Influence of Biocellulose Derived Fuel Blends on Injection Properties

Sorin Sacareanu, Anghel Chiru, Alexandru Bogdan Muntean and Cornel Stan

Abstract Today, 88 % from the total amount of energy used worldwide is represented by fossil fuels (oil, natural gas and coal). Oil dependence required a diversification of fuels in the transport sector in general and road transport in order to stop global warming. Alternative fuels difference slightly in terms of such phisical properties as: density, viscosity and bulk modulus, properties which influence the fuel injection parameters such as penetrability, Sauter Mean Diameter and vaporization rate. The European Union adopted Directive 2003/30/EC to enforce the use of biofuels and other alternative fuels. EU member states must achieve a target of 20 % of alternative fuels used in the transport sector. These lead to different combustion characteristics. The main objective of this paper is to determine the influence of alternative fuels produced by Fischer–Tropsch synthesis from the gasification of biomass used for compression ignited engines.

Keywords Biofuels · Diesel injection · Coupled 1D–3D simulations

1 Considerations Regarding the Tested Fuels

In order to evaluate the influence of biofuel characteristics on ICE performances, experimental research has be done in virtual and real environment. The tendency is to increase the concentration of synthetic fuels in the mixture leading to a 50 % after 2020.

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In this study, mixtures of FT fuel and classic diesel have been used during numerical simulations. The concentrations were 20 % FT fuel and 80 % fossil diesel named FT20, and 50 % FT fuel and 50 % fossil diesel named FT50. These specific concentrations were chosen based on the European Commission Directive 2003/30/CE. Pure FT fuel combustion performances have been also studied.

ICE's energetic and ecologic parameters are in a direct dependence on fuels characteristics and on injection systems performances. Thus, it is necessary to optimize injection system's the parameters (penetrability, fuels spray atomization, pressure, injected volume) of the injection system considering the working regime and the fuel used. The optimization of the injection system requires experimental research as well as numerical simulations. In the last decade, the techniques of numerical simulations have evolved, presenting advantages such as possibilities of substantial time saving analysis, reduced number of materials, an increased number of parameters being studied, both design and functional, ease in designing a prototype stand. The properties of the fuels investigated in this work are presented in Table 1.

To be able to use the advantages of numerical simulations, the application must comply with certain criteria. Thus, it must perform the following functions:

- To be able to modeling the complex phenomena of the fuel injection;
- Consideration of most important parameters;
- Using a friendly interface;
- Optimum results for the desired parameters [4, 5].

In this study, LMS Image Lab AMESim application was used for the one-dimension simulation and AVL Fire for the 3D simulations. These applications meet the requirements previously mentioned.

2 Common-Rail Fueling System

At the moment, common-rail injection systems are the most common ones on the CI and SI engines market. The main characteristics of common-rail injection systems are: even fuel distribution on each cylinder, many injections per cycle due to injector electronic control, high injection pressure at low speed.

The virtual model of the common-rail injection system was done by "Forschung– und Transferenz Zentrum Zwickau (FTZ)" and was validated on the test-bed. The model was designed so it can be easily adapted to different requests coming from the analysis of the influence of fuels properties or from different working regimes. For the modeling part, the main components of the system were taken into consideration: the high pressure pump, the common-rail, the shape of the signal that controls the solenoid's valve, the injector, which is made of two parts (the solenoid with the discharge valve and the injection module with needle, needle spring and nozzle). The masses of the components and interaction with the fuel were also considered. The model illustrated in Fig. 1 represents a BOSCH CRI injection system with a

Table 1 Physical–chemical properties of tested fuels [3]

Property	Standard	Unit	EN590	B0	FT/B0 20/80	FT/B0 50/50	FT
Cetane number	EN ISO 5165		>51	52.1	62.7	65.8	76.7
Density at 15 °C	EN ISO 12185	kg/m^3	820–845	829	817	799	769.5
Viscosity at 40 °C	EN ISO 3104	mm^2/s	2.0–4.5	2.54	2.4	2.24	2.07
Inflammability point	EN ISO 2719	°C	>55	62	63	68	78
CFPP		°C		−12	−11	−10	−4
Lower calorific value	DIN 51900	MJ/kg		42.985	43.209	43.407	43.781
Elastic modulus		(bar)		15800	15200	14400	13000

