Utilization of Biodiesel Produced from Different Feedstocks for Use as Diesel Engine Fuel

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Abstract. The effect of fuel variability in Thailand is that diesel fuel is one of the fuels affected by fuel variability. The use of alternative energy is an alternative to diesel engines. Therefore, this research is interested in studying the physicochemical properties of test fuels, engine efficiency, combustion characteristics, and engine-out emissions of the engine in order to evaluate the production of biodiesel from different feedstocks as an alternative fuel in a single-cylinder diesel engine. Biodiesels produced from castor oil and pork lard oil by transesterification process with methanol using potassium hydroxide (KOH) catalyst. The fatty acids of biodiesel produced from castor oil (COME) and pork lard oil (PLOME) were characterized by Gas Chromatography–Mass Spectrometer (GC–MS) techniques. It can be seen that the main fatty acids in COME and PLOME are ricinoleic acid (C18:1 OH) and oleic acid (C18:1), respectively. The test fuel properties were examined according to the international fuel standards. The results indicated that the fuel properties of COME and PLOME are well-accepted biodiesel standards and testing methods except in the case of the kinematic viscosity of COME. The engine was operated at a fixed speed of 1,500 rpm with variation in load conditions. The experimental results of the engine performance showed that the use of COME and PLOME had higher brake specific fuel consumption (BSFC) and lower brake thermal efficiency (BTE) compared to diesel fuel. The combustion of COME and PLOME increased CO, HC and smoke emissions while decreasing NOX emissions in comparison with diesel fuel. Consequently, biodiesel derived from castor oil and pork lard oil is not recommended for use as a pure component in the diesel engine, while the use of such biodiesels as a blend component with diesel fuel can be a feasible way to alleviate the current fuel price crisis, which is intensely dependent on oil imports.

Keywords: Diesel Engine · Combustion Characteristics · Engine Performance · Castor Oil · Pork Lard Oil

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1 Introduction

Energy is the most important factor in the world because it is a critical reason for national economic development and social development. Therefore, energy demand will continue to increase due to the growth of the world population. On the contrary, production declined due to the reduction of reserves. The fossil fuel reserves can be divided into three categories: fuel oil, natural gas, and coal, which is estimated to be available again for a limited time. The shortest period of fuel oil reserves is less than 50 years, followed by natural gas and coal, with reserves of less than 100 and 200 years, respectively. The crisis can be seen as an opportunity for long-term clean energy development to reduce dependence on fossil energy and become energy independent. Thailand is facing energy problems from the high cost of fossil fuels. These issues have forced researchers to look for an alternative energy resource. Nowadays, the conversion of waste to energy as fuel is one approach that can also help reduce the use of fossil fuel. Therefore, investigating alternative fuel sources has become vital in this modern society, and biodiesel is considered to be a potential candidate to replace diesel fuel. Biodiesel is one of the alternative resources of energy due to its renewable fuel, environmentally friendly nature, biodegradability, and ability to be used in diesel engines. Biodiesel burns more cleanly than petroleum diesel fuel and it produces fewer greenhouse gas emissions and particulate matter. Moreover, the benefit of using biodiesel is that the sulfur content of biodiesel is lower with respect to diesel fuel. Therefore, when biodiesel is burned, the sulfur dioxide emissions are lower than those of diesel fuel [1, 2]. Since it contains oxygen-containing moieties in this biodiesel, namely the carboxylic acid groups, it has been successfully used as lubricity enhancer. An environmentally attractive alternative to conventional petroleum diesel fuel, biodiesel is defined as the mono-alkyl esters of vegetable or animal fats. Triglycerides (fats or oils) react with alcohol to form esters and glycerol. Several renewable feedstocks, including vegetable oils, animal fats, used cooking oils, and algae, can be produced into this biodiesel by a transesterification reaction in which triglycerides and alcohol (methanol or ethanol) are reacted. This reaction reduces the oil viscosity. As a result, the biodiesel is simply ignited and ready for use in a diesel engine. However, biodiesel made from non-edible feedstock is more attractive to avoid the competition between food and fuel. Most non-edible oil sources have the potential to produce biodiesel at a low cost.

