CHAPTER 3

RESULTS

3.1 Fuel properties

Fuel properties, including kinematic viscosity, density, flash point, cloud point, pour point and heating value were tested and results are shown in Table 3.1. The properties of two community biodiesel samples are compared with those of CB and specifications of Thai biodiesel standards for agricultural diesel engines. This engine was specified for horizontal single-cylinder, four strokes and water-cooled system. Moreover, methyl ester standards (MES), notification from the Department of Energy Business, were also used to compare with those of both community biodiesel samples.

The kinematic viscosity values of CBS and CBU samples are agreed with Thai biodiesel standards for agricultural diesel engines. In CBU samples, the kinematic viscosity is in the range of methyl ester standard and out of range in Thai diesel standards notification from Department of Energy Business. In CBS samples, there kinematic viscosity is out of range in both MES and TBS notification from Department of Energy Business. The specific density of CBU is 875 ± 1 kg/m^3 while CBS is 888 ± 1 kg/m^3 . TBS and MES ranges are 860-900 kg/m^3 . Both of community biodiesel fuels are in the range of TBS and MES.

Flash points, the lowest temperature at which it can vaporize to form an ignitable mixture in air, showed in CBU (172.0 ± 3.1**ºC**) and CBS (132.7 ± 2.5 **ºC**) were accepted with TBS and MES standard (more than 120 **°C)**. Cloud point and pour point are not showen in TBS and MES standard because both of that value necessary and appears in temperate country. Heating value of community biodiesels are higher than diesel because of their chemical structures. Moreover, heating value related to fuel consumption rate.

Table 3.1 Properties of tested fuel

Fuel	**Kinematic viscosity**	**Density**	**Flash point**	**Cloud point**	**Pour point**	**Heating value**
	(cSt)	**(kg/m^3)**	**(°C)**	**(°C)**	**(°C)**	**(MJ/kg)**
CBU	4.672 ± 0.003	875 ± 1	172.0 ± 3.1	16.0 ± 0.0	13.0 ± 0.0	38.35 ± 0.50
CBS	5.580 ± 0.009	888 ± 1	132.7 ± 2.5	12.0 ± 0.0	10.0 ± 0.0	36.32 ± 0.19
CBD	3.103 ± 0.002	829 ± 1	68.7 ± 0.6	10.0± 0.0	4.0 ± 0.0	44.36 ± 1.54
TBS[1]	**1.9-8.0**	**860-900**	**$\geq$120**	**-**	**-**	**-**
MES[2]	**3.5-5.0**	**860-900**	**$\geq$120**	**-**	**-**	**-**
TDS[3]	**1.8-4.1**	**-**	**$\geq$52**	**-**	**$\leq$10**	**-**

[1] TBS: Thai biodiesel standards for horizontal single-cylinder, four strokes and water-cooled system agricultural engines (Appendix A)

[2] MES: Methyl ester standards and [3] TDS: Thai diesel standards notification from Department of Energy Business (2006) [24]

The biodiesel properties including kinematic viscosity, density, flash point, cloud point, pour point, heating value and sources were compared in others studies [4,9,25-27].

In Table 3.2. The sources of biodiesel fuel came from various sources in various study depending on country located, fuel plants's price and government's need. Moreover, cetane number (CN) ,measurement of the combustion quality of diesel fuel during compression ignition, was also determined in this study. CN of CBU is 67.8 while CN of CBS is 66.7 [28]. Both CN from 2 fuels is in a range of Methyl ester standards (>47-51)[24]. Phalakornkule *et al.* reported that Thai biodiesel which was produced from community biodiesel scale plant demonstrated quite high value of CN (III). It was also suggested that the use of fuel with high CN could lead to smoother running of the engine with less noise [27].

Table 3.2 The comparison of biodiesel properties in others studies

Author	**Kinematic Viscosity (cSt) at 40°C**	**Density (kg/m^3) at 15 °C**	**Flash point (°C)**	**Cloud point (°C)**	**Pour point (°C)**	**Heating value (MJ/kg)**	**Cetane Number**	**Source**
Lin *et al.*, 2006b [9]	4.38	874	176	NA	15	39.84	63.7	Palm seed
Lin *et al.*, 2008 [25]	4.40	873	166	14	NA	NA	64.0	Palm seed
Karavarakis *et al.*, 2009 [26]	4.4	881.6	166	NA	6	36.91	NA	Soy bean
Phalakornkule *et al.*, 2009 [4]	4.476	877.8	163	NA	NA	NA	74.4	Palm
Ballesteros *et al.*, 2010[27]	5.160	887.0	NA	NA	NA	39.26	NA	Waste cooking
This study CBU	**4.672**	**875**	**172**	**16.0**	**13.0**	**38.35**	67.8	**Used palm oil**
CBS	**5.580**	**888**	**132**	**12.0**	**10.0**	**36.32**	66.7	**Waste cooking**

