CHAPTER 3

RESULTS

3.1 Fuel properties

Tested fuel properties, including kinematic viscosity, density, flash point, cloud point, pour point and heating value, are shown in Table 3.1 and 3.2. The properties of various CBF samples were compared with those of CDFs and specifications of Thai biodiesel standards, for agricultural diesel engine and methyl ester standard, notification from the Department of Energy Business, were used to compare with those of CBF samples. Agricultural diesel engine was specified for horizontal single-cylinder, four strokes and water-cooled system. High speed diesel engine was specified for four-cylinder, four strokes and water-cooled system.

The viscosity values of all CBF samples were completely agreed with Thai biodiesel standards for agricultural diesel engines and nearly meet the specifications required by methyl ester standards. For high speed diesel engine, the viscosity were not tested due to a limitation of the instrument, The density values of all CBF samples were completely agreed with methyl ester standards for high speed diesel engine. Almost CBF samples also demonstrate comparable flash points with those standards. Furthermore, some fuel properties, such as cloud point and pour point, were not comparable because the values are not specified in the standards. All these properties could significantly affect the engine performance. For example, the high values of cloud point and pour point may lead to the poor performance of the engine under cold condition.

The density, flash point and pour point of CDFs, which was used as a control group, were measured and also met the specification of Thai diesel standard compared with CBF samples, the CBF samples showed higher density, flash point, cloud point and pour point, but lower in gross heating value. The lower heating values of CBF samples could lead to higher fuel consumption to produce the same power as compared to that of CDFs.

Table 3.1 The properties of tested fuel for agricultural diesel engine (Yanmar TF 75-LM)

Abbriveation	Fuel type and sources	Kinematic viscosity	Density	Flash point	Cloud point	Pour point	Heating value
		(cSt)	(kg/m^3)	(^oC)	(^oC)	(^oC)	(MJ/kg)
UMO	CBF-100 Umong (used palm oil)	4.672 ± 0.0	875 ± 1.0	172.0 ± 2.0	16.0 ± 0.0	13.0 ± 0.0	38.30 ± 0.5
SAM	CBF-100 Sankampheang (used mix oil)	5.026 ± 0.0	877 ± 0.0	163.0± 1.0	19.0 ± 0.0	10.0 ± 0.0	38.87± 0.6
SAN	CBF-100 Sankampheang (palm oil)	5.580 ± 0.0	888 ± 1.0	133.0 ± 2.5	12.0 ± 0.0	10.0 ± 0.0	36.34 ± 0.1
DIE	CDF-98 PTT (B2)/BBDF-2	3.103 ± 0.0	829 ± 0.0	69.0 ± 0.6	10.0 ± 0.0	4.0 ± 0.0	44.38 ± 1.5
PTT B5	CDF-95 PTT (B5)/BBDF-5	3.243 ± 0.0	832 ± 0.0	63.0 ± 1.0	10.0 ± 0.0	3.0 ± 0.0	41.95 ± 0.4
TBS[1]		**1.9-8.0**	**860-900**	**≥120**	**-**	**-**	**-**
MES[2]		**3.5-5.0**	**860-900**	**≥120**	**-**	**-**	**-**
TDS[3]		**1.8-4.1**	**-**	**≥52**	**-**	**≤10**	**-**

[1] TBS: Thai biodiesel standards for horizontal single-cylinder, four strokes and water-cooled system agricultural engines (2006) (Appendix A) [2] MES: Methyl ester standards and [3] TDS: Thai diesel standards notification from Department of Energy Business (2007)

Table 3.2 The properties of tested fuel for high speed diesel engine (ISUZU 4JB1)

