academicJournals

Vol. 4(7), pp. 143-154, November 2013
DOI: 10.5897/JPTAF2013.0096
ISSN 2360-8560 ©2013 Academic Journals
http://www.academicjournals.org/JPTAF

Journal of Petroleum Technology and Alternative Fuels

Full Length Research Paper

Numerical investigations on the use of waste animal fats as fuel on DI diesel engine

Hamza Bousbaa[1]*Abdelkrim Liazid[1], Awad Sary[2] and Mohand Tazerout[2]

[1]Research Laboratory LTE-ENSET, P. O. BOX 1523 El Mnaour 31000-Oran, Algeria.
[2]DSEE Department, Ecole des Mines de Nantes, La chantrerie, 4, Rue Alfred Kastler, BP Nantes Cedex 3, France.

Accepted 26 November, 2013

Biodiesel is a promising alternative to petroleum-based diesel fuel because it is renewable and its extensive use in unmodified engines has proved to be very successful. However, its future use may be limited by the higher oxides of nitrogen (NOx) emissions that are typically generated relative to petroleum diesel. This paper deals with the numerical investigations on the use of Waste Animal Fat (WAF) as alternative fuel in diesel engine. The advanced CFD code CONVERGE is used to perform this work. Computational methods were developed to estimate the physical and thermodynamic properties of biodiesel for combustion modeling. The data of physical WAF properties were input in the fuel library into CONVERGE program for modeling of the spray, ignition, combustion, and NOx emissions of biodiesel in diesel engine. The result validation is based on experimental data obtained from the a single cylinder direct injection diesel engine operated at its rated speed of 1800 rpm with a large range of applied loads. Comparison with the neat diesel fuel in achieved. The engine combustion parameters such as pressure, temperature, heat release rate are determined, and exhaust emissions (soot and NOx) are also evaluated at all operating conditions. Results show that when the engine is operated with WAF fuel, the combustion characteristics are slightly changed when compared to the neat diesel fuel. Also, the use of WAF fuel leads simultaneously to reduce soot and nitrogen oxides (NOx) species. This work is an achieved step with in-cylinder simulation of WAF fuel combustion and has illustrated that advancing the injection timing to 30 CA BTDC, improves pressure and consequently the brake thermal efficiency when using WAF fuel. In addition, the results reported in this paper illustrate that the numerical simulation can be one of the most powerful and beneficial tools for the internal combustion engine design, optimization and performance analysis.

Key words: Diesel engine, waste animal fats, combustion, simulation, polluants.

INTRODUCTION

Diesel engines are mainly used in industrial, transport and agricultural applications due to their high efficiency and reliability. However, they suffer from high smoke and nitric oxide emissions (Larsen et al., 1996; Summers et al., 1996; Ladommatos et al., 1998). The increase in prices of diesel fuel, reduced availability, more stringent governmental regulations on exhaust emissions and the fast depletion of world-wide petroleum reserves provide a strong encouragement to the search for alternative fuels. It is commonly accepted that clean combustion in diesel engines can be achieved only if engine development with fuel reformulation and the use of alternative fuels are

*Corresponding author. Email: bou_sbaa@yahoo.fr

implemented (Xing-cai et al., 2004). Alcohols, vegetable oils, hydrogen, compressed natural gas etc., are used as good alternative fuels for internal combustion engines (Humke and Barsic, 1981; Czerwinski, 1994; Senthil et al., 2003a). Among this, animal fats and vegetable oils hold out good promise for compression ignition engines. Animal fats and vegetable oils treated have properties comparable to diesel and can be used to run a compression ignition engine without any modifications (Muniyappa et al., 1996; Senthil et al., 2003b; Tashtoush et al., 2004).

One of the limiting factors on the use of vegetable oils and animal fats as fuel in diesel engine is their tendency to solidify at normal cold operating temperatures. Neat fats and vegetable oils are too viscous to be used directly in diesel engines. A number of methods such as dilution, micro-emulsions and transestérification have been tried in the past to use vegetable oils and animal fats efficiently in diesel engines. Fuels derived from animal fats have properties comparable to diesel and can be used to run a compression ignition engine without any modifications (Kerihuel et al., 2005a; Senthil et al., 2006). It boosts reduction in toxic emissions (except NOx emissions) compared to diesel fuel (Senthil et al., 2005a; Sun et al., 2010; Guru et al., 2011).

Though several research projects have been carried out on a number of alternative fuels in diesel engines, not much data is available on the performance of constant speed stationary diesel engine fuelled with animal fat. Boyd et al. (2007) used mineral diesel and biodiesel performed from 80% tallow (animal fat) and 20% canola oil to run a CI engine. However, animal fats and vegetable oils hold out good promise for CI engines. Araya (1987) converted sunflower and fish oil to methyl esters, tested in a single cylinder diesel engine and concluded that, the maximum output with both methyl esters was higher (0.11 kW, 3%) than the diesel fuel. Hulya (2002) analyzed qualitatively and quantitatively, crude commercial fish oil by gas liquid chromatography. The major fatty acids detected in this oil were as follows: 24.8% stearic, 23.6% palmitic, 9.84% myristic, and 6.56% octadecatetraenoic acids. The physical and chemical properties of crude commercial fish oil were established. Steigers (2002) demonstrated the use of fish oil as fuel in a large stationary diesel engine.

Many studies showed that the use of biodiesel resulted in similar performances to diesel fuel with slight reduction in maximum power; and in terms of pollutant emissions, the presence of oxygen bonds in biodiesel leaded to drastic reduction in unburned hydrocarbons, carbon monoxide and soot emissions, however, nitric oxides emissions increased (Rakopoulos et al., 2006; Karabektas 2009; Reyes and Sepulveda 2006; Meng et al., 2008; Rahimi et al., 2009). The use of straight animal fat and vegetable oils resulted in comparable performances and reduction in nitric oxides emissions, but the unburned hydrocarbons, carbon monoxide and particulate matter emissions were increased (Senthil et al., 2005b; Nwafor, 2004; Rakopoulos et al., 2006). In this context, the numerical simulation and optimization of mixture formation and combustion processes is today becoming more and more important. One advantage of using simulation models is that in contrast to experiments, results can often be achieved faster and cheaper. Much more important is the fact that despite the higher uncertainty compared to experiments, the numerical simulation of mixture formation and combustion processes can give much more extensive information about complex in-cylinder processes than experiments could ever provide (Carsten, 2006).

The theoretical models used in the case of internal combustion engines can be classified into two main groups' viz., thermodynamic models and fluid dynamic models. Thermodynamic models are mainly based on the first law of thermodynamics and are used to analyze the performance characteristics of engines. Pressure, temperature and other required properties are evaluated with respect to crank angle or in other words with respect to time. The engine friction and heat transfer are taken into account using empirical equations obtained from experiments.

These models are further classified into two groups namely: single-zone models and multi-zone models. On the other hand, multi-zone models are also called computational fluid dynamics models. These are also applied for the simulation of combustion process in internal combustion engines. They are based on the numerical calculation of mass, momentum, energy and species conservation equations in either one, two or three dimensions to follow the propagation of flame or combustion front within the engine combustion chamber. Several software, which are based on the above models, were commercialized in order to be used for the simulation of compression ignition engines, namely; Fluent, KIVA and CONVERGE Software etc.

