to SDG 8 (Decent Work and Economic Growth) by identifying a possible avenue for value creation from locally available agricultural resources. These connections represent potential contributions rather than demonstrated socioeconomic or environmental outcomes. By examining both formulation performance and the potential for agricultural waste

utilization, this study provides a basis for further research into more resource-efficient approaches to industrial chemical production.

## 2. METHODOLOGY

**Research Design**

This study employed an experimental laboratory research design to evaluate potassium hydroxide (KOH) derived from cacao pod husk (CPH) as an alkaline agent for industrial degreaser formulation. The experimental procedures involved converting CPH into ash, extracting potassium carbonate, converting the extracted compound into KOH through causticization, and incorporating the resulting alkali into degreaser formulations. The effects of varying KOH concentrations, preparation temperatures, and mixing times were evaluated through physicochemical characterization, stability assessment, and cleaning performance tests.

**Research Locale or Study Setting**

The study was conducted at RFT Laboratory in Batangas City, Philippines, where the preparation, extraction, formulation, and experimental evaluation of the cacao pod husk-derived industrial degreaser were performed. Cacao pod husk (CPH) was dried and ashed to obtain the material for potassium recovery. The extracted potassium carbonate was subsequently converted into potassium hydroxide (KOH) and incorporated into the degreaser formulations. Laboratory activities included physicochemical characterization, foaming capacity and stability testing, and oil removal evaluation using contaminated metal surfaces. A commercially available industrial degreaser was also tested as a reference for comparative performance assessment. All experiments were conducted under controlled laboratory conditions.

**Participants or Data Sources**

The study employed an experimental sampling approach using cacao pod husk (CPH) as the primary raw material for potassium recovery and degreaser formulation. The experimental treatments were organized using the Design of Experiments (DOE) feature of Minitab to evaluate the effects of KOH concentration, mixing temperature, and mixing time on the formulated degreaser. Three trials were conducted for each treatment to assess the consistency and repeatability of the experimental results.

**Research Instruments or Materials**

The study utilized dried cacao pod husk (CPH), calcium hydroxide, hydrochloric acid, calcium chloride, distilled water, surfactants, xanthan gum, and other formulation ingredients. A commercially available industrial degreaser served as the reference product. The instruments used included an analytical balance, drying oven, muffle furnace, grinder, sieve, filtration apparatus, pH meter, viscometer, density measurement apparatus, mechanical mixer, thermometer, graduated cylinders, burette, and standard laboratory glassware. Metal plates and carbon steel coupons were used for oil removal and corrosion testing, respectively. Appropriate laboratory methods and equipment were also employed to evaluate foaming capacity, physical stability, biodegradability, and volatile organic compound (VOC) content.

**Data Gathering Procedure**

Experimental data were obtained through laboratory testing and measurements conducted at each stage of the study. Cacao pod husk ash was characterized in terms of moisture content, ash yield, potassium content, particle size, and pH. The extracted potassium carbonate was assessed through flame and limewater tests, pH, solubility, and density measurements. The resulting potassium hydroxide (KOH) was evaluated through flame testing, pH measurement, solubility testing, acid–base titration, and calcium chloride testing. The formulated degreasers

were subsequently assessed based on pH, density, viscosity, foaming capacity, physical stability, and oil removal efficiency.

**Data Analysis**

The experimental data were analyzed using descriptive statistics to compare the physicochemical properties, physical stability, and cleaning performance of the formulated degreasers. The Design of Experiments (DOE) approach in Minitab was used to organize and evaluate the effects of KOH concentration, mixing temperature, and mixing time on the measured responses. Oil removal efficiency was calculated using the gravimetric method, while the water-break test was used to assess surface cleanliness. The formulation with the most favorable overall results was selected and compared with a commercially available degreaser based on the measured performance indicators.

**Ethical Considerations**

The study involved laboratory experimentation using cacao pod husk and chemical formulations; therefore, human participant consent and confidentiality were not applicable. Ethical and safety considerations focused on the responsible handling of laboratory materials and chemicals, particularly potassium hydroxide, which is caustic. Appropriate personal protective equipment, proper labeling and storage of chemicals, and safe handling and disposal of laboratory residues were observed in accordance with applicable laboratory safety procedures. The study also aimed to promote the responsible utilization of agricultural waste through the development of a value-added industrial cleaning product.

