COMPUTER SIMULATION OF CI ENGINES FUELLED WITH BIOFUELS BY MODELLING INJECTION iRATE LAW

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Abstract: *This paper presents scientific studies on the development and use of analytical models of the processes occurring during operation of a single cylinder compression ignition engine with direct injection, powered by biofuels. Combustion parameters like cylinder pressure, rate of increased pressure and rate of heat released have been obtained experimentally, and they were studied by simulation, using the injection law iRate. The use of biofuels has been boosted by the severity of current rules on emissions standards and requirements for keeping satisfactory performance in compliance with these rules. The present rules promote the use of biofuels for replacing classic fuels, to help promote use of renewable energy. The AVL MCC combustion model is extended to predict the rate of injection based on the nozzle flow calculation with the injection law iRate. This model determines the injection rate of fuel flow delivered by the injectors. To validate the experimental data measured by test data obtained from simulations is necessary to change the ignition delay time of ignition defined in the optimization model for the engine. In simulations with various models of biodiesel (B10, B20, B50 and B100) showed a decrease of heat released from burning due to low calorific value that is biodiesel. The levels of emissions of nitrogen oxides* NO_x *emissions increase as the concentration of biodiesel due to increased concentration of oxygen in biodiesel. Also due to increased concentration of oxygen in biodiesel concentration values of CO decreases with increasing participation by mixing biodiesel use. Pollutant emissions that have been studied in the simulations with biofuel are nitrogen oxides* NO_x *and CO carbon monoxide. Reduction of* NO_x *content of exhaust gases can be controlled by setting an optimal point of advance depending on load and engine speed and combustion gas recirculation inlet in place of oxygen for decrease the fuel combustion temperature.*

Key words**:** *biofuels, simulation, rate of heat released, pollutant emissions, iRate, AVL Boost.*

INTRODUCTION

Studies and research on the performance of engines that work with biofuels planned the efficiency of opportunities to demonstrate the use of alternative fuels at a moment when Europe is undertaken to reducing pollution and consumption of conventional energy sources and development of alternative energy.

To analyse the processes occurring during operation of a single cylinder compression ignition engine, was created and developed a theoretical model for the simulation engine. After the development of the experimental model for the single cylinder compression ignition engine and after validation of the results, the classical diesel fuel was replaced with various types of biofuels: from pure B100 biodiesel mixtures in various concentrations of diesel and biodiesel (B10, B20 and B50). For all these types of biofuels there were repeated simulations using the theoretical model of engine, then they analysed results that show the differences that occur between the quantities of heat released from burning the differences that occur between pollutant emissions.

The AVL MCC combustion model predicts the rate of heat release and NO_x production in DI-Diesel engines based on the amount of fuel in the cylinder and on the turbulent kinetic energy introduced by the fuel injection. The model requires the number of injector holes, the hole diameter, the discharge coefficient of the injector holes and the rail pressure to calculate with the effective hole area, the velocity and thus the kinetic energy of the fuel jet [4].

Combustion mixture formation is described by the following parameters: injection pressure, injection time, development of the jet fuel, air movement and air mass. All these quantities have an influence on emissions and fuel consumption of the engine. NO_x formation is favoured by the high temperature of combustion and the high oxygen concentration inside of the combustion chamber.

MATERIAL AND METHODS

For research and study of the processes and phenomenon, occurring during operation of internal combustion engine with the compression ignition was used single cylinder research diesel engine model AVL 5402 that together with control systems are embedded in the experimental test stand called testbed.

For the experimental study and simulation of the theoretical model was created and developed single cylinder engine in AVL 5402 in AVL Boost application. For the development of experimental models was used the data from technical books of the engine, together with the diagrams and the experimental data have been extracted from measurements in the laboratory and stored in the post processing software AVL Concerto [12].

