ENCIT-2018-0792
SIMULATION OF A DIESEL ENGINE USING AVL FIRE SOFTWARE

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Abstract. This paper had as objective to present the study of the software AVL FIRE ESE DIESEL, using its application in the simulation of a Cummins engine, located in the Engine Laboratory of the Faculdade de Engenharia Mecânica, at UFPA, using pure diesel (B0) and the diesel (B7) as fuel. The results showed that the values of temperature, pressure and NO concentration in the combustion chamber decreased with B7, while the concentration of particulates increased at the end of combustion. The software AVL FIRE showed the preliminary results consistently, which can still be improved, from the insertion of more accurate geometric data of the combustion chamber and the injector.

Keywords: Combustion, Software, simulation.

1. INTRODUCTION

Due to the environmental impacts caused by fossil fuels used in internal combustion engines, it is sought to replace them partially or totally with renewable fuels (ROCHA, 2016). In this context, the use of various alternative fuels continues to be investigated, as is the case with biodiesel. Currently, diesel oil in Brazil contains 7% biodiesel (B7 diesel), which changes several fuel characteristics. Therefore, it is necessary to make a computational simulation, in order to optimize experimental tests by performing the variation of operational parameters.

Computational simulation is an important tool for the development of internal combustion engines, both in the design part and in the increase of efficiency (SOUZA, 2016). In compression ignition engines, one of the factors that affects combustion is the ignition delay of the fuel. Changing operating parameters affects the pressure conditions and temperatures inside the cylinder, especially the ignition delay. On reaching optimum operating points, they have as a result the decrease of the specific consumption and an increase in thermal overall efficiency (Barros, 2013).

The application of the CFD (Computational Fluid Dynamics) tool in engineering has been growing gradually in recent times, especially in Internal Combustion Engines (ICE). Computational analysis can significantly reduce the number of laboratory tests, thus reducing project costs and time. However, the difficulties are focused on the problem, which presents parts with complex geometries, associated with a mutual movement of both the piston and the intake and exhaust valves, which makes meshing difficult. The turbulent flow inside the cylinder, into the inlet and exhaust channels is established due to the existing high pressure gradients, in these channels the flow is highly transient and turbulent. In addition, this dynamics and its geometries control the air-fuel mixture process in ICE, being fundamental the analysis of the spray along with the combustion process itself (BARROS, 2013).

2. METHODOLOGY

The simulation was composed of two steps: the assembly of the computational model and a verification. The assembly of the model is based on obtaining real engine data and inserting these into the program. Verification consists of comparing the results with the actual model and changing certain parameters to refine the model, respectively.

2.1 Simulation Modeling

The modeling of this work was based on studies performed in the Cummins diesel generator set, model C50D6 of 63 kVA and 50 kW, with 04 cylinders in line, 1800 RPM, compression ratio 16,5: 1, water cooled and direct injection.

Figure 1. Generator set Cummins model C50D6.

2.2 Simulation Parameters

The simulation in AVL Fire was done as follows:

2.2.1 General Data

It allows the user to specify general parameters of the simulated engine in the present project, that is, data that is characteristic of the engine. The data was input according to the manufacturer's manual.

2.2.2 Sketcher

The insertion of the geometric data of the piston, injector and block structure is used. In this sketch, four parameters are defined, in addition to the cross-sectional format of the upper part of the piston. In this simulation, the available piston format in the database that most closely resembled the actual piston geometry of the engine was inserted.

2.2.3 Mesher

Allows you to define all the merge parameters that describe the computational grid to be created for the motor geometry defined in the sketch.

2.2.4 Simulation Parameters

Allows input of various types of input data, for adjustment of used models, initial conditions and data selection that will be used for simulation convergence and output data.

Solver control

The solver control parameters are the main factors that control the math of the CFD solution. The definition of these parameters is important for the stability of the solution as well as the speed of convergence (AVL, 2017).