## 3. RESULTS AND DISCUSSION

### 3.1 Characterization of Cacao Pod Husk Ash as a Precursor for Potassium Recovery

The cacao pod husk (CPH) ash was characterized to establish its initial physicochemical properties before its conversion into potassium carbonate. The characterization focused on moisture content, ash yield, potassium content expressed as potassium oxide ($K_2O$), water-soluble potassium, and pH. These parameters provided preliminary information on the composition and alkaline characteristics of the ash and its potential for further processing. The results are presented in Table 1.

***Table 1.*** *Characterization Results of Cacao Pod Husk Ash*

| *Parameter* | *Results* | *Interpretation* |
|---|---|---|
| *Moisture Content (Dried CPH)* | 8.99% | Indicates the residual moisture content of the dried cacao pod husk. Its suitability for storage should be assessed against an established reference. |
| *Ash Yield* | 13.57% | Represents the proportion of ash obtained from the cacao pod husk after ashing. |
| *Potassium Content (as K2O)* | 26.2% | Indicates the potassium content expressed as potassium oxide equivalent and suggests potential for potassium recovery. |

| | | |
|---|---|---|
| *Water-Soluble K* | Highly Soluble | Suggests that potassium-containing compounds may be readily extracted through aqueous leaching. |
| *pH Level* | 10.71 | Indicates alkaline characteristics of the prepared ash sample under the test conditions. |

*Note: CPH = cacao pod husk; $K_2O$ = potassium oxide*

The dried cacao pod husk (CPH) exhibited 8.99% moisture content, indicating adequate drying before ashing. Its ash yield of 13.57% represents the inorganic residue available for potassium recovery. The ash contained 26.2% potassium expressed as $K_2O$ equivalent, indicating its potential as a potassium source. Neenu et al. (2025) confirmed the potassium-rich nature of CPH-derived biochar, while Hussein et al. (2026) investigated the production of alkali extracts from CPH ash.

The observed high potassium solubility supports aqueous leaching as a recovery method. This is consistent with Konan et al. (2025), who investigated raw potash extraction from cocoa pod ash using distilled water. The measured pH of 10.71 indicates the alkaline nature of the ash, suggesting the presence of basic inorganic constituents. These findings support the suitability of CPH ash as a precursor for potassium recovery and subsequent potassium carbonate production.

### *3.2.* Extraction and Characterization of Potassium Carbonate from Cacao Pod Husk Ash

The extraction of potassium carbonate from cacao pod husk (CPH) ash served as the second stage of the study, following the initial characterization of the ash. The objective was to obtain a potassium-containing extract that could be used as the precursor for the subsequent conversion of potassium carbonate into potassium hydroxide (KOH). The extracted material was characterized using a flame test, limewater test, pH measurement, water solubility assessment, and density measurement. The results are summarized in Table 2.

***Table 2.*** *Characterization Results of Potassium Carbonate Extracted from Cacao Pod Husk Ash*

| *Parameter* | *Results* | *Interpretation* |
|---|---|---|
| *Flame Test* | Lilac flame | Indicates the presence of potassium ions, consistent with potassium-containing compounds in the extract. |
| *Limewater Test* | Milky/turbid | Indicates a positive qualitative response consistent with the presence of carbonate ions, which form a precipitate when reacting with calcium hydroxide in limewater. |
| *pH Level* | 11.48 | Indicates that the extract is alkaline under the test conditions. |
| *Solubility in water* | Soluble | Indicates that the extracted material dissolves in water, supporting its use in an |

| | | |
|---|---|---|
| | | aqueous extraction process. |
| *Density* | 1.091 g/mL | Represents the measured density of the prepared extract under the test conditions. |

*Note: The flame and limewater tests provide qualitative evidence consistent with the presence of potassium and carbonate ions, respectively. These tests alone do not confirm the purity or concentration of potassium carbonate in the extract. The pH and density values should be interpreted in relation to the sample concentration and measurement conditions.*

The lilac flame coloration confirmed the presence of potassium ions, consistent with the characteristic flame emission of potassium (Dou et al., 2026). Similarly, the milky appearance in the limewater test indicated carbonate ions through the formation of insoluble calcium carbonate (Song et al., 2022). These qualitative observations support the presence of potassium and carbonate constituents in the extract.