AVL Boost is a software tool that consists in a pre-processing program, used for initial data entry and technical characteristics of the engine to be designed as model. After forming the engine assembly with annexes systems, mathematical equations and algorithms of the model with the graphical user interface (GUI) will analyse and calculate the processes that are required during simulation [7, 9]. The model for the engine AVL 5402 designed in AVL Boost application is shown in figure 1:

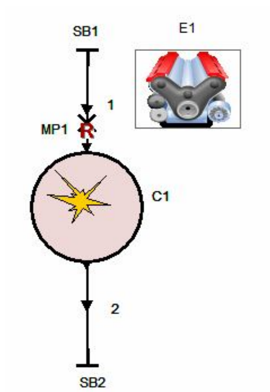

Figure 1. The model for the engine AVL 5402

The main features of the engine AVL 5402 that have been used as initial data to define the cylinder parameters are presented in table 1.

Cylinder (C1) of the model in AVL Boost is connected with element Engine (E1), and it defines the type of engine used, operating speeds on it, moments of inertia and break mean effective pressure (BMEP). Combustion method is chosen for the experimental MCC AVL combustion model (Mixing Controlled Combustion) model that predicts the rate of heat released (ROHR) and NO_x emissions on the quantity of fuel in the cylinder and the turbulent kinetic energy introduced by the injection of fuel [2].

Table 1

The main technical features of engine AVL 5402:

Name	**Value**	**Unit**
Bore / Stroke / Con-Rod	85 / 90 / 138	[mm]
Ratio	17.5	[-]
Piston Pin Offset	10	[mm]
Piston Area	5810	[mm^2]
Cylinder Area	7500	[mm^2]
Liner Area	250	[mm^2]
Intake / Exhaust Inner Seat	24.9 / 24.5	[mm]
Valve Lift	8,5	[mm]
Intake / Exhaust Scaling Factor	1.3243 / 1.3319	[-]
Engine Speed	1800	[min^{-1}]

The AVL MCC combustion model is extended to predict the rate of injection based on the nozzle flow calculation. This mode is activated by selecting calculated from the rate of injection pull-down menu. [11].

Initialization conditions when setting the cylinder used for start of high pressure (SHP) are defined by the following parameters [6, 10]:

= *start_hp* is the pressure in the cylinder when all valves are closed [bar];
=*air* is the amount of air (m_{air}) required to fuel (m_{fuel}) injected into the cylinder [kg/h];
=*fuel* is fuel injected into the cylinder [kg/h];
=*fuel_cyc* is the quantity of fuel consumed per cycle [kg/h];
=*inj_holen* is the number of injector holes [-];
=*inj_diam* is the injector hole diameter [m];
=*inj_dc* is the discharge coefficient of injector [-];
=*inj_railp* is the pressure in the common rail [bar];
=*mcc_igndel* is the ignition delay calibration factor [-];
=*mcc_compar* is the combustion parameter [-];
=*mcc_turbpar* is the turbulence parameter [-];
=*mcc_disspar* is the dissipation parameter [-].

The MCC AVL model calculation variant iRATE injection rate determines the injection rate of fuel flow delivered by the injectors. To validate the experimental data measured by test data obtained from simulations is necessary to change the ignition delay time of ignition defined in the optimization model [11]. This has been assigned the following global parameters (figure 2):

=*delay_ts* is the delay time for start of injection, global parameter [s];
=*delay_te* is the delay time for end of injection, global parameter [s];
=*delay_tu* is the delay time for up of injection, global parameter [s];
=*delay_td* is the delay time for down of injection, global parameter [s].

To delimit the pilot injection from the main injection, the following parameters were defined global values in °CA at the beginning and end of pilot injection, respectively at the beginning and end of the main injection:

=*son_pre* is the value for begin of the pilot injection (*signal on preinjection*) [°CA];
=*soff_pre* is the value for end of the pilot injection (*signal off preinjection*) [°CA];
=*son_main* is the value for begin of main injection (*signal on main injection*) [°CA];
=*soff_main* is the value for end of main injection (*signal off main injection*) [°CA].

