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Ammonia as carbon free fuel for internal CombusTion engIne driVen AgriculTural vEhicle

ACTIVATE

Work Package 2
Deliverable Report

Topic: D2.3

Report from test carried out at the test-rig with engine fuelled with diesel and biodiesel

Programme operated by: The National Centre for Research and Development

Project consortium: Silesian University of Technology; NTNU Norwegian University of Science and Technology; LOGE Polska Sp. z o.o.; University of Agriculture in Krakow

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Contents

1 Development of computational model of engine

1.1 One dimensional (1D) model of the Lifan engine for performance indicators

The engine one-dimensional (1D) model has been developed to investigate in-cylinder parameters as well as the indicated parameters. For this model, the data for the setup covers the basic dimensions of the cylinder like bore, stroke, compression ratio, piston pin offset, plus information on the combustion characteristics, heat transfer, scavenging process and valve/port specifications for the attached pipes. Therefore, the cylinder dimensions and inlet and exhaust valves lift profiles from our measurements of the engine have been used to set the 1D model. As initialization, the cylinder conditions, pressure, temperature, and gas composition at the end of the high pressure exhaust valve opening were set. Furthermore, the initial conditions for the calculation of the cylinder have been specified.

Moreover, for ensuring the accuracy of the results, the numerically modeled pressure profile is compared with the experimentally measured one in the same operating condition. By comparing the simulated in-cylinder pressure for the motored and combustion operation along with the measured data, it can be found that the equations which were used for modeling fluid flow, combustion, and heat transfer are accurate. Therefore, the results of the 1D model for the investigation of the engine performance are reliable.

1.2 Determining the braking and transmission system losses

To calculate the engine performance as well as the 1D model, the friction of the engine, shaft, and electric motor have to be determined. Hence, the required torque to run the engine at different speeds has been measured as well as the total torque needed to run the engine and shafts and electric motor has been measured. Additionally, the friction of the engine and electric motor have been calculated by 1D simulation. The FMEP, IMEP, and BMEP have been determined in motored operation.BMEP indicates the relative average pressure to run the engine shaft and electric motor at one speed. Therefore, BMEP is the sum of the FMEP and IMEP for motoring conditions.

1.3 Determining the compression ratio of the engine

Compression Ratio (CR) is the essential input data for simulation and 1D model. According to the engine user manual, the CR for the Lifan engine is 20:1. However, the experimentally measured in-cylinder pressure trace shows that the CR should be around 16.5. Hence, the 1D model was carried out to determine what CR is the closest to the experimental data in a wide range of CR. Therefore, the in-cylinder pressure profile for CR between 15 to 20 has been calculated and compared with the measured pressure trace. The modeled pressure profile of CR 16.5 is the closest to the experimental data. The experimentally measured CR by the cylinder and piston geometry was about 16.7. Therefore, the experimentally calculated CR based on cylinder volume and displacement confirm the experimentally calculated CR.

1.4 Measuring and calculating the air mass flow rate of intake manifold

To make sure that flow through the valves, pipe, restrictions in the pipes, air cleaner, and most importantly the amount of air entering into the cylinder have been correctly modeled, the air mass flow rate in different engine speeds have been measured and compared by the numerical model. By comparing the experimental and simulation values, it can be found that the error of the 1D model is low.

2 Experimental setup and procedure for biodiesel and diesel

2.1 Experimental setup

In order to determine the ammonia injection strategy with diesel and biodiesel, the experiment was conducted on the test rig using pure biodiesel and diesel at different speed and loads. Figure 2.1 shows the photo of the test rig where different fuel doses of both fuels or different loads have been tested. Moreover, this figure shows the equipment in the experiment with biodiesel and diesel. As presented in this figure, the measured data includes emissions in the concentration of species in dry and wet exhaust in the ppm unit using the gas analyzer as well as FTIR, lambda, exhaust gas temperature, fuel consumption, PM, torque, engine speed, etc.