Using numerical simulations, it is possible to calculate the temporal behaviours of every variable of interest at any place inside the computational domain. This allows the obtainment of a detailed knowledge of the relevant processes and is a prerequisite for their improvement. Furthermore, numerical simulation can be used to investigate processes that take place at time and length scales or in places that are not accessible and thus cannot be investigated using experimental techniques.

Numerical investigations for bio-fuel combustion are less commonly found in literatures. Some authors have used CFD software to analyze the combustion of biodiesel produced from different kinds of raw materials. Their results showed that the combustion process was dependent of the raw material used for the production of biodiesel (Sahoo and Das, 2009; Gumus, 2010). Rajendra and Tamilporai, (2010) have developed a combustion model that predicts the heat release and in-cylinder pressures of a single cylinder four strokes engine

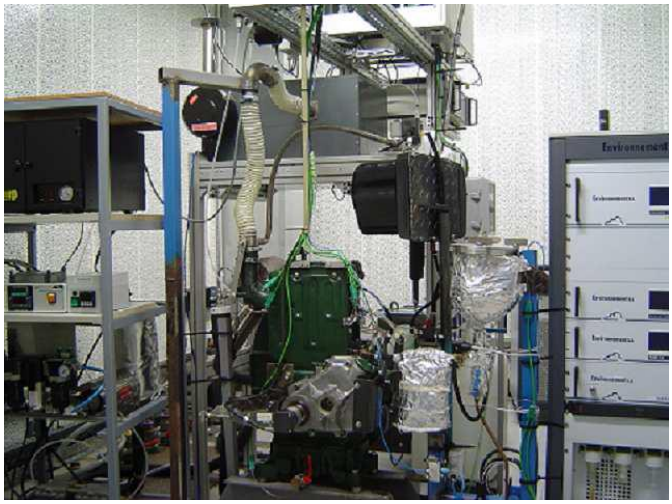


Figure 1. Overall view of experimental setup.

operated on Jatropha seed oil biodiesel. The model also predicted performance parameters with reasonable agreements with experimental results. Nitrogen monoxide can also be predicted using this model. But the other types of pollutants cannot be predicted with single zone models. Rakopoulos et al. (2007) developed a two dimensions model, to predict the formation of soot and nitric oxides during the closed part of the combustion cycle. The authors concluded that the model predicts adequately well both performances and emissions for all used fuels. Some authors have also used the fluid dynamic approach using the three dimensional models to understand better the factors of controlling the NO and soot emissions (Choi and Reitz, 1999; Yuan et al., 2005; Ndayishimiye et al., 2011).

The main problems associated with the use of animal fats as fuel in diesel engines are their high viscosity and poor volatility. A number of methods have been tried in the past to use animal fats efficiently in diesel engines. Some of them are transesterification, blending the oils with diesel and alcohols, fuel preheating, dual fuelling with gaseous and liquid fuels, use of additives, etc. (Barsic and Humke, 1981; Vellguth, 2000; Senthil et al., 2005c). Transesterification shows significant reduction in viscosity, enhancement in cetane number, and other physical properties (Senthil et al., 2000).

Thus, the advantage of transesterification is that it transforms the triglycerides into fatty acid methyl esters mixture that has a lower viscosity, which is 7 - 11 times lower than the original oil (Awad et al., 2009; Demirbas, 2009; Singh and Singh, 2010). This mixture, so called “biodiesel”, is biodegradable, has a very good stability and it can be safely transported due to its high flash point; it has a higher cetane number than diesel oil and can be used in diesel engines without any modification (Sary et al., 2009; Demirbas, 2009; Rahimi et al., 2009; Rakopoulos et al., 2006; Tashtoush et al., 2007). In this work, the WAF fuel is elaborated by transesterification process described by Rakopoulos et al. (2006) and Srivastava and Verma (2008). The transesterification is performed with methanol using sulfuric acid H_2SO_4 as catalyst. The materials and methods are detailed in the reference Sary et al. 2010. Experiments were conducted at an engine rated speed of 1800 rpm with variable load conditions. The numerical simulation by CFD code CONVERGE was used for carrying out the numerical study of the combustion of biofuel for compression ignition engine, it was noticed from the experimental investigations, that it is difficult and cost expensive. However, in this present work the main reason of using the software is to do a numerical study of the combustion, spray and pollutions emissions characteristics of a DI diesel engine fueled with animal fats bio-fuel.

EXPERIMENTAL SETUP

The engine is connected to an automatic controlled eddy current dynamometer. In-cylinder pressure, TDC and injection pressure signals are acquired with a rapid data acquisition system (AVL-Indiwin) and stored in a computer. The data from 100 consecutive cycles are recorded and processed with specific AVL software. The pollutant measurements are achieved using the technique of exhaust gas sampling. This method involves taking a sample of burned gas from the engine exhaust manifold and transport it to the pollutant analyzers via the so called ‘hot line’ which avoids the condensation of heavy hydrocarbons.

The probe sampling is located just after the exhaust valve, to get measures closer than real values. Nitric oxide (NO) in the exhaust gas is measured by using a Beckman chemiluminescence analyzer. Exhaust gas analyzers are calibrated before making measurements. Observations are made for NOx and soot to analyse the emission characteristics. The data acquisition of the pollutants is processed with specific software provided by the pollutant analyzers manufacturer. Overall view of the engine test-rig is shown in Figure 1. The engine specifications are given in Table 1. The engine is always operated at its rated speed of1800 rev/min.

Table 1. Engine and dynamometer specifications.

Parameters	Specifications
Engine type	Lister Petter Type S1
N° of cylinders	Single cylinder
N° of strokes	Four-stroke
Rated Power	5.4 kW (7.3 hp) @ 1800 rev/min
Cylinder Bore	95.25 mm
Stroke length	88.5 mm
Bowl depth	15.10 mm
Upper bowl diameter	45.00 mm
Compression ratio	18:1

Table 2. Properties of WAF and Neat Diesel

Average Properties	Neat Diesel	WAF
Density (kg/m^3)	820	870
Calorific value (MJ/kg)	45.00	37.00
Viscosity (mPa.s)	2.10 (39°C)	5.13 (40°C)
Flash point (°C)	75	160
Cetane number	50	> diesel

Table 3. Fuel injection Specifications

Number of Nozzle Holes	3
Nozzle Hole Diameter	0.25 mm
Included Spray Angle	125°
Fuel injection timing	22° BTDC

Four applied loads were selected such as the engine operates on a wide brake power range. The engine is mechanically and thermally stabilized before taking all measurements. At each applied load, all the data are acquired and stored simultaneously with a full automatic process.

In all cases, pressure crank angle data are recorded and processed to get combustion parameters. Experiments are initially carried out on the engine using diesel as fuel in order to provide base line data. During the entire investigation, the injection timing is set at 22° before TDC. The average properties of the studied bio-fuel WAF are determined experimentally and summarized in Table 2. Details of the injection data are summarized in Table 3.

