CHARACTERISTIC STUDY OF PHYSIOCHEMICAL PROPERTIES OF HYBRID BIOFUEL (PALM OIL AND ALCOHOL BLEND) FOR COMPRESSION IGNITION ENGINE APPLICATION

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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1. Refined Palm Oil   : RPO
2. Ethanol   : E
3. Cajuput Oil   : MCO
4. Diesel   : D
5. American Society for Testing and Materials : ASTM

ABSTRAK

Pertumbuhan pesat industri automotif telah meningkatkan permintaan petroleum dan tenaga. Usaha dalam mencari satu bentuk tenaga yang baru untuk menampung pengurangan bahan api fosil dan keadaan kemerosotan alam sekitar harus dicari. Minyak sayuran asli ialah alternatif yang boleh diperbaharui untuk bahan api diesel pada masa yang sama menyediakan pembakaran yang lebih bersih, tetapi mempunyai kelikatan yang tinggi berbanding diesel. Dalam journal ini, sifat fizikil dan kimia diesel, minyak kayu putih, campuran minyak sawit bertapis dan etanol dalam pelbagai komposisi telah dikaji. Kelikatan kinematik sebagai fungsi masa, ketumpatan dan nilai kalori biofuel ini telah dikaji untuk dibandingkan dengan Persatuan Amerika untuk Ujian dan Bahan Standard (ASTM D6751) bagi merumuskan bahan api bio yang boleh digunakan sebagai bahan api diesel dalam enjin pencucuhan mampatan. Keputusan menunjukkan bahawa kelikatan kinematik biofuel menurun dengan peningkatan suhu. Dalam 24 sampel, biodiesel yang terbaik dirumuskan adalah 10% minyak sawit ditapis dengan 90% diesel (10RPO: D 90), diikuti oleh 20% minyak kayu putih dengan 80% diesel (20MCO: 80D). Untuk biofuel, 60% minyak kayu putih dengan 40% minyak sawit ditapis (60MCO: 40RPO) adalah biofuel yang terbaik. Pengkomersilan biodiesel ini boleh membantukan penurunan kebergantungan terhadap diesel semata-mata untuk enjin pencucuhan mampatan. Penemuan ini menyumbang dengan mencadangkan minyak sayuran asli baru iaitu minyak kayu putih yang belum lagi dikaji dari segi keupayaan bahan api, menggantikan bahan api diesel konvensional.

Kata kunci:

Biodiesel, Biofuel, Kelikatan, Ketumpatan, Nilai Kalori, Ujian Pemisahan Minyak

ABSTRACT

Exponential growth of industrialization and motorization has led arising of petroleum and energy demand. This results in the search for a new form of energy to cater the depletion of fossil fuel and the environmental degradation condition. Straight vegetable oils is a renewable alternatives to diesel fuel at the same time provide a cleaner burning, but having high viscosity compared to diesel is undesirable for diesel engines. In this work, the physiochemical properties of diesel fuel, cajuput oil, refined palm oil and ethanol mixtures at various compositions were studied. Kinematic viscosity as a function of time, density and calorific value of these biofuel were studied to be compared to American Society for Testing and Materials Standard (ASTM D6751) to formulate a biofuel that could be as reliable as diesel fuel running in compression ignition engine. The results indicate that kinematic viscosity of biofuel decrease with an increase in temperature. Among all 24 samples, the best formulated biodiesel is 10% refined palm oil with 90% diesel (10RPO:90D), followed by 20% cajuput oil with 80% diesel (20MCO:80D) .While for biofuel, 60% cajuput oil with 40% refined palm oil (60MCO:40RPO) is the best formulated biofuel. The commercialization of this particular biodiesel and biofuel could result in the decrease reliance towards using diesel fuel solely for compression ignition engine. This finding contributes by proposing a new straight vegetable oil which is cajuput oil that has not yet being studied in term of its fuel capability to substitute conventional diesel fuel.

Keywords:

Biodiesel, Biofuel, Viscosity, Density, Calorific Value, Separation Test

1. INTRODUCTION

There has been an increase in efforts to reduce the reliance on petroleum fuels by the electricity generation and transport sectors throughout the world. In the exponential growth of global energy requirement, research is carried to develop and to use variety of renewable fuels. Remaining global oil resources appear to be sufficient to meet demand until 2030 as projected by International Energy Agency (IEA). World consumption of fossil fuels is 100,000 times faster than their natural production. The world is growing towards a sustainable energy era where society emphasis on energy efficiency and use of renewable energy sources [1]. Concerns on the long-term availability of diesel fuel have motivated the search for a renewable alternative to diesel fuel to overcome these problem. Diesel engines that is widely used in the agriculture, transportation, and power sectors for small energy needs could be a potential source of decentralized energy generation for electrification. Biodiesel has been considered as good alternative to diesel in the past couple of years. The renewable sources of energy reduce chemical and radioactive waste, providing lesser emission, produce clean and limitless energy. Advantages of the vegetable oils as engine fuels lie in their renewable nature and wide availability from the variety of sources. This is particularly attractive to countries lacking sources of liquid fossil fuels [1].

The use of straight vegetable oils or SVOs as a fuel for diesel ignition engines is somehow constrain by certain unfavourable properties, particularly their viscosity. High molar masses of the oils and the presence of unsaturated fatty acids causes high viscosity. At high temperature, polymerization of unsaturated fatty acids happen because cross-linking starts to occur between molecules, resulting in the formation of very large agglomerations and consequent gumming. Poor fuel atomization happens due to high viscosities of SVOs, that leads to incomplete fuel combustion and carbon deposition on the valve seat and injector causing in serious engine failure. Injectors become choked after a few hours when running

using SVOs in which choking results in poor fuel atomization and incomplete combustion. Due to incomplete combustion, partially burnt vegetable oil that passes through the cylinder walls affects the condition of lubricating oil. [2]

This research project present the analysis of kinematic viscosity, density and calorific value by focusing on the formulation of hybrid biofuel and biodiesel that is of close resemblance to diesel in term of physiochemical characteristics. The formulated sample were then tested for their physiochemical characteristics in term of kinematic viscosity, density and calorific value. Data obtained were compared to ASTM D6751 for kinematic viscosity. Density and calorific value were compared to diesel baseline fuel properties. Besides that, separation test were done to select sample to find which blending method could result in the longest phase stability of mixture. There are 3 types of Biodiesel, Biodiesel A is the mixture of ethanol (E) with refined palm oil (RPO), Biodiesel B is the mixture of refined palm oil (RPO) with diesel (D), Biodiesel C is the mixture of cajuput oil (MCO) with diesel (D). There are 1 type of Biofuel which is Biofuel D consist of the mixture of cajuput oil (MCO) with refined palm oil (RPO). Regression analysis was done to kinematic viscosity of Biofuel D and calorific value of Biodiesel C to further predict the ratio that results in physiochemical characteristic being in range with test limit. Lastly, the formulated hybrid biofuel and biodiesel were compared to commercialized Palm Oil Methylester (PME). This work will result in the obtaining of the best biofuel and biodiesel sample to operate in compression ignition engine hence reducing the demand on fossil fuel.