Abbrevation	Fuel type	Kinematic viscosity	Density	Flash point	Cloud point	Pour point	Heating value
		(cSt)	(kg/m^3)	(^oC)	(^oC)	(^oC)	(MJ/kg)
UOL	CBF-100 Used mix oil	n.a.	888 ± 0.0	176.0 ± 7.2	14.0 ± 1.0	4.7 ± 1.2	44.00 ± 0.6
UPO	CBF-100 Used palm oil	n.a.	888 ± 0.0	150.0 ± 6.6	17.0 ± 1.0	6.7 ± 1.2	46.37± 3.8
CPO	CBF-100 Community palm oil	n.a.	888 ± 0.0	162.0 ± 6.6	19.0 ± 1.0	6.7 ± 1.2	45.35 ± 0.5
DIE100	CDF-100 PTT (BO)	n.a.	827 ± 0.0	56.0 ± 4.5	7.0± 1.0	-7.7 ± 1.2	49.08 ± 2.9
PTT B3	CDF-97 (B3)/BBDF-3	n.a.	840 ± 0.0	59.0 ± 3.7	6.0 ± 1.0	-6.3 ± 1.2	49.76± 1.0
TBS[1]	-	**1.9-8.0**	**860-900**	**≥120**	**-**	**-**	**-**
MES[2]	-	**3.5-5.0**	**860-900**	**≥120**	**-**	**-**	**-**
TDS[3]	-	**1.8-4.1**	**-**	**≥52**	**-**	**≤10**	**-**

[1] TBS: Thai biodiesel standards for horizontal single-cylinder, four strokes and water-cooled system agricultural engines (2006) (Appendix A) [2] MES: Methyl ester standards and [3] TDS: Thai diesel standards notification from Department of Energy Business (2007)

n.a.**:** not analysis

3.2 Toxic and green house gases concentration emissions in various tested fuel exhausts

The mean concentration of toxic and green house gases and concentration ranges were varied from 2.1 to 86.8-UMO, 3.4 to 124.2-SAM, 3.7 to 144.2-SAN, 3.6 to 151.3-DIE, 3.0 to 130.7-PTTB5 from agricultural diesel engine and 5.6 to 396.6-UOL, 4.4 to 352.8-UPO, 4.3 to 349.3-CPO, 3.7 to 279.7-DIE100, 4.4 to 362.3-PTTB3 from high speed diesel engine were shown in Table 3.3, it can be seen that the toxic and green house gases concentrations of all CBF samples showed lower than CDF samples in agricultural diesel engine. In the case of high speed diesel engine found to be slightly high than agricultural diesel engine and the CBF samples showed higher than CDF. Statistical analysis technique was parametric by T-test and One-Way ANOVA test was used for statistical analysis of all emissions data sets. The samples were divided into 5 groups- 3 CBFs and 2 CDFs for agricultural diesel engine, in high speed diesel engine also divided into 5 groups- 3 CBFs and 2 CDFs. The agricultural diesel engine was specified for horizontal single-cylinder, four strokes and water-cooled system, and indirect injection at full load operating on 1800 rpm and high speed diesel engine was specified for four-cylinder, four strokes, turbocharged, water-cooled system and direct injection at full load operation on 1500 rpm, which the agricultural engine and high speed diesel engine were difference in specification of engine, engine condition and fuel sample. This kind of engine is usually used in local community in northern Thailand.

Table 3.3 The means average of toxic and green house gases emission in various tested fuel exhausts

Fuels	Toxic and green house gases concentration					
	Mean ± (SD)	Mean± (SD)	Mean ± (SD)	Mean± (SD)	Mean ± (SD)	Range
	CO (ppm)	CO_2 (%)	NO (ppm)	NO_2 (ppm)	NO_X (ppm)	
UMO	26.1±0.3	2.1±0.1	80.6±2.2	6.5±0.1	86.8±2.3	2.1-86.8
SAM	41.4±1.3	3.4±0.0	116.9±0.8	7.3±0.4	124.2±0.5	3.4-124.2
SAN	56.8±1.2	3.7±0.1	139.0±5.4	5.3±0.5	144.2±5.0	3.7-144.2
DIE	49.0±5.3	3.6±0.2	145.4±5.4	5.9±0.7	151.3±5.1	3.6-151.3
PTT B5	37.1±0.8	3.0±0.0	124.0±0.4	6.8±0.1	130.7±0.4	3.0-130.7
UOL	275.6±1.6	5.6±1.4	369.0±14.8	27.4±2.9	396.6±16.4	5.6-396.6
UPO	261.9±11.7	4.4±0.1	333.8±20.7	19.0±0.2	352.8±20.6	4.4-352.8
CPO	295.2±7.5	4.3±0.0	310.1±3.9	39.7±2.2	349.3±4.6	4.3-349.3
DIE100	249.0±6.8	3.7±0.1	255.5±11.9	24.8±2.8	279.7±9.2	3.7-279.7
PTT B3	318.6±9.7	4.4±0.1	355.6±8.1	6.9±3.1	362.3±10.4	4.4-362.3

