Volume 1 | Issue 2 | Jul - Dec 2023
ISSN: 2984-9896

# Pyrolytic Extraction of Diesel from Polypropylene Face Mask

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## ABTRACT

During the past three years, the COVID-19 served as a catalyst for the continuous and rapid increase of disposable face mask wastes and with its slow decomposition, it piled up in landfills for a long time. As they are made of polypropylene plastics, they have a good amount of energy content. Pyrolysis repurposes this end-life face masks into liquid fuel such as diesel. Three temperature ranges were used in the pyrolysis namely 200-250°C, 250-300°C, and 300-350°C. One-kilogram face mask sample per treatment were pyrolyzed, each being repeated three times for accuracy. It was found that the optimal pyrolysis temperature is at 250-300°C. At this temperature range,593.67 mL of pyrolytic oil was produced. From this pyrolytic oil, 125.33 mL of diesel was extracted through the use of fractional distillation at 260-350°C. The density, which was determined at 21°C was corrected and yield a value of 811.47 kg/m3 at 15°C. This density is almost similar to the density of the Shell Fuel Save Diesel density showing possibility of it to be marketed. Lastly, the calorific value of the diesel is 44.95599 MJ/kg which is higher than the European standard which is at least 35 MJ/kg which means that the extracted diesel has a high quality. By-products such as gasoline, kerosene, and residual oil was also produced. The amount of gasoline yield is 132.45 mL, kerosene yield is 120.67 mL, and residual oil yield is 215.71 mL.

***Keywords:*** *disposable face masks, pyrolysis, diesel, calorific value, waste-to- energy*

## INTRODUCTION

Despite resource conservation efforts, the world is nevertheless awash in solid waste. The Philippines generated 214,265,676 metric tons of waste in 2020 with Metro Manila producing 3,466,469 (1.62%) metric tons. This problem worsened when the Corona Virus Disease (COVID-19) was declared a pandemic by the World Health Organization (WHO) on March 11, 2020. The Philippine's Inter-Agency Task Force for the Management of Emerging Diseases (IATF-EID) issued a resolution mandated the use of facemasks to every region in the country.

WHO reported roughly 89 million medical masks are necessary every month in order to respond to COVID-19. The Philippines has created 52,000 metric tons of medical waste since the lockdown began in the early months of 2020. One hundred twenty-nine billion face masks were used and thrown away globally, which might be the next plastic disaster.

Although plastics can be easily recycled, hazardous plastic wastes – especially medical plastic wastes are only disinfected until it is declared nonhazardous to be buried in landfills. This could take decades before it properly decomposes. Plastics are considered to contain calorific value making it a viable source for fuel energy.

There are numerous ways in order to realize this possibility, that is through incineration, gasification, hydrothermal liquefaction, and pyrolysis. These methods are often associated with Treatment, Storage, and Disposal (TSD) Facilities, yet plastic wastes are yet to undergo these processes. The realization of the production of the possibility of a new source of energy parallels to the United Nations Sustainable Development Goal (UN SDG) 7, which seeks to ensure universal access to modern energy services while transitioning to cleaner and more sustainable energy sources in order to create a more sustainable and equitable future, along with UN SDG 13 where it primarily combats the threat of climate change and its effects. Its reduction to the global accumulated solid wastes and its potential to be a new renewable energy source directly and indirectly minimize the impacts of climate change and, in a way, relates to the principles of circular economy. Moreover, the researchers see the possibility of extracting energy in the form of fuel from face mask waste relating the amount of yield, properties, and energy produced in varying temperatures since there is no past and current studies that deal with those that are available at this time. The researchers aim to conduct a pyrolysis where disposable face mask waste is the feedstock. This still will not only contribute to the reduction of the solid waste but also to create an idea of making the used products an innovative source of materials that contributes to the lesser use of natural raw materials.

### *Objectives of the Study*

This study focuses on the production of diesel from polypropylene face masks, aiming to address key questions. Firstly, it aims to investigate how different pyrolysis temperature ranges affect the yield of pyrolytic oil. Secondly, it seeks to understand the impact of these temperature variations on both the yield and density of the diesel obtained through distillation. Lastly, the study aims to determine how the pyrolysis temperature range influences the calorific value of the extracted diesel. By exploring these factors, the research aims to contribute valuable insights into the feasibility and potential benefits of recycling polypropylene face masks into a useful energy source, such as diesel fuel.