2. MATERIALS AND METHODOLOGY
2.1 Separation Test

Phase stability is a crucial element when it comes to blending different types of biodiesel. This is because certain blended fuel will separate after a short period of time. Separation test was done using different blending methods which are Mechanical Stirrer, Magnetic Stirrer, and Ultrasonic Homogenizer to obtain the phase stability period of fuel hence

selecting the best blending method. The only sample used for separation test is 20E:80RPO. This is because 20E:80RPO has a relatively short phase stability period hence by blending this sample, separation will occur faster compared to other samples with longer phase stability period. The drastic occurrence of separation of 20E:80RPO will help in obtaining result faster for analysis. Samples are blended using Mechanical Stirrer, Magnetic Stirrer and Ultrasonic Homogenizer. Assuming for 20% ethanol + 80% RPO using Mechanical Stirrer (IKA RW20 Digital), the amount of sample to be prepared is 15ml. A clean 100ml beaker was used as mixing medium in which 12 ml of refined palm oil (RPO) was carefully poured into 100ml measuring cylinder and a remaining 3 ml of ethanol was then poured in. The sample was blended under 270rpm for 5 minutes. Using Magnetic Stirrer (WiggenHauser MSC-400), same amount of measured sample was prepared. Magnetic bead was carefully placed inside the beaker. The sample was blended up to maximum blending period of 5 minutes. For Ultrasonic Homogenizer, sample was prepared in a beaker and the beaker was placed inside UH which was set to continuous-pulse for 5

minutes.

Figure 1: Ultrasonic Homogenizer blending sample.
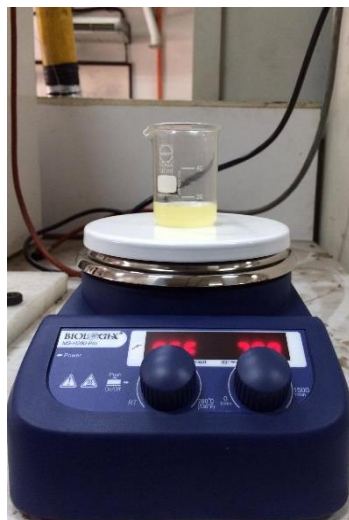
Figure 2: Magnetic Stirrer blending sample.

Figure 3: Mechanical Stirrer blending sample.

2.2 Viscosity Test

A major concern about the use of straight vegetable oils (SVO) in diesel engines is due to the fact that SVO inherit high viscosity which down the line causes poor fuel atomization and inefficient mixing with air in combustion chambers[3]. That is the reason behind blending

SVOs such as refined palm oil and cajuput oil with diesel and ethanol as this help in reducing viscosity of fuel. The objective of conducting viscosity test is to obtain the kinematic viscosity data of every sample of Biodiesel A, Biodiesel B, Biodiesel C and Biofuel D to be compared to ASTM D6751 test limit. Device used is Brookfield DV-III ULTRA Programmable Rheometer. Each sample of Biodiesel A, Biodiesel B, Biodiesel C and Biofuel D were tested under 4 different temperature settings which are 20 °C, 40 °C, 60 °C and 80 °C using spindle size 21. Water bath was used to regulate the temperature. Spindle was zeroed each time a new sample is being placed.

2.3 Density Test

Density is an important criteria in choosing the best fuel because high density fuel would lead to more mass of fuel being injected to combustion chamber by fuel injector. This definitely would affect the fuel economy of selected fuel[4]. Objective of conducting density test is to obtain density data of every sample of Biodiesel A, Biodiesel B, Biodiesel C and Biofuel D to be compared to diesel test limit. Note that density value was obtained via dividing mass of sample to its volume in which this method is not based on ASTM D6751. 10ml measuring cylinder was used because it offer a more accurate measurement compared to beaker. Empty cylinder mass was recorded. 5ml of sample was poured into the cylinder and the mass are recorded. Eyes of observer was make sure to be perpendicular to scale of measuring cylinder during the process to reduce parallax error which is caused by viewing the object at an oblique angle with respect to the scale, making the object appear to be at a different position on the scale.

2.4 Calorific Value

Energy content of fuel can be obtained from its respective calorific value. A larger mass of fuel is required for fuel with lower energy content. Besides that, higher calorific value results

in higher combustion temperature which affects oxides of nitrogen production[5]. The objective of conducting calorific value test is to obtain calorific value data of every sample of Biodiesel A, Biodiesel B, Biodiesel C and Biofuel D to be compared to diesel test limit. Device used for this test is Yoshida Bomb Calorimeter. 0.55g – 0.60g of sample was used for every sample during this test. Formula used to calculate High Calorific Value (kJ/kg) are as follows:-

$$HCV \ (kJ/kg) = \frac{[(2100+604) \ x \ (Tcorr)(4.19)]-[(Mass \ of \ paper \ x \ 16190)+(Length \ of \ fuse \ wire \ burnt \ x \ 2.3 \ x \ 4.19)]}{Mass \ of \ sample}$$

3. RESULT AND DISCUSSION
3.1 Separation Test

The phase stability of biofuel at different ratios under different blending methods which are mechanical stirrer, magnetic stirrer and ultrasonic homogenizer (USH) were observed. A sample was used for this test (20E:80RPO).

Table 1: Separation test result.

