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PERFORMANCE OF DIESEL ENGINE USING DIESEL OIL, DME AND THEIR MIXTURES

Bambang Suwondo Rahardjo
BPP Teknologi, Gedung II Lantai 22 Jl. M.H. Thamrin No.8 Jakarta 10340
Email: bamsr52@yahoo.com

ABSTRACT

Fuel atomization plays a main role in determining the performance of diesel engines, where fuel spray pattern can predict the quality of fuel combustion occurs in the combustion chamber. Fuel spray test results showed that fuel evaporation characteristics at a certain pressure will be improved. The higher the injection pressure the lower the diameter of the fuel droplets (lower SMD), thus speeding up evaporation and mixing processes between fuel and air in the combustion chamber and this resulted in the more complete combustion process. Numerical study of atomization process at injection pressure 150 bar has shown the distribution of SMD, temperature and concentration of air-fuel mixture in fuel spray. Experimental study also has shown that DME is feasible to be used as alternative fuel in diesel engines by adding 2–5% lubricant additives. The use of diesel-DME mixture at 50% v/v provides the lowest fuel consumption by generating power of 3x2975 watts.

Keywords: diesel–mix–DME, engin performance, atomizing simulation, fluid–dynamic

1. INTRODUCTION

Efforts to develop alternative fuels as a substitute for fuel oil (BBM) to demand an increasingly higher, where Di-methyl ether (DME) has been projected as one of the alternative fuel sources that are environmentally friendly.

DME is non-toxic compounds and do not contain sulfur (S) and nitrogen (N), so emissions (SOx, NOx, particulates and soot) are much lower than diesel (diesel) and does not damage the ozone layer. In addition, DME is not corrosive to the metal so it does not require special modifications to the existing infrastructure of LPG when used as a replacement or mixing LPG [A. Troy, Semelsberger, L. Rodney, Borup, L. Howard, Greene. 2006].

Cetane Number (CN) of DME is high (55 ~ 60) as a measure of combustion quality during compression ignition, so it can be used a substitute for diesel oil [Constantine Arcoumanis, Choongsik Bae, Roy Crookes, Eiji Kinoshita, 2008].

Use of DME means has increased economic value and as an effort to reduce dependence on oil as well as solve the problem of environmental pollution. The use of DME as a fuel in diesel engines requiring modifications to the existing injection system, because of the characteristic differences between diesel and DME.

Advantages of DME shows the potential to be an alternative fuel in diesel engines, while the drawbacks to be applied is a challenge that must be answered by testing.

The results of previous testing [M.S. Boedoyo, Bambang SR, Taufik Y., Wargiantoro P., Suharyono, 2010] shows the interaction or influence of injection pressure (150 bar, 180 bar, 235 bar) and physical chemical properties of the fuel atomization characteristics of fuel (diesel, DME, and mixtures), where the higher injection pressure will reduce fuel grain size after injection, thus speeding evaporation and mixing of fuel and air in the combustion chamber. In addition, the higher the content of DME Kabutan the penetration distance will become shorter, the faster the evaporation rate, the greater the angle α fogging, the mixing of fuel and air more perfect that the burning will be more perfect, it is caused by the formation of steam faster and more at the start fogging.

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2. TESTING

Testing the performance of DME and their mixtures with diesel oil on diesel engines performed at the Laboratory of Motor-Fuel and Propulsion Motor Technology Center (BTMP) - PUSPIPTEK - Serpong.

2.1. Purposes

Getting a diesel engine performance map through experimental testing on diesel engines. Previously done also simulated fuel fogging process to obtain representation or prediction of the quality of atomization and the quality of mixing fuel with air. Simulation results fogging process can also be used to predict the quality of combustion in diesel engines. Simulation of the fogging process of DME, diesel oil and mixtures performed on injection pressure 150 bar, 180 bar and 235 bar using CFD software (Computational Fluid Dynamic) OpenFOAM.

2.2. Material

Table 1 and Table 2 respectively show the characteristics test of DME and diesel oil.

2.3. Equipments

Figure 1 shows the performance of diesel engine test equipment, comprising:

- Diesel oil storage tank (1), DME (2) at a pressure of 5 bar.
- N2 gas tube (3) to provide additional pressure to a minimum of 12 bars on the mixing tank (4).
- Mixing Tank (4) diesel oil and DME perfectly.
- Pressure regulator (5) as a regulator of pressure of fuel injection into the diesel engine through a pump (6) and injector (7).
- Injector (7) as a supplier of fuel to the combustion chamber, where the pressure setting using a cartridge injector test master on the condition of 70 bar, 120 bar and 185 bar.
- Electronic Scales (8) to determine the weight of the fuel injected into a diesel engine (9).
- Engine Yanmar 10 KVA diesel generator (9) with technical specifications as shown in Table 3 and Table 4.
- Air Flowmeter (10) to determine the flow rate of air as a medium burner.
- *Mist analyzer* (11) to determine levels of exhaust smoke emission fuel.
- *Software Computational Fluid Dynamic* (CFD) *OpenFOAM*.

