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THE PERFORMANCE OF DIESEL ENGINE USING BIODIESEL FUEL FROM RUBBER SEED OIL PRODUCTION BY CATALYTIC METHOD

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ABSTRACT

The performance test of CI engine which uses biodiesel fuel from vegetable oils and its blends with diesel fuel is essential to be carried out. This research investigates the quality of rubber seed oil methyl ester (RSOME) which is produced via catalytic method dry wash system which uses magnesol (magnesium silicate) as absorbent based on Indonesian Biodiesel Forum (FBI) standard in 2005 and the performance of CI engine, which uses its blends with diesel fuel (B-10, B-20, and B-30). The best engine performance is then compared with RSOME which is produced via non-catalytic method, namely, superheated methanol high temperature atmospheric pressure and diesel fuel (B-0). The engine test shows that B-20 produces the best engine performance at 2550 rpm. Compared to RSOME non-catalytic method and diesel fuel, RSOME catalytic method and non-catalytic method yield the same effective power, whereas diesel fuel is lower than both methods. The engine which uses RSOME non-catalytic method needs the same specific fuel consumption as diesel fuel, but a bit more than catalytic method. The thermal efficiency of RSOME non-catalytic method is higher than catalytic method and diesel fuel, but catalytic method has lower efficiency than diesel fuel. The emission of non-catalytic method is the most eco-friendly, catalytic method is the next, and diesel fuel is the one with the highest emission levels.

Keywords: Catalytic and non-catalytic; CI engine; Dry wash system; RSOME

1. INTRODUCTION

Biodiesel production processed from vegetable oils can be done via catalytic method i.e. dry wash system or wet wash system and non-catalytic method i.e. high temperature high pressure or high temperature low pressure. The properties of neat rubber seed oil (RSO) are as follows: the viscosity is 5.19 cSt, the density is 0.9209 g/ml, the water content is 0.2%, free fatty acid (FFA) is 6.66%, and the boiling point is 305^{o}C. The main problems in using vegetable oils as the fuel of CI engine are its lower thermal efficiency and its higher opacity if compared to those of diesel fuel. Nevertheless, the mixture of biodiesel and diesel fuel show that the thermal efficiency, the opacity, the CO and HC emission can be accepted (Pradeep & Sharma, 2005).

The performance test and the emission evaluation of CI engine using RSOME as fuel and diesel fuel as comparator has been reported. Biodiesel is produced via catalytic method wet wash system, the process is carried out in two steps because of high free fatty acid (FFA more than 2.5%) i.e. esterification and transesterification (Ramadhas, et al., 2004).

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The lower the RSOME mixture in diesel fuel, the higher the thermal efficiency and the lower of the specific fuel consumption will be. The emission decreases when the RSOME concentration increases. Long time engine testing shows that compared with diesel fuel, the mixture of RSOME and diesel fuel yields higher carbon residue in the combustion chamber. Therefore, the fuel filter, the pump, and the combustion chamber must be cleaned frequently (Ramadhas, et al., 2005).

If the RSO as the main fuel together with diethyl ether (DEE) as the combustion cocker in which DEE is injected to the intake manifold during the inhale stroke, (whereas the RSO is injected directly to the cylinder in the end of the compression stroke 23^o before top death point), then the thermal efficiency increases from 26.5% to 28.5% with DEE injected on 200 g/hr mass flow rate. The opacity decreases significantly from 6.1 to 4.0 BSU (Edwin Geo, et al., 2009).

The production process development of biodiesel from RSOME non-catalytic method with superheated methanol atmospheric pressure and transesterification, which takes place in a bubble column reactor (BCR), has been reported. The test of biodiesel quality based on FBI standard in 2005 shows that the carbon residue is still outside of the standard. If biodiesel from this vegetable oil is used as the fuel of CI engine, then it must be mixed with diesel fuel with a particular comparison degree in order to be able to lessen the main problem above (Susila, 2009). The performance test of the engine which uses B-0, B-5, B-10, B-15, and B-20 shows that B-10 produces the best performance (Susila, 2010).

The objective of this study is to compare the best engine performance between the one which uses RSOME catalytic method dry wash system with magnesol as absorbent with the one that uses RSOME non-catalytic method, superheated methanol high pressure atmospheric pressure, and finally another comparison with the one that uses diesel fuel.