In-cylinder numerical investigation

The numerical investigation is done with the computer CFD code CONVERGE (Richards et al., 2008) under windows environment. The simulation will cover compression, spray, combustion, and expansion. Since intake and exhaust will not be simulated, the valves have been omitted from the surface. The CFD code solves the following governing equations:

Continuity equations for species m:

$$\frac{\partial \rho_m}{\partial t} + \nabla(\rho_m . u) = \nabla\left[\rho D \nabla\left(\frac{\rho_m}{\rho}\right)\right] + \dot{\rho}_m^c + \dot{\rho}^s \delta_{m1}$$

Where ρ_m is the mass density of species m and ρ is the total mass density, u is the velocity, $\dot{\rho}_m^c$ is the source term due to the chemistry and $\dot{\rho}^s$ is the source term due to the spray, and δ is the Dirac delta function. By summing the previous equation over all species, we obtain the total fluid density equation:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho . u) = \dot{\rho}^s$$

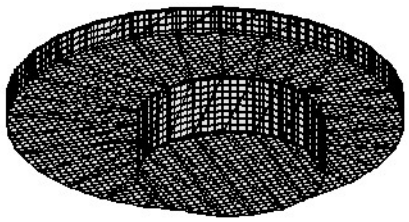
Since mass is conserved in chemical reactions, the fluid momentum equation for the fluid mixture is:

$$\frac{\partial \rho u}{\partial t} + \nabla(\rho . u . u) = -\frac{1}{\alpha^2}\nabla p - A_0 \nabla\left(\frac{2}{3}\rho k\right) + \nabla\sigma + F^s + \rho g$$

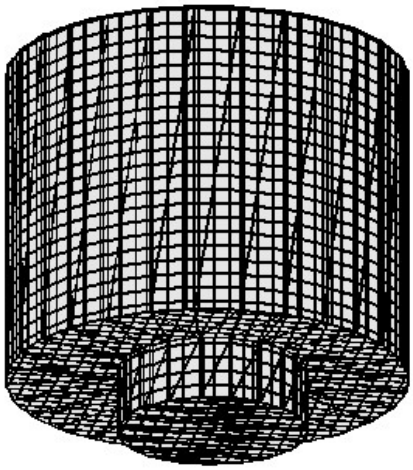
Where P is the fluid pressure, F^s is the rate of momentum gain per unit volume due to the spray, $A_0 = 0$ for laminar calculations, and $A_0 = 1.0$ when the turbulence is activated.
Where the viscous stress tensor σ is given as:

$$\sigma = \mu\left[\nabla u + (\nabla u)^T\right] - \frac{2}{3}\mu\,(\nabla . \vec{u})\, I$$

The compressible form of the energy equation is given by:



Mesh at 25 CA BTDC



Mesh View at 125 CA BTDC

Figure 2. Mesh of computational grid domain at two different CA positions.

$$\frac{\partial \rho\, E}{\partial t} + \nabla(\rho u E) = -p\nabla.u + (1 - A_0)\sigma:\nabla.J + A_0\rho\varepsilon + \dot{Q}^c + \dot{Q}^s$$

Where E is the specific internal energy, ρ is density, σ is the stress tensor. $\dot{Q}^s$ and $\dot{Q}^c$ are source terms due to spray interactions and chemical heat, respectively.
The heat flux vector J is the sum of contributions due to heat conduction and enthalpy diffusion,

$$J = -K\,\nabla T - \rho\, D \sum_m H_m\, \nabla\left(\frac{\rho_m}{\rho}\right)$$

T is the fluid temperature, H_m is the specific enthalpy of the species m and K is the thermal conductivity.
The *3D* numerical simulation is performed using the RANS approach with the following assumptions:

(1)Non stationary regime
(2)Compressible fluid
(3)Radiation neglected
(4)Ideal gas

To simulate the airflow field, the turbulence modelling was achieved by the rapid distortion RNG (k-ε) model (Han and Reitz, 1995). The atomization process was computed using the model based on KH-RT models (Baumgarten 2006; Richards et al., 2008). For combustion, the multi-scale CTC model (Song et al., 1995; Richards et al., 2008) associated with Shell ignition model (Hamosfakidis and Reitz, 2003; Richards et al., 2008) is used. For NOx prediction, extended Zeldovich NOx model (Heywood, 1988; Ramos, 1989; Richards et al., 2008) is adopted. Finally the Hiroyasu soot model is used for soot prediction (Hiroyasu and Kadota, 1976; Richards et al., 2008).

Meshing method

The mesh was created such that the boundary was flagged and adjusted to have the real geometry (bore, stroke, etc). The AMR (Adaptive Mesh Refinement) technique is used in this work detailed in the reference Richards et al. (2008). It enhances the mesh resolution automatically based upon various variable gradients. In the current study, the AMR is activated for velocity and the temperature at 20°C CA BTDC. AMR is activated because it is difficult to determine a priori where embedding should be added. AMR algorithms add automatically the embedding where the flow field is most under-resolved or where the sub-grid is the largest. Consequently, the cell size and the total number of cells are not constant and change during the simulation process. For example, the total cell number at the start of simulation was 17271 cells, at 25 CA degrees and it becomes 23073 cells, at 125 CA degrees. The Figure 2 shows a view of the computation grid domain.

Boundary conditions

In order to solve the previous governing transport equations, boundaries and boundary conditions must be specified for each equation. Three types of wall boundaries are chosen. Only the first (piston head) is set as translate and other boundaries were set as stationary and smooth boundaries. The standard law of the wall is a logarithmic curve fit of a turbulent boundary layer. In practice, the law of the wall profile is used to determine the tangential components of the stress tensor at the wall.
The gas temperature and velocity at the wall are set as below:

Piston wall: moving wall;
Ugas=Upiston; Tpiston=533K;
Cylinder wall: stationary wall (not moving); Ugas=0; Tcylinder-wall= 433K, Cylinder head: stationary wall;
*U*gas=0; *T*cylinder-Thead= 523K
Initial conditions in the combustion chamber are:

355 K	gas temperature
1.2470e+05 Pa	gas pressure
62.02 m²/s²	initial turbulent kinetic energy
17.18 m²/s²	initial turbulent dissipation

RESULTS AND DISCUSSION

The used of the CONVERGE code to experiment data needs prior determination of the evolution of physical fuel properties (viscosity, surface tension, density, conductivity, evaporation pressure, latent heat of evaporation and specific heat) according to temperature until critical value. Some of these properties are recapitulated in the Figure 3.

The determination of combustion characteristics is based on the cylinder pressure variation with respect to crank angle. The Figures 4 to 7 shows cylinder pressure profiles at different loads (80% and 100%) for WAF and diesel fuel. Good agreement between the measured and

