INFLUENCE OF FATTY ACID METHYL ESTERS IN BIODIESEL

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Abstract - Biodiesel processed from vegetable oils is the most common biofuel for diesel engines nowadays.The vegetable oils compose of fatty acids and therefore, biodiesel'sphysical and chemical properties,combustion characteristics and exhaust gas emissions are influenced by fatty acids.In this study, in order to examine the influence of fatty acid methyl esters (FAMEs) in biodiesel, five common FAMEs were chosen.Then the total of six forms of FAMEs,two were in straights and four were in blends, were formulated from five FAMEs. These were(i)methyl laurate 100wt% (ML100); (ii) methyl oleate100wt%(MO100); (iii)methyl laurate 50wt%+methyl oleate 50wt% blend (MOL50); (iv) methyl myristate 50wt%+methyl oleate 50wt% blend (MOM50);(v)methyl palmitate 50wt%+methyl oleate 50wt% blend (MOP50); and (vi)methyl stearate 50wt%+methyl oleate 50wt% blend (MOS50). To study their physical and chemical properties, combustion characteristics and exhaust gas emissions,the analyses and engine test experiments were done. Regarding the physical and chemical properties of FAMEs,they were within the reasonable range of a fuel.From the engine test experiments, the ignition delays of FAMEsdecreased with the longer straight chain of hydrocarbon molecules. The brake thermal efficiencies of FAMEswere competitiveand hadgood energy conversion rates.From the exhaust gas emissions, HC and CO emissions from all FAMEsvaried with the oxygen contents.The NOx emissions from FAMEswere seen along with the fuel injection timings of combustion. The smoke emissions of FAMEs were influenced by the oxygen contents and the more oxygen in FAMEs caused the less smoke emissions.

Keywords - Biodiesel, Fatty Acid Methyl Esters, Physical and Chemical Properties, Combustion Characteristics, Exhaust Gas Emissions.

I. INTRODUCTION

Biodiesel, a renewableandbiodegradable alternative diesel fuel, is the most common type of biofuel. It has many environmental benefits andproduces less toxic pollutants and greenhouse gases than diesel fuel[1], [2]. It can be used in straight form (B100) or can be blended with the diesel in the form of B2 (2% biodiesel, 98% diesel), B5 (5% biodiesel, 95% diesel) and B20 (20% biodiesel, 80% diesel). Biodiesel can be used in the diesel engine without modification to the engine and the fuel injection system[3]. At the present, many countries promote the use of biodiesel by themandatory of the governments. Therefore total world biodiesel consumption is rising from 1.1 billion liters in 2001 and 35.2 billion liters in 2016[4]. The most consuming countries are United States, Brazil, France, Indonesia and Germany.

Biodiesel can be processed from the variety of vegetable oils including edible and nonedible,and the most commonly processed arefrom palm oil, rapeseed oil and soybean oil.Among the various kind of vegetable oils, palm oil and coconut oil compose of the larger amount of saturated fatty acids, such as palmitic acid and lauric acid respectively. But in rapeseed and soybean oils, these mostly consist of oleic acid and linoleic acid,unsaturated fatty acids. The fatty acid compositions of some vegetable oils are as shown in Table 1[5].Generally, most of vegetable oils contain fatty acids usually with the carbon numbers ranging from C6 to C18. Some of these fatty acids are saturated, while others are unsaturated. The saturated fatty acids do not contain carbon-carbon double bond and while unsaturated fatty acids have carbon-carbon double bond[6].Depending on the feedstock used in its production, biodiesel is diverted into several different compositions of FAMEs.

Fatty acid	C:N	Vegetable oil (*wt%*)			
		Coconut	Palm	Rapeseed	Soybean
Caproic	6:0	0.4	-	-	-
Caprylic	8:0	0.7	-	-	-
Capric	10:0	0.6	-	-	-
Lauric	12:0	47.5	0.3	-	-
Myristic	14:0	19.1	1.1	-	-
Palmitic	16:0	9.8	44.1	4.3	10.5
Palmitoleic	16:1	-	0.2	0.1	-
Stearic	18:0	3.8	4.5	1.9	3.8
Oleic	18:1	5.9	40.1	59.7	25
Linoleic	18:2	0.4	9.1	21.7	52.2
Linolenic	18:3	0.1	0.6	9.4	7.6
Gadoleic	20:1	-	-	1.5	0.3
Behenic	22:0	-	-	0.4	0.4
Erucic	22:1	-	-	0.6	-

