Catalytic pyrolysis of waste oil into hydrocarbon fuel utilizing cerium oxide catalyst

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Abstract−The depletion of fossil fuels has prompted research into alternative fuels made from regeneration of waste materials. Pyrolysis is a method of converting waste oil into valuable products, such as char, gas, and fuel. This study presents the catalytic pyrolysis of waste oil for producing fuel utilizing cerium oxide, CeO_2/Al_2O_3 and zinc oxide, ZnO/Al_2O_3 catalyst. The catalyst and oil were characterized using several characterization techniques to find the physicochemical properties of the catalyst and oil. The optimum condition for catalytic pyrolysis was a reaction temperature at 500 °C, with the heating rate at 10 °C/min, utilizing CeO_2/Al_2O_3 catalyst calcined at 700 °C. The catalytic pyrolysis successfully converted the waste oil into fuel and the oil product obtained was 93.01 wt% with a high calorific value (54.2 MJ/kg). The pyrolysis oil is comprised of aliphatic hydrocarbon (C_5-C_{15} hydrocarbon) that is within the hydrocarbon range for gasoline and diesel. The oil product was also detected to have a low content of oxygen (3.07 wt%) and sulfur (0.60 wt%), indicating its potential to serve as a cleaner, fuel reducing the sulfur dioxide, SO_X formation. The results reveal that pyrolysis reactors have the ability to convert waste oil into hydrocarbon fuel.

Keywords: Waste Lubricant Oil, Fuel, Catalyst, Pyrolysis, Pyrolysis Reactor

INTRODUCTION

Over the past few years, million tons of waste oil have been disposed, becoming one of the most crucial concerns as the waste oil is toxic and hazardous to people and environment if the oil is not handled properly. The use of lubricant oil is important as it helps to maintain good engine performance, avoid increase of wear, overheating, and seizure of rubbing surface and preventing corrosion to engine components [1]. Waste lubricant oil comprises constituents such as polycyclic aromatic hydrocarbon (PAH), metallic, degraded additives, soot and sulfur that are harmful to the human health and environment [2]. Therefore, the recycling and reuse of waste oil has received special attention in the past few years. Recycling and reuse of the waste oil would decrease the consumption of the petroleum-based fuels and also decrease toxic and hazardous chemical production. There are many methods of conversion of waste lubricant oils in practice, for example, the acid/clay refinery process and solvent extraction/distillation process. The most common method used is the pyrolysis reaction. Pyrolysis has lately emerged as an alternative for converting waste oils into potentially chemical feedstocks and valuable fuels [3]. This process breaks up large molecule hydrocarbon chains ($>C_{50}$) of waste lubricant oil and allows to obtain diesel [4]. Pyrolysis is a technique for thermal decomposition of materials within inert atmosphere at higher temperature, which result is that the oil is thermally cracked into shorter hydrocarbon chains (C_1-C_{12}) in the form of solid char, gases, and hydrocarbon liquid products [5]. Pyrolysis reaction has its own unique characteristics and cracking mechanism that is suitable in conversion of waste lubricant oil as the process is aimed to ensure the optimal product yield, limiting the chemical used and waste volume produced [6]. From the economic and ecological disposal method perspective, pyrolysis is favorable as the process is very environmentally friendly. As many approaches have been taken to convert waste lubricant into fuel, pyrolysis is considered as a sustainable way to generate energy from waste. Pyrolysis performance can be promoted when combined with an appropriate catalyst. In addition, Aburas et al. [7] reported that sulfur content in the waste lubricant oil was decreased in the presence of catalyst. The application of catalyst in the pyrolysis reaction leads to a supplemental improvement in the pyrolysis oil product quality as reported by Zouad et al. [8]. Thus, pyrolysis of waste lubricant oil in the presence of catalysts would produce a promising result. Metal oxide catalysts such as CeO_2 and ZnO catalysts have been successful in reducing oxygenated compounds such as acids, sugars, and phenols [9]. Accord-

ing to Babich et al. [10], the presence of metal oxide catalysts reduces the temperature required to break down the biomass and lower the acidity of the bio oil. Pyrolysis over CeO_2 catalysts resulted in bio-oil containing low oxygen content, 6.78%. Besides, cerium oxide has been tested for catalytic pyrolysis because it presents significant oxidative properties which can favor decarboxylation reaction [11]. Khalil et al. [12] suggested that Ce could reduce the coke deposition during pyrolysis reaction and the product composition of pyrolysis depends on the catalyst properties, such as stability, pore size and structural properties of catalyst. To date, only a few researchers have investigated cerium and zinc oxide as base catalyst towards catalytic pyrolysis of waste lubricant oil even though they provided good catalytic activity. Moreover, cerium and zinc metal are preferred over noble metals because of high availability and low cost. Besides, up to our knowledge, there is no reported study using alumina supported CeO and ZnO catalyst for catalytic pyrolysis of waste lubricant oil. Since waste oil is a non-renewable natural resource, which is also considered as waste, the regeneration of this waste for further use in the production of hydrocarbon fuel this promote sustainable consumption and production patterns, which is line with SDG 12. Waste oil was transformed into hydrocarbon fuel using slow pyrolysis method due to the promising finding from the cracking mechanism during pyrolysis. In this study, cerium oxide was used since base catalyst was reported that might enhance the deoxygenation activity. Therefore, this research focuses on studying the performance of Ce and Zn catalyst in pyrolysis reaction and optimizing the pyrolysis condition to obtain a potentially useful oil product. The physiochemical properties of the catalyst and oil were also studied and discussed to evaluate the potential for use as fuel.

