CFD SIMULATION OF ULTRASONIC CONDITIONING INFLUENCES ON BIODIESEL INJECTION PROCESS

F. MARIASIU[1], D. MOLDOVANU[1], L. KOCSIS[1]

[1] *The Technical University of Cluj-Napoca, ARMA dept., Bdul.Muncii 103-105, Cluj-Napoca*
E-mail: florin.mariasiu@arma.utcluj.ro

Abstract: *In case of using biodiesel to fuel compression ignition engines, there is a decrease in effective power of the engine by 5 ... 15% [2,4], but with concomitant reduction in the amounts of polluting gases (CO, CO_2, HC). The currently researches and also the solutions proposed regarding the external conditioning process of fuel or fuel-air mixture (trough ultrasounds) aimed at improving overall performance of the engine, the functional characteristics (primarily engine power and efficiency), increasing speed of chemical reactions and, consequently, reduces the duration of burning, acting on some physico-chemical properties of the fuel in a controlled manner [3,5,8,10,11]. This paper presents an originally and novelty CFD simulation study on temporal development inside a diesel engine combustion chamber of a fuel injection process using a biodiesel fuel conditioned trough ultrasounds. It shows the values of Combustion Equivalence Ratio (CER) variations for the ultrasonic conditioned biodiesel. In the horizontal section of the combustion chamber, according to data obtained by simulation, it is apparent that for the case of biodiesel ultrasonic conditioned injection, the occupied area by the fuel-air mixture is 6.77% higher than when using biodiesel classic unconditioned. In the case of biodiesel conditioning exist an area that is characterized by a higher CER = 1.4-2.0, occupying 11% of mixture total area. A lower value of the mixture area in the combustion chamber of CERs = 0.8-1.4 (for biodiesel ultrasonic conditioned), lead to influence the burning process by a lower value of the adiabatic flame temperature, which determinate lower values of NO_x emissions resulting from the combustion process. A lower value of the area air-fuel mixture all available surface relative to the combustion chamber (in the case of ultrasonic conditioning) increase the premix phase of combustion and realize further increase the diffusion phase of combustion that conduct to reduced emissions of NO_x. Taking into account the complex nature of the interaction of ultrasounds with liquid media and their action at the molecular level of biodiesel, further studies are needed to determine the effect on diesel engine functional parameters, the level of pollutants emissions and to confirm the above obtained results trough experimental researches.*

Key words: *CFD simulation, biodiesel, external conditioning, ultrasounds, combustion equivalence ratio.*

INTRODUCTION

The solutions currently proposed regarding the external conditioning process of fuel or fuel-air mixture aimed at improving overall performance of the engine, the functional characteristics (primarily power and efficiency), increasing speed of chemical reactions and, consequently, reduces the duration of burning, acting on some physico-chemical properties of the fuel in a controlled manner.

To control spray droplet diameter is aimed at decreasing surface and interface tensions by creating tensions with opposite sign due to determine additional moves and influence the spray droplet dynamics. It is possible to control the degree of homogeneity of the fuel-air mixture and even the orientation in space of air-fuel mixture molecules with direct influence on the engine functional processes [8, 14].

Chemical composition of fuel has the greatest effect on reaction speed, which in turn has a direct connection with the fuel burning rate. The molecular structure of the components determines the value of activation energy (Figure 1), and the reaction rate is inversely proportional to it, as follows (Eq.1):

$$E = E_r - E_{ci} \quad , \qquad (1)$$

, where E is the activation energy; E_r - the energy input required of the reaction; E_{ci} - initial average kinetic energy of molecules; Q - heat of reaction ($Q = E_{ci} - E_f$) and E_f - molecules final energy.

