

DIESEL ENGINE EXHAUST GAS EMISSIONS INVESTIGATION BY USING MEASUREMENT DATA AND NUMERICAL ANALYSIS

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Abstract: Paper presents an exhaust gas emission investigation for a high speed turbocharged direct injection diesel engine MAN D0826 LOH15 during the fuel and air mass flow variation. Emission analysis is based on a two measurement sets at two different engine rotational speeds (1500 rpm and 2400 rpm). The analyzed diesel engine operates with a standard diesel fuel. Measured emissions were nitrogen oxides (NO_x), unburned hydrocarbons (HC) and soot emissions. Calculated emissions were carbon dioxide (CO_2) emissions by using equations from the literature. For the observed diesel engine, much higher NO_x and HC emissions were obtained at the lower engine rotational speed. Soot emission of the analyzed engine, in general, does not have to depend on engine rotational speed. Calculated CO_2 emissions depend primarily on the fuel mass flow and the carbon mass fraction in used fuel.

Keywords: DIESEL ENGINE, EMISSIONS, ENGINE MEASUREMENTS, FUEL MASS FLOW, AIR MASS FLOW

1. Introduction

Engine measurements are unavoidable in internal combustion engines operating parameters analysis [1].

Investigation of diesel engines can be performed in several different ways [2]. Experimental analysis of diesel engines requires proper engine management [3] and repairing processes [4]. Along with diesel engine measurements, numerical simulations have been developed to make easier, faster and cheaper investigations of engine operating parameters. But still, each numerical model must necessarily be validated in a few measured operating points of the diesel engine, [5] and [6].

Emissions from the diesel engines are intensively explored [7] and researchers investigated ways for their reduction [8].

Instead of standard diesel fuels, alternative fuels and its blends with standard diesel fuels represent an alternative which can significantly reduce engine emissions [9]. A review of alternative fuels for diesel engines can be found in [10] while a review of performance, combustion and emission characteristics of bio-diesel fuels used in diesel engines is presented in [11].

Diesel engine optimization can provide further emissions reducing. Optimization methods are multi-objective optimization [12], genetic algorithm optimization [13] and optimization by using Artificial Neural Networks (ANN) [14].

This paper presents exhaust gas emissions of a turbocharged high speed direct injection diesel engine during the fuel and air mass flow variation. Emissions measurement and calculation were performed in two measurement sets, on two different engine rotational speeds. Measurements were obtained with a standard diesel fuel D2. Measured exhaust gas emissions were nitrogen oxides (NO_x), unburned hydrocarbons (HC) and soot emissions. By using equations from the literature, CO_2 emissions for each engine operating point were calculated. The aim was to examine the behavior of all mentioned emissions at different engine rotational speeds.

2. Turbocharged diesel engine specifications

The investigated diesel engine is turbocharged high speed direct injection diesel engine MAN D0826 LOH15. The main engine specifications are presented in Table 1.

Table 1. Engine specifications

The total operating volume	6870 cm ³
Number of cylinders	6
Peak effective power	160 kW
Cylinder bore	108 mm
Cylinder stroke	125 mm
Nozzle diameter	0.23 mm
Number of nozzle holes	7
Compression ratio	18

3. Diesel engine measurement results and measuring equipment

Engine measurement was performed in the Laboratory for Internal Combustion Engines and Electromobility, Faculty of Mechanical Engineering, University of Ljubljana, Slovenia.

The engine was connected to an eddy current brake Zöllner B-350AC, Fig.1. Measurements control was secured with a control system KS ADAC/Tornado. Cylinder pressure was measured with pressure sensor AVL GH12D, placed in an extra hole in the cylinder head. The cylinder pressure signal was led to a 4-channel amplifier AVL MicroIFEM. The crankshaft angle was measured by crank angle encoder Kistler CAM UNIT Type 2613B.

The heated measuring tube (tube temperature was maintained constant at 195 °C) was used for guidance of "wet" exhaust gases into the Horiba OBS-2200 exhaust gas analyzer [15]. Horiba OBS-2200 exhaust gas analyzer measure unburned hydrocarbons (HC) in FID cell (FID = Flame Ionization Detector) and nitrogen oxides (NO_x) in CLD cell (CLD = ChemiLuminescence Detector).