## MATERIALS AND METHODS

***Safety Precautions and Measures.*** Safety precautions and measures were conducted before, during, and after the experimentation process. A professional in the field of fuel production assisted the researchers in the experimentation. Moreover, during the experimentation, the researchers used personal protective equipment such as laboratory gown, laboratory shoes, disposable gloves, disposable masks, and laboratory glasses.

***Sample Preparation.*** The researchers bought approximately 13 kilograms (130 boxes) of disposable face masks from UNITOP Tuguegarao City. In each trial, approximately 286 pieces (1 kg) of face masks were needed. The string and pliable metal were removed from the face masks to ensure homogeneity of the samples. The masks were also reduced to 0.5 – 1.5 cm in size for ease in feeding and melting.

***Construction of a Makeshift Pyrolysis Set-Up.*** The researchers constructed a makeshift pyrolysis set-up and installed it in outdoors. This is for precaution to possible emission of non- condensable gases. The constructed set-up installed is illustrated below.

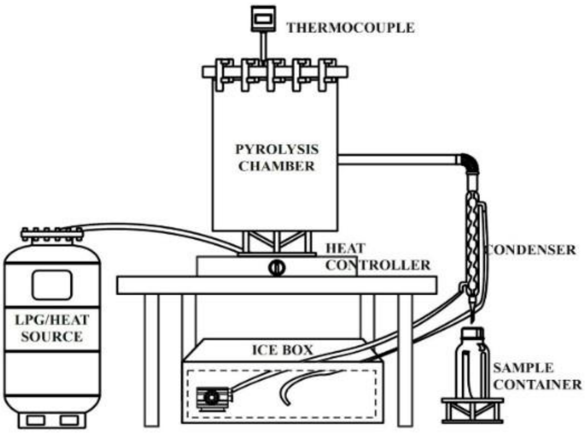


**Figure 1.** Pyrolysis Set-up Diagram

The materials used are a 21-L Stainless Steel Sealed Barrel, Condenser, K-Type Thermocouple, Gas Stove, Liquified Petroleum Gas (LPG), G-clamps, 1-L HDPE Container, Cooling Water, Cooler, Metal Stand, and Rubber Tube. The Stainless-Steel Sealed Barrel was welded with a long metal pipe as a means to connect the chamber to the condenser. The entering water was maintained at a temperature of 18°C and pumped using a water pump. LPG was used as the source of heat for the pyrolysis with a gas stove as the heat controller. The set-up was adopted from the study of (Anis, et. al. 2021).

Extraction of Pyrolytic oil using Pyrolysis. For each conduct of the experimentation, 1 kilogram of face mask underwent a pyrolysis for a controlled time of 2 hours. Three temperature treatments were conducted with three replicates each.

Extraction of Diesel from Pyrolytic oil using Fractionation Distillation. After the pyrolysis, the extracted pyrolytic oil was subjected to distillation in order to extract the diesel yield of the face masks. The set-up used is the distillation set-up of the Department of Public Works and Highways. The samples were subjected to a range of temperatures until it reached the maximum amount of fraction to boil. The temperature ranges involved in the fractional distillation were adopted from, where gasoline, kerosene, and diesel can be extracted at 30- 180°C, 180-260°C, and 260-350°C, respectively. These temperature ranges served as the temperature to extract each fraction in the treated samples. Moreover, the residual oil left inside the distillation flask after it reached the temperature 350°C was also collected.

Determining the Density and Calorific Value of Diesel. The density of the fuel fractions was calculated using their masses and volumes. The maintenance of density values within acceptable limits is crucial for achieving optimal air-to-fuel ratios, which in turn ensures complete combustion. The diesel yield was sent to the Chemical Engineering Analytical Laboratory of the University of the Philippines Diliman for the testing of its calorific value.

Disposal of Products and By-products. As the products and by-products are classified as hazardous waste, proper disposal should be only done by assigned authorities. Hence, an approval from the Tuguegarao City Municipal Environment and Natural Resources are for approval.

Data Analysis. Numerous statistical methods were employed to treat the data gathered in the study. As there are three trials per treatments, the mean amount for all data were calculated using descriptive statistics. This is followed by

**Table 1.** Process Conditions in Each Treatment

| TREATMENTS | | |
|---|---|---|
| Treatment 1 | Treatment 2 | Treatment 3 |
| Samples subjected to pyrolysis at 200-250°C | Samples subjected to pyrolysis at 250-300°C | Samples subjected to pyrolysis at 300-350°C |

## RESULTS AND DISCUSSION

In May 2023, it was announced by the World Health Organization that COVID-19 is no longer treated as a public health emergency due to the continuous lowering of the mortality rate (Rice, 2023). Regardless, there are still numerous disposable facemasks being used and marketed. These facemasks are disposed of in landfills and are left to decompose. However, the decomposition would take decades hence the growing amount of solid wastes in landfills. These disposable facemasks contain polypropylene which is a type of plastic with a calorific value. Hence, the researchers took interest in turning this type of waste into energy using the concept of Pyrolysis.