The solver control data was inserted as recommended in the manual. The convergence criteria were inserted in order to make the simulation occur within a viable time period as well as to avoid problems. However, due to computational limits, the refinement was done seeking optimization of the process, as figure 2 shows.
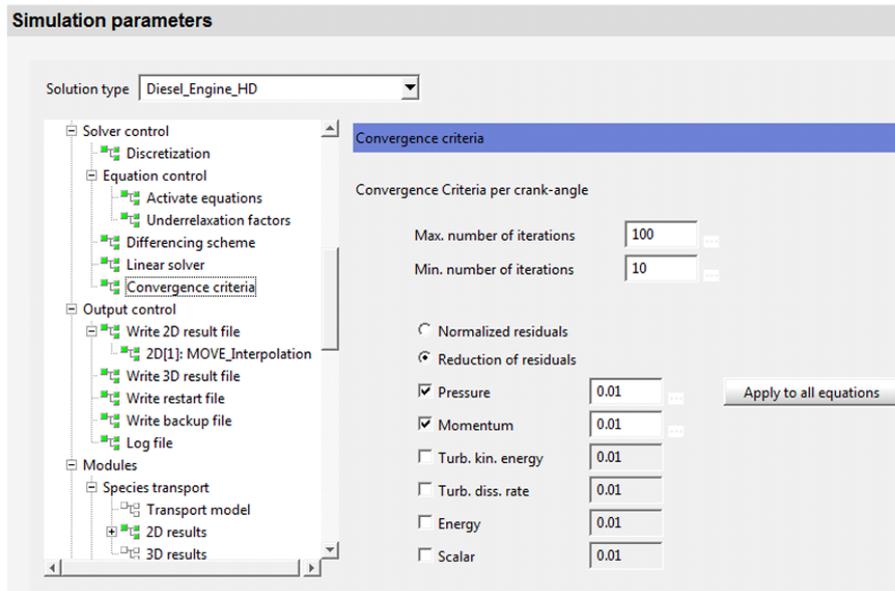
Figure 2. Solve's convergence criteria.

Models

Species Transport

For general species transport problems, such as multi-component mixtures, catalyst applications or user-defined reaction systems, an arbitrary number of chemical species with a set of arbitrary properties can be defined by selecting General for the Transport Model. Gaseous and liquid mixtures can be treated with this model (AVL, 2017).

When the standard model is selected according to figure 3, no further specification is required for the type of fluid properties (e.g. initial conditions, boundary conditions, 2D and 3D results).
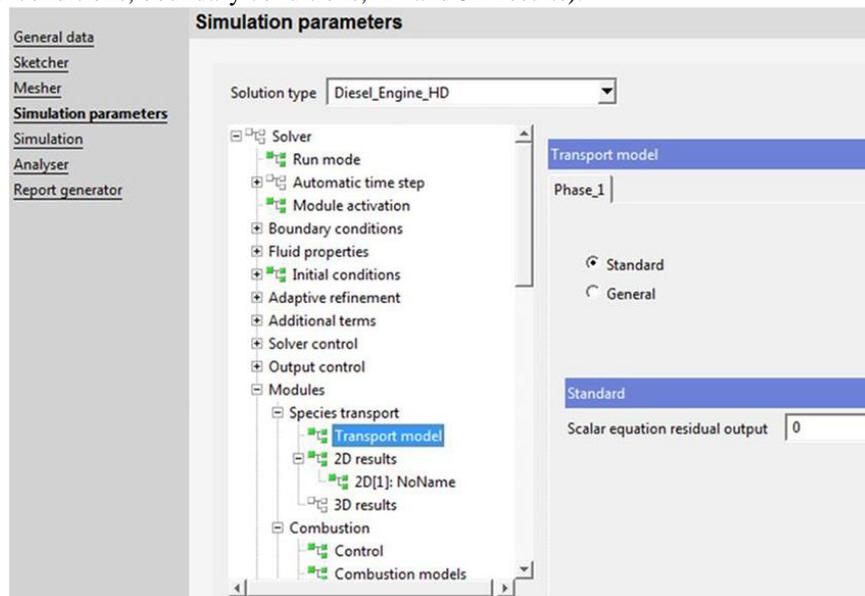

Figure 3. Species transport configuration window.