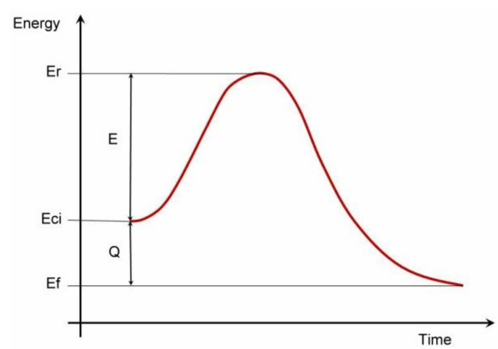

Figure 1. Variation in time of fuel molecules needed activation energy

The activation of fuel trough external energy conditioning process (using ultrasounds, microwaves, ultraviolet, magnetic fields) results in increased reaction speed, a faster and more complete burning and improve the overall efficiency of internal combustion engines. By transfer this type of energy on fuel structure it's increasing the intensity of translational motion of molecules (especially of the oscillation motion of atoms or groups of atoms that form molecules), leading to their superior energetic activation [8, 14].

Thus, by biodiesel ultrasounds conditioning process can achieve higher energy efficiency, with direct implications on improving the diesel engines functional performances and achieve a lower level of polluting emissions.

MATERIAL AND METHODS

The biodiesel external energy conditioning was set up by the ultrasonic process. The research device was constructed experimentally by transforming a Sonorex Bandelin RK11 type ultrasonic bath, that consist of an PZT oscillator type system with 35 kHz frequency emission, power 30 / 120 W, 220V, 0.3-liter stainless steel capacity tank, adjustable and programmable timer (Figure 2).

Density of studied biofuels in the experiment was determined using the Anton Paar 5000 apparatus. Determinations were made according to standard specifications for measuring SR EN ISO 3675 (at 20° C reference temperature).Variation of biodiesel density under ultrasonic conditioning process have been experimentally determined [8, 9] and are presented in Figure 3. Ultrasonic conditioning time was 600 seconds.

To achieve the simulation were used FIRE CFD software package developed by AVL GmbH [15], a software package that has proven accurate in several comparisons between the results obtained by simulation and their corroboration with the experimental data obtained on test stands. The initial conditions to achieve the simulation consisted of defining the geometric characteristics of the combustion chamber, the piston crown shape, the exhaust and admission pipes (Figure 4) and the particularities of engines functional process (Table 2).

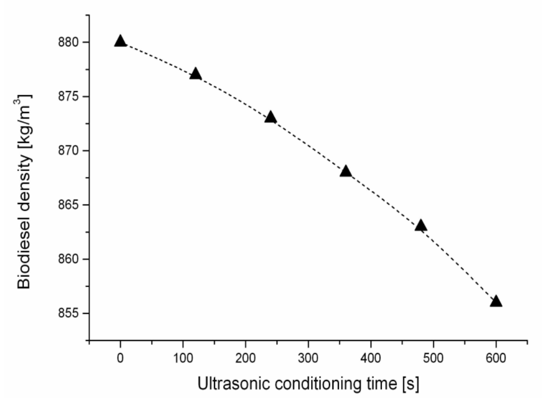

Figure 1: Density variation during the process of biodiesel ultrasonic conditioning

Table 1

Fuel main characteristics used in the experiment

Property	**RME (Rapeseed Methyl Ester)**
Chemical formula	C_{16}-C_{18}
Molecular weight [g/mol]	209,6
Density at 20°C [kg/m^3]	879
Kinematic viscosity at 40°C [mm^2/s]	4.9
Boiling point [°C]	322
Net heating value [MJ/kg]	37,5
Carbon content (%)	78,7
Sulphur content (ppm)	0,036
Water content [mg/kg]	86
Cetan index	52.7

