COMPARISION OF MODEL CALCULATIONS AND EXPERIMENTAL RESULTS OF DIESEL ENGINE FUELLED WITH BIODIESEL

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Abstract. This paper describes the results of the investigation the aim of which was to find out the impact of biodiesel and its blends on engine dynamical and economical parameters. A model for in-cylinder thermodynamics is implemented for easy simulation of internal combustion engine performance. The model is verified with the experimental data from an engine fuelled with biodiesel (RME). The experimental investigation was carried out on a direct injection diesel engine *XD2P* with industrial application located at the Engine Testing and Biofuels Laboratory. The tests were performed using regular diesel fuel (DD), 5 %, 20 %, 35 % and 100 % biodiesel blends (5RME, 20RME, 35RME, 100RME). Biodiesel used for blending meets the EN14214 standard. The present analysis reveals, via diagrams and formulas, how the main engine performance parameters can be affected by the testing conditions and biodiesel addition quantity. The results indicate that power for biodiesel and blends is lower than with ordinary diesel. The reduction in the torque and increase in fuel consumption are also observed. The matching between the experimental and predicted results is not higher than 3 %, with exception of some parameters at different engine speeds. Another situation is according to the fuel consumption, which is more affected by biodiesel addition, especially, when the addition exceeds 10 %.

Keywords: biodiesel, power, fuel consumption.

Introduction

Nowadays fossil fuels play an important role in the economy of any country. Decrease of petroleum reserves, increase of fuel prices and consequences of global warming contribute to the use of alternative fuels. One of such valuable fuels is biodiesel, which has been commercially used since 1988 in many European countries and now is sold in some filling stations in pure form also in Latvia.

In the last 10 years, numerous studies and measurements of power and fuel consumption from diesel engines fuelled with biodiesel have been published [1-3]. The results of the testing procedures with rapeseed methyl ethers (RME) have generally shown a slight reduction of power, a slight increase of fuel consumption, a decrease of visible pollutant and particulate emissions and a slight increase of NO_x emissions. However, most of the reports were focused on experimental investigation, not theoretical research.

This study was carried out to find out relationships between theoretical and experimental research done at the Latvia University of Agriculture. During the recent years there is increasing interest in providing of main dynamical and economical parameters of a diesel engine without experimental work, only using thermodynamical calculation. Therefore, a thermodynamical model is prepared for the engine *XD2P* simulation in work with any kind of biodiesel fuel blends.

Materials and methods

For the theoretical analysis only the basic properties of fuels were used (composition, density, etc.) and a thermodynamic model, which was created for the diesel engine *XD2P* operation analysis. The experimental investigation was carried out on a four-cylinder, four stroke, water cooled, 22:1 compression ratio direct injection diesel engine *XD2P* with the industrial application located at the Engine Testing and Biofuels Laboratory. The maximum torque was 139 Nm at 2000 rpm, and the maximum engine power was 49 kW at 4200 rpm.

The experimental setup consists of a diesel engine, an engine test bench *VEM-100* and microscales (Figure 1). The fuel consumption was determined by the mass (gravimetric) method. The power, torque, and fuel mass consumption calculation is based on the obtained data.

The fuel (100RME) used in the tests was produced in a local biodiesel company. The tests were performed using the regular diesel fuel (DD), 5 %, 20 %, 35 % and 100 % biodiesel blends (5RME, 20RME, 35RME, 100RME). The pure rapeseed methyl ether used for blending meets the EN14214 standard.

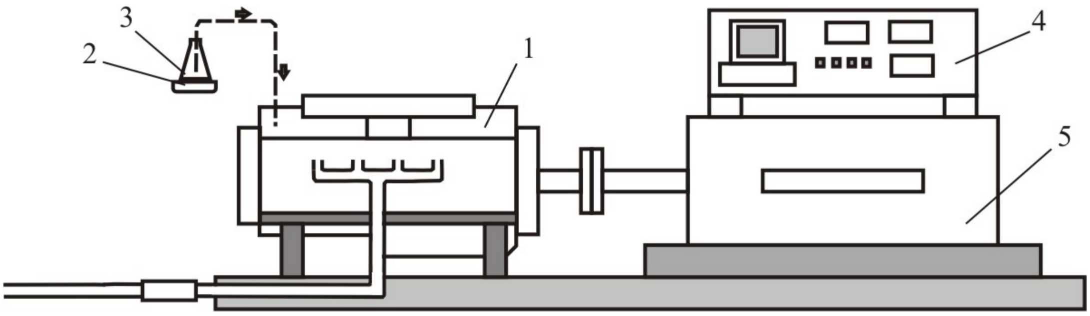


Fig. 1. **Schematic diagram of the experimental setup:**
1 – engine; 2 – electronic scales; 3 – inlet fuel flask; 4 – control unit; 5 – dynamometer

Each of the fuels was tested on full open throttle position at a variety of steady engine running points: 2000-4000 rpm. The same points were used for the engine operation simulation using the thermodynamic model. The general testing procedure was as follows – after completion of a warm-up procedure, the data collection was performed at different engine speeds (firstly, the engine was stabilized for some time and only then the measurement parameters were recorded). The engine was tested with all the fuels in random order and the results of all replications were averaged and reported.

