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OBSERVATION OF IN-CYLINDER GAS PRESSURE AND COMBUSTION RELATED PARAMETERS WITH TWO OXYGENATE BLENDS

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ABSTRACT

Diesel engine performance, in-cylinder gas pressure, rate of pressure rise, rate of heat release (ROHR) and cumulative heat release (CHR) were investigated with two oxygenated fuel blends. The base fuel selected was European diesel fuel (EDF), while diethylene glycol di methyl ether (DGM), and a biodiesel (BD) selected were as oxygenates. A 7 vol% DGM was added to EDF, while a 20 vol% BD was added to EDF for maintaining same oxygen in the fuel blends. In the text and in the Figures, the EDF-BD blend is designated as DB, while the EDF-DGM as DDGM. The experiment was conducted with a six-cylinder, four-stroke, turbocharged diesel engine. Results revealed that both DB and DDGM blends showed identical in-cylinder gas pressure, rate of pressure rise, ROHR and CHR. At high load, brake specific fuel consumption (BSFC) with DDGM was higher and thermal efficiency was slightly lower relative to DB blend.

Keywords: European Diesel Fuel, Diesel Engine, Engine Performance.

1. INTRODUCTION

It is well-known that diesel engine is known as one of the reliable power sources for its fuel economy, performance and durability. Particulate matter (PM) and oxides of nitrogen (NOx) emissions are the major harmful pollutants from diesel engine and have raised increased interest over the recent years [1]. Researchers concentrate their research to alleviate such harmful pollutants. As a matter of fact, to abate such harmful emissions, all researchers are doing their research in three broad areas, such as, changing of conventional petroleum fuel with alternative fuel, changing the design of combustion chamber and using device at exhaust system to purify the exhaust gas. Due to their inherent emission reduction nature, BDs have recently gained a tremendous interest. About 10% oxygen present in BD molecule and this extra oxygen are believed to be reducing exhaust emissions. BD is not only produced from straight vegetable oils but also from waste cooking oils, animal fats or even from grease. Transesterification is the well-known process by which all vegetable oils, waste cooking oils, animal fats or grease can be converted to BD. The properties of BD are close to those of diesel fuel or even better in some cases. BD offers several advantages: it is biodegradable in nature, non toxic and can be blended in any ratios with petroleum diesel fuel. Several reports elucidated lower emissions from BD combustion [2-5]. Concerning NOx emissions, some investigations reported higher NOx emissions, while some others reported lower. [5-10] NOx emissions. As mentioned before that BD contains around 10% oxygen in its molecule and thus it can be treated as oxygenated fuel. Like fuels, other oxygenated fuels, like methanol, ethanol, methyl tertiary butyl ether (MTBE), dimethoxy methane (DMM), DGM, diethylene glycol di ethyl ether (DEE), di-n-butyl ether (DBE), ethyl hexyl acetate (EHA) etc can reduce THC, CO and smoke emissions due to the presence of oxygen in their molecular structures. Nabi et al. [11] reported smoke-free stoichiometric diesel combustion even at engine's worst operating condition with a combination of different oxygenated fuels, high exhaust gas recirculation (EGR) and a three way catalyst. Ogawa et al. [12] conducted similar experiments with another oxygenated fuel, DMM and confirmed similar results to Nabi et al. [11].

The objective of the current study is to investigate combustion related parameters, in-cylinder gas pressure and engine performance with different blends of two oxygenates. A blend will be suggested for future alternative fuel for diesel engine from the investigation.

2. EXPERIMENTAL

The experiment was performed with a four-stroke, six-cylinder, direct injection turbocharged Scania DC 1102 diesel engine. The specifications of the tested engine are shown in Table 1. All engine experiments were performed with 1400 rpm [1], dynamic fuel injection timing was set at 20 °CA before top dead center (BTDC). The volumetric blending ratios of DGM and BD to EDF were around 7% and 20% respectively. To investigate the same fuel oxygen on combustion and engine performance, the blending ratios of oxygenates to

EDF were set at 7 and 20 vol%. Some selected properties of the tested fuels are shown in Table 2**.** The in-cylinder gas pressure data were recorded with a pressure transducer (PCB–M112B11). The in-cylinder gas pressure was relied on continual sampling with data logged online with a personal computer. The air temperature and humidity were monitored periodically and the measurements were corrected as per international standards.