The measured pH of 11.48 demonstrated the alkaline nature of the extract, consistent with aqueous potassium carbonate solutions (Ameri, 2025). Its water solubility and density of 1.091 g/mL further established its physicochemical characteristics and suitability for subsequent processing. The qualitative and physicochemical results confirmed the successful recovery of potassium- and carbonate-containing constituents from CPH ash. These findings provided a sound basis for the subsequent causticization process using calcium hydroxide to produce potassium hydroxide.

### 3.3 Conversion of Potassium Carbonate into Potassium Hydroxide and Characterization of the Derived Product

The conversion of potassium carbonate extracted from cacao pod husk (CPH) ash into potassium hydroxide (KOH) represents the third stage of the study. This process aimed to obtain an alkaline product for subsequent use in industrial degreaser formulation. The derived product was evaluated through a flame test, calcium chloride test, pH measurement, solubility assessment, and acid–base titration. The results are presented in Table 3.

***Table 3.*** *Characterization of the Results of the Potassium Carbonate into Potassium Hydroxide*

| ***Parameter*** | ***Results*** | ***Interpretation*** |
|---|---|---|
| *Flame Test* | Lilac flame | Indicates the presence of potassium ions, consistent with a potassium-containing product. |
| *Calcium Chloride Test* | No significant precipitate | Suggests that carbonate ions were not detected at a visually significant level under the test conditions. |
| *pH Level* | 13.25 | Indicates strongly alkaline characteristics of the derived product. |
| *Solubility in water* | 0.84 mol/L | Reports the measured or calculated solubility-related value; the test method and basis should be specified. |
| *Acid-Based Titration* | 1.091 g/mL | This unit represents density, not a titration result. Verify the original measurement and report |

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|---|---|---|
| | | titration results using the appropriate units. |

*Note: The flame and calcium chloride tests provide qualitative evidence regarding the presence of potassium and carbonate ions, respectively. These tests alone do not confirm the identity or purity of potassium hydroxide. The pH and solubility results should be interpreted in relation to the test conditions.*

The flame test produced a lilac coloration, confirming the presence of potassium ions in the derived product, consistent with the characteristic emission of potassium (Dou et al., 2026). The calcium chloride test produced no significant precipitate, indicating that carbonate ions were substantially reduced during causticization. This is consistent with the conversion of potassium carbonate into potassium hydroxide using calcium hydroxide (Turakulov et al., 2026). The measured pH of 13.25 confirmed the strongly alkaline nature of the product, supporting its suitability as an alkaline ingredient in degreaser formulations. The potassium identification, reduced carbonate indication, and high alkalinity demonstrate the successful production of a potassium-based alkaline product through causticization.

### *3.4 Formulation and Physicochemical Characterization of Industrial Degreaser Using Cacao Pod Husk-Derived Potassium Hydroxide*

The formulation of the industrial degreaser was evaluated to determine the influence of varying concentrations of cacao pod husk (CPH)-derived potassium hydroxide (KOH) solution, mixing duration, and mixing temperature on the physicochemical properties and cleaning performance of the developed product. Three formulations were prepared containing 10% (Degreaser 1), 15% (Degreaser 2), and 20% (Degreaser 3) CPH-derived KOH solution (v/v), with distilled water adjusted to 82.50%, 77.50%, and 72.50%, respectively, to maintain a final volume of 100 mL. The remaining ingredients were maintained at constant concentrations, consisting of 5% coco glucoside, 2% glycerin, and 0.50% lemon essential oil (v/v), as well as 0.20% sodium citrate and 1.00% xanthan gum (w/v). The mixing duration was varied at 30, 45, and 60 minutes, while the mixing temperature was adjusted to 25°C, 40°C, and 55°C to determine their effects on the resulting formulations. These experimental variations allowed the researchers to assess the individual and combined influences of KOH concentration, mixing duration, and mixing temperature on the product's alkalinity, density, foaming capacity, physical stability, and oil-removal performance. The results of the physicochemical characterization, particularly pH and density, are presented in Table 4.