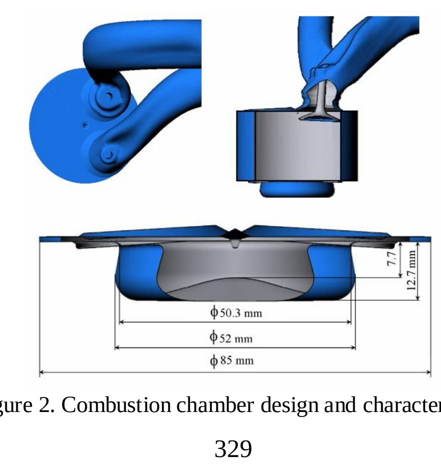

Figure 2. Combustion chamber design and characteristics

Table 2

Simulation initial conditions

Parameter	**Value**
Speed [min^{-1}]	4000
Swirl ratio	1.5
Stroke [mm]	90
Bore [mm]	85
Compression ratio	14
Injection pressure [10^5 Pa]	100
Combustion chamber pressure [10^5 Pa]	16
Combustion chamber temperature [K]	770
Biodiesel temperature [K]	293
Number of injector holes	8
Nozzle orifice diameter [mm]	0.230
Nozzle discharge coefficient	0.76

The injection process consists of two phases: the first phase of pilot injection followed by the main injection phase. Variation of fuel mass flow depending on the angle of rotation of the engine crankshaft is shown in Figure 5.

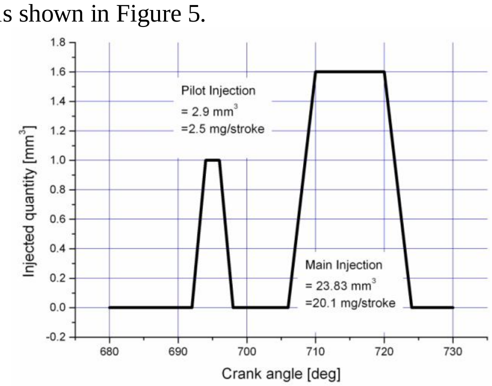

Figure 3. The injection process map

RESULTS AND DISCUSSIONS

Data obtained from simulations have been processed and are presented in Figures 6-9. To reveal differences arising by ultrasonic conditioning process of RME biodiesel were measured corresponding values of Combustion Equivalence Ratio (CER) areas inside of combustion chamber, both in horizontal section as well as in the vertical section (at 738^{o}CA piston position). The results are presented in Tables 3 and 4.

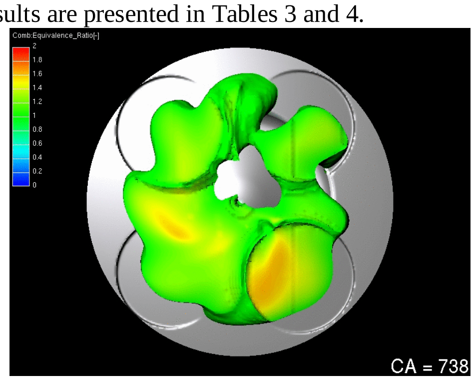

Figure 4. The combustion equivalence ratio area development for biodiesel (horizontal section)

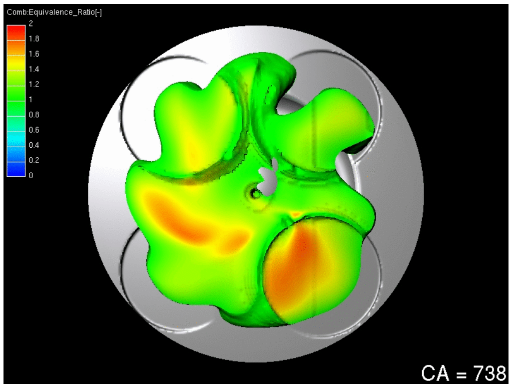

Figure 5. The combustion equivalence ratio area development for ultrasounds conditioned biodiesel (horizontal section)

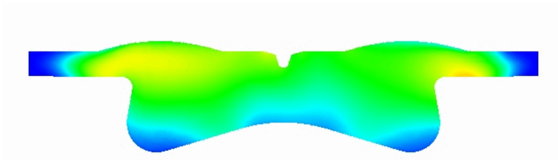

Figure 6. The combustion equivalence ratio area development for biodiesel (vertical section)