Table 1: Specifications of tested engine

Engine type	**Scania DC 1102**
Compression ratio	18:1
Number of cylinders	06
Bore x stroke	127 x 140 mm
Maximum power	280 kW @ 1800 rpm
Injection pressure	220 bar
Number of holes	8
Size of hole	ϕ 0.216 mm

Table 2 Properties of tested fuels

Properties	**Neat EDF[1]**	**Neat DGM[13]**	**Neat BD[13]**
Density @15°C (g/cc)	0.84	0.950	0.88
Kin. vis@40°C (cSt)	2.58	N/A*	3.72
Cal value (MJ/kg)	42.4	24.50	37.1
Boiling point (°C)	324	162.00	341
Cetane number	49.5	126.00	65.0
Carbon (wt %)	85.9	53.73	76.1
Hydrogen (wt %)	14.0	10.44	12.6
Oxygen (wt %)	0.00	35.82	11.3

*N/A: Not available.

3. RESULTS AND DISCUSSION

In this section, combustion related parameters, such as, in-cylinder gas pressure, rate of pressure, ROHR, CHR and the engine performance parameters include BSFC and engine thermal efficiency were discussed. Recalling that all the parameters will be discussed for the two oxygenates as both blends contain same oxygen in their molecules.

3.1 In-cylinder gas pressure

Figures 1 and 2 illustrate in-cylinder gas pressure for the two oxygenates at different engine loads. The loads were categorized as low load (12.5 and 25%), medium load (50%) and high load (75%). The numbers 12.5, 25, 50 and 75 inside the Figuers represent the percentage of loads mentioned above. It can be observed from Figures 1 and 2 that in-cylinder gas pressures are higher at higher engine loads. It can also be observed that the gas pressures with DB blend are higher than those of DDGM for all engine loading conditions. The maximum pressures at 12.5, 25, 50 and 75% loads with DB blend are found to be 66.4, 79.1, 108.5 and 128.1 bars respectively. On the contrary, with DDGM blend, the corresponding values are 65.7, 78.4, 106.6 and 124 bars respectively. For better understanding, Figure 10 is drwan for the difference of maximum pressures with two blends. As at high load the pressure difference is higher thus, Figure 10 is drawn only for 75% load. Inside Figure 10, the legend within bracket P represents pressures, while DP represents rate of pressure rise. It is clearly evident from the Figure that the maximum pressure with DB blend is higher than that of DDGM blend.

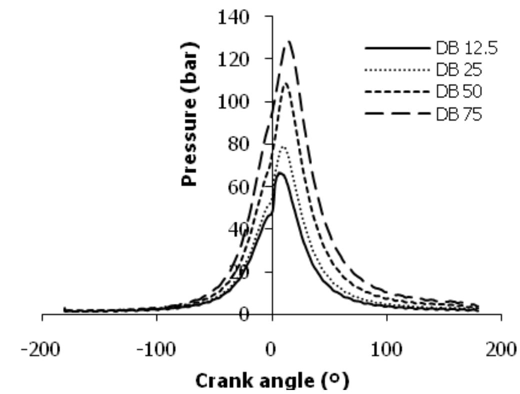

Fig 1. In-cylinder gas pressure with DB blend

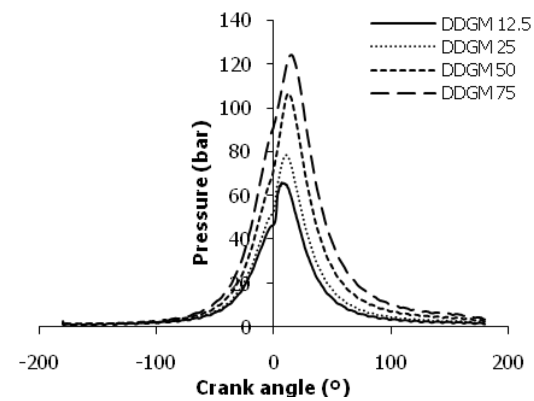

Fig 2. In-cylinder gas pressure with DDGM blend

3.2 Rate of pressure rise

Figures 3 and 4 exhibit rate of pressure rise for the same blends and for the same engine loading condition as

