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

Selman Aydin[1], Cenk Sayin[2], Hüseyin Aydin[3], Rifat Yakut[4]
[1]Department of Automotive Engineering, Faculty of Technology, University of Batman, Batman, Turkey
[2]Department of Mechanical Engineering, Faculty of Technology, University of Marmara, Istanbul, Turkey
[3]Department of Mechanical Engineering, Faculty of Engineering and Architecture, University of Batman, Batman, Turkey
[4]Department of Mechanical Engineering, Faculty of Technology, University of Batman, Batman, Turkey

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 : Lowheatrejection
STD : Standard
CI : Compressioninjection
WB20 :Volumes of 20% biofuelto 80% dieselfuel
WB100 : Purebiofuel
MgO_2 : Magnesiumoxide
NiCrAl : Chromiumnickelaluminum
Al_2O_3 :Aluminumoxide
ZrO_2 : Zirconia
µm : Micrometer
CAs : Crankangles
AGT : Averagegastemperature
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 : Heatrelease 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].Thusthe 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 İgnition 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].

engine components, such as 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. EXPERİMANTAL 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 CI engine that have a cylinder volume of 510 cm^3, compression ratio of 17.5/1 and output power of engine 9 kW have been used to implement this experiment [20]

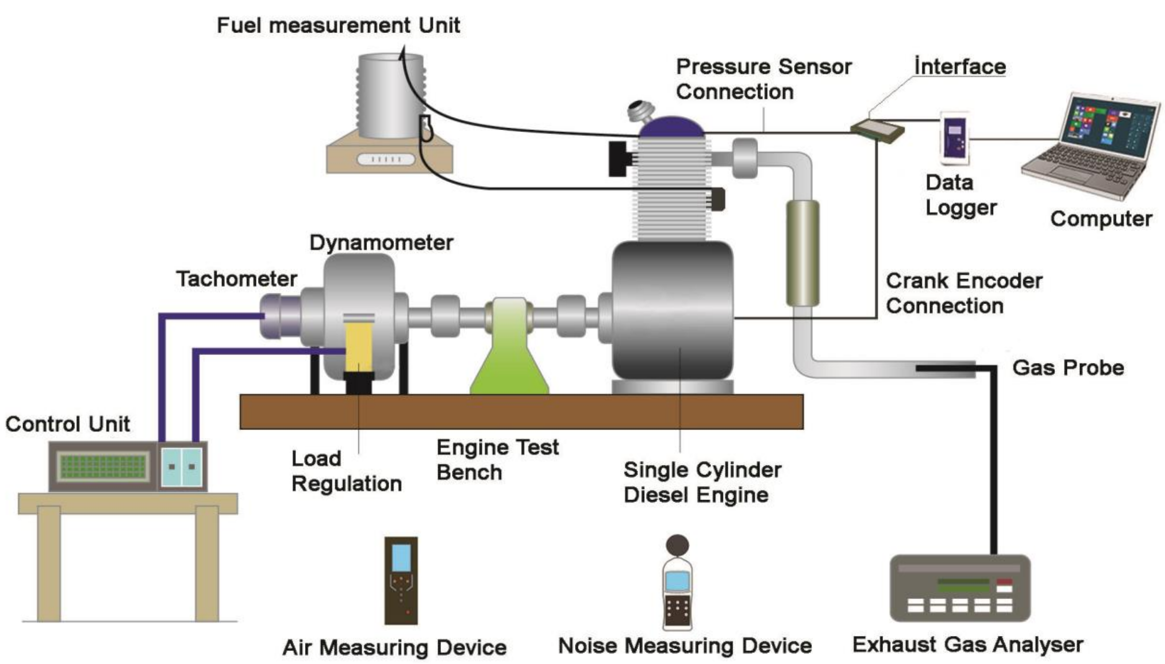

Figure1. Schematic of Experimental Setup

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 ZrO_2, 4% of MgO and 8% of Al_2O_3 [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 characteristicsof DF, WB20 and WB100 fuels are presented in Table 1.

