FLOW SIMULATION IN ENGINE CYLINDER WHEN A COMBUSTIBLE SUBSTANCE (DEE) IS INJECTED INTO A DIESEL ENGINE INTAKE, METHOD TO IMPROVE COLD STARTING

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Abstract: *There are many solutions developed to improve the cold storability of diesel's engines. This paper presents results from numerical simulation of the air flow in Compression Ignition Engine (CI engine) cylinder and also the investigation of an injection of diethyl ether module used to improve the cold starting of a diesel engine at the low temperature.*
The most usual numerical method in Computational Fluid Dynamics (CFD) is finite volume. In this investigation an important common fluid flow patterns in CFD simulations, namely, swirl motion typical in automotive engines and RNG k-e turbulence model were used. A three-dimensional unsteady turbulent compressible FLUENT solver was utilized in the present study to investigate the intake injection method of a four-valve direct injection compression ignition engine.
The intake process is complicated considering the gas dynamics of the intake manifold when the walls of the intake system and cylinders are cold, a much smaller percentage of the fuel will vaporize than in normal steady-state operation. The engine turns very slowly, being driven only by the starting motor, and a greater amount of the compressive heating during compression is lost by heat transfer to the cold walls.
This is made worse by the cold viscous lubricating oil that resists motion and slows the starting speed even more. All of these factors contribute to the need for a very rich air-fuel ratio when starting a cold engine. DEE (diethyl ether) was inducted as an ignition improver through the induction manifold. Results of these simulations aid in the improved understanding of the intake process and its influence on direct injection compression.

Keywords: DEE, Flow field, intake manifold, evaporation, CFD, cold start.

INTRODUCTION

When a cold engine is started, an overreach supply of fuel must be supplied to assure enough fuel vapors to create a combustible gas mixture. When the walls of the intake system and cylinders are cold, a much smaller percentage of the fuel will vaporize than in normal steady-state operation. The fuel is also cold and does not flow as readily. The engine turns very slowly, being driven only by the starting motor, and a greater amount of the compressive heating during compression is lost by heat transfer to the cold walls. If adding the actual concern for the alternative fuels, the problem of the diesel engine cold starting becomes even more difficult when using biofuels.
However, despite its improvements, the diesel engine still has problems at cold starting, which has negative effects on market acceptance and practical use. The cold starting characteristics deteriorate as the ambient temperature lowers.
This paper presents the results of the numerical analysis study to investigate the intake injection method of a four-valve direct injection compression ignition engine. The method involves injecting a combustible substance (diethyl-ether) inside the engine intake manifold to improve the quality of the cold. This is a special starting fluid for aiding engine startup in extremely cold temperatures. Even when everything is very cold, a small percentage of fuel vaporizes and a combustible air and vapor mixture can be obtained. This mixture is ignited, and after only a few cycles of combustion, the engine

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begins to heat up. Within a few seconds it starts to operate in a more normal mode, but it can take many minutes before fully warmed steady-state operation is reached. Once the engine starts to warm, all of the excess fuel that was originally input vaporizes and a short period of overreach operation is experienced.
This work is carried out within the frame of a research project entitled "Research upon the development of a method to improve the cold starting of biodiesel engines for special destination vehicles", which is granted by the Romanian Council for Scientific Research in the Higher Education (CNCSIS).

CFD SIMULATION

Many mathematical models have been developed to help understand, correlate, and analyze the operation of engine cycles. These include combustion models, models of physical properties, and models of flow into, through, and out of the cylinders. Substances like diethyl ether with very high vapor pressures evaporate more readily than gasoline and give a richer air-fuel vapor mixture for initiating combustion. These fluids generally are obtained in pressurized containers and are sprayed into the engine air intake before starting.
This section describes the mathematical model for turbulent particle dispersion and vaporization assuming that the particles are sufficiently dispersed so that particle – particle interaction is negligible. The method to solve the continuous phase is based on the solution of the conservation equations for momentum and mass. Turbulence is modeled with the ''k -□'' turbulence model of Launder and Spalding [7] and governing equations (continuity, momentum, turbulent kinetic energy, dissipation, enthalpy, and vapor mass fraction) constitute a set of coupled partial differential equations that can be reduced to a single convective–diffusive conservation equation.