Results and discussion

The combustion process in the compression ignition engine is very complicated and depends on the type of fuel used. Fuels often form mixtures of hydrocarbons, with bonds between hydrogen and carbon atoms. During combustion these bonds are broken and new bonds are formed with oxygen atoms. The main difference is that some of the fuels, such as biodiesel, have large oxygen content. The presence of oxygen in biodiesel leads to more complete combustion processes. The average composition of oxygen (11 %) leads to a lower stiochiometric air-fuel ratio compared to fossil diesel – computation results showed a decrease by 10.8 %. However, it impacts also the composition of the main combustion by-products: carbon dioxide, water, oxygen and nitrogen. The fuel composition affects also the heating value, which reduced by 1.2 % (5RME), 3.0 % (20RME), 4.5 % (35RME) and 11.6 % (100RME). Of course, all these changes leave an impact on other stroke parameters of the cycle.

During the simulation of the diesel engine operation it was obtained that the pressure and the temperature at the end of compression for biodiesel reduced accordingly by 0.6 % and 0.7 %. Similar features were obtained also at the end of the combustion process - the temperature at the end of the combustion processes for biodiesel reduced by 2.0 % compared to fossil diesel. Analogue reduction was obtained also concerning the temperature and the pressure at the end of expansion. For example, the temperature at the end of expansion for biodiesel reduced by 3.6 % and the pressure for biodiesel reduced by 2.7 %. On the other hand, it could be a positive reason due to the fact that decrease in pressure allows to use kinetical energy of the gas more completely in useful work.

The simulation also showed reduction of the average indicative pressure for biodiesel and its blends. It impacts the indicative efficiency and indicative specific fuel consumption. The last of the mentioned parameters is also directly connected with the fuel heating value. As biodiesel develops a reduced gross heating value compared to fossil diesel, it results in a higher volume consumption if diesel fuel fully or partly is substituted by biodiesel. The decrease of the fuel heating value promotes increase of the indicative specific fuel consumption and further also increase of the effective specific fuel consumption. Table 1 summarises the above results.

The thermodynamic model, developed for the simulation of DI diesel engine *XD2P* operation, was verified with the experimental data from an engine fuelled with biodiesel RME and its blends with fossil diesel.

Figures 2a and 2b show a typical example of the measurements. Figure 2a investigates variations of the effective power under steady state conditions using fuel with different biodiesel addition. The results indicate that the power for biodiesel and blends is lower than with ordinary diesel and depends on the biodiesel content – increase of biodiesel content promotes reduction of the effective power. More pronounced reduction of power is obtained at engine speeds over 2500 rpm at all biodiesel blends compared to fossil diesel. The reduction in torque is also observed and it also depends on the biodiesel content.

Table 1

Results of simulation for biodiesel and its blends at 2000 rpm

Parameters	DD	5RME	20RME	35RME	100RME
Lower heating value, MJ·kg^{-1}	42.725	42.213	41.428	40.800	37.771
Pressure at the end of compression, MPa	6.391	6.391	6.372	6.372	6.352
Temperature at the end of compression, K	1009	1009	1006	1006	1002
Temperature at the end of combustion, K	2260	2260	2243	2240	2216
Pressure at the end of expansion, MPa	0.298	0.297	0.295	0.294	0.290
Temperature at the of expansion, K	1005	1002	993	986	969
Average indicative pressure, MPa	0.913	0.911	0.901	0.899	0.888
Indicative efficiency	0.477	0.475	0.470	0.468	0.461
Effective power, kW	29.0	29.0	28.6	28.5	28.1
Torque, Nm	138.7	138.4	136.6	136.1	134.1
Fuel mass consumption, kg·h^{-1}	6.19	6.26	6.39	6.49	7.04

Figure 2b investigates variations of effective fuel mass consumption under steady state conditions using fuel with different biodiesel addition. Increase in fuel consumption is observed in work with all fuels. More pronounced increase of fuel consumption is obtained at engine speeds over 2500 rpm with the biodiesel content over 10 % in fuel. Such increase of fuel mass consumption was stated also in the simulation of the diesel engine *XD2P* operation.

The matching between the experimental and theoretical results is quite good for all operating points, with an exception of some parameters at different engine speeds, where the difference achieved up to 7 %. In all other points the difference between the experimental and theoretical results was not higher than 3 %. The basic results for 100RME at 2000 rpm are given in Table 2. The difference in the results could prevent correcting and supplementing the calculation formulas, which are used by the simulation model for thermodynamic analysis.