Combustion

According to H. Xue (2001), the Eddy Breakup Model is based on the solution of species transport equations for concentrations of reagents and products. The reaction mechanism must be explicitly identified and may be single reactions or multistage reactions. The turbulence controlled combustion model was not activated as shown in figure 4, due to the difficulty of finding the necessary data for the modeling. The ignition model was also not activated, leaving the parameters of the program as standard. To activate this model for diesel engines it is necessary to know the reaction rate of the mixture.
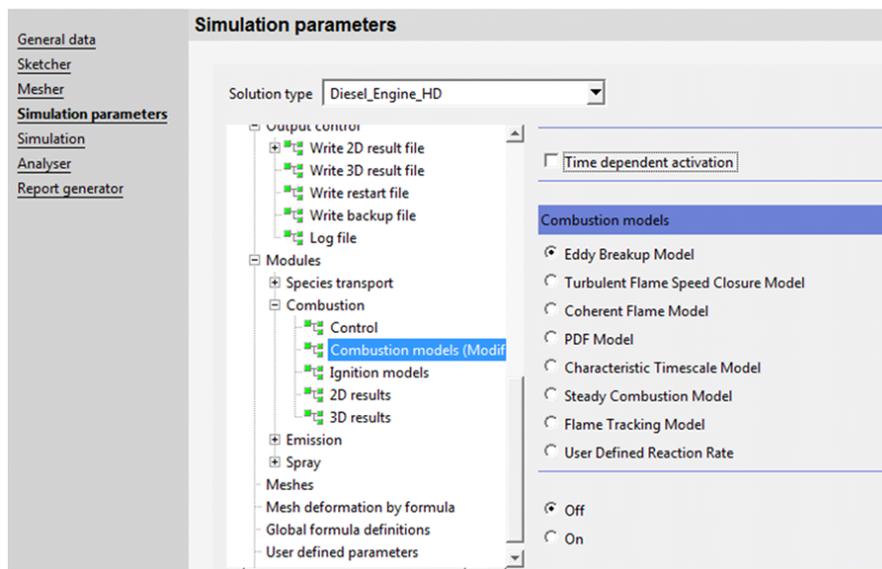
Figure 4. Combustion model selection window.

Emissions

FIRE models have been developed and tested extensively for all types of internal combustion engine applications as well as other combustion applications. The models have the ability to reflect NO formation characteristics during combustion processes. One of the main prerequisites for a realistic calculation of NO emission levels, however, is the correct prediction of the spatial and temporal evolution of liquid fuel spray, fuel vapor, and finally the release of heat and temperature (AVL, 2017).

The model chosen was the Extended Zeldovich, according to figure 5, because according to FIRE (2017), this model is recommended for combination with all combustion models.
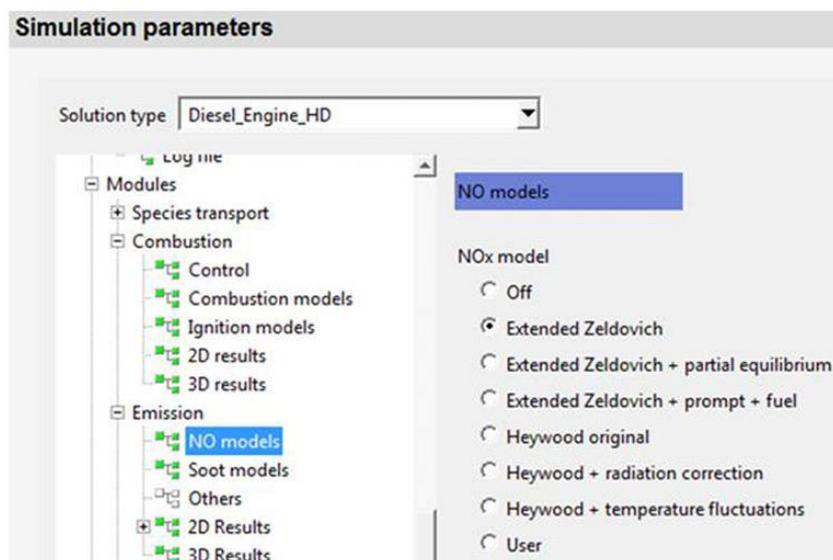

