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# Conversion of Grease Scum to Biodiesel Via Acid Esterification-Alkaline Transesterification as an Alternative Fuel for Kerosene Lamp

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***Abstract—*** *Improper disposal can lead to the accumulation of grease scum, resulting in blockages in drainage systems and causing operational issues in wastewater treatment facilities. The viability and potential of turning grease scum into biodiesel was evaluated in this work using light intensity and combustion duration as criteria in comparison to kerosene fuel. The conversion process involved acid esterification and alkaline transesterification. In acid esterification, hydrochloric acid was added to methanol and grease scum, and the mixture was heated. In alkaline transesterification, sodium hydroxide was added, and the mixture was further heated. The results revealed that the treatment with a higher methanol to grease scum ratio exhibited greater light intensity compared to the lower ratio. A significant difference was observed between the lower ratio and the control setup, indicating that the control provided better light intensity performance. However, no significant difference was found between the higher ratio and the control. In terms of burning duration, both treatments showed significant differences compared to the control, implying that kerosene had a longer burning duration than both biodiesel treatments. No significant difference was observed between the two treatments regarding burning duration. The study suggests that the higher ratio can serve as an alternative to kerosene in terms of light intensity, while kerosene remains more effective for burning duration. Recommendations include increasing temperature during the conversion processes and comparing the effects of ethanol and methanol on burning duration and light intensity. Additionally, using a separation funnel to isolate the biodiesel from glycerol and conducting tests on the biodiesel composition would enhance fuel quality and performance.*

***Keywords—*** *Acid esterification, Alkaline transesterification, Biodiesel, Burning duration, Grease scum, Kerosene, Light intensity.*

## I. INTRODUCTION

The growing global energy demand and environmental consequences of conventional energy sources may result in an upcoming energy crisis. Petroleum will become scarce and expensive, highlighting the impact of fossil fuel use on climate change (Cayetano López Universidad Autónoma de Madrid et al., n.d.). To tackle these challenges, it is vital to minimize the environmental footprint of current energy sources and explore renewable alternatives, one of which is biodiesel. Biodiesel, a fuel that is obtained from various sources like waste vegetable oils, animal fats, or recycled restaurant grease, is recognized for its eco-friendly characteristics. It finds primary application in diesel vehicles and presents numerous benefits compared to conventional petroleum diesel. Biodiesel produces fewer harmful pollutants and greenhouse gases during combustion (Rodrigues et al., 2008).

In the Philippines, many people particularly in rural areas lack access to electricity and rely on kerosene lamps for lighting. However, these lamps emit harmful fumes equivalent to smoking two packs of cigarettes and pose burn risks. Additionally, the price of kerosene is a significant financial strain for many households, as well as its use contributes to pollution and health issues (Path Foundation Philippines, Inc., n.d.). Biodiesel offers a cleaner and safer alternative to kerosene, with reduced carbon dioxide emissions and lower health risks. According to experts, substituting petroleum diesel with biodiesel can potentially reduce greenhouse gas emissions by up to 78.45% (Rinkesh, 2023).

While biodiesel production holds great potential, the cost of raw materials remains a significant obstacle, making biodiesel economically impractical. Furthermore, large-scale cultivation of oil-producing crops can negatively impact water resources. Thus, researchers are exploring the utilization of waste triglycerides as a cost-effective input for biodiesel production. Waste oils and grease, including waste frying oil and grease trap residue, can be utilized, reducing pollution and serving as a means of sewage treatment (Ribeiro et al., 2017). However, waste triglycerides often possess significant quantity of free fatty acids (FFA), which can disrupt the biodiesel production process. Traditional transesterification methods using alkaline catalysts are unsuitable for these feedstocks due to their high FFA and moisture content. To attain increased yields of biodiesel and prevent the formation of soap, it is recommended to implement acid esterification followed by alkaline transesterification. This combination targets FFAs and converts them into biodiesel efficiently (Canakci & Van Gerpen, 2001, Urrutia et al., 2015).