Soot emission was measured by Bosch EFAW 65A/6 smoke detector [16]. Obtained soot measurement results were re-calculated into the BSU (Bosch Smoke Unit).

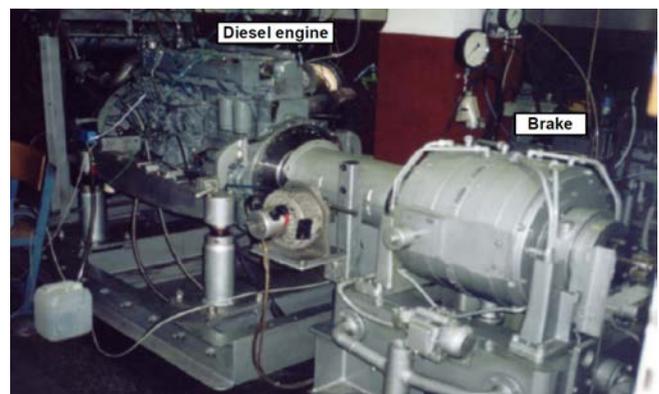


Fig.1. Diesel engine MAN D0826 LOH15 during measurements

From several obtained measurement sets, two measurement sets presented in Table 2 and Table 3 are selected for exhaust gas emissions analysis. Measurement Set 3 has almost constant engine rotational speed of 1500 rpm while measurement Set 4 has constant engine rotational speed of 2400 rpm. Fuel and air mass flow were varied in each observed measurement set, for every observed engine operation point. In each measurement set was used standard diesel fuel D2 with a lower heating value 42700 kJ/kg and with the carbon mass fraction of 85% in its chemical composition.

Table 2. Engine measurement results - Set 3

	Measurement No.	Fuel mass flow (kg/h)	Air mass flow (kg/s)	Rotational speed (rpm)	Effective power (kW)	BMEP* (bar)
SET 3	1	9.743	0.09761	1501	41.93	4.88
	2	13.977	0.10337	1498	61.82	7.21
	3	18.673	0.12048	1501	86.12	10.02
	4	23.358	0.13943	1500	108.66	12.65

* BMEP = Brake Medium Effective Pressure

Table 3. Engine measurement results - Set 4

	Measurement No.	Fuel mass flow (kg/h)	Air mass flow (kg/s)	Rotational speed (rpm)	Effective power (kW)	BMEP* (bar)
SET 4	1	16.045	0.18775	2400	56.76	4.13
	2	21.961	0.21650	2400	87.92	6.40
	3	30.086	0.25726	2400	123.49	8.99
	4	36.001	0.28798	2400	145.56	10.60

* BMEP = Brake Medium Effective Pressure

4. Engine measured and calculated emissions with discussion

Fig.2 presents nitrogen oxides (NO_x) emission change in ppm (ppm = parts per million) for measurement Set 3 and Set 4. In those two measurement sets trend lines of NO_x emission change are not the same and in both sets were not found continuous and permanent change of NO_x emissions during the increase in fuel mass flow.

In Set 3 NO_x emission for the lowest fuel mass flow of 9.743 kg/h amounts 1958 ppm. With an increase in fuel mass flow from 9.743 kg/h to 13.977 kg/h, NO_x emission increases from 1958 ppm to 2449 ppm. Further increase in fuel mass flow resulted with a decrease in NO_x emission. Therefore, for the fuel mass flow of 18.673 kg/h NO_x emission amounts 1897 ppm, while the lowest NO_x emission in this measurement set amounts 1647 ppm for the fuel mass flow of 23.358 kg/h.

Measurement Set 4 showed different behavior in NO_x emissions change in comparison with measurement Set 3. For the fuel mass flow of 16.045 kg/h NO_x emission amounts 995 ppm. With an increase in the fuel mass flow on 21.961 kg/h NO_x emission amounts 955 ppm, what is the lowest value in Set 4. With further increase in fuel mass flow, NO_x emission increases, firstly at 1082 ppm for the fuel mass flow of 30.086 kg/h and then at 1211 ppm for the highest fuel mass flow in this measurement set of 36.001 kg/h.