2. EXPERIMENTAL

In this study, the RSOME fuel catalytic method, dry wash system was obtained by pressing the kernel of the rubber seeds until the RSO is obtained, and then using the degumming process to bind fast of gum and dirt which was contained in RSO. In the degumming process, phosphate acid (H_3PO_4) 0.2% by volume of RSO was used as gum and dirt binder. RSO has high FFA; therefore the next process was esterification to decrease the FFA until it is lower than 2.0% by using methanol. This is around 10% of the RSO's volume and sulfuric acid catalyst (H_2SO_4) and around 0.5% of the RSO's mass. The next process was transesterification by using methanol, which is around 20% of the RSO's volume and the base catalyst (NaOH) is around 0.6% of RSO's mass at a temperature 60^oC, and with 20 minutes stirring time.

The output of the transesterification process was the mixture between fatty acid methyl ester (FAME) and glycerol. Glycerol was separated from FAME by a separator apparatus. FAME then went through dry wash system purification process using magnesol around 0.5 to 1.0% of crude mass as the dirt binder. The dirt was separated, and then RSOME quality was tested, based on the FBI standard in 2005. The RSOME above was ready to be mixed with diesel fuel to be B-10, B-20, and B-30 as the fuels in the CI engine at constant revolutions 1350, 1750, 2150, 2550, and 2950 rpm. The best engine performance was then compared with the RSOME non-catalytic method, superheated methanol high temperature atmospheric pressure (B-10) (Susila, 2010). Then, the result was compared with diesel fuel too.

The flow diagram of biodiesel production process from rubber seeds via catalytic method dry wash system using magnesol as absorbent is illustrated in Figure 1, and the schematic diagram of the performance test of CI engine is illustrated in Figure 2.

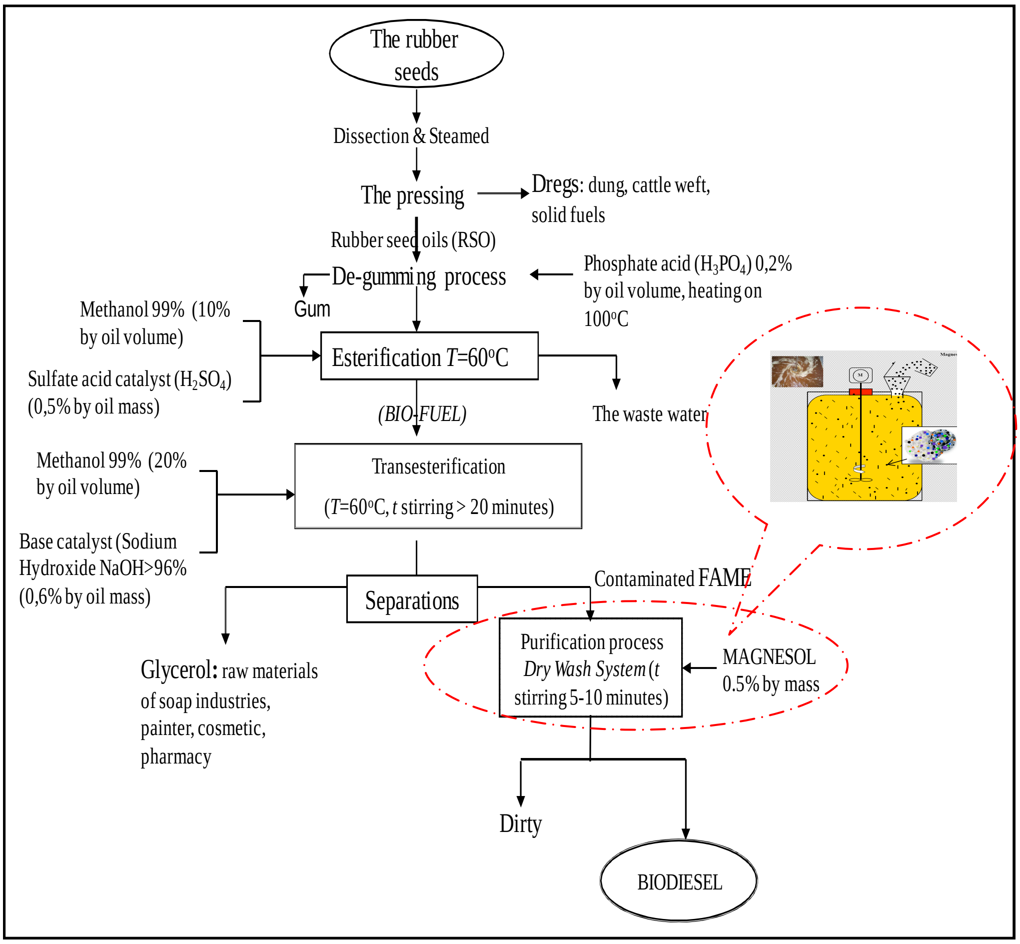

Figure 1 Flow diagram of biodiesel production process from rubber seeds via catalytic method, dry wash system using magnesol as absorbent