EXPERIMENTAL

1. Catalyst Preparation

The catalyst Ce/Al_2O_3 was synthesized using wet impregnation method. 0.5 g based cerium(iii) nitrate hexahydrate ($Ce(NO_3)_3 \cdot 6H_2O$) was dissolved in 10ml of distilled water. 5.0 g of alumina beads (Al_2O_3) was weighted and dipped into the base solution

within 1 hour and coated for three (3) times. After that, the catalyst was aged in oven at temperature of 90 °C for 24 hours. Then the catalyst was calcined at 700 °C and 800 °C for 5 hours with ramp rate 5 °C/min. The procedure was repeated by using zinc (ii) nitrate hexahydrate ($Zn(NO_3)_2 \cdot 6H_2O$) as a base.

2. Sample Preparation

The waste lubricant oil obtained from industry was sampled as a source in production of pyrolytic fuel. Before the pyrolysis, the waste lubricant oil was filtered using filter paper to remove large solids. After the layers of impurities formed, this layer was removed using dropper and separated from the 'clear' waste lubricant oil.

3. Characterization

The surface area evaluation of the catalyst was determined using Micromeritics Surface Area and Porosity Analyser (ASAP 2020, United Kingdom) to characterize their porous structure and to determine their surface area. The structure of catalyst was also analyzed using X-Ray diffraction (XRD). The pyrolytic oil was analyzed with thermogravimetric analysis (TGA), Fourier transform infrared (FTIR) and elemental analyzer (CHNS). The calorific meter and viscosity meter were also used to study on the physical and chemical properties of the waste lubricant oil and pyrolysis oil.

4. Pyrolysis Setup

The pyrolysis setup of the bench-scale fix bed reactor as shown in Fig. 1 below consists of three main parts: sample holder (pyrolyzer), furnace and condensing system. Nitrogen gas were supplied during experimentation to maintain an inert atmosphere in the pyrolyzer. The pyrolyzer was connected to the condenser system (Liebig condenser), which aided in cooling of the gas product. Gaseous product connected through the hose will let to flow in the fume hood.

Experiment was conducted using 50 g of filtered waste lubricant oil mixed with 2.5 g of the catalyst. The mixture was transferred into the pyrolyzer after being stirred with magnetic stirrer for 45 min. The pyrolyzer then was placed inside the furnace. The air presence in the pyrolyzer was removed by passing through the nitrogen gas at flowrate of 1 L/min for 15 min. The operating temperature was altered in range of 400 °C to 600 °C with heating rate varied from 8 °C/min to 15 °C/min. After the condensation of the pyro-
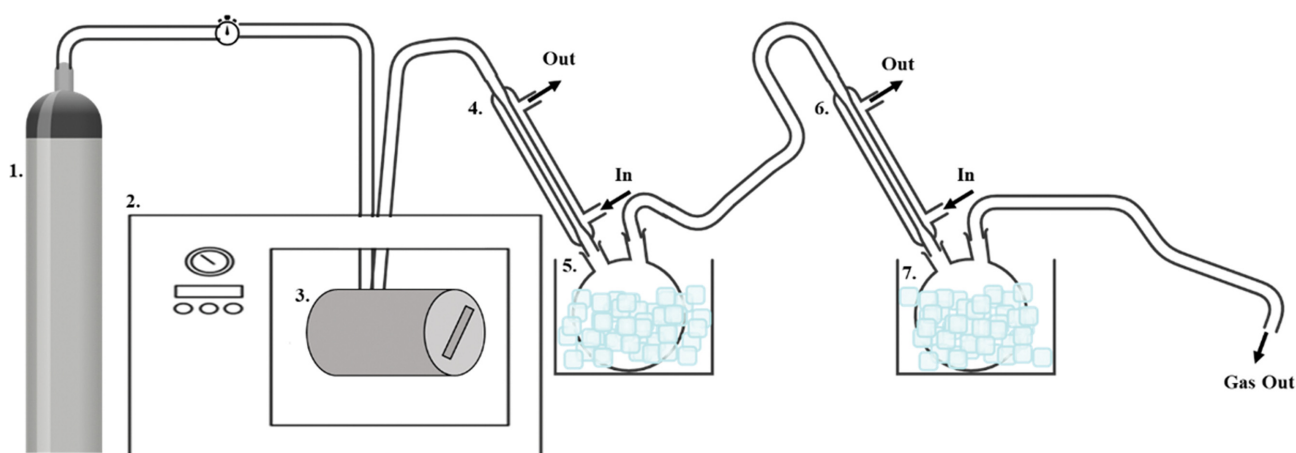

Fig. 1. Slow pyrolysis setup diagram.
　　1. Nitrogen gas　　　　2. Furnace　　　　3. Pyrolyzer　　　　4. & 6. Liebig condenser　　　　5. & 7. Round bottom flask (2-neck)

lytic product, the apparatus used was weighed to measure the total weight of liquid products. Data presentation of the product was then calculated based on the weight of the product in weight percentage using the formula as below.

$$\text{Weight percent (wt\%)} = \frac{\text{Total weight of product (g)}}{\text{Weight of waste oil use (g)}} \times 100$$

5. Statistical Analysis

ANOVA analyzes two or more groups at the same time to see if there is any relationship between the groups in the dataset. In the Input Range, type the upper left and lower right corner cells of data e.g. B2:C7. For the Labels, in the first row of sheet, put Label of output with the name 'Terminal Temperature and Pyrolysis Oil'. On the Output location, type in the cell address of the upper left corner of where you want to place the output in the current sheet. Meanwhile, regression analysis is a set of statistical techniques used to estimate the relationship between a dependent variable and one or more independent variables.

RESULTS AND DISCUSSION

1. Characterization

The characteristics of waste lubricant oil and pyrolysis oil are shown in Table 1. The waste lubricant oil and pyrolysis oil underwent GC-MS analysis, and it was found that waste lubricant oil was primarily comprised of C_1-C_{30} of aliphatic hydrocarbons (65.27%) and aromatic hydrocarbon (20.76%). This result was then compared to pyrolysis oil, which was comprised of C_1-C_{15} of aliphatic hydrocarbons (78.54%) and aromatic hydrocarbon (9.76%). The result shows that the presence of long chain hydrocarbons has been converted into light hydrocarbons and could be potentially used as a fuel.