Blending Method	Biofuel	Phase Stability (min)
Mechanical Blender	20E:80RPO	2 minutes
Magnetic Stirrer	20E:80RPO	3 minutes
Ultrasonic Homogenizer (USH)	20E:80RPO	N/A

The experimental results of the phase stability reveals that the 20E:80RPO is not stable and separated after 2 minutes using mechanical blender and 3 minutes using magnetic stirrer whereas for Ultrasonic Homogenizer (USH) , the sample does not separate even after 109th day. Blending using Ultrasonic Homogenizer can affect the microstructure of the biofuel. Ultrasound from the spindle exert vibration towards the molecular structure of biodiesel. Vigorous vibration of the molecular structure causing them to break apart and this will cause ethanol and refined palm oil to mix. The mixing action of these two materials produce enthalpy of mixing or heat of mixing. It is the enthalpy liberated or absorbed from a substance upon mixing. When a substance or compound is combined with any other substance or compound

the enthalpy of mixing is the consequence of the new interactions between the two substances or compounds. Enthalpy of mixing were released exothermically and heat can be felt at the mixing beaker even after the mixing has finished. In extreme cases it could even cause explosion[6]. A higher ultrasonic power would cause a higher vibration amplitude. Adding heat energy to biodiesel increase the motion which result in better and faster mixing process. Hence, Ultrasonic Homogenizer not only act as an agitator to mix biofuel but the heat generated from mixing further assist the mixing process of sample.

Ultrasonic homogenizing is very efficient in reducing the size of particle to an evenly distributed and uniformly small liquid particles. It is based on cavitation where liquids are exposed to intense ultrasonication sound waves that propagate through the liquid causing alternating high-pressure and low-pressure cycles of approximately 20000 cycles/sec. During the low-pressure cycle, high-intensity small vacuum bubbles are created in the liquid, as the liquid vapour pressure is attained. When the bubbles reach a certain size, they collapse violently during a high-pressure cycle. Right after the implosion, a very high pressures and high speed liquid jets are generated locally. The resulting currents and turbulences disrupt particle agglomerates and lead to violent collisions between individual particles which result in mixing. Biodiesel blended under this condition will provide a longer phase stability[7].

Using Magnetic Stirrer to blend 20E:80RPO result in a phase stability for a short period of 3 minutes only. This is due to the fact that heat applied to the base of mixing beaker during mixing process. Heat as we know facilitate the mixing process of ethanol and refined palm oil. Due to the high viscosity of refined palm oil, the magnetic stir bar or flea cannot spin quickly hence this result in a poor mixing of both ethanol and refined palm oil. Besides that, the stirring was set for 5 minutes only for all 3 mixing methods hence this short stirring period and high viscosity of liquid result in an improper mixing of 20E:80RPO. The mixture managed to settle in stability phase for a period of 3 minutes but after that a separation layer starts to form causing

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ethanol to settle on top of refined palm oil since ethanol has a density lower than refined palm oil. The chronological image are as shown in Figure 4, Figure 5, and Figure 6.

Figure 4: 20E:80RPO sample right after stirring.

Figure 5: Sample starts to separate during the 3rd minutes after stirring process.

Figure 6: Sample fully separated after 3 minutes.

Magnetic Stirrer were an option because it provide a quieter, more efficient, and have no moving external parts to break or wear out other than the simple bar magnet itself. Magnetic stir bars work well in glass vessels commonly used for chemical reactions, as glass does not appreciably affect a magnetic field. They do not require lubricants which could contaminate the reaction vessel and the product but due to its limitation dealing with high viscous fluid, some sort of mechanical stirring is needed. Mechanical Stirrer was used to mix 20E:80RPO for 5 minutes as well. Even though it provide a powerful stirring action to mix both materials, the blended biofuel separated after 2 minutes due to the fact that no heat energy supplied to the mixing container during mixing process. Ethanol having a density of 735 kg/m^3 and refined palm oil having density of 899 kg/m^3. These two material does not mix not because of them having different density but because ethanol

Figure 7: Separation test samples.

and refined palm oil are immiscible liquids. The word "miscibility" describes how well two substances mix. In order to allow immiscible liquids to mix, heat energy need to be applied during mixing.

As a result for separation test, in order to blend biofuel/biodiesel, the best mixing device is Ultrasonic Homogenizer because it results in a better phase stability by keeping the integrity of the blend intact, followed by Magnetic Stirrer, and then Mechanical Stirrer. Figure 7 shows the resulting state of 3 mixing device blending a sample under the same controlled condition (5 minutes mixing period).

3.2 Physiochemical Characteristic Test

Along the process of physiochemical testing, there are a standard guideline used to make sure the results obtained is comparable to other data produced under the same standard. The standard used is the American Society for Testing and Materials (ASTM). The standard for biodiesel is ASTM D6751. Test data for kinematic viscosity were compared to ASTM D6751 limit. Density and calorific value data were compared to the limit of baseline diesel. Data obtained are in Table 2. As for the record, 50E:50RPO sample was marked "VOID" because it does not mix even after 5 minutes of blending using Ultrasonic Homogenizer. Hence, this sample cannot be used in compression ignition engine as refined palm oil with high viscosity could lead to incomplete fuel combustion. These high viscosity which results from high molar mass of oil and the presence of unsaturated fatty acids. During high temperature engine operation, polymerization of unsaturated fatty acids forms as cross-linking start to occur between molecules, causing formation of large agglomerations and gumming. Refined palm oil having a high viscosity of 37.6 cSt cause poor fuel atomization that leads to incomplete fuel combustion and carbon deposition at the valve seat and injector that could make the engine fouling[2].Therefore, 50E:50RPO sample is eliminated from the formulation list. Note that for

every sample of kinematic viscosity, density and calorific value test, the data obtained are an average of 3 times data accumulation.

Table 2: Physiochemical characteristic test result.