Table 1. The Characteristics of Biofuel and Diesel fuel [20]

Fuel Properties	Unit	ASTM D675	EN 1421	WB20	WB100	Diesel Fuel
Intensity	g/cm^3 @ 20ºC	-	0.86-0.90	0.847	0.885	0.842
Cin. viscosity	mm^2/s @ 40ºC	1.9-6	3.5-5	3.871	4.753	3.146
Lower heating value	kJ/kg	-	-	39465	38980	43085
Flash point	ºC	130 min.	120 min.	81	108	67
Cetane index	-	-	-	52.80	53.5	49

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 collectingdata from sensor of cylinder pressureand crank encoder after this process analyzed. The cylinder volume, cylinder gas pressure, average piston speed and piston acceleration versus crank angles (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 following equations

$$\dot{Q} = \frac{\gamma}{\gamma-1} PdV + \frac{1}{\gamma-1} VdP + Q_w \qquad (1)$$

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

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

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

$$\frac{dQ_w}{d\theta} = hA(T - T_w) \qquad (3)$$

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

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

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

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

where γ 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 (m^3) 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 O_2 amounts of biofuel fuels decrease ignition delay for biofuel usage [25] and so knock density in the engines decrease.

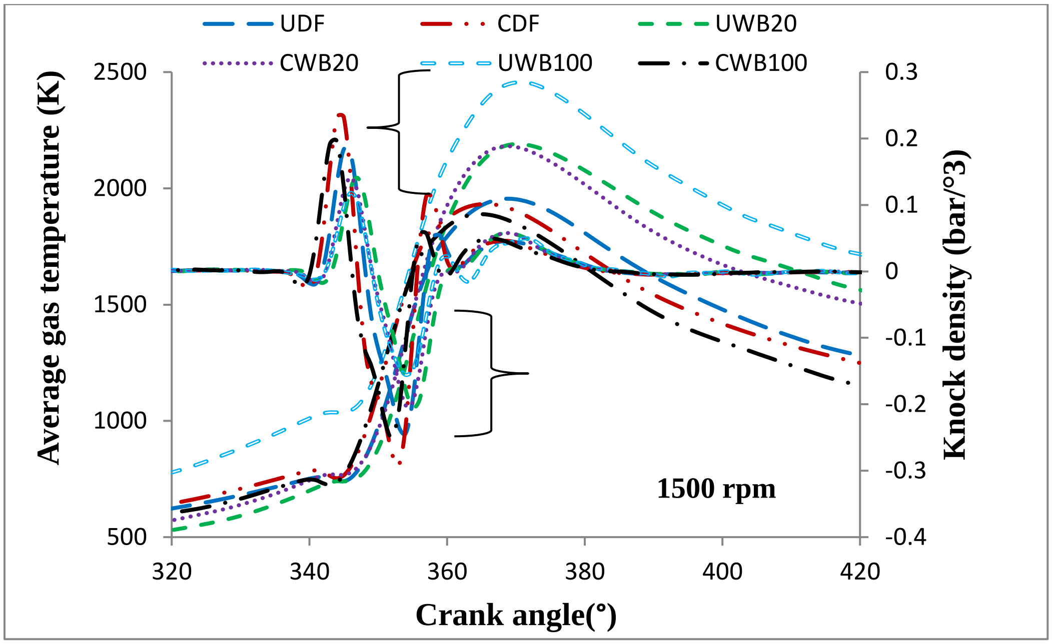

Figure 2. AGT And Knock Density Curves At 1500 Rpm Engine Speed

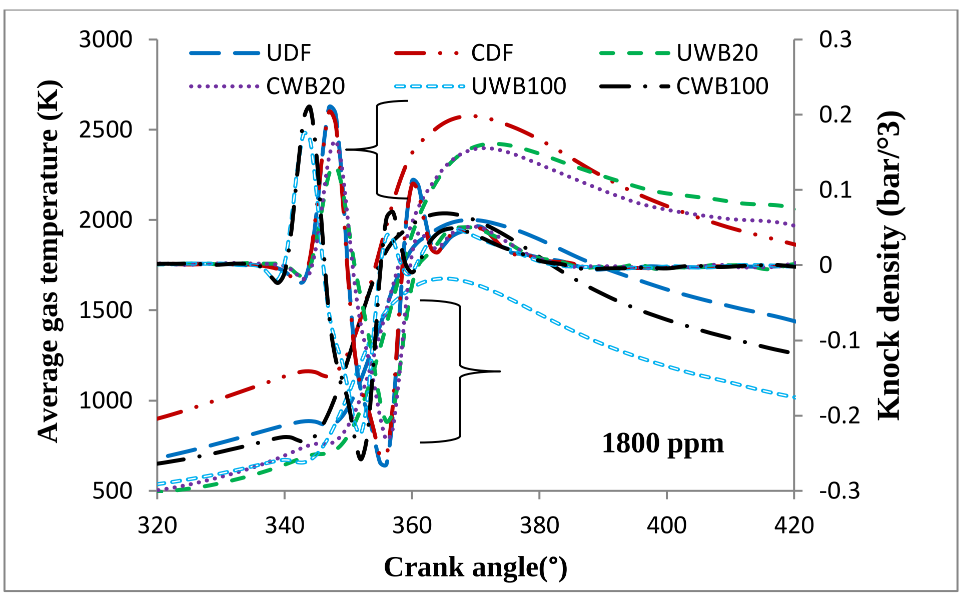

Figure 3.AGT and Knock Density Curves at 1800 rpm Engine Speed

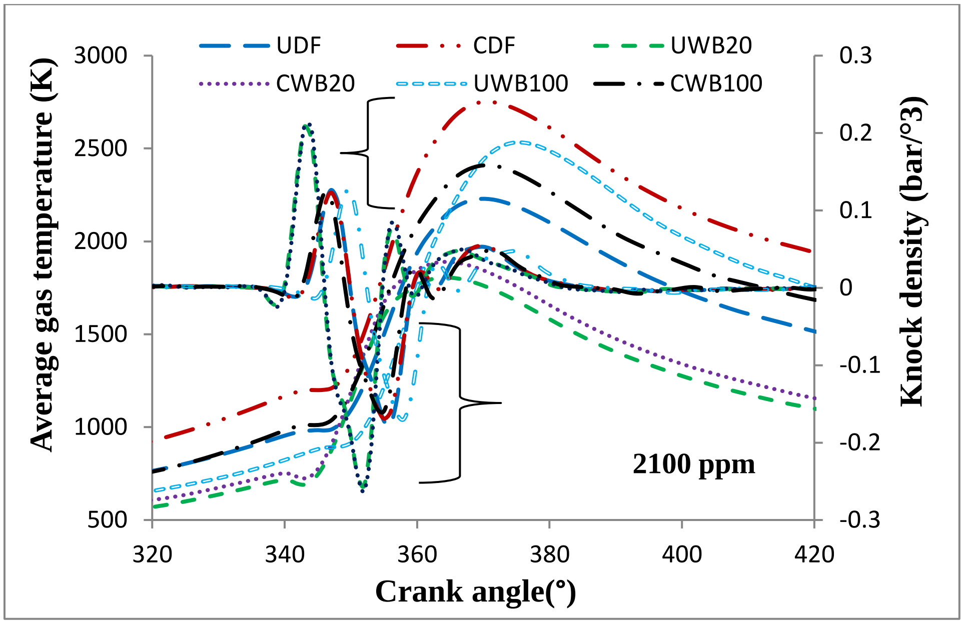

Figure 4.AGT and Knock density Curves at 2100 rpm Engine Speed

Changes of the velocity of heat transferand 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 anddiverse speeds of CI engine operation conditions. The apparent velocity of heat transferand 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/º 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/º 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/º 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