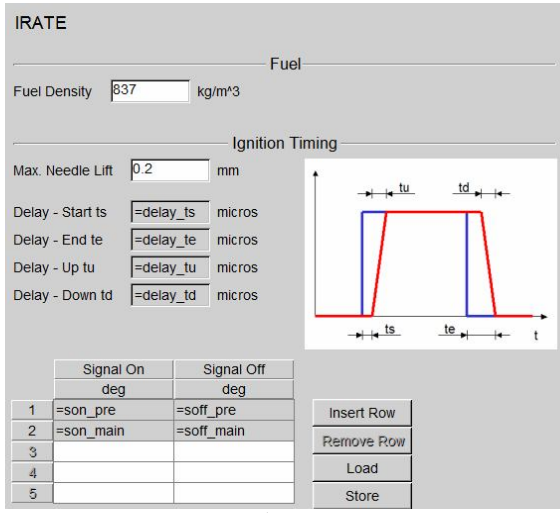

Figure 2. Law for injection iRATE

It was further defined the volume of fuel (Volume Flow) injected (figure 3). Fuel flow rate (Volume Flow) through injector nozzles (Nozzle Flow) is calculated from open needle (Needle Elevator). Values for these data are taken from manual of single cylinder experimental engine 5402 [12].

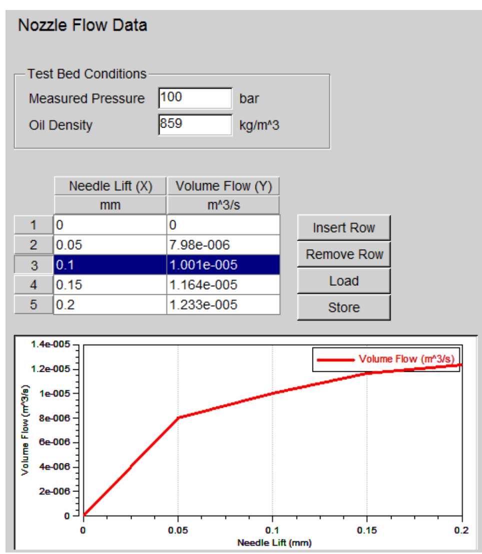

Figure 3. Volume flow from injector nozzle

Injected fuel flow increases exponentially with the opening of the injector needle opening up to its maximum value [6, 10].

In the next window was enter the data for values of cylinder pressure, where the global parameter values (=*PRESS_FILE*) was extracted from measurements in AVL Concerto (figure 4).

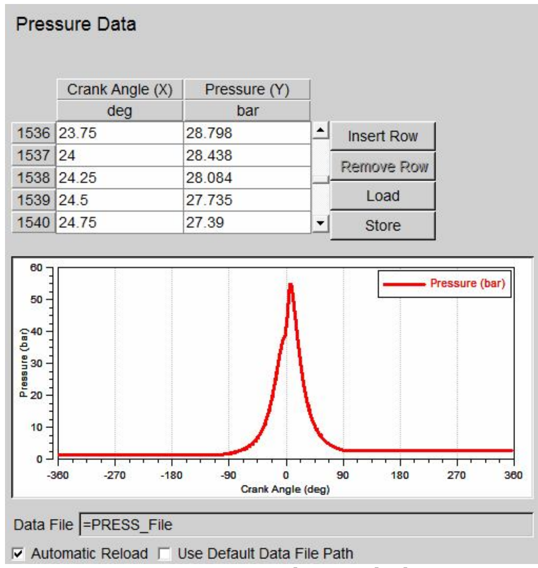

Figure 4. Pressure data in cylinder

The calculation method iRATE injection rate is presented in figure 5 and is generated automatically by the program AVL Boost, after initial data entry to define the model:

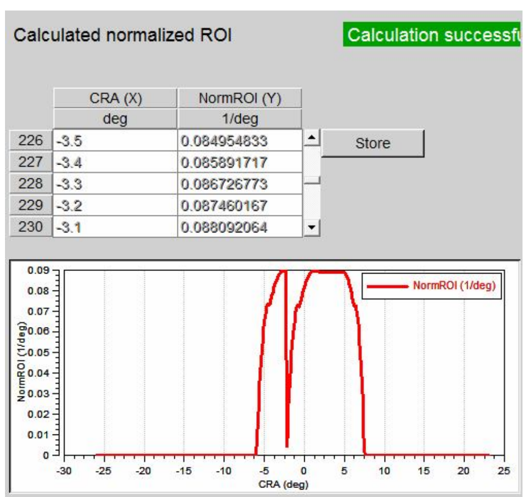

Figure 5. Calculated normalized ROI for *iRATE*

Optimizing simulation results is changing from the delay time of injection (Delay Timing) by adjusting parameter values = *delay_ts*, = *delay_te*, = *delay_tu*, = *delay_td* [6, 10].