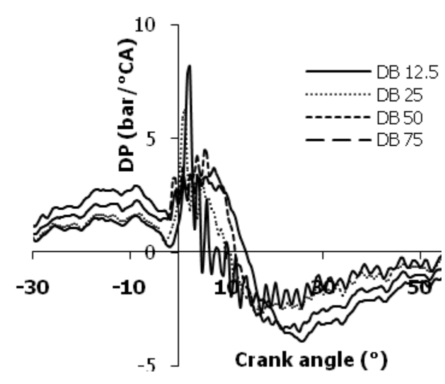

Fig 3. Rate of pressure rise with DB blend

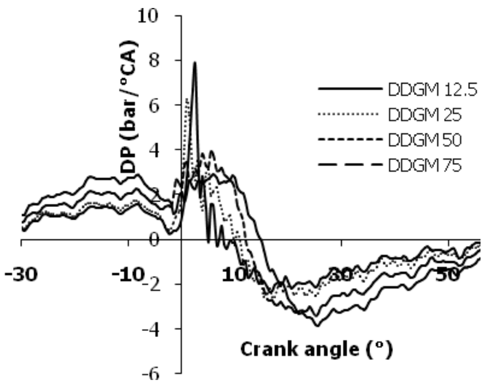

Fig 4. Rate of pressure rise with DDGM blend

desribed in Figures 1 and 2. Like pressure in Figure 1, rate of pressure rise with DB blend is higher than that of DDGM blend. Figure 10 compares the maximum rate of pressure rise for the two blends at 75% load. It is evident from the Figure that the rate of pressure rise for the DB blend is higher than that of DDGM blend.

3.3 ROHR

Figures 5 and 6 depict the comparison of ROHR for the DB and DDGM blends. The ROHR was calculated with equation given below [14]:

$$\frac{dQ}{d\theta} = \frac{\gamma}{\gamma - 1} P \frac{dV}{d\theta} + \frac{1}{\gamma - 1} V \frac{dP}{d\theta} \quad --(1)$$

Where,
$dQ/d\theta$: ROHR
P: In-cylinder gas pressure
V: In-cylinder gas volume
γ: ratio of specific heat (γ was calculated from the mean gas temperature and gas composition).

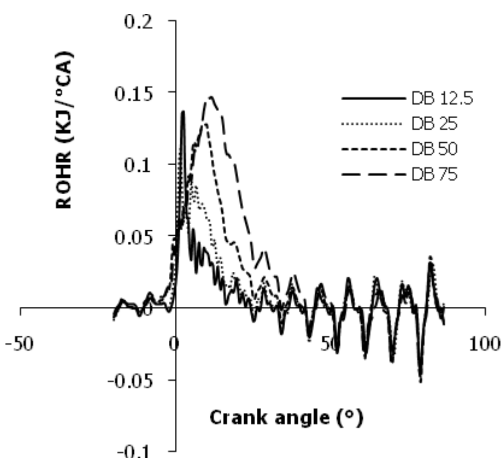

Fig 5. ROHR with DB blend

The maximum values of ROHRs for DB blend at four loads (12.5, 25, 50 and 50%) are found to be 0.11, 0.12,