Pyrolysis of waste lubricant oil was studied through a thermo-

Table 1. Characteristics of waste lubricant oil and pyrolysis oil

Properties	Waste lubricant oil (%)
Before treatment	
Alkane	59.55
Alkene	0.47
Cycloalkane	1.79
Polycyclic aromatic hydrocarbons (PAH)	20.76
C_1-C_{10}	11.78
C_{11}-C_{15}	31.33
C_{16}-C_{20}	19.81
C_{21}-C_{30}	2.35
C_{30}>	0.73

	Pyrolysis oil (%)
Alkane	41.34
Alkene	27.87
Cycloalkane	20.06
Polycyclic aromatic hydrocarbons (PAH)	9.76
C_1-C_{10}	37.20
C_{11}-C_{15}	41.34
C_{16}-C_{20}	10.15
C_{21}-C_{30}	2.22

gravimetric and derivative thermogravimetry analysis in nitrogen atmosphere and was conducted at a terminal temperature ranging from 30 °C to 600 °C with heating rate of 20 °C/min. TG and DTG curves present similar shapes but occurring at very different temperature ranges. The mass loss in both cases can be attributed to distillation during the pyrolysis reaction. In Fig. 2, it can be observed that as temperature increased, the partial pressure was also increased, which accelerated the vaporization of lighter com-
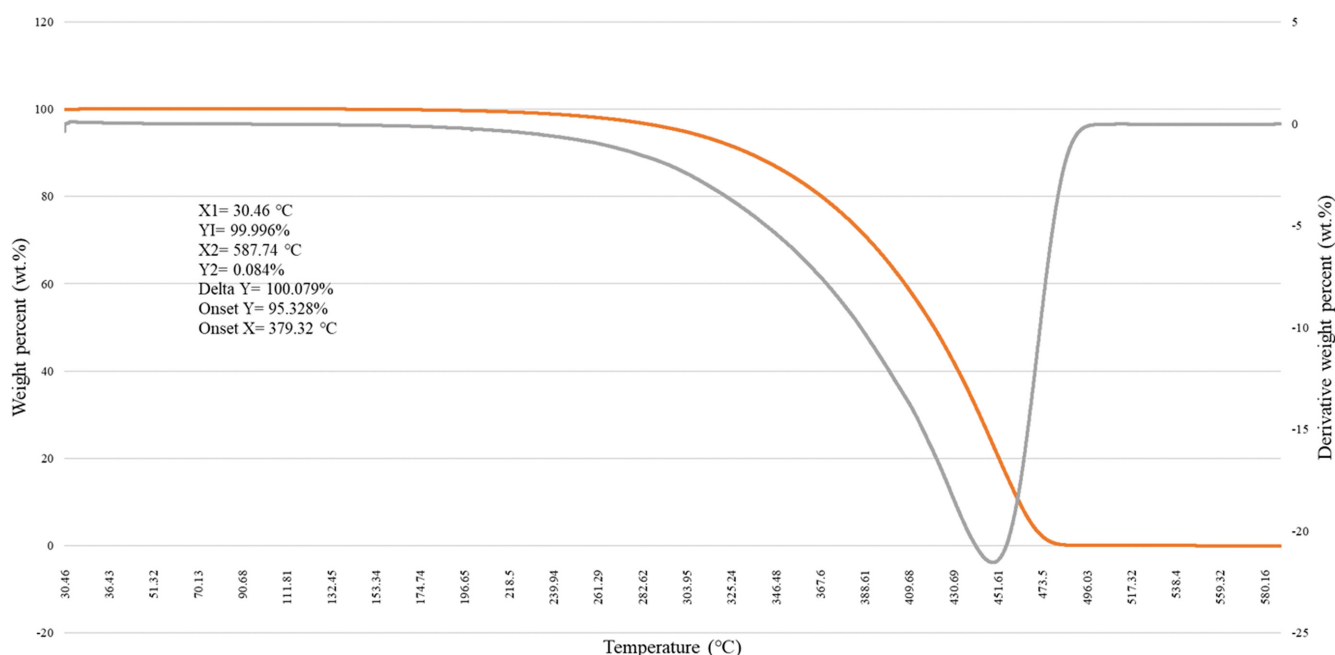

X1= 30.46 °C
YI= 99.996%
X2= 587.74 °C
Y2= 0.084%
Delta Y= 100.079%
Onset Y= 95.328%
Onset X= 379.32 °C

