Analysis of Combustion Characteristics of a LHR-STD Diesel Engine Fuelled with Biofuel and Diesel Fuel

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Abstract

It is important to efficiently use of alternative fuel in CI (compression ignition) engine, because of the lack of energy shortages will be in the present and coming years. Therefore this study, the top surfaces of the piston, exhaust and inlet valves of a four-stroke, direct injection, single cylinder CI engine was coated with a mixture of insulation materials by use of plasma spray method. After that, determine of combustion characteristics of standard (STD) CI engine and the low heat rejection (LHR) CI engine were tested under the same experimental conditions and the same experimental setup, fuelled with the WB20, WB100 and DF fuels. The results of both engines are compared with each other so that analyze how this modification is effect on the combustion parameters. Experimental results showed that LHR diesel engine generally is partly similar to STD diesel engine in terms of the knock density, mass burning rate, average gas temperature, velocity of heat transfer, coefficient of heat transfer and total heat transfer.

Keywords: Combustion characteristics, Diesel engine, Low heat rejection, Waste cooking oil biofuel

Nomenclature

LHR  : Low heat rejection  
STD  : Standard  
Ci  : Compression injection  
WB20  : Volumes of 20% biofuel to 80% diesel fuel  
WB100  : Pure biofuel  
MgO2  : Magnesium oxide  
NiCrAl  : Chromium nickel aluminum  
Al2O3  : Aluminum oxide  
ZrO2  : Zirconia  
μm  : Micrometer  

CAs  : Crankangles  
AGT  : Average gas temperature  
UDF  : DF fuel in the STD engine  
UWB20  : WB20 fuel in the STD engine  
UWB100  : WB100 fuel in the STD engine  
CDF  : DF fuel in the LHR engine  
CWB20  : WB20 fuel in the LHR engine  
CWB100  : WB20 fuel in the LHR engine  
HRR  : Heat release rate

I. INTRODUCTION

Researchers continuously try to improve the combustion characteristics of the internal combustion engines due to certain technological and environmental requirements and rapid increase in the cost of the fuel. Conversely the improvements in engine materials become increasingly important thanks to the introduction of new alternative fuels [1]. Thus the fast depletion of fossil fuels and rapid increase in fuel price also increased interest in alternative fuels for CI engines, in recent years. In this scope, LHR CI engine operation on biofuels and vegetable oils can be an important subject matter to explore [2]. Thermal barrier coating is predominantly used by many researchers to increase the heat resistance inside the combustion chamber in order to improve the thermal efficiency of the existing engines. Ceramic coatings not only act as heat resisting medium, but also prevent the thermal fatigue and shocks in protecting the substrates. In the past hundred years, extensive theoretical and experimental researches have been occurred for the development of thermally insulated diesel engine, more commonly called LHR CI engines [3-6]. Within the LHR CI engine concept, the combustion chamber is
insulated by using high thermal insulated material on CI pistons, cylinder head, valves, cylinder liners and exhaust ports [7-13]. Theoretically, if the rejected heat could be reduced, after that the thermal efficiency would be improved, at least up to the limit set by the 2nd law of thermodynamics[14]. Combustion characteristics of LHR CI engines are different from STD CI engines in four ways; (a) Shortens Ignition delay period; (b) Increases diffusion burning period while premixed burning period decreases; (c) Increases total combustion duration; (d) Decreases heat release rate in diffusion burning period [15]. A lot of resources reported on the application of LHR concept in CI engine stating that the energy of biofuel can be released more efficiently under LHR CI engine operation [16-20].

From the literature review, analysis of combustion characteristics of a LHR CI engine has not been clearly studied when using residual frying oil of cottonseed origin biofuel and its blends in a diesel engine. For this reason, these subject need to be investigated to make up for lack of in the literature. In our study, waste frying oil of cottonseed origin biofuel blended with low sulfur diesel fuel (DF) by volumes of 20% biofuel to 80% diesel fuel (WB20). Then, WB20 and pure 100% (WB100) biofuel were tested in a LHR CI engine and standard (STD) CI engine at the same experimental conditions and the same experimental setup. The usability and stability of waste frying oil of cottonseed origin biofuel as alternative fuel in a thermally insulated CI engine of which have surfaces of combustion chamber parts were coated with insulation material.