### *Pyrolysis Product Percent Yield*

The percent yield of both the pyrolytic oil and the char are calculated by dividing the average amount yield per treatment by the total amount of sample used which is one kilogram. A figure was made in order to visually present the percent yield in each treatment. Different temperature ranges were employed by the researchers in the conduct of the pyrolysis namely 200-250°C, 250-300°C, and 300-350°C. Each treatment underwent three trials for data accuracy. However, the amount of non-condensable gases was not measured during the conduct of the study due to lack of appropriate apparatus.

From the graph, it can be seen that in Treatment 1 (200-250°C), the pyrolysis was able to produce 28.39% pyrolytic oil, and 0.00% char. The cause of the lack of char production in Treatment 1 is due to the low temperature ranges set and the low reaction time. According to Spears (2018), char is a charcoal-like substance. The ones remaining in the makeshift pyrolysis chamber do not physically appear like charcoal, rather a solidified melted plastic. Hence, for Treatment 1, it is concluded that there is no char produced. This could imply that the temperature level and reaction time for treatment 1 is not enough to properly extract all the pyrolytic oil contained in the sample.

It is also worth noting that the total amount of char and pyrolytic oil is not equivalent to the initial amount of the sample. This is because there are gases that are non-condensable, hence escape during the pyrolysis. At lower temperatures, longer reaction time is needed to fully pyrolyze the sample (Basu, 2013). In Treatment 2 (250-300°C), 45.05% pyrolytic oil and 36.38% char were produced. And in Treatment 3 (300-350°C), 56.9% pyrolytic oil was derived while 34.52% char remained in the

### Comparing the Average Amount of Char Produced in Each Treatment

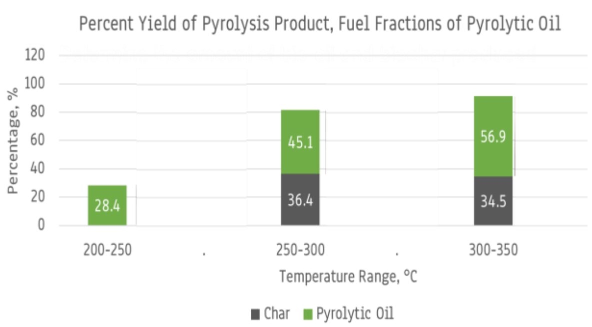


**Figure 2.** Pyrolysis Product Percent Yield

chamber. The values showed that there is an increase from Treatment 1 to Treatment 2, and a decrease in Treatment 2 to Treatment 3 in terms of char yield.

In order to determine if there is a significant difference on the average amount of char collected, One-Way Analysis of Variance (One-Way ANOVA) was applied to the means of each treatment. The results from the data treatment are shown below.

From the ANOVA table, the significance level for the mean amount of char collected in each treatment is 0.000. For a 5% significance level, the calculated significance level is lower. This means that there is a significant difference between the mean amount of char collected in

Treatments 1, 2, and 3. It can be implied that temperature has an effect to the amount of char produced in the pyrolysis of disposable facemasks. The trend of this effect will be discussed later on.

**Table 3.** One-Way ANOVA of Char Collected in Each Treatment

| | SUM OF SQUARES | DF | MEAN SQUARE | F | SIG. |
|---|---|---|---|---|---|
| Between Groups | 0.252 | 2 | 0.126 | 903.455 | 0.000 |
| Within Groups | 0.001 | 6 | 0.000 | | |
| Total | 0.253 | 8 | | | |

Certainly, here's the information presented in a table format:

| **Source** | **Sum of Squares** | **Degrees of Freedom (DF)** | **Mean Square** | **F-Value** | **Significance (SIG)** |
|---|---|---|---|---|---|
| Between Groups | 0.252 | 2 | 0.126 | 903.455 | 0.000 |
| Within Groups | 0.001 | 6 | 0.000 | | |
| Total | 0.253 | 8 | | | |

**Amount Pyrolytic oil Produced in Each Treatment**

The liquid product of the pyrolysis is the pyrolytic oil which has undergone three different temperatures, hence the treatments, and three replicates