Sample	Ratio	Kinematic Viscosity (cSt) at 40°C	Density (kg / m³)	Calorific Value (MJ/kg)
Biodiesel A	100E	0.95238	735.0	25.5
	100RPO	37.5970	899.0	38.2
	10E90RPO	38.2130	881.9	37.1
	20E80RPO	30.8210	866.3	35.7
	30E70RPO	20.0000	850.0	34.4
	50E50RPO (VOID)	-	-	-
Biodiesel B	100D	2.9412	850.0	46.2
	100RPO	37.5970	899.0	38.2
	10RPO90D	4.4460	854.7	45.6
	20RPO80D	4.6539	859.5	44.3
	30RPO70D	6.5949	864.3	42.7
	50RPO50D	12.0070	874.5	41.9
Biodiesel C	100MCO	2.0882	862.0	41.7
	100D	2.9412	850.0	46.2
	10MCO90D	2.9343	852.0	45.8
	20MCO80D	2.6983	852.4	45.3
	30MCO70D	2.6948	853.5	44.6
	50MCO50D	2.3362	856.1	43.9
Biofuel D	100MCO	2.0882	862.0	41.7
	100RPO	37.5970	899.0	38.2
	10MCO90RPO	33.7490	897.8	38.6
	20MCO80RPO	25.4320	896.5	39.0
	30MCO70RPO	22.6130	893.3	39.3
	50MCO50RPO	11.8380	887.0	39.9
Test limit		ASTM D6751 1.9-6.0	Diesel baseline 824-855	Diesel baseline 42.7-45.6

3.2.1 Kinematic Viscosity

Kinematic viscosity data was obtained at a temperature of 40 °C. The biodiesel in range to ASTM D6751 are 10RPO:90D, 20RPO:80D, 10MCO:90D, 20MCO:80D, 30MCO:70D, and 50MCO:50D.

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3.2.1.1 Kinematic Viscosity of Ethanol-Refined Palm Oil Blends

Figure 8 shows the kinematic viscosity (cSt) data obtained for blends of ethanol with refined palm oil as a function of temperature. Note that the ASTM D6751 for kinematic viscosity is between 1.9 to 6 cSt. For every ratio, as temperature increase the kinematic viscosity decrease. Figure 8 shows that biodiesel viscosity decrease non-linearly with the increase in
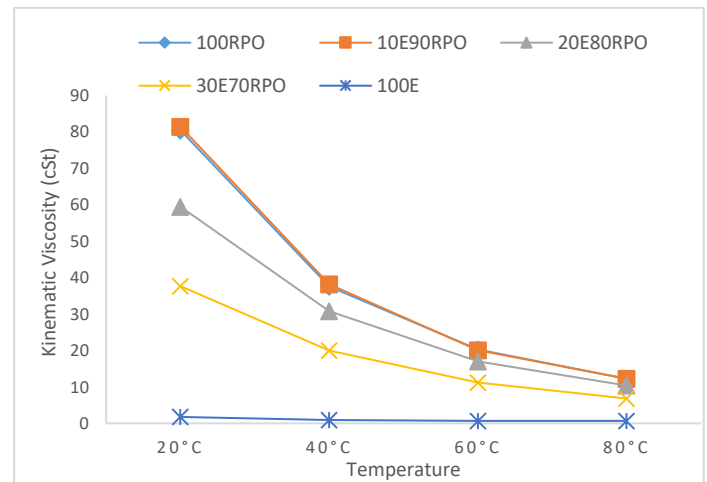

Figure 8: Kinematic Viscosity of Biodiesel A with respect to Temperature.

temperature. Franco on his research found that oil viscosities generally increases with concentration of saturated fatty acids, and decreases with polyunsaturated content[8]. The studies done by Abramovic and Klofutar [9]and Santos et al. [10] on similar pure vegetable oils in which viscosity of vegetable oils could be related more to concentration of polyunsaturated chains than the monounsaturated fatty acid content. Refined palm oil with high content of palmatic acid which is 46.7% by weight prove that as the ratio of refined palm oil is high in the sample, kinematic viscosity will also increase [11]. 10E:90RPO have higher kinematic viscosity at every temperature increment compared to 20E:80RPO and 30E:70RPO. This is because the other samples are having lower percentage of refined palm oil in its composition. . The kinematic viscosity of 30E:70RPO is 20 cSt whereas maximum ASTM limit lies at only 6 cSt, which means 108% increase compared to ASTM biodiesel viscosity limit. It can be concluded that even the least amount of refined palm oil present in Biodiesel A sample, it still cannot substitute diesel since the biodiesel viscosity is tremendously high. As compression ignition engine rely on fuel injection system, high viscosity fuel oil leads to improper atomization which in turn leads to incomplete combustion. An efficient atomization is the basic need for a perfect mixing of fuel and heated air, without which, no ignition or

combustion can be derived [4]. High viscosity could cause problem in cold weather because as temperature decrease, viscosity will increase [12][13]. Thus, it is absolutely important to set the viscosity value in the right range. Variations in kinematic viscosity among the different ratios become less significant at higher temperatures.

3.2.1.2 Kinematic Viscosity of Refined Palm Oil-Diesel Blends

Kinematic viscosity of Biodiesel B in Figure 9 shows the same trend as in Biodiesel A. Note that the ASTM D6751 for kinematic viscosity is between 1.9 to 6 cSt. Kinematic viscosity decrease with an increase in temperature. At 40 °C, refined palm oil have a higher viscosity which is 37.597 cSt compared to diesel
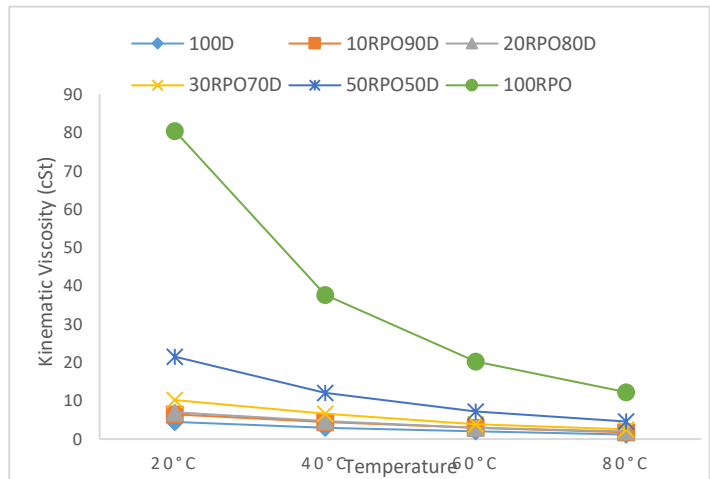

Figure 9: Kinematic Viscosity of Biodiesel B with respect to Temperature.

which only possess 2.9412 cSt. This huge viscosity difference affect the trend in Figure 9 because as more refined palm oil is being added in, the total viscosity of the sample will increase dramatically. At 40 °C, 30RPO:70D have 6.5949 cSt but with just an increase of 20% more refined palm oil into the sample forming 50RPO:50D, the viscosity almost doubled to 12.007 cSt. This phenomenon is also verified by other researchers since vegetable oil viscosity depends on molecular structure and decreases with the unsaturation of fatty acids which exist in refined palm oil [14].