II. EXPERIMENTAL TESTS SETUP

Combustion characteristics were tested at the engine test laboratory of Faculty of Technical Education of Batman University. Schematic of experimental setup is given in Figure 1. A single cylinder, and four strokes engine components, such as

![Figure 1. Schematic of Experimental Setup](image)

The piston and valves of the model of Lombardini 3LD 510 CI engine coated with the 100 μmNiCrAl as lining layer by plasma spray method. After that, the same surfaces were coated with 400 μm material of coating that is the mixture of 88% of ZrO₂, 4% of MgO and 8% of Al₂O₃ [20]. Experimental studies would be occurred at fully loaded in LHR and STD CI engine process. Hydraulic dynamometer was used for both engines
combustion characteristics. Some of the important chemical and physical characteristics of DF, WB20 and WB100 fuels are presented in Table 1.

<table>
<thead>
<tr>
<th>Fuel Properties</th>
<th>Unit</th>
<th>ASTM D675</th>
<th>EN 1421</th>
<th>WB20</th>
<th>WB100</th>
<th>Diesel Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td>g/cm³ @ 20°C</td>
<td>-</td>
<td>0.86-0.90</td>
<td>0.847</td>
<td>0.885</td>
<td>0.842</td>
</tr>
<tr>
<td>Cin. viscosity</td>
<td>mm²/s @ 40°C</td>
<td>1.9-6</td>
<td>3.5-5</td>
<td>3.871</td>
<td>4.753</td>
<td>3.146</td>
</tr>
<tr>
<td>Lower heating value</td>
<td>kJ/kg</td>
<td>-</td>
<td>-</td>
<td>39465</td>
<td>38980</td>
<td>43085</td>
</tr>
<tr>
<td>Flash point</td>
<td>°C</td>
<td>130 min.</td>
<td>120 min.</td>
<td>81</td>
<td>108</td>
<td>67</td>
</tr>
<tr>
<td>Cetane index</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>52.80</td>
<td>53.5</td>
<td>49</td>
</tr>
</tbody>
</table>

The experimental results of the combustion characteristics of the LHR-STD CI engines are presented in the following sections.

A. Calculation Methods

The combustion analysis software of Febris was used in collecting data from sensor of cylinder pressure and crank encoder after this process analyzed. The cylinder volume, cylinder gas pressure, average piston speed and piston acceleration (CAs) have been collected by use of this software. In this study, engine cylinder gas pressure and other parameter values were used to evaluate the knock density, mass burning rate, average gas temperature (AGT), velocity of heat transfer, coefficient of heat transfer and total heat transfer which simplified thermodynamic model. The mentioned parameters were calculated using the first law analysis of thermodynamics. The parameters at each CAs were determined by the following equations

\[ Q = \frac{\gamma}{\gamma - 1} P dV + \frac{1}{\gamma - 1} V dP + Q_w \] (1)

The ratio of specific heats is given next formula benefited with the average gas temperature [21].

\[ \gamma = 1,338 - 60 \times 10^{-5} T + 10^{-8} T^2 \] (2)

The HRR (J) from the cylinder wall to outside calculated connection with the Hohenberg correlation [19].

\[ \frac{dQ_w}{d\theta} = hA(T - T_w) \] (3)

Hohenberg heat transfer coefficient in used the parameters of combustion analysis that is given next formula [23].

\[ h = C_0 V^{-0.06} p^{0.8} T^{-0.4} [c_m + 1.4]^{0.8} \] (4)

The knock density has been calculated from cylinder pressure and other parameters that is given next formula [24].

\[ dp(\theta) = \frac{86(p_{i-4} - p_{i-1}) + 142(p_{i+3} - p_{i-3}) + 193(p_{i+2} - p_{i-2}) + 126(p_{i+1} - p_{i-1})}{1118d\theta} \] (5)

where \( \gamma \) is the ratio of specific heats, \( Q \) is heat release rate (J), which is calculated according to an empirical formula [5,22], \( P \) is the cylinder pressure (bar), \( V \) is volume of the cylinder (m³) and \( Q_w \) is HRR (J) from the wall to outside calculated connection with Hohenberg correlation [23].