Mean ± (SD) from total average is 9 replications in 3 testing

Table 3.4 The means average of toxic and green house gases emission in various tested fuel exhausts in the power characteristic

Fuels	Toxic and green house gases concentration					
	CO (ppm) / Break power (kW)	**CO_2 (%)/ Break power (kW)**	**NO (ppm)/ Break power (kW)**	**NO_2 (ppm)/ Break power (kW)**	**NO_X (ppm)/ Break power (kW)**	**Range**
UMO	11.86	0.95	36.63	2.95	39.45	0.95-39.45
SAM	17.25	1.41	48.70	3.04	51.75	1.41-51.75
SAN	24.69	1.60	60.43	2.30	62.69	1.60-62.69
DIE	9.24	1.38	55.92	2.26	58.19	1.38-58.19
PTT B5	14.26	1.15	47.69	2.61	50.26	1.15-50.26
UOL	76.55	1.55	102.5	7.61	110.16	1.55-110.16
UPO	72.75	1.22	92.72	5.27	98.00	1.22-98.00
CPO	72.00	1.04	75.63	9.68	85.19	1.04-85.19
DIE100	59.28	0.85	60.83	6.04	66.59	0.85-66.59
PTT B3	75.85	1.04	84.66	1.64	86.26	1.04-86.26

3.3 Toxic and green house gases from the combustion of low speed and high diesel engine

Determination of toxic and green house gases in fuel exhaust sample in this study was simultaneously performed with CO, CO_2, NO, NO_2 and NO_X and were tested with two type of diesel engine, agricultural diesel engine (Yanmar TF 75-LM) and high speed diesel engine (ISUZU 4JB-1) were used because of high percentage of its usage in Northern Thailand. The main study was focusing on high speed diesel engine due to the lack of investigated in Northern Thailand. However in this study also investigated fuel exhaust sample in agricultural diesel engine for compared the suitable of engine and confirmed the toxic and green house gases emissions. Determination of CO, CO_2, NO, NO_2 and NO_X was detected with multi gas analyzer.

The toxic and green house gases compounds can be detected in fuel exhaust sample from agricultural diesel engine and high speed diesel engine, the concentration of CO, CO_2, NO, NO_2 and NO_X composition in tested fuel exhausts from agricultural diesel engine and high speed diesel engine are shown in Figure 3.1, it can be seen that NO_X, NO and CO was the most abundant composition in the fuel exhaust. Moreover, NO_X, NO and CO was also mostly found in CDFs, the petroleum diesel fuel (DIE) was a main emission and lowest emission was UMO (Used palm oil). Figure 3.2, NO_X, NO and CO was the most abundant composition in the fuel exhaust while CBFs was not lower than CDFs in all the tests. The main exhaust emission was UOL (Used mix oil).