The thermal efficiency is calculated with formulas as follow:

$$\eta_i = \frac{N_i}{Q_b} \times 632 \times 100\ \% \quad (1)$$

$$Q_b = FC \times LHV_{fuel} (kcal/hr) \quad (2)$$

$$FC = \frac{b}{t} \times \rho \times \frac{3600}{1000} (kg/hr) \quad (3)$$

In which b is the fuel consumption in cc along t seconds, t is the time measurement (second), ρ is the fuels density (g/ml), FC is the fuel consumption (kg/hr), LHV is fuel low heating values (kcal/kg), Q_b is combustion heat (kcal/hr), N_i is indicative power (PS), η_i is efficiency thermal indicative (%).

3. RESULTS AND DISCUSSION

3.1. Quality of RSOME catalytic method dry wash system

The comparison of the RSOME catalytic and non-catalytic method (B-100) qualities is based on FBI standard in 2005 is presented in Table 1.

3.1.1. Density

Table 1 shows that the density of non-catalytic method is within an acceptable range (882 kg/m^3), but the catalytic method is not because it is above the maximum limit (919 kg/m^3). The density of catalytic method is higher than that of non-catalytic method because not all magnesol can be taken out together with the dirt in biodiesel washing process. The density of magnesol is higher than that of RSO so that the density of RSOME catalytic method is higher than that of non-catalytic method.

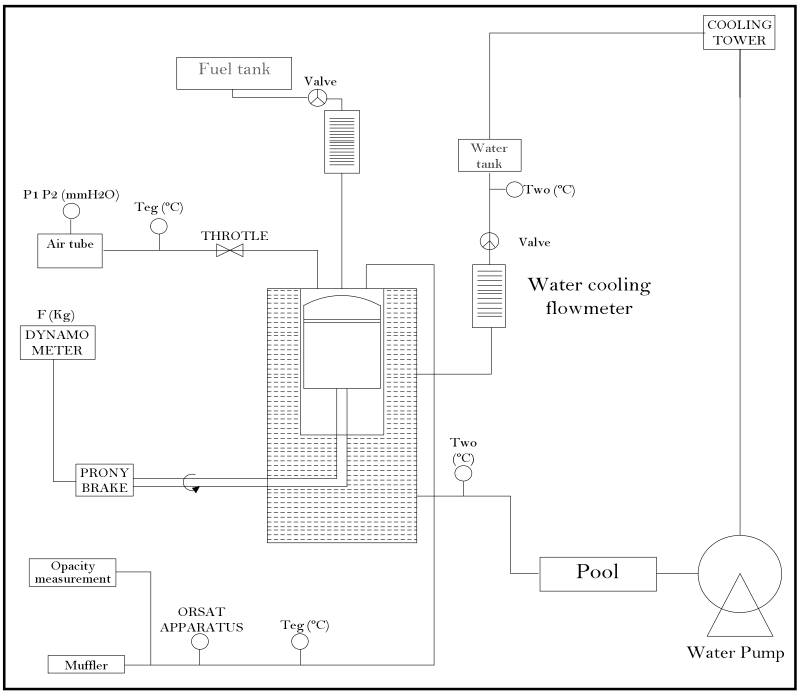

Figure 2 Schematic diagram of the performance test of CI engine

3.1.2. Viscosity

The kinematic viscosity of RSOME non-catalytic method is acceptable (5.19 cSt), but the one of the catalytic methods is outside of the standard (16.21 cSt). Higher viscosity fuels could cause poor fuel combustion that could leads to deposit formation and higher fuel spray in cylinder penetration which can result in elevated engine oil dilution with fuel.