In a related study conducted by Hasuntree et al. (2011) entitled, "*The Potential of Restaurant Trap Grease as Biodiesel Feedstock,"* the method of conversion to biodiesel primarily focused on acid esterification without incorporating a preceding process such as alkaline transesterification to convert the remaining triglyceride in the biodiesel. However, in contrast to that study, the objective of this present study is to examine the viability of biodiesel production as a substitute for fuel lamp from fast food restaurant grease scum by utilizing an acid esterification–alkaline transesterification



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process. Furthermore, there are no existing studies that have explored the utilization of both acid esterification and alkaline transesterification processes for biodiesel production from grease scum. This alternative approach holds the potential to reduce production costs and minimize solid waste from grease traps, thereby addressing issues related to drainage systems. Additionally, no studies have investigated the use of grease scum biodiesel as an alternative for kerosene lamp.

## II. Methodology

### A. Pre-treatment of Grease Scum

The 7.65 kg grease scum was obtained from a certain fast food restaurant in Pasonanca, Zamboanga City. The target amount for the grease scum preparation was 2000 grams, with the aim of determining an allowable amount for the production of biodiesel. The grease scum, which consisted of a mixture of fats and oils, underwent a pre-treatment process to remove the unnecessary particles that could disrupt the conversion of grease scum to biodiesel. In the pre-treatment process, the grease scum, which was contained in a 1000 mL beaker, was subjected to a temperature of 120˚C for a duration of 5 minutes in order to eliminate moisture. The heating stage of grease scum during the pre-treatment process was based on the study of Thaiyasuit et al., (2012) from the "Acid Esterification-Alkaline Transesterification Process for Methyl Ester Production from Crude Rubber Seed Oil." The heating process of grease scum helped in separating solid impurities and allowed for better filtration. After which, the heated grease scum was passed through a strainer to remove larger particles such as food debris. After filtration, the grease scum was allowed to settle in a 1000-mL beaker.

### B. Moisture Content of Grease Scum

At a water content of 5%, the esterification process is disrupted (Thaiyasuit et al., 2012). Therefore, the grease scum should have had at most 5% moisture content before the esterification process. To determine the moisture content in the grease scum, the Gravimetric Method was incorporated in this study. This method involved measuring the weight loss of the grease scum after heating it at 120˚C for 5 minutes. By comparing the initial weight with the weight after heating, the moisture content could be determined.

### C. Fatty Acid Composition and Methanol Content

Due to the unavailability of equipment, the study utilized the related literature from Oliveira et al. (2016) titled 'Transesterification of Sanitation Waste for Biodiesel Production' to determine the fatty acid composition of grease scum. The fatty acid composition results from Oliveira et al. (2016) were used to calculate the molar mass of grease scum, which was essential for biodiesel production. The fatty acid composition of grease scum is shown below.

The molar mass of each fatty acid in the grease scum can be determined by adding together the atomic masses of its constituent atoms, using the molecular formulae of the fatty acids listed in Table 1. In the periodic table, one may locate the atomic masses. The resulting molar masses of the fatty acids in the grease scum would be multiplied by their corresponding compositions (%). Finally, these values would be added to obtain the molar mass of the grease scum. However, it was impossible to obtain the accurate molar mass of the fatty acids in the "Others" category from Table 1 since the fatty acids were unknown. Therefore, an assumption was made by computing the average molar mass of all the known fatty acids present in Table 1 and assigning it to the "Others" category. In this study, the fatty acid composition from the SGT-UR (Scum from the Grease Trap of the University Restaurant) was applied since the grease scum sample was collected from a fast food restaurant.