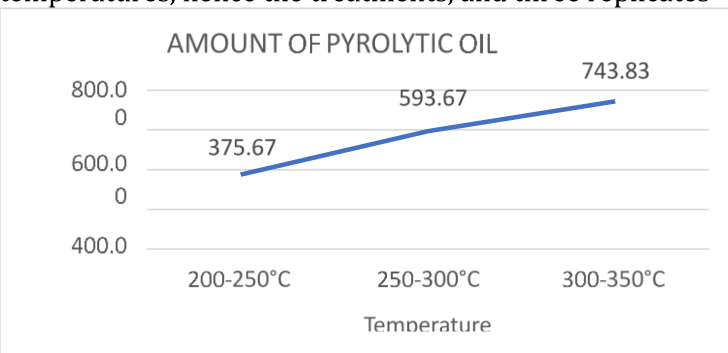


**Figure 3.** Amount of Pyrolytic oil

The figures above display the average amount (in milliliters) of pyrolytic oil produced in each treatment and their corresponding densities. From the figure, there is an increase in amount for the volume of the pyrolytic oil. One-Way ANOVA was used in order to test whether these amounts differ from each other.

**Table 3.** One-Way ANOVA of Amount of Pyrolytic oil in each Treatment.

| | | SUM OF SQUARES | DF | MEAN SQUARE | F | SIG. |
|---|---|---|---|---|---|---|
| Pyrolytic oil Extracted ($m^3$) | Between Groups | .000 | 2 | .000 | 369.047 | .000 |
| | Within Groups | .000 | 6 | .000 | | |
| | Total | .000 | 8 | | | |

The result implies that there is a significant difference between the volume of pyrolytic oil extracted under different treatment temperatures as has a value of 0.000 significance, which is lower than the significance level of 0.05 or 5%. This means that the amount of pyrolytic oil extracted is distinct.

From the study of Hariadi et al. (2021), the amount of pyrolytic oil produced increases as temperature increases. Similar study shows similar outcome by Prurapark et al. (2020) where yields in each treatment increases, which implies that higher reaction temperature results in higher amount and density. This corresponds to the result of the amount of pyrolytic oil extracted as they mirror a significant difference in the increasing temperatures of each treatment.

**Table 4.** Scheffe Post Hoc Analysis of Amount of Pyrolytic oil Collected in Each Treatment

| Dependent Variable | (I) Treatment | (J) Treatment | Mean Difference (I-J) | Std. Error | Sig. |
|---|---|---|---|---|---|
| Pyrolytic oil Extracted (L) | Treatment 1 | Treatment 2 | -0.2180000 | 0.0136279 | .000 |
| | | Treatment 3 | -0.3681667 | 0.0136279 | .000 |
| | Treatment 2 | Treatment 1 | 0.2180000 | 0.0136279 | .000 |
| | | Treatment 3 | -0.1501667 | 0.0136279 | .000 |
| | Treatment 3 | Treatment 1 | 0.3681667 | 0.0136279 | .000 |
| | | Treatment 2 | 0.1501667 | 0.0136279 | .000 |

The Table 4 reveals that in the amount of pyrolytic oil extracted, there is a significant difference between a treatment to another treatment as their results display a significance level of below 0.05 or 5%. From this, the optimal temperature for the highest yield of pyrolytic oil is at the temperature range of 300-350°C.

However, the densities of pyrolytic oil of each treatment did not undergo Post Hoc Analysis because density cannot tell the quality of a fuel because it can vary in different temperature conditions. Therefore, the optimal temperature range for the quality fuel according to its density cannot be determined.

**Table 5.** Pearson's Bivariate Correlation Between the Treatments and the Amount of Pyrolytic oil Produced.

| | | Pyrolytic oil Extracted ($m^3$) |
|---|---|---|
| Treatment | Pearson Correlation | 0.990 |
| | Sig. (2-tailed) | 0.000 |
| | N | 9 |

The amount of pyrolytic oil extracted, and the treatment has a correlation coefficient of positive 0.990 which indicates a strong correlation because it is close to +1 and perfectly positive relationship because r>0.5 on all 9 observations. The same is true to the Pearson correlation test of the density of the pyrolytic oil extracted and the treatment. The correlation coefficient is positive 0.877 which is close to +1 and is greater than 0.5. The significance level calculated for are 0.000 and 0.002 which is lesser than the set alpha level (0.05) inferring that there is a significant difference between the amounts in different treatments.