***Table 4.*** *Physicochemical Characterization of the Formulated Industrial Degreaser Using Cacao Pod Husk-Derived Potassium Hydroxide*

| *Formulation (KOH % Concentration)* | *Mixing Time (mins)* | *Mixing Temperature (°C)* | *pH Level* | *Density (g/mL)* | *Viscosity (mPa·s)* |
|---|---|---|---|---|---|
| *0* | 30 | 25 | 7.82 | 1.018 | 8.70 |
| | | 40 | 7.85 | 1.016 | 8.40 |
| | | 55 | 7.88 | 1.014 | 8.10 |
| | 45 | 25 | 7.86 | 1.021 | 9.30 |
| | | 40 | 7.89 | 1.019 | 9.00 |
| | | 55 | 7.92 | 1.017 | 8.70 |
| | 60 | 25 | 7.86 | 1.023 | 9.80 |
| | | 40 | 7.89 | 1.021 | 9.50 |
| | | 55 | 7.92 | 1.019 | 9.20 |
| *10* | 30 | 25 | 11.42 | 1.035 | 9.80 |
| | | 40 | 11.48 | 1.030 | 9.30 |
| | | 55 | 11.51 | 1.025 | 8.90 |
| | 45 | 25 | 11.45 | 1.045 | 10.50 |
| | | 40 | 11.53 | 1.040 | 10.10 |

| | | | | | |
|---|---|---|---|---|---|
| | | 55 | 11.56 | 1.035 | 9.70 |
| | 60 | 25 | 11.47 | 1.050 | 11.20 |
| | | 40 | 11.54 | 1.045 | 10.80 |
| | | 55 | 11.58 | 1.040 | 10.30 |
| *15* | 30 | 25 | 12.31 | 1.080 | 12.50 |
| | | 40 | 12.37 | 1.075 | 12.10 |
| | | 55 | 12.40 | 1.070 | 11.70 |
| | **45** | **25** | **12.36** | **1.095** | **14.80** |
| | | **40** | **12.43** | **1.085** | **14.26** |
| | | **55** | **12.46** | **1.058** | **14.90** |
| | 60 | 25 | 12.38 | 1.1 | 16.10 |
| | | 40 | 12.45 | 1.09 | 16.50 |
| | | 55 | 12.48 | 1.08 | 16.90 |
| *20* | 30 | 25 | 12.91 | 1.125 | 20.50 |
| | | 40 | 12.97 | 1.115 | 19.90 |
| | | 55 | 13.01 | 1.105 | 19.20 |
| | 45 | 25 | 12.94 | 1.135 | 22.10 |
| | | 40 | 13.02 | 1.125 | 21.30 |
| | | 55 | 13.05 | 1.115 | 20.60 |
| | 60 | 25 | 12.97 | 1.145 | 23.80 |
| | | 40 | 13.04 | 1.135 | 22.90 |
| | | 55 | 13.08 | 1.125 | 22.00 |

*Note: The 0% KOH formulation served as the control. The target physicochemical specifications for the formulated industrial degreaser were pH 12.0–14.0, density 1.05–1.10 g/mL, and viscosity 14.0–15.0 mPa·s. These ranges were adopted as the study's formulation selection criteria. The pH, density, and viscosity measurements were used to evaluate the physicochemical characteristics of the products. Meeting these criteria indicates conformity with the specified formulation targets but does not independently establish cleaning efficiency, chemical purity, or long-term product stability.*

The results showed that increasing CPH-derived KOH concentration increased pH, from 7.82–7.92 in the control to 12.91–13.08 in the 20% formulation. This indicates enhanced alkalinity, which supports oil and organic residue removal through alkaline cleaning mechanisms (Tsompou & Kocherbitov, 2025). Density also increased with KOH concentration, from 1.014–1.023 g/mL in the control to 1.105–1.145 g/mL in the 20% formulation. The 15% formulation consistently satisfied the target range of 1.05–1.10 g/mL, whereas the 20% formulation exceeded the upper limit. Similarly, viscosity increased with KOH concentration, reaching 19.20–23.80 mPa·s in the 20% formulation. This may be associated with interactions between dissolved salts and xanthan gum, which influence rheological behavior (Nsengiyumva et al., 2024). The 15% formulation mixed for 45 minutes consistently met the target viscosity of 14.0–15.0 mPa·s across all three temperatures, unlike the 30- and 60-minute conditions. The 15% KOH formulation mixed for 45 minutes satisfied the specified physicochemical requirements, making it suitable for subsequent cleaning performance evaluation.