Geometry and mesh generation

The geometry and meshing of the intake manifold was created using CATIA V5R19 and ANSA software's, and are represented in figure 1.

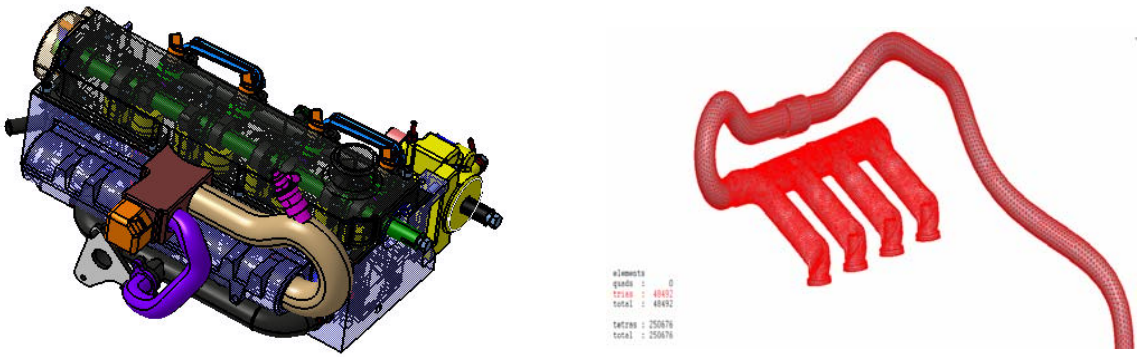

Figure 1. Geometry model and mesh generation

Boundary conditions

Regarding the boundary conditions, simulation is done considering the mean temperature 250^0K or (-23^0C), inlet pressure in the intake manifold is atmospheric, and for each drum part was considered a depression in the intake valve of 0.89 bars. Injection of combustible substance begins practically from the moment t = 0 seconds and lasts for the entire period of numerical simulation. In the table below are shown the conditions to limit the air intake manifold and fuel injection substance.
Table 1 presents the main boundary conditions of the model.

Table 1. Boundary comditions

Intake manifold pressure [Pa]	101325
Valve inlet pressure [Pa]	89124
Intake valve diameter [mm]	36

Mass flow rate [kg/s]	0.005
Ambient temperature [^{0}K]	250
Injection velocity [m/s]	32

Setting the injector position

As shown to the figure below have been taken into account three arbitrary position of the location area of the injector on the manifold to establish the correct position of the injector.

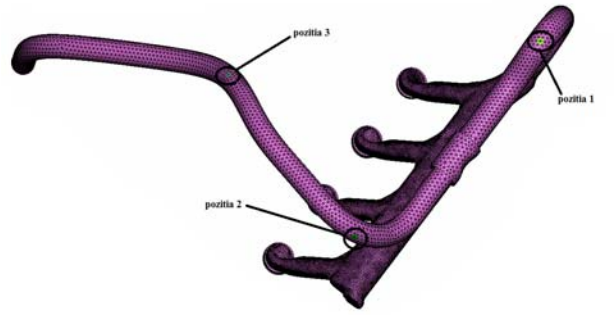

Figure 2: Geometry vs. Injector positions on the intake manifold

Properties of diethyl ether

Diethyl ether [8] is considered as a renewable fuel because it can be produced from ethanol through the dehydration process. Low auto ignition and boiling temperature of DEE are reasons for selecting it as an ignition improver along with lethargic fuels like biogas. Also, DEE has a higher energy density than ethanol. The important properties of DEE are given in Table 2. Generally, DEE is used as a cold starting aid in CI engines. DEE is also blended with
diesel for improving the brake thermal efficiency and reducing emissions in CI engines.

Table 2. Properties of diethyl ether.