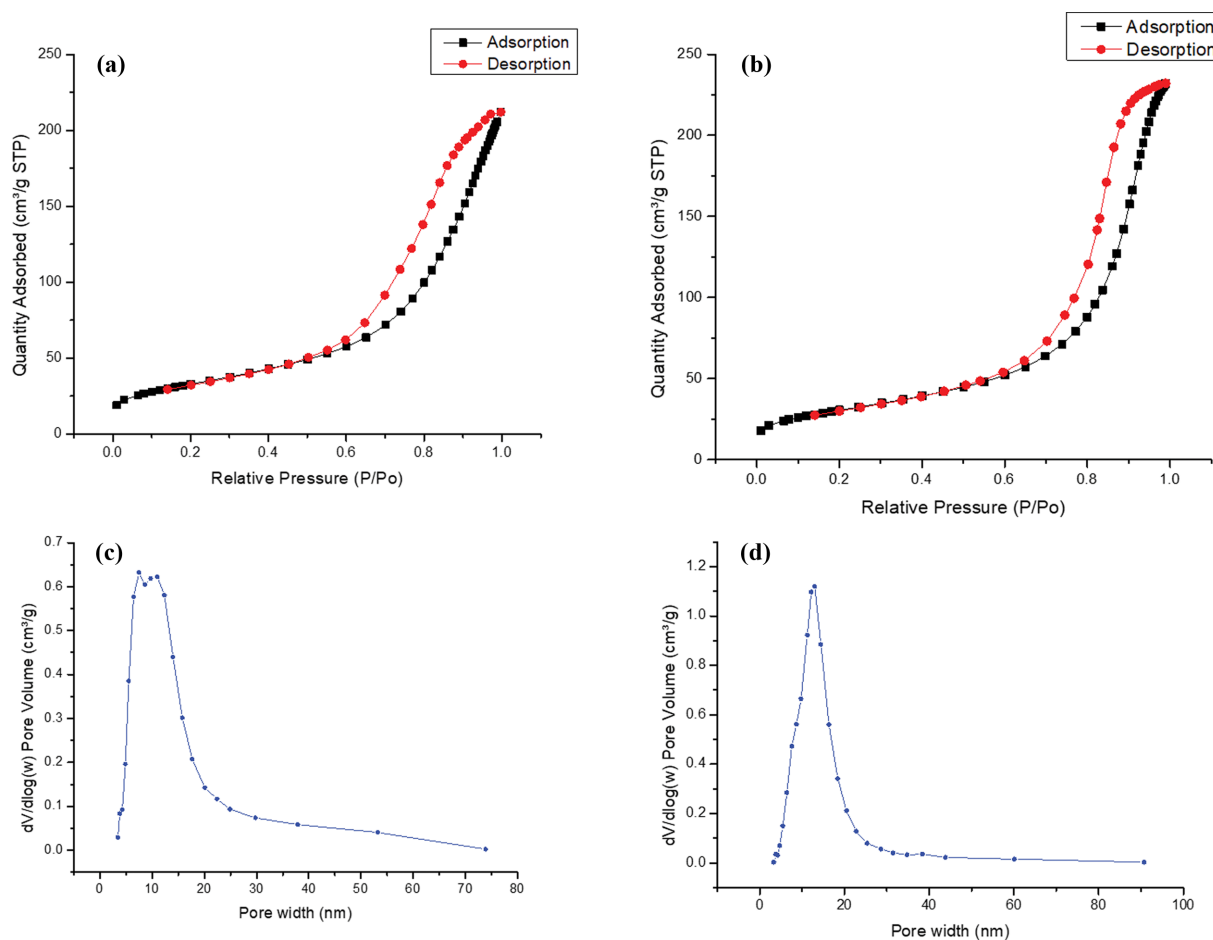**Fig. 2. TG-DTG curve for pyrolysis of waste lubricant oil.**

Fig. 3. Isotherm curves of (a) Ce700 catalyst and (b) Ce800 catalyst and pore size distribution graph of (c) Ce700 catalyst and (d) Ce800 catalyst.

ponents of the waste lubricant oil. The sample was completely stable at 587 °C with a residual weight of 0.084%. The initial weight loss for the waste lubricant oil was 0.004% at 30.5 °C. Also, it was noticed that the second weight loss related to the main devolatilization of carbon and hydrogen compounds was released at 379 °C with the weight reduction of 4.672% waste lubricant oil.

Fig. 3(a) and (b) show the nitrogen adsorption/desorption isotherm curves for the cerium catalyst that was calcined at 700 and 800 °C. The BET surface area (S_{BET}) results in Table 2 show that catalyst Ce700 has higher S_{BET} (112.61 m^2/g) than Ce800 (104.65 m^2/g). Higher calcination temperature causes particles to sinter together, resulting in agglomeration, leading to smaller surface area [13]. From the results of the BET analysis, we could infer that the high reactivity of cerium oxide on promoting the conversion of waste lubricant oil might be attributed to its high surface area. Both catalysts exhibited isotherm Type IV with H3 hysteresis loops, indicating the presence of mesoporous materials. Based on Table 2, the increasing of pore size as the calcination temperature increases, implying that the pores expand as the calcination temperatures increase [14].
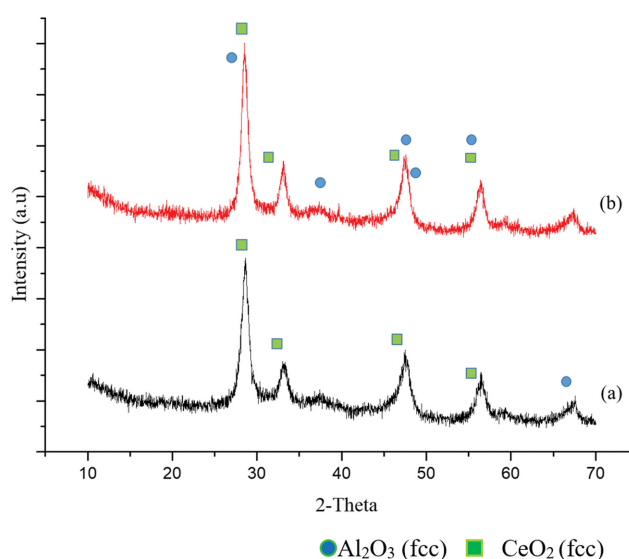

Fig. 4. XRD diffractograms of Ce/Al$_2$O$_3$ with different calcination temperatures of (a) 700 °C, and (b) 800 °C for 5 hours.

Table 2. Pore characteristic of catalyst used in pyrolysis reaction

Catalyst	Ce700	Ce800
BET surface area (m^2/g)	112.61	104.65
Pore volume (cm^3/g)	0.31	0.36
Average pore size (nm)	11.15	13.59

Fig. 5. Effect of reactor bed temperature on the product yield (weight percent).