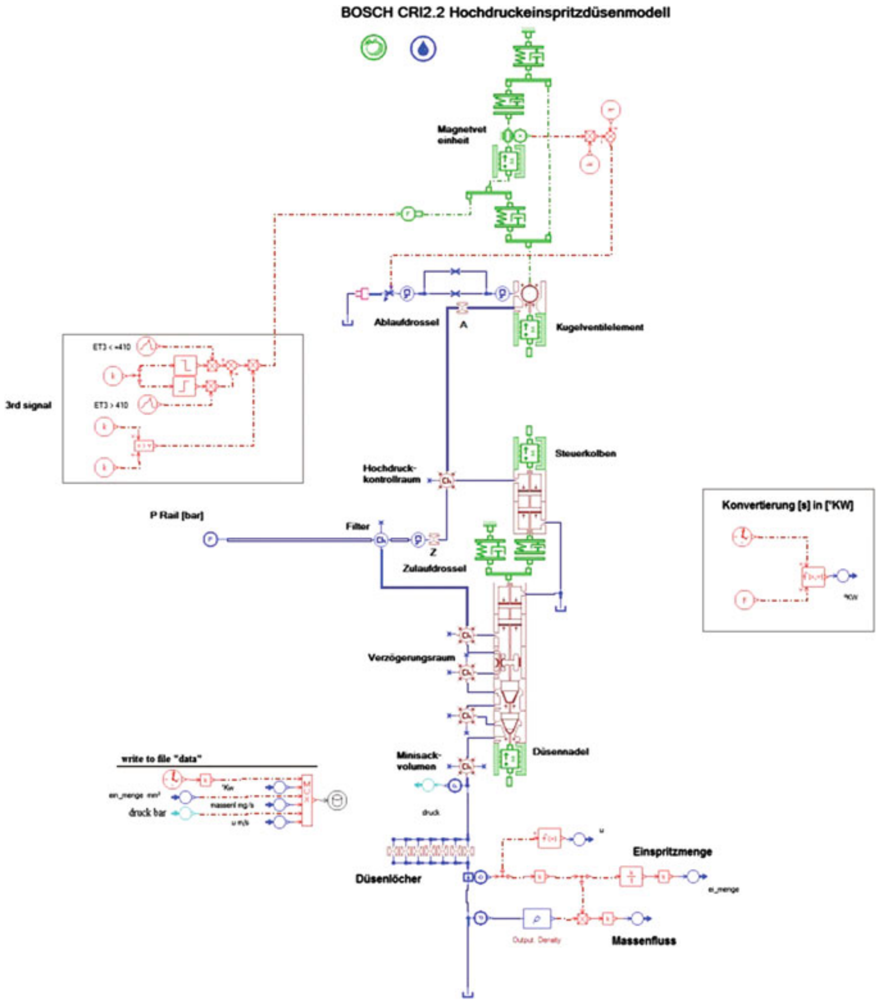

Fig. 1 AMESim model of the injection system [2]

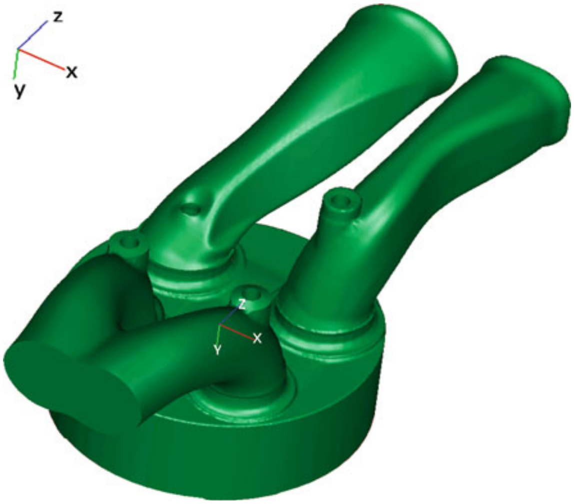

Fig. 2 CAD mode of the engine

Table 2 Characteristics of the simulated points

Engine speed (rpm)	2000	2000
M.E.P. (bar)	2	15
Rail Pressure (bar)	640	1150
Pilot injection	Da	Da

pressure of the common-rail ranging from 1000 to 1800 bar. The control of Injector's is done by a solenoid which determines the needle lift and the fuel injection through seven holes with a diameter of 200 µm. Besides the main injection, the system can provide two pilot injections.

The simulations have also considered the alternative fuels influences on the injection parameters such as the pressure in the injector's nozzle, injected fuel volume and mass flow, as well as the sprayed fuel speed. The simulations were done for two regimes as presented in Table 2 and the results were further used as input data for the 3D module.