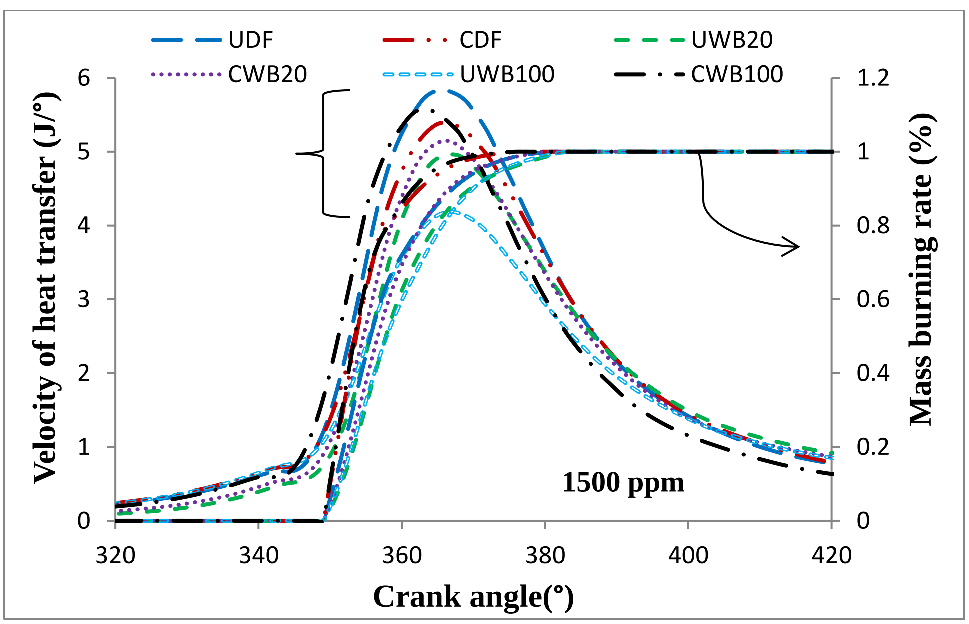

Figure 5. Velocity of heat transfer and mass burning rate curves at 1500 rpm engine speed

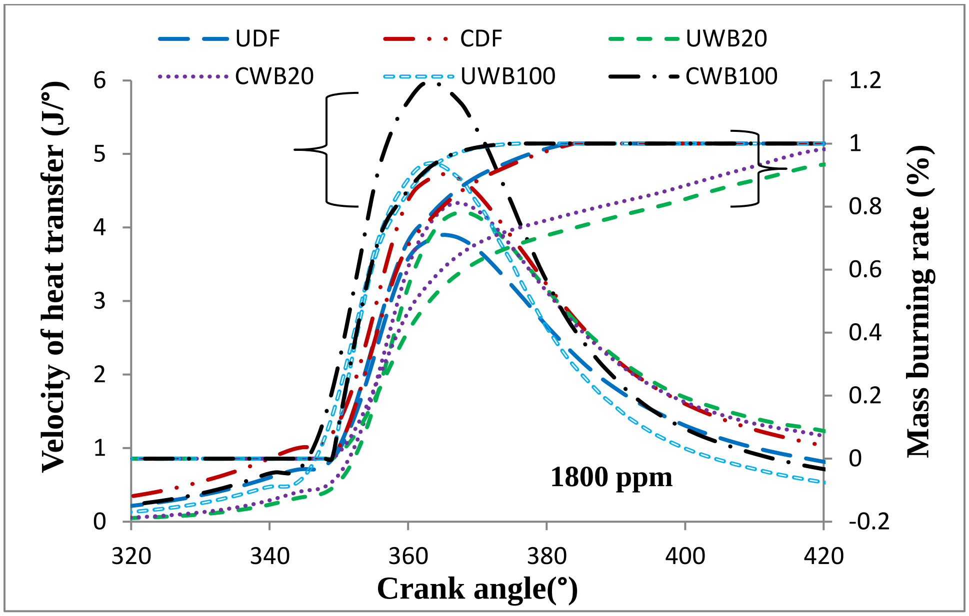

Figure 6. Velocity of heat transferand mass burning rate curves at 1800 rpm engine speed