Fig. 6. Variation of heating rate towards the product yield formed (weight percent).

Comparing the data, Ce800 has larger pore size than the Ce700 catalyst.

As shown in the Fig. 4, all the peaks could be indexed to the cubic phase of ceria with fluorite structure and the cubic phase of alumina. Two discernible peaks at $2\theta=28.61^{\circ}$ (I_{100}) and 67.53° ($I_{9.4}$) appeared at calcination temperature a of 700 $^{\circ}$C, which were attributed to CeO_2 (fcc) and Al_2O_3 (fcc). The degree of crystallinity of the Ce/Al_2O_3 catalyst enhanced as the calcination temperature of the catalyst increased. This occurred because the calcination temperature caused the crystal lattice to rearrange, resulting in the narrow and sharp peaks attributed to the crystalline phase.

2. Effect of Reactor Bed Temperature

Pyrolysis reaction of waste lubricant oil was performed at various terminal temperatures as shown in Fig. 5. The liquid fraction varied between 42.70 wt% and 93.10 wt%, while the highest product was 93.1 wt% at terminal temperature of 500 $^{\circ}$C. The pyrolysis reaction was conducted at constant heating rate and flow rate of nitrogen gas, 10 $^{\circ}$C/min and 1 L/min, respectively. When the pyrolysis reactor was heated above 350 $^{\circ}$C, the conversion of waste lubricating oil into pyrolysis oil began to occur, yielding about 40% wt. pyrolysis oil, with the remaining products consisting of non-condensable pyrolysis solid residue and gases. This was proved in the TGA-DTG (Fig. 2) results, which the vaporization starts at 30.46 $^{\circ}$C and the major volatilization of waste lubricant oil occurs at 379.32. The residue obtained was mostly of char with no presence of residual waste oil when the pyrolysis was performed at higher terminal temperatures ($\geq$450 $^{\circ}$C). The solid residues showed a harder texture, smaller size, and darker color. It was also noticed that the waste lubricant oil conversion generated very low proportion of solid residue as compared to liquid and gaseous fractions. Solid residue varied between 0.1 wt% to 0.5 wt% while the gaseous fractions varied between 1.79 wt% to 56.8 wt%.

3. Effect of Heating Rate

The variation in heating rate with respect to weight percent for a pyrolysis reaction with constant temperature, 500 $^{\circ}$C, is depicted in Fig. 6. A maximum heating rate of 15 $^{\circ}$C/min was observed at the starting stage for pyrolysis reaction. Heating rate remained constant along the pyrolysis reaction occurring. The time duration for reaching the terminal temperature varied depending on the heating rate applied. The longest time taken for the pyrolysis reaction to achieve its terminal temperature (500 $^{\circ}$C) was 63 min with heat-
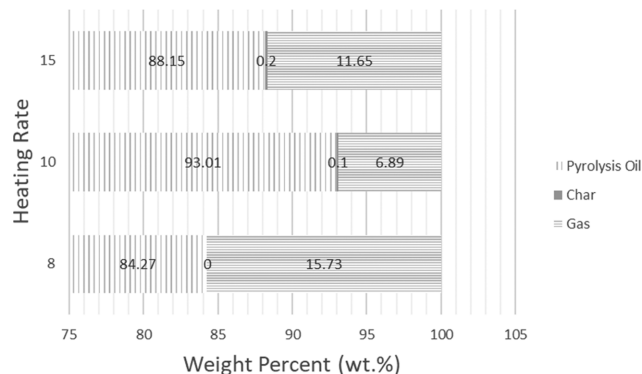
ing rate of 8 $^{\circ}$C/min. For reaction with heating rate of 10 and 15, $^{\circ}$C/min, the time taken for the reaction to achieve the terminal temperature was 50 min and 34 min, respectively. Low viscosity pyrolysis fuel and greater non-condensable products emerge from a lower heating rate in the pyrolysis reaction [15]. This is because the C-C bond fission may create a radical between substituted carbons due to the prolonged residence period. The early-stage of the pyrolysis reaction resulted in the formation of white volatile gases which occurred at around 300 $^{\circ}$C to 400 $^{\circ}$C, due to the incomplete cracking of molecules. Comparing the pyrolysis reaction, the reaction with heating rate of 10 $^{\circ}$C/min obtained a higher amount of low viscous pyrolysis fuel, that is, 93.01 wt% with low char residue (0.1 wt%) and gaseous (6.89 wt%) produced. The lower residence time reduced the production of short-chain hydrocarbons [15].

4. Catalyst Effect on Pyrolysis Oil Properties

The effect of catalyst used on waste oil conversion through the pyrolysis reaction is demonstrated in Fig. 7. The study showed that the waste oils were thermally cracked to pyrolysis oil (85-91 wt%) and char product which is normally much less. The yield of pyrolysis oil was higher while the gaseous produce was lower in the presence of cerium catalyst compared to zinc catalyst. It was found that the catalyst does not give significant effect to the yield of the pyrolysis oil but affects the properties of the pyrolysis oil. The catalyst in
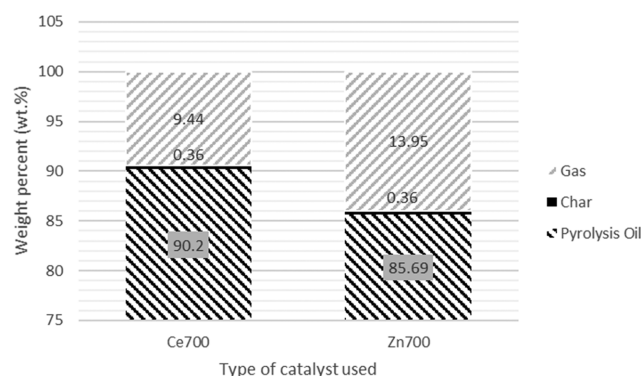