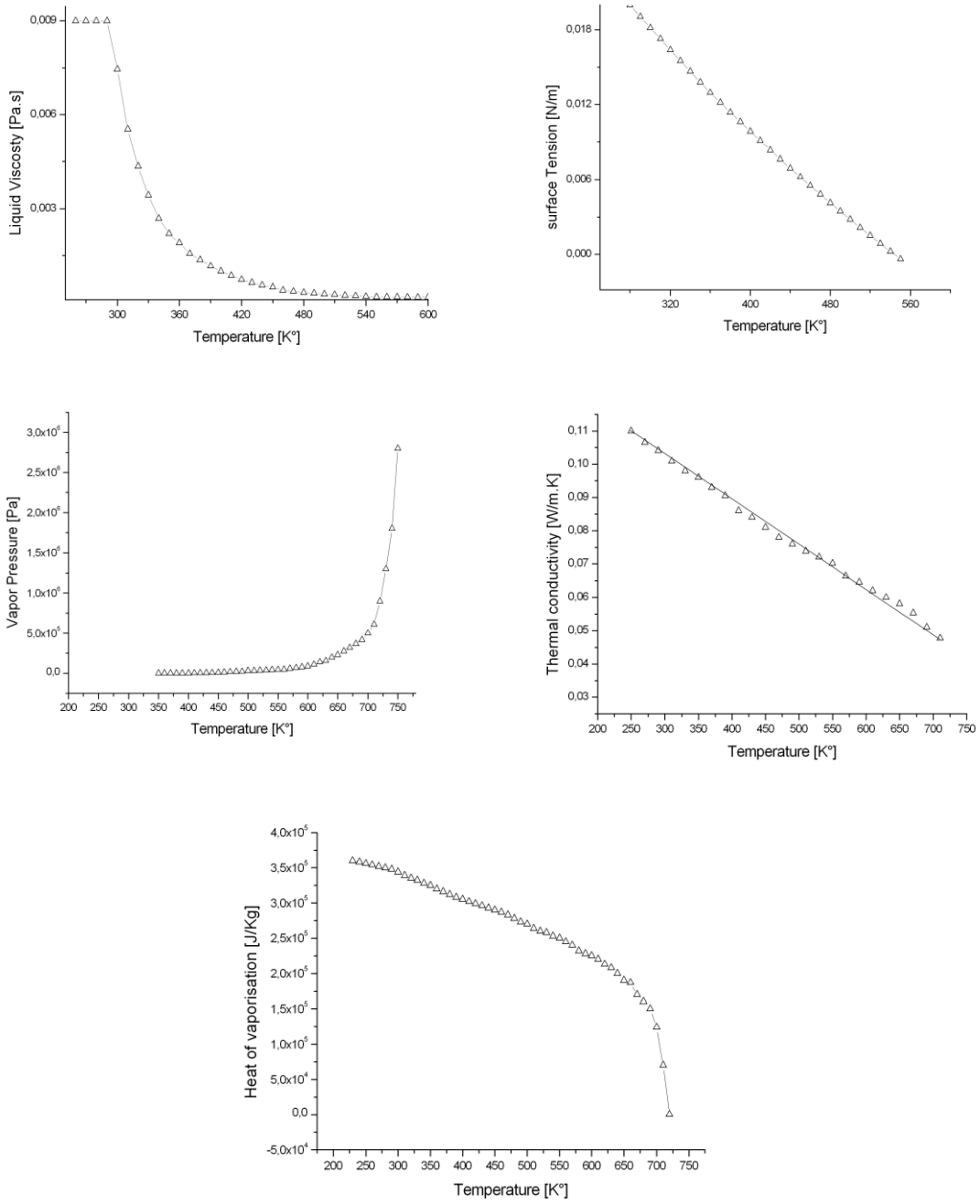


Figure 3. Thermo-physical properties of WAF fuel (unit KMS)

computed in-cylinder pressure for the studied fuels is observed. The average error does not exceed (3%) for all cases. The cylinder peak pressure is highest with diesel followed by animal fat as seen in Figures 4 to 7. These differences are respectively of 2 bars and 1.5 bars according to the corresponding load (80% and 100%). The maximum pressure for all fuels occurs within the range of 4-6 CA ATDC. The in-cylinder pressure calibration of the WAF fuel showed in Figures 4 and 5 indicate small delay in the prediction of the starting combustion time. This indicates that the ignition delay (which will be explained later) is longer with the animal fat as compared to neat diesel. The heat release rate for the tested fuels at both loads is given in Figures 8 and 9.

For all fuels it is observed a rapid premixed burning followed by diffusion combustion as is typical for a compression combustion engine. After the ignition delay period, the premixed fuel-air mixture burns rapidly releasing heat at a very rapid rate, after which non-premixed combustion regime takes place, where the

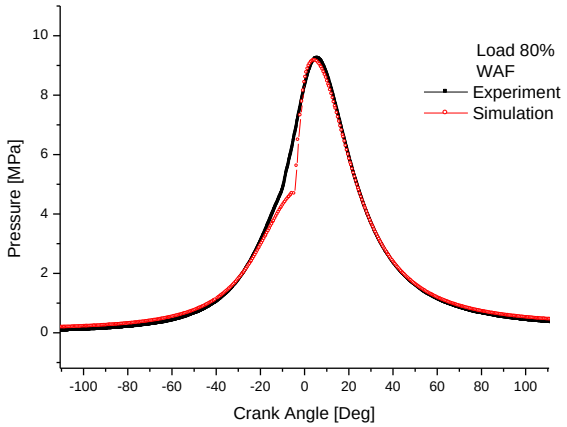


Figure 4. Comparison of predicted and measured engine cylinder pressure at load, 80% WAF fuel.

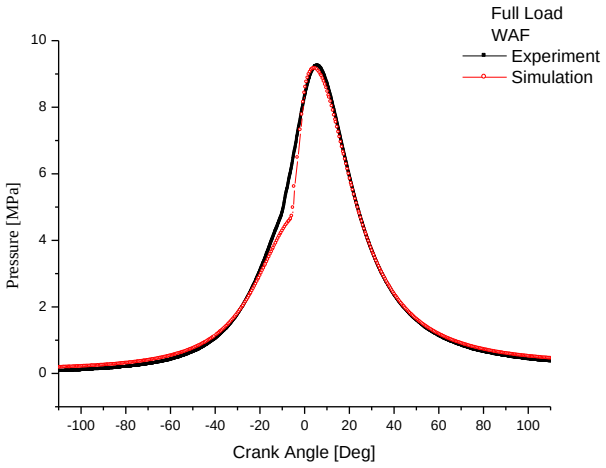


Figure 7. Comparison of predicted and measured engine cylinder pressure at full load. Neat Diesel.

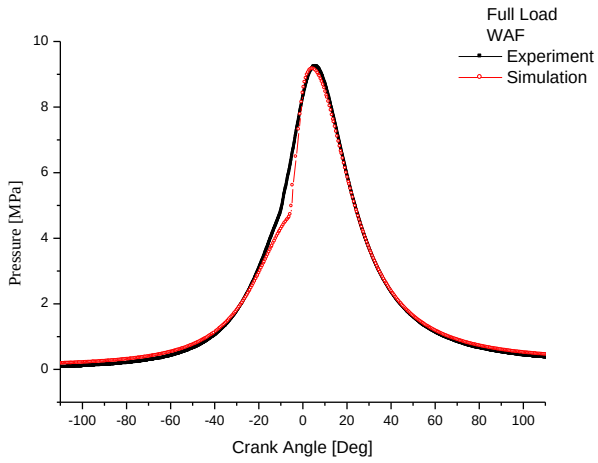


Figure 5. Comparison of predicted and measured engine cylinder pressure at full load. WAF fuel.

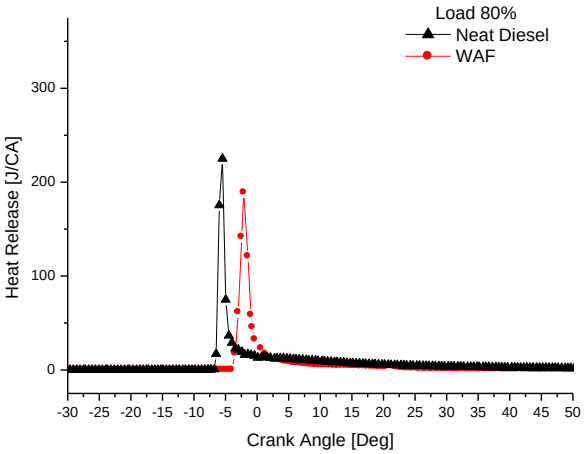


Figure 8. Heat released rate for Neat Diesel and WAF, at 80% load.