3.2.1.3 Kinematic Viscosity of Cajuput Oil-Diesel Blends

As predicted, the trend in Figure 10 shows that kinematic viscosity decrease as temperature increase. Note that the ASTM D6751 for kinematic viscosity is between 1.9 to 6 cSt. The increase in temperature enhances the movements of the molecules and reduces intermolecular forces so the layers of the liquid easily pass over one another and thus contribute
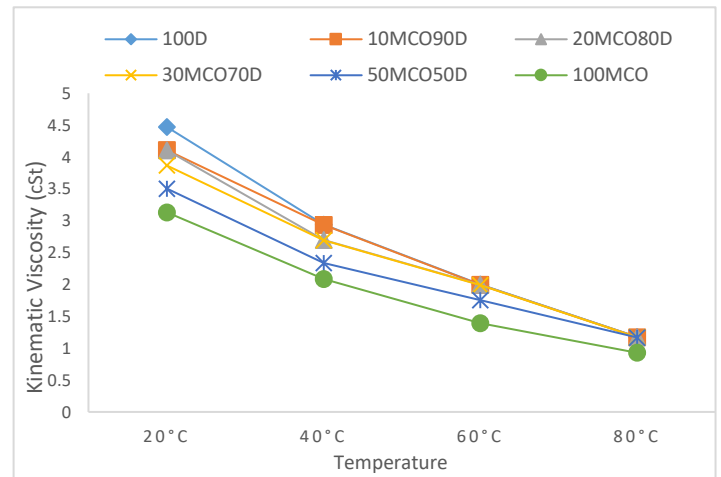

Figure 10: Kinematic Viscosity of Biodiesel C with respect to Temperature.

to the reduction of viscosity [15]. Among all the 4 ratios, 10MCO:90D is the biodiesel having the highest viscosity along all the 4 temperature settings. This is because the ratio of diesel is high in the composition which is 90%. Somehow, diesel and cajuput oil kinematic viscosity is not far from each other. At 40 °C, diesel viscosity is 2.9412 cSt while cajuput oil viscosity is 2.0882 cSt. These insignificant viscosity gap results in the pattern of Figure 10 being close to one another.

3.2.1.4 Kinematic Viscosity of Cajuput Oil-Refined Palm Oil Blends

Figure 11 exhibit the pattern similar to previous biodiesel viscosity graph since kinematic viscosity decrease with an increase in temperature. Note that the ASTM D6751 for kinematic viscosity is between 1.9 to 6 cSt. Biofuel D is made up from various ratios of cajuput oil and refined palm oil. Among all 4 ratios, 10MCO:90RPO possess the highest kinematic
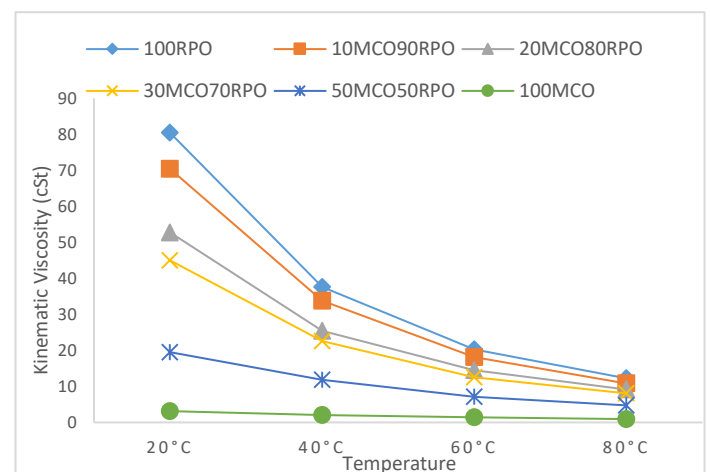

Figure 11: Kinematic Viscosity of Biofuel D with respect to Temperature.

viscosity along all 4 temperature setting. The lowest viscosity obtained by Biofuel D is at ratio of 50MCO:50RPO. At 40 °C, the viscosity is 11.838 cSt. This shows that even if half of the sample were filled with cajuput oil, it still in the range of high viscosity and does not comply with ASTM D6751 limit which is 6 cSt. The goal is to find Biofuel D composition which its kinematic viscosity being at least 6 cSt. Regression lines can be used as a way of visually depicting the relationship between the temperature (x) and kinematic viscosity (y) variables in the graph. The correlation coefficient, R^2 describe how well the equation fits the data. The closer R to 1, the better the fit. To determine a relationship between viscosity and different ratios of cajuput oil-refined palm oil blends, empirical correlations towards Figure 11 trend line was made and it was found that the kinematic viscosity dependence of the different ratios of cajuput oil-refined palm oil blends could be satisfactorily described by:-

$$\nu = -7.0313(MCO\% \times 10) + 46.829$$

where ν is kinematic viscosity in cSt, MCO is the percentage of cajuput oil exist in the composition. The above equation having correlation coefficient of 0.9689. Plug in the value 6 cSt in the formula result in 58.1%
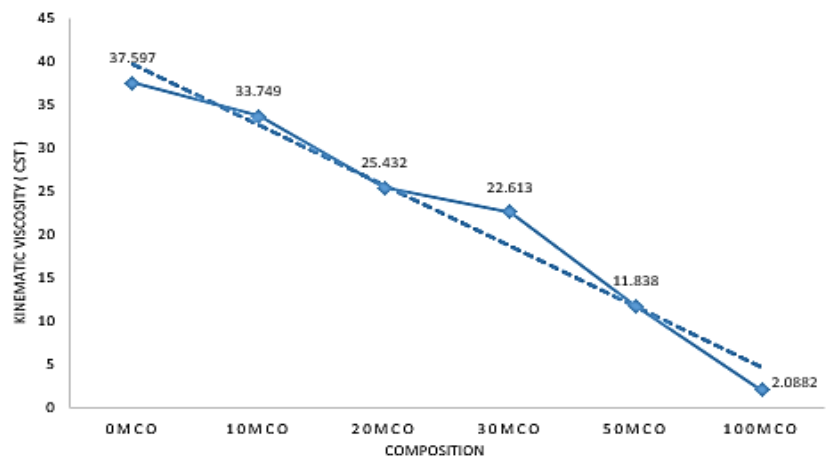

Figure 12: Kinematic viscosity with respect to various composition of Biofuel D.