Figure 5. NO_x emission models window.

Spray

In this step, a set of data can be provided and the software will solve several equations to describe how the fuel is injected into the combustion chamber. In the figure, we have as input data DIESEL-D1 and DIESEL-EN590-B7 (composed of pure diesel with the addition of 7% biodiesel composed of fatty acids).
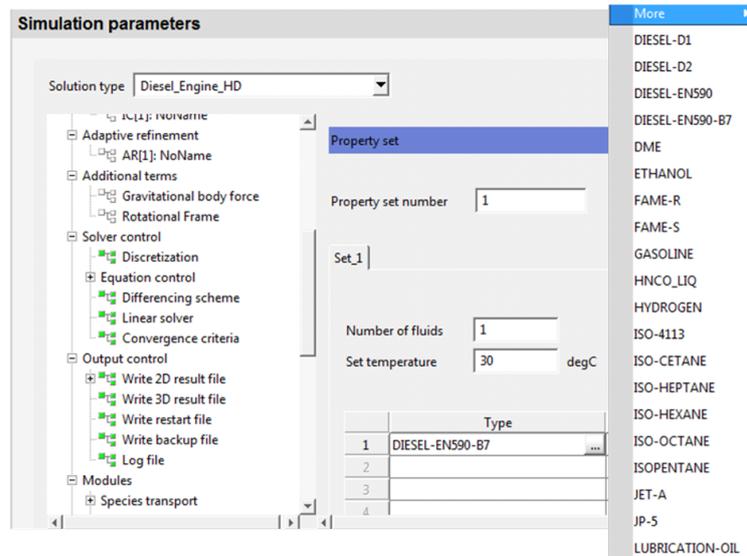
Figure 6. Fuel initial parameters window.

3. RESULTS AND DISCUSSION

3.1 Pressure Inside the Cylinder

Figure 7 shows, on the vertical axis, the pressure inside the cylinder, and on the horizontal axis, the angle of the crankshaft, with the engine operating with B0 and B7. The analysis was performed from the compression time, extending up to the expansion, because in this interval the fuel injection and the work generated in the engine occur. The fuel injection angle was 13 ° APMS (707 °). After the injection of fuel there was a rapid increase of the pressure, which indicated the beginning of the combustion. The peak pressure occurred at 7 ° DPMS (727 °), pushing the cylinder towards the bottom dead center, and consequently decreasing the pressure.