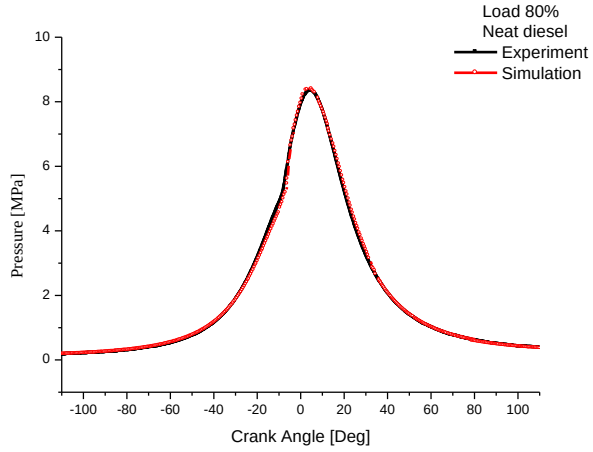


Figure 6. Comparison of predicted and measured engine cylinder pressure at load, 80%.Neat Diesel.

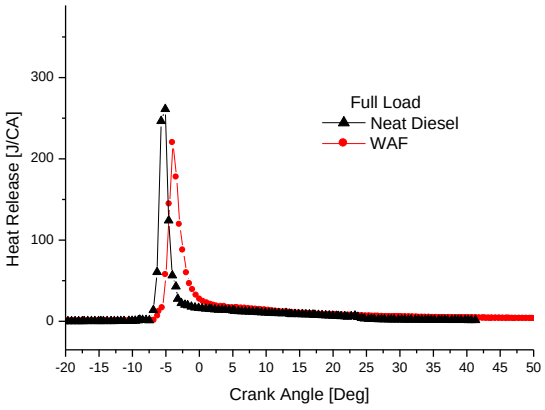


Figure 9. Heat released rate for Neat Diesel and WAF, at full load.

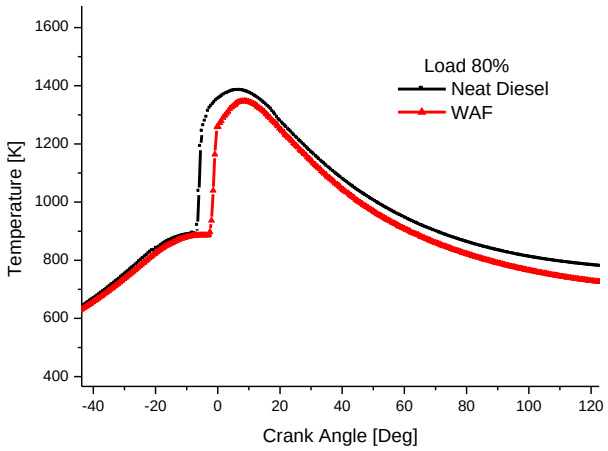


Figure 10. In- cylinder average temperature Diesel and WAF, at 80% load.

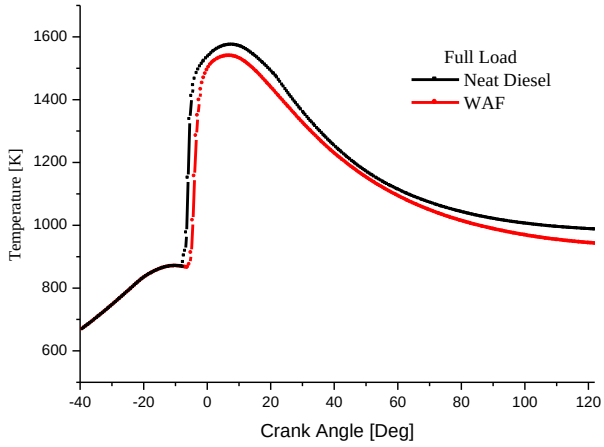


Figure 11. In- cylinder average temperature Diesel and WAF, at full load.

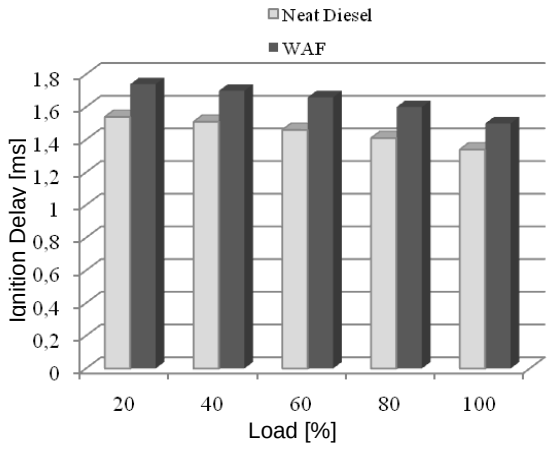


Figure 12. Predicted ignition delays in (ms) as a function of loads.

burning rate is controlled by the availability of fuel-air mixture. By analyzing these figures, it can be deduced easily that when engine is fuelled with WAF, the combustion starts later due to a longer ignition delay. The peak of heat release rate is higher for neat Diesel. This leads to more fuel being prepared for rapid combustion with neat diesel after the ignition delay. Figures 10 to 11 show the average in-cylinder temperature evolutions for the studied fuels. It is observed a higher level for neat diesel since starting combustion.

Figure 12 shows the ignition delay for neat diesel and WAF at all loads. The ignition delay period of all the fuels tested is calculated based on the dynamic injection timing. The duration between the points of the start of injection to the point of ignition is taken as the ignition delay. The point of fuel injection is found by using a piezoelectric pressure sensor that gives the online fuel injection pressure. The start of combustion is determined from the rate of pressure rise variation. This shows a sudden rise in the slope at the point of ignition due to the high premixed heat release rate. Ignition delay shown in Figure 12 is longer with neat animal fat as compared to neat diesel due to the low cetane number. With neat animal fat, due to high viscosity, poor atomization and vaporization, physical delay becomes longer as compared to neat diesel. The ignition delay is found as 6 deg CA crank angle with neat diesel and 8 deg CA with neat animal fat at normal temperature. These results are confirmed by diverse studies like that of Senthil (2006). Figure 13 shows that corresponding CA position of in-cylinder pressure peak the temperature contours at full load for the studied fuels. This is an indication of the flame stretch. One can observe the larger density of flame when the engine is fuelling with neat Diesel. This indicates also a larger amount of initial mixture prepared during the ignition delay period.

Emissions

Figures 14 and 15 show the total in-cylinder NOx variation with crank angle for the two loads 80% and 100%. The NOx emissions trends are predicted well when compared to the measured NOx results. NOx formation in diesel engine is due to the high combustion temperature and the availability of oxygen. It forms mainly in the high-temperature regions of the product gases. It is seen that the neat animal fat emits lower NOx levels as compared to standard diesel at both loads and most of the NOx is predicted to be produced after the peak cylinder pressure. The reduction in NOx emission with animal fat is mainly associated with the reduced premixed burning rate following the delay period. The lower air entrainment and fuel-air mixing rates with the animal fat result in low peak temperature and the resulting NO levels. This confirms earlier studies concerning various biofuels studied by diverse searchers (Yuan, 1991; Rajasekar et al., 2010; Encinar et al., 2011).