3.1.3. Cetane number

Especially for Cetane number, Calculated Cetane Index (CCI) is used, and it is calculated based on ASTM D 976-91. Diesel fuel must have a Cetane Index minimum 45. Cetane Index is always lower than Cetane number about 2 to 3 (Van Gerpen, et al., 2004). Cetane Index of RSOME non-catalytic method is 47.5. This means that they have Cetane number of about 50.5 which is closer to the standard rating. The Cetane Index of RSOME catalytic method is outside of the standard rating, therefore, is not acceptable (40.15). Lower Cetane number causes poor engine performance, but higher Cetane numbers help to start the machine easily in cold conditions and minimize the formation of white smoke.

3.1.4. Pour point

Pour point is the ability of the liquid fuels to flow at surrounding cold conditions. Both RSOME catalytic and non-catalytic method were in standard range, therefore both are acceptable. Catalytic method flows slightly more easily than non-catalytic method so that it resists cold environmental better.

3.1.5. Flash point

Flash point deals with the conditions in which the fuel will be stored. Flash point is the temperature in which the fuels will be automatically ignited in storage. The lower temperature of flash point, the easier self ignition will be, and vice versa. The flash point minimum according to FBI standard is 100°C. The non-catalytic method has a flash point of 200°C whereas the catalytic method is 295°C. Therefore, both methods meet the set standard, but the catalytic method is better than the non-catalytic method because it has better resistance to environmental temperature. The non-catalytic method uses much more methanol than the catalytic method which has a molar ratio of methanol and RSO 160:1 whereas for the catalytic method is 6:1. The methanol residue in the fuel is a safety issue because although it is very small in amount, it can reduce the flash point.

Table 1 The quality comparison of the RSOME catalytic and non-catalytic method (B-100) based on FBI standard in 2005

No	Quality of biodiesel based on FBI standard in 2005					Test results	
	Chemical Properties	Units	Range		ASTM method	Non-catalytic method *"superheated methanol"* atmospheric pressure♣	Catalytic method *"dry wash system"* used magnesol as absorbent
			Min	Max			
1	Density at 15°C	kg/m^3	850	890	D-1298	882	919
2	Kinematic viscosity (40°C)	cSt	2.3	6.0	D-445	5.19	16.21
3	Cetane number	-	51	-	D-613	47.5♦	40.15♦
4	Pour point	°C	-	18	D-97	- 6	-7
5	Flash point	°C	100	-	D-93	200	295
6	Copper strip corrosion (3 hours at 50°C)	No. ASTM	-	No.3	D-130	No.1b	No.1a
7	Carbon residue:						
	• 100% sample	% of mass	-	0.05	D-4530	0.126	0.192
	• 10% deposit distillation		-	0.3		2.87	2.616
8	Water and sediment	% of volume	-	0.05	D-2709	0.01	0.15
9	90% Distillation temperature	°C	-	360	D-1160	347	350
10	Sulfated ash	% of mass	-	0.02	D-874	0.01	0.0138
11	Sulfur	% of mass	-	0.05	D-5453	0.72	0.115
12	Acid number	mg-KOH/g	-	0.8	D-664	0.01	0.02
13	Free glycerin	% of mass	-	0.02	D-6584	ND	ND
14	Total glycerin	% of mass	-	0.24	D-6584	ND	ND

♣Susila, (2009); ♦CCI, calculated based on ASTM D 976-91 with formula: $CCI = 454.74 - 1641.416 D + 774.74 D^2 - 0.554 B + 97.803 (\log B)^2$; which D = density at 15°C (g/ml) test method ASTM D-1298 or ASTM D-4052, B = *mid boiling temperature* (°C). For RSOME catalytic method, distillation temperature: IBP = 310°C; 10%Rec = 315°C; 50%Rec = 323°C; 90%Rec = 350°C.
LHV B-100 catalytic method = 9192.58 kcal/kg and B-100 non-catalytic method = 9193.0 kcal/kg (based on ASTM D-240 test).

3.1.6. Copper strip corrosion

Copper strip corrosion of RSOME non-catalytic method is No.1b and RSOME catalytic method is No.1a, both are acceptable because the copper strip corrosion meets the standard maximum No.3.

