

THE EFFECT OF WASTE COOKING OIL AND SUNFLOWER OIL BIOFUELS ON PERFORMANCE AND SOOT EMISSION OF A DIESEL ENGINE

Bogdan Cornel BENEĂ

Transilvania University of Brasov, b.benea@unitbv.ro

Abstract — Continued growth in the number of a motor vehicle has steadily increased the fuel consumption in recent years. Reserves of fossil used to produce fuels for internal combustion engines are limited and it is estimated that in the next 20 years to run out. Following the Kyoto Protocol are trying to replace polluting fossil fuels with fuels alternation, less polluting. The paper presents theoretical and experimental research on the influence of biofuels on power and soot emission of the engine fueled with biofuels. The results obtained from the simulation were compared with experimental ones.

Keywords—Biofuels, emission reduction, renewable energy, soot

I. INTRODUCTION

After world oil crisis it began the research to develop alternative fuels, trying to use oil to power diesel engine. The pollution produced by vehicles became a problem, due to the global warming.

After Kyoto meeting it has begun work on developing cleaner fuels produced from renewable resources. The most simple and inexpensive process was getting them from biomass. Biomass is the biodegradable fraction of products, waste and residues from agriculture.

It is important for biomass production do not affect the environment. The biomass obtained from agricultural and forestry has a minimal impact on the environment, while environmental benefits of energy crops are limited.

According to EC directive 2009/28/EC until 2020 should be used 10% biofuels blended with diesel.

The physical and chemical properties of biofuels depend on raw materials used for their production have a major impact on performance and engine emissions.

The particles emitted by the diesel engine can cause aggravation of cardiovascular and pulmonary diseases, can affect the central nervous system and can lead to cancer.

In this context, additive the fuel with biofuels is a

policy line for the future.

II. TEST DESCRIPTION

The tests were performed on a Renault diesel engine using neat diesel fuel and blends of biodiesel produced from sunflower and waste cooking oil. The blends were made in two different volume of biodiesel blended with diesel fuel. The volume ratios of biodiesel fuel were 6% for B6 and 10% for B10. Fuels properties are presented in TABLE I.

TABLE I
TESTED FUELS' PROPERTIES

Fuel	D	B6SF	B10SF	B6W	B10W
Density at 20°C (kg/m ³)	840.2	841.9	843.1	842.7	844.4
Viscosity at 20°C (mm ² /s)	5.34	5.27	5.10	5.41	5.98
Cetane number	51.1	54.5	57.6	54.1	58.9
Flash point (°C)	67	67.2	67.8	70.8	71.2
Caloric value (MJ/kg)	43.16	42.58	42.19	42.52	42.14

D – diesel fuel

B6W – 6% blend of biofuel from waste cooking oil with diesel fuel

B10W – 10% blend of biofuel from waste cooking oil with diesel fuel

B6SF – 6% blend of biofuel from sunflower oil with diesel fuel

B10SF – 10% blend of biofuel from sunflower oil with diesel fuel

The engine is equipped with an electronic commanded

common-rail injection system. The characteristics of the engine are presented in TABLE II.

TABLE II
TEST ENGINE SPECIFICATIONS

Engine type	Renault K9K four stroke
Number of cylinders	4
Bore (mm)	76
Stroke (mm)	80.5
Total displacement (cm ³)	1451
Compression ratio	15.3
Fueling	Common-rail direct injection

The engine test bed was equipped with a Dynas₃ LI250 dynamometer, which is designed for operated within a range of 0-8000 (rotations per minute). It can measure engine power up to 250 (kW) with an accuracy of ±2%.

The pressure in the engine's cylinder was measured using a Kistler 6005 piezoelectric pressure transducer mounted in the first engine cylinder. This pressure transducer can measure dynamic pressure up to 1000 (bar) and has an accuracy of ±0.8%.

The smoke meter AVL 415S was used to determinate the quantity of soot emitted by the engine. It can measure up to 32000 (mg/m³), with an accuracy of 0.01 (mg/m³).

The engine was tested for five different engine speeds (1700, 2200, 2700, 3200 and 3700 (rpm)). All the tests were made on full throttle positions.

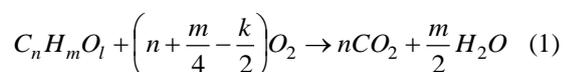
III. SIMULATION MODEL

The AVL Fire simulation program was used for numerical testing of the test engine.