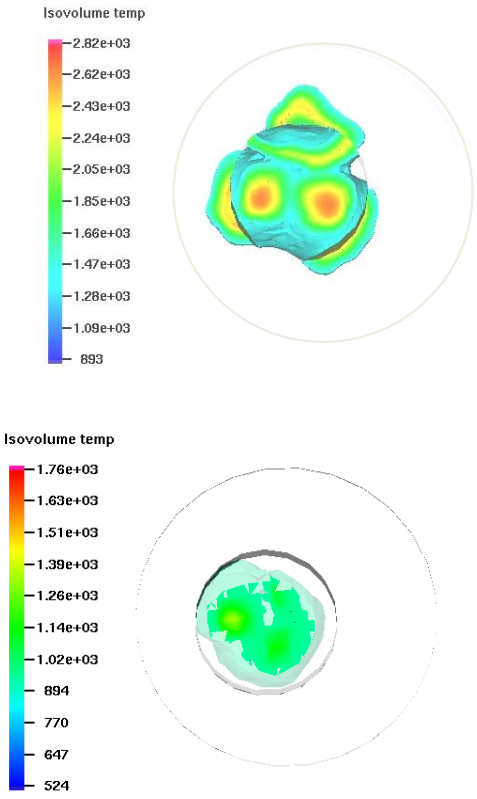


Figure 13. Temperature contours at pressure Peak, Full load case.

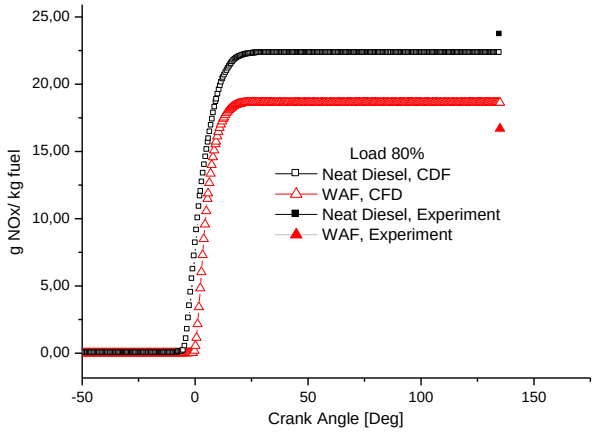


Figure 14. Predicted total in-cylinder and measured engine-out NOx data, at 80% load.

The variation of particulate emission for the tested fuels as a function of crank angle for the two loads 80% and 100% is presented in Figures 16 and 17. Again, the soot emission trends are predicted well when compared to the measured soot results. However, the soot emissions

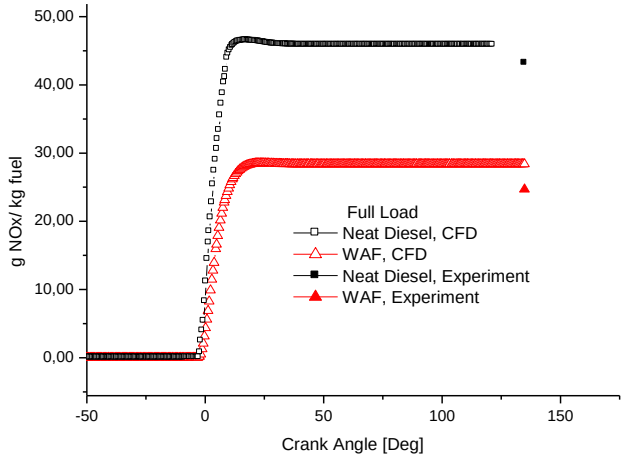


Figure 15. Predicted total in-cylinder and measured engine-out NOx data, at Full load.

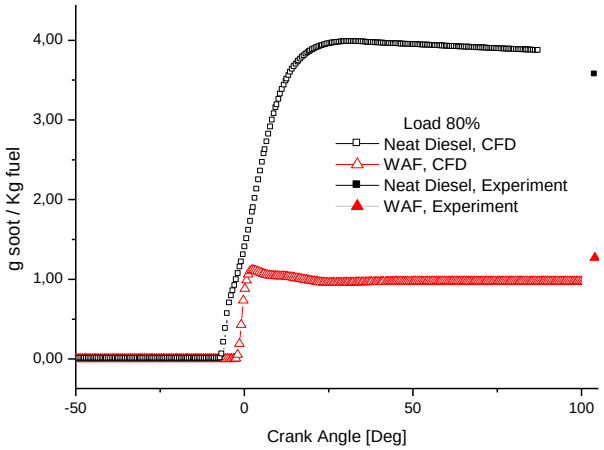


Figure 16. Predicted total in-cylinder and measured engine-out soot data, at 80% Load.

reach to their maximum at the end of the premixed combustion phase but decrease slowly to become lower at the end of non-premixed phase. It is seen that the particulate emissions of biodiesel are lower than that of diesel fuel at both loads. This reduction in smoke emission with neat fats is due to the presence of in-built oxygen with the fats.

The high oxygen content in the animal fats helps in complete oxidation of the fuel and reduces soot concentration in the exhaust gas. This confirms earlier studies concerning various biofuels studied by diverse searchers (Senthil, 2006; Armas et al., 2006). Hence biodiesel's fuel NOx and soot emissions can be effectively managed and eliminated by engine optimization like adjustment of injection timing and introduction to exhaust gas recirculation (Tsolakis et al.,

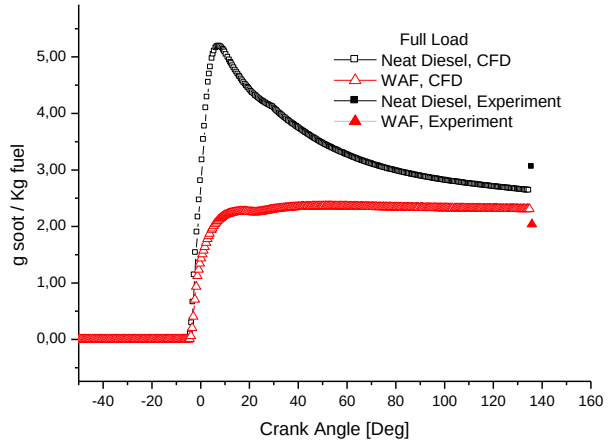
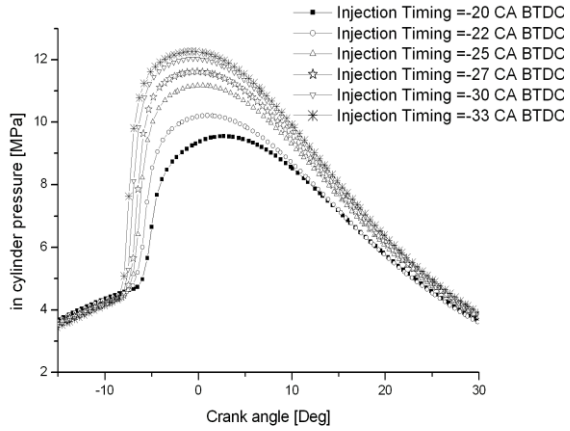


Figure 17. Predicted total in-cylinder and measured engine-out soot data, at Full load.



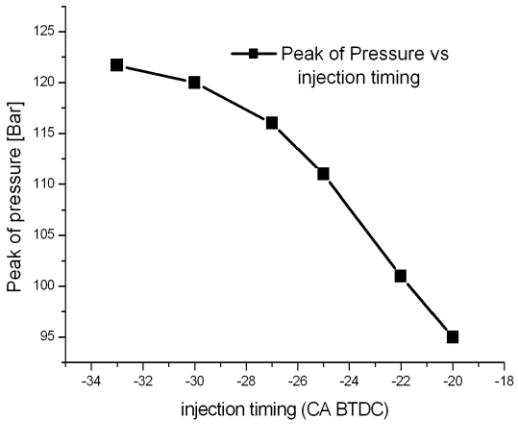


Figure 18. Influence of injection timing on in-cylinder pressure, (a) in-cylinder pressure vs. Injection timing, (b) maximum in-cylinder pressure vs. injection timing.