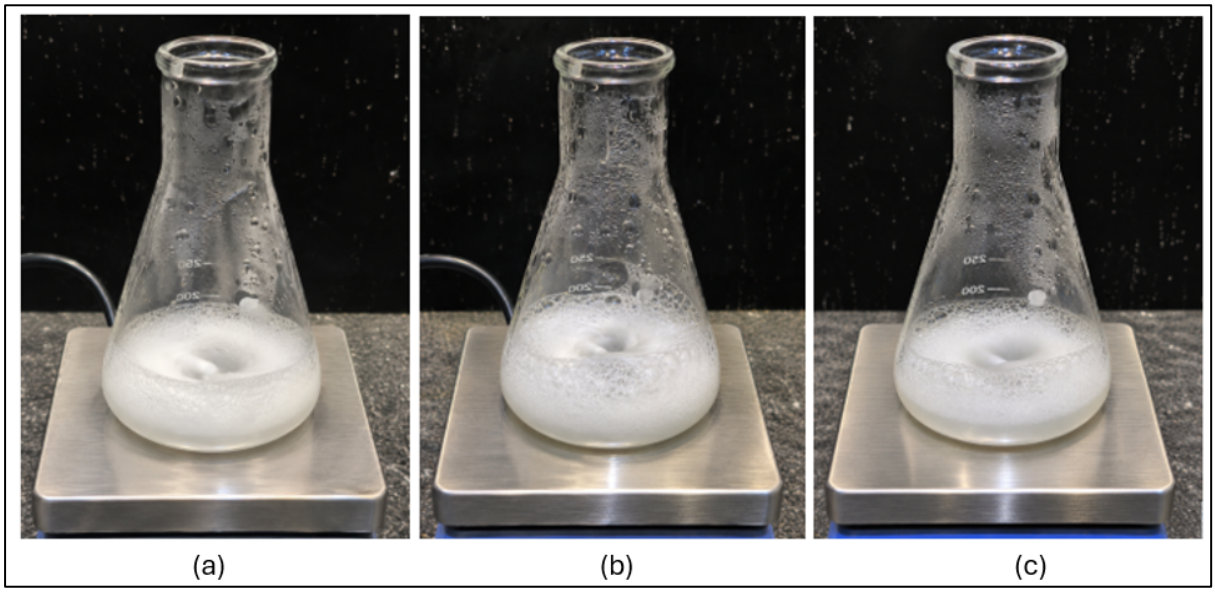
***Table 5.*** *Foaming Capacity and Physical Stability of the Formulated Product at Different Mixing Temperatures*

| ***Parameter*** | ***15% KOH Concentration; Mixing Time (45 mins); Mixing Temp (25 C)*** | ***15% KOH Concentration; Mixing Time (45 mins); Mixing Temp (40 C)*** | ***15% KOH Concentration; Mixing Time (45 mins); Mixing Temp (55 C)*** |
|---|---|---|---|
| *Foaming Capacity (%)* | 48 | 52 | 50 |
| *Phase Separation After 7 days (%)* | 2.5 | 0% | 5.2% |
| *Sedimentation* | Trace | None | Slight |
| *Change in Viscosity After 7 days (%)* | 6.3 | 1.8 | 13.2 |
| *Change in pH Level After 7 days (%)* | 0.07 | 0.03 | 0.13 |

*Note: All formulations were prepared using a constant KOH concentration of 15% and a mixing time of 45 minutes, while the mixing temperature was varied at 25 °C, 40 °C, and 55 °C. Physical stability was evaluated after seven days of storage. Sedimentation was assessed qualitatively, whereas phase separation, viscosity change, and pH change were recorded quantitatively.*

The results indicate that the formulation prepared at 40°C exhibited the most favorable overall foaming performance and physical stability among the three mixing temperatures evaluated. It achieved the highest foaming capacity of 52%, suggesting that this temperature provided more favorable conditions for foam formation. Furthermore, the formulation showed no observable phase separation or sedimentation after seven days of storage. It also recorded the lowest viscosity change (1.80%) and pH change (0.03%), indicating better consistency in its physicochemical properties throughout the observation period.