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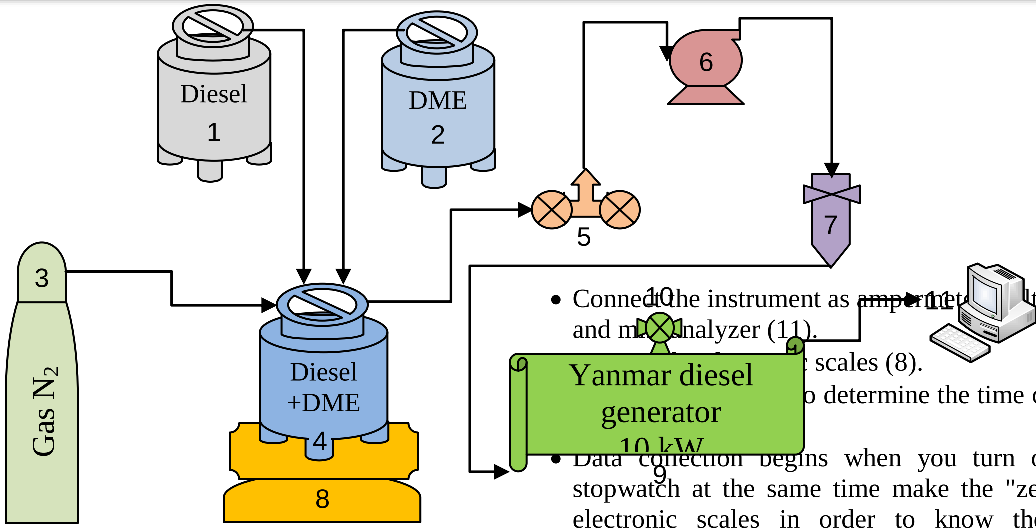

Figure 1. Process flowchart of diesel engine performance test equipment

2.4. Methodology

- Drain the fuel from the fuel storage tank of diesel oil (1) and or DME (2) using a hose with a pressure regulator into the mixing tank (4).
- Mixing diesel oil and DME perfectly in the mixing tank (4).
- Provide additional pressure by opening the valve on the tube N2 gas regulator (3) to the pressure in the mixing tank (4) a minimum of 12 bar to avoid cavitation in the injector nozzle (7) so that the fuel flow smoothly.
- Open the tank valve diverting flow to the diesel engine (position of the valve at the bottom of the tank) and open the fuel flow valve that is diesel engine itself so that the fuel into the injection pump (6).
- Turn on the diesel engine at 1500 rpm engine speed conditions and wait for ± 10 minutes to heat up the machine stable rotation.
- Connect the instrument as amperemete... ...ltmeter, and m... ...nalyzer (11).
- ... scales (8).
- ...o determine the time of data
- Data collection begins when you turn on the stopwatch at the same time make the "zero" of electronic scales in order to know the fuel consumption per 5 minutes.
- ...urrent (Ampere), fuel consumption (kg), soot emissions per 5 minutes for 1 hour.

3. RESULT AND DISCUSSION

Parameters and conditions of the simulation modeling results fuel atomization of diesel oil, DME and mixtures thereof at a pressure of 150 bar injection are shown in Table 5.

Numerical simulations are several patterns of physical chemical parameters atomization fuel since the beginning of fuel injection to the air at the time of interaction with the termination of the atomization process. Physical chemical parameters produced a pattern of size distribution and temperature mist of fuel-air mixture.

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Table 1. Parameters and conditions of simulation

Parameters	Conditions
Position	(0 0.0995 0)
Direction	(0 –1 0)
Diameter	0.00019 m
Cd	0,9
Mass	6e–06
Temperature	298^{o}K
Pressure	150, 180, 235 bar
Mass flow rate	(0 0.1272) (4.16667e-05 6.1634) (8.33333e–05 9.4778)