C: No. of carbon, N: No. of carbon-carbon double bond

TABLE I
FATTYACIDCOMPOSIONSOF SOME VEGETABLE OILS

From our previous studies, rapeseed oil biodiesel (rapeseed oil methyl ester-RME) and soybean oil biodiesel(soybean oil methyl ester-SME) hadcomparable fuel properties and better combustion characteristics, and lower HC, CO and smoke emissions and higher NOx emission than that of the diesel[7],[8]. Also palm oil biodiesel(palm oil methyl

ester-PME)hadfavorable fuel properties and combustion characteristics andlower NOx emission compared tothe diesel.And coconut oil biodiesel(coconut oil methyl ester-CME) showedcompetitive fuel properties, better combustion characteristicsand lessexhaust gas emissions than those of thediesel [8]. Therefore, it is clear that the variation in fuel properties, the combustion characteristics, and the exhaust gas emissions of biodiesel are influencedby the compositions of FAMEs in it.

The purpose of this study was to clarify the influence of FAMEs in biodiesel. Therefore, five common FAMEs of vegetable oils, methyl laurate, methyl myristate, methyl palmitate, methyl stearate and methyl oleate were chosen. And then the total of six forms of FAMEs, two were in straights and four were in blends, were formulated from five FAMEs. These were (i) methyl laurate 100wt% (ML100); (ii) methyl oleate 100wt% (MO100); (iii) methyl laurate 50wt%+methyl oleate 50wt% blend (MOL50); (iv) methylmyristate 50wt%+methyl oleate 50wt% blend (MOM50); (v) methyl palmitate 50wt%+methyl oleate 50wt% blend (MOP50); and (vi) methyl stearate 50wt%+methyl oleate 50wt% blend (MOS50).The analyses were carried out to investigate the physical and chemical properties and the engine test experiments weredone to studythe combustion characteristics and the exhaust gas emissions.

II. TESTFUELS

The six forms of FAMEs are expressed in Table 2.

FAMEs	Mixture 1	Mixture 2
ML100	Methyl laurate 100wt%	
MO100	Methyl oleate 100wt%	
MOL50	Methyl laurate 50wt%	Methyl oleate50wt%
MOM50	Methylmyristate50wt%	Methyl oleate50wt%
MOP50	Methyl palmitate 50wt%	Methyl oleate50wt%
MOS50	Methyl stearate 50wt%	Methyl oleate50wt%

TABLE II
SIX FORMS OFFAMEs

In the test fuel formulation process, methyl oleate which has lower pour point (-15.0˚C) was used as a based mixture for blending and to liquefy the methyl stearate, which has very high pour point (39.1˚C), solid state at room temperature.The six forms of FAMEs were (i) methyl laurate 100wt% (ML100); (ii) methyl oleate 100wt% (MO100); (iii) methyl laurate 50wt%+methyl oleate 50wt% blend (MOL50); (iv) methylmyristate 50wt%+methyl oleate 50wt% blend (MOM50); (v) methyl palmitate 50wt%+methyl oleate 50wt% blend (MOP50); and (vi) methyl stearate 50wt%+methyl oleate 50wt% blend (MOS50). The JIS No. 2 diesel was also used as a test fuel for reference and comparison. The properties of test fuels are shown in Table 3.

The net calorific values of FAMEs were calculated from the Carbon (C), Hydrogen (H) and Oxygen (O) contents. Comparing the net calorific value of FAMEs, ML100 was the lowest and MOS50 was the highest. But the net calorific values of all FAMEs were about 10-15% lower than that of the diesel. The densities of FAMEs were between 865-878 kg/m^3 and those of ML100 and MO100 were the lowest and the highest respectively. The densities of all FAMEswere higher than that of the diesel. The kinematic viscosity of ML100 and MOL50 were lower than the other FAMEs and their value were closer to that of the diesel. The pour point of MOS50 was 25˚C and MO100 was -15˚C. MOL50 had the same pour point that of the diesel and which was -12.5˚C. The oxygen content in FAMEs variedin the range of 10.77-14.95 wt%. ML100 had 14.95wt% of oxygen and it wasthe highest content in the FAMEs. Also it was found that the more oxygen contents in FAMEsreduced the net calorific values.