MCO. Given the fact that correlation coefficient is not exactly unity (1), the result is less accurate but it gives an idea of where the true value lies in. In order for cajuput oil-refined palm oil blends to achieve viscosity of 6 cSt, it requires almost 60MCO:40RPO composition. Viscosity test was done for that composition and it was found that at 40 °C the viscosity is 5.6689 cSt which is within the ASTM D6571 range.

3.2.2 Density

Density data was obtained at room temperature approximately 27 °C. The density test limit are based on diesel density at room temperature which are 824-855 kg/m^3 obtained from various researches [2] [9] [4] [5] [16] [17] [18] [19] [20].The biodiesel in range to diesel baseline are 30E:70RPO, 10RPO:90D, 10MCO:90D, 20MCO:80D and 30MCO:70D. Note that the data accumulation was done only at specific ratio (10%, 20%,30%,50%) and not every 10% increment which result in the graph data line not being linear but if every 10% increment data is recorded, a linear trend line is to be expected.

3.2.2.1 Densities of Ethanol-Refined Palm Oil Blends

Figure 13 dotted line shows the trend line of density decreases as ethanol ratio increases. This is because ethanol has low density of just 735 kg/m^3 while refined palm oil has a higher density of 899 kg/m^3. Hence, the addition of ethanol to refined palm oil causing the mixture's
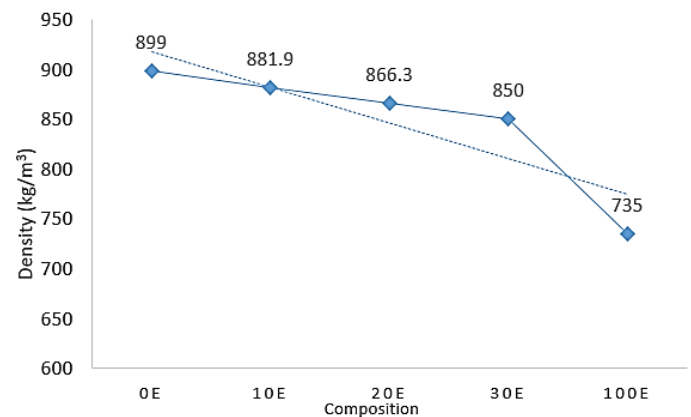

Figure 13: Density of Biodiesel A at room temperature.

density to decrease in a linear pattern. Density of test limit is in the range of 824-855 kg/m^3 while Biodiesel A are having density way above this except for 30E:70RPO. Despite the fact that density of biodiesel is much greater, energy content of which is lower both on a mass and a volume basis compared to baseline diesel hence more fuel need to be injected into the combustion chamber in order to gain the same power from the engine. This is an important factor increasing the fuel consumption. Besides that, density of biodiesels will vary with the fatty acid composition.[21]. M. H. M. Yasin in his research reported that viscosity and density of biodiesel blended with diesel was reduced because of presence of alcohol in the concentration of blends but there was a significant increase in cetane number as alcohol

concentration starts too increased that result in shorter ignition delay which in turn makes the engine performs better and easier to start [22].

3.2.2.2 Densities of Refined Palm Oil-Diesel Blends

Figure 14 dotted line shows the trend line of density increases as refined palm oil ratio increases. This is because refined palm oil has higher density of 899 kg/m^3 while diesel has a lower density of 850 kg/m^3 in which the addition of refined palm oil to diesel causing the mixture's
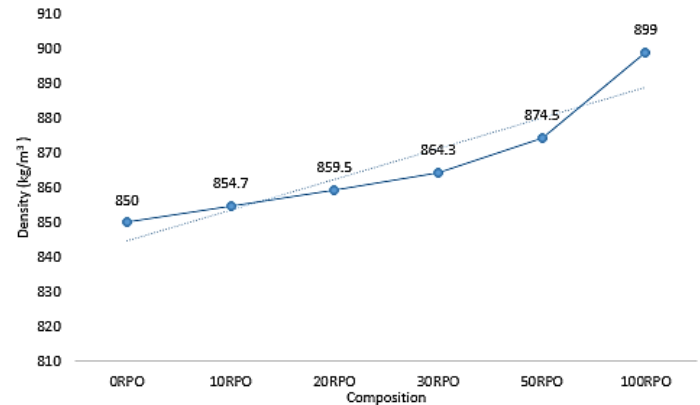

Figure 14: Density of Biodiesel B at room temperature.

density to increase in a linear pattern. Among all 4 samples, 10RPO:90D has the density that falls within test limit of diesel fuel. Comparatively, the maximum limit of density for diesel fuel is 855 kg/m^3. Hence, 10RPO:90D only differs to diesel density by 0.035%.

3.2.2.3 Densities of Cajuput Oil-Diesel Blends

Figure 15 dotted line shows the trend line of density increases as cajuput oil ratio increases. This is because cajuput oil has higher density of 862 kg/m^3 while diesel has a lower density of 850 kg/m^3. Hence, the addition of cajuput oil to diesel causing the mixture's density to increase in
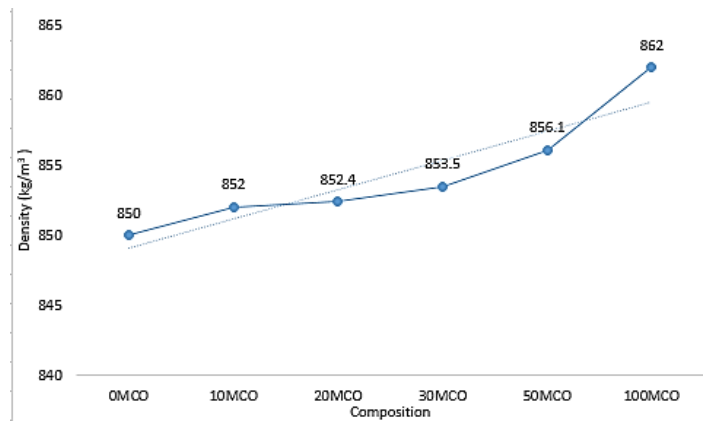

Figure 15: Density of Biodiesel C at room temperature.

a linear pattern. Among all 4 samples, 10MCO:90D, 20MCO:80D and 30MCO:70D densities value lies within test limit of diesel fuel. Given that the maximum limit of density for diesel fuel is 855 kg/m^3 and 30MCO:70D density value is closest to it by 0.18% percentage difference.