The 3D model of the cylinder head channels (intake and exhaust) and combustion chamber, as illustrated in Fig. 2, were done in CATIA. Next, the parameters of the working fluids and the initial conditions were considered. The coefficients of fuel injection and combustion mathematical models request special attention.

3 Low Load Engine Simulation

The first regime investigated was at a speed of 2000 rpm and 2 bar MEP. In this case, the duration of the pilot injection was 0.41 ms (4.56 °CAD, with 19.6 °CAD

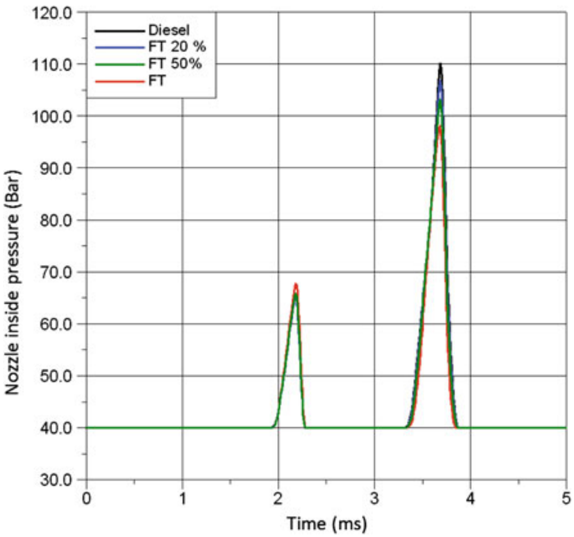

Fig. 3 Comparison of fuel pressure evolution

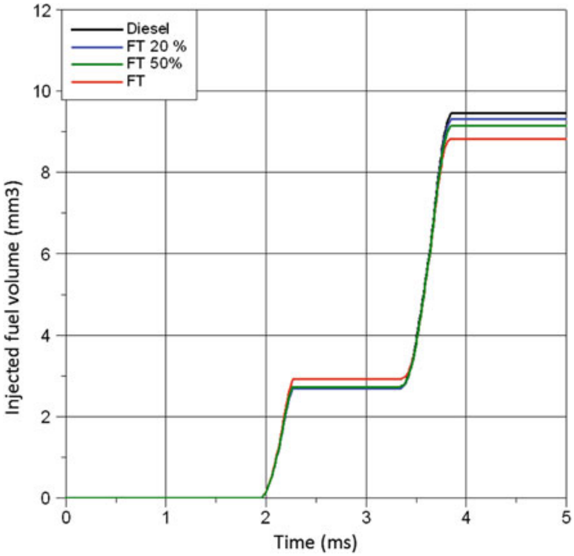

Fig. 4 Comparison of injected fuel volume

before TDC) and that of the main injection was 0.53 ms (6.72 °CAD, with 2 °CAD before TDC) [1].

The influence of fuel properties on pressure at the injector's nozzle, the injected volume and mass flow, as well as on the fuel speed at the injector's output is

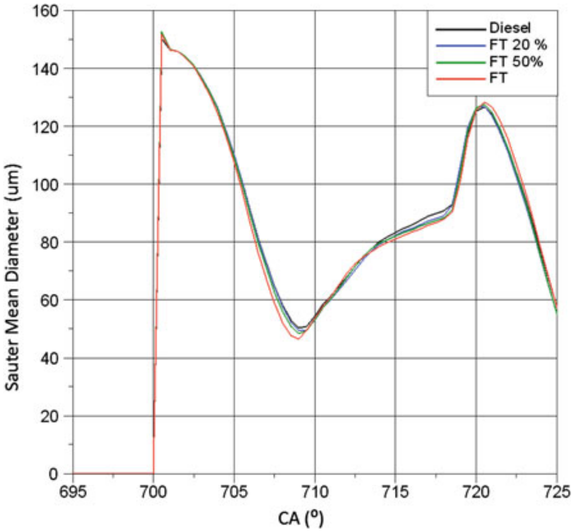

Fig. 5 Sauter Mean Diameter

presented in Figs. 3 and 4. It can be noticed that for the pilot injection, while increasing the FT fuel concentration in the mixture, the maximum pressure increased as well (with 4 % for pure FT fuel). At the same time, the main injection showed an opposite situation. The pressure in the injector's nozzle decreased with the increase of the FT fuel concentration up to the point where for pure FT the main injection pressure was with 11 % less than for reference diesel (98.3 bar for FT fuel compared to 110 bar for diesel fuel).