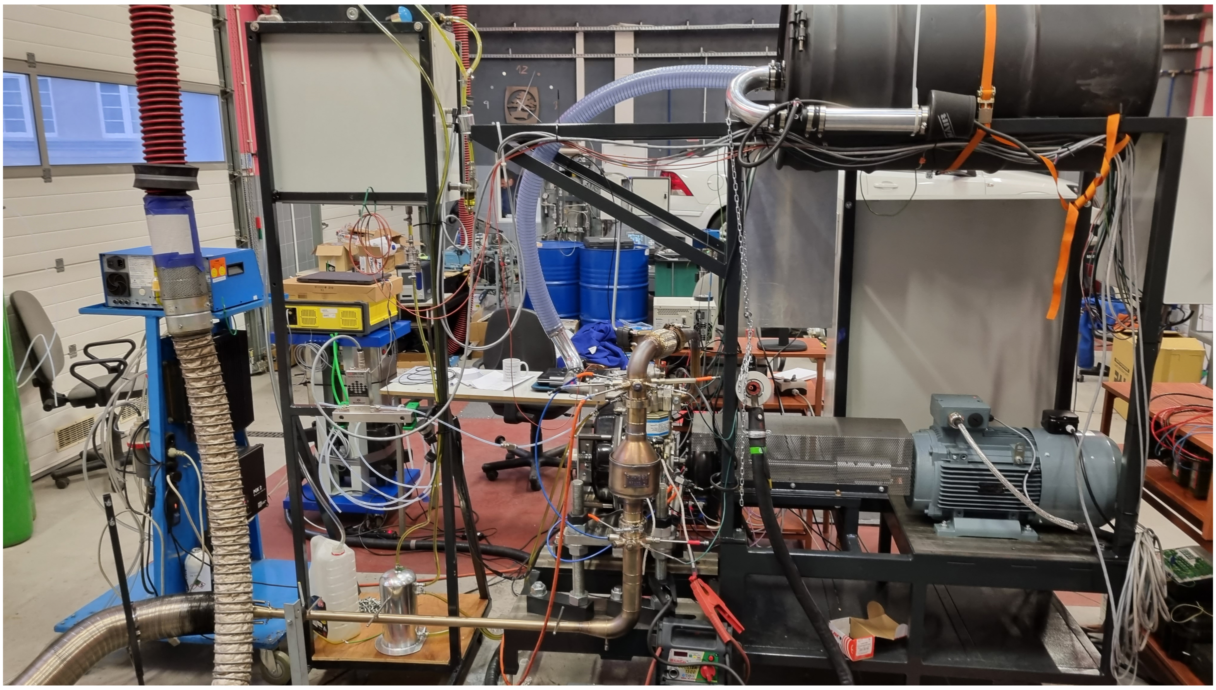

Figure 2.1: Experiments on test rig by using biodiesel and equipment.

Therefore, The experiments of biodiesel and diesel were carried out on the test rig at different load and speed. For each operating point, each parameter has been measured after the steady state running engine. In addition, the in-cylinder pressure profiles have been measured for each point. Later, these in-cylinder pressure traces will be used to calculate the engine performance and in-cylinder parameters.

Furthermore, A 1D model has been developed for the investigation of the engine performance, indicator parameters and emissions. This model has been validated by experimental data that have been measured, like in-cylinder pressure, torque, emissions, and fuel consumption. Then, this developed model was used to obtain the cycle and crank angle depending results. The results of biodiesel and diesel tests will be compared with ammonia/biodiesel and ammonia/diesel operation in the next step.

As a result, these parameters listed down below have been calculated and investigated in biodiesel and diesel tests for different engine loads and speed:

- Brake Thermal Efficiency (BTE)
- Heat release rate
- MFB 5%, 10%, 50%, and 90%
- Start of Combustion (SOC)
- Combustion Duration (CD)
- Heat and friction loses
- Emissions in 5% of O_2 and specific emissions
- Pressure trace
- Brake Specific Fuel Consumption (BSFC)
- Intake and exhaust gas temperatures

2.2 Experimental procedure for biodiesel and diesel

As mentioned before, the experimental data have been collected for both fuels of diesel and biodiesel in a wide range of rotational speeds under different loads in the CI Lifan engine with the original manufacturer's configuration. However, in this report, only the experimental data of the engine operation at 1500rpm in different loads are discussed. Therefore, tables 2.1 and 2.2 shows the example of the engine operation parameters. Moreover, the measured concentrations of each species in dry condition have been measured by a gas analyzer and presented in tables 2.3 and 2.4.