3.2.2.4 Densities of Cajuput Oil-Refined Palm Oil Blends

Figure 16 dotted line shows the trend line of density decrease as cajuput oil ratio increases. This is because refined palm oil has higher density of 899 kg/m^3 while cajuput has a lower density of 862 kg/m^3. Addition of cajuput oil to refined palm oil causing the mixture's density to decrease in a linear pattern. Theoretically, it is
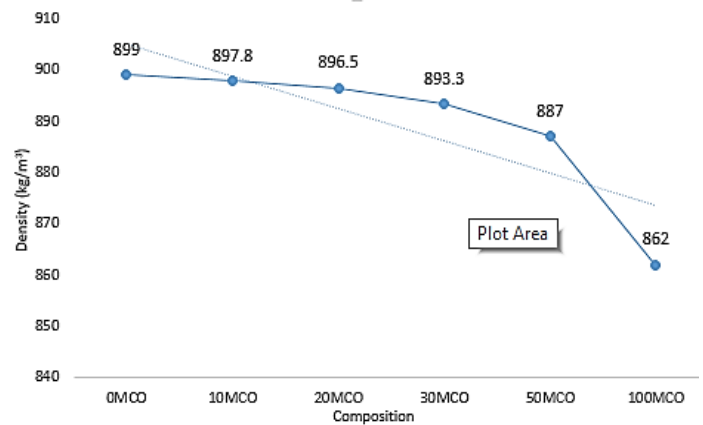

Figure 16: Density of Biofuel D at room temperature.

impossible for Biofuel D to achieve maximum limit for density (855 kg/m^3) because even if 100%MCO were used, the value of density is still 0.815% higher than density test limit.

3.2.3 Calorific Value

Calorific value data was obtained at room temperature approximately 27 °C. The test limit are based on diesel calorific value at room temperature which are 42.7-45.6 MJ/kg obtained from various researches [2][5][16][17][20][23][24][25][26]. The biodiesel in range to diesel baseline are 10RPO:90D, 20RPO:80D, 30RPO:70D, 20MCO:80D, 30MCO:70D and 50MCO:50D. Note that the data accumulation was done only at specific ratio (10%,20%,30%,50%) and not every 10% increment which result in the graph data line not being linear but if every 10% increment data is recorded, a linear trend line is to be expected.

3.2.3.1 Calorific Value of Ethanol-Refined Palm Oil Blends

The trend of Figure 17 shows a decreasing pattern as ethanol content is increased in the composition. This is because ethanol's calorific value is lower (25.5MJ/kg) compared to refined palm oil (38.2MJ/kg). The closest possible sample ratio to diesel calorific value test limit (42.7MJ/kg) is

Figure 17: Calorific Value of Biodiesel A at room temperature.

10E:90RPO with calorific value of 37.1 MJ/kg. Even if all the ratio are dominated by ethanol (100E), still its calorific value will not reach the minimum limit of calorific value test. Hence, any sample of Biodiesel A with specific amount of ethanol and refined palm oil could not compete with the performance of diesel fuel in compression ignition engine in term of calorific value. This is due to the lower calorific value of ethanol which in return requires a larger amount of fuel injection in order to produce the same power output as engine running with diesel fuel[27].
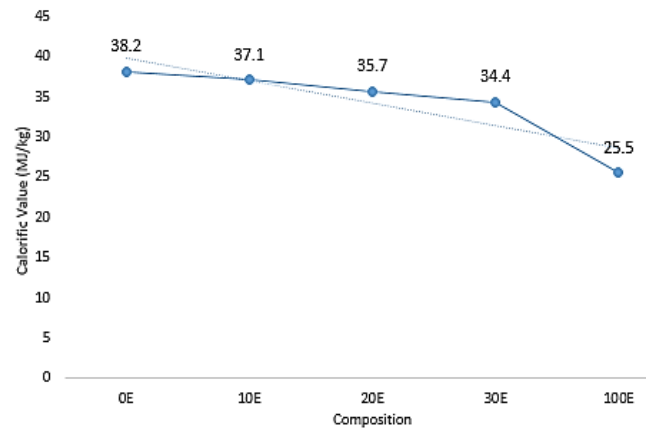
3.2.3.2 Calorific Value of Refined Palm Oil-Diesel Blends

Figure 18 shows similar decreasing pattern as Figure 17 as the ratio of refined palm oil increases due to the fact that refined palm oil has a lower calorific value of 38.2MJ/kg while diesel has a higher calorific value of 46.2MJ/kg. This result in the even a slightest addition of refined palm oil into diesel results in the calorific value to decrease but then the value are within the range of test limit until 30RPO:70D

Figure 18: Calorific Value of Biodiesel B at room temperature.

having calorific value of 42.7MJ/kg. Having calorific value in range shows that the

composition have energy content relatively as much as diesel fuel. Since fuel injection interval varies with the calorific value of the fuel, fuel with lower calorific value is needed in greater amount to liberate the same amount of heat in the combustion chamber causing the fuel to take longer fuel injection time compared to one having higher calorific value[28].

3.2.3.3 Calorific Value of Cajuput Oil-Diesel Blends

The MCO-D composition in Figure 19 shows a decreasing pattern as cajuput oil (MCO) is being added into the composition because cajuput oil has a lower calorific value which is 41.7MJ/kg compared to diesel which is 46.2MJ/kg. To determine a relationship between calorific value and different ratios of
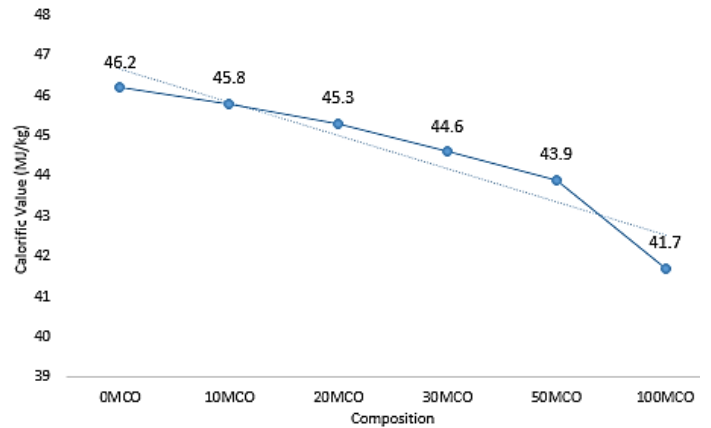