3.1. Results

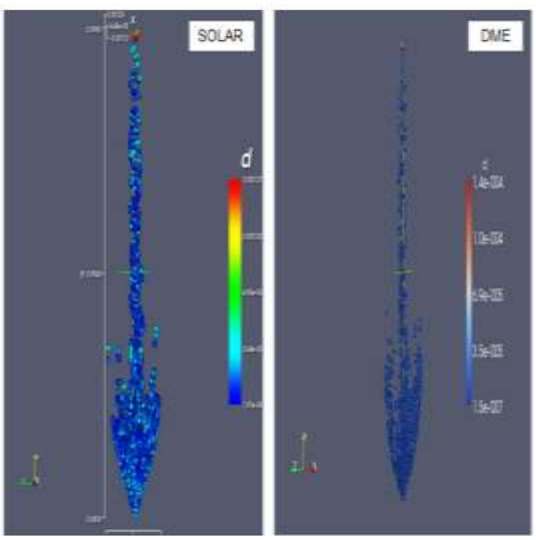

Figure 2 Size and temperature distribution pattern of 100%Diesel oil and 100%DME

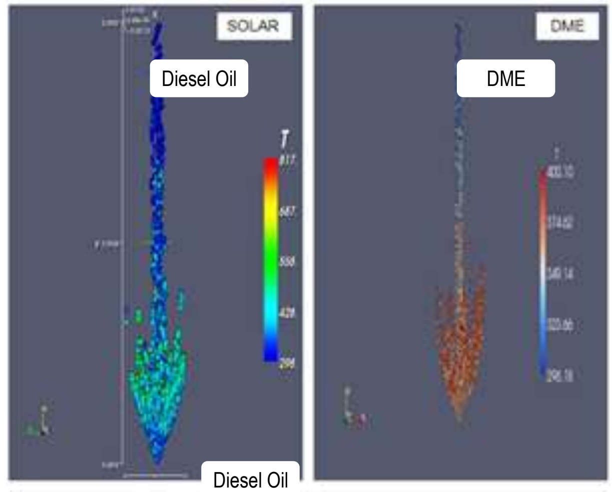

Figure 3
Size and temperature distribution pattern of of 100%Diesel oil and 100%DME (0.0015 sec, 150 bar)

. Figure 2 and Figure 3 respectively show the size and temperature distribution pattern of 100%Diesel oil with 100%DME at a pressure of 150 bar during injection time 0.0015 seconds.

Figure 4 and Figure 5 respectively show the size and temperature distribution pattern of the 100%diesel oil with 100%DME at a pressure of 150 bar during injection time 0.0017 seconds.

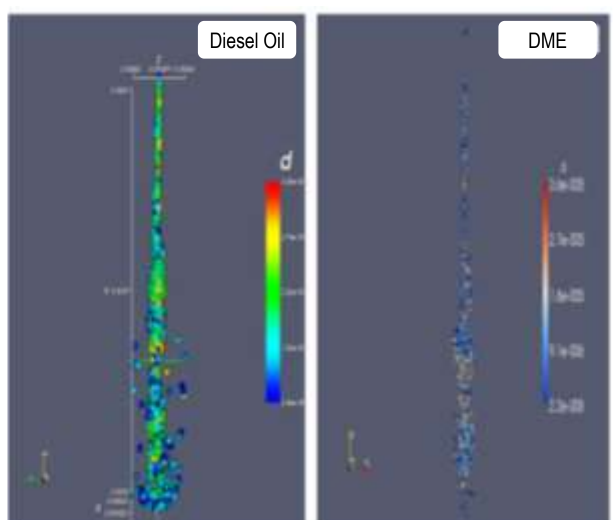

Figure 4
Size distribution pattern of 100%Diesel oil and 100%DME (0,0017 sec, 150 bar)

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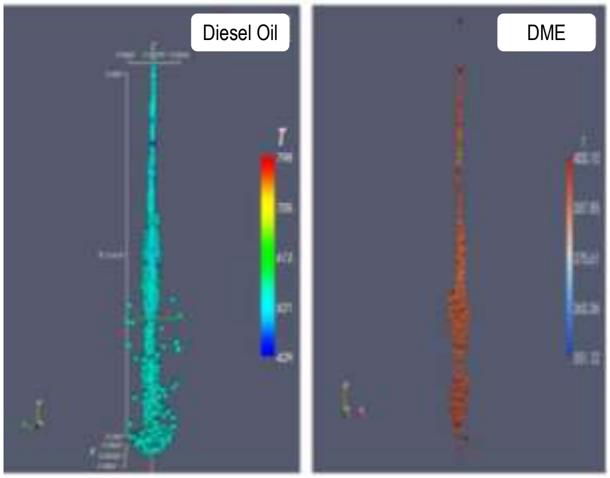

Figure 5
Temperature distribution pattern of 100%Diesel oil and 100% DME
(0.0017 sec, 150 bar)

Figure 6 and Figure 7 respectively show the concentration and temperature distribution patterns of 100%diesel oil with 100%DME at a pressure of 150 bar during injection time 0.0049 seconds

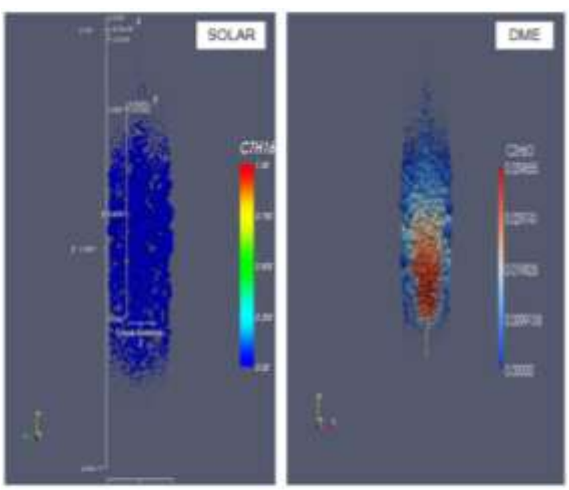

Figure 6
Concentration distribution pattern of 100%Diesel oil and 100%DME
(0.0049 sec, 150 bar)