***Amount of Product and By-products in Fractional Distillation***

The Pyrolytic oil produced from the pyrolysis underwent distillation in different temperature ranges to extract the fractions present in the Pyrolytic oil. The study focused on extracting three fuel fractions namely bio-gasoline, biokerosene, and diesel. The temperatures for each fraction respectively are 30-180°C, 180-260°C, and 260-350°C (Mooro, 2015).

***Fractional Distillation Product Percent Yield***

The percent yield the fractions derived in the distillation are calculated by dividing the average amount yield per treatment by the total amount of sample used which is equivalent to the amount of pyrolytic oil per treatment. A figure was made in order to visually present the percent yield by mass in each treatment.

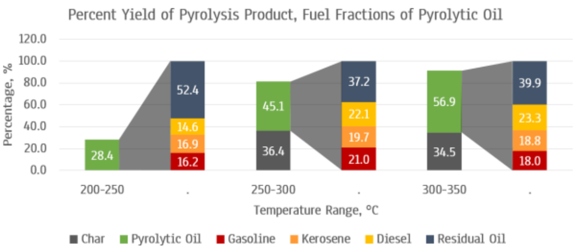


**Figure 4.** Fractional Distillation Product Percent Yield

From the graph, it can be seen that in Treatment 1 (200-250°C), the researchers were able to extract 16.17% gasoline, 16.86% kerosene, and 14.59% diesel with a residual oil of 51.73% from a 0.2839 kg pyrolytic oil. In Treatment 2 (250-300°C), the amount of gasoline, kerosene, diesel, and residual oil are 20.96%, 19.72%, 22.12%, and 37.20% from a 0.4505 kg pyrolytic oil. And in Treatment 3 (300-350°C), the distillation of 0.569 kg pyrolytic oil resulted to 18.01% gasoline, 18.80% kerosene, 23.32% diesel, and a residual oil of 39.87%. Further analysis on these fractions is detailed as the means of the mass are subjected to One-Way Analysis of Variance (ANOVA) to determine if there is a significant difference in the amount of fractions extracted among the treatments.

Table 6 shows that at a significance level of 0.05, the calculated significance value of each fraction falls below the alpha level indicating that there is a significance difference in the amount of each fraction produced in each treatment. This implies that temperature by which the pyrolytic oil was produced has an effect to the amount of fuel fractions extracted during distillation. Similar results can be seen diesel yield in Avila, et. Al. (2022), as an increase in temperature yield larger amounts of fractions. In a study conducted by O. C. Nwufo about the effect of temperature on the diesel yield of various vegetable oils, it showed that there is a direct relationship between the temperature and the diesel yield. This can be implied in the above data that there is a relationship between the treatments' temperature and the extracted.

In table 7, comparing Treatments 1 and 2, it obtains a calculated significant value of 0.020 for extracted diesel. The result of the analysis indicates that Treatment 2 yielded a significantly higher amount of extracted diesel compared to Treatment 1, with a difference of 0.05823 liters. This suggests that utilizing a temperature range of 250 to 300 °C may result in a greater yield of extracted diesel. However, the amount produced in Treatment 2 is comparable to that of Treatment 3, as the increase between Treatments 2 and 3 is only 0.03300 liters. As a result, the optimal temperature has already been determined at 250 to 300 °C.

**Comparing the Means of the Fractions in Each Treatment**

**Table 6**. One-Way ANOVA of Amount of Fractions Extracted from the Distillation Process

| | | SUM SQUARES | OFDF | MEAN SQUARE | F | SIG. |
|---|---|---|---|---|---|---|
| Gasoline Extracted | Between Groups | 0.006 | 2 | 0.003 | 49.385 | 0.000 |
| | Within Groups | 0.000 | 6 | 0.000 | | |
| | Total | 0.006 | 8 | | | |
| Kerosene Extracted | Between Groups | 0.006 | 2 | 0.003 | 1143.493 | 0.000 |
| | Within Groups | 0.000 | 6 | 0.000 | | |
| | Total | 0.006 | 8 | | | |
| Diesel Extracted | Between Groups | 0.013 | 2 | 0.006 | 20.386 | 0.002 |
| | Within Groups | 0.002 | 6 | 0.000 | | |
| | Total | 0.015 | 8 | | | |
| Residual Oil | Between Groups | 0.010 | 2 | 0.005 | 13.010 | 0.007 |
| | Within Groups | 0.002 | 6 | 0.000 | | |
| | Total | 0.012 | 8 | | | |