The evolution of the injected volume (Fig. 4) shows a perfect correlation with the pressure evolution discussed above. For pure FT fuel case the injected volume was 9 % higher than for diesel fuel due to a lower viscosity of the synthetic fuel. For the main injection case, the evolution of the injected volume showed that while increasing the FT concentration, the volume decreased due to a higher compressibility of the FT fuel (Table 1). For the FT fuel, the total volume injected was with 7 % lower compared with the diesel injected volume.

The evolution of Sauter Mean Diameter for the fuel drop was also analyzed in this studie, as presented in Fig. 5. The analysis showed that the maximum values of the Sauter diameter were the same for all the fuels investigated. It can be noticed that the value of the average diameter of the drops at the end of the pilot injection for biofuels was lower than the value for the reference diesel used.

When analysing the impact of different fuel properties on spray tip penetration, we can see no major differences between them (Fig. 6).

By using fuel blends with high mass fraction of FT (20–50 %), the spray tip penetration will decrease with approximate 1 mm.

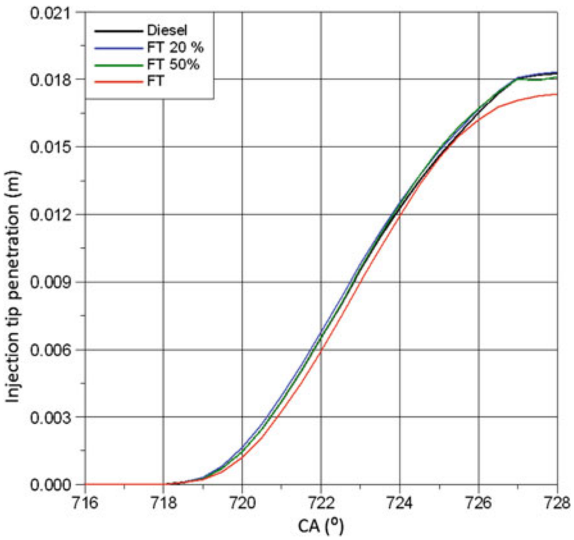

Fig. 6 Spray tip penetration for main injection

4 High Load Point Engine Simulation

Another topic which was studied is related to high load behavior of the injection system. The simulation point has the following characteristics: Mean Effective Pressure: 15 bar; Engine speed: 2000 rpm; Pilot Injection Time: 0.3 ms Pilot Injection Timing: 19.5° BTDC; Main Injection Time: 0.95 ms; Main Injection Timing: 10°.

The results of this simulation are presented in Fig. 7. By using synthetic fuels the peak in cylinder pressure will rise. Regarding the fuel injected volume, we can notice (Fig. 8) a slow increasing of this one. In previous cases, an increasing of FT mass fraction in fuel blend, leads to higher injected fuel volume.

On observing of pilot injection, the greatest differences were detected for 100 % FT, and the percentage volume was 4 % higher than pure diesel fuel.

The main injection case, also presents an increase of 6 % injected volume of pure FT in comparision with 100 % pure diesel.

Regarding SMD for pilot and main injection, presented in Fig. 9, we have found no significant differences. A very small decrease of SMD, was observed on the pilot injection. After the injector needle closes the nozzle holes, the SMD of the alternative fuels, presents a small decrease. This is due to the better atomization of the fuel.

If we exam the evolution of spray tip penetration, no major differences can be seen. However, the synthetic fuels have a slight increase of this parameter (Fig. 10).