TABLE 1. Fatty acids composition of grease scum

| Fatty acid (%) | SGT-FPP | SGT-UR | SGT-WTS | SSST |
|---|---|---|---|---|
| C 12:0 (Lauric) | 4.52 | 4.54 | 4.47 | ND |
| C 14:0 (Myristic) | 10.39 | 10.08 | 10.93 | 27.05 |
| C 16:0 (Palmitic) | 19.37 | 24.45 | 16.50 | 20.73 |
| C 18:0 (Stearic) | 15.83 | 15.60 | 12.96 | 10.89 |
| C 18:1 (Oleic) | 19.45 | 24.52 | 16.57 | 20.80 |
| C 18:2 (Linoleic) | 4.86 | 15.10 | 8.82 | 15.68 |
| C 18:3 (Linolenic) | 0.26 | 2.09 | 1.36 | 2.36 |
| Others | 25.32 | 3.62 | 28.39 | 2.49 |

Once the molar mass of grease scum is determined, the amount of methanol can be computed by using these equations:

$$(100\text{ g})/(\frac{\text{g}}{\text{mol}}\text{ of grease scum}) = (\text{g of Methanol})/(3(32.04\text{ g/mol})) \quad (1)$$

$$(100\text{ g})/(\frac{\text{g}}{\text{mol}}\text{ of grease scum}) = (\text{g of Methanol})/(6(32.04\text{ g/mol})) \quad (2)$$

Equation (1) refers to 3:1 molar ratio of methanol to grease scum, whereas 6:1 molar ratio of methanol to grease scum refer to (2).

### D. Acid Esterification and Alkaline Transesterification Computation Process

The hydrochloric acid was utilized as the acid catalyst since it is found to be used in a wide range of esterification reactions due to its general reactivity. Sodium hydroxide, on the other hand, was utilized as the alkaline catalyst because it is versatile and compatible with a wide range of triglycerides and alcohols. In addition, sodium hydroxide is readily available and relatively inexpensive. The amount of both hydrochloric acid and sodium hydroxide needed in the acid esterification and alkaline transesterification for a 6:1 molar ratio of methanol to grease scum was 1 gram. The amount of both catalysts was based on the laboratory experiment of *"Transesterification of Vegetable Oil and Alcohol to Produce Ethyl Esters (Biodiesel)"* from Biodiesel Education (2017). The same amount of sulfuric acid and sodium hydroxide was in corporated in the 3:1 molar ratio of methanol to grease scum due to the unavailability of related literature.

### E. Grease Scum Biodiesel Production

The production process of biodiesel from grease scum involved several steps. First, the collected grease scum, which was typically composed of fats and oils from a local food establishment in Pasonanca, Zamboanga City, underwent pre-treatment steps to remove impurities and improve the quality of the feedstock. The collected grease scum was contained in a 1000-mL beaker. The pre-treatment of grease scum involved heating at 120˚C for 5 minutes using a heating mantle, filtering it through a strainer, and allowing it to settle to separate solid particles, water, and other undesirable substances from the grease scum. The filtered grease scum was then subjected to acid esterification. In this step, a 1 gram hydrochloric acid was added to the grease scum using a glass dropper. Methanol, serving as both a reactant and a solvent, was also introduced into the mixture. In this case, Treatment 1, with a 36.14 g, was subjected to a molar ratio of 3:1 methanol to grease scum. Treatment 2, on the other hand, with a 72.27 g, was subjected to a molar ratio of 6:1 methanol to grease scum. A 1 gram of hydrochloric acid facilitated the reaction between the fatty acids present in the grease scum and the methanol, which led to the formation of biodiesel, specifically fatty acid methyl esters, along with glycerol. The reaction temperature of 60˚C was utilized in this study for the acid esterification reaction for a duration of 1 hour. In this step, a liquid-in-glass thermometer was used to monitor the required temperature. The reaction mixture, which contained the grease scum, sulfuric acid, and methanol, was heated using a heating mantle and maintained at around that temperature. This esterification process helped convert the free fatty acids into biodiesel components. After the acid esterification, the mixture was allowed to undergo a sedimentation process for a period of 4 hours, and the glycerol layer separated from the fatty acid esters. To complete the conversion of the esters into biodiesel, alkaline transesterification took place. In this step, a 1 gram base catalyst such as sodium hydroxide, which was contained in a 125-mL Erlenmeyer flask, was added to the ester mixture along with 35.14 g and 72.27 g of methanol for treatment 1 and treatment 2, respectively. The mixture was heated at 65˚C and agitated for 1 hour, allowing the transesterification reaction to occur. In this step, a liquid-in-glass thermometer was used to monitor the required temperature. This reaction converted the esters into biodiesel and produced glycerol as a byproduct. The mixture was allowed to undergo a sedimentation process for a period of 4 hours to allow the biodiesel to float on top. The resulting biodiesel was stored in a 500-mL Erlenmeyer flask with an aluminum foil serving as a cover.