**Table 7**. Scheffe Post Hoc Analysis of the Amount of Fuel Fractions in Each Treatment

| (I) TREATMENT | | (J) TREATMENT | MEAN DIFFERENCE (I-J) | SIG. |
|---|---|---|---|---|
| Diesel | Treatment 1 | Treatment 2 | -0.05823 | 0.020 |
| | | Treatment 3 | -0.09123 | 0.002 |
| | Treatment 2 | Treatment 1 | 0.05823 | 0.020 |
| | | Treatment 3 | -0.03300 | 0.154 |
| | Treatment 3 | Treatment 1 | 0.09123 | 0.002 |
| | | Treatment 2 | 0.03300 | 0.154 |

**Table 8.** Pearson's Bivariate Correlation Between the Treatments and the Amount of Diesel Extracted

| | | Treatment | Diesel Extracted (kg) |
|---|---|---|---|
| Treatment | Pearson Correlation | 1.000 | 0.922 |
| | Sig. (2-tailed) | | 0.000 |
| | N | 9 | 9 |

Table 8 presents the data calculated using Pearson's Bivariate Correlation between the Treatments and the Diesel produced. A Pearson correlation of 0.922 with a significant value of 0.000 was calculated using the analysis tool, which is lower than the 0.05 level of significance. It can be implied that the variations of the temperatures used each treatment made a significant difference in the production of diesel, allowing the researchers to reject the null hypothesis. In addition, as the Pearson Correlation appear to be a positive slope in the trendline, it can also be interpreted as such that the temperature and the yield of diesel has a direct relationship with each other. It was cited in a study conducted by L. Kalsum, et. al. (2019) that an increase in temperature makes higher percentage yield of diesel. This is due to faster movements of molecules inside the system, increasing its rate of reaction. This can be implied similarly to the data above. As the temperature rises, the percentage of diesel yield will increase as well.

***Densities of Fuel Fractions***

Density plays a vital role in determining the energy content, storage capacity, transportation efficiency, practicality, infrastructure compatibility, and safety considerations associated with liquid fuels. The density was calculated and measured at 21°C. The density calculated in each trial are summarized below:

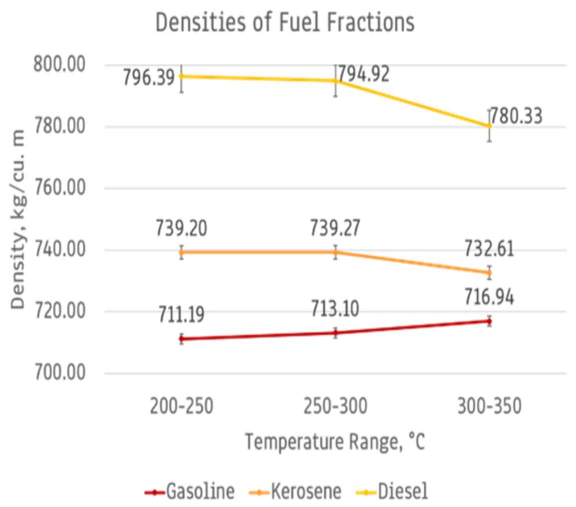


**Figure 5.** Average Densities of Each Fractions in Each Treatment

It can be seen that diesel has the highest amount of density and the least is gasoline. Based on Van der Waals force of attraction, increasing the number of carbon atoms allows the molecules to occupy less volume while its mass increases. Hence, the density increases with the number of carbon atoms. Gasoline has the least number of atoms ranging from 6-12, while Kerosene has 10-14 carbon atoms. Lastly, Diesel has 14-19 carbon atoms (Prurapark, et. Al., 2020). This value was corrected by calculating the density of this diesel at the temperature of 15°C. The following formula was used:

$$\rho 1T1 = \rho 2T2$$

$$P2 = \frac{\rho 1T1}{T2}$$

Where ρ1 is the experimental density, ρ2 is the corrected density, T1 is the temperature by which the experimental density was measured at °K, and T2 is the desired temperature at °K.

This yields an amount of 811.47 kg/m3. The fuel of the Shell Company in the Philippines are mostly imports from their manufacturer in Bangkok, Thailand. One of these fuel being imported is the Shell FuelSave Diesel B7. This has a density of 810 – 870 kg/m3 at 15°C. The corrected density of the extracted diesel falls within this range. This could mean that we could reasonably assume that since this is being marketed in the Philippines, then the extracted diesel from the polypropylene face masks can also be accepted for commercial use having met the density requirements of the marketed diesel.