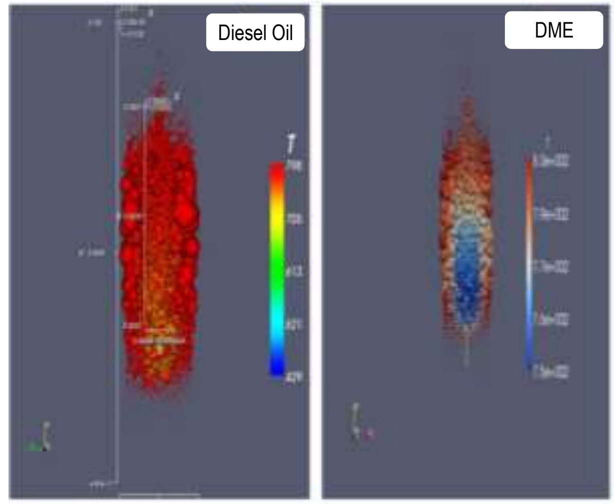

Figure 7
Temperature distribution pattern of 100%Diesel oil and 100%DME
(0.0049 sec, 150 bar)

Figure 8 and Figure 9 respectively show the size and temperature distribution pattern of 100% diesel oil with Diesel–mix–DME 50/50, at a pressure of 150 bar during injection time 0.0015 seconds.

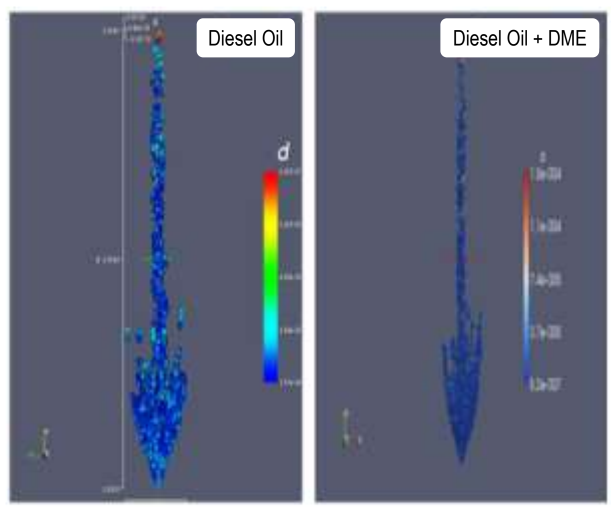

Figure 8
Size distribution pattern of 100%Diesel oil and Diesel oil–mix–DME 50/50
(0,0015 sec, 150 bar)

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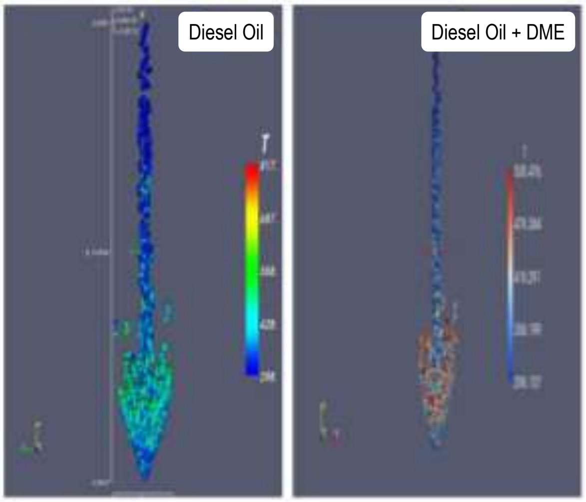

Figure 9
Temperature distribution pattern of 100%Diesel oil and Diesel–mix–DME 50/50 (0,0015 sec, 150 bar)

Figure 10 show the size and temperature distribution pattern of 100% diesel oil with diesel–mix–DME 50/50 at a pressure of 150 bar during injection time 0.0017 seconds

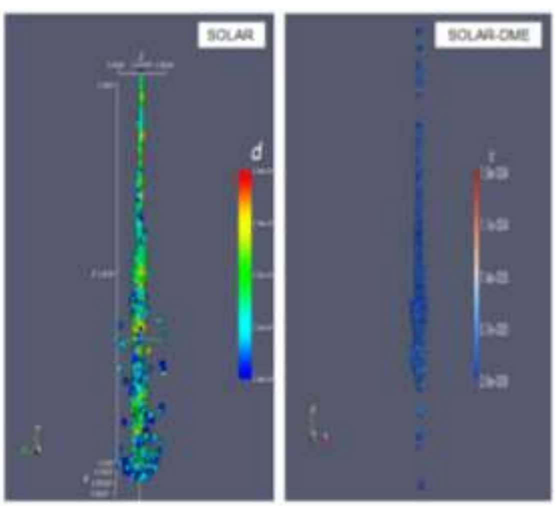

Figure 10
Size distribution pattern of 100%Diesel oil and Diesel–mix–DME 50/50

Figure 12 and Figure 13 respectively show the concentration and temperature distribution patterns of 100% Diesel oil with Diesel–mix–DME 50/50 at a pressure of 150 bar during injection time 0.0049 seconds.