### *F. Selection of Lamp*

A Small Glass Jar type with a black, bronze, and silver lid was utilized for the lamp. It was constructed with durable glass and air-tight lids. Cotton fabric was used as the wick material for the lamp. It had thread strands that aided in drawing up a consistent fuel supply for burning in the lamp. A total of 20 lamps were used for the two treatment groups, consisting of the molar ratios 3:1 and 6:1 of methanol to grease scum. Additionally, 10 lamps were allocated for the control setup, which employed kerosene as the fuel source. The selection of lamps for each of the two treatments (3:1 and 6:1 methanol to grease scum) and the control setup (kerosene lamp) was conducted using the Lottery Method. A total of 10 trials were conducted for each group. The Lottery Method ensured a random allocation of lamps to the two treatments (3:1 and 6:1 methanol to grease scum) and the control setup (kerosene lamp), providing an unbiased distribution for the experiment. To implement the Lottery Method, pieces of paper were prepared, with each piece containing a number from 1 to 30. The pieces of paper were thoroughly mixed in a box to ensure a random distribution. One piece of paper was drawn at a time until 10 lamps were assigned to each of the two treatments (3:1 and 6:1 methanol to grease scum) and the control setup (kerosene lamp).

### *G. Data Gathering Procedure*

In this study, two treatments were prepared, namely a 3:1 and 6:1 molar ratio of methanol to grease scum. Each treatment consisted of ten trials, and a control setup using a kerosene lamp was also included. A comparison was made between the lighting output and burning duration of the grease scum biodiesel obtained from the treatments and the kerosene lamp. To evaluate the lighting output, a Luxmeter was used, and the measurements were recorded in lux units. The burning duration was measured using a timer, and the results were recorded in hours.

*Measuring of Lighting Output*

To measure the lighting output, the luxmeter was positioned at the location where the light was emitted from the converted grease scum biodiesel and kerosene lamp. Each lamp was placed inside a box measuring 13x13x10 cm, and these boxes were placed 30 cm away from each other. The luxmeter then detected and quantified the amount of light in lux units. The measurement of lighting output started when the amount of grease scum biodiesel (3:1 and 6:1 methanol to grease scum) and kerosene lamp was at 40 mL of 80 mL fuel. This measurement helped assess the effectiveness of grease scum biodiesel as an alternative fuel for the kerosene lamp by comparing the lighting output to traditional kerosene fuel. A total of 20 lamps were employed for the two treatment groups, comprising the molar ratios 3:1 and 6:1 of methanol to grease scum. Additionally, 10 lamps were designated for the control setup, utilizing kerosene as the fuel source.

*Measuring of Burning Duration*

The process involved starting the timer at the beginning of the burning process when the converted grease scum biodiesel and kerosene lamp were ignited. Each lamp was placed in a 13x13x10 cm box with a distance of 30 cm away from each other. A total of 20 lamps were employed for the two treatment groups, involving the molar ratios 3:1 and 6:1 of methanol to grease scum. Additionally, kerosene was used as the fuel source for the 10 lamps that were set up for the control system. The timer was recorded when the flame extinguished.