Table 2

Results of theoretical and experimental investigations for 100RME at 2000 rpm

Parameters	Theoretical results	Experimental results	Difference
Effective power, kW	28.1	28.0	0.4 %
Torque, Nm	134.1	133.7	0.3 %
Fuel mass consumption, kg·h^{-1}	7.04	6.54	7.0 %

Characteristics of the theoretical results obtained by the simulation model more fulfil to linear changes than it is with the experimental results whose character is polynomial. Therefore, for the evaluation of the effective power N_e and fuel mass consumption G_D during engine operation, simple relations of the following type have to be used:

$$N_e = 25.93 \cdot n - 2.49 \cdot n^2 + 7.75 \times 10^{-3} \cdot W_{Bio} + 1.37 \cdot 10^{-4} \cdot W_{Bio}^2 - 0.014 \cdot n \cdot W_{Bio} - 13.31 \quad (1)$$

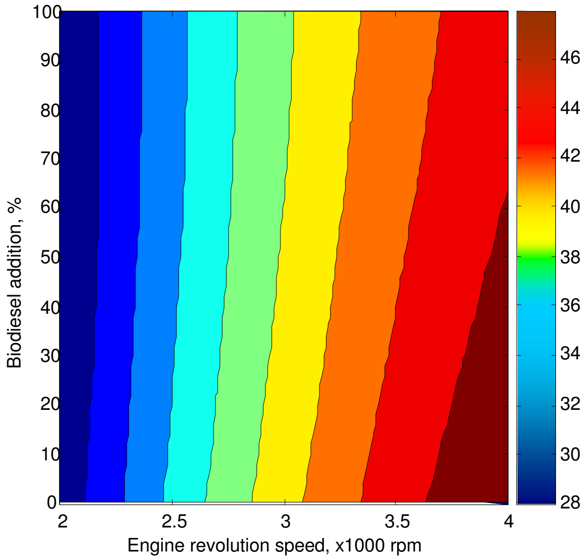
The determination coefficient for expression (1) is $R^2 = 0.98$, which gives a good characterization of the theoretical and experimental results. In that case biodiesel addition on the value of the engine effective power was not observed, with an exception at engine speeds over 3000 rpm (Figure 2a).

Expression (2) characterizes the changes of fuel mass consumption based on engine operation and biodiesel addition. The increase of the fuel mass consumption depends on the biodiesel content – increase of the biodiesel content promotes increase of the fuel mass consumption.

$$G_D = 1.733 \cdot n + 0.233 \cdot n^2 + 3.8 \times 10^{-5} \cdot W_{Bio} - 8.5 \cdot 10^{-5} \cdot W_{Bio}^2 + 4.46 \cdot 10^{-3} \cdot n \cdot W_{Bio} + 1.96 \quad (2)$$

where n – engine speed, rpm;

W_{Bio} – biodiesel addition, %.



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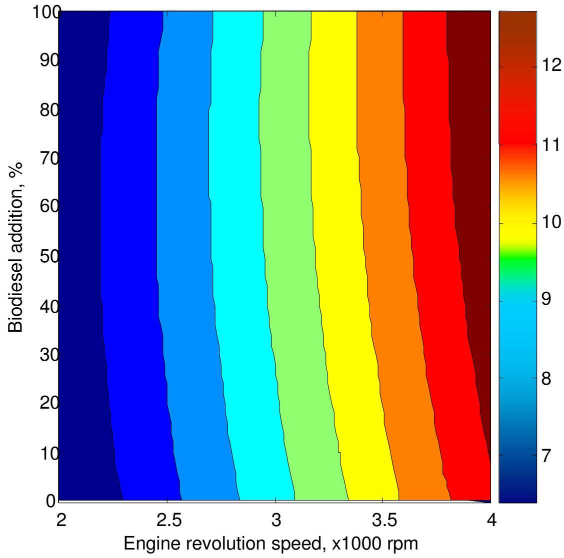

b

Fig. 2. **Maps of an effective power (a) and fuel mass consumption (b) of a diesel engine *XD2P* using biodiesel**

The use of the given expressions could help predict the results of effective power and fuel mass consumption more precisely.

Conclusions

1. A diesel engine fuelled on biodiesel and its blends with fossil diesel provides slightly lower power and higher fuel mass consumption – the theoretical analysis and experimental investigation confirmed these facts.
2. The effective power and fuel mass consumption concepts applied during the research allow to find the impact of the engine operation condition and biodiesel addition.
3. The effective power and fuel mass consumption expressions obtained during the research allow to find out the values of the parameters based on the engine operation condition and biodiesel addition.
4. Further improvement of the simulation model is required based on experimental data.

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