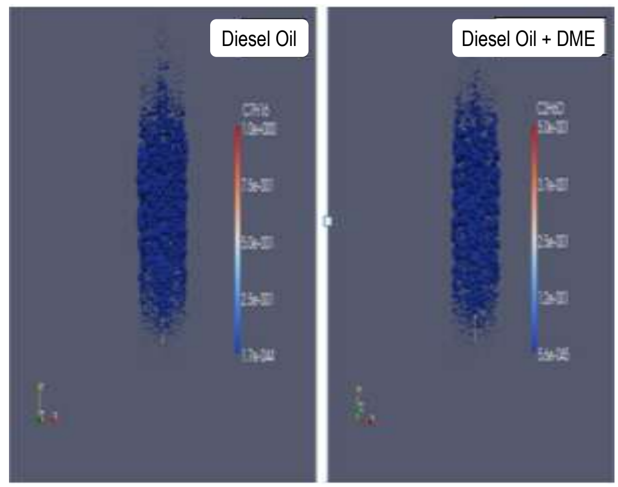

Figure 12
Concentration distribution pattern of 100%Diesel oil and Diesel–mix–DME 50/50

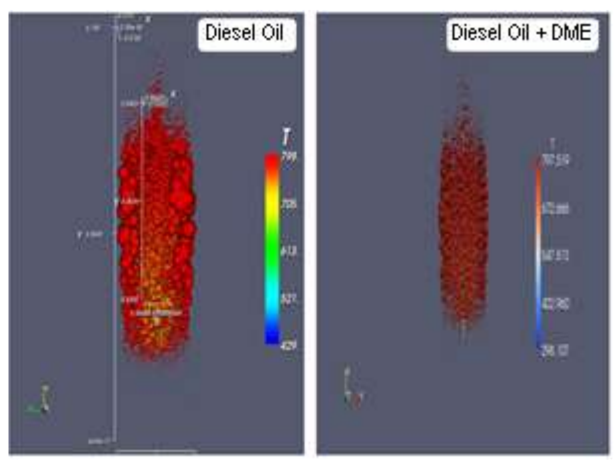

Figure 13
Temperature distribution pattern of 100%Diesel oil and Diesel–mix–DME 50/50

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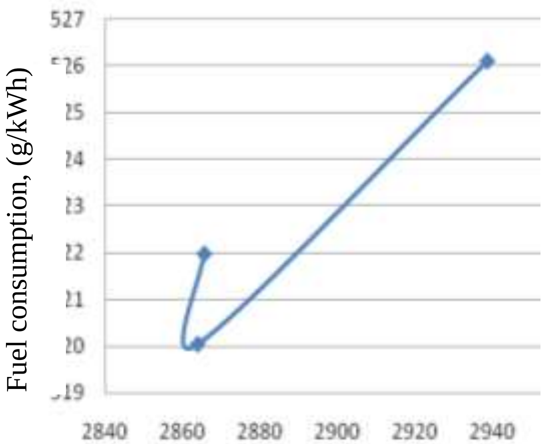

Power Output, (Watt)

Figure 14. Correlation of fuel consumption and *power output* (1500 rpm)

Figure 14 shows the correlation of fuel consumption (g / kWh) for motor power (Watts) is generated at 1500 rpm per minute.

3.2. Discussion

Result analysis of simulation fuel atomization at injection pressures of 150, 180 and 235 bar made to the size distribution, temperature and concentration of the fuel–air mixture.

3.2.1. Size distribution of fuel *droplets*

Figure 2 shows the size distribution pattern of 100% Diesel oil and 100% DME (0.0015 sec, 150 bar), where the mist size of 100% DME is $1{,}5.10^{-7}$~$3{,}5.10^{-5}$m, while the mist size of 100 % Diesel oil ranged $1{,}97.10^{-6}$~$3{,}58.10^{-5}$m. At a pressure of 180 bar during injection time 0.0015 seconds, respectively mist size was 2.2 10^{-8}~3.5 10^{-5}m (100% DME) and 2.86 10^{-8}~3.43 10^{-5}m (100% diesel oil). At a pressure of 180 bar during injection time 0.0015 seconds, respectively mist size was 2.2 10^{-8}~3.5 10^{-5}m (100% DME) and 2.86 10^{-8}~3.43 10^{-5}m (100% diesel oil). At a pressure of 235 bar during injection time 0.0015 seconds, respectively mist size is 1.5 10^{-7}~3.5 10^{-5}m (100% DME) and 1.97 10^{-6}~3.58 10^{-5}m (100% diesel oil). Thus, the size distribution of 100% DME mist is significantly smaller than the size distribution of 100% Diesel oil mist, because the DME evaporation process occurs more rapidly than diesel oil.

Figure 4 shows the size distribution pattern of 100%Diesel oil and 100%DME (0.0017 sec, 150 bar), where the mist size of 100% DME is $2{,}2.10^{-8}$~$2{,}7.10^{-5}$m, while the mist size of 100 % Diesel oil ranged $2{,}86.10^{-8}$~$3{,}7.10^{-5}$m. At a pressure of 180 bar during injection time 0.0017 seconds, respectively mist size was 2.2 10^{-8}~3.5 10^{-5}m (100% DME) and 2.86 10^{-8}~3.43 10^{-5}m (100% diesel oil). At a pressure of 235 bar during injection time 0.0017 seconds, respectively mist size was 2.2 10^{-8}~3.5 10^{-5}m (100% DME) and 2.86 10^{-8}~1.26 10^{-5}m (100% diesel oil). Here look that the trend of the size distribution of mist for 100% Diesel oil and 100% at the time of injection for DME 0.0017 seconds remained the same compared to the size distribution of mist at the time of injection of 0.0015 seconds.