Figure 19: Calorific Value of Biodiesel C at room temperature.

cajuput oil-diesel blends, empirical correlations towards Figure 19 trend line was made and it was found that the calorific value dependence of the different ratios of cajuput oil-diesel blends could be satisfactorily described by:-

$$CV=-0.4645(MCO\%x10) +46.578$$

where CV is calorific value in MJ/kg, MCO is the percentage of cajuput oil exist in the composition. The above equation having correlation coefficient of 0.9871. Plug in the value 42.7MJ/kg in the formula result in 83.5% MCO. Given the fact that correlation coefficient is not exactly unity (1), the result is less accurate but it gives an idea of where the true value lies in. In order for Biodiesel C to achieve minimum test limit for calorific value, it requires relatively 80MCO:20D composition. Calorific value test was done for that composition and it was found that at room temperature the calorific value is 42.2MJ/kg which is within the diesel test limit.

3.2.3.4 Calorific Value of Cajuput Oil-Refined Palm Oil Blends

The increase in cajuput oil composition in the biofuel results in a higher calorific value of mixture. This is the reason for the trend line of Figure 20 to be increasing. Cajuput oil has a higher calorific value than refined palm oil by 8.8%. Somehow, given the fact that 100% cajuput oil has calorific value of only 41.7MJ/kg, this shows that
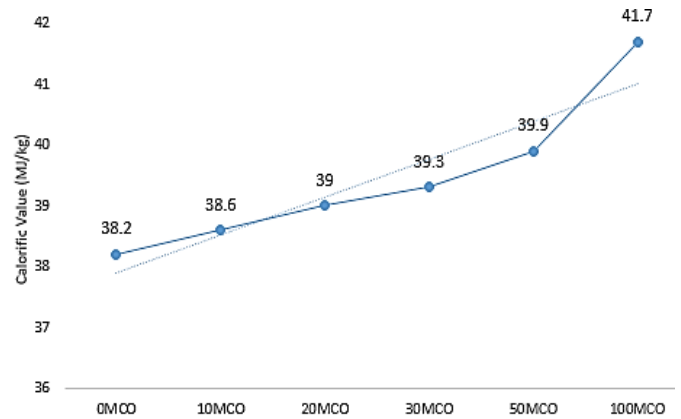

Figure 20: Calorific Value of Biofuel D at room temperature.

even if the biofuel is blended with maximum amount of cajuput oil, the calorific value still lies below minimum test limit which is 42.7MJ/kg. Low calorific value is an unfavourable characteristic of biofuel since Antony and Samaga reported that the higher exhaust temperature of vegetable oil is an indication of their delayed combustion, partly because of their slower combustion rates and partly due to prolonged injection on account of their lesser calorific value and hence lesser thermal efficiency [28].

3.3 Comparison with Palm Methyl-Ester

From 2014, Malaysia uses B7 (7% palm oil methyl-ester and 93% diesel fuel) as fuel source to power diesel engine. Since then, almost all petrol station utilized B7 composition in their diesel pump as mandated by the Malaysian government. Hence, this paper focus in comparing the best formulated biodiesel and biofuel with commercialized B7 in term of kinematic viscosity, density and calorific value. Physiochemical characteristic test has been done to B7 sample and it was recorded that it possess kinematic viscosity of 3.5 cSt at 40°C, density of 854 kg/m^3 and calorific value of 43.6 MJ/kg. The reference value of diesel are the average value of test limit which are 3.95 cSt, 839.5 kg/m^3 and 44.2 MJ/kg. Table 3 shows the percentage difference between the best formulated biofuel/biodiesel and commercialized PME to diesel fuel. Weightage are calculated by using the formula as follows:-

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$$\text{Weightage (\%)} = \frac{\%viscosity + \%density + \%calorific\ value}{300\%} \times 100$$

Table 3: Comparison of samples to diesel fuel.

Type	Composition	Percentage difference in term of :			Weightage (%)
		Kinematic Viscosity at 40°C	Density	Calorific Value	
Biodiesel	10RPO:90D	11.82%	1.79%	3.12%	5.58%
	20MCO:80D	37.66%	1.53%	2.46%	13.88%
Biofuel	60MCO:40RPO	35.74%	4.94%	9.73%	16.8%
Palm Oil Methyl-Ester	B7	12.08%	1.71%	1.37%	5.05%

Based on the weightage in Table 3, it can be seen that palm oil methyl-ester (PME) are having the lowest weightage which is 5.05% compared to others. This shows that PME physiochemical properties are the closest to diesel fuel compared to others which make sense why the government mandated the B7 composition in almost every petrol station in Malaysia. Somehow B7 requires a special production process known as transesterification oil or fat are converted into methyl or ethyl esters of fatty acid, which constitutes to biodiesel. It requires not only palm oil but addition of methanol and catalyst to assist the reaction. Byproduct formed are glycerol which are requires another setup to remove it [26]. Hence, to produce PME it requires an additional cost for the transesterification process. On the other hand, 10RPO:90D having weightage of close to PME by 0.53% requires no addition cost because it is just the blending of two separate material with no transesterification whatsoever. 20MCO:80D is still among the best biodiesel formulated having weightage lower than biofuel 60MCO:40RPO by 2.92%. This shows that the newly discovered application of cajuput oil has the potential to be commercialized as biodiesel due to its physiochemical properties in range with test limit.

4. CONCLUSION

In term of physiochemical characteristics, the best formulated biodiesel is 10% refined palm oil with 90% diesel (10RPO:90D), followed by 20% cajuput oil with 80% diesel (20MCO:80D) .While for biofuel, 60% cajuput oil with 40% refined palm oil (60MCO:40RPO) is at the top of the list. The most efficient blending method are ultrasonic homogenizer which gives biofuel/biodiesel the longest phase stability. Comparatively, 10RPO:90D and commercialized B7 could compete in the biodiesel market since both of them having small weightage percentage of just 5.58% and 5.05% respectively.

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