3.1.7. Carbon residue

The carbon residue contained in RSOME of both methods does not meet the standard, thus it is not acceptable, because the acceptable carbon residue according to standard maximum is 0.05% of mass (for a 100% sample). The carbon residue of a sample of RSOME non-catalytic method is 0.126% and catalytic method is 0.192% of mass. For 10% deposit distillation, RSOME non-catalytic method has a carbon residue of 2.87% of mass whereas RSOME catalytic method has a measure of 2.616% of mass (standard maximum 0.3% of mass). It is predicted that the high existence of carbon residue in RSOME non-catalytic method occurs because the production process did not undergo degumming process so that the gum did not decrease, although the reaction occurs at a higher temperature (290^{o}C). The gum has the potential to form the cokes in the engine combustion chamber (Ramadhas et al., 2005). If the fuels are to be used as fuel in CI engine, they must be mixed with diesel fuel at particular degree comparisons such as B-5, B-10, B-15, or B-20 until the cokes decrease and meet the standard (Susila, 2009). In RSOME catalytic method sampling, it is predicted that higher carbon residue occurs because the production process is conducted at a lower temperature (60^{o}C), although it has undergone degumming process. Besides, RSO has high FFA also (6.67%).

3.1.8. Water and sediment

Water and sediment content of RSOME non-catalytic method are acceptable because its water and sediment content 0.01% of the volume is lower than the maximum limit that is determined by standard (0.05% of the volume). But RSOME catalytic method is out of the standard range because its content is 0.15% of the volume, which is higher than maximum limit that is determined by standard (0.05% of volume). Poor separation techniques during manufacturing can cause RSOME catalytic method measurements to be outside of specification levels for sediment content. Fuel oxidation can also raise the sediment levels.

3.1.9. 90% distillation temperature

The distillation temperature of both the RSOME non-catalytic and catalytic method is acceptable.

3.1.10. Sulfated ash

The sulfated ash of both the RSOME non-catalytic and catalytic method is acceptable. The sulfated ash test measures the amounts of residue alkali catalyst present in the biodiesel as well as any other ash forming compounds that could contribute to injector deposits or fuel system fouling.

3.1.11. Sulfur

The sulfur content of both the RSOME non-catalytic and catalytic method is outside of the standard range, thus it is not acceptable. Sulfur is limited to reduce sulfate and sulfuric acid pollutant emissions and to protect the catalyst exhaust systems when they are deployed on CI engine in the future. Sulfur content will react with oxygen in combustion process to yield SO2 as an emission.

3.1.12. Acid number

The acid number of both methods is acceptable, but the acid number of the RSOME catalytic method is slightly higher than RSOME non-catalytic method because it uses the sulfate acid catalyst in the production process which probably does not fully react with RSO. A high acid content can cause corrosion and damage on a fuel filter or pump.

There are six aspects which are not acceptable in RSOME catalytic method dry wash system, i.e. density, kinematic viscosity, Cetane Number or CCI, carbon residue, water and sediment, and sulfur content. However, in the RSOME non-catalytic method there are only two aspects which are not acceptable, i.e. carbon residue and sulfur content.

3.2. Performance of diesel engine

The engine performance of B-10, B-20, and B-30 RSOME catalytic method, dry wash system is presented in Table 2. The optimum condition is gained at 2550 rpm.

Table 2 Effective power, specific fuel consumption, thermal efficiency, and emission at optimum conditions for many mixed fuels: the RSOME catalytic method dry wash system uses magnesol as an absorbent

Fuels	Effective power [PS]	Specific fuel consumption [kg/PS.hr]	Thermal efficiency [%]	Emission CO [%]	Emission CO_2 [%]
B-0 (diesel fuel)	36.26	0.256	57.070	2	8
B-10	36.09	0.251	61.172	2.4	5.6
B-20♣	36.95	0.238	56.560	0.8	5.6
B-30	36.95	0.254	59.700	1.6	6

♣Recommended

It is obvious that the emission drop with B-20 mixture occurs because biodiesel, which is yielded through washing process with magnesol, shows a significant improvement in its oxidation stability. Magnesol has strong cohesive property for the polar mixture, therefore it actively filters out the remnants of methanol, free glycerin, monoglyceride, diglyceride, metal contaminants, FFA residue, soap, and water. All unwanted materials are disposed from the process through filtration. Glycerol is a polar molecule, therefore it is easily absorbed by magnesium silicate. This is the reason why magnesol is added into the process after the glycerol is separated. The B-30 emission is higher than B-20 perhaps because the glycerol separation process is not perfect. The B-20 thermal efficiency decreases because the fuel consumption is lower than B-10 and B-30.