Figure 8 shows the size distribution pattern of 100%Diesel oil and Diesel–mix–DME 50/50 (0.0015 seconds, 150 bar), where the size of mist for 100% DME range $8{,}2.10^{-7}$~$3{,}7.10^{-5}$m, while the size of 100% Diesel oil mist ranged $1{,}97.10^{-6}$~$3{,}58.10^{-5}$m. Meanwhile, at a pressure of 180 bar during injection time 0.0015 seconds, respectively mist size was 2.8 10^{-8}~3.7 10^{-5}m (100% DME) and 2.86 10^{-8}~3.43 10^{-5}m (100% diesel oil). While the size of 100% Diesel oil mist ranged 1.97 10^{-6}~3.58 10^{-5}m. Meanwhile, at a pressure of 180 bar during injection time 0.0015 seconds, respectively mist size was 2.8 10^{-8}~3.7 10^{-5}m (100% DME) and 2.86 10^{-8}~3.43 10^{-5}m (100% diesel oil). At a pressure of 235 bar during injection time 0.0015 seconds, respectively mist particle size was 2.8 10^{-8}~3.7 10^{-5}m (100% DME) and 1.97 10^{-6}~3.54 10^{-5}m (100% diesel oil). It appears that the mist size of Diesel–mix–DME 50/50 is smaller than the mist size of 100% Diesel oil, but the differences were not as great when compared to 100% DME. This is because of the oil content of 50% diesel oil inside of diesel–mix–DME 50/50.

Figure 10 shows the size distribution pattern of 100% Diesel oil and Diesel–mix–DME 50/50 (0.0017 seconds, 150 bar), which after injection the range mist size of Diesel–mix–DME 50/50 is about 2.8 10^{8}~3.7 10^{5} m, while the mist size of 100% Diesel oil is about 2.86 10^{8}~1.26 10^{5}m. Meanwhile, at a pressure of 180 bar during injection time 0.0017 seconds, respectively mist size for Diesel–

mix–DME 50/50 was 2.8 10^{-8}~3.7 10^{-5}m and 2.86 10^{-8}~3.43 10^{-5}m for 100% diesel oil. While the pressure of 235 bar during injection time 0.0017 seconds, each the mist size of Diesel–mix–DME 50/50 was 2.8 10^{-8}~3.7 10^{-5}m and 2.86 10^{-8}~1.26 10^{-5}m for 100% diesel oil. Here look that the difference in the mist size of Diesel–mix–DME 50/50 with 100% diesel oil mist gets smaller during injection time approximately 0.0017 seconds.

3.2.2. Temperature distribution of fuel

Figure 3 shows differences of the temperature distribution pattern between 100%Diesel oil and 100%DME at 150 bar injection pressure, in which the temperature distribution of 100%Diesel oil mist range 298 ~ 687^{o}K with mist tip area reaches the highest temperature (817^{o}C). The same trend was also experienced by 100% DME mist, in which the temperature distribution range about 298~400^{o}K (150 bar) and 298~540^{o}K (235 bar), while the temperature distribution mist 100% diesel oil and 100% of DME at 180 bar injection pressure has a range the same is 298~798^{o}K. Temperature distribution of 100% DME mist is lower due to DME has a low boiling point (-25^{o}C or 248^{o}K) so when DME is injected at room temperature 298^{o}K instantly transformed into a gas phase. Once that happens the heat transfer from the air to the DME which runs very slow, because of DME thermal conductivity is very low. Meanwhile, diesel oil which has a high boiling point (> 100°C) when at initial injection that diesel oil phase is a liquid that has a higher conductivity than DME, so that the temperature distribution of 100% Diesel oil higher.

Figure 5 shows the temperature distribution pattern of 100% Diesel oil mist at 150 bar injection pressure is higher (± 521^{o}K) compared to 100%DME (387~400^{o}K), while the temperature distribution of 100%Diesel oil mist at 235 bar injection pressure (±521^{o}K) is in between the temperature distribution 100% DME (479~540^{o}K). Instead the temperature distribution of 100%DME mist at 180 bar pressure (673~796^{o}K) higher than the temperature distribution of 100% Diesel oil mist (423^{o}K).

Figure 7 shows the growth pattern of 100%Diesel oil mist and 100%DME mist at 150 bar injection pressure when the nozzle has stopped injecting at condition in which all the mist of 100%Diesel oil and 100%DME has become vapor phase and mixes with air. It appears that 100%Diesel oil has become homogeneous at about 798^{o}K (150 bar), 797^{o}K (180 and 235 bar), while the temperature of 100% DME varied 750~800^{o}K (150 and 180 bar). At this time, both fuel has become phase in which 100%diesel oil and 100%DME will start to burn.