The formation of particulates involves a large number of different chemical and physical processes, like the formation and growth of large aromatic hydrocarbons, their subsequent conversion to particles, the coagulation of primary particles, and the growth of solid soot particles due to the accumulation of gaseous components [1].

The soot particle formation process is characterized by a gaseous-solid conversion, whereby the solid phase does not exhibit a uniform chemical and physical topology.

Under ideal conditions, the combustion of hydrocarbon fuels forms CO₂ and H₂O. The necessary amount of oxygen is the stoichiometric oxygen requirement O_{2,st} calculated from the following equation:



The real amount of oxygen, available for the combustion, is expressed by the air access ratio

$\lambda = O_2/O_{2,st}$ or by the equivalence ratio Φ :

$$\Phi = \frac{1}{\lambda} = \frac{O_{2,st}}{O_2} \quad (2)$$

For conditions at equivalence ratios $\Phi > 1$, there is a big potential for soot formation.

The most important parameters during the soot formation are the local air/fuel ratio (C/H ratio and C/O-ratio), temperature, pressure and residence time.

Theoretically soot is not produced if there is one oxygen atom available for each carbon atom. The combustion process forms CO and H₂. The theoretical C/O-ratio is one. The stoichiometric combustion produces CO₂ and H₂O. The stoichiometric C/O-ratio has the form:

$$\left(\frac{C}{O} \right)_{st} = \frac{n}{2n + \frac{m}{2}} \quad (3)$$

The soot formation starts at a critical C/O-ratio:

$$\left(\frac{C}{O} \right)_{st} < \left(\frac{C}{O} \right)_{cr} < 1 \quad (4)$$

The critical C/O-ratio is dependent on the temperature. Up to 1500 (K) it drops rapidly and above 1500 (K) it increases nearly linearly with the temperature [2], [3].

The temperature is one of the main parameters influencing the soot formation processes [4]. An increased soot formation rate was observed using an increased initial temperature of the air/fuel mixture [5], [6].

Up to 1600 (K) the soot concentration is increasing through a progressive surface growth rate, and above 1650 (K) the amount of soot becomes reduced by increased oxidation [7].

Surface growth through the soot formation process is done by hydrocarbon and acetylene addition. With increasing pressure, the surface growth rate is increased, whereas the acetylene concentration decreases ([7]-[9]). At high pressure (10 (bar)) the soot formation can become independent of the fuel composition [10].

The residence time affects the mechanism which limits the soot formation process [11]. The soot concentration is turbulence controlled in turbulent diffusion flames. The turbulent mixing rate is larger than the chemical reaction rate. In this case, the soot concentration increases with the residence time. Soot formation is controlled by the chemistry in laminar diffusion flames. The soot concentration is a function of the local species concentration and temperature, and independent of the residence time.

The soot formation rate is defined as:

$$S_{\Phi_s} = S_n + S_g + S_{O_2} \quad (5)$$

S_{Φ_s} – source term of the conservation equation, S_n – nucleation source, S_g – surface growth source, S_{O_2} – oxidation source.

The processes of particle formation and surface growth are taken to be related functions of the local fuel and soot nuclei concentration, and the predominating flame temperature governing the Arrhenius rate coefficient of the particle mass addition term ([12]-[15]).

Nucleation source:

$$S_n = C_n e^{\left(-\frac{(f-f_n)^2}{\sigma_n^2}\right)} \quad (6)$$

with:

C_n – maximum nucleation rate (1/m³s)

f – mixture fraction (of fuel)

f_n – a mixture of the fraction for maximum nucleation rate

σ_n – predefined f_n variance.

Surface growth source:

$$S_g = A \cdot F(f, \phi_s) \cdot p^{0.5} \cdot e^{\left(-\frac{E_a}{RT}\right)} \quad (7)$$

with:

A – pre-exponential factor

E_a – activation energy

R – universal gas constant (J/molK)

p – pressure (bar)

T – temperature (K)

$F(f, \phi_s)$ – specific surface growth

f – mixture fraction

ϕ_s – mass fraction of soot

The particle oxidation of the soot involves O₂ and OH radicals. Due to the domination of the reaction with oxygen, the oxidation through OH can be neglected.