***Figure 1.*** *Foaming Capacity of the Formulated Degreaser at 15% KOH Concentration, 45-Minute Mixing Time, and Different Mixing Temperatures: (a) 25°C, (b) 40°C, and (c) 55°C.*




As shown in Figure 1, the formulation prepared at 25°C exhibited lower foaming capacity (48%) and trace sedimentation. In contrast, the 55°C formulation showed 5.20% phase separation, slight sedimentation, and the highest viscosity change (13.20%), indicating reduced physical stability. These findings identify 40°C as the most favorable mixing temperature at 15% KOH concentration and 45-minute mixing time. Its higher foaming capacity and minimal physicochemical changes indicate better formulation consistency.

### 3.5 Evaluation of Degreasing Performance on Oil-Contaminated Metal Surfaces

All formulations were prepared using a constant KOH concentration of 15% and a mixing time of 45 minutes, while the mixing temperature was varied at 25 °C, 40 °C, and 55 °C. Oil removal efficiency was determined to evaluate the cleaning performance of each formulation. The water break test was conducted to qualitatively assess the wettability of the cleaned surface. A passing result indicates that the surface exhibited continuous water-film formation, suggesting effective removal of residual oil or hydrophobic contaminants.

***Table 6.*** *Oil Removal Efficiency and Wettability Performance of the Formulated Product at Different Mixing Temperatures*

| ***Parameter*** | ***15% KOH Concentration; Mixing Time (45 mins); Mixing Temp (25 C)*** | ***15% KOH Concentration; Mixing Time (45 mins); Mixing Temp (40 C)*** | ***15% KOH Concentration; Mixing Time (45 mins); Mixing Temp (55 C)*** |
|---|---|---|---|
| *Oil Removal Efficiency (%)* | 82.27 | 92.20 | 87.67 |

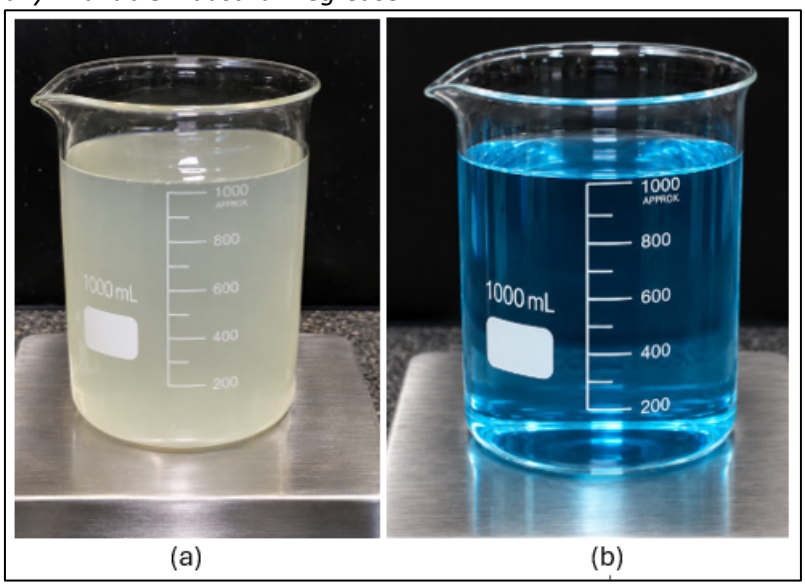
| | | | |
|---|---|---|---|
| *Water Break Test* | Pass | Pass | Pass |

The results indicate that the formulation prepared at 40 °C achieved the highest oil removal efficiency of 92.20%, followed by the formulation prepared at 55 °C (87.67%) and 25 °C (82.27%). This suggests that the mixing temperature significantly influences the cleaning performance of the formulated product. All three formulations passed the water break test, indicating that each formulation demonstrated acceptable surface wettability under the test conditions. The formulation prepared at 40 °C exhibited the most favorable cleaning performance, achieving the highest oil removal efficiency while also demonstrating favorable physical stability based on the results presented in Table 5.