In the present study, biodiesel is derived from non-edible and edible feedstocks, consisting of castor oil and pork lard oil. This is because castor oil has two remarkable properties as raw material for biodiesel production. Firstly, its use as an energy source does not compete with food production. Secondly, its cultivation does not need high inputs. Another interesting raw material for preparing biodiesel in Thailand is pork lard oil, which is used in to produce a variety of foods like sausages, fermented pork, and pork baloney sausage. Because of the large amount of waste pork lard generated during production and processing, environmental issues may arise. In addition, the properties of high molecular mass facts are that they are stable and not very reactive. When it burns or decomposes, it provides more energy than other types of biofuels. Therefore, it is possible that the pork fat can improve its quality and be converted into alternative energy. As a result, the pork lard oil will be used to produce biofuels. It is also considered to reduce environmental pollutants in one method. As an outcome, castor oil and pork lard oil were selected for this study to investigate their effects on physicochemical properties, engine efficiency, combustion characteristics, and engine-out emissions compared to diesel fuel for use as diesel engine fuel under variable load conditions. This was done to evaluate the suitability of using diesel engines to replace fossil fuels.

2 Material and Methods

2.1 Biodiesel Production

The biodiesel production from different feedstocks with methanol in the presence of a homogeneous base catalyst was done on a laboratory scale. The raw materials to be converted into biodiesel were collected from the local market in Nakhon Ratchasima, Thailand. Biodiesel production was performed for the study at the Engineering Laboratory, Suranaree University of Technology in Thailand. Two biodiesels were prepared through the transesterification of castor oil and pork lard oil. The reaction was activated by the use of methanol and a KOH catalyst. Triglycerides have their high viscosity reduced with this method, making fats and vegetable oils more usable as fuel for diesel engines. The schematic of the biodiesel production process for castor oil and pork lard oil is presented in Fig. 1. Moreover, Table 1 presents the parameters used during the transesterification of castor oil and pork lard oil. The methyl esters from castor oil and pork lard oil were designated as COME and PLOME, respectively.

2.2 Determination of Physicochemical Properties of Test Fuels

Gas chromatography-Mass Spectrometer (GC-MS) is one of the techniques used in the analysis to determine the type and quantity of substances of interest in a sample. The substance or sample that will be analyzed using this method must have volatile characteristics. This is because this technique is used to separate mixtures in the gaseous state based on the differences in the solubility and adsorption capacity of each substance in

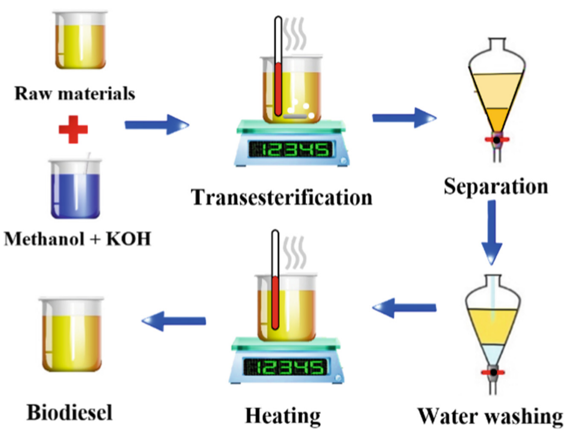

Fig. 1. Schematic of biodiesel production process.

Table 1. Conditions for Biodiesel Production.

Feedstocks	Condition Parameters			
	Molar ratio	Catalyst concentration	Reaction temperature	Reaction time
COME	9:1	1.0%KOH	30	30
PLOME	7.5:1	1.26%KOH	20	60

the mobile phase and stationary phase. The working principle of the gas chromatography technique is that when the mixture is introduced into the injection, the mixture evaporates and is carried into the column by convection gas, which acts as a moving phase Each mixture is separated by solubility and adsorption capacity in the column, which acts as a stationary phase. Subsequently, the substances removed from the column were measured with appropriate probes to record the retention time and signal size of each substance in a chromatogram. In this study, GC-MS methods were used to identify the fatty acids in biodiesel produced from castor oil and pork lard oil. The produced fuel is a complicated chemical combination, and GC-MS is a chemical analytical technique used to separate and identify chemical compositions at the molecular level. Previous publication provides a comprehensive description of the GC-MS methods used for the analysis [4]. The ASTM standards, which are widely accepted biodiesel standards and testing methods, were used to examine the physicochemical properties such as specific gravity, density, viscosity, flash point, gross calorific value, distillation temperature and cetane index of COME, PLOME, and diesel fuel. However, the kinematic viscosity of COME was the exception.