The soot oxidation source term can be described according to Magnussen and Hjertager [16] as:

$$S_{O_2} = -F(\phi_s, p_{O_2}, \tau) \quad (8)$$

with:

ϕ_s – mass fraction of soot

p_{O_2} – the partial pressure of oxygen

τ – the integral turbulent time scale

IV. RESULTS

Fig. 1 shows the numerically and experimentally obtained results of engine power for all test regimes.

The results presented in Fig. 1 indicates that the highest experimentally obtained power was observed when using B6 from sunflower. Simulation results indicate the same trend as experimentally obtained results.

The lowest engine power was obtained numerically and experimentally for B10 from sunflower.

The lower calorific value of biodiesel blends influences the reduction of engine power on some tests. Higher biodiesel density raises the mass of injected fuel and compensates for the lower calorific value.

The results of engine power show good agreement between the numerical and experimental results. The numerical results are higher than the experimental results. The maximum difference between the numerical and the experimental results are about 5%.

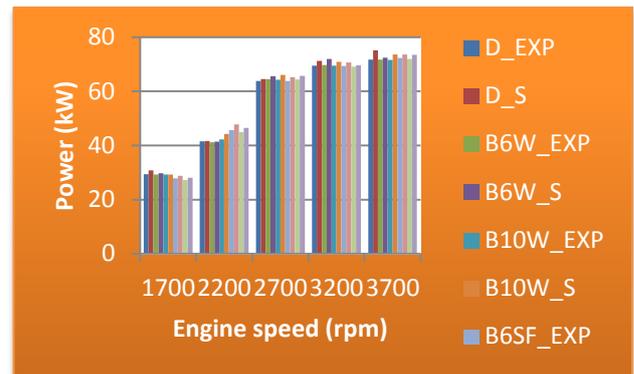


Fig. 1. Numerical and experimental engine power

D_EXP – experimental test using diesel fuel

B6W_EXP – experimental test using B6 from waste cooking oil

B10W_EXP – experimental test using B10 from waste cooking oil

B6SF_EXP – experimental test using B6 from sunflower oil

B10SF_EXP – experimental test using B10 from sunflower oil

D_S – simulating using diesel fuel

B6W_S – simulating using with B6 from waste cooking oil

B10W_S – simulating using with B10 from waste cooking oil

B6SF_S – simulating using with B6 from sunflower oil

B10SF_S – simulating using with B10 from sunflower oil

Fig. 2 shows the numerically and experimentally result of maximum pressure from the cylinder for an engine speed of 3700 (rpm).

The maximum pressure was obtained experimentally for diesel fuel, and numerically for B6 form sunflower.

Fig. 3 shows the numerically and experimentally result

of soot emission of the engine.

The maximum emission of soot was obtained when the engine was fueled with neat diesel fuel at a low speed (1700 (rpm)).

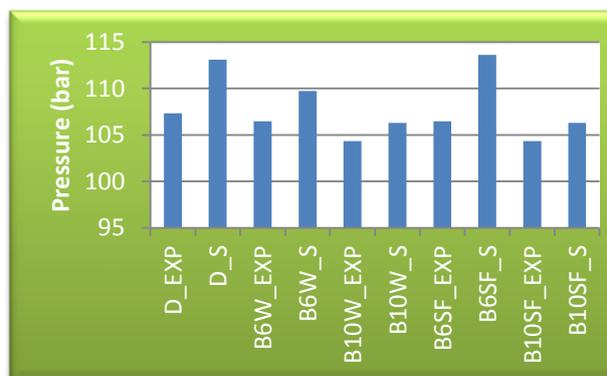


Fig. 2 Maximum pressure from cylinder

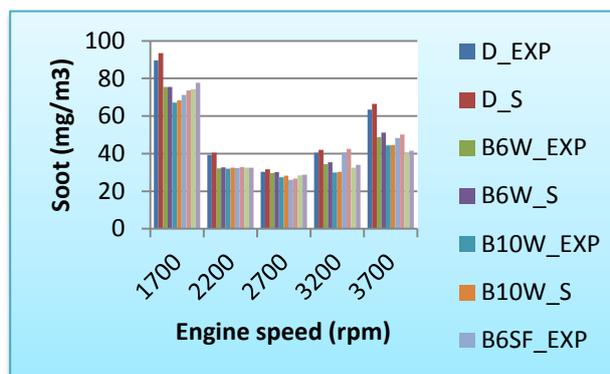


Fig. 3 Numerical and experimental soot emission

The lowest emission was obtained for a 2700 (rpm) engine speed, when the engine was fueled with B6 form sunflower oil.