Calorific value	33.9
Density at15 ^{0}C (g/cm^3)	0.713
Boiling point (^{0}C)	34.6
Stoichiometric air fuel ratio (mass basis)	11.1
Autoignition temperature (^{0}C)	160 ^{0}C
Cetane number	>125
Heat of evaporation (kJ/kg)	360
Viscosity la 40 ^{0}C	0.23
Oxygen content (%)	21

RESULTS AND DISCUSIONS

Fluent 6.3 is employed for the numerical solution of the steady state continuity, momentum, and species balance equations, including the standard k–ε model equations. The default parameters were used as defined in the Fluent manual. An upwind first-order scheme was used in all cases. The pressure correction scheme followed the SIMPLE algorithm. Considering the case of cold start simulation when the engine turn with 120 rpm, a numerical simulation was performed by injecting a combustible substance for 1 second for all four cylinders which it follows that for each drum part during the simulation is 0.25 seconds, after which the data post processing was performed. That means for each cylinder was performed four analyses.
In case of cylinder 1 the results are shown in figures bellow:

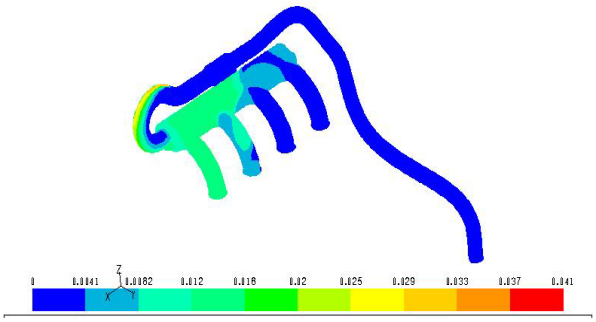

Figure 3. Mass fraction of combustible substance admitted to the cylinder 1.

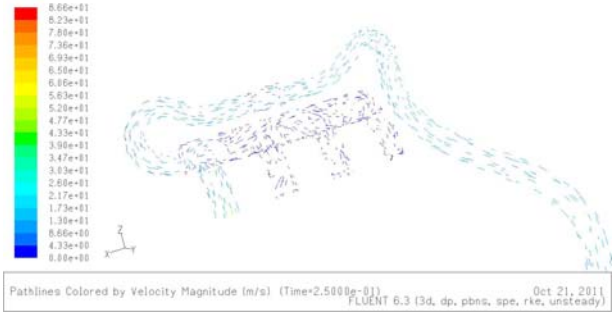

Figure 4. Velocity of the air admitted in the cylinder 1.

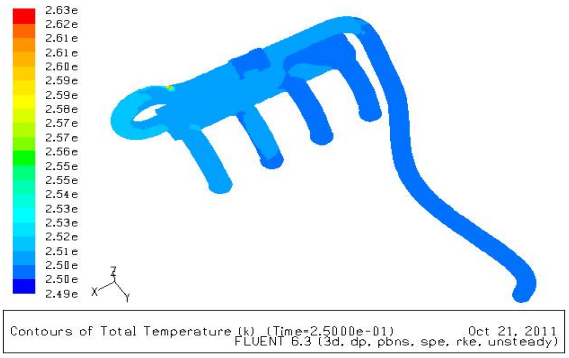

Figure 5. Temperature evolution for the first cylinder.

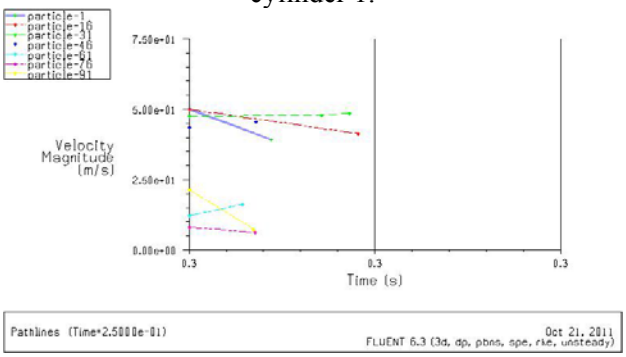

Figure 6. Velocity of the DEE bubble's admitted in cylinder 1.