Figure 9 shows the temperature distribution pattern of 100%Diesel oil and Diesel–mix–DME 50/50 at a pressure of 150 bar during injection time 0.0015 seconds, in which the temperature distribution of 100%DME and Diesel–mix–DME 50/50 likely lower (538^{o}K) compared to temperature distribution of 100% Diesel oil (817^{o}K). A similar trend occurred at a pressure of 235 bar, where the temperature distribution of Diesel–mix–DME 50/50 mist lower (797^{o}K) versus temperature distribution of 100% Diesel oil mist (817^{o}K). This is due to the boiling point and thermal conductivity of Diesel–mix–DME 50/50 is lower than 100%Diesel oil. While the temperature distribution of Diesel–mix–DME 50/50 mist and 100% Diesel oil mist at 180 bar injection pressure is approximately equal to 798^{o}K.

Figure 11 shows the trend of the temperature distribution pattern of Diesel–mix–DME 50/50 mist at 150 bar injection pressure is lower (540^{o}K) compared to the temperature distribution of 100%Diesel oil mist (798^{o}K). The presence of 50% diesel oil inside of Diesel–mix–DME 50/50, in addition to result in a significant temperature increase from about 400^{o}K to 540^{o}K (a mixture of diesel oil + DME 50/50), also increases the boiling point and thermal conductivity of a mixture of Diesel–mix–DME 50/50.

Figure 13 shows the temperature distribution pattern of Diesel–mix–DME 50/50 at 150 bar injection pressure (797.5^{o}K) temperature distribution pattern approach 100% Diesel oil mist (798^{o}K). In contrast, the temperature distribution of Diesel–mix–DME 50/50 at a pressure of 180 and 235 bar injection (797.5^{o}K) slightly exceeds the temperature distribution of 100% Diesel oilmist (797^{o}K).

3.2.3. Concentration distribution of fuel–mix–air

Figure 2 shows that the mist pattern of 100% DME will be easier to mix with air to form a homogeneous mixture is flammable.

Figure 6 shows the concentration distribution patterns of 100%diesel oil and 100% DME when changing phase gas / vapor after injection for 0.0049 seconds at a pressure of 150 bar. Concentration or vapor fraction of 100% Diesel oil to air looks homogeneous and more dispersed (0 ~ 0.04), and also a similar thing happened at a pressure of 180 bar injection. While the injection pressure of 235 bar more diffuse (0 ~ 1).

Figure 8 shows that the mist pattern of Diesel–mix–DME 50/50 will be a little easier to mix with air homogeneously than 100% Diesel oil mist with air.

Figure 12 shows the concentration distribution patterns of 100% Diesel oil and Diesel–mix–DME 50/50 at 150 bar injection pressure which occurred sometime after the injection for 0.0049 seconds finished with the condition almost all DME and Diesel oil has changed the phase to be gas.

3.2.4. Performance of diesel engine

Fogging test results of DME fuel at injection pressure (185 bar and 235 bar) above normal pressure fuel injection diesel oil (150 bar) resulted in the evaporation of DME faster. Against the background of this, the diesel engine performance test refers to the three (3) variations in pressure, ie: 185, 120, and 70 bar.

From the fuel blending process of diesel oil and DME resulted decreasing viscosity that followed increased the mass fraction of DME were mixed. Viscosity of DME blended with diesel oil below the limit specified by ASTM would be ideal if a mixture of> 25%.

Fuel consumption of Diesel–mix–DME 50/50 at a pressure of 70 bar higher than the pressure of 120 and 185 bar, while the lowest fuel consumption which is at a pressure of 120 bar although the difference was not significant.

At 120 bar pressure consumes Diesel–mix–DME 50/50 for 520 grams/kWh produced the lowest exhaust gas temperature (294^{o}C), but the fuel consumption of Diesel–mix–DME 50/50 is slightly higher (522-526 grams/kWh) increase exhaust gas temperature reaches about 300^{o}C (70 bar and 185 bar). While the highest temperature of the exhaust gas is diesel fuel oil (320^{o}C), followed by DME (312^{o}C).

The correlation between fuel consumption with a power output as shown in Figure 14 shows that the use of Diesel–mix–DME 50/50 provides the lowest fuel consumption while a raised power output of 2975 watts. Fuel consumption of 100% DME increased, while the output power generated is similar to Diesel–mix–DME 50/50, while the use of 100% diesel oil at the same engine rpm gives the greatest power output reaches 2940 watts.