2.3 Experimental Setup and Testing

In order to evaluate and compare the results of using different test fuels, the experimental investigation was put to the test. An eddy current dynamometer was also used to test a Kirloskar TV1, four-stroke, water-cooled, direct injection diesel engine. The specifications of diesel engine are presented in [4]. The experimental procedure is schematically shown in Fig. 2. The engine was operated at a constant 1,500 rpm with varying engine loads for all test fuels. A burette was used to measure fuel consumption on a volumetric basis, and a digital timer was used to record the time required to consume 10 ml of fuel. In the meanwhile, a charge amplifier and a data collecting board were coupled to an in-cylinder pressure sensor mounted on the cylinder head. During the combustion chamber of engine, the shaft encoder was used to measure the crank angle. The engine's tailpipe was located where the exhaust gas emission probe was placed. A Testo 350 flue gas analyzer was used to evaluate nitrogen oxides (NOX), carbon monoxide (CO), and unburned hydrocarbons (HC), and a Testo 308 smoke meter was used to measure smoke emissions. The technical specifications of exhaust gas analyzers are shown in [4]. After the diesel engine was already running steadily, all of the resulting data was read. Three measurements of each parameter were taken to confirm the reliability of the experiment results.

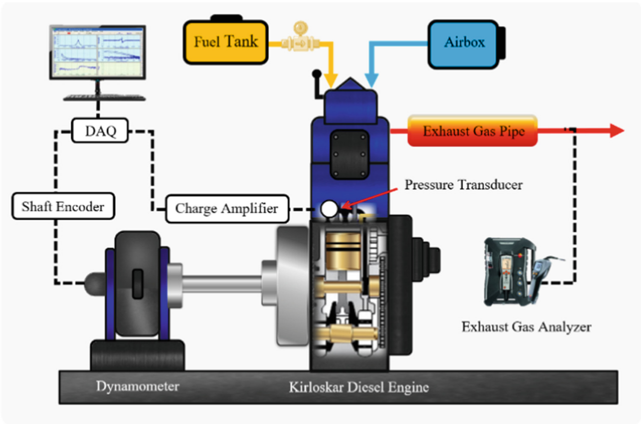

Fig. 2. Schematic representation of the experimental setup.

3 Material and Methods

The main factors affecting the suitability of tested fuel are its basic fuel properties, engine efficiency, combustion characteristics, and engine-out emissions. A diesel engine using biodiesel prepared with different feedstocks was studied without any modification.

3.1 Basic Fuel Properties of Test Fuels

The content of the fatty acid composition of biodiesel from castor oil (COME) and pork lard oil (PLOME) was investigated using GC-MS analysis. The recording of the results of GC MS analysis is recorded in the form of a chromatogram containing time and signal magnitude. The content of each fatty acid in biodiesel in this study was calculated by the area normalization method. It was calculated using the area under curve compared to the total area under curve. The experimental results of the fatty acid profiles and percent composition of COME and PLOME are summarized in Table 2. As a result, it can be observed that ricinoleic acid (C18:1OH), which comprises about 85.15 percent of the total weight of COME, is the most abundant fatty acid. In addition, the better combustion processes are enhanced by the oxygen content of COME and the hydroxyl groups present in ricinoleic acid [5]. While oleic acid (C18:1), palmitic acid (C16:0), and stearic acid (C18:0), which together account for about 43.12%, 23.15%, and 1.055% of the weight, are the major characteristics of PLOME. In fact, oleic acid also comprises the majority of many oils and fats. Furthermore, PLOME has a high content of fatty acids with shorter chain lengths, including myristic acid (C12:0), capric acid (C10:0), and lauric acid (C12:0) (C14:0).