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Analysis of Combustion

Changes of AGT and knock density values according to various CAs, for both LHR and STD engines, at full loaded and different speeds of engine operation conditions, are shown in Figs. 2, 3 and 4. The apparent AGT and knock density values are calculated from the measured cylinder gas pressure values according to the method mentioned above. These characteristics are sufficient to define the combustion of
an engine, effect of operating conditions on LHR and STD engines under the same operating conditions. The figures reveals that the AGT values of LHR diesel engine process are slightly higher than the values of STD diesel engine process for almost all the test fuels. The increase in temperature is mainly because of thermally insulation coatings applied to the combustion chamber surface. Heywood [5] states that the frequency of the pressure fluctuations due to knock corresponds to the first transverse mode of gas vibration in the cylinder. Knock density values in LHR and STD engine process were found partly similar with each other. The higher cetane index and higher O₂ amounts of biofuel fuels decrease ignition delay for biofuel usage [25] and so knock density in the engines decrease.

Figure 2. AGT And Knock Density Curves At 1500 Rpm Engine Speed

Figure 3. AGT and Knock Density Curves at 1800 rpm Engine Speed
Changes of the velocity of heat transfer and the mass burning rate values according to various CAs, are shown in Figs 5, 6 and 7 for both LHR and STD engines under fully loaded and diverse speeds of CI engine operation conditions. The apparent velocity of heat transfer and mass burning rate values are calculated from the measured cylinder gas pressure values versus CAs data, according to the method mentioned above. The maximum velocity of heat transfer for both LHR and STD engine and also for all the test fuels-engine speeds were obtained after top dead center (TDC). At 1500 rpm engine test condition, the maximum value of the velocity of heat transfer occurred as 5.83 J° for UD2 fuel is reached at CAs 370. On the contrary, at 1800 rpm engine test condition, maximum value of velocity of heat transfer occurred as 5.97 J° for UD2 fuel is reached at CAs 367. In addition, at 2100 rpm engine test condition, the highest value of velocity of heat transfer occurred as 4.74 J° for CD2 fuel is reached at CAs 371.

In both velocity of heat transfer and mass burning rate values an important factor is the completeness of combustion [5]. Since the figures are showed that the mass burning rate values of LHR and STD CI engine process were found partly similar for all the test fuels.
Changes of the coefficient of heat transfer and the total heat transfer values according to various CAs, are shown in Figs. 8, 9 and 10 for both engines under fully loaded and diverse speeds of engine operation conditions. Hohenberg heat transfer coefficient in used the combustion analysis that is given by equation (4). By analyzing these figures it can be observed that coefficient of heat transfer values of LHR and STD CI engine process were found partly similar with each other for almost all the test fuels. The high total heat transfer values in LHR engine are attributed to its capability of thermally insulation surfaces of combustion chamber that parts were coated with ceramic materials. The engine heat loses because of incomplete combustion, gas leakage and dissociation are usually ignored and heat transfer losses by convection and radiation are estimated using empirical correlations. In most cases the radiation component is ignored in spite of its importance, particularly in CI engines [26].
Figure 8. Coefficient of heat transfer and total heat transfer curves at 1500 rpm engine speed

Figure 9. Coefficient of heat transfer and total heat transfer curves at 1800 rpm engine speed
IV. CONCLUSIONS

Combustion characteristics of the LHR and STD diesel engines were tested fuelled with the WB20, WB100 and DF fuels. The same LHR and STD CI engine out parameters were obtained and analyzed on account of discover how this insulation material would change the combustion parameters. The average gas temperature values of LHR diesel engine operation are higher than the values of STD diesel engine process for nearlyWB20, WB100 and DF test fuels. The mass burning rate values and knock density of LHR and STD diesel engine process were found partly similar with each other for almost all the test fuels but a bit shorter ignition delay probably because of the increased in-cylinder temperature. The higher total heat transfer values from gases to surfaces of the combustion chamber in LHR CI engine are observed for all fuels

REFERENCES