### *H. Data Analysis*

The obtained results of light intensity and burning duration of the treatment groups (3:1 and 6:1 molar ratios of methanol to grease scum) and control setup (kerosene) were the basis for the data analysis and interpretation. The results were analyzed through the representation of tables and graphs that evaluate the light intensity and burning duration of grease scum biodiesel and kerosene. The assumptions for ANOVA were verified using free software online. Levene's Test Calculator (https://www.statskingdom.com/230var_levenes.html) was used for homogeneity of variance and Shapiro-Wilk Test Calculator (https://www.statskingdom.com/shapiro-wilk-test-calculator.html) for normality testing. Since the assumption for normality was violated in light intensity and burning duration, a non-parametric Kruskal-Wallis followed by Dunn-Bonferroni analysis was used in the determination of significant difference among the treatment 1 (3:1 methanol to grease scum), treatment 2 (6:1 methanol to grease scum), and control setup (kerosene) at 5% level of significance. The assumptions were verified using free software online (https://www.statskingdom.com/kruskal-wallis-calculator.html).

## III. Results and Discussion

### A. Light Intensity

The light intensity measurements were taken by pointing the luxmeter's sensor towards the light source. A single reading of light intensity was recorded for each treatment: treatment 1, treatment 2, and control setup. The luxmeter provided an instant reading, displaying the light intensity in lux unit.

Table 2 shows the results of the light intensity measurements for each treatment and the control setup, including the mean and standard deviation analysis. The mean light intensity values provide an indication of the average brightness produced by each treatment and control setup. In this case, the control setup had highest mean light intensity of 67.7 lux. The standard deviation values reflect the variability or spread of the light intensity measurements within each treatment and control setup. Treatment 1 had a relatively high standard deviation of 46.977 lux, indicating that the light intensity values varied more widely around the mean. Treatment 2 had a slightly lower standard deviation of 50.688 lux, suggesting a moderate level of variability. The control setup showed the lowest standard deviation of 31.667 lux, indicating a relatively more consistent light intensity. Based on these results, the treatment 2 and the control setup generally produced higher average light intensities compared to treatment 1. However, treatment 1 exhibit greater variability in light intensity measurements compared to treatment 2 and the control setup.

Among the treatment groups, the result indicated that treatment 2 has higher light intensity compared to treatment 1. But, when compared to the two therapies, kerosene has a higher light intensity. Methanol-based biodiesel fuels generally have slightly higher pour and cloud points, and slightly viscosities (Musa, 2016). Biodiesel fuels with higher cloud points or the presence of solid particles may scatter or block the passage of light to some extent, potentially reducing light transmission and affecting illumination. The increased amount of methanol minimized the presence of undesirable byproducts or unreacted triglycerides, potentially resulting in a purer biodiesel product. Kerosene is a fuel that undergoes a higher level of refining in a lower presence of impurities compared to biodiesel fuel (Pohuski, 2023). The lower impurity content in kerosene contributes to improve light illumination, producing a steady and brighter flame.

TABLE 2. Light intensity results

| Parameters | Trials | Light Intensity (lux) | Mean (lux) | Std Dev. |
|---|---|---|---|---|
| Treatment 1 (3:1 Methanol to Grease Scum) | 1 | 150 | 21.28 | 46.977 |
| | 2 | 21 | | |
| | 3 | 38 | | |
| | 4 | 1.5 | | |
| | 5 | 1.2 | | |
| | 6 | 0 | | |
| | 7 | 1.1 | | |
| | 8 | 0 | | |
| | 9 | 0 | | |
| | 10 | 0 | | |
| Treatment 2 (6:1 Methanol to Grease Scum) | 1 | 84 | 58.9 | 50.688 |
| | 2 | 130 | | |
| | 3 | 156 | | |
| | 4 | 50 | | |
| | 5 | 18 | | |
| | 6 | 66 | | |
| | 7 | 17 | | |
| | 8 | 0 | | |
| | 9 | 0 | | |
| | 10 | 68 | | |
| Control setup (Kerosene) | 1 | 113 | 67.7 | 31.667 |
| | 2 | 58 | | |
| | 3 | 54 | | |
| | 4 | 21 | | |
| | 5 | 100 | | |
| | 6 | 91 | | |
| | 7 | 111 | | |
| | 8 | 54 | | |
| | 9 | 42 | | |
| | 10 | 33 | | |