The fuel properties of COME, PLOME, and diesel fuel were tested using standard ASTM method. It is determined by the Department of Energy Business, Ministry of Energy, Thailand. The fuel properties of all test fuels analyzed include kinematic viscosity, specific gravity, density, flash point, gross calorific value, cetane index, and distillation. The experimental results of fuel properties are summarized in Table 3. The

Table 2. Fatty Acid Composition of Biodiesel.

Common Name (Structure)	Fatty acid composition (%wt)	
	COME	PLOME
Caprylic acid (C8:0)	0.02	Not Detected
Capric acid (C10:0)	0.01	0.08
Lauric acid (C12:0)	Not Detected	0.42
Myristic acid (C14:0)	Not Detected	1.96
Palmitic acid (C16:0)	1.34	23.15
Stearic acid (C18:0)	1.44	10.55
Oleic acid (C18:1 - cis (n9))	3.37	43.12
Ricinoleic acid (C18:1 OH)	85.15	Not Detected
Linoleic acid (C18:2 - cis (n6))	5.09	16.12
Arachidic acid (C20:0)	0.02	0.26
Others	3.56	4.34

kinemetric viscosity, specific gravity and flash point of COME and PLOME are higher than diesel fuel, while gross calorific value, and cetane index are lower. However, it is evident that the kinematic viscosity, specific gravity, gross calorific value, and cetane index of biodiesels are above the limit prescribed by the diesel fuel standard. This implies that the direct use of pure biodiesel in a diesel engine may need some engine modification or may produce poor combustion behavior, resulting in high exhaust emissions.

3.2 Analysis of Engine Performance

Engine performance is the ability of various aspects of an engine to work together, such as engine power, torque, efficiency, and fuel consumption. Each engine is designed to have different performance, measurement, and testing of engine performance. In order to use the data to analyze the design and improvement of the engine to be suitable or the most efficient. In this study, the engine performance of diesel engines using COME and PLOME without any engine modification was evaluated and compared with diesel fuel operation in terms of brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE).

The variation of BSFC and BTE for COME, PLOME, and diesel fuel with engine load is shown in Fig. 3. According with experiment results, BSFC decreased for all test fuels as engine load increased. This is because the increment in brake power is higher than that of the increase in fuel consumption [7]. Due to their lower energy content as compared to diesel fuel, the COME and PLOME are shown with higher BSFC than diesel fuel [8]. This is because diesel fuel requires more fuel to create the same amount of power. Furthermore, the reduction in BSFC may also be related to better thermal efficiency of an engine, which increases along with engine load. The BSFC of COME was also found to be higher than that of POME, whereas for all test fuels, the BTE of

Table 3. Physical and Chemical Properties of Test Fuels.

Fuel properties	Test fuels		
	Diesel	*COME*	*PLOME*
Kinematic viscosity @ 40 °C (cSt)	3.37	18.02	5.05
Specific gravity at 15 °C	0.830	0.910	0.875
Density @ 15 °C (kg/m^3)	829	909	874
Flash point (°C)	78	190	152
Gross calorific value (MJ/kg)	43.48	37.15	39.53
Cetane index	63.44	38.34	48.03
Distillation temperature (°C)			
Initial boiling point (°C)	188	148	306
10% Recovered (°C)	228	264	312
50% Recovered (°C)	290	316	330
90% Recovered (°C)	342	374	338
Final boiling point (°C)	348	378	346

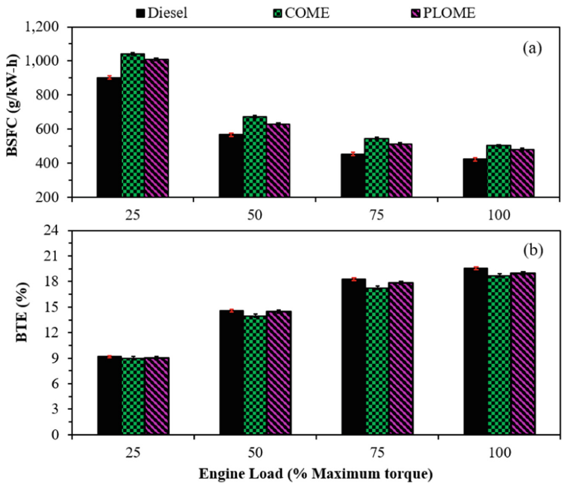

Fig. 3. Engine performance of test fuels at various engine loads.

