International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 10, October- 2014

The Effect of Exhaust Gas Recirculation on Diethyl Ether Fumigation in DI Diesel Engine with Ethanol Blended Diesel

S. Sudhakar
Department of Mechanical Engineering,
Annamalai University, Annamalainagar Tamil Nadu, India

S. Sivaprakasam
Department of Mechanical Engineering,
Annamalai University, Annamalainagar
Tamil Nadu India

Abstract **- Depletion of fossil fuel and threat from automobile pollution to environment drives the researchers to find out alternatives. Present work involves the fumigation effect of Diethyl ether with ethanol blended diesel has been experimentally evaluated for partial replacement of fossil fuel. The performance and combustion characteristics were evaluated and compared. This study also involves the effect of exhaust gas recirculation to reduce the emission caused by diethyl ether injection through fumigation. The increment of diethyl ether injection was 10 percent ranging from 0 to 30 percentages with respect to mass flow rate of pilot fuel. From the observations, increased amount of oxides of nitrogen emissions were noticed. In order to reduce the oxides of nitrogen emission while injecting the diethyl ether at higher volume into the inlet manifold, the exhaust gas recirculation (EGR) setup has installed with an existing experimental setup. The EGR percentages were varied from 0 to 20 percent with 5 percent increment. The results obtained from this experimental study with EGR clearly shows that 20 percent Diethyl ether injection through inlet manifold with 15 percent EGR performs better on decreasing the NOx emission and slight decrease in maximum cylinder pressure and heat release rate were recorded while compare with neat diesel and E-15.**

KEY WORDS: Combustion, Performance, Emission, Diethyl ether, Ethanol, Fumigation, Exhaust Gas Recirculation (EGR).

I. INTRODUCTION

The depletion of fossil fuel is the major concern for today's research activities in the field of alternative fuels. Especially in liquid alternative, the alcohols are the better substitute for fossil fuels. The alcohol fuel such as methanol and ethanol can be partially or fully replacement for current fossil fuels. These alcohols can be produced at large scale from the bio solid wastes, vegetable waste and other bio products like sugarcanes, maize, gaze etc..In this study bio Ethanol has taken for partial replacement to fossil fuel. The optimum percentage of ethanol blend with diesel was selected from the previous experimental study conducted by author. The 15% ethanol miscible with diesel for prolonged time can be best and was chosen as a pilot fuel for this experimental study. In order to increase the substitute of alcohol fuel into the fossil fuel, the diethyl ether has been chosen for this investigation. The large quantity of diethyl ether can be produced from bio ethanol by dehydrating process. Though the optimum blending was achieved by ethanol, it is necessary to find out the way to use the diethyl ether in large quantities. From the various types of duel fuel injection methods, the fumigation of secondary fuel into the intake manifold method was adopted for this study due to eliminate the design modifications of test engine. The fumigation of secondary fuel and varying the injection timing were the best methods to introduce or substitute alcohol fuel at very large quantities in IC Engines [1-2].However the Duel fuel operation needs much modification in IC engines, but the injection of secondary fuel into the inlet manifold method doesn't need any major alteration in design of existing test rig.

From the earlier studies, it was observed that ethanol blend with diesel produced the decreased brake thermal efficiency while compare with neat diesel due to the lower calorific value of ethanol [4]. The ethanol fuel having low cetane number compare with diesel results in the property of ignition delay and lowers the heat release rate [5]. To avoid all these, the high cetane number and increased calorific value fuel diethyl ether (as a product from ethanol by dehydration) was chosen as a secondary fuel for this study [6 -8].

The fumigation of alcohols revealed the increased amount of emissions [8]. The Exhaust gas recirculation is viable method to control the NOx emission [9]. The maximum best EGR percentages are fixed by preliminary runs of test rigs with fumigated Diethyl ether and E15 is a base fuel in various percentages into the inlet manifold on IC engines while run on ethanol blended diesel as a prime fuel.

II. TEST FUEL PROPERTIES AND CASE RUN DISCUSSIONS

In present investigation, pilot fuel for test rig was prepared by diesel purchased from the commercial outlet, an anhydrous ethanol 99.9% pure was used to blend with diesel to prepare E15 (15 % of ethanol, 85% of diesel). An emulsifier is used for increase the miscibility of ethanol into diesel and subjected to the stability test. Then the 99.5% pure Diethyl ether was chosen as a secondary fuel, which is going to fumigate at various percents into the inlet manifold of test engine with air. The increment of diethyl ether injection was 10 percent ranging from 0 to 30 percentages. The properties of test fuels are shown in table 1.