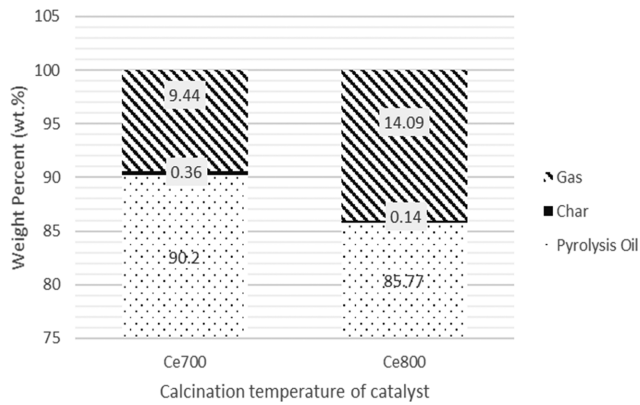Fig. 7. Type of catalyst used on pyrolysis reaction with respective product yield (weight percent).

Fig. 8. Calcination effect on the product yield (weight percent).

Table 3. Calorific value of pyrolysis oil

Calorific value ((MJ/kg)	References
44.90	Zandi-Atashbar et al. [19]
46	Wan Mahari et al. [1]
45.58	Santhoshkumar et al. [15]

the reaction increased the number of hydrocarbons and lowered the oxygen content in the oil product [16]. As reported by Hussain et al. [16], the presence of a catalyst increases the number of esters while lowering the amount of carboxylic acid. Besides, it

was reported by Aburas et al. [7] the catalyst also can act as additive, which affects the sulfur content, viscosity and yield of pyrolysis oil. Comparing from the elemental analysis of the waste lubricant oil and the pyrolysis oil with the application of the catalyst (Ce700), the amount of nitrogen was decreasing abruptly from 0.65 wt% to 0.005 wt%. The amount of oxygen was decreased to 3.07 wt% and sulfur decreased to 0.60 wt%, respectively. This value indicates that the application of catalyst in pyrolysis system produced a greater effect on the properties of the pyrolysis oil.

5. Effect of the Calcination Temperature

As shown in Fig. 8, the catalytic activity decreases when increasing the temperature to 800 $^{\circ}$C, maybe due to increase in crystallinity
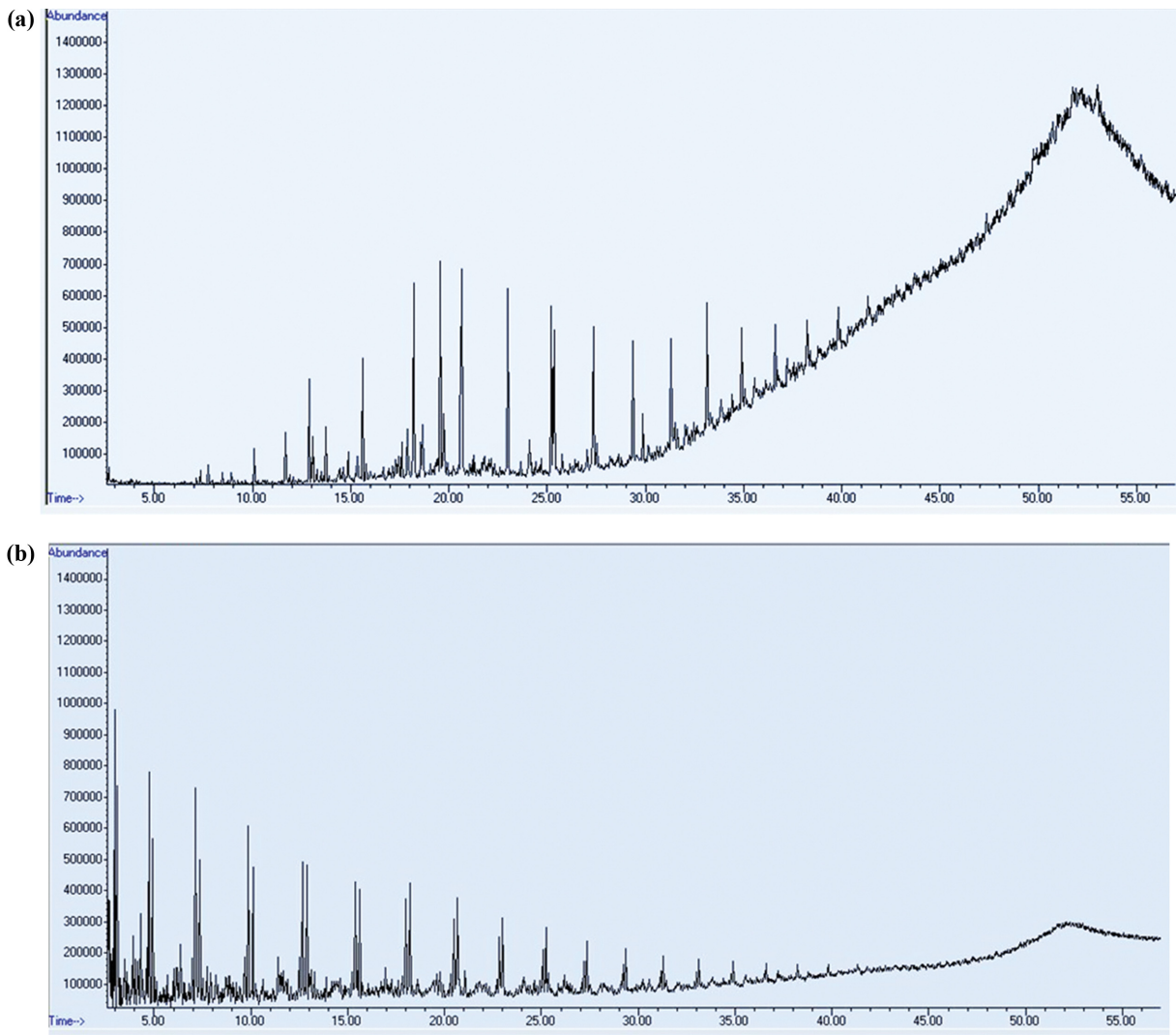

Fig. 9. GC-MS chromatogram of (a) Waste lubricant oil and (b) Pyrolysis oil.

of the catalyst [17]. According to Xu et al. [18], during the pyrolysis process, a calcined catalyst might effectively enhance the deoxygenation of esters and acids to form aldehydes, ketones, alcohol, and hydrocarbons. Calcined catalyst also shows a potential additive to produce high quality of pyrolysis oil via pyrolysis process.

