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Influence of 1-butanol addition on diesel combustion with palm oil methyl ester/gas oil blends

Y. Yoshimoto [a,*], E. Kinoshita [b], L. Shanbu [c], T. Ohmura [d]

[a] Mechanical and Control Engineering, Niigata Institute of Technology, Fujihashi 1719, Kashiwazaki, Niigata 945-1195, Japan
[b] Faculty of Engineering, Kagoshima University, Japan
[c] Graduate school of Technology, Niigata Institute of Technology, Japan
[d] Niigata Diamond Electronic Co., Ltd, Japan

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ABSTRACT

PME (Palm oil methyl ester) is a promising alternative fuel among biodiesels, because palm oil is the most produced feedstock and its yield is the highest among vegetable oil crops. However, PME has a serious drawback in its relatively high pour point. The aim of this investigation is to extend the range of utilization of PME by improving its low temperature fluidity. The present study used three kinds of blended fuels composed of PME/gas oil/1-butanol to show the effect of lower pour points. Neat PME has a pour point of 19 °C, for a PME blend with 20% PME (PME20) the pour point is −5 °C, and with 40 mass% 1-butanol blended into the PME20 the pour point is −10 °C. Using four kinds of PME/gas oil blends as the base fuels the influence of 1-butanol addition on the engine performance, combustion characteristics, and exhaust emissions of a small single cylinder DI (direct injection) diesel engine was examined. The brake thermal efficiency of the base fuels changed little when 1-butanol was added up to 40 mass%. The results also showed that at the rated output condition the smoke emissions decreased considerably with increasing 1-butanol addition ratios.

1. Introduction

Development of sustainable alternative energy sources and environmental protection are important issues and there are many practical applications and approaches being evaluated, such as wind power, solar energy, biomass utilization and others [1–6]. Biodiesel which is a transesterified vegetable oil using an alcohol, mainly methanol, is a promising alternative energy source because biodiesels as biomass fuels are renewable and sulfur free and offer potential reductions in carbon dioxide emissions compared with other diesel fuels, and a number of studies have been conducted with this kind of diesel fuel substitute [7–17]. Transesterified feedstock contains different compositions of fatty acid methyl ester, RME (rape oil methyl ester) is mainly used in Europe and SME (soybean oil methyl ester) in the USA while PME (palm oil methyl ester) is also considered a promising alternative fuel among biodiesels as it is produced in the largest amounts among this type of feedstock. Table 1 shows the worldwide production of major vegetable oil crops [18], their yields [19], and properties after transesterification with methanol [14]. As shown in Table 1, palm oil is the most produced feedstock and its yield is the highest among vegetable oil crops. However, PME has the serious drawback of a relatively high pour point, limiting PME use to warmer climates like that of Southeast Asia.

The purpose of this study is to extend the range of utilization of PME by improving its low temperature fluidity. The present study used three kinds of PME/gas oil/1-butanol blends, 1-butanol is a biomass fuel made from acetone–butanol–ethanol fermentation and its pour point is much lower than gas oil. The experimental results showed that compared with the pour point of 19 °C with neat PME, the pour point of a blended fuel with 80% gas oil and 20% PME, termed PME20, was −5 °C. Further, the pour point with 40 mass% 1-butanol blended into the PME20 resulted in a further decrease in the pour point, to −10 °C. Using four kinds of PME/gas oil blends as the base fuels (PME0, PME20, PME50, and PME100), the influence of 1-butanol addition on the engine performance, combustion characteristics, and exhaust emissions of a small single cylinder DI (direct injection) diesel engine was examined. The brake thermal efficiency of the base fuels changed little when 1-butanol was added up to 40 mass%. It was also found that at the rated output condition the smoke emissions decreased considerably with increasing 1-butanol addition ratios.

To improve the low temperature fluidity of PME, studies have been conducted using blended fuels with low pour point fuels: for example, a blended fuel with gas oil [15], ethanol [13,15], or DME (dimethyl ether) [15]. Okamoto et al. [15] report that the pour point of PME

* Corresponding author. Tel./fax: +81 257 22 8116.
E-mail address: yosimoto@mce.niit.ac.jp (Y. Yoshimoto).