First picture shows the results for mass fraction of combustible substance which are passing the intake valve, (The percent of mass fraction which is admitted in cylinder is [1.27%]). The particle devolatilization rates are strongly dependent on the particle temperature. As mentioned, the instantaneous particle temperature is influenced by the turbulent gas fluctuation. Thus it is necessary to further explore the effects of gas temperature fluctuation on the instantaneous devolatilization of pulverized coal particles.

Figure 4 displays the computational results of the path lines of the air velocity, where we can read the results. So, the air velocity is about 40 m/s. Figure 5 shows the contour plot of the gas temperature computed with the present method. Taking into account the boundary condition for the simulation, the maximum gas temperature for this cylinder was found around 263K. The maximum velocity bubbles are recorded 50 m/s.

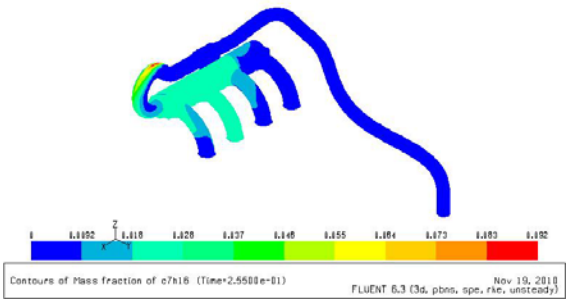

Figure 7. Mass fraction of combustible substance admitted to the cylinder 2 for the first position of injector.

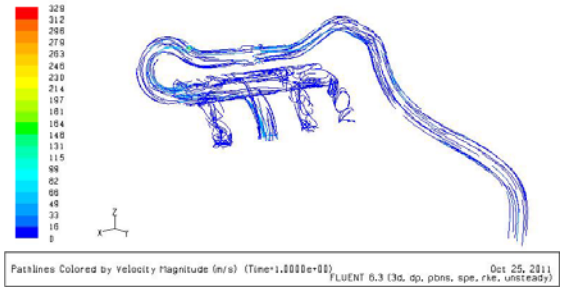

Figure 8. Velocity of the air admitted in the cylinder 2.

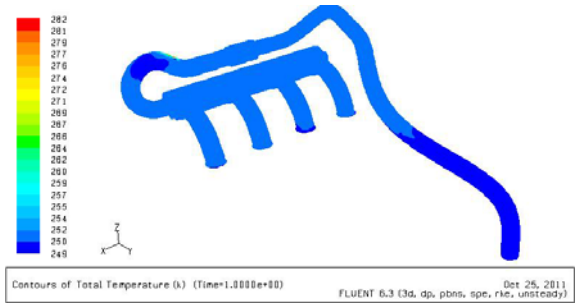

Figure 9. Temperature evolution for the second cylinder.

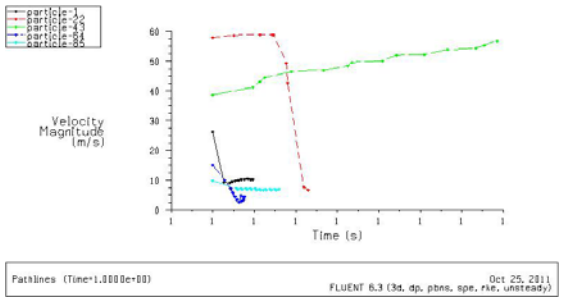

Figure 10. Velocity of the DEE bubble's admitted in cylinder 2.

Comparing the results with those obtained for the first cylinder can be seen that in this cylinder, the percentage of mass fraction entering the cylinder is double. The maximum percentage is 3.64 [%]. The velocity of the air admitted in the cylinder is around 66 m/s, so, also double comparing to the previous cylinder. Regarding temperature of the mixture inside of the intake manifold, the maximum value is found 282K. The explanation of this increasing temperature is because for this cylinder, the flow takes place in the last part of simulation, which means in the last 0.25 seconds of numerical calculation. For this cylinder we found a velocity for the DEE bubbles around of 60 m/s. Those things explain the amount of the increasing of mass fraction for that cylinder.