To verify the assumptions of ANOVA, Levene's Test Calculator (https://www.statskingdom.com/230var_levenes.html) was used to test the homogeneity of variance, the result showed that the average of data was considered to be equal with a $p = 0.216 > 0.05$. Moreover, Shapiro-Wilk's Test Calculator (https://scistatcalc.blogspot.com/2013/10/shapiro-wilk-test-calculator.html) was used to test the normality of light intensity, the result showed a significant departure from normality with $p = 0.000 < 0.05$ in treatment 1 (3:1 methanol to grease scum). As a result of the assumptions testing, the data did not meet the normal distribution, thus, a non-parametric Kruskal Wallis Test followed by Post-Hoc Dunn's Test (https://www.statskingdom.com/kruskal-wallis-calculator.html) was employed.

The result of Kruskal-Wallis analysis at 5% level of significance is shown in Table 3. The obtained results indicated that there are statistically significant difference among the two treatment groups of methanol to grease scum ratio and kerosene since the $p < 0.05$.

TABLE 3. Summary of Kruskal-Wallis result on light intensity

| | $Chi^2$ | df | p |
|---|---|---|---|
| Light intensity | 7.83 | 2 | 0.02 |

To further investigate the specific group differences, a Post-Hoc Dunn's Test was performed. The basis of the result was the application of the Bonferroni correction, which adjusted the p-values. The results of Dunn's Test shown in Table 4 indicate a significant difference was found when



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comparing treatment 1 and treatment 2. With an adj. $p < 0.05$, this indicates that treatment 1 significantly differs from treatment 2 in terms of light intensity. The result suggests that treatment 2 is more effective than treatment 1 in terms of light intensity. A significant difference was also observed between treatment 1 and the control setup with an adj. $p < 0.05$. This implies that the control setup is more effective than treatment 1 in terms of light intensity. Furthermore, the results indicate that there is no significant difference between treatment 2 and the control setup since the adjusted p-value is found to be greater than the 5% level of significance. This suggests that both treatment 2 and the control setup have similar performance, and treatment 2 could be considered as an alternative to kerosene in terms of light intensity.

TABLE 4. Post-hoc Dunn's test results on light intensity

| Pair | Mean Rank Difference | Std. Error | Std. Test Statistic | p | Adj. p |
|---|---|---|---|---|---|
| Treatment 1 to Treatment 2 | -7.45 | 3.920 | 1.900 | 0.057 | 0.029 |
| Treatment 1 to Control setup | -10.7 | 3.920 | 2.729 | 0.006 | 0.003 |
| Treatment 2 to Control setup | -3.25 | 3.920 | 0.829 | 0.407 | 0.203 |

*B. Burning Duration*

Table 5 indicates the results of burning duration for each treatment and control setup, including the mean and standard deviation analysis. Treatment 1 showed a range of burning duration between 0 to 8.67 mL/min. Whereas treatment 2 exhibited a range of 0 to 9.62 mL/min. The control setup, on the other hand, had a wider range of burning duration from 0.14 mL/min to 0.47 mL/min. Treatment 1 had a mean duration of 0.065 hours with a standard deviation of 0.060 hours. Treatment 2 had a slightly longer mean duration of 0.085 hours with a smaller standard deviation of 0.050 hours. In contrast, the control setup had a significantly longer mean duration of 4.448 hours, with a larger standard deviation of 2.080 hours. All three groups initially began with a quantity of 80 mL. After burning, treatment 1 reduced to 77 mL, while treatment 2 had reduced to 76.6 mL. In the control setup, the quantity dropped to 0 mL. Based on these results, both treatment 1 and treatment 2 resulted in relatively short burning durations and a minor reduction in quantity. In contrast, the control setup demonstrated a significantly longer burning duration and completely consumed the initial quantity of 80 mL.