NA, not available

3.2 $PM_{2.5}$ emissions in the exhaust of agricultural diesel engine

PM emission in engine exhaust which could be formed during combustion, heavy hydrocarbon condensation or absorption on the soot is represented in term of mean PM concentration and standard deviation (n=3). $PM_{2.5}$ concentrations (mg/m^3) are defined as the $PM_{2.5}$ mass emitted per cubic meter of exhaust that flow through filter. As present in Table 3.3, when compared CD (B2) with CD (B5), CD(B5) can reduce emitted by 25.6% of $PM_{2.5}$ concentration. When CBU and CBS used as pure fuel, they can reduce sharply (39.0% for CBU and 30.7% for CBS). Mixing fuel (CBU(CB50) and CBS(CB50)) showed slightly reduced (10.3% from CBU(CB50) and 9.4% from CBS(CB50). The mean $PM_{2.5}$ concentration of two community biodiesel samples (four samples) were varied from 4.25 to 6.31 mg/m^3. CD(B5) and CBU(CB100) exhibited the significant difference from CD(B2) (p<0.05).

Table 3.3 PM emission in various tested fuel exhausts

Fuel	**PM concentration (mg/m^3)**		**Emission change (%)**
	Mean ± SD	**Range**	
CD(B5)	5.19 ± 0.23[a]	4.96-5.42	-25.6
CBU(CB50)	6.25 ± 0.73	5.52-6.98	-10.3
CBS(CB50)	6.31 ± 1.07	5.24-7.38	-9.4
CBU(CB100)	4.25 ± 0.37[a]	3.88-4.62	-39.0
CBS(CB100)	4.83 ± 0.28	4.55-5.11	-30.7
CD(B2)	6.97 ± 1.56	5.41-8.53	

[a]significant difference from CD(B2) at 95% confidence level (p<0.05)

3.3 1-Nitropyrene emission in exhaust of agricultural diesel engine

3.3.1 1-NP concentration in the exhaust of tested fuel

Determination of 1-nitropyrene in fuel exhaust samples in this study were simultaneously performed with 1-NP and 1-NP-$_{d9}$ as internal standards (IS). Figure 3.1 shows HPLC chromatograms of analyzed for 1-NP in CB sample solution (A) and standard solution (B). The switching-valve status was referred in Table 2.4 .

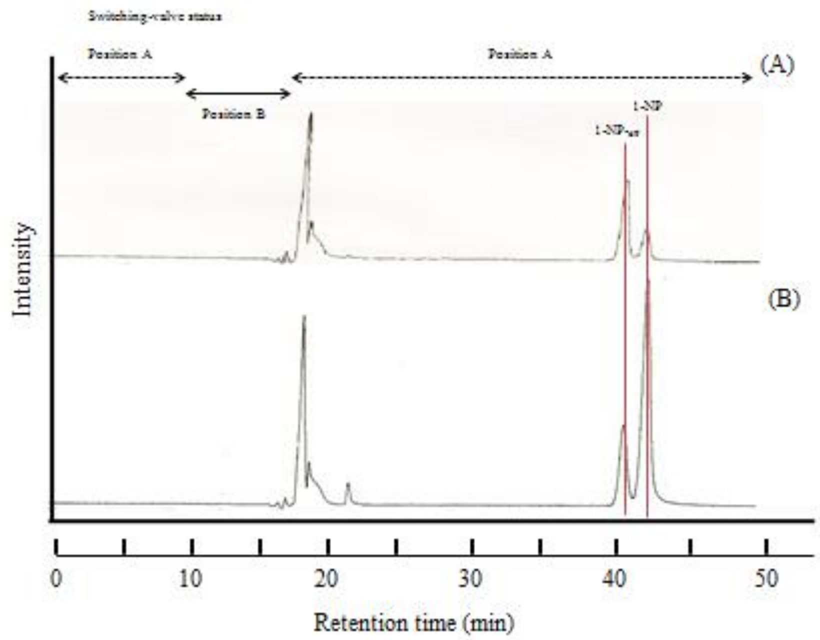

Figure 3.1 HPLC chromatograms of sample solution (A) and standard solution (B)

In this study, the determination of 1-NP was absorbed on the soot or particle-phase. As shown in Table 3.4, it can be seen that 1-NP in all samples reduced when compared to CD(B2) with no significantly difference.