For the simulations with different biodiesel fuel type, engine model created using the AVL Boost, which has enabled the *Classic Species Transport* [8]. To generate the types of biodiesel used in *Boost Gas Properties Tools* were defined the models of biofuel using characteristics from table 2.

Table 2

Properties of biofuels

Type of Fuel	**Heating Value [kJ/kg]**	**A/F Ratio [-]**	**Density [kg/m^3]**	**Carbon/Total Mass Ratio [%]**	**Oxygen/Total Mass Ratio [%]**	**Molar Mass [g/mol]**
Diesel	44800	14,70	834	86,20	-	226
B10	42270	14,29	848	85,37	1,21	282
B20	38040	14,07	856	82,24	4,47	254
B50	34240	13,40	880	81,33	5,55	271
B100	30620	12,29	884	76,05	11,14	276

Boost Gas Properties Tools allows the user to define the properties of products by combustion for a fuel blend components that can be used later in simulations of AVL Boost. In the fractions that define, the components are specified gas mass, gas volume, fluid volume and density of the liquid [3, 5].

RESULTS AND DISCUSSIONS

After definition of the used biofuels has been run a series of simulations, and then plot the results in *Impress Chart* were was analysed by comparing the curves that define for the rate of heat released ROHR (figure 6).

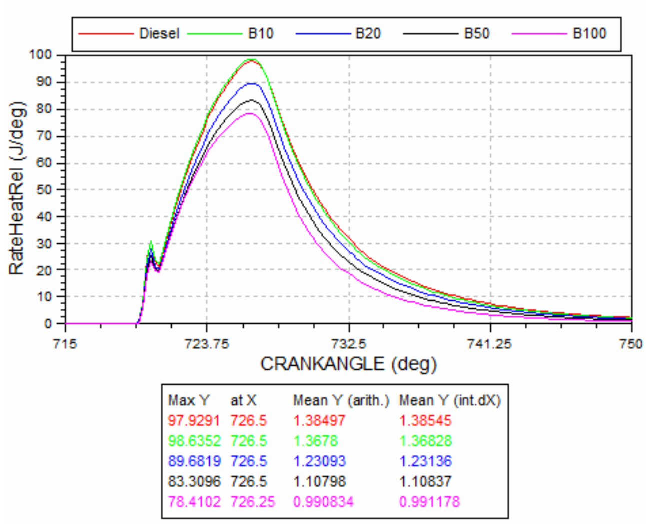

Figure 6. ROHR simulation results for biofuels

In the simulations with various blends of biodiesel (B10, B20, B50 and B100) showed a decrease for rate of heat released (ROHR) from burning process, because the biodiesel have low calorific value.

Mean values (int.dX) for the rate of heat released ROHR, NO_x emissions, and CO emission obtained from simulations with biodiesel was present in table 3:

Table 3

The mean values for ROHR, NO_x, and CO:

Biofuels:	**Diesel**	**B10**	**B20**	**B50**	**B100**
ROHR [J/°CA]	1.38545	1.36828	1.23136	1.10837	0.99118
NO_x [kg]	4.23138e-007	5.84035e-007	8.60292e-007	9.53314e-007	9.85880e-007
CO [kg]	6.53453e-008	6.34367e-008	4.28342e-008	3.76844e-008	3.27409e-008

Pollutant emissions that have been studied in the simulations with biofuel are nitrogen oxides NO_x and CO carbon monoxide.