an engine increased as engine load increased. It is clear that the relation between BTE and BSFC is inverse. The principal reason of this could be because when engine load is increased, temperature and pressure inside the combustion chamber increase, resulting in higher conversion and lower heat loss. For all engine loads, COME and PLOME have significantly lower BTE than diesel fuel as compared to diesel fuel. The lower BTE of COME and PLOME than that of diesel fuel may be caused by the low calorific value, and the influence of higher viscosity results in poor atomization and fuel vaporization [9]. Additionally, the results showed that COME had a lower BTE than PLOME. This result might indicate the abovementioned reason.

3.3 Analysis of Combustion Characteristics

A diesel engine is a type of internal combustion engines that burns diesel fuel as the fuel. This is combustion, also known as burning, in which the chemical energy of the fuel is converted into thermal energy and the thermal energy is converted into mechanical energy. A diesel engine will ignite the mixture between air and fuel, which is called compression ignition. Fuel is injected into a combustion chamber and air is ignited. As a result of combustion, the pressure and temperature increase, thereby causing the crankshaft to rotate. These working principles can be analyzed by combustion characteristics. For that reason, the combustion characteristics of COME and PLOME compared to diesel fuel in terms of in-cylinder pressure (ICP) and rate of heat release (RoHR) were investigated.

The ICP is a significant necessity for engine behavior and provides key information on the combustion process which takes place inside a combustion chamber of diesel engine [10]. Figure 4 presents the results of this experiment for all test fuels. It is clear that increasing engine load caused the peak ICP to increase. High fuel supply volumes along with an increase in engine load are the main factors of increased ICP. For all engine loads, using COME and PLOME results in higher cylinder pressure than diesel fuel. The RoHR profile may also be used to obtain information on the combustion characteristics of diesel engine inside the combustion chamber. Due to the low ignition delay of engine comparing to the high engine load, the peak RoHR tended to decrease with increased engine load, as can be noticed from the RoHR results. When compared to diesel and PLOME, RoHR of COME showed a longer ignition delay. This is because COME has a longer igniting delay because to its higher viscosity and lower cetane index [11]. In contrast, when compared to diesel fuel, it can be shown that ignition delay of PLOME advances during the ignition delay period at all engine loads. This may be due to the higher oxygen content in chemical properties of PLOME, which has reduced ignition delay [12].

3.4 Analysis of Exhaust Gas Emissions

One method of analysis for characterizing combustion and able to understand the engine of an engine under various conditions is the measurement of the exhaust gas emissions produced from the combustion of an engine. The analysis of the exhaust gas emissions from diesel engines that use biodiesel from different feedstocks as a fuel are presented. This section discusses exhaust gas emissions, including those of nitrogen oxides (NOX), carbon monoxide (CO), unburned hydrocarbons (HC), and smoke.

The experimental result of exhaust gas emissions with increasing engine load for COME and PLOME compared to diesel fuel is shown in Fig. 5. It can be observed that the exhaust gas emissions (NOX, CO, HC, and smoke index) increased with increasing engine load for all test fuels.