6. Nitrogen, Sulfur and Oxygen Analysis

Catalytic pyrolysis that involves the use of Ce700 exhibits lower oxygen content from 4 to 3.07 wt% of pyrolysis oil. Sulfur that was originally present in the waste lubricant oil (2.16 wt%) was reduced in the presence of catalyst (Ce700) to 0.60 wt%. This may be due to the presence of a catalyst in the waste lubricant oil, which aided the heating and cracking process at a higher temperature to remove sulfur-containing compounds and oxygenated compounds from the waste lubricant oil. Moreover, the nitrogen had also been reduced from 0.65 to 0.005 wt%. This suggests the effective role of catalyst as a reductant. The calorific value of waste lubricant oil before treatment is 45.86 MJ/Kg. Interestingly, the pyrolysis oil developed in this investigation with presence of catalyst, Ce700 was detected to possess high calorific value (54.2 MJ/kg), with with lower viscosity (28 mPa·s), lower content of oxygen, sulfur, and nitrogen, thus showing promising features as a 'cleaner' fuel source with the potentially reduced formation of tar (an oxygenated by-product) and low emission of SO_x during the use of the oil as fuel in the combustion process. Table 3 shows the comparison of calorific value of pyrolysis oil obtained from previous literature.

7. Characterization of Pyrolysis Oil

Pyrolysis oil was analysed using the GC-MS to study the carbon content in the waste lubricant oil and pyrolysis oil as shown in the Table 1 and presented in Fig. 9. The catalytic cracking drastically increased the low molecular weight hydrocarbons. It was observed that the heavier hydrocarbon components (C_1-C_{30}) of waste lubricant oil were cracked into lighter hydrocarbon components (C_1-C_{15}) in the catalytic pyrolysis system. The concentration of lighter hydrocarbon (C_1-C_{15}) in the pyrolysis oil increased significantly after pyrolysis. The lighter hydrocarbons components in C_5-C_{15} range showed a potential to serve as transport grade fuel, as it was in the range for gasoline and diesel.

FT-IR analysis was performed to examine the chemical functional groups present in the pyrolysis oil produced. An important observation on the pyrolysis oil is that the composition of the pyrolysis oil resembled those in commercial diesel. Fig. 10 displays the IR spectrum comparison of main functional groups between waste lubricant oil and pyrolysis oil produced using catalyst (Ce700) and non-catalyst. The pyrolysis oil shows characteristic vibrational modes 2,850-2,975 cm^{-1} for the C-H stretching in alkane, 1,575-1,675 cm^{-1} for the C=C stretching in alkene, 1,475-1,575 cm^{-1} for C=C stretch-
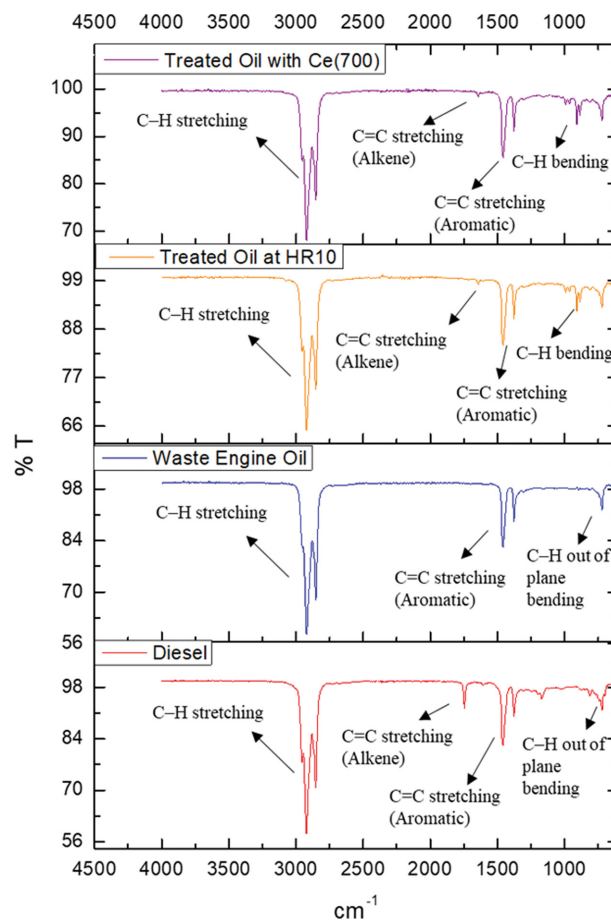

Fig. 10. Data obtained from FTIR-ATR of the waste lubricant oil and pyrolysis oil from various parameter.

ing in aromatic, 900-1,200 cm^{-1} for the C-H bending in alkenes, and 675-850 cm^{-1} for the C-H out of plane bending in single ring aromatics. An absorption peak centring at 2,921 cm^{-1} for the C-H stretching in alkane is observed in the spectra of the commercial diesel, waste lubricant oil and the pyrolysis oil; meanwhile, at absorption peak centered at 907.14 cm^{-1} was observed in the spectra of pyrolysis oil, indicating the presence of alkene in small amounts. During pyrolysis, short-chain hydrocarbon production and subsequent reactions enhanced the aromatic and alkene content of the pyrolysis oil [15]. This statement is supported with GC MS analysis as shown in Table 1.