The pressure curve of B0 in relation to B7 was slightly higher. This effect occurs because the energy available in diesel B7 is lower. With the reduction of available energy, the energy released during the combustion occurs, but the simulation showed that the points of the curves were similar.
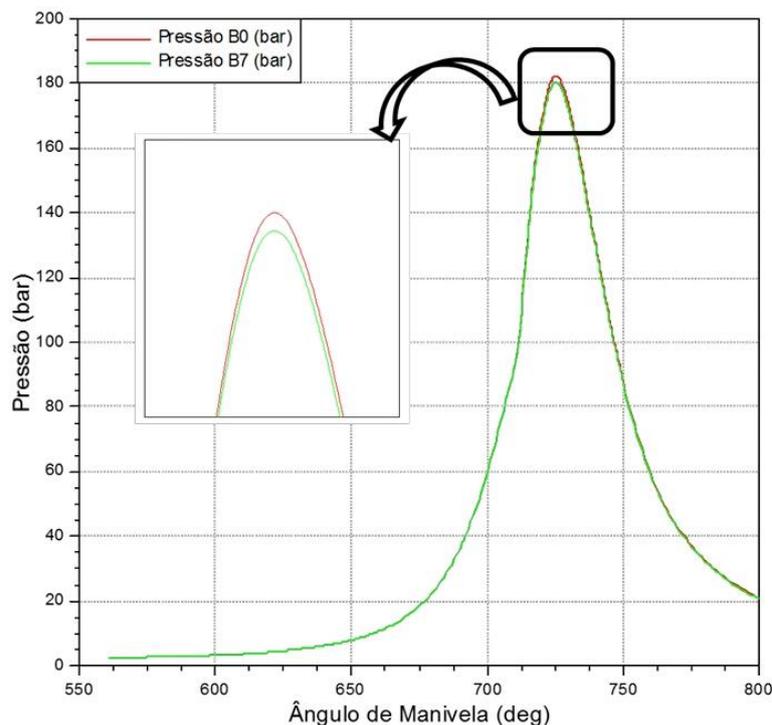
Figure 7. Pressure inside the cylinder.

3.2 Temperature in the Combustion Chamber

Figure 8 shows the average temperature inside the cylinder for the diesel B0 and B7 as a function of the angle of the crankshaft. The temperature curves behaved in a similar way, but the B0 diesel curve is slightly higher when compared to the B7 diesel curve. As there was less energy available in the B7 diesel, for the same amount of fuel, the simulation presented a lower temperature in the combustion chamber when the engine operated with B7, in relation to the B0.
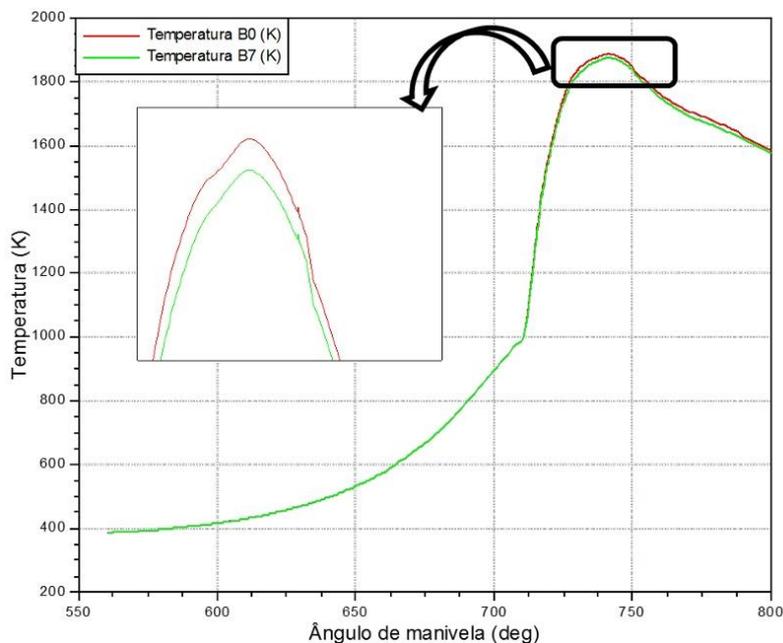

Figure 8. Temperature inside the cylinder.

3.3 Emissions

Figure 9 shows NO and particulate emissions. Before fuel injection, the emissions are practically nil because they are generated after the fuel has been burned.

