

Comparison of Performance and Combustion Characteristics of Diesel Fuel and Vegetable Oils in DI Diesel Engine

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ABSTRACT

GT-Power, an engine modeling software, is used to study the combustion characteristics of cottonseed, linseed and peanut oils in a heavy-duty direct-injection diesel engine. The fuel properties library in GT-Power is expanded to include cottonseed oil, linseed oil and peanut oil, using either theoretical methods or experimental measurements. The numerical model is calibrated with experimental data and good agreement is observed. The simulation results show that combustion characteristics and engine performances differ when vegetable oil is used instead of no. 2 diesel fuel. Raising the injection pressure significantly alters the combustion characteristics without improving the brake performances. However, higher injection pressure does reduce both NO_x emission and combustion noise.

INTRODUCTION

The interest in vegetable oil as energy source has been increased significantly [1] with the rapid depletion of fossil fuel and environmental issues associated with the combustion of fossil fuels. Vegetable oil is made of fatty acid molecule that contains carbon, hydrogen, oxygen atoms and no sulphur, nitrogen and polycyclic aromatic compounds. The physical-chemical properties are comparable with petroleum derived diesel fuel except for viscosity at low temperature [2, 3]. Vegetable oil is safer than diesel fuel in handling and storage due to its higher flash point. In addition, vegetable oil can be produced from locally available sources, thus reducing the dependence on external oil imports. This provides immunizations against fluctuations in global energy prices. So vegetable oil is frequently considered a renewable, clean alternative to replace diesel fuels in engines. However, neat vegetable oils could pose some problems in fuel flow and poor atomization, because of higher viscosity and lower volatility. Therefore, they can only be used in engines with appropriate modifications. This paper presents the

computational examination of the combustion process of both vegetable oils and diesel fuel in a heavy duty direct injection diesel engine. Numerical calculations are done by GT-Power, an engine modeling software developed by Gamma Technologies. The fuel property library is expanded to include the properties for cottonseed oil, linseed oil and peanut oil using either theoretical methods or experimental measurements reported in the literature.

CONSTRUCTION OF ENGINE MODEL

GT-Power, a software package developed by Gamma Technologies, is used for modeling an HSDI diesel engine. The software is based on one-dimensional gas dynamics and considers partly three-dimensional flow in the junctions. System-integrated templates are used in the construction of different parts of the engine under consideration. Modeling effort is significantly reduced in GT-Power since the user simply provides the geometric details of the parts and the software will construct the model. The applications of cottonseed oil, linseed oil and peanut oil are examined. Selected properties of the vegetable oils and diesel fuel are shown in Table 1.

Table 1. Properties of diesel and vegetable oils

Fuel Properties	Density (at 25°) [kg/m ³]	Kinematic Viscosity (at 40°) [mm ² /s]	Lower Heating Value [kJ/kg]
No. 2 Diesel	830.0	4.1	42350
Cottonseed oil	884.2	33.5	36800
Linseed oil	897.7	22.2	36860
Peanut oil	894.2	39.6	36995

FUEL LIBRARY CONSTRUCTION

The GT-Power program comes with its own model for diesel fuel, which is used as the baseline for comparisons compare with the three vegetable oils under consideration.

GT-Power requires fuel properties, as shown in Table 2, for both liquid and vapor phases. As there are physical limits preventing the measurements of properties, such as viscosity, density and heat of vaporization, over a wide range of temperatures, they are estimated from their fatty acid profile. The estimations are compared with published experimental data to assess the accuracy. The fatty acid compositions of three vegetable oils are tabulated in Table 3.

Table 2. Properties required for simulation

State	Properties
Liquid	Heat of Vaporization at 298K
	Density at 298K
	Enthalpy of Liquid
	Viscosity of Liquid
	Thermal Conductivity of Liquid
Vapor	Lower Heating Value
	Critical Temperature
	Critical Pressure
	Enthalpy of Vapor
	Viscosity of Vapor
	Thermal Conductivity of Vapor
	Number of Carbon Atoms in Each Molecule
	Number of Hydrogen Atoms in Each Molecule
	Number of Oxygen Atoms in Each Molecule

Table 3. Fatty acid composition of vegetable oils

	Cottonseed Oil	Linseed Oil	Peanut Oil
C12:0	0	0	0
C14:0	0	0	0
C16:0	28	5	11
C18:0	1	2	8
C18:1	13	20	48
C18:2	58	18	32
C18:3	0	55	1
C22:1	0	0	0