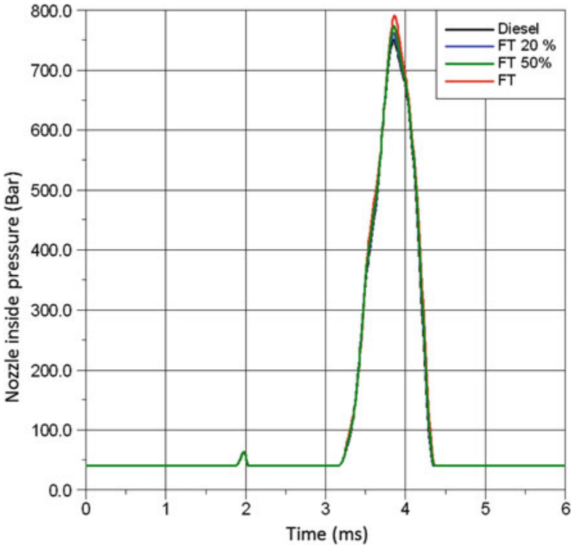

Fig. 7 Comparison of fuel pressure evolution

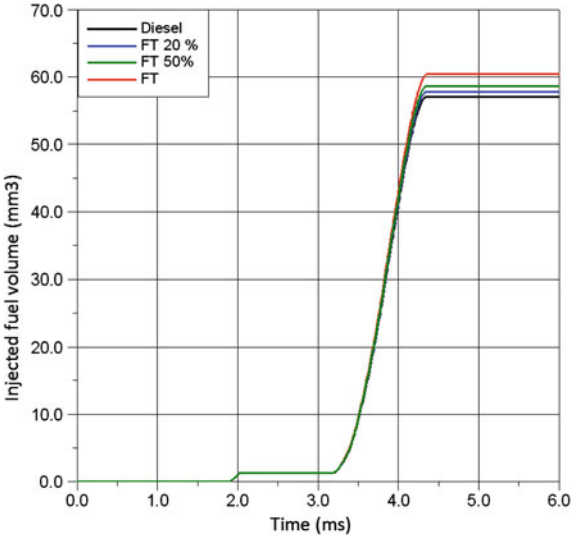

Fig. 8 Comparison of injected fuel volume

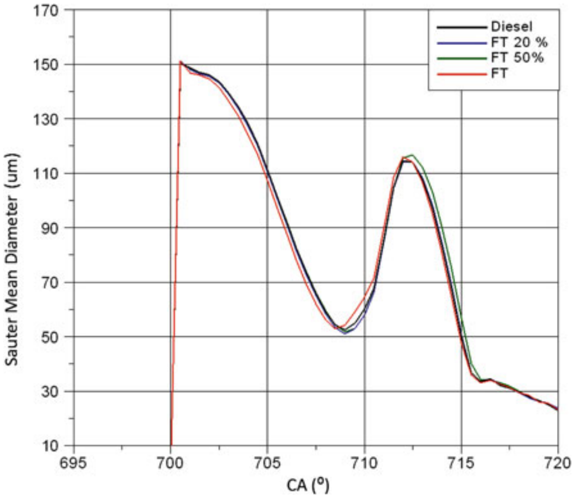

Fig. 9 Sauter Mean Diameter

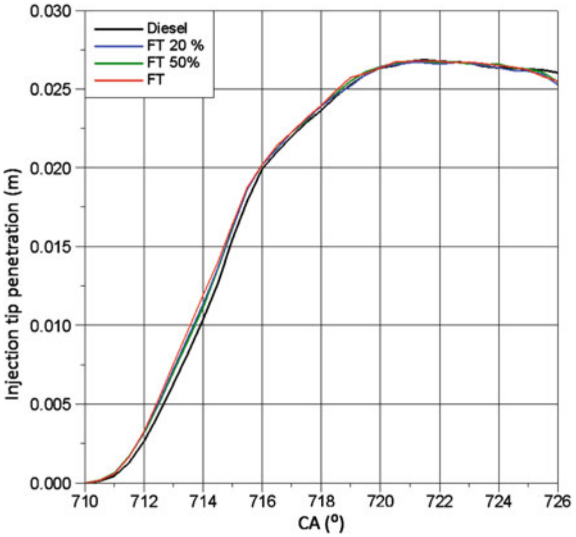

Fig. 10 Penetrability during main injection

5 Conclusions

The numerical analysis of sintetical fuels (FT) injection process regarding different sintetic fuels, leads to the following conclusions:

- The total volume of FT injected, was 7 % less than the reference fuel;
- In both cases: low engine loads, high engine loads, the injection process paramenters (Injection pressures, SMD, Spray tip penetration) have not been influenced too much;
- The FT fuel blends, especially FT 20 and FT 50, are recommended in reciprocating engines without any disadvantages on fuel injection system.

The experience which was gained during the research stage in this study, correlated with engine development engineer‘s know-how, from Romania and Germany, allowed for the observation of the impact of mathematical coefficients on injection process performances. Those values can be used on new engine concepts.

This is the first time the sintetic fuel has been produced by FT technology. It has been tested and a simulation model of the injection process was built. All the information presented in this paper is very useful for engine development specialists.

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