In this study, the influence of hot EGR was examined to control the emissions and evaluate the effect of EGR with Diethyl ether injection on diesel engines. The performance, emission and combustion characteristics were determined for pilot fuel (E15), E15D10 (10% of diethyl ether injection), E15D20 (20% of diethyl ether injection) and E15D30 (30% of diethyl ether injection) respectively without EGR and with different percentages of hot EGR. The percentage variations of EGR were from 0 to 20 with the increment of 5 percent. The maximum percentages for hot EGR was limited and fixed as 20 percent by the observations made by initial run of test engine by author and same percent of EGR was adopted for every Diethyl ether injection percentages of this investigation. All case runs with nomenclature for this study is shown in table 2.

III. EXPERIMENTAL SETUP

The experiment was conducted on Kirlosker TV-1 engine. The specifications of the engine are shown in table 3. The engine ran at constant speed at 1500 rpm for different load conditions for 20 minutes to attain steady state. An eddy current dynamo meter was used to apply loads to the engine and the smoke density was measured using an AVL smoke meter. Nitrogen oxides emissions were measured using AVL Di-gas analyzer.

The exhaust gas temperature was measured by the thermocouple connected with digital indicator. Combustion parameters like cylinder pressure, heat release rate and maximum pressure were measured by AVL combustion analyzer and specifications of all measuring instruments were given in table 4.

The injector will help to attain better ionization of Diethyl ether and improves the mixture rate by minimizing the droplet size of Diethyl ether with inlet air. The secondary fuel injector is connected with pressure gauge with control valve to adjust the injection pressure. The other end of the pressure gauge connected with fuel pump with return valve. The fuel pump is placed inside the Diethyl ether tank, which is mounted on weighing gauge. By the use of control and return valve, the variations of the injection pressures can be restored. The electronic device is connected with injector to adjust the interval of injection. The electronic device was receiving the signals continuously from the RPM sensors placed in fly wheels of the test engine.

The Exhaust Gas Recirculation setup has the flow by pass from outlet of the engine exhaust into the air inlet manifold with a control valve. The percentage of EGR can be controlled by the control valve placed in the bypass pipe. The flow bypass exhaust gases were allowed to mix directly into the inlet manifold by control valve and it does not have any cooling circuit for exhaust gases.

TABLE 1: PROPERTIES OF TEST FUEL.

Properties	Diesel	Ethanol	E15	Diethyl Ether
Density (Kg/m³)	833	722	821.3	713.4
Specific Gravity	0.831	0.719	0.813	0.712
Flash Point (°C)	64	13	59	-40
Kinematic Viscosity @40°C (cST)	3.05	1.295	2.8	0.223
Lower Calorific Value(KJ/Kg)	42500	26800	40145	33890
Cetane number	49	8	43	119
Auto Ignition Temperature (°C)	315	235	-	160
Oxygen Content (%)	0	34.8	-	21.6