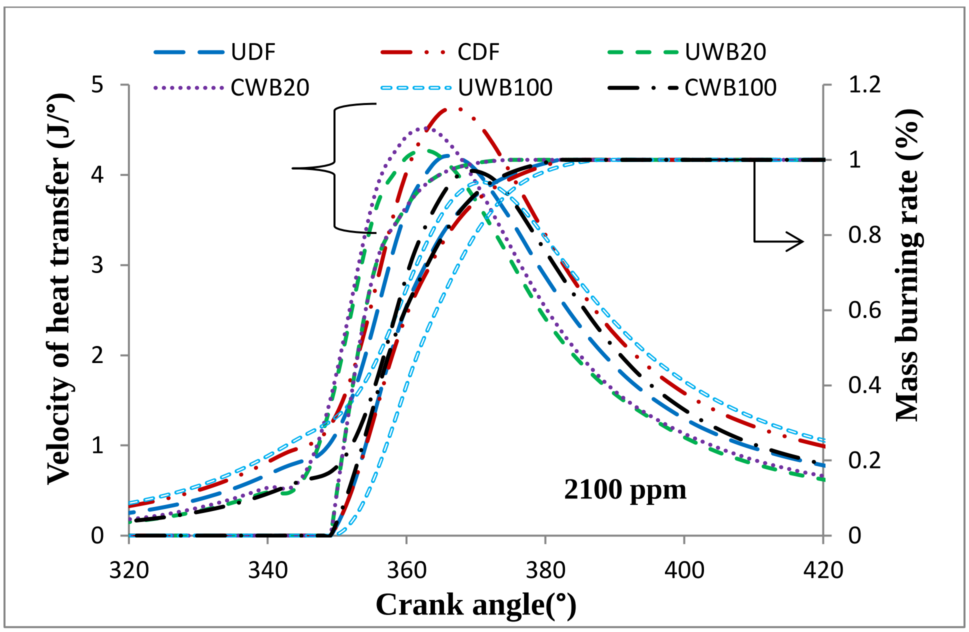

Figure 7. Velocity of heat transferand mass burning rate curves at 2100 rpm engine speed

Changes of the coefficient of heat transfer and the total heat transfervalues 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 thatcoefficient 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 transfervalues 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].

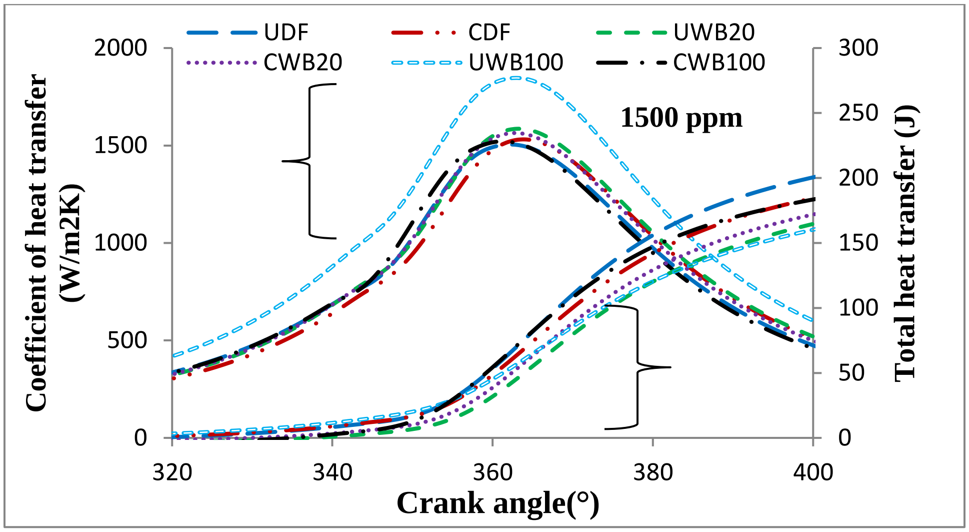

Figure 8.Coefficient of heat transfer and total heat transfer curves at 1500 rpm engine speed