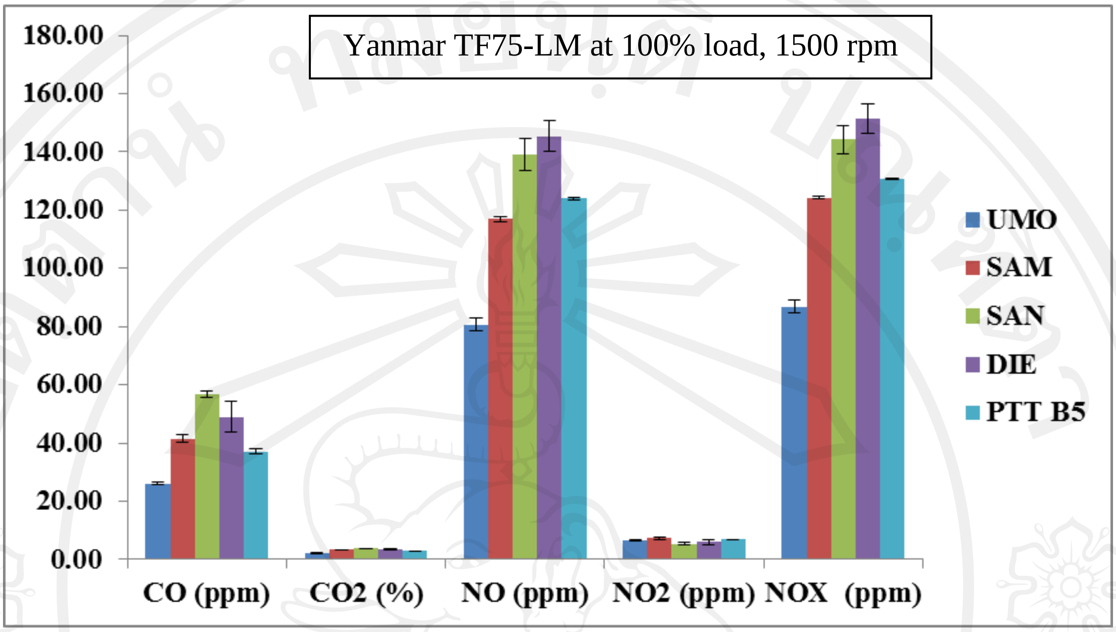

Figure 3.1 Toxic and green house gases concentration in various tested fuel exhausts from agricultural diesel engine

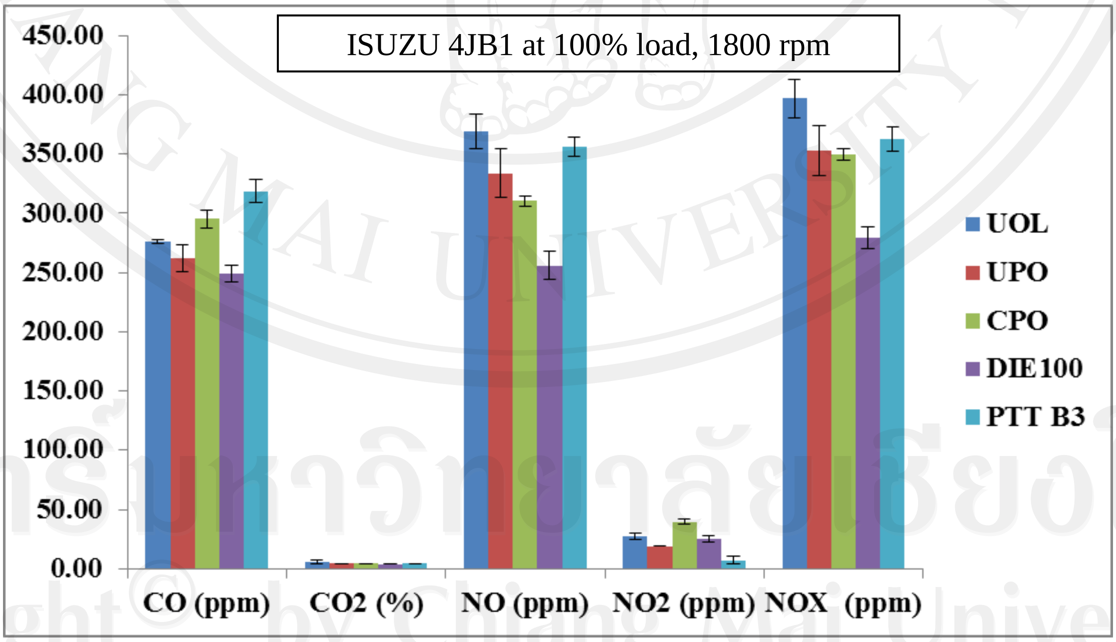

Figure 3.2 Toxic and green house gases concentration in various tested fuel exhausts from high speed diesel engine

The concentration of CO, CO_2, NO, NO_2 and NO_X composition in tested fuel exhausts from agricultural diesel engine and high speed diesel engine can compared to diesel and The reductions of CO, CO_2, NO, NO_2 and NO_X were shown in the percentage of emission exchange as presented in Table 3.4 and 3.5, emission change were varied from-46.73 to 15.91%, -41.66 to 2.77%, -44.56 to -4.40%, -10.16 to 23.72%, -42.63 to -4.69% of CO, CO_2, NO, NO_2 and NO_X from agricultural diesel engine, respectively, and +5.18 to 27.95%, +16.21 to 51.35%, +21.36 to 44.42%, -72.17 to 60.08%, +24.88 to 41.79% of CO, CO_2, NO, NO_2 and NO_X from high speed diesel engine, respectively. In this study were determined fuel temperature, ambient temperature and deice temperature.