From table 7, the density of gasoline has a significant difference among the treatments given implying that density is affected by the temperature range of the pyrolysis. Similar implications are given to kerosene and diesel. Temperature affects the movement of molecules making them move faster, collide, and spread apart. This occurrence allows them to take up more space hence a decrease in density (University of California Museum of Paleontology, n.d.)

### Comparing the Mean Density of the Fractions in Each Treatment

**Table 7.** One-Way ANOVA of Amount of Fractions Extracted from the Distillation Process

| | | SUM OF SQUARES | DF | MEAN SQUARE | F | SIG. |
|---|---|---|---|---|---|---|
| Gasoline Extracted | Between Groups | 51.507 | 2 | 25.753 | 13.589 | 0.006 |
| | Within Groups | 11.371 | 6 | 1.895 | | |
| | Total | 62.878 | 8 | | | |
| Kerosene Extracted | Between Groups | 87.798 | 2 | 43.899 | 11.923 | 0.008 |
| | Within Groups | 22.091 | 6 | 3.682 | | |
| | Total | 109.889 | 8 | | | |
| Diesel Extracted | Between Groups | 472.939 | 2 | 236.469 | 50.532 | 0.000 |
| | Within Groups | 28.077 | 6 | 4.680 | | |
| | Total | 501.016 | 8 | | | |

**Table 8.** Pearson's Bivariate Correlation Between the Treatments and the Density of Diesel Extracted

| | | Diesel Density (kg) |
|---|---|---|
| Treatment | Pearson Correlation | -0.879 |
| | Sig. (2-tailed) | 0.002 |
| | N | 9 |

Diesel showed a similar relationship to temperature along with Kerosene. It was mentioned in a study conducted by Luqman Razza, et. al. (2020) that the temperature plays a huge factor influencing the density of a diesel. Their study on Modeling Viscosity and Density of Ethanol- Diesel- Diesel Ternary Blends for Sustainable Environment showed that the density of their sample diesel decrease as their temperature increases from 15 °C to 105 °C. This just further supports the previous discussion that there is a significant relationship between the densities of Diesel and the temperature variations.

### Calorific Value of Diesel Produced

The calorific value of a fuel is a measure of the energy content it possesses. It refers to the amount of heat energy released when a specific quantity of fuel is completely burned. This also indicates the quality of the fuel produced (Siddiqua, et. Al., 2015). European (EU 14214) standard calorific value is 35 MJ/kg, while the United States (ASTM D6751) did not give any standards. Currently, the study of Li et. Al (2022) involving catalytic pyrolysis of face mask holds the highest calorific value for diesel produced from face masks amounting to 43.5 MJ/kg. The diesel extracted from the distillation process was tested by the UP Chemical Engineering Analytical Laboratory using a 6220 EF Isoperibol Calorimeter.

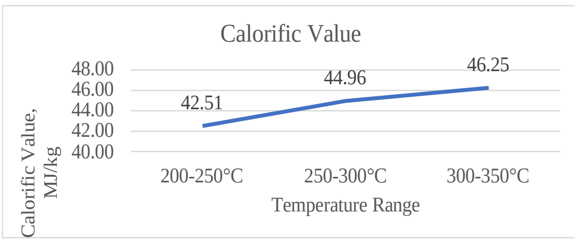


**Figure 6.** Calorific Value of Diesel in Each Treatment

The mean calorific value shows that there is a difference in their value per treatment hinting on the possibility of temperature affecting the calorific value. The calorific value of this study ranges from 42.51 to 46.25 MJ/kg. This implies that it is possible to produce diesel of almost similarly high quality without the addition of another feed, catalyst, or equipment to aid in the production in contrast to the study of Li et. Al., (2022). The conduct of their study involved soaking the masks in distilled water, drying, and cutting before undergoing pyrolysis. This feedstock preparation may have brought an effect to the physicochemical properties of the face masks. In contrast, the conduct of the study only involved size reduction before pyrolysis.

**Table 9.** One-Way ANOVA of the Calorific Value of Diesel in each Treatment.

| Sum of Squares | | | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Calorific (MJ/kg) | ValueBetween Groups | 21.635 | 2 | 10.817 | 11.073 | .010 |
| | Within Groups | 5.862 | 6 | 0.977 | | |
| | Total | 27.469 | 8 | | | |

As stated earlier, to determine whether the difference of the calorific value between the treatments are significant, One-Way ANOVA was used with a significance level of 0.05. The calculated significance, 0.10, falls below this significance level indicating that the difference between each treatment's calorific value is significant.