8. Statistical Analysis

The selected parameters for statistical analysis were terminal

Table 4. ANOVA data for terminal temperature with response (pyrolysis oil, %)

Source of variation	SS	df	MS	F	P-value	F crit
Between groups	469,432.9	1	469,432.9	139.1	2.45E^{-06}	5.3
Within groups	26,999.6	8	3,374.9			
Total	496,432.5	9				

R^2=0.9273

Fig. 11. Polynomial determination coefficient of terminal temperature.

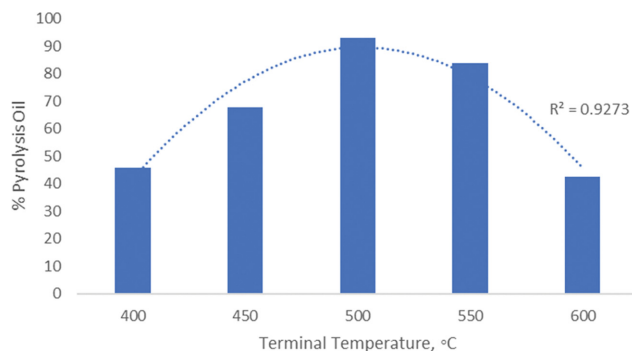**Fig. 12. Polynomial determination coefficient of heating rate.**

temperature, (400-600 °C), and heating rate, (8-15 °C/min). If the p-value is greater than 0.05 in the ANOVA summary table, it means that there is a no significant difference between the groups. Meanwhile, the coefficient of determination, R^2, is a measure used to explain that variability in one factor can be caused by correlation with another related factor. The value of 0.990 above represents a reliable model for future prediction. The p-values and polynomial determination coefficient (R^2) of terminal temperature are shown in Table 4. From the table, the ρ-value for terminal temperature was $2.45E^{-06}$ and it is below than <0.05, thus signifying that the data was significant. In addition, Fig. 11 shows the polynomial determination coefficient of terminal temperature with the R^2 value, 0.9273. This indicated that the model is a moderately reliable factor.

On the other hand, the p-value of the heating rate was $1.89E^{-05}$, which implied the significance of the model with polynomial determination coefficient, R^2 of 0.9864, as shown in Table 5. Fig. 12 shows the polynomial determination coefficient of heating rate.

Ultimately, both parameters, terminal temperature and heating rate, significantly influenced the formation of pyrolysis oil. For the regression analysis as shown in Table 6, the R^2 obtained was 0.2147 and F value of 0.048. The low R^2 indicates that terminal temperature and heating rate parameters are independent of each other.
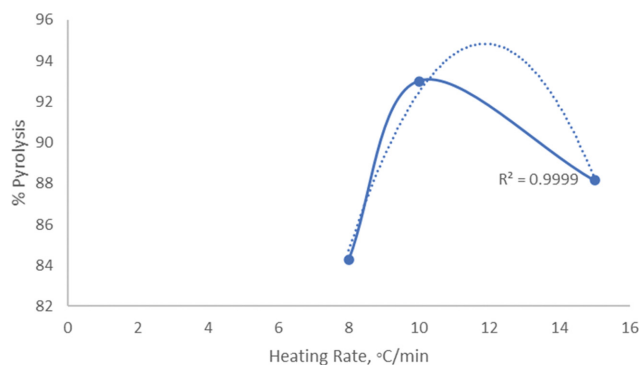
Meanwhile, the F value obtained is below the significance level of F as in Table 6. This suggests that the sample data provide sufficient evidence to conclude that regression model fits the data better than the model with no independent variables.

CONCLUSION

The up-gradation of the pyrolysis oil is a significant challenge to be considered in order to provide a solution for enhanced pyro oil quality by eliminating oxygen content. Cerium oxide, CeO_2/Al_2O_3, was found to be a potential catalyst in the pyrolysis reaction due to the potential in removal of nitrogen, sulfur and oxygen. This suggests the effective role of cerium oxide catalyst as a reductant during pyrolysis cracking. The physical properties of the pyrolysis oil were found to be approximately same as the diesel fuel. The optimum conditions obtained for catalytic pyrolysis were reaction temperature at 500 °C, with heating rate at 10 °C/min, utilizing CeO_2/Al_2O_3 catalyst calcined at 700 °C. The oil product obtained from these setups was 93.01 wt% with a calorific value of the product of 54.2 MJ/kg and the viscosity value 28 mPa·s. The pyrolysis oil consisted of C_5-C_{15} hydrocarbons that represent hydrocarbon range for gasoline and diesel. The pyrolysis oil also has low content of sulfur and oxygen, thus showing promising features as a 'cleaner'

Table 5. ANOVA data for heating rate with response (pyrolysis oil, %)

Source of variation	SS	df	MS	F	P-value	F crit
Between groups	9,003.9	1	9,003.9	559.6	$1.89E^{-05}$	7.7
Within groups	64.3	4	16.1			
Total	537,739	5				

R^2=0.9864

Table 6. ANOVA data for regression analysis with parameter terminal temperature and heating rate

Source of variation	df	SS	MS	F	Significance F
Regression	1	1.76	1.76	0.048	0.862
Residual	1	36.58	36.58		
Total	2	38.34			

R^2=0.214

fuel source. Based on the results, the slow pyrolysis reactor showed potential as an alternative treatment to transform the waste lubricant oil into fuel. Finally, it can be concluded that pyrolysis of organic waste is a great solution to improve the global security by reducing fossil fuel dependency and promoting renewable energy from the scraps.

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