Table 2.1: Engine performance parameters with diesel test

load	speed	$\dot{m}_{diesel}$	T_{Ex}	P_e	BTE
[%]	[rpm]	[g/s]	[$^\circ C$]	[kW]	[%]
23,1	1500	0,100	167,5	1,14	26.1
36,0	1500	0,120	206,5	1,48	29.0
47,0	1500	0,140	241,8	1,77	29.9
59,1	1500	0,163	284,5	2,09	30.2
70,6	1500	0,188	327,1	2,40	30.0
88,1	1500	0,231	397,0	2,87	29.3
100,0	1500	0,270	437,2	3,19	27.8

Table 2.2: Engine performance parameters with biodiesel test

load	speed	$\dot{m}_{bio}$	T_{Ex}	P_e	BTE
[%]	[rpm]	[g/s]	[$^\circ C$]	[kW]	[%]
20,5	1500	0,113	167,4	1,07	25,3
35,8	1500	0,137	218	1,48	28,8
48,2	1500	0,155	268,5	1,75	30,2
60,0	1500	0,184	300	2,12	30,8
70,0	1500	0,202	332,4	2,39	31,6
91,4	1500	0,245	431,6	2,96	32,2
100,0	1500	0,267	485,4	3,19	31,8

Table 2.3: Measured exhaust gas composition of diesel experiment

load	PM	CO	CO_2	HC	O_2	NO
[%]	[mg/m^3]	[ppm]	[%]	[ppm]	[%]	[ppm]
23,1	7,02	760	2,4	20	18,10	192
36,0	9,00	530	3,0	19	17,30	293
47,0	10,54	340	4,0	25	16,00	490
59,1	10,13	220	4,8	23	15,00	610
70,6	12,46	260	5,6	24	13,80	696
88,1	17,43	460	6,6	23	12,50	756
100,0	30,12	1470	7,6	21	11,00	740

Table 2.4: Measured exhaust gas composition of biodiesel experiment

load	PM	CO	CO_2	HC	O_2	NO
[%]	[mg/m^3]	[ppm]	[%]	[ppm]	[%]	[ppm]
20,59	18,42	649	3,13	27	16,10	457
35,88	18,05	739	3,94	34	15,08	476
48,24	20,74	903	4,70	47	14,12	576
60,00	29,30	1090	5,59	56	13,00	700
70,00	32,32	1465	6,37	62	11,91	778
91,47	45,91	3350	7,45	77	10,02	829
100,00	57,54	6340	8,40	92	8,65	783

Moreover, the engine has been retrofitted to utilize ammonia by injecting into the intake manifold. Therefore, the experimental study has been carried out to investigate the effects of ammonia port injection on combustion, engine performance, and emissions in dual fuel mode with biodiesel and the results have been compared with pure biodiesel. The manuscript has been prepared and submitted to the top 10 journals and currently is in "Under Review" status.

3 Results processing and discussion

The brake thermal efficiency (BTE) in the tables 2.1 and 2.2 is calculated by the equation 1.

$$BTE = \frac{P_i + P_{friction}}{\dot{m}_f \cdot LHV_f} \tag{1}$$

Where BTE is brake thermal efficiency, P_i is indicated power, $P_{friction}$ is friction Power which has been determiesd in the wide range of rotatinal speed, $\dot{m}_f$ is mass fuel flow, and finally LHV$_f$ is lower heating value of biodiesel and diesel.

The LHV of biodiesel and diesel has been measured several times and the obtained value for biodiesel is $37.4MJ/kg$ and for diesel is $42.51MJ/kg$. Additionally, The concentrations of exhaust gases stated in the tables 2.3 and 2.4 are recalculated in the 5% of oxygen. This is because of the different air flow and composition for each operating point. Hence, the figures of concentration of each species in the 5% of oxygen and in ppm unit have been prepared and discussed.

$$[X_i]_{5\%O_2} = [X_i]_m \left[\frac{20.9\% - 5\%}{20.9\% - [O_2]_m} \right] \tag{2}$$

Where $(X_i)_{5\%O_2}$ is recalculated concentration of each species in $5\%O_2$. However, $(X_i)_m$ and $(O_2)_m$ are measured concentration of each species and measured concentration of O_2, respectively.

The concentrations of CO_2 in biodiesel and diesel operation recalculated by the 5% of oxygen and plotted in figure 3.1. As can be seen in this figure, CO_2 curve for diesel operation is slightly higher compared to biodiesel. This is, firstly due to the low mole fraction of carbon in biodiesel since biodiesel has oxygen atoms and secondly due to higher CO emission in biodiesel test as can be seen in figure 3.2. Therefore, biodiesel produces lower CO_2 relative to diesel at the same operating point.