III. EXPERIMENTALAPPRATUS AND PROCEDURE

A single cylinder DI diesel engine used for the experiments was a naturally aspirated, water-cooled, 4-stroke diesel engine. The specifications of the engine are shown in Table 4. The same fuel injection system was used in both six FAMEs and the diesel.Before starting the experiments, the engine was warmed up by idling speed to get stability by checking engine revolution and the coolant temperature. When engine got stability the experiments were started. The engine speed was setat 2000 rpm and the loads were applied from 0% to 25%, 50%, 75% and 100%,step by step.At 100% load; brake mean effective pressure, Pmewas 0.67 MPa. From exhaust gas emissions, the CO emission was measured by non-dispersive infrared detector (NDIR), the HC emission was measured by flame ionization detector (FID), the NOx emission was measured by chemiluminescent detector (CLD) and the smoke emission was measured by light transmitting type smoke meter (opacimeter). Also the cylinder pressure and the needle lift of fuel injector were measured at all load levels.

Properties	ML100	MO100	MOL50	MOM50	MOP50	MOS50	Diesel
Cetane number	-	-	-	-	-	-	56
Net Calorific value(MJ/kg)	36.64	38.8	37.72	38.27	38.7	39.07	43.12
Density(kg/m^3)	865	878	870	872	872	875	832
Kinematic Viscosity(mm^2/sec)	4.1	7.1	5	5.63	7.1	6.5	4.7
Pour point(˚C)	2.5	-15	-12.5	2.5	10	25	-12.5
C(% mass)	72.9	77.03	74.9	75.7	76.29	76.77	87.3
H(% mass)	12.5	12.16	12.16	12.28	12.38	12.46	12.5
O(% mass)	14.95	10.81	12.88	12.02	11.33	10.77	0

TABLE III - PROPERTIESOFTESTFUELS

Description	Specification
Engine	Singlecylinder, Fourstroke, DI Diesel
Bore × Stroke	110 mm × 106 mm
Stroke volume	1007 cm^3
Compression ratio	16.3
Rated power	11.77 kW / 2200 rpm
Nozzleopening pressure	19.6 MPa
Injection nozzle type	Hole (ϕ 0.33 mm × 4)
Injection timing	18 deg. CA BTDC
Cooling System	Water Cooled

TABLE IV
SPECIFICATIONS OFTEST ENGINE

IV.RESULTSAND DISCUSSION

The injection timings, the ignition delays and the ignition timings of the test fuelsare shown in Fig.1.These data were derived from the needle lift of fuel injector and the heat release rate of combustion chamber of the test engine. The fuel injection timing of MO100 and MOS50 were slightly faster than the other FAMEs in most load levelsand ML100 was almost the same as that of the diesel. The faster injection timings were due to the higher density of these FAMEs.

The ignition delay time of MOS50 was shorter than those of the other FAMEs at all load levels and the ignition delay times increased as the following ascending order; MOS50<MOP50<MOM50<MO100<MOL50<ML100. The shorter ignition delay time means the better ignition ability. Therefore, it can be assumed that the ignition ability of FAMEs will also be in the following ascending order; methyl laurate<methyl oleate<methyl myristate<methyl palmitate<methyl stearate. Generally, the saturated fatty acid with long chain and unbranched have higher cetane number and better ignition ability while unsaturated fatty acid with carbon-carbon double bonds have lower cetane number and poor ignition ability [9]. From experimental results, the ignition delays of saturated FAMEs(methyl laurate, methyl myristate, methyl palmitate and methyl stearate) decreased with the longer straight chain of hydrocarbon molecules.And among FAMEs with the same carbon numbers (methyl oleate and methyl stearate), the ignition delays werelonger with increasing carbon-carbon double bond. Comparing the ignition delays between FAMEs and the diesel, all FAMEs had shorter. From this result, FAMEs had better ignition ability than that of the diesel.