The average of fuel temperature were 95.4°C of UMO, 91.9°C SAM, 94.0°C SAN, 85.2°C DIE and 87.3°C B5, the average of ambient temperature found 33.4°C of UMO, 33.3°C SAM, 36.6°C SAN, 38.1°C DIE and 33.6°C B5, the average of device temperature found 34.7°C of UMO, 36.0°C SAM, 36.7°C SAN, 38.3°C DIE and 35.0°C B5 in all test of agricultural diesel engine.

The average of fuel temperature were 36.9°C of UOL, 60.4°C UPO, 64.2°C CPO, 34.3°C DIE and 35.7°C B3, the average of ambient temperature found 36.3°C of UOL, 37.6°C UPO, 35.2°C CPO, 29.4°C DIE and 34.1°C B3, the average of device temperature found 37.6°C of UOL, 36.5°C UPO, 35.6°C CPO, 30.9°C DIE and 36.6°C B3 in all test of high speed diesel engine.

Table 3.5 Percentage of emission change in various fuel exhausts compare to conventional diesel from agricultural diesel engine

Fuel	Emission Change (%)				
	CO	CO_2	NO	NO_2	NO_X
UMO	-46.73	-41.66	-44.56	+10.16	-42.63
SAM	-15.51	-5.55	-19.60	+23.72	-17.91
SAN	+15.91	+2.77	-4.40	-10.6	-4.69
PTT B5	-59.2	-16.66	-14.71	+15.25	-13.61
DIE	-	-	-	-	-

(-) is reduction emissions

(+) is increases emissions

Table 3.6 Percentage of emission change in various fuel exhausts compare to conventional diesel from high speed diesel engine

Fuel	Emission Change (%)				
	CO	CO_2	NO	NO_2	NO_X
UOL	+10.70	+51.35	+44.42	+10.48	+41.79
UPO	+5.18	+18.91	+30.64	-23.38	+26.31
CPO	+18.55	+16.21	+21.36	+60.08	+24.88
PTT B3	+27.95	+18.91	+39.17	-72.17	+29.53
DIE100	-	-	-	-	-

(-) is reduction emissions

(+) is increases emissions

For each sample, the toxic and green house gases concentration was obtained from CO, CO_2, NO, NO_2 and NO_X compounds. These compounds are known as human toxic and a direct cause of cardiovascular illness and respiratory illness. Toxic and green house gases in this study including CO, CO_2, NO, NO_2 and NO_X were detected in the fuel exhaust from the use of almost CBF and CBD samples. Their mean concentration and standard deviations are depicted in Table 3.3.

The hypothesis in the study it was observed that the significantly difference between agricultural and high speed diesel engine, at the first were compared the toxic and green house gases emission from agricultural and high speed diesel engine by T-test which hypothesis is emission of toxic and green house from high speed diesel engine higher than agricultural diesel engine or not at the significant difference 95% confident level ($p<0.05$). Regarding in this study,

The null hypothesis is high speed diesel engine emitted toxic and green house gases same as with agricultural diesel engine. The alternative hypothesis is high speed diesel engine emitted toxic and green house gases higher than agricultural diesel engine, The test statistics found emission of CO was significant difference between high speed diesel engine and agricultural, the value of asymtotic significance (2-tailed) was 0.000 and the others gases also found similar results were 0.000, 0.000, 0.000, 0.000 significant difference of CO_2, NO, NO_2 and NO_X, respectively (p-value less than 0.05, $p<0.05$). As presented in the Table 3.7 and showed the variances, means, medians and standard deviations values. These results can accept the alternative hypothesis and reject the null hypothesis, which concluded high speed diesel engine emitted toxic and green house gases higher than agricultural diesel engine at the significant difference is $p<0.05$.When compared the community biodiesel and conventional diesel were no significant difference ($p>0.05$) for CO, CO_2 and NO, NO_X emissions, was accepted NO_2.