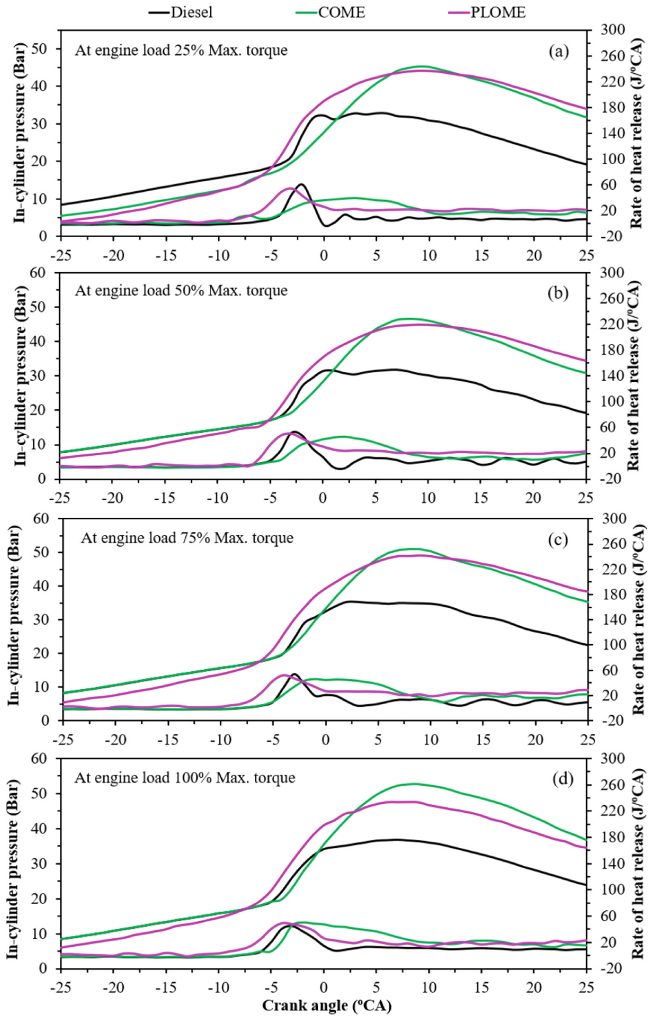

Fig. 4. Combustion characteristics of test fuels at various engine loads.

One of the main exhaust gas emissions produced by diesel engines is NOX emissions. Diesel engines generate NOX emissions by three major mechanisms: the thermal mechanism, the prompt mechanism, and the fuel mechanism [13]. The NOX emissions from COME and PLOME were lower than those from diesel fuel for all engine loads, according to the experimental results. Although biodiesel has a higher oxygen content than diesel fuels, this helps to improve combustion efficiency. Inversely, the higher viscosity of COME and PLOME can be attributed to the injection of larger droplets and more biodiesel, which increases the temperature in the combustion chamber and enhances NOX emissions [14]. As comparing between COME and PLOME, NOX emissions of PLOME was higher than the combustion of COME owing to the advance in start of combustion of PLOME leads to more available time for the fuel combustion which tends to

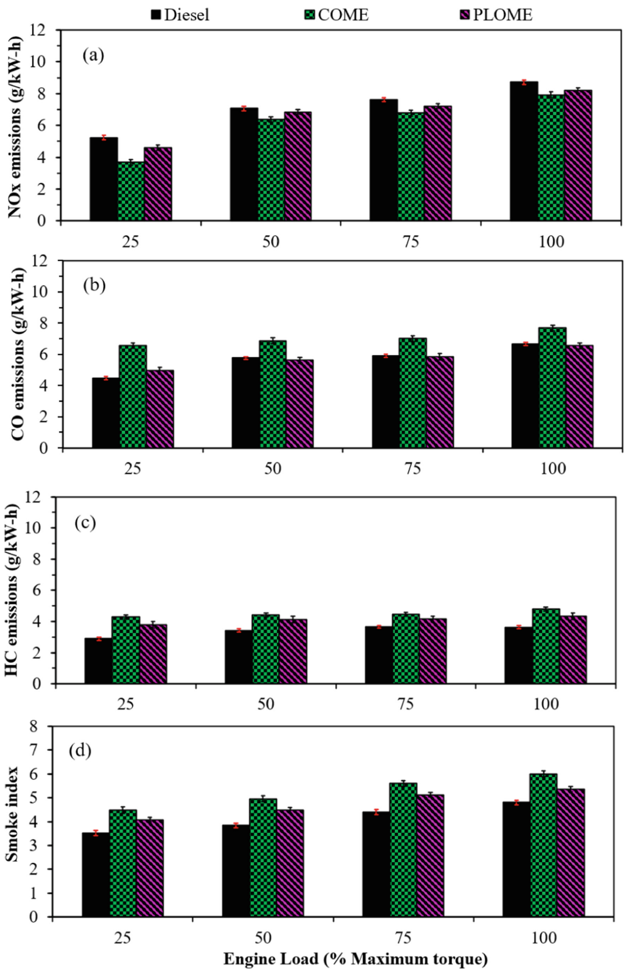

Fig. 5. Emission characteristics of test fuels at various engine loads.

produce more complete combustion, resulting in higher in-cylinder temperature which favors NOX formation. In addition, the extremely high viscosity of COME, which tends to reduce the in-cylinder temperature can be used to justify the lower NOX with the combustion of COME compared to PLOME.