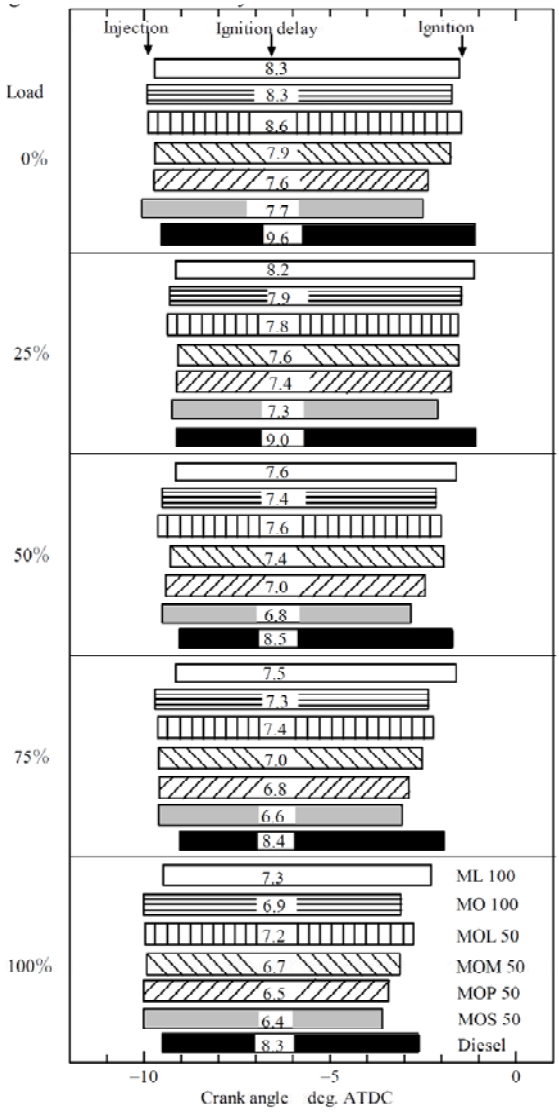


Fig. 1Injection timing, ignition delay and ignition timing

The brake thermal efficiencies of the test fuels are shown in Fig. 2.The brake thermal efficiencies of FAMEs hadnot much difference between each other. But all FAMEs showed slightly higher brake thermal efficiencies than that of the diesel. From this finding, FAMEs with more than 10% oxygen contentshad better combustion process and therefore they had

better energy conversion rates compared to the diesel. The brake specific fuel consumption of the test fuels are shown in Fig.3. In all FAMEs, brake specific fuel consumption of ML100 is the highest, because of its lowest net calorific value. The brake specific fuel consumption was changed along with the net calorific value of FAMEs and application of load levels. The higher brake specific fuel consumptions of FAMEs were due to the lower in net calorific value of those compared to the diesel.

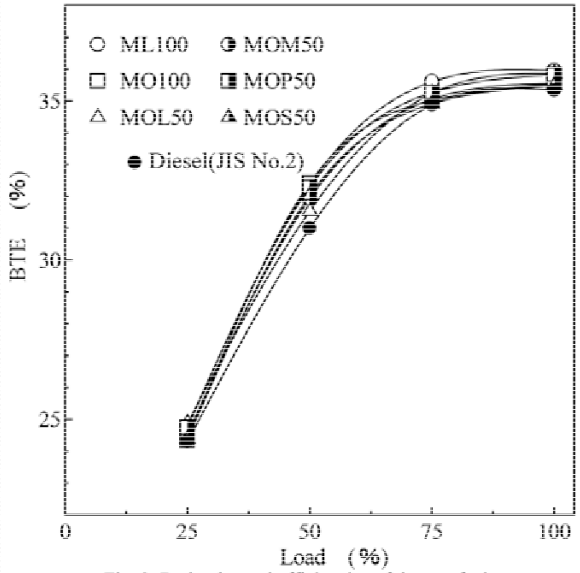


Fig. 2 Brake thermal efficiencies of the test fuels

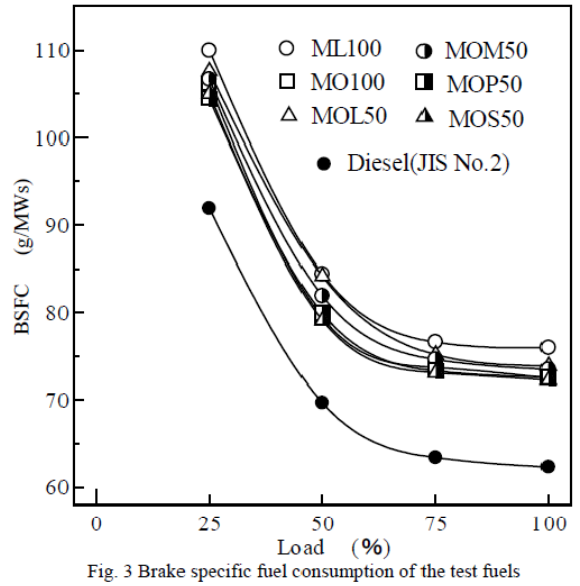


Fig. 3 Brake specific fuel consumption of the test fuels

The HC emissions from the test fuels are shown in Fig. 4. The HC emission from ML100 was the lowest and from MO100 was the highest in all FAMEs. Lower HC emission from ML100 will be related with the better combustion process. This was assumed due to the more oxygen content in MOL100,it carriedout more complete combustion process. Furthermore, the lower kinematic viscosity formed the better fuel air mixture and reduced fuel rich zone or incomplete combustion. The HC emissions from all FAMEs varied with the oxygen contents as well as kinematic viscosities, and they had loweremissions than that of the diesel.