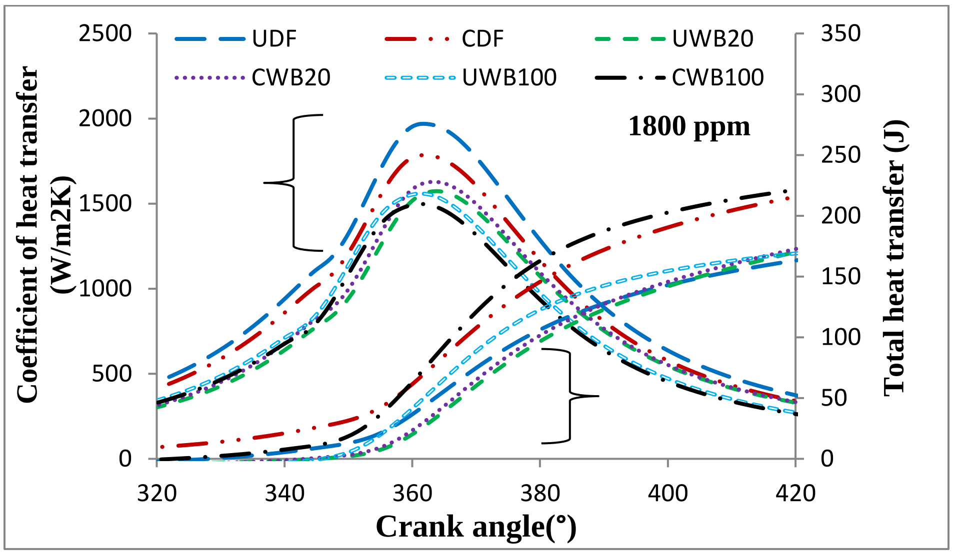

Figure 9. Coefficient of heat transfer and total heat transfer curves at 1800 rpm engine speed

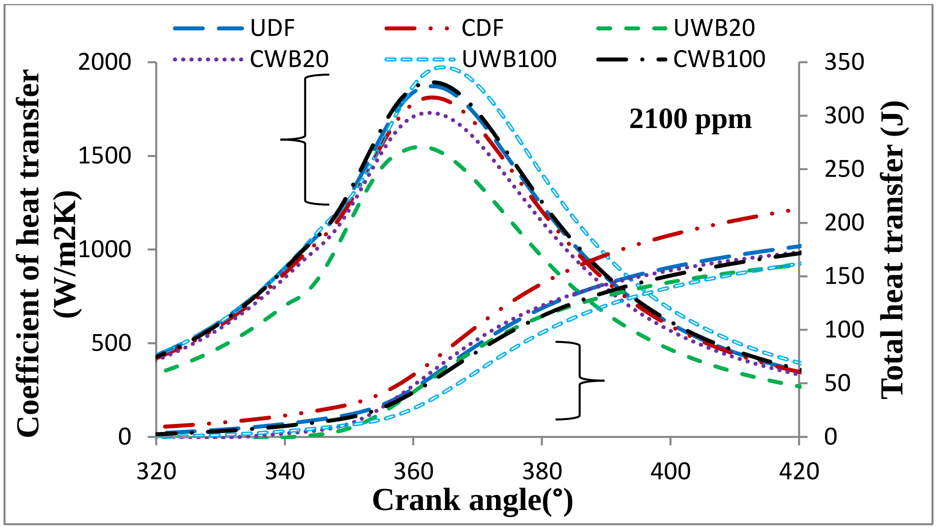

Figure 10. Coefficient of heat transfer and total heat transfer curves at 2100 rpm engine speed

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 discoverhow 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

[1] Assanis, D.N., 2012, "The effect of thin ceramic coatings on petrol engine performance and emissions",Int. J. Veh. Des. 13 (4), 378–387.

[2] Rahman, S., Masjuki, H., Kalam, M., Abedin, M., Sanjid, A., Sajjad, H., 2013, "Production of palm and calophylluminophyllum based biodiesel and investigation of blend performance and exhaust emission in an unmodified diesel engine at high idling conditions", Energy Conversion Management, 76, 362–7.

[3] Benson, R.S., Whitehouse, N.D., 1979, "Internal Combustion Engines, Pergamum Press", Oxford

[4] Ferguson, C.R., 1986, Internal Combustion Engines, John Wiley, New York.