**Table 10.** Scheffe Post Hoc Analysis of Calorific Value in Each Treatment

| (I) TREATMENT | (J) TREATMENT | MEAN DIFFERENCE (I-J) | SIG. |
|---|---|---|---|
| :atment 1 | Treatment 2 | -2.44241 | .062 |
| | Treatment 3 | -3.73980 | .010 |
| :atment 2 | Treatment 1 | 2.44241 | .062 |
| | Treatment 3 | -1.29738 | .341 |
| :atment 3 | Treatment 1 | 3.73980 | .010 |
| | Treatment 2 | 1.29738 | .341 |

From the table above, Treatment 1 is lower than Treatment 2 by -2.44241 MJ/kg. This difference is not significant as the calculated significance is higher than the set alpha level (0.05). Treatment 1 also has a lower calorific value than Treatment 3 by -3.73980 MJ/kg. This difference is deemed significant. Treatment 3 has a nonsignificant difference of 1.29738 MJ/kg with Treatment 2. This would mean that even at 200-250°C, a high calorific value is already attained. This shows that all treatments produced a comparable calorific value. Hence, the optimal temperature based on this analysis is 200-250°C. As all the calorific value exceeded the EN standard, the optimal temperature must be traced back on the optimal temperature of the diesel yield because the focus of this study is to see which could help sustain the energy demand of the Philippines. Hence, the optimal temperature for calorific value of diesel is 250- 300°C. As the calorific value is affected by the pyrolysis temperature (Thahir, et. Al, 2018), this could imply that significant changes only occur between pyrolysis temperatures with more than 100°C difference.

**Table 11.** Pearson's Bivariate Correlation Between the Treatments and the Calorific Value of the Diesel Produced.

| | | Calorific Value |
|---|---|---|
| Treatment | Pearson Correlation | 0.873 |
| | Sig. (2-tailed) | 0.002 |
| | N | 9 |

The Pearson's Bivariate Correlation further expands the trend of the differences between each treatment. From the result, a Pearson correlation of 0.873 was calculated. This indicates that the relationship between the temperature ranges and the calorific value is strongly positive (Corpuz, 2022). This implies that as the pyrolysis temperature increases, the calorific value also increases. Similar results were showed in the study of Li, et. Al, and Park, et. Al. However, this trend stops once the pyrolysis reaches an optimal temperature (Park, et. Al, 2021). At some point, the calorific value decreases with increasing temperature. In the case of this study, the optimal temperature range have not been reached as the temperatures of the treatments used were the lowest temperatures for pyrolysis to be conducted.

## CONCLUSION

The demand for fuel energy, particularly transportation fuels, is continuously growing due to global population growth, industrialization, and increased mobility. As the demand for fuel rises, the need to find alternative sources of energy becomes more pressing. By converting plastic waste into fuel, it is possible to utilize this abundant waste stream as a valuable resource. Although various studies have explored the recycling and upcycling of plastic waste, limited research has focused specifically on the conversion of polypropylene face masks into diesel. The study has proven that in terms in amount, density, and calorific value, polypropylene face masks could be used as one of the alternative sources for liquid fuel. At the optimal temperature of 250-300°C, the amount of pyrolytic oil produced from one (1) kilogram of face mask is 593.67 mL. From this 593.67 mL, 125.33 mL of diesel was derived with 811.47 kg/m3 and a calorific value of 44.96 MJ/kg. By-products such as gasoline, kerosene, and residual oil was also produced. The amount of gasoline yield is 132.45 mL, kerosene yield is 120.67 mL, and residual oil yield is 215.71 mL. By investing in its production and development, the researchers believe that once this is implemented, it can help not only in the reduction of face mask wastes accumulated, but also the reduction of greenhouse gas emissions from the decomposition of these wastes. More importantly, this could serve as a stepping-stone for the addition of plastic wastes as a viable energy source in the Philippine energy mix.

## RECOMMENDATIONS

To properly address the UN Sustainable Development Goals, the following actions are recommended in response to the findings of the study.

In terms of research:

1. Conduct a full analysis on the physicochemical properties of the extracted diesel in order to determine its performance characteristics.
2. Conduct an experiment to the production and properties of extracted diesel from a mixture of different types of face masks.
3. Conduct similar experiment with the addition of disinfection for used face masks.
4. Conduct similar experiment with the optimal temperature at varying reaction time.
5. Conduct a market analysis on the production and sale of diesel derived from polypropylene face masks.

In terms of policies and programs:

1. Strict implementation on the segregation of face mask wastes from other wastes.
2. Construct TSD Facilities for the storage, disinfection, and treatment of face mask wastes.

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