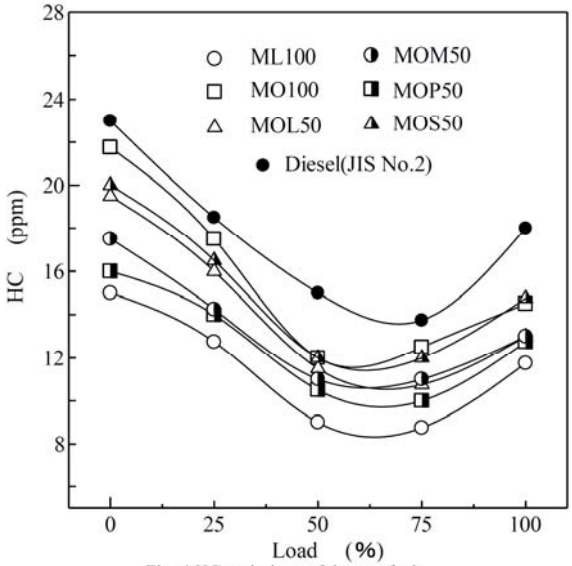


Fig. 4 HC emissions of the test fuels

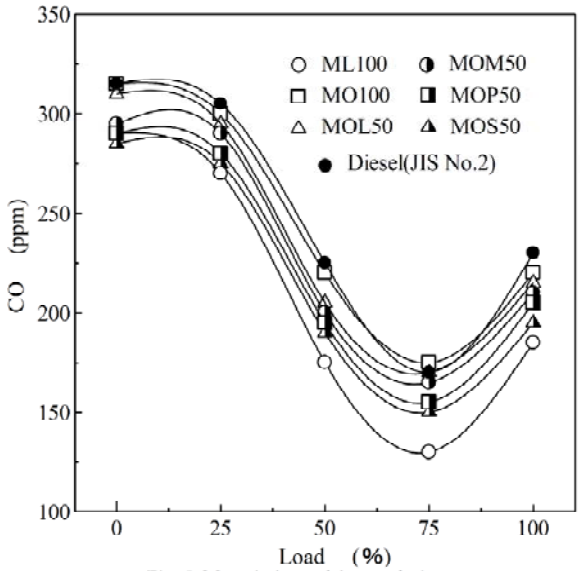


Fig. 5 CO emissions of the test fuels

The CO emissions from the test fuels are shown in Fig.5. The CO emission from ML100 was lower and MO100 was higher than the other FAMEs, in most of the load levels. The cause and formation of CO emission were similar as that of HCemission. At 100% load level the CO emissions from FAMEs were lower than that of the diesel.

The NOx emissions from test fuels are shown in Fig.6. The NOx emissions from ML100 and MOM50were slightly lower and, MO100 and MOS50 were higher than the other FAMEs. But the NOx emission differences in MOL50, MOM50 and MOP50 were very small. It is a bit complicate to deduce the reason, because the NOx formation in combustion process hasmanydifferent causes. Generally, the earlier combustion timing can cause higher combustion

temperature and to higher NOx emission [10]. Therefore, the NOx emissions from FAMEs willbe concerned and influenced with the fuel injection timing.And most of the NOx emissions were in accordance with the fuel injection timing as shown is Fig.1.