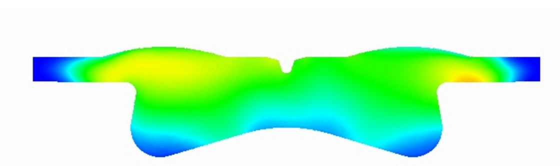

Figure 7. The combustion equivalence ratio area development for ultrasounds conditioned biodiesel (vertical section)

Table 3

CER distribution in combustion chamber horizontal section

Area of	Biodiesel	Ultrasonic conditioned biodiesel	Biodiesel	Ultrasonic conditioned biodiesel	Differences
	[mm^2]		[%]		[-]
Combustion chamber section	5674.33	5674.33	100	100	0.00
Injected fuel	4810.31	5194.33	84.77	91.54	- 6.77
Corresponding to 0.8-1.4 CER	4182.23	3942.08	73.70	69.47	+4.23
Corresponding to 1.4-2.0 CER	628.08	1252.25	11.07	22.07	-11.00

In the horizontal section of the combustion chamber, according to data obtained by simulation, it is apparent that for the case of biodiesel ultrasonic conditioned injection, the occupied area by the fuel-air mixture is 6.77% higher than when using biodiesel classic unconditioned. This is due to the influence of ultrasonic conditioning process by reducing the density of fuel, with immediate effect in increasing the length of the liquid phase penetration of jet fuel [1, 13]. Thus, in the case of biodiesel conditioning exist an area that is characterized by a higher CER = 1.4-2.0, occupying 11% of mixture total area. A lower value of the mixture area in the combustion chamber of CERs = 0.8-1.4 (for biodiesel ultrasonic conditioned), lead to influence the burning process by a lower value of the adiabatic flame temperature, which determinate lower values of NO_x emissions resulting from the combustion process [6,7,12]. Also, overall, a lower value of the area air-fuel mixture all available surface relative to the combustion chamber (in the case of ultrasonic conditioning) increase the premix phase of combustion and realize further increase the diffusion phase of combustion that conduct to reduced emissions of NO_x [6,12].

Table 4

CER distribution in combustion chamber vertical section

Area of	Biodiesel	Ultrasonic conditioned biodiesel	Biodiesel	Ultrasonic conditioned biodiesel	Differences
	[mm^2]		[%]		[-]
Combustion chamber section	1498.35	1498.35	100	100	0.00
Corresponding to 0.0-0.6 CER	775.45	672.34	51.75	44.87	+ 6.88
Corresponding to 0.6-1.2 CER	544.37	633.96	36.33	42.31	- 5.98
Corresponding to >1.2 CER	178.53	192.05	11.92	12.82	-0.90

In the analysis of areas occupied by fuel mixtures different in vertical section of combustion chamber regarding the distribution values CER, the differences are relatively small and lower implications (due to lower values) on mixing and combustion process.

CONCLUSIONS

The ultrasonic conditioning of biodiesel leads to lower its density, decreasing process with direct influence of injection process parameters. Thus, we obtain a longer spray liquid phase length penetration causing the existence of elevated values of CER (1.4-2.0). The elevated values of CER increase thermodynamically period of burning stages in compression ignition engine with direct influence on NO_x emission.

The results of ultrasonic conditioning process for reformatting the biodiesel fuel are confirmed totally (density variation) and partially (pollutant emission) by other researchers in the field [14], differences being caused by the characteristics and particularities of ultrasonic conditioning process [8, 14] as well as possible caused by the nature and manufacturing technology use to produce RME biodiesel [12].

The biodiesel ultrasonic conditioning can obtain values of the parameters that characterize and influence the injection process close to those of fossil fuels (diesel fuel), with implications for their ease of use (without any major technical modifications) in compression-ignition engine power.

The results obtained through CFD simulation show that is some potential to reduce the NOx emission, emissions that characterize the functional processes of compression ignition engines and especially of those that are fuelled with biodiesel (knowing the fact that the emission of NOx is greater comparatively with petroleum diesel fuel [2,6,7,12]).