The sample were divided into 5 groups, 3-CBFs and 2-CDFs (between groups) in both of agricultural diesel engine and high speed diesel engine and then were analyzed using the One-Way ANOVA analysis of variance in product of CBFs and CDFs from agricultural diesel engine emission, the two group was dependent. The null hypothesis is CBFs and CDFs do not have difference effect on toxic and green house emission from agricultural diesel engine combustion. The alternative hypothesis is CBFs and CDFs have difference effect on toxic and green house emission agricultural diesel engine combustion. The test statistics was rejected null hypothesis and accepted alternative hypothesis owing to its p-value which is less than 0.05., product of CBFs and CDFs from agricultural diesel engine emission showed significantly difference for CO, CO_2 and NO, NO_X and NO_2 emission, are found asymtotic significance value 0.000, 0.000, 0.000, 0.002 and 0.000, respectively. As shown in Table 3.8

The sample was divided into 5 groups, 3-CBFs and 2-CDFs (between groups) in high speed diesel engine same as in high speed diesel engine but difference source of fuels. The null hypothesis is CBFs and CDFs do not have difference effect on toxic and green house emission from high speed diesel engine combustion. The alternative hypothesis is CBFs and CDFs have difference effect on toxic and green house emission high speed diesel engine combustion. The test statistics was rejected null hypothesis and accepted alternative hypothesis owing to its p-value which is less than

0.05., product of CBFs and CDFs from agricultural diesel engine emission showed significantly difference for CO, CO_2 and NO, NO_X and NO_2 emission, are found asymtotic significance value 0.000, 0.000, 0.000, 0.000 and 0.000, respectively and was showed in Table 3.9. According to the test statistics found significantly difference comparative between CBFs and CDFs at the p value is 0.05, CO, CO_2 and NO, NO_X and NO_2 emission in CBFs less than CDFs from tested of agricultural diesel engine In contrast with high speed diesel engine found CO, CO_2 and NO, NO_X and NO_2 emission in CBFs higher than CDFs and significantly difference comparative between CBFs and CDFs at the p value is 0.05. These results were also accordance with the investigation of author name. All authors reported that CO emission in neat biodiesel or blended biodiesel exhaust were lower that of petroleum diesel but slightly increased in NO_X [19-26], the test have difference effect on toxic and green house emissions in agricultural and high speed diesel engine combustion. It showed amount of CO, CO_2, NO, NO_2 and NO_X exhaust emission level from high speed diesel engine higher than agricultural. When comparative between CBFs and CDFs CO, CO_2 and NO, NO_X and NO_2 emission in CBFs less than CDFs from tested of agricultural diesel engine. Toxic and green house from CBFs and CDFs with high speed diesel engine found community biodiesel slightly higher than conventional diesel. Nevertheless, there is the lack of evident information related to this results but this founding might be indicate that the use of community biodiesel with the combustion of high speed diesel engine is unsuitable when concerning their toxic and green house gases, However, Many research found the emission of CO CO_2, NO, NO_2 and NO_X when used biodiesel or biodiesel blend tested with car diesel engine, four stoke, four cylinder, direct inject, various speed and load was decreased compared to conventional diesel [53-60]. Therefore, effect of biodiesel was high variation results depended on the engine type, engine system, operating mode and other operating parameters, type of fuels and properties and many factors that should do in the further work.

Table 3.7 Test statistic comparison of toxic and green house gases emission from agricultural and high speed diesel engine

Parameters	**Engine type**	**Variance**	**Mean**	**Median**	**SD**	**P-value***
CO	agri	150.6	41.5	41.0	12.2	(.000)
	high	659.1	280.8	278.0	25.6	
CO_2	agri	0.423	3.1	3.2	.65037	(.000)
	high	0.776	4.4	4.2	.88068	
NO	agri	589.0	121.1	125.0	24.2	(.000)
	high	1778.8	325.4	339.0	42.1	
NO_2	agri	1.4	6.3	6.6	1.2	(.000)
	high	130.0	23.6	25.5	11.4	
NO_X	agri	586.6	127.6	132.0	24.2	(.000)
	high	1610.3	348.8	354.0	40.1	