TABLE 5. Burning duration results

| Parameters | Trials | Burning duration (hour) | Qty (mL) before burning | Qty (mL) after burning | Mean (hour) | Std. Dev. (hour) | Qty (mL) before burning | Ave. qty (mL) after burning |
|---|---|---|---|---|---|---|---|---|
| Treatment 1 (3:1 Methanol to Grease Scum) | 1 | 0.1 | 80 | 70 | 0.065 | 0.060 | 80 | 77 |
| | 2 | 0.1 | 80 | 75 | | | | |
| | 3 | 0.1 | 80 | 75 | | | | |
| | 4 | 0.13 | 80 | 75 | | | | |
| | 5 | 0.07 | 80 | 77 | | | | |
| | 6 | 0 | 80 | 80 | | | | |
| | 7 | 0.15 | 80 | 78 | | | | |
| | 8 | 0 | 80 | 80 | | | | |
| | 9 | 0 | 80 | 80 | | | | |
| | 10 | 0 | 80 | 80 | | | | |
| Treatment 2 (6:1 Methanol to Grease Scum) | 1 | 0.13 | 80 | 75 | 0.085 | 0.050 | 80 | 76.6 |
| | 2 | 0.13 | 80 | 75 | | | | |
| | 3 | 0.08 | 80 | 77 | | | | |
| | 4 | 0.1 | 80 | 77 | | | | |
| | 5 | 0.08 | 80 | 75 | | | | |
| | 6 | 0.12 | 80 | 75 | | | | |
| | 7 | 0.08 | 80 | 77 | | | | |
| | 8 | 0 | 80 | 80 | | | | |
| | 9 | 0 | 80 | 80 | | | | |
| | 10 | 0.13 | 80 | 75 | | | | |
| Control setup (Kerosene) | 1 | 2.85 | 80 | 0 | 4.448 | 2.08 | 80 | 0 |
| | 2 | 2.9 | 80 | 0 | | | | |
| | 3 | 6.63 | 80 | 0 | | | | |
| | 4 | 9.45 | 80 | 0 | | | | |
| | 5 | 4.13 | 80 | 0 | | | | |
| | 6 | 3.1 | 80 | 0 | | | | |
| | 7 | 4.05 | 80 | 0 | | | | |
| | 8 | 4.37 | 80 | 0 | | | | |
| | 9 | 3.1 | 80 | 0 | | | | |
| | 10 | 3.9 | 80 | 0 | | | | |

Fig. 1 below shows the reduction levels of the quantities for two treatment ratios and the control setup. Treatment 1 shows an average burning duration of 3.9 minutes (0.065 hours) and a reduction of 77 mL in the quantity of grease scum biodiesel, while treatment 2 demonstrates a reduction of 76.6 mL at 5.1 minutes (0.085 hours). The control setup demonstrates complete consumption of kerosene fuel, resulting in zero reduction in quantity after a burning duration of 266.88 min. (4.448 hours).



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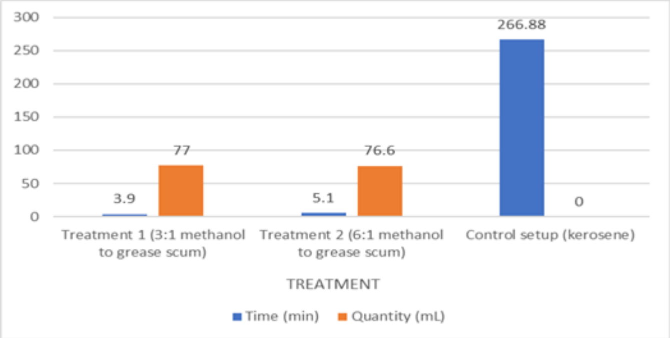


Fig. 1. Grease scum biodiesel and kerosene quantity level reduction on burning duration

Based on the results, the control setup produced a strong and sustained flame that lasted until all the fuel in the lamp was consumed. Both treatment 1 and treatment 2 yielded a poor burning duration. The Methanol Institute (2018) claims that methanol is more difficult to ignite, burns at a slower rate, and produces less heat. Additionally, methanol has a higher heat capacity and a higher stoichiometric air-fuel ratio. This means that methanol requires more heat energy to achieve complete combustion. The higher heat capacity of methanol allows it to absorb more heat from its surroundings, which can contribute to a slower burning rate (Verhelst et al., 2019).