[5] Heywood, J.B., 1988, Internal Combustion Engine Fundamentals, McGraw-Hill, New York.

[6] Obert, E.F., 1973, "Internal Combustion Engines and Air Pollution", Intext Educational Publishers, New York.

[7] Gataowski, J.A., 1990, "Evaluation of a selectively- cooled single-cylinder 0.5-l Diesel engine" SAE paper No. 900693.

[8] Schwarz, E., Reid, M., Bryzik, W., 1993, Danielson E. Combustion and performance characteristics of a low heat rejection engine. SAE paper, No. 930988.

[9] Bryzik, W., Kamo, R., 1983, "Tacom/Cummins adiabatic engine program". SAE paper No. 830314.

[10] Dhinagar, S.J., Nagalinga, B., Gopalakrishnan, K.V., 1992,"Spark assisted Diesel operation in a low compression ratio low heat rejection engine", SAE paper No. 920245.

[11] Kawamura, H., Sekiyama, S., Hirai, K., 1991, "Observation of combustion process in a heat insulated engine", SAE paper No. 910462.

[12] Hay, N., Watt, P.M., Ormerod, M.J., Burnett, G.P., Beesley, P.W., French, B.A., 1990, "Design study for a low heat loss version of the Dover engine", Proc I Mech E 200, 53–60.

[13] Siegla, D.C., Amman, C.A., 1995, "Exploratory study of the low heat rejection Diesel for passenger car applications" SAE paper No. 840435.

[14] Beardsley, M.,Happoldt, P., Kelley, K., Rejda, E., Socie, D., 1999, "Thermalbarriercoatingsforlowemission, highefficiencydiesel engine applications", SAE technicalpaper, 1999-01- 2255.

[15] Sun, X., Wang, W., Bata, R.,1994, "Performance evaluation of low heat rejection engines" ASME Transactions, 116, 758-64.

[16] Parlak, A., Yasar, H., Eldogan, O., 2005, "The effect of thermal barrier coating on a turbocharged diesel engine performance and exergy potential of the exhaust gas", Energy Convers Manage, 46, 489–99.

[17] Aydin, H., 2013, "Combined effects of thermal barrier coating and blending with diesel fuel on usability of vegetable oils in diesel engines", Applied Thermal Engineering, 51, 623-629.

[18] Musthafa, M.M., Sivapirakasam, S.P., Udayakumar, M., 2011, "Comparative studies on fly ash coated low heat rejection diesel engine on performance and emission characteristics fueled by rice bran and pongamia methyl ester and their blend with diesel", Energy, 36(5), 2343-2351.

[19] Parlak, A., 2005, "The effect of heat transfer on performance of the Diesel cycle and exergyof the exhaust gas stream in a LHR diesel engine at the optimum injection timing". Energy Convers. Manage., 46, 167–179.

[20] Aydin, S., Sayin, C.,2014, "Impact of thermal barrier coating application on the combustion, performance and

emissions of a diesel engine fueled with waste cooking oil biodiesel–diesel blends", Fuel, 136, 334-340.

[21] Brunt, M., Platts, K., 1999, "Calculation of Heat Release in Direct Injection Diesel Engines" SAE Technical Paper, 01-0187.

[22] Brunt, M.F.J., Rai, H., Emtage, A.L., 1998, "The calculation of heat release energy from cylinder pressure data", SAE Paper No. 981052.

[23] Hohenberg, GH., 1979, "Advanced approaches for heat transfer calculations" SAE Paper No. 790825

[24] Checkel, M., Dale, J.,1986, "Computerized Knock Detection from Engine Pressure Records" SAE Technical Paper, 860028.

[25] Özener, O., Yüksek, L., Ergenç, A.T., Özkan, M., 2014, "Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics", Fuel, 115, 875-883.

[26] Ghojel, J., Honnery, D., 2005, "Heat release model for combustion of diesel oil emulsions in DI diesel engine", Applied Thermal Engineering, 25,2027-2085.