Critical Properties

The Ambroes' method [4-6], which has been proved to be more accurate than other methods is used in estimating the critical pressure and critical temperature.

$$T_c = T_b [1 + (1.242 + \Sigma \Delta T)^{-1}] \quad (1)$$

$$P_c = M (0.339 - \Sigma \Delta T)^{-2} \quad (2)$$

where T_b is the boiling point at 1 atm, M is the molecular weight and ΔT or ΔP are the contributions for various atoms or groups of atoms. The estimation results are shown in Table 4.

Viscosity

Viscosity at low temperature is estimated using the method by Orrick and Erbar [4], shown in equation (3). The correlation developed by Chung et al., as shown in

equation (4), [4] is used to estimate viscosity at high temperature.

$$\ln \left(\frac{\eta_\ell}{\rho_\ell M} \right) = A + \frac{B}{T} \quad (3)$$

$$\eta_\ell = 40.785 \frac{F_c (MT)^{1/2}}{V_c^{2/3} \Omega_v} \quad (4)$$

Table 4. Critical properties of vegetable oils.

Oil Type	T_c (K)	P_c (bar)	V_c (mL/mole)
Cottonseed oil	780.8	12.8	981.4
Linseed oil	790.2	12.9	1006.9
Peanut oil	778.7	12.5	1021.4

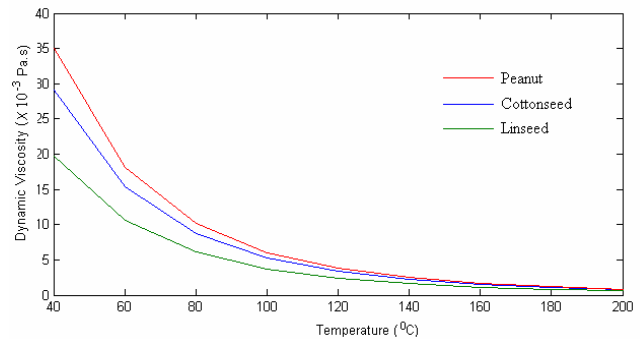


Figure 1. Comparison of estimated viscosities of vegetables oils

The estimated viscosities of cottonseed, linseed oil and peanut oil are shown in Figure 1. Peanut oil has a highest viscosity among the three kinds of vegetable oils. The comparison of the cottonseed oil viscosity with the experimental results [7] is shown in Figure 2 and the estimations from equations (3) and (4) match with experimental measurements.

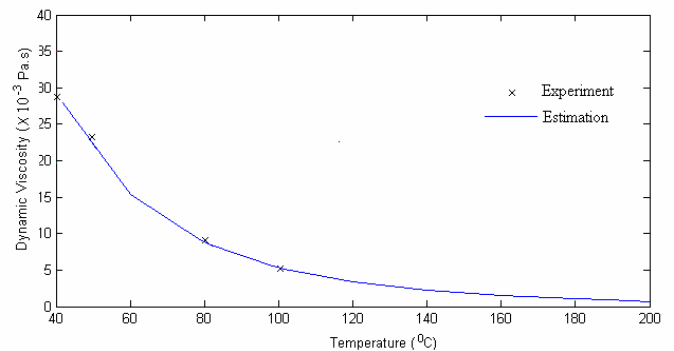


Figure 2. Comparison of experimental and estimated viscosity of cottonseed oil

Thermal Conductivity

Thermal conductivity is estimated using the method by Latini et al. [4].

$$\lambda_L = \frac{A(1 - T_r)^{0.38}}{T_r^{1/6}} \quad (5)$$

where

$$A = \frac{A^* T_b^\alpha}{M^\beta T_c^\gamma} \quad (6)$$

and T_r is the reduced temperature, A^* , β , α and γ are correlation parameters. The estimation results are shown in Figure 3. The results indicate that the vegetable oils have similar thermal conductivities that decrease almost linearly with temperature.