To verify the assumptions of ANOVA, Levene's Test Calculator (https://www.statskingdom.com/230var_levenes.html) was used to test the homogeneity of variance, the result showed that the average of data was considered to be equal with a $p = 0.061 > 0.05$. Moreover, Shapiro-Wilk's Test Calculator (https://scistatcalc.blogspot.com/2013/10/shapiro-wilk-test-calculator.html) was used to test the normality of the burning duration, the result showed a significant departure from normality with $p = 0.000 < 0.05$ in all groups. As a result of the assumptions testing, the data did not meet the normal distribution, thus, a non-parametric Kruskal Wallis Test followed by Post-Hoc Dunn's Test (https://www.statskingdom.com/kruskal-wallis-calculator.html) was employed.

Table 6 presents the findings of the Kruskal-Wallis analysis on burning duration conducted at a 5% level of significance. The results obtained from the analysis suggest that there is a significant difference between the two treatment groups in terms of the ratio of methanol to grease scum and kerosene, with a p-value less than 0.05.

TABLE 6. Summary of Kruskal-Wallis results on burning duration

| | $Chi^2$ | df | p |
|---|---|---|---|
| Burning duration | 19.83 | 2 | < 0.001 |

To further examine the differences between specific groups, a Post-Hoc Dunn's Test was conducted. The outcomes of the test, as presented in Table 7, reveal a significant distinction between treatment 1 and control setup, and between treatment 2 and control setup. The findings, with a p-value less than 0.05, indicate that both treatment 1 and treatment 2 significantly vary from the control setup in terms of burning duration. This suggests that kerosene is more effective than both treatment 1 and treatment 2 when considering burning duration. On the other hand, no significant difference was observed between treatment 1 and treatment 2 as the p-value exceeded the 5% level of significance. This implies that both treatment 1 and treatment 2 perform similarly in terms of burning duration.

TABLE 7. Post-hoc Dunn's test results on burning duration

| Pair | Mean Rank Difference | Std. Error | Std. Test Statistic | p | Adj. p |
|---|---|---|---|---|---|
| Treatment 1 to Treatment 2 | -1.8 | 3.910 | 0.460 | 0.645 | 0.323 |
| Treatment 1 to Control setup | -15.9 | 3.910 | 4.066 | < 0.001 | 0.00002393 |
| Treatment 2 to Control setup | -14.1 | 3.910 | 3.606 | < 0.001 | 0.0001557 |

## IV. CONCLUSION

Treatment 2 exhibited a higher light intensity compared to Treatment 1, with an adjusted $p < 0.05$. Additionally, the control setup demonstrated greater light intensity than Treatment 1, also with an adjusted $p < 0.05$. However, no significant difference was noted between Treatment 2 and the control setup, as the adjusted p-value > 0.05. This indicates that Treatment 2 and the control setup perform similarly in terms of light intensity, suggesting that Treatment 2 could be a viable alternative to kerosene for achieving comparable light intensity. The increased amount of methanol used in Treatment 2 minimized the presence of unreacted triglycerides, resulting in a purer biodiesel with less grease scum compared to Treatment 1. Kerosene, with its lower impurity content, enhances light illumination, producing a steadier and brighter flame (Pohuski, 2023). In terms of burning duration, kerosene proved to be more effective than both treatments. There was no significant difference in burning duration between Treatment 1 and Treatment 2, as indicated by a $p > 0.05$. Methanol, utilized in both treatments, is harder to ignite, burns at a slower rate, and produces less heat intensity compared to kerosene (U.S. Department of Transportation, 2018). Furthermore, methanol's higher heat capacity and stoichiometric air-fuel ratio contribute to its slower burning rate and the requirement for more heat energy to achieve complete combustion (Verhelst et al., 2019).

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