If compared measurement Set 3 and Set 4 for the same fuel mass flow (fuel mass flow range from 16 kg/h up to 23 kg/h), it can be seen from Fig.2 that much higher NO_x emissions were obtained in Set 3, at the lower engine rotational speed (1500 rpm).

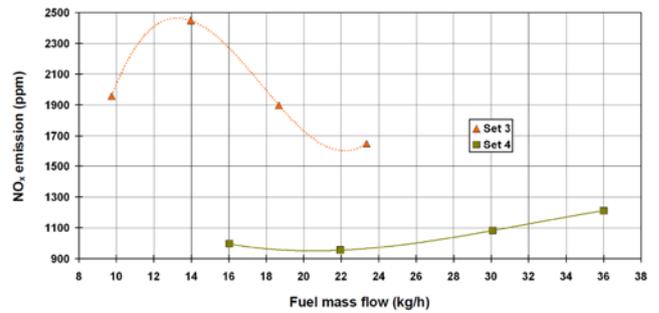


Fig.2. Measured NO_x emissions for measurement Set 3 and Set 4

For measurement Set 3 and Set 4 unburned hydrocarbons (HC) emission is presented in Fig.3. Trend lines of HC emissions are not the same in both measurement sets. In both measurement sets HC emission have no continuous and permanent change during the increase in fuel mass flow.

In measurement Set 3, HC emission for the lowest fuel mass flow amounts 107 ppm. With an increase in fuel mass flow, HC emission increases to 114 ppm for the fuel mass flow of 13.977 kg/h and to 126 ppm for the fuel mass flow of 18.673 kg/h. In the last operating point in Set 3, for the fuel mass flow of 23.358 kg/h, HC emission decreases to 115 ppm in comparison with the previous observed operating point.

An HC emission in measurement Set 4 has a different trend in comparison with measurement Set 3. At fuel mass flow of 16.045 kg/h, HC emission amounts 94 ppm, after which decreases to 61 ppm at fuel mass flow of 21.961 kg/h. With the further increase in fuel mass flow, HC emission firstly increases to 80 ppm at fuel mass flow of 30.086 kg/h, after which decreases to 62 ppm at the highest fuel mass flow in this measurement set.

When compared HC emissions in measurement Set 3 and Set 4 for the same fuel mass flow, from Fig.3 can be seen that at lower engine rotational speed (1500 rpm - Set 3) HC emissions are significantly higher in comparison with Set 4 (2400 rpm).

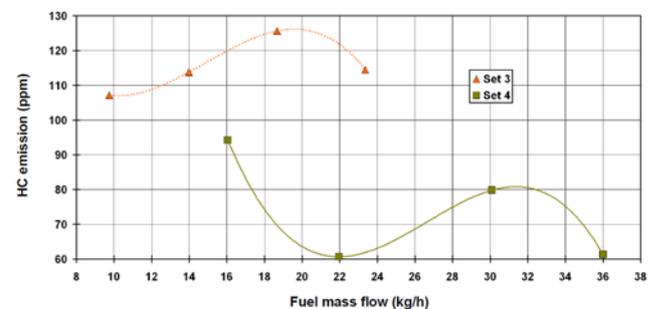


Fig.3. Measured HC emissions for measurement Set 3 and Set 4

In measurement Set 3, soot emission continuously increases during the increase in fuel mass flow, from 0.1 BSU at fuel mass flow of 9.743 kg/h up to 0.45 BSU at fuel mass flow of 23.358 kg/h, Fig.4. The trend line of soot emission change in Set 3 is not nearly similar to trend line of soot emission change in measurement Set 4.

Soot emission in measurement Set 4 amounts 0.3 BSU at the lowest observed fuel mass flow of 16.045 kg/h. During the increase in fuel mass flow in Set 4, soot emission firstly increases to 0.65 BSU at fuel mass flow of 21.961 kg/h, after which follows decrease to 0.45 BSU (fuel mass flow of 30.086 kg/h) and to 0.2 BSU (fuel mass flow of 36.001 kg/h).