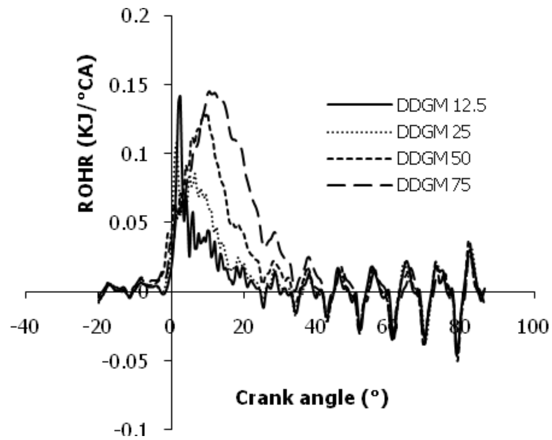

Fig 6. ROHR with DDGM blend

0.13 and 0.14 kJ/°CA respectively, while the corresponding values for the DDGM blend are 0.10, 0.11, 0.12 and 0.13 kJ/°CA respectively. It can be observed from Figures 5 and 6 that at higher loads the peaks of the ROHR shifted form left to right. Also, it is intersting to note that at low loads (12.5 and 25%) there are two peaks (premixed and diffusion combustion) can be found, while at higher loads (50 and 75%) only one peak (diffusion combustion) can be found. Figure 11 shows a comparison of ROHR with two oxygenated blends for 75% loading condition. The ROHR is slightly higher with DB blend compared to the DDGM blend.

3.4 CHR

CHR with DB and DDGM blend can be seen in Figures 7 and 8. It is clearly evident that the CHR is significantly higher at higher engine loads. Compared to DDGM, DB blend shows higher CHR. With DB blend, the four maximum CHRs at four loads are 0.824, 1.89, 2.08 and 3.00J respectively. For the DDGM blend, the CHRs at same loads are found to be 0.820, 1.39, 2.03 and

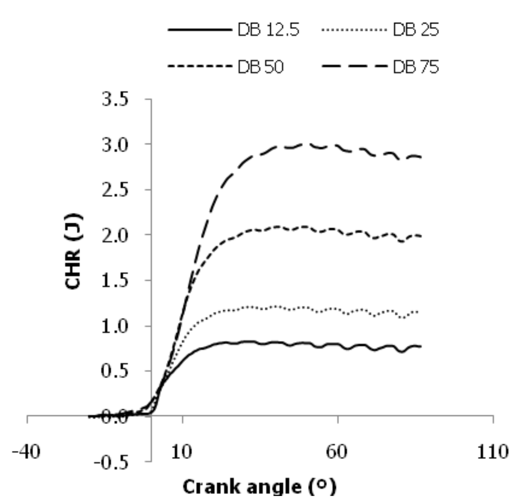

Fig 7. CHR with DB blend

2.96J respectively. Figure 11 clearly distinguish the CHRs with the two oxygenates. Compared to DDGM, DB shows a higher CHR.

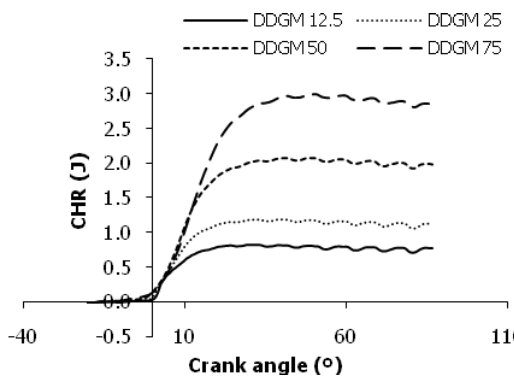

Fig 8. CHR with DDGM blend

4. ENGINE PERFORMANCE

In this section, BSFC and brake thermal efficiency are discussed for the two oxygenates for four engine loads (12.5, 25, 50 and 75%). The engine operating conditions were: engine speed of 1400 rpm and dynamic fuel injection timing of 20 °CA BTDC.

4.1 Brake thermal efficiency

The brake thermal efficiency is defined as the ratio of brake power and input power. The brake thermal efficiency was calculated by the following equation:

$$\eta_b = \frac{BP \times 3600 \times 100}{\dot{m}_f \times LHV} \qquad --(2)$$

Where,
η_b is the brake thermal efficiency in percentage
BP is the brake power in kW
LHV is the lower heating value of fuel in kJ/kg
$\dot{m}_f$ is mass flow rate of fuel in kg/hr

Figure 9 exhibits brake thermal efficiency for the two oxygenate blends at wide operating load ranges. Compared to the DDGM, DB blend shows higher thermal efficiency, especially at high load. At 75% loading condition, the brake thermal efficiency with DB blend is found to be 43.28%, while the corresponding value for the DDGM blend is found to be 42.8%.