Due to a lack of oxygen during the combustion process, CO emissions are products of incomplete combustion inside the combustion chamber [15]. The experiment showed that the amount of CO emissions increased as engine load increased for all test fuels, and that for all engine loads, COME and PLOME had higher CO emissions levels than diesel fuel. The main factor contributing to higher CO emissions was the high viscosity of COME and PLOME, which had an impact on poor atomization and increased CO emissions [16]. When COME and PLOME were compared, CO emissions of COME were more than PLOME at all engine loads. The lower cetane index, which results in less time for combustion and causes incomplete combustion, is the reason for the longer ignition delay period of COME [17].

Unburned hydrocarbons are produced as a result of incomplete fuel combustion, which is the cause of the formation of HC emissions in engine exhaust gas emissions. According to the experimental results of HC emissions, COME and PLOME had higher HC emissions than diesel fuel because of kinematic viscosity and lower gross calorific value of biodiesel. For all engine loads, HC emissions of COME were higher than PLOME when compared to each other. Due to poor atomization caused on by high viscosity of COME during combustion, the combustion properties decline and HC emissions increase [18].

Incomplete combustion results in smoke emissions, which form in the rich mixture zone of combustion chamber of a diesel engine. The smoke index of COME and PLOME was higher than diesel fuel for all engine loads, according to the experimental results of smoke emissions. In fact, biodiesel's high oxygen content increases combustion efficiency [19]. On the other hand, higher density and kinematic viscosity of POME and PKOME will have a significant effect on atomization and the process of volatilization, leading to more smoke. In a comparison of COME and PLOME, smoke emissions of COME were higher than PLOME for all engine loads. This is because COME has a richer mixing zone in the combustion chamber, which causes the fuel to burn incompetently and resulting in increased smoke emissions [20]. This is because COME has a higher viscosity, a lower cetane index, and a longer ignition delay period.

4 Conclusion

The aim of this study is to evaluate, without modifying the engines, whether alternative feedstocks (castor oil and pork lard oil) affect the physical and chemical properties, engine performance, combustion characteristics, and exhaust gas emissions of diesel engines. The following conclusions may be obtained from the present study:

- The fatty acid in COME is ricinoleic acid (C18:1OH), comprising about 85.15% by weight. While the major constituents of PLOME are oleic acid, palmitic acid, and stearic acid (C18:0) at about 43.12%.
- The fuel properties of COME and PLOME are well-accepted biodiesel standards and testing methods, unless in the case of the kinematic viscosity of COME.
- The use of COME and PLOME tended to increase BSFC, resulting in a decrease in BTE with respect to diesel fuel for all engine loads.
- According to the combustion characteristics results, COME and PLOME increased in-cylinder pressure as engine load increased, resulting in an effect on combustion characteristics. Furthermore, using PLOME causes combustion to start faster than with diesel fuel, which results in a lower rate of heat release. The ignition delay of COME was longer than that of diesel fuel and PLOME. While the ignition delay of COME was longer than that of diesel fuel and PLOME.
- According to the results of an exhaust gas emissions experiment, combustion of COME and PLOME generated more CO, HC, and smoke emissions while emitting less NOX when compared to combustion of diesel fuel. Exhaust gas emissions are caused mainly by the characteristics and chemical composition of the fuel used.

- The use of biodiesel derived from castor oil and pork lard oil is not recommended for use as a pure component in the diesel engine, while using such biodiesels as a component of diesel fuel blends could be a feasible solution to the current fuel price crisis, which is significantly dependent on oil imports.

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