### 3.6 Comparative Performance Evaluation of the Cacao Pod Husk-Derived Degreaser and a Commercial Degreaser

The comparative evaluation assessed the optimized CPH-derived degreaser against a commercial industrial degreaser. The optimized formulation contained 15% CPH-derived KOH, prepared at 40°C for 45 minutes, based on the preceding optimization results. The comparison covered physicochemical properties, foaming capacity, physical stability, oil removal efficiency, water break performance, biodegradability, VOC content, and carbon steel corrosion rate.

***Figure 2.*** *Visual Comparison of (a) the Optimized Cacao Pod Husk-Derived Industrial Degreaser and (b) the Commercially Available Industrial Degreaser.*




As shown in Figure 2, the developed degreaser exhibited a light, slightly cloudy appearance, while the commercial product displayed a clear blue coloration. These differences reflect variations in formulation composition. Both products were subjected to the same performance tests to evaluate the developed formulation's potential as an alternative industrial degreaser. The comparative results are presented in Table 7.

***Table 7.*** *Comparison with Commercial Degreaser*

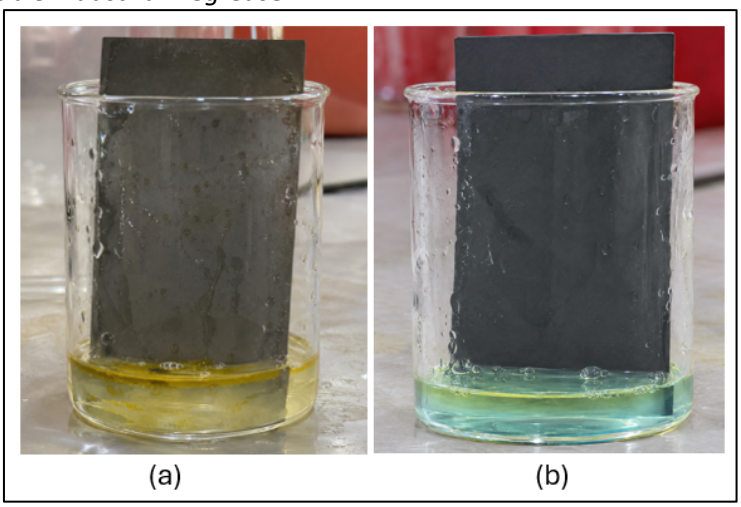
| *Parameter* | *15% KOH Concentration; Mixing Time (45 mins); Mixing Temp (40 C)* | *Commercial Industrial Degreaser* | *Standard Properties of Degreaser* |
|---|---|---|---|
| *pH Level* | 12.43 | 13.80 | 7.0-14.0 |
| *Density* | 1.08 g/mL | 1.07 g/mL | 0.90-1.20 |

| | | | |
|---|---|---|---|
| *Viscosity* | 14.26 mPa.s | 13.80 mPa.s | 10-20mPa.s |
| *Foaming Capacity* | 52% | 55% | 40-60% |
| *Physical Stability* | Stable | Stable | Stable/ No visible phase separation |
| *Oil Removal Efficiency* | 92.20% | 94.10 | ≥90% |
| *Water Break Test* | Pass | Pass | Continuous, unbroken water film on the cleaned surface |
| *Biodegradability* | 68.50% | 42.30% | ≥60% within 28 days |
| *VOC Content* | 8.50 (g/L) | 35.00 (g/L) | No universal degreaser limit |
| *Carbon Steel Corrosion Rate* | 0.045 mm/year | 0.085 mm/year | No universal degreaser limit |

The developed degreaser recorded a pH of 12.43, compared with 13.80 for the commercial product. Both exhibited strongly alkaline characteristics, supporting their potential for oil and grease removal. Alkalinity contributes to cleaning through fatty contaminant saponification, while surfactants promote wetting and emulsification (Fernandes et al., 2022; Khalid et al., 2023). The developed formulation had a density of 1.08 g/mL, slightly higher than the commercial product (1.07 g/mL). Both met the specified range of 0.90–1.20 g/mL, indicating comparable physical characteristics. Similarly, the developed degreaser recorded a viscosity of 14.26 mPa·s, compared with 13.80 mPa·s for the commercial product. Both satisfied the target range of 10–20 mPa·s, suggesting comparable flow and application characteristics.