4.2. BSFC

It is well known that BSFC is the ratio between fuel consumption and power output. The BSFC was calculated with the following equation:

$$BSFC = \frac{\dot{m}_f}{BP} \qquad --(3)$$

A comparison of BSFCs with DB and DDGM blends can be seen in Figure 9. At 75% loading condition, the BSFC with DB blend is lower than that of DDGM. At high load (75%), the BSFCs for the DB and DDGM blends are found to be 0.20 and 0.205 kg/kWh respectivly. The slightly higher BSFC with DDGM results in lower brake thermal efficiency [Figure 9].

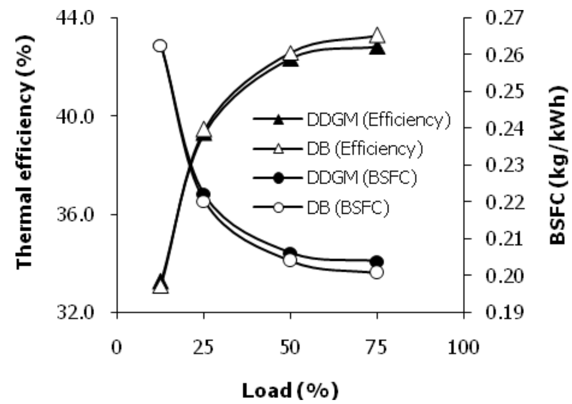

Fig 9. Comparison of BSFC and thermal efficiency with two blends

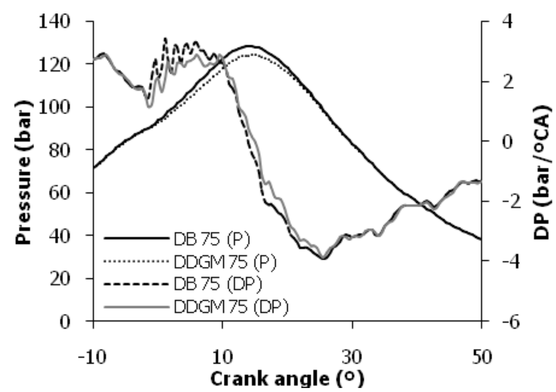

Fig 10. Comparison of in-cylinder pressure and rate of pressure rise with two blends

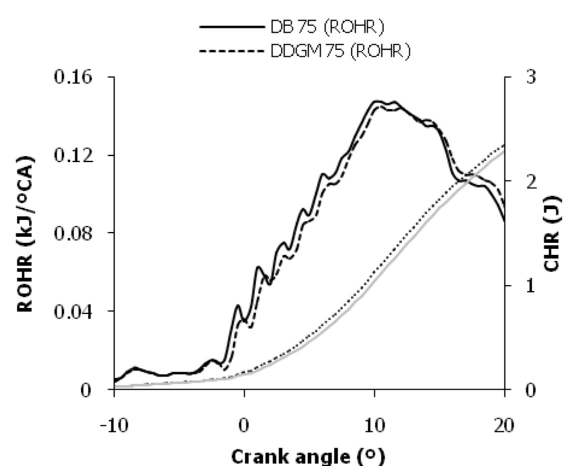

Fig 11. Comparison ROHR and CHR with two blends

5. CONCLUSIONS

In the current study, engine performance and combustion related parameters with two oxygenates were compared for wide operating load range. To investigate the effect of same oxygen content in the two oxygenate blends, different percentages of BD and DGM were added to the base EDF. The results of this investigation can be summarized as follows:

- The in-cylinder gas pressure with DB blend is higher compared to DDGM blend. The higher difference is found at higher engine loads.
- Like in-cylinder gas pressure, rate of pressure rise with DB blend is higher than that of DDGM.
- The ROHR and CHR are found to be higher with DB blend relative to the DDGM blend. Interesting finding is that the peak of ROHR shifts from left to right at higher loads.
- Engine thermal efficiency and BSFC are better with DB blend compared to DDGM blend.

Having same oxygen content in DB and DDGM blends, DB blend shows better engine performance and combustion parameters. Thus, both blends can be considered as competitors for alternative fuels for compression ignition (CI) engine, but DB blend can be suggested an excellent competitor for alternative fuel for its engine performance and combustion benefits.

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