***Significantly different at 95% confident level (*p*<0.05) by (T- test)**

Table 3.8 Test statistic of toxic and green house gases emission of various tested fuels from community biodiesels and conventional diesel in agricultural diesel engine

	CO	**CO_2**	**NO**	**NO_2**	**NO_X**
F	67.85	90.13	87.02	5.07	76.53
Asymp.Sig*	0.000	0.000	0.000	0.002	0.000

***Significantly different at 95% confident level (p<0.05) by (One-Way ANOVA)**

Table 3.9 Test statistic of toxic and green house gases emission of various tested fuels from community biodiesel and conventional diesel in high speed diesel engine

	CO	**CO_2**	**NO**	**NO_2**	**NO_X**
F	65.60	11.04	100.22	121.40	87.00
Asymp.Sig*	0.000	0.000	0.000	0.000	0.000

***Significantly different at 95% confident level (p<0.05) by (One-Way ANOVA)**

3.4 Engine performance

The engine performance (fueled) with CBFs and CDF is presented in terms of brake specific fuel consumption (BSFC) and thermal efficiency (TE) at speed around 1,800 rpm for agricultural diesel engine and 1,500 for high speed diesel engine under full load as, respectively, As the results are presented in Table 3.9 and 3.10.

The term ‘‘brake specific’’ refers to quantities which have been normalized by dividing by the engine’s power. Hence, the BSFC is equal to the fuel flow rate divided by the power of the engine [8, 67, 80, 81, 82]. The mean BSFC of CBFs and PTT B5 of agricultural diesel engine are varied from 0.30 to 0.38 kg/kWh. The mean increasing of BSFCs for CBFs to PTT B5 are 30.2%, 31.9%, 25.0%, and 3.4%, respectively, compared with that of CDF (DIE = 0.29 kg/kWh). Likewise, the mean BSFC of CBFs and PTT B3 of high speed diesel engine are varied from 0.59 to 0.80 kg/kWh. The mean increasing of BSFCs for CBFs to PTT B3 are 37.9%, 8.6%, and 34.4.% and .7%, respectively, compared with that of CDF (DIE100 = 0.58 kg/kWh)

The TE 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 [8]. The TE of all CBFs tests was lower than that of CDF. The mean reduction of the TE values for CBFs to PTT B5, agricultural diesel engine are 11.3%, 13.5%, 4.3%, and 0.7%, respectively, compare with that of CDF (CDF = 28% TE). Likewise, the TE of all CBFs tests was lower than that of CDF. The mean reduction of the TE values for CBFs to PTT B3, high speed diesel engine are 18.0%, 1.6%, 18.0%, 1.6%, respectively, compare with that of CDF (CDF = 12% TE).

Table 3.10 Brake specific fuel consumption and Thermal efficiency of various tested fuels in agricultural diesel engine

Fuel	Brake specific fuel consumption (kg/(kW h))		Thermal efficiency (%)	
	Mean	**Change (%)**	**Mean**	**Change (%)**
UMO	0.38 ± 0.01	+30.2	25.0 ± 0.9	-11.3%
SAM	0.38 ± 0.01	+31.9	24.4 ± 0.5	-13.5%
SAN	0.36 ± 0.01	+25.0	27.0 ± 0.2	-4.3%
PTT B5	0.30 ± 0.00	+3.4	28.0 ± 0.5	-0.7%
DIE	0.29 ± 0.01		28.2 ± 0.8	

Table 3.11 Brake specific fuel consumption and Thermal efficiency of various tested fuels in high diesel engine

Fuel	Brake specific fuel consumption (kg/(kW h))		Thermal efficiency (%)	
	Mean	**Change (%)**	**Mean**	**Change (%)**
UOL	0.80 ± 0.01	+37.9	10.0 ± 0.0	-18.0%
UPO	0.63 ± 0.01	+8.6	12.0 ± 0.0	-7.6%
CPO	0.78 ± 0.01	+34.4	10.0 ± 0.0	-18.0%
PTT B3	0.59 ± 0.01	+1.7	12.0 ± 0.0	-7.6%
DIE100	0.58 ± 0.01		13.0 ± 0.0	