The results analyse of simulations for NO_x emissions are shown in figure 7:

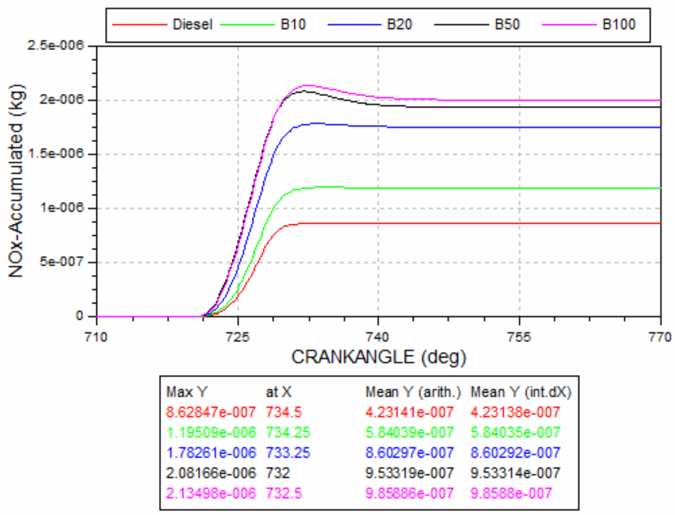

Figure 7. Emissions of NOx from biodiesel simulations

Reduction of NO_x content of exhaust gases can be controlled by setting an optimal point of advance depending on load and engine speed and combustion gas recirculation inlet in place of oxygen for decrease the fuel combustion temperature. The levels of emissions for nitrogen oxides NO_x increase as the concentration of biodiesel increased due to increased concentration of oxygen in biodiesel.

The analyses of simulations results for CO are present in figure 8.

The catalyst that transforms pollutants into clean gas by optimizing fuel dosage and injection advance timing [1], can reduce carbon monoxide content of flue gases. Also, due to increased oxygen concentration in biofuel, CO concentration values decrease with increasing participation by biodiesel in blends.

CONCLUSIONS

In the simulations performed, it was found that pure biodiesel is approximately 85% of the energy potential of diesel oil. When biodiesel is blended with diesel oil to more than 20%, the blends behave as conventional diesel. In terms of environmental protection, biodiesel pollutes less than diesel oil, with significant quantities of pollutants, except NO_x levels higher. Biodiesel can be used as fuel in any diesel engines. He has excellent combustion properties leading to a combustion process without sudden increase of pressure and a good running engine has an oxygen content of only 11%, which means smaller quantities of soot emitted and has properties good lubrication, engine wear is less than [1].

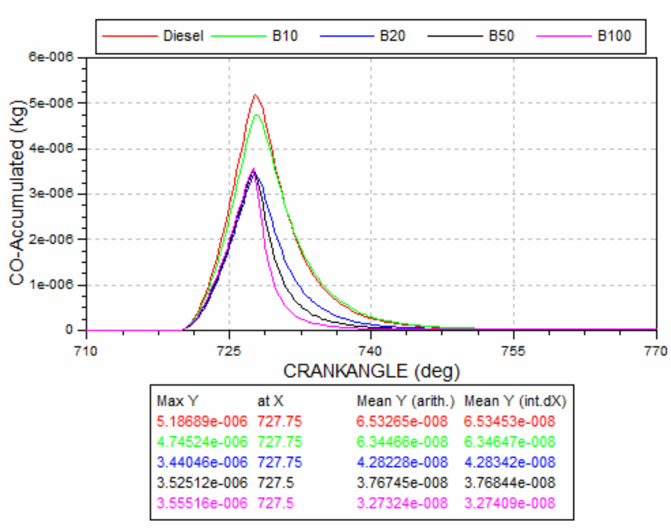

Figure 8. Emissions of CO in the simulations with biodiesel

In simulations with various models of biodiesel (B10, B20, B50 and B100) showed a decrease of heat released from burning due to low calorific value that is biodiesel. The levels of emissions of nitrogen oxides NO_x emissions increase as the concentration of biodiesel due to increased concentration of oxygen in biodiesel. Also due to increased concentration of oxygen in biodiesel concentration values of CO decreases with increasing participation by mixing biodiesel use.

Main trends in the development of compression ignition engines are reducing emissions and improving fuel economy, namely energy efficiency and environmentally friendly.

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