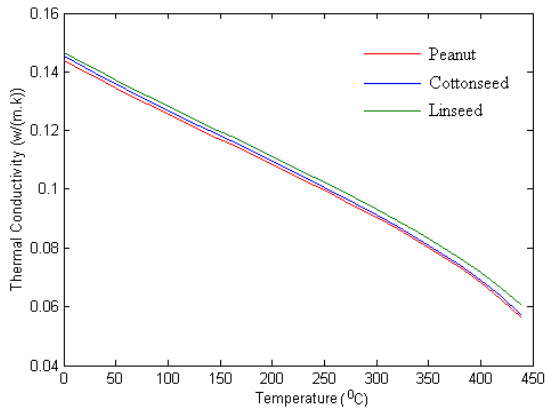


Figure 3. Variation in thermal conductivity of vegetable oils with temperature

Enthalpy

The specific heat capacity of liquid vegetable oils is estimated with the Rowlinson-Bondi equation [8]:

$$C_p - C_p^0 = 1.45 + 0.45 (1 - T_r)^{-1} + 0.25 \omega \times [17.11 + 25.2 (1 - T_r)^{1/3} T_r^{-1} + 1.742 (1 - T_r)^{-1}] \quad (7)$$

$$\text{where } C_p^0 = (\sum_j n_j \Delta_a - 37.93) + (\sum_j n_j \Delta_b + 0.21) \times T \quad (8)$$

and ω is the acentric factor and n_j is the number of groups of the j^{th} type of atoms. The enthalpies for both liquid and vapor phases are computed from the specific capacity. The enthalpy of the liquid fuel used is fitted using the following equation:

$$h - h_{ref} = a_1 (T - T_{ref}) + a_2 (T - T_{ref})^2 + a_3 (T - T_{ref})^3 \quad (9)$$

The vapor enthalpy of the fuel is computed from the following equation:

$$h - h_{ref} = a_1 (T - T_{ref}) + a_2 (T - T_{ref})^2 + a_3 (T - T_{ref})^3 + a_4 (T - T_{ref})^4 + a_5 (T - T_{ref})^5 \quad (10)$$

where the constants a_i 's are tabulated in Table 5.

COMPUTATION MODELLING OF ENGINE

The engine for this study is a heavy-duty direct injection diesel engine. The specification is shown in Table 6.

Model results are calibrated with experimental measurements. Ignition delay, cylinder pressure and cumulative heat release predictions are compared with the measured values. The calibration of cylinder pressure is shown in Figure 4.

Table 5. Enthalpy constants for liquid and vapor fuel

	Enthalpy constants	Cotton seed	Linseed	Peanut
Liquid	a_1	1940	1800	1920
	a_2	4.3	3.3	4.6
	a_3	0	0	0
Vapor	a_1	1900	1750	1700
	a_2	4	3	4
	a_3	0	0	0
	a_4	0	0	0
	a_5	0	0	0

Table 6. Specifications of the diesel engine.

Bore	13.0 cm
Stroke	16.8 cm
Connecting Rod Length	26.93 cm
Displacement Volume	2334 cm ³
Compression Ratio	16:1
Engine Speed	1255 rpm
Injection Pressure	2000 bar (recommended), 2500 bar, 3000 bar
Increasing Pressure Ratio	1.8
Engine Type	Single cylinder

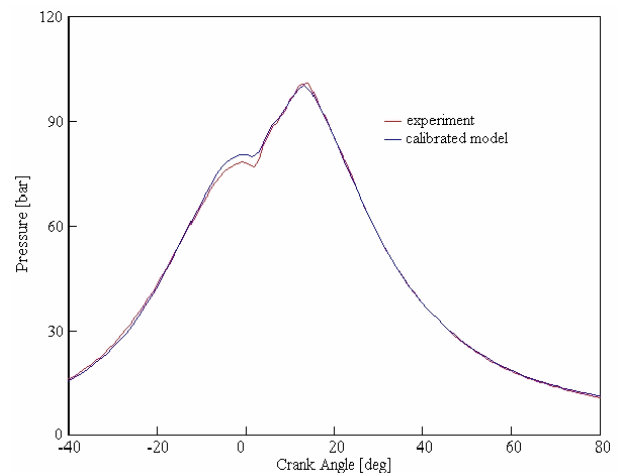


Figure 4. Calibration of cylinder pressure

RESULTS AND DISCUSSION

COMBUSTION CHARACTERISTICS OF VEGETABLE OILS

Ignition Delay

The ignition delay is obtained by analyzing the fuel injection curves and pressure diagram as shown in Table 7.