From data in Table 2, B-20 catalytic method with magnesol as an absorbent is recommended for fuels in CI engines because the effective power of B-20 is the same as with B-30, and higher than B-10 or B-0. Specific fuel consumption is the lowest and emission of CO or CO_2 is also the lowest. Furthermore, this study will compare the optimum performance of engine produced by the RSOME catalytic method (B-20 only), the RSOME non-catalytic method (B-10 only) and diesel fuel (B-0) (Susila, 2010). That is why B-20 and B-30 with non catalytic and B-10 and B-30 with catalytic method are not discussed.

3.2.1. Effective power

The comparisons of effective power yielded by using the B-0, B-10 (RSOME non-catalytic method), and B-20 (RSOME catalytic method dry wash system) are presented in Table 3 and Figure 3.

Figure 3 shows that at higher engine rotation, the effective power is higher and the optimum condition is gained at a rotation level of 2550 rpm. Faster than 2550 rpm, the effective power decreases because of its loss of friction power. Table 3 shows that at an optimum condition, both methods produce the same engine power, i.e. 36.95 PS. The power produced by diesel fuel is lower than all other methods, i.e. 36.264 PS. On average, the RSOME catalytic method produces the highest power, the next one is non-catalytic method, and the last one is diesel fuel.

This is because the density of B-20 (RSOME catalytic method) is higher than B-10 (RSOME non-catalytic method) and diesel fuel. High density causes the fuel to enter the combustion chamber at a greater rate. Compared with diesel fuel, B-10 (the RSOME non-catalytic method) can increase the power from 24.84 PS to 25.150 PS, whereas the power of B-20 (RSOME catalytic method) increases to 25.512 PS. The power increase happens because RSOME non-catalytic method has a CCI higher than diesel fuel (the CCI RSOME non-catalytic method is 47.5 based on Table 1, whereas CCI of diesel fuel is 45 that is based on Directorate General of Gas and Oil Republic of Indonesia number: 3675.K/24/DJM/2006). The CCI catalytic method is either a bad reading or outside of the standard range.

3.2.2. Specific fuel consumption

The comparison of specific fuel consumption is presented in Table 3 and Figure 4. The Specific Fuel Consumption in Table 3 shows that, at optimum conditions, B-10 (the RSOME non-catalytic method) needs the same specific fuel consumption as diesel fuel around 0.256 kg/PS.hr, whereas the power it gained is higher than diesel fuel. B-20 (RSOME catalytic method) is more economical than B-10 (the RSOME non-catalytic method) and B-0.

It needs 0.238 kg/PS.hr only. Figure 4 shows that the type of the graph is nearly the same, B-20 (the RSOME catalytic method) is the lowest, which means that it is the most economical, and the next is B-10 (RSOME non-catalytic method) and then diesel fuel (B-0) respectively. Above an optimum condition, the fuel needed increases extremely, but on the contrary, the power obtained decreases. Therefore the engine cannot be operated on a higher than optimum condition.