2007; Pradeep and Sharma, 2007; Fujia et al., 2009; Soltic et al., 2009).

The influence of injection timing of WAF fuel mode on in-cylinder pressure is studied. The Figure 18 shows that after 30 CA BTDC, the in-cylinder pressure peak increases very slowly and it can be considered as remaining constant while we compare the raise rate between 20 to 30 CA BTDC. This led us to think that 30 CA BTDC is a better value of injection timing leading to better mechanical performances. Also, it can be seen that the in-cylinder peak pressure is advanced with increasing the injection timing. Hence at 30 CA BTDC, the peak pressure appears before TDC. More numerical investigations must be achieved in several operating engine conditions to get some complete conclusions. This constitutes our next work. Also, further study is required for the long-term durability of the engine.

Conclusion

The aim of this study is to investigate the suitability of animal fats biodiesel as an alternative to diesel fuel. Some properties of WAF show that it is not possible to fuel diesel engines with this crude oil due to problems generated by its high viscosity and low volatility. In order to decrease the oil viscosity, transesterification technique is carried out under optimum reaction condition (Sary et al., 2010).

Analysis of basic properties of biodiesel shows that transesterification process is successfully employed to make the viscosity and other characteristics comparable to those of diesel fuel. Computer simulations were then used to better understand the controlling factors in NOx and soot formation. In-cylinder numerical simulation was successfully performed with the CONVERGE code. Fuel viscosity characteristics were modified to better account for fuel effects in the computer simulation. The main obtained results are summarized as follows:

(1)A good agreement between the predicted and experimental values ensures the accuracy of the numerical predictions collected with the present work.
(2)Ignition delay is higher with animal fat as compared to diesel at all power outputs.
(3)Neat animal fat results in increased exhaust temperature as compared to neat diesel.
(4)The highest concentrations of soot were observed with the neat diesel. This may be due to the duration of combustion, thus, increasing the soot emissions.
(5)NOx pollutants are simultaneously reduced by using the WAF fuel. This is an important result in spite of the well know antagonism between these two pollutants. This confirms earlier studies concerning bio-fuel of animals studied by diverse searchers (Senthil et al., 2005a; Kerihuel et al., 2005b; Sary et al., 2010; Sun et al., 2010;

Guru et al., 2011).
(6)With advancing the injection timing to 30 CA BTDC for WAF, in-cylinder pressure and brake thermal efficiency improved moderately.
Finally, the results reported in this paper illustrates that the numerical simulation can be one of the most powerful and beneficial tools for the internal combustion engine design, optimization and performance analysis.

ACKNOWLEDGEMENTS

The authors wish to express their deep appreciation to the Convergent Science Inc., Middleton USA, for the remarkable cooperation.

NOMENCLATURE

α Diffusion coefficient

F^S Rate momentum gain per unit volume due to the spray

p Pressure

g Specific body force

I Specific internal energy

$\dot{Q}^s$ Spray source term

$\dot{Q}^c$ Chemical source term

J Heat flux vector

T Temperature

k Turbulent kinetic energy

ε Turbulent dissipation rate

σ Viscous stress tensor

ρ Density

ρ_m Density of chemical species m

ρ_m^s Mass density source term for species m due to Spray

ρ_m^c Mass density source term for species m due to chemistry

t Time

u, v, w Gas velocity composents

Notations

AMR: Adaptive Mesh Refinement.
ATDC: After TDC.
AVL: Automatic Vehicles Localisation
BTDC: Before TDC.
CA: Crank Angle.
CFD: Computational Fluid Dynamic.
CI: Compression Ignition.
CTC: Characteristic Time Combustion.
DI: Direct Injection
RANS: Reynolds-averaged Navier Stokes.
RNG: Re-Normalization Group.
KH-RT: Kelvin-Helmholtz/Rayleigh-Taylor
TDC: Top Dead Center
WAF: Wastes Animal Fat

REFERENCES

Araya K (1987). Diesel engine performance with sunflower oil and fish oil, J Senshu University Hokkaido (Nat Sci), 20:137-54.
Armas O, Hernández JJ, Cárdenas MD (2006). Reduction of diesel smoke opacity from vegetable oil methyl esters during transient operation, Fuel 85:2427–2438.
Barsic NJ, Humke AL (1981). Performance and Emission Characteristics of a Naturally Aspirated Diesel Engine With Vegetable Oils, Society of Automotive Engineers Paper No. 810262.
Boyd MW, Doolan CJ, Kestell CD (2007). Autoignition and Combustion Comparison of Tallow Biodiesel and Pump Diesel, Proceedings of the Australian Combustion Symposium December 9-11, University of Sydney.
Baumgarten C (2006). Mixture Formation in Internal Combustion Engines, Springer-Verlag Berlin Heidelberg, 2006, New York.
Carsten B (2006). Mixture Formation in Internal Combustion Engines, Springer-Verlag Berlin Heidelberg.
Choi CY, Reitz RD (1999). A numerical analysis of the emissions characteristics of bio-diesel blended fuels, Trans ASME, J. Eng. Gas Turbines Power, 121:31-7.
Czerwinski J (1994). Performance of HD-DI diesel engine with addition of ethanol and rapeseed oil, Trans. Soc. Automot . Eng. 940545.
Demirbas A (2009). Progress and recent trends in biodiesel fuels, Energy Conversion and Management, 50:14-34.
Encinar JM, Sánchez N, Martínez G, García L (2011). Study of biodiesel production from animal fats with high free fatty acid content, Bioresource Technology, 102:10907-10914.
Fujia W, Jianxin W, Wenmiao C, Shijin S (2009). A study on emission performance of a diesel engine fueled with five typical methyl ester biodiesels, Atmospheric Environment 43: pp.1481-1485.
Guru Metin, Koca Atilla, Can Ozer, Cınar Can, Sahin Fatih (2010). Biodiesel production from waste chicken fat based sources and evaluation with Mg based additive in a diesel engine, Renew Energy, 35: 637- 43.
Gumus M (2010). A comprehensive experimental investigation of combustion and heat release characteristics of a biodiesel (hazelnut kernel oil methyl ester) fueled direct injection compression ignition engine, Fuel 89:2802–2814.
Humke AL, Barsic NJ (1981). Performance and emission characteristics of a naturally aspirated diesel engine with vegetable oils (Part-2), Transactions of Society of Automotive Engineers, 810955.
Hulya C (2002). Commercial fish oil. Cilt: Trakya Universities Bilimsel, 3:1-6.
Han Z, Reitz RD (1995). Turbulence Modeling of Internal Combustion Engines Using RNG-(k.ε) Models, Combust. Sci. Tech. P. 106.
Hamosfakidis V, Reitz RD (2003). Optimization of hydrocarbon fuel ignition model for two single component surrogates of diesel fuel, Combustion and flame 132:433-450.
Heywood JB (1988). Internal Combustion Engine Fundamentals, McGraw Hill, Inc.
Hiroyasu H, Kadota T (1976). Models for Combustion and Formation of Nitric Oxide and Soot in DI Diesel Engines, SAE Paper No. 760129.
Kerihuel A, Senthil KM, Bellettre J, Tazerout M (2005a). Use of animal fats as CI engine fuel by making stable emulsions with water and methanol, Fuel, 84:1713-1716.
Kerihuel A, Senthil KM, Bellettre J, Tazerout M (2005b). Investigations on a CI engine using animal fat and its emulsions with water and methanol as fuel, SAE Paper No. 05011729.
Larsen C, Oey F, Levendis YA (1996). An optimization study on the