The formation of the particulates is mainly by the adhesion of the unburned fuel to the wall of the cylinder, because when the fuel is injected in the cylinder, part of it is not surrounded by the turbulence in the combustion chamber adhering the wall of the cylinder. As combustion happens quickly, the fuel that has adhered to the cylinder wall is not burned. The formation of NOx occurs when Nitrogen is subjected to high temperatures, because at room temperature, Nitrogen is a stable molecule. However, when subjected to high temperatures, the molecules break with energy accumulation, forming the NOx. The mass fraction of B0 particles is smaller in comparison to B7, whereas with the mass fraction of NOx the inverse effect happens. One of the causes of the particulate difference is caused by the time of burning, since the pure diesel burns faster than with the addition of biodiesel. However, NOx occurs because of the maximum temperature difference in the combustion chamber, since it is generated at high temperatures.
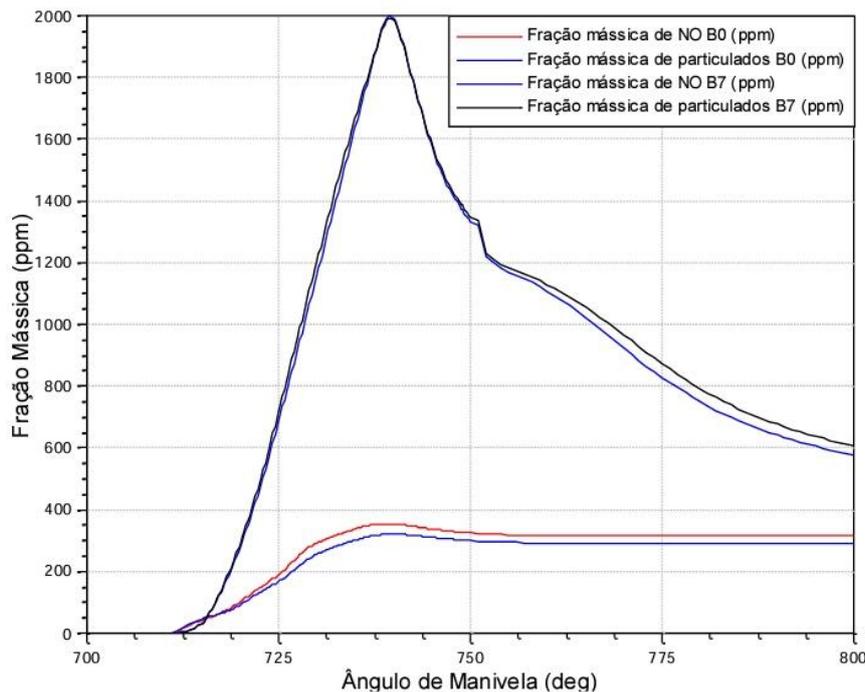
Figure 9. Emissions of particulate NO.

4. CONCLUSION

This work presented the application of the AVL FIRE™ software for the combustion analysis, from the insertion of the geometric data to the results analysis, which behaved coherently with the literature, proving the applicability of AVL FIRE software already used in several works.

The pressure curves for both the Diesel B0 and the Diesel B7 presented values well above the actual values of the CUMMINS engine analyzed in the experimental tests. These divergences may have occurred due to the absence of geometric data from the piston as well as the injector, but the B0 diesel had a higher pressure peak than with B7 diesel.

The simulation showed that the average temperature inside the cylinder was higher for the diesel B0. This result was already expected because pure diesel has more available energy. Nonetheless the temperature distribution inside the cylinder initially occurred evenly before fuel injection. During combustion the temperature increased rapidly in the central regions of the cylinder. With the advance of the burning of the fuel, the zones of high temperature remained uniform.

Particulate and NOx emissions behaved differently, as the mean NOx concentration was higher for pure diesel while the particulate emissions behaved inversely. The distribution inside the cylinder, for both fuels, occurred in different regions. The simulation indicated that the NOx was concentrated in the central region and the particulates in the regions closer to the cylinder wall.

The work reached its objective in which for the first time the AVL Fire computational tool was used for application in the Engine Laboratory - UFPA, being this work as a guide for other students and future works to be developed.

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6. RESPONSIBILITY NOTICE

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