In both cases (numerically and experimentally) the soot emission are lower when the engine is fueled with blended of biodiesel and diesel. The emission of soot decreases for biofuels due the higher contents of oxygen that allows a complete combustion and a better oxidation of soot. The absence of polyaromatics from the structure of biodiesel reduces also the amount of soot.

V. CONCLUSIONS

The present paper studied the influence of mineral diesel fuel and four blends of diesel and biofuels on diesel engine performance and soot emissions. Testing was performed experimentally on a Renault Diesel engine and numerically using the AVL Boost simulation program.

The following conclusion can be made:

- 1) *The lower calorific value of blends influences the engine power.*

- 2) *The Higher density of biodiesel blends increases the mass of injected fuel.*
- 3) *Higher oxygen contents contribute to a better oxidation process which reduces the amount of engine soot.*
- 4) *In general, the experimental and numerical results agree well. The good agreement indicates that the proposed model parameters are able to accurately determine the parameter values if the fuel's properties are known.*
- 5) *The usage of models enables to run a numerical simulation without experimental tests.*

REFERENCES

- [1] H. Bockhorn, F. Fetting, A Heddrich and G. Wannemacher, "Investigation of the Surface Growth of Soot in Flat Low-Pressure Hydrocarbon Oxygen Flames." Twentieth International Symposium on Combustion. Pittsburgh: The Combustion Institute, 1985: 879.
- [2] D. Böhm, H. Gg. Wagner, D.Hesse, H.Jander, B.Lüers, J. Pietscher and M.Weiss, "The Influence of Pressure and Temperature on Soot Formation in Premixed Flames." 21th International Symposium on Combustion. Pittsburgh: The Combustion Institute, 1988: 403
- [3] E. Glassmann, "Combustion". London: Academic Press, 1977
- [4] J.H. Kent and D.R. Honnery, "Soot Mass Growth in Laminar Diffusion Flames - Parametric Modeling." Soot Formation in Combustion. Henning Bockhorn (Ed.). Springer, 1994.
- [5] Ö.L. Gülder, "Soot Formation in Laminar Diffusion Flames at Elevated Temperatures". The Combustion Institute Publishing Co. Inc., 1992.
- [6] B.Bartenbach and W.Leuckel, "Untersuchungen zur Rußbildung aus gasförmigen Kohlenwasserstoffen unter den Bedingungen technischer Diffusionsflammen." Deutscher Flammentag. Germany: Tagungsband, 1995.
- [7] H. Böhm, M. Böniq, Ch. Feldermann, H. Jander, G. Rudolph and H. Gg. Wagner, "Pressure Dependence of Formation of Soot and PAH in Premixed Flames." Soot Formation in Combustion. Springer, 1994.
- [8] M.Houben, "Rußbildung im Dieselmotor bei lokaler Kraftstoff/Luft-Mischung." Dissertation TH Aachen, 1990.
- [9] Wiese und Homann. Oberflächenwachstum und Koagulation von Rußpartikeln in Niederdruckflammen. VDI-Berichte 1193, 1995.
- [10] C. Feldermann, "Untersuchungen des Massenwachstums und der Koagulation von Rußteilchen in vorgem. Flammen bei Drücken bis zu 10 bar", Diss. U of Göttingen, 1992.
- [11] J.H Kent and H.Gg. Wagner, "Who do diffusion flames emit smoke", Combustion Science and Technology 41 (1984): 245-269.
- [12] H. Hiroyasu and K. Nishida, "Simplified Three-Dimensional Modeling of Mixture Formation and Combustion in a DI Diesel Engine." SAE 890269, 1989.
- [13] R. Tatschl, K. Pachler, H. Fuchs and W. Almer, "Multidimensional Simulation of Diesel Engine Combustion - Modeling and Experimental Verification." Proceedings of the Fifth Conference 'The Working Process of the Internal Combustion Engine'. Graz, Austria, 1995.
- [14] P.A. Tesner, T.D. Snegriova and V.G. Knorre, "Kinetics of Dispersed Carbon Formation." Combustion and Flame 17 (1971): 253-260.
- [15] AVL Fire – ICE Physics – Chemistry, Graz 2010
- [16] B.F. Magnussen and B.H. Hjertager, "On mathematical modeling of turbulent combustion with special emphasis on soot formation and combustion." Sixteenth International Symposium on Combustion. Pittsburgh: The Combustion Institute, 1977.