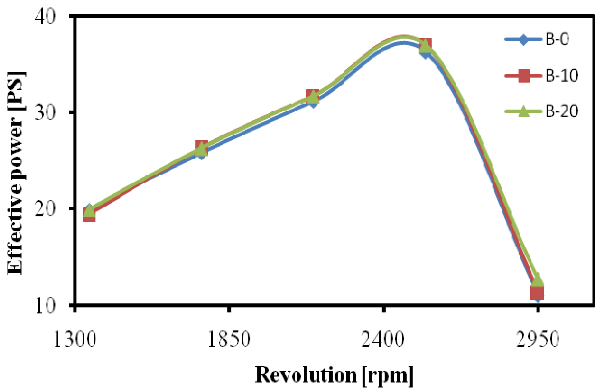

Figure 3 The comparison of effective power

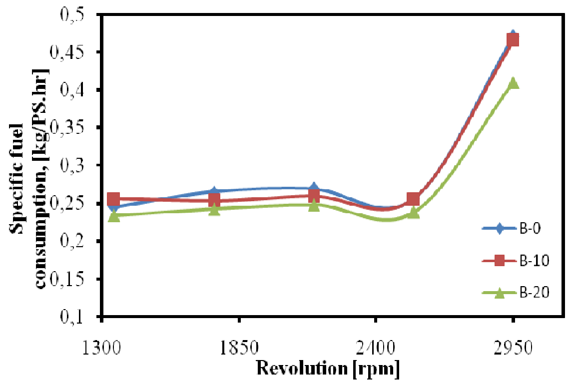

Figure 4 Specific fuel consumption comparison

3.2.3. Thermal efficiency

The thermal efficiency comparison is presented in Table 3 and Figure 5. The indicative thermal efficiency in Table 3 and Figure 5 both show that at optimum condition, the thermal efficiency of B-10 fuel (the RSOME non-catalytic method) is high enough, i.e. 58.45%, which is 1.38% higher than diesel fuel, and 1.89% higher than B-20 (the RSOME catalytic method). But B-20 (RSOME catalytic method) has a lower efficiency than diesel fuel. On average, the RSOME catalytic method has the highest efficiency, followed by the RSOME non-catalytic method and diesel fuel. Compared with diesel fuel, the RSOME catalytic method can increase the thermal efficiency from 48.50% to 54.11%, and the RSOME non-catalytic method from 48.50% to

50.73%. Above the optimum condition or at 2950 rpm, the thermal efficiency decreases extremely or drops drastically because the revolution is very high so that very high heat loss occurs through the exhaust gas.

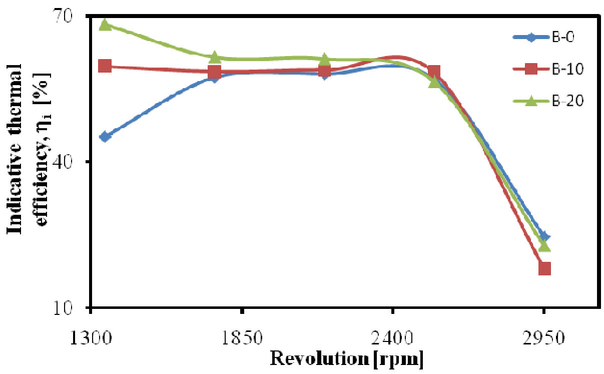

Figure 5 The comparison of thermal efficiency

Table 3 Comparison of effective power, specific fuel consumption, and thermal efficiencies

Part	Type	Revolution (rpm)					Average
		1350	1750	2150	2550*	2950	
Effective power, [PS]	B-0 (diesel fuel)[♥]	19.923	25.826	31.152	36.264	11.082	*24.840*
	B-10 (RSOME non-catalytic method *Superheated Methanol Atmospheric Pressure*)	19.440	26.295	31.729	36.950	11.346	*25.150*
	B-20 (RSOME catalytic method *Dry Wash System*)	19.923	26.295	31.729	36.950	12.665	*25.512*
Specific Fuel Con-Sumption, sfc, [Kg/Ps.Hr]	B-0 (diesel fuel)	0.245	0.265	0.269	0.256	0.471	*0.300*
	B-10 (Rsome non-catalytic Method *superheated methanol atmospheric pressure*)[♥]	0.256	0.253	0.259	0.256	0.465	*0.290*
	B-20 (RSOME catalytic method *dry wash system*)	0.234	0.242	0.248	0.238	0.410	*0.274*
Indicative Thermal Efficiency, η_i , [%]	B-0 (Diesel Fuel)	45.27	57.40	58.13	57.07	24.64	*48.50*
	B-10 (RSOME non-catalytic method *superheated methanol atmospheric pressure*)[♥]	59.73	58.53	58.90	58.45	18.07	*50.73*
	B-20 (RSOME catalytic method *dry wash system*)	68.37	61.59	61.23	56.56	22.80	*54.11*

*Optimum Condition; [♥]Susila, 2011

3.3. Exhaust Emission

3.3.1. CO content

In Table 4 and Figure 6 both show that at an optimum condition, the emission of non-catalytic method has the lowest CO content (0.4%), and the next result is the one yielded by catalytic method (0.8%). The diesel fuel is the highest (2.0%). On average, the catalytic method is the most eco-friendly, whereas the non-catalytic method and diesel fuel are the second and third respectively. Compared to diesel fuel, the catalytic method can reduce CO emissions from 2.4% to 0.88%, whereas non-catalytic method reduction ranges from 1.36% to 0.88%. It means that the non-catalytic method is more eco-friendly when compared with diesel fuel. Yet it is less eco-friendly if compared with the catalytic method. High CO emissions will result in a negative impact on human health and can harm the ozone (O_3) layer because it forms CO_2 with the reaction: $CO + O_3 \rightarrow CO_2 + O_2$. If the ozone layer is damaged, then the sun rays will directly reach the earth's atmosphere. Global warming will occur, the ice pole will melt and many islands will be drowned. Besides, abrasion and erosion by sea water will also happen.