For foaming capacity, the developed formulation achieved 52%, while the commercial product recorded 55%. Both were within the specified range of 40–60%. Although the commercial product generated slightly more foam, this difference does not necessarily indicate superior cleaning effectiveness, as oil removal also depends on surfactant-mediated wetting and emulsification (Zhao et al., 2024).

***Figure 3.*** *Oil removal test (a) the Optimized Cacao Pod Husk-Derived Industrial Degreaser and (b) the Commercially Available Industrial Degreaser.*




As shown in Figure 3, both the CPH-derived and commercial degreasers effectively removed oil contaminants from the metal surfaces, consistent with their quantitative cleaning results. The developed formulation achieved 92.20% oil removal efficiency, slightly lower than the

commercial product (94.10%). Its foaming capacity was also comparable at 52%, versus 55% for the commercial product. Both formulations passed the water break test and demonstrated physical stability, indicating comparable cleaning and formulation characteristics.

In terms of the environmental and material compatibility, the CPH-derived degreaser exhibited higher biodegradability (68.50%) and lower VOC content (8.50 g/L) than the commercial product (42.30% and 35.00 g/L, respectively). It also recorded a lower carbon steel corrosion rate of 0.045 mm/year, compared with 0.085 mm/year for the commercial formulation. The developed degreaser demonstrated competitive cleaning performance and more favorable results in the measured biodegradability, VOC content, and corrosion rate parameters. These findings support the potential use of cacao pod husk as a value-added raw material for developing alternative industrial cleaning formulations.

## 4. CONCLUSIONS AND RECOMMENDATIONS

The study demonstrated the potential of cacao pod husk (CPH) ash as a renewable source of potassium-containing compounds for developing an alternative industrial degreaser. The characterization results established the alkaline properties and potassium content of the ash, while subsequent extraction and conversion produced a strongly alkaline potassium-containing material suitable for formulation evaluation. Among the experimental conditions, the formulation containing 15% KOH, mixed for 45 minutes at 40°C, exhibited the most favorable combination of physicochemical properties, physical stability, and cleaning performance. It achieved the established formulation specifications and demonstrated 92.20% oil removal efficiency, supported by a passing water break test. Comparative evaluation further showed that its cleaning performance and physicochemical characteristics were comparable to those of the commercial degreaser. The findings establish the feasibility of valorizing cacao pod husk waste into a potentially useful industrial cleaning product, particularly for applications involving oil-contaminated metal surfaces.

Based on the findings of the study, the 15% CPH-derived KOH formulation prepared at 40°C for 45 minutes is recommended as the preferred operating condition for further development of the industrial degreaser. Future studies should conduct quantitative chemical analyses, particularly acid–base titration, to determine the actual KOH concentration and purity of the extracted and converted products. Standardized biodegradability, VOC, and carbon steel corrosion tests are also recommended to validate the environmental performance and material compatibility of the formulation. Furthermore, extended storage studies and repeated cleaning-cycle evaluations should be conducted to establish its long-term stability, shelf life, and consistent cleaning effectiveness. Further formulation improvements may also be explored to enhance oil removal efficiency and optimize product characteristics. Pilot-scale production and testing under actual industrial conditions, particularly in oil and gas equipment maintenance, are recommended to assess its practical applicability, scalability, and potential for commercial development.

The findings are limited to the experimental materials, formulation concentrations, mixing durations, temperatures, and testing conditions employed in the investigation. Physical stability was evaluated over a seven-day period, which does not establish long-term shelf life. The qualitative flame and precipitation tests provide preliminary chemical evidence but cannot independently confirm product purity or complete conversion to KOH. Additionally, the reported titration-related measurement requires verification, while the biodegradability, VOC, and corrosion results require further methodological validation. The findings should therefore be

interpreted within the scope of the laboratory evaluation and validated through standardized analytical procedures, longer observation periods, and additional industrial-scale testing.

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