4. Conclusions and Suggestions

4.1. Conclusions

Based on the results of the simulation analysis process fuel injection diesel oil, DME and their mixtures at a pressure of 150 bar, 180 bar and 235 bar could be concluded as follows:

- The temperature distribution pattern of diesel oil mist is generally higher than the DME at beginning and the end of the injection, as well as the size distribution of diesel oil mist greater than the DME, so DME will evaporate more quickly and uniformly mixed with air.
- DME combustion temperature and exhaust gas temperature tends to be lower than diesel oil.
- DME combustion is faster and perfect, because in addition to DME has cetan number (CN_{DME} = 55-64) is higher than diesel oil (oil CN_{Diesel} = 49-55) also the DME mist size smaller than diesel oil, so it mixes with the air more perfectly.
- The time period of injection is longer than the injection of diesel oil, due to at the DME liquid phase has density and low calorific value, thus requiring more DME volume (at least 1.8 times the volume of diesel oil) to supply energy for injecting inside of gasifier.
- An increase in temperature at the injection pump shows a heavy engine work due to cavitation and / or poor lubrication. In this test using a lubricant additive 1% castor oil.
- DME is feasible as a fuel substitute for diesel oil in diesel engines by adding 2-5% lubricant additive.
- The use fuel of Diesel–mix–DME 50/50 provides the lowest fuel consumption, while power output 2975 watt generated.
- Fuel consumption of 100%DME increased by producing power output that almost the same as Diesel–mix–DME 50/50, while the use of 100% diesel oil in the engine speed (rpm), which provide the greatest power output reaches 2940 watts .

4.2. Suggstions

- Fuel injection system should be pressure, including the storage tanks as well as the

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pressurized LPG tank, it is given system pressure fuel DME covered as a low boiling point (-25.1 ° C, 1 atm).

- The fuel injection system has the potential to cavitation, because DME has a high evaporation pressure, so it is necessary the pressure (1.2~3.0 Mpa) to flow DME from the storage tank through a pipe into the combustion chamber in order to the injection operation is stable.
- Vulnerable leakage between the plunger and the barrel since DME has a low viscosity values.
- Vulnerable damage to the sealing materials and other plastic parts because of DME is not compatible with the elastomer. For further testing is recommended to replace that seal and rubber fuel lines with stainless steel.

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Table 2. Characteristics of DME

Physical Propertes		DME
Chemical formula		CH_3-O-CH_3
Molecul weight	g/mol	46
C	% mass	52.2
H	%mass	13
O	% mass	34.8
Ratio C/H		0.337
Critical point	^oK	400
Critical pressure	MPa	5.37
Critical density	kg/m^3	259
Density (liquid)	kg/m^3	667
Relative density gas (air=1)		1.59
Cetane number		>55
Auto-ignition temperature	^oK	508
Stoichiometric air/fuel mass ratio		9.0
Boiling point at 1 atm	^oK	248.1
Enthalpy evaporation	kJ/kg	467.13
Lower heating value (LHV)	MJ/kg	27.6
Specific capacity of hot gas	kJ/kgK	2.99
Ignition limits	%Vol air	3.4/18.6
Modulus of elasticity	N/m^2	6.37E+0.8
Kinematic viscosity of liquid	cSt	<1
Surface tension (298^{o}K)	N/m	0.012
Vapour pressure (298^{o}K)	kPa	530

Source : Elana M. Chapman, 2003

Table 3. Characteristics of *diesel* (diesel fuel)

Physical Propertes		Diesel oil
Chemical formula		-
Molecul weight	g/mol	170
C	% mass	86
H	%mass	14
O	% mass	0
Ratio C/H		0.516

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Critical point	°K	708
Critical pressure	MPa	3.00[a]
Critical density	kg/m^3	-
Density (liquid)	kg/m^3	831
Relatif density gas (air=1)		-
Cetane number		40-50
Auto-ignition temperature	°K	523
Stoichiometric air/fuel mass ratio		14.6
Boiling point at 1 atm	°K	450 – 463
Enthalpy evaporation	kJ/kg	300
Lower heating value (LHV)	MJ/kg	42.5
Spesific capasity hot gas	kJ/kgK	1.7
Ignition limits	%Vol air	0.6/6.5
Modulus of elasticity	N/m^2	14.86E+08
Kinematic viscosity of liquid	cSt	3
Surface tension (at 298 K)	N/m	0.27
Vapour pressure (at 298 K)	kPa	<<10

Source : Elana M. Chapman, 2003

Table 4. Specific of *diesel*

Parameters		Technical Data
Engine type		*Diesel* horizontal 4 langkah berpendingin air
Combustion system		*direct injection*
Number of cylinder		1 (satu) silinder
Fogging time		19° sebelum TMA
Diameter x Stroke	mm	110 x 106
Volume of cylinder	cc	1007
Power Continuous	dk/ppm	16 / 2200
Power max	dk/ppm	19 / 2200
Torque max	kgm/ppm	7,42 / 1600
Compression ratio		16,3
Fuel consumption	gr/dk.jam	1,79
Fuel pump		Tipe Bosch
Injector pressure	kg/cm^2	200
Capacity (tank)	liter	13,7
Capacity lubricants	liter	3,6
Type of lubricant		SAE 40 kelas CC ata CD

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Cooling system	Radiator
Capacity of cooling tank liter	4,0

Source : Hyun Kyu Suh, Chang Sik Lee, 2007

Table 5. Specific of generator

Parameters		Technical Data
Merk		Denyo
Model		FA – 12.5F
Output	KVA	12,5
Phase		3 / U – V – W
Voltage	Volt	380
Current	Ampere	19
Frequency	Hz	50
Power factor		0,8
Rating		*Continuous*
Speed	rpm	1500
Weight	kg	155

Source : Hyun Kyu Suh, Chang Sik Lee, 2007