When compared above mentioned emissions (NO_x, HC, soot), soot emission is the only one where for the same fuel mass flow, higher emissions were obtained at higher engine rotational speed of 2400 rpm (Set 4) in comparison with the lower engine rotational speed of 1500 rpm (Set 3).

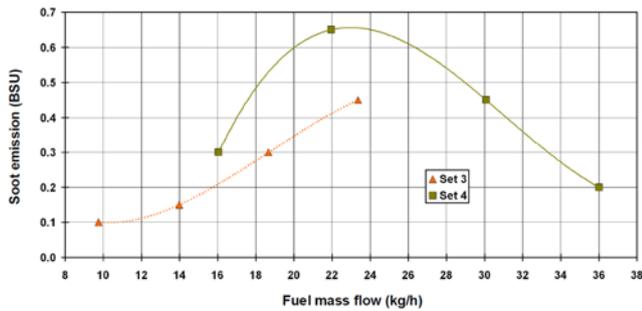


Fig.4. Measured soot emissions for measurement Set 3 and Set 4

Carbon dioxide (CO₂) emissions were calculated by using equations from [17] and [18]. The main components of these equations are the fuel mass flow and the carbon mass fraction in used fuel during the engine measurements.

CO₂ emissions in kg/h were presented in Table 4 for measurement Set 3 and Set 4. From Table 4 can be seen linear dependence of CO₂ emissions on fuel mass flow. With the increase in fuel mass flow, CO₂ emissions proportionally rise.

In measurement Set 3 the lowest CO₂ emissions were 30.366 kg/h at the lowest fuel mass flow and then continuously rises up to 72.798 kg/h at the highest fuel mass flow. In measurement Set 4, CO₂ emissions were much higher, due to higher fuel mass flow if compared with measurement Set 3. In Set 4, CO₂ emissions were in the range from 50.006 kg/h up to 112.203 kg/h from the lowest to the highest used fuel mass flow.

CO₂ emissions can be significantly reduced by using fuels with higher heating values or by using fuels with lower carbon mass fraction in its composition. Research and development of bio-fuels and other alternative fuels for use in diesel engines can fulfil the goal for CO₂ emissions reduction.

Table 4. Calculated CO₂ emissions for measurement Set 3 and Set 4

	Fuel mass flow (kg/h)	CO ₂ emission (kg/h)
SET 3	9.743	30.366
	13.977	43.562
	18.673	58.197
	23.358	72.798
SET 4	16.045	50.006
	21.961	68.446
	30.086	93.767
	36.001	112.203

5. Conclusion

Change in exhaust gas emissions for a high speed direct injection turbocharged diesel engine MAN D0826 LOH15 during the fuel and air mass flow variation was presented. Analysis is based on a two measurement sets at two different engine rotational speeds (1500 rpm and 2400 rpm).

During the engine laboratory experiments were measured nitrogen oxides (NO_x), unburned hydrocarbons (HC) and soot emissions in each observed measurement point. Carbon dioxide (CO₂) emissions for the all measurement points were calculated by using equations from available literature.

Presented measurement and calculation results showed that much higher NO_x and HC emissions are observed at the lower engine rotational speed (1500 rpm) in comparison with the higher engine rotational speed (2400 rpm).

Soot emissions change for the observed measurement sets are opposite to NO_x and HC emissions. On a wide range of fuel mass flow rates, soot emission is higher at engine rotational speed of 2400 rpm - Set 4 in comparison with the lower engine rotational speed of 1500 rpm - Set 3.

According to equations from the literature, CO₂ emissions depend primarily on the fuel mass flow and the carbon mass fraction in used fuel. This fact was confirmed also for the engine analyzed in this paper.

In future research of this diesel engine will be interesting to compare the same emissions with those obtained when engine uses alternative fuels or its blends with standard diesel fuel.

6. Acknowledgments

The authors express their thankful regards to the whole team at the Laboratory for Internal Combustion Engines and Electromobility (LICeM), at the Faculty of Mechanical Engineering, University of Ljubljana, Slovenia. This work was supported by the University of Rijeka (contract no. 13.09.1.1.05) and Croatian Science Foundation-project 8722.

7. References

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