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Nomenclature

FAME	fatty acid methyl ester
MO	methyl oleate
MP	methyl palmitate
PME	palm oil methyl ester (substituted with equal proportions of MO and MP)
PME**	blended fuel with PME and gas oil, ** represents PME addition ratio in fuel (mass%)
PME** + B##	blended fuel with PME** and 1-butanol, ## represents the 1-butanol addition ratio to the base fuel (mass%)
η_e	brake thermal efficiency
BSFC	brake specific fuel consumption
BMEP	brake mean effective pressure
IMEP	indicated mean effective pressure
Q_{buta}/Q_{base}	1-butanol addition ratio (heat energy ratio of blended 1-butanol to base fuel)
$(dQ/d\theta)_{max}$	maximum heat release rate
η_{glh}	degree of constant volume of combustion
COV (P_i)	coefficient of variance of IMEP

blended fuels at a constant 50 mass% addition with ethanol, gas oil, and DME reduced the pour point by 13, 6, and 23 °C, respectively. Kinoshita et al. [12] report that compared with PME, the pour point decreased by 5 °C by esterification with ethanol (i.e. PEE (palm oil ethyl ester)). While, the PME/gas oil/1-butanol blend (40 mass% 1-butanol blended into the PME20) in the present study showed a 29 °C reduction in the pour point from the original value (+19 °C). Therefore, the improvement with the low temperature fluidity of the present study is remarkable and the significant reduction in smoke emissions can be obtained keeping the brake thermal efficiency similar to normal fuel operation. Chotwichien et al. [16] report that the blended fuel composed of PME/gas oil/butanol has good stability in long term storage at room temperature and the practical utility of this type of blend is also very high. Compared with bio-ethanol, butanol can easily be used in diesel engines due to the higher cetane number and better miscibility. Recently, studies have focused on utilizing butanol as an alternative diesel fuel [20–26], however our search of the literature yielded no reports of the present ternary fuels which investigated the fuel properties, engine performance, combustion characteristics, and exhaust emissions systematically. Details of the results are described in the following.

Table 3
Engine specifications.

Engine model	4 stroke, Horizontal, Water cooled
Stroke volume	411cc (Single cylinder)
Compression ratio	18
Combustion chamber	DI (Toroidal type)
Rated output	5.1 kW/2400 rpm (BMEP = 0.62 MPa)
Injection pump	Bosch PFR (Plunger 7 mm)
Injection nozzle	DLLA 150 (4–0.2 mm)
Opening pressure	21.7 MPa
Injection timing	Fixed (19°CA.BTDC)

2. Experimental apparatus and methods

2.1. Fuel

Palm oil methyl ester (PME) is composed of FAME (fatty acid methyl esters) and more than 80% (mass ratio) is accounted for by MO (methyl oleate) and MP (methyl palmitate), in nearly equal proportions [17]. The present study used simulated fuels made of commercial FAME fuels: MO (purity 70%) and MP (purity >95%) in equal proportions. In this study, the blended fuel with the simulated PME and gas oil is represented as PME**, with ** the mass% ratio of PME in the PME/gas oil blends. Further, the blended fuel with the PME** and 1-butanol is represented by PME**+B##,

Table 1
Global vegetable oil production [18], production efficiency of oil crops [19], and the fuel properties after transesterification [14] (○ good, △ average, ×poor).

Oil	Production [×1000 ton]			Yield [ton/ha]	Iodine value[a]	Oxidation stability	Pour point of FAME [°C]	Low temp. fluidity
	2009/10	2010/11	2011/12 (Prospects)					
Palm	46,060	49,123	51,488	4	50–55	○	14	×
Soy bean	38,887	41,384	41,724	0.3 ~ 0.5	124–139	×	−10	○
Rapeseed	23,745	23,620	23,639	0.5 ~ 1.1	94–126	△	−10	○
Sunflower	12,620	12,446	14,631	0.4 ~ 1.1	120–141	×	−12	○
Palm karnel	5285	5509	5824	0.4 ~ 0.5	14–22	○	−5	△
Coconut	3634	3101	3119	0.3 ~ 0.5	7–11	○	−5	△
Jatropha	–	–	–	1.8 ~ 2.8	95–106	△	−2.5	△

[a] Quoted from JAS standards.

Table 2
Properties of the tested fuels.

	Gas oil	MO, Methyl oleate	MP, Methyl palmitate	PME, MO:MP = 1:1	1-butanol
Density [15 °C] (g/cm^3)	0.819	0.877	0.852	0.865	0.813
Viscosity [30 °C] (mm^2/s)	2.8	6.3	–	4.2	2.8
B.P. at 20% distillation (°C)	232	214 (at 2 kPa)	191 (at 2 kPa)	316	118
Pour point (°C)	−18	−17	28	19	−90[a]
Cetane number	60.2[b]	56	74.3	65[c]	17[d]
Carbon (mass%)	86.1	77.0	75.5	76.3	64.9
Hydrogen (mass%)	13.8	12.2	12.7	12.5	13.5
Oxygen (mass%)	–	10.8	11.8	11.3	21.6
Lower heating value (MJ/kg)	42.87	37.26	37.12	37.19	33
Stoichiometric air–fuel ratio	14.6	10.8	11.8	11.3	11.2

[a] Freezing point
[b] Cetane index
[c] Estimated value
[d] From Ref. [23].