Taking into account the complex nature of the interaction of ultrasounds with liquid media and their action at the molecular level of biodiesel, further studies are needed to determine the effect on diesel engine functional parameters (the ignition delay, power, combustion temperature), the level of pollutants emissions and to confirm the above obtained results trough experimental researches.

Acknowledgement

This work was supported by CNCSIS –UEFISCSU, project number PNII – IDEI 175/2008.

BIBLIOGRAFY

1. BARABAS, I., TODORUT, A., BRANZAS, P. AND MARIASIU, F. Comparative analysis of the atomization characteristics of biodiesel fuels. In First International Conference „Motor Vehicle and Transportation - MVT 2006”, 15-17 November, 2006, Timisoara, Romania, paper MVT20061002.
2. BURNETE, N. et al. Research concerns the Diesel engine using vegetal oil as fuel. In World Automotive Congress FISITA, Barcelona, Spain, 23-27 may 2004, paper F2004V047.
3. DZIDA, M. AND PRUSAKIEWICZ, P. The effect of temperature and pressure on the physicochemical properties of petroleum diesel oil and biodiesel fuel. *Fuel*, 2008, 87, 1941-1948.
4. GRABOWSKI, M. AND MCCORMICK, R. Combustion of fat and vegetable oil derived fuels in diesel engines. *Progress in Energy and Combustion Science*, 1998, 24(2), 131-132.
5. KANG, J., LEE, K., KOH, C. AND NAM, S. The Kinetics of the Sonochemical Process for the Destruction of Aliphatic and Aromatic Hydrocarbons. *Korean J. Chem. Eng.*, 2001, 18(3), 336-341.
6. LAPUERTA, M., ARMAS, O. AND RODRIGUEZ-FERNANDEZ, J. Effect of biodiesel fuels on diesel engine emissions. *Progress in Energy and Combustion Science*, 2008, 34(2), 198-223.
7. MONYEM, A., VAN GERPEN, J.H. AND CANAKCI, M. The effect of timing and oxidation on emission from biodiesel fueled engines. *Trans ASAE*, 2001, 44(1), 35-42.
8. MARIASIU, F. The influence of external energetic conditioning process on IC engines functional parameters and pollutant emissions fueled with biofuels (in Romanian). *Intermediate Report, research grant CNCSIS PN II 2008 ID 175*, 2009.
9. MARIASIU, F., BURNETE, N. AND DEAC, T. Possibilities to determinate the biofuels physically parameters in functional conditions. *Research Journal of Agricultural Science*, 2009, 41(2), 451-456.
10. MARIASIU, F. AND VARGA, B. Possibilities to improve the cold start process of tractors engines fuelled with biodiesel, *Journal of Food, Agriculture and Environment*, 2010, 8 (3&4), accepted paper.
11. PARK, H.S., YOON, S.H., SUH, H.K. AND LEE, C.S. Effect of the temperature variation on properties of biodiesel and biodiesel-bioethanol blends fuels. *Oil & Gas Science and Technology*, 2008, 63(6), 737-745.
12. SUN, J., CATON, A.J. AND JACOBS, T.J. Oxides of nitrogen emissions from biodiesel-fuelled diesel engines. *Progress in Energy and Combustion Science*, 2010, 36(6), 677-695.
13. WATTS, K. AND ALLEN, C. Comparative analysis of the atomization characteristics of fifteen biodiesel fuel types. *Trans ASAE*, 2000, 43 (2), 207-211.
14. WU, P., YANG, Y., COLUCCI, J. AND GRULKE, E.A. Effect of Ultrasonication on Droplet Size in Biodiesel Mixtures. *J. Am. Oil Chem. Soc.*, 2007, 10, 1746-1760.
15. *** - FIRE v.2009, user manual, AVL GmbH, Graz, Austria.