For the third cylinder were obtained the following results:

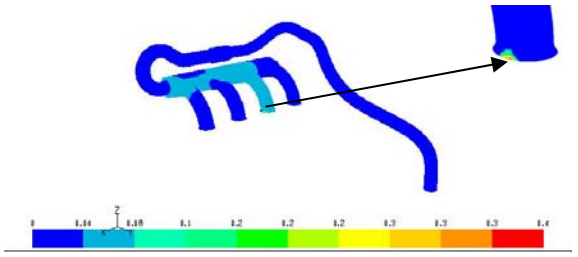

Figure 11. Mass fraction of combustible substance admitted to the cylinder 3 for the first position of injector.

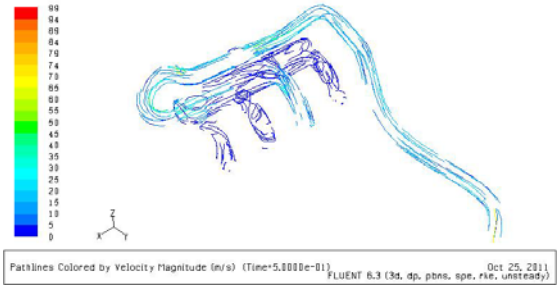

Figure 12. Velocity of the air admitted in the cylinder 3.

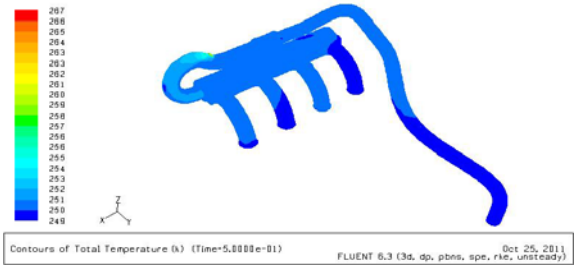

Figure 13. Temperature evolution for the third cylinder.

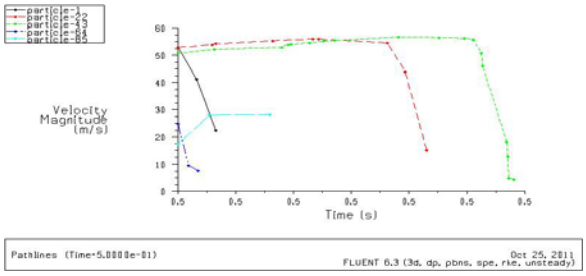

Figure 14. Velocity of the DEE bubble's admitted in cylinder 3.

For the third cylinder is observed the phenomenon of evaporation of mass fractions appears and their quantity is calculated as 0.29 grams. We found mass fractions like 5.8 [%] from the injected mass. Temperature is found 267K. There is a small increasing comparing with the first cylinder and it is normal is normal considering that we are in the second part of the simulation, namely to 0.25 seconds. Regarding the simulation results for the fourth cylinder is shown as if the other cylinders in the next figures.

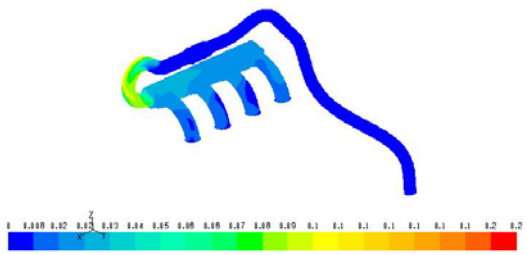

Figure 15. Mass fraction of combustible substance admitted to the cylinder 4 for the first position of injector.

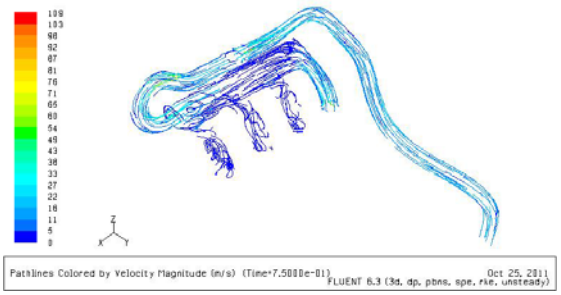

Figure 16. Velocity of the air admitted in the cylinder 4.