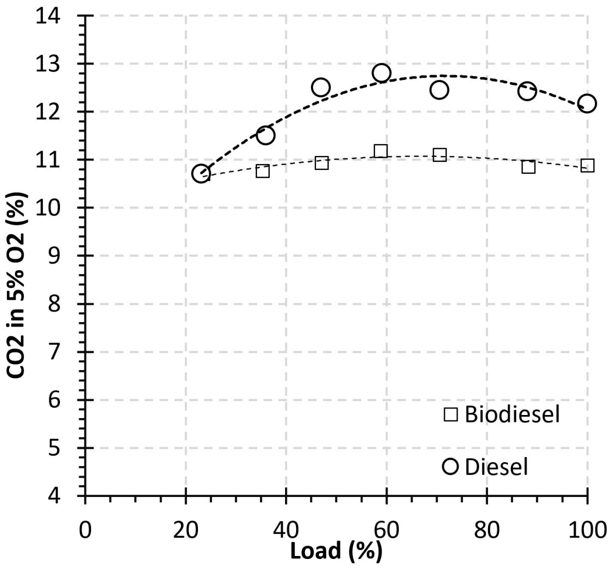

Figure 3.1: CO_2 of diesel and biodiesel at 1500 rpm and different load

The CO levels seen in figure 3.2 are almost constant for biodiesel under low loads and until 70% does not drift from the initial value. However, for diesel operation, it decreases notably under lower loads and then increases. In the case of both fuels, CO levels rise sharply when the engine is heavy loaded. The maximum CO emission value for diesel is four times smaller than for biodiesel at full load. The HC levels in figure 3.3 for diesel and biodiesel operation, follow a nearly mirrored pattern, with HC concentration in diesel falling almost linearly with increasing load. However, HC from biodiesel operation increases by increasing the load and reaches 120ppm at full load which is three times higher than diesel at full load. Therefore, biodiesel produces a higher amount of HC relative to diesel in the same operating point.

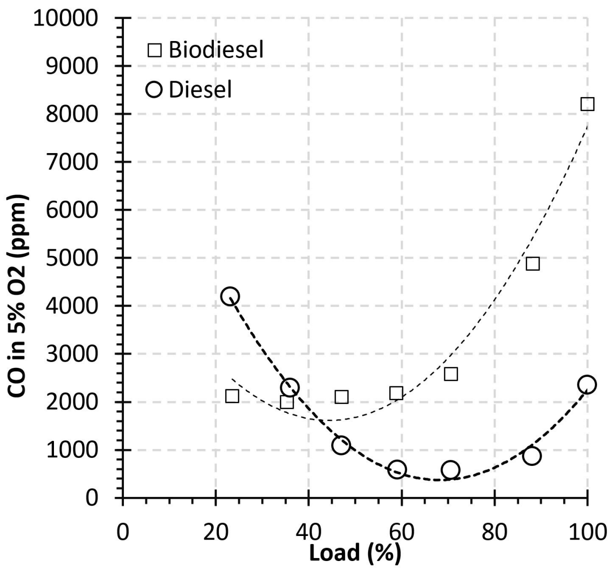

Figure 3.2: CO of diesel and biodiesel at 1500 rpm and different load

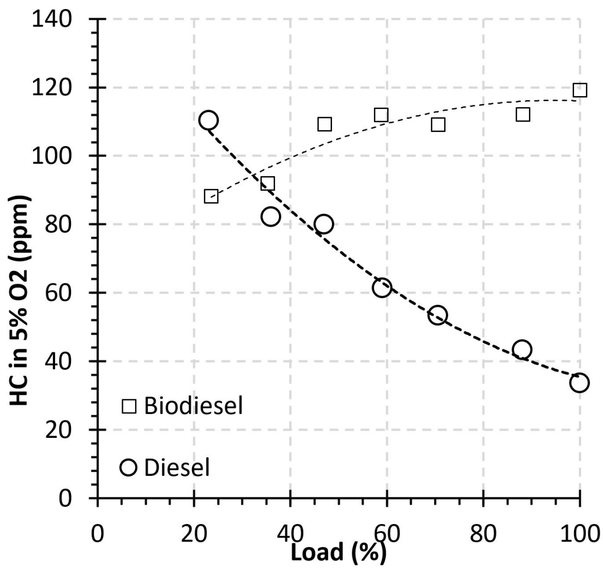

Figure 3.3: HC of diesel and biodiesel at 1500 rpm and different load

As can be noticed in figure 3.4 the NO emission trends are similar for both fuel in different loads. First increasing then decreasing towards the highest loads. However, NO emission of diesel operation is slightly higher compared to the biodiesl.