control of NOx and particulate emissions from diesel engines, Society of automotive engineers, Paper No. 960473.
Ladommatos N, Abdelhalim S, Zhao H (1998). Control of oxides of nitrogen from diesel engines using diluents while minimizing the impact on particulate pollutants, Appl Thermal Eng, 18(1): 963-80.
Muniyappa PR, Brammer SC, Noureddini H (1996). Improved conversion of plant oils and animal fats into biodiesel and co-product, Bioresour. Technol. 56(1):19-24.
Ndayishimiye P, Naima K, Liazid A, Tazerout A (2011). Performance and Emission Characteristics of a DI Compression Ignition Engine Operated on PODL Bio-fuel, Journal of Renewable Energy Technology, 2: 324-344.
Pradeep V, Sharma RP (2007). Use of HOT EGR for NOx control in a compression ignition engine fuelled with bio-diesel from Jatropha oil, Renewable Energy, 32:1136-1154,
Rajendra PB, Tamilporai P (2010). Shabir Mohd.F, Analysis of combustion, performance and emission characteristics of low heat rejection engine using biodiesel, International Journal of Thermal Sciences 49: 2483-2490.
Rakopoulos CD, Antonopoulos KA, Rakopoulos DC (2007). Development and application of multi-zone model for combustion and pollutants formation in direct injection diesel engine running with vegetable oil or its bio-diesel, Energy Conversion and Management, 48:1881-1901.
Rahimi H, Ghobadian B, Yusaf T, Najafi G, Khatamifar M (2009), Diesterol: An environment-friendly IC engine fuel, Renewable Energy, 34: 335-342.
Rakopoulos C, Antonopoulos KA, Rakopoulos D, Hountalas D, Glakoumis E, (2006), Comparative performance and emissions study of a direct injection Diesel engine using blends of Diesel fuel with vegetable oils or bio-diesels of various origins, Energy Conversion and Management, 47:3272–3287.
Richards KJ, Senecal PK, Pomraning E (2008). CONVERGETM (Version 1.3), Convergent Science, Inc., Middleton, WI.
Ramos JI (1989). Internal Combustion Engine Modeling, Hemisphere Publishing Co.
Rajasekar E, Murugesan A, Subramanian R, Nedunchezhian N (2010). Review of NOx reduction technologies in CI engines fuelled with oxygenated biomass fuels, Renewable and Sustainable Energy Reviews, 14:2113-2121.
Summers JC, Houtte SV, Psaras D (1996). Simultaneous control of particulate and NOx emissions from diesel engines, Appl Catal B: Environ,10(1–3):139-156.
Senthil KM, Ramesh A, Nagalingam B (2003). Use of hydrogen to enhance the performance of a vegetable oil fuelled compression ignition engine, Int J Hydrogen Energy, 28(10):1143-54.
Senthil KM, Ramesh A, Nagalingam B (2003). An experimental comparison of methods to use methanol and Jatropha oil in a compression ignition engine, Biomass Bioenergy, 25(3):309-318.
Senthil KM, Kerihuel A, Bellettre J, Tazerout M (2005). Experimental investigations on the use of preheated animal fat as fuel in a compression ignition engine, Renewable Energy, 30:1443-1456.
Sun J, Caton JA, Jacobs TJ (2010). Oxides of nitrogen emissions from biodiesel-fuelled diesel engines, Prog. Energy Combust. Sci. 36: 677-95.
Senthil KM, Kerihuel A, Bellettre J, Tazerout M (2005). Experimental investigations on the use of preheated animal fat as fuel in a compression ignition engine. Renew. Energy, 30:1443-56.
Steigers JA (2002). Demonstrating the use of fish oil as fuel in a large stationary diesel engine. UniSea fish oil demonstration project, pp. 1-5.
Senthil KM, Ramesh A, Nagalingam B (2001). Complete Vegetable Oil Fuelled Compression Ignition Engine, Society of Automotive Engineers Paper No. 2001-28-0067.
Senthil KM, Kerihuel A, Bellettre J, Tazerout M (2005). Investigations on the Use of Preheated Animal Fat as Fuel in a Diesel Engine, Renewable Energy, 30(9):1443-1456.
Senthil KM, Ramesh A, Nagalingam B (2000). Performance Studies on a CI Engine Using Methyl Ester of Jatropha oil as Fuel, Proceedings of XVI National Conference on I. C. Engines and Combustion, Calcutta, pp. 89-94.
Sary A, Basa I-A, Paraschiv M, Tazerout M (2009). Characterisation and Optimization of Biodiesel's Production from Waste Cooking Oil, 4th International conference on energy and environment, CIEM09, 12-14 Novembre, Bucharest, Romania.
Srivastava PK, Verma M (2008). Methyl ester of karanja oil as an alternative renewable source energy, Fuel, 87:1673-1677.
Sary A, Paraschiv M, Tazerout M (2010). Biodiesel elaboration from municipal fat wastes. Environment Engineering and Management Journal, 9(10): 1347-1350.
Sahoo PK, Das LM (2009). Combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine,; Fuel, 88:994-999.
Song CK, Zhiyu H, Rolf DR (1995). The development and application of a diesel ignition and combustion model for multidimensional engine simulation, SAE Paper 950278.
Soltic P, Edenhauser D, Thurnheer T, Schreiber D, Sankowski A (2009). Experimental investigation of mineral diesel fuel, GTL fuel, RME and neat soybean and rapeseed oil combustion in a heavy duty on-road engine with exhaust gas after treatment, Fuel 88:1-8.
Tashtoush GM, Al-Widyan MI, Al-Jarrah MM (2004). Experimental study on evaluation and optimization of conversion of waste animal fat into biodiesel. Energy Convers Manage, 45: 2697-711.
Tashtoush GH, Al-Widyan M, Albatayneh A (2007). Factorial analysis of diesel engine performance using different types of biofuels, J. Environ. Manage. 84:401-411.
Tsolakis A, Megaritis A, Wyszynski ML, Theinnoi K (2007). Engine performance and emissions of a diesel engine operating on diesel-RME (rapeseed methyl ester) blends with EGR (exhaust gas recirculation), Energy 32:.2072-2080.
Vellguth G (1983). Performance of Vegetable Oils and Their Monoesters as Fuel for Diesel Engines, Society of Automotive Engineers Paper No. 831358.
Xing-cai Lu, Jian-guang Y, Wu-gao Z, Zhen H (2004). Effect of cetane number improver on heat release rate and emissions of high speed diesel engine fueled with ethanol–diesel blend fuel. Fuel, 83(14–15):2013-20.
Yuan W (2005). Computational modeling of NOx emissions from biodiesel combustion based on accurate fuel properties. Ph.D. dissertation, University of Illinois at Urbana-Champaign, Department of Agricultural and Biological Engineering.
Yuan W (1991). Computational Modeling of NOx Emissions from Biodiesel Combustion Based on Accurate Fuel Properties, Fuel. 84:943-950.