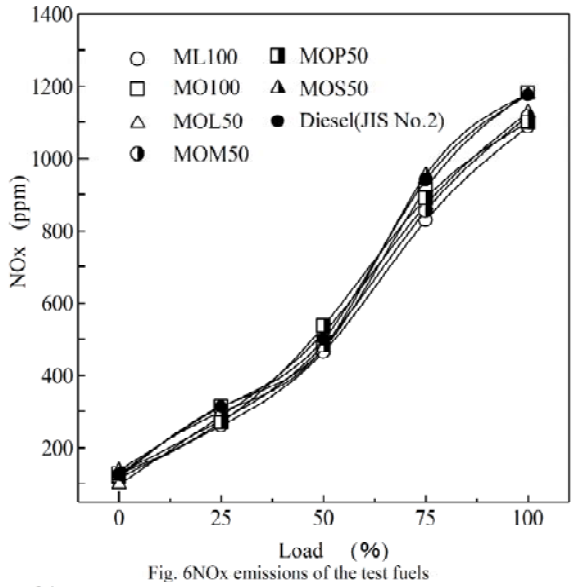


Fig. 6NOx emissions of the test fuels

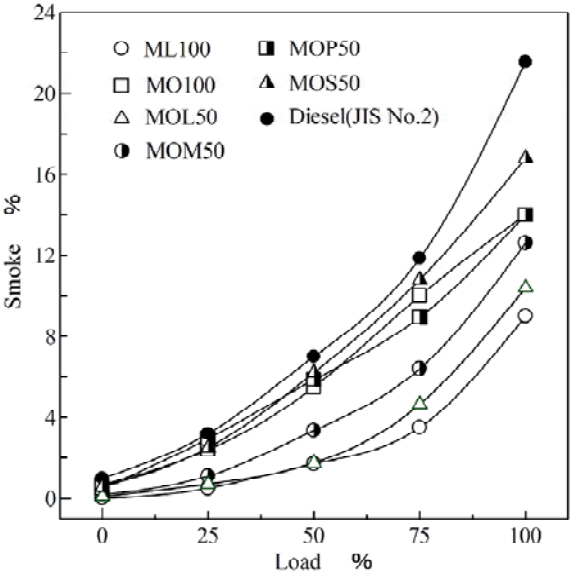


Fig. 7 Smoke emissions of the test fuels

The smoke emissions of the test fuels are shown in Fig.7. The smoke emission in FAMEs varied with the oxygen content in those and the less smoke emissions can be found in FAMEs with the more oxygen contents. Therefore, the smoke emission from ML100 was seen the lowest and MOS50 was the highest in the FAMEs. The smoke emissions from all FAMEs were lower than that of the diesel.

V.CONCLUSIONS

In order to study the influence of FAMEs in biodiesel,analyses were carried out to investigate physical and chemical properties and the engine test experiments were done to find out the combustion characteristics and the exhaust gas emissions.The six forms of FAMEs,ML100, MO100, MOL50, MOM50, MOP50 and MOS50 were prepared from five common FAMEs of vegetable oils. From the results, the following conclusionscould be drawn.

A. For six forms of FAMEs test fuels

1)The physical and chemical properties of FAMEs:
Net calorific value:
ML100<MOL50<MOM50<MOP50<MO100<MOS50
Density:
ML100<MOL50<MOM50=MOP50<MOS50<MO100
Kinematic Viscosity:
ML100<MOL50<MOM50<MOS50<MO100=MOP50
Pour point:
MO100<MOL50<ML100=MOM50<MOP50<
MOS50
Oxygen content:
MOS50<
MO100<MOP50<MOM50<MOL50<ML100
2)The combustion characteristics:
Ignition delay:
MOS50<MOP50<MOM50<MO100<MOL50<ML100
Brake thermal efficiencies:
ML100≈MO100≈ MOL50≈ MOM50≈ MOP50≈MOS50
3)The exhaust gas emissions (at 75% load):
HC emission:
ML100< MOP50< MOL50< MOM50< MOS50< MO100
CO emission:
ML100<MOS50<MOP50<MOM50<MOL50<MO100
NOx emission:
ML100<MOM50<MOL50<MOP50<MO100<MOS50
Smoke emission:
ML100< MOL50< MOM50< MOP50< MO100<MOS50

B. For five common FAMEs (Assumption)

1) Methyl laurate and methyl myristate:Have betterphysical and chemical properties compared to methyl palmitate, methyl stearate and methyl oleate.
2)Methyl stearate and methyl palmitate:Havebetter combustion characteristics than those of methyl laurate, methyl myristare, and methyl oleate.
3)Methyl laurate and methyl myristare:Have less exhaust gas emissions than those of methyl palmitate, methyl stearate and methyl oleate.

Therefore, by understanding physical and chemical properties, combustion characteristics and exhaust gas emissions of each of FAMEs, and the influence of FAMEs in biodiesel, we can enhance the quality of

biodieseland producebetter and moreeco-friendly biodiesel. Consequently, biodiesel with favorable fuel properties, better combustion characteristics and less exhaust emissions can be processedfromblending ofvegetable oils, based on the selection of fatty acid compositions.

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