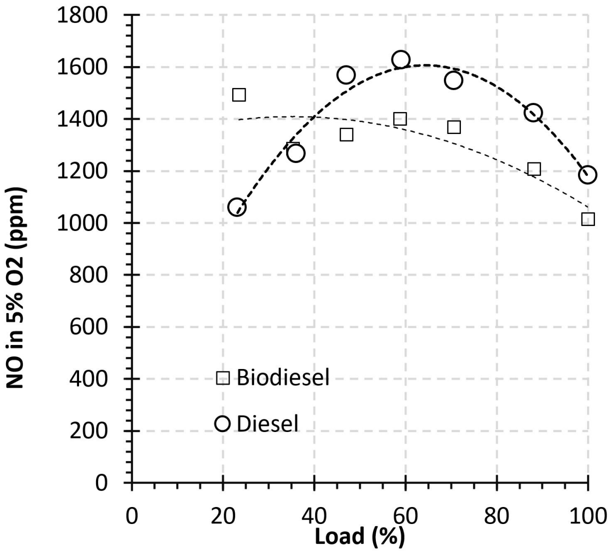

Figure 3.4: NO of diesel and biodiesel at 1500 rpm and different load

Figure 3.5 shows variations of particulate emission under varying engine loads for diesel and biodiesel fuel at constant engine speed, it is noteworthy that particulate emission is higher in biodiesel exhaust than diesel exhaust. Moreover, PM emission is increased by increasing the engine load due to higher amount of fuel and then the spray collides the cylinder wall which causes combustion on the walls. This phenomenon causes higher amount of PM emissions in higher loads.

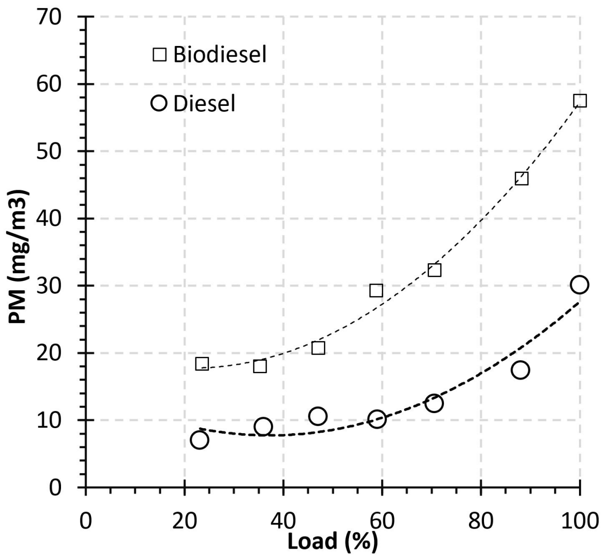

Figure 3.5: PM of diesel and biodiesel at 1500 rpm and different load

Figure 3.6 shows the comparison of biodiesel and diesel brake thermal efficiencies against various loads. There is a difference between diesel and biodiesel BTE at lower loads. However, this difference is increased by increasing the load. This is probably due to the oxygen atom in biodiesel causes better combustion in high loads. Therefore, biodiesel has higher efficiency compared to diesel in higher loads.

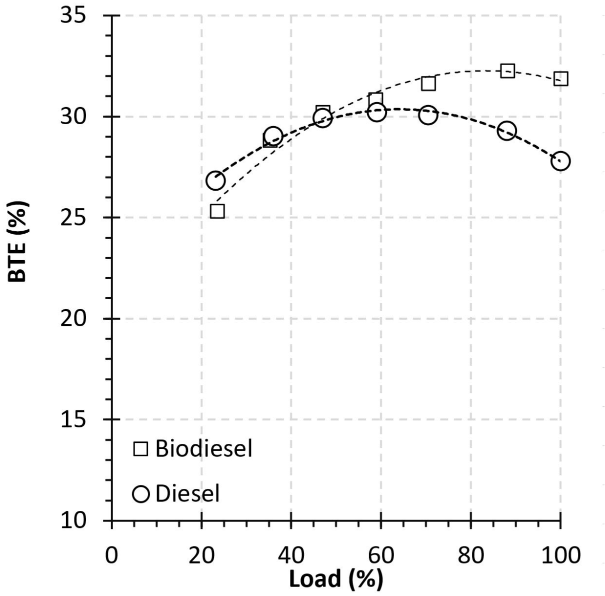

Figure 3.6: BTE of diesel and biodiesel at 1500 rpm and different load