Table 4 The comparison of CO and CO_2 content

Part	Type	Revolution (rpm)					Average
		1350	1750	2150	2550*	2950	
CO content [%]	B-0 (diesel fuel)	2.0	0.4	4.0	2.0	2.6	*2.4*
	B-10 (RSOME non-catalytic method *superheated methanol atmospheric pressure*)♥	2.0	1.2	1.6	0.4	1.6	*1.36*
	B-20 (RSOME catalytic method *dry wash system*)	1.000	1.000	1.000	0.800	0.600	*0.880*
CO_2 content [%]	B-0 (diesel fuel)	8.0	8.0	4.0	8.0	7.0	*7.0*
	B-10 (RSOME non-catalytic method *superheated methanol atmospheric pressure*)♥	2.0	4.0	4.8	3.6	3.2	*3.52*
	B-20 (RSOME catalytic method *dry wash system*)	4.00	6.00	6.00	5.60	3.50	*5.02*

*Optimum condition; ♥Susila, 2011

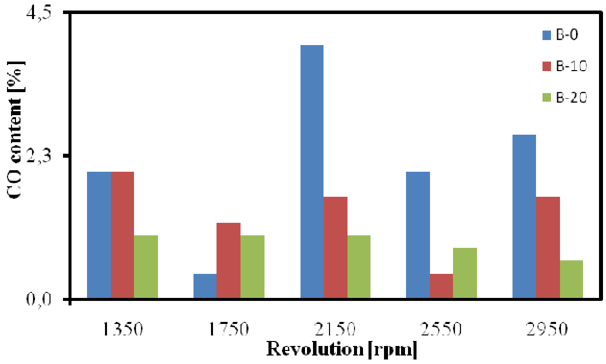

Figure 6 The comparison of CO content

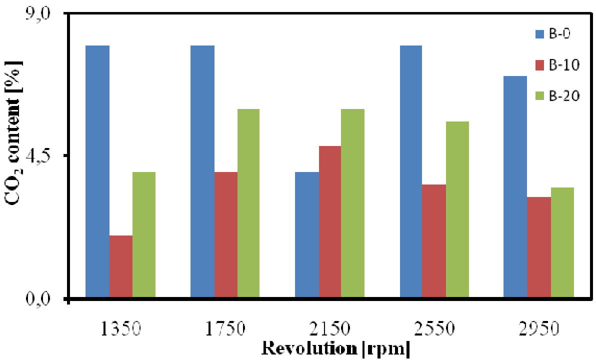

Figure 7 The comparison of CO_2 content

3.3.2. CO_2 content

In Table 4 and Figure 7 both show that at an optimum condition, the emission of B-10 non-catalytic method has the lowest CO_2 content (3.6%), followed by B-20 catalytic method (5.6%), and the highest is diesel fuel (8.0%). Each rotation shows the same facts. On average, compared with diesel fuel, the non-catalytic method can reduce CO_2 emissions from 7.0% to 3.52%, whereas the catalytic method results in a reduction from 5.02% to 3.52%. It means that the non-catalytic method is the most eco-friendly in comparison with the catalytic method and the diesel fuel. The emissions of the RSOME catalytic and non-catalytic method are lower than diesel fuel.

4. CONCLUSION

There are six aspects which are not acceptable in the RSOME catalytic method, dry wash system i.e. the density, the kinematic viscosity, the Cetane Number or CCI, the carbon residue, the water and sediment, and the sulfur. However, there are only two aspects which are not acceptable in the RSOME non-catalytic method, i.e. the carbon residue and the sulfur content. The engine test shows that at an optimum condition, the RSOME catalytic and non-catalytic method, as fuels of the CI engine, produce the same power, but diesel fuel produces smaller power ratings than the others. The engine which uses the RSOME non-catalytic method needs the same specific amount of fuel consumption as diesel fuel, but needs a bit more than catalytic method. The thermal efficiency of the RSOME non-catalytic method is higher than the catalytic method and diesel fuel, but the catalytic method has a lower efficiency rating than diesel fuel. The emissions levels of non-catalytic method are the most eco-friendly, the catalytic method is the next and is followed by diesel fuel as the one with the highest emissions rating.

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