3.3.2 1-NP compare with total PAHs

The emission concentrations of 10 PAHs: Frt, Pyr, BaA, Chr, BbF, BkF, BaP, BghiPe, DBA and IDP in previous study [28, 29] were shown and compared with 1-NP concentration in Table 3.4. The results showed same trend of reduction of 1-NP (58.73-83.66% emission reduction) and Total PAHs (46.70-73.23% emission reduction).

Table 3.4 1-Nitropyrene emissions compared with total PAHs emission

Fuel	**1-NP**		**Total PAHs**	
	Mean ±SD (µg/m^3)	**Emission change** (%)	**Mean ±SD** (µg/m^3)	**Emission change** (%)
CD(B5)	113.44±24.51[a]	-45.52	404.19±32.66[a]	-46.70
CBU(CB50)	89.60±46.00[a]	-56.97	368.57±111.82[a]	-51.40
CBS(CB50)	44.91±32.15[a]	-78.43	202.83±83.97[a]	-73.23
CBU(CB100)	88.75±8.25[a]	-57.37	399.46±88.98[a]	-47.33
CBS(CB100)	112.10±14.28[a]	-46.16	314.30±76.85[a]	-58.55
CD(B2)	208.23±34.59		758.38±595.21	

[a]significantly different from CD(B2) at 95% confidence level (p<0.05)

The previous results of pyrene emissions [28, 29] were compared with 1-NP because pyrene in diesel engine exhaust particle is source of 1-NP [30] so, The comparison showed in Table 3.5 with 1-NP/pyrene ratio with no significant difference (p>0.05).

Table 3.5 1-Nitropyrene emissions compared with pyrene emission

Fuel	**1-NP (μg/m^3)**	**Pyr(μg/m^3)**	**1-NP/Pyrene**
	Mean ± SD	**Mean± SD**	**Ratio**
CD(B5)	113.44 ± 24.51^a	219.92±40.21^a	0.52
CBU(CB50)	89.60 ± 46.00^a	182.31±47.79^a	0.49
CBS(CB50)	44.91 ± 32.15^a	141.22±44.98^a	0.32
CBU(CB100)	88.75 ± 8.25^a	190.73±39.45^a	0.46
CBS(CB100)	112.10 ± 14.08^a	155.92±42.15^a	0.72
CD(B2)	208.23 ± 34.59	390.03±307.24	0.53

^{a}significantly different from CD(B2) at 95% confidence level (p<0.05)

3.4 Engine performance

The engine performance (fueled) with community biodiesels and CD is presented in terms of brake specific fuel consumption (BSFC) and thermal efficiency (TE) at 1,800 rpm speed controlled under full load as presented in Table 3.6.

The term of ‘‘brake specific’’ refers to quantities which have been normalized by the engine’s power. While, the BSFC is equal to the fuel flow rate divided by the power of the engine [31]. BSFC from tested fuels are varied from 0.34 to 0.36

kg/kWh. The mean increasing of BSFCs for tested fuels are varied from +6.25% to +13.25%, respectively, compared with that of CD (B2) (CD (B2) = 0.32 kg/kWh).

The Thermal efficiency is the ratio between the power output and the energy introduced through fuel injection, the latter being the product of the injected fuel mass flow rate and the lower heating value. It can be also determined by using the inverse of the BSFC and heating value [31]. The TE of all tested fuels were lower than that of CBD. The mean reduction of the TE values for tested fuels are -2.7% to -9.3% respectively, compare with that of CD (B2) (CD (B2) = 28% TE).

Table 3.6 Brake specific fuel consumption and thermal efficiency of various tested fuels

Fuel	**Brake specific fuel consumption (kg/ kW h)**		**Thermal efficiency (%)**	
	Mean	**Change (%)**	**Mean**	**Change (%)**
CD(B5)	0.35 ± 0.02	+8.3	25.0 ± 1.7	-2.7
CBU(CB50)	0.36 ± 0.00	+12.5	25.0 ± 0.0	-2.7
CBS(CB50)	0.35 ± 0.01	+9.4	24.3 ± 0.6	-5.4
CBU(CB100)	0.34 ± 0.00	+6.25	24.0 ± 0.0	-6.6
CBS(CB100)	0.36 ± 0.02	+13.5	23.3 ± 0.6	-9.3
CD(B2)	0.32 ± 0.02		25.7 ± 1.5	