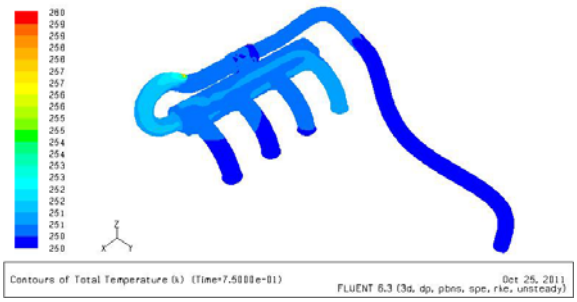

Figure 17. Temperature evolution for the fourth cylinder.

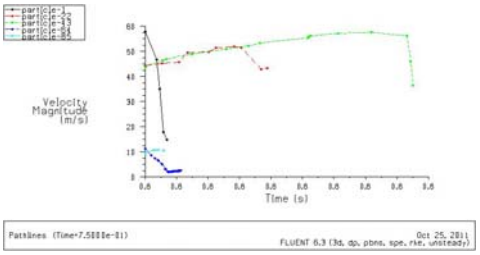

Figure 18. Velocity of the DEE bubble's admitted in cylinder 4.

Again, notice that the position in which combustible substance is injected is most favorable in terms of percentage of mass fraction which is entering in the cylinder. The maximum value is 4.08 [%].
The result of the mixture velocity it is found 48 m/s. Maximum temperature recorded on the walls of the intake manifold is 260K and bubbles velocity for this cylinder is found around 60 m/s.

CONCLUSIONS AND FUTURE WORK

A turbulent diethyl-ether/air spray has been simulated using a probability density function method. The equations have been closed using a RANS formulation for the turbulent flow field. The numerical results of the gas velocity, the gas temperature, and the mass fraction of diethyl-ether vapor and droplet velocity are studied. They are almost statistically independent when evaporation is initiated and no major mixing is found.
According to the numerical results and analysis mentioned above, this study was done in order to find a solution for mounting additional intake manifold injector. As is apparent from the numerical simulations showed that the injector should be placed in position as a combustible substance injected into this position through a shorter distance and thus the mass fractions of mixture reach combustible substance in excess of engine cylinders. The only cylinder that the combustible substance comes in the vapor mixture is cylinder number 3, namely 0.29 g.
Actually, this paper presented the initial steps made by the authors on this topic. The final goal is to build an auxiliary plant supply with diethyl-ether to confirm the numerical calculations to start at very low temperature with a large percentage of biodiesel within the fuel. In order to examine this technique, the authors rely on CFD numerical simulation.
This subject is also to be developed within the frame of the research project [6], which is financially supported by the Romanian Council for Scientific Research in the Higher Education (CNCSIS).

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REFERENCES

[1] G-F Xiao1, X-Q Qiao, Z Huang, Z-P Chen, “Improvement of startability of direct-injection diesel engines by oxygen-enriched intake air”, Proceedings of IMechE, Vol. 221, Part D Journal of Automobile Engineering, 2007

[2] N Brown, V Gupta, A La Rocca, P J Shayler, M Murphy, I Pegg, M Watts, “Investigations of fuel injection strategy for cold starting direct-injection diesel engines”, Proceedings of IMechE, Vol. 221, Part D Journal of Automobile Engineering, 2007

[3] Lippert A., Stanton D., Reitz R., Rutland C, Hallett W, “Investigating the effect of spray targeting and impingement on diesel engine cold start”, SAE Paper 2000-01-0269

[4] Zahdeh A., Henein N., Bryzik W., “Diesel cold starting: actual cycle analysis under border-line conditions”. SAE paper 900441

[5] Niculescu R, Clenci A, Stroe S., “On the methods used in order to improve diesel startability”, International Conference ESFA, Bucuresti, 2009

[6] Niculescu R., Clenci A et al “Research upon the development of a method to improve the cold starting of biodiesel engines for special destination vehicles”, Research project, University of Pitesti-CNCSIS, Romania

[7] Launder BE, Spalding DB. The numerical computation of turbulent flows. Computational Methods Appl Mech Eng 1974;3:269–89.

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Diethyl ether as an ignition improver for biogas homogeneous charge compression ignition (HCCI) operation - An experimental investigation.