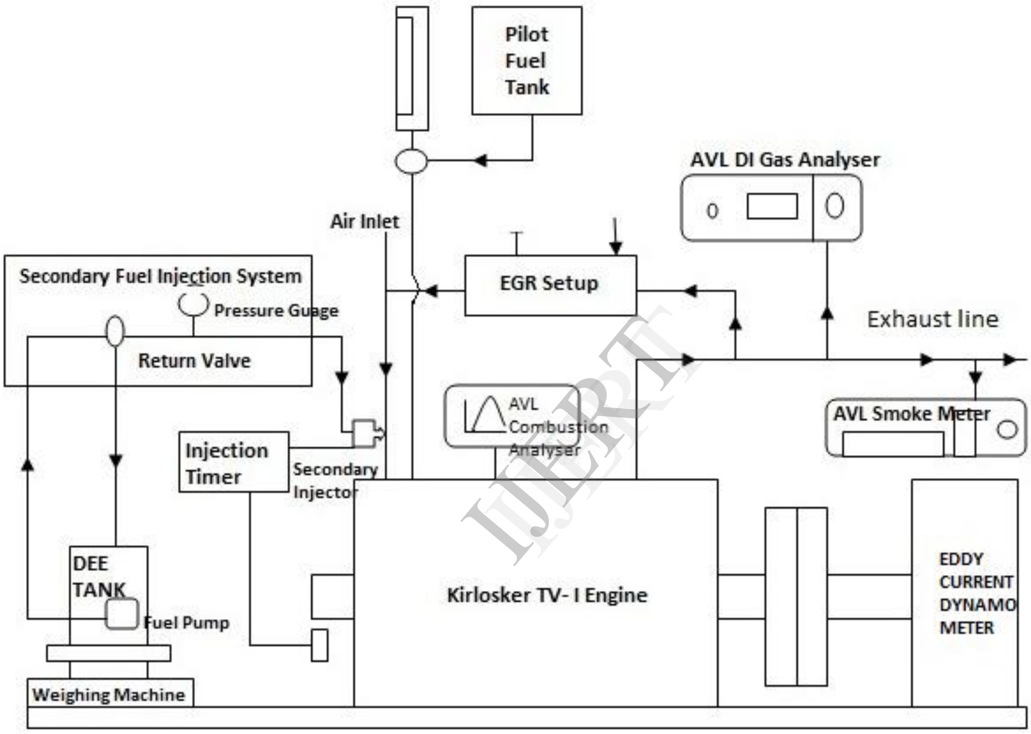

Figure 1: Layout of Test Engine.

TABLE 2: TEST FUEL NOMENCLATURE.

Pilot Fuel	Secondary Fuel injection in inlet	% of EGR	Nomenclature for case run on test rig
E15	--	--	E15
E15	10% DEE	----	E15D10
		5% EGR	E15D10-5h
		10% EGR	E15D10-10h
		15% EGR	E15D10-15h
		20% EGR	E15D10-20h
E15	20% DEE	----	E15D20
		5% EGR	E15D20-5h
		10% EGR	E15D20-10h
		15% EGR	E15D20-15h
		20% EGR	E15D20-20h
E15	30% DEE	----	E15D30
		5% EGR	E15D30-5h
		10% EGR	E15D30-10h
		15% EGR	E15D30-15h
		20% EGR	E15D30-20h

TABLE 3: SPECIFICATIONS OF TEST ENGINE.

Engine type	Single cylinder, 4stroke,DI
Bore	87.5 mm
Stroke	110 mm
Comp. ratio	17.5 : 1
Rated power	5.2 KW
Rated speed	1500 rpm
Fuel type	Diesel
Cooling System	Water
Injection pressure	220 kgf/cm^2
Ignition Timing	23° Before TDC

TABLE 4: SPECIFICATIONS OF MEASURING INSTRUMENTS.

TYPE	MEASURING RANGE
AVL- Smoke meter	0 – 99.99 opacity in %
AVL-DIGAS Analyzer	HC (ppm): 0 - 20000 CO (%): 0 – 10, NOx (ppm): 0 – 4000, CO2 (%): 0 – 20.
AVL-Combustion Analyzer	Upto 250 bar

So it is considered as hot EGR. The manometer is fixed with the EGR setup is used to find out the percentages of EGR. Then the mass flow rate of air is calculated for all possible loads with EGR. The flow rate of secondary injected fuel can be altered by varying sequence of injector with constant pressure. Before placing the secondary fuel injector in inlet manifold, the injected fuel collected in test tube and measured twice for verification. The layout of experimental setup is shown in figure 1.

IV. RESULT AND DISCUSSIONS

From the experimental evaluation of Diethyl ether injection shows the better results in specific fuel consumptions and brake thermal efficiency. The figure 2, 3 and 4 shows the comparison of specific fuel consumption of E15D10, E15D20 and E15D30 respectively for various percentages of hot EGR.

The variations of SFC for different percentage of EGR at full load condition were shown in figure 5. When injection of diethyl ether increases, specific fuel consumption decreases marginally due to the enrichment of DEE in inlet air. That enrichment of DEE in air improves calorific value of combustible mixture. The hot EGR has proven better SFC than others. The addition of Diethyl ether improves the calorific value of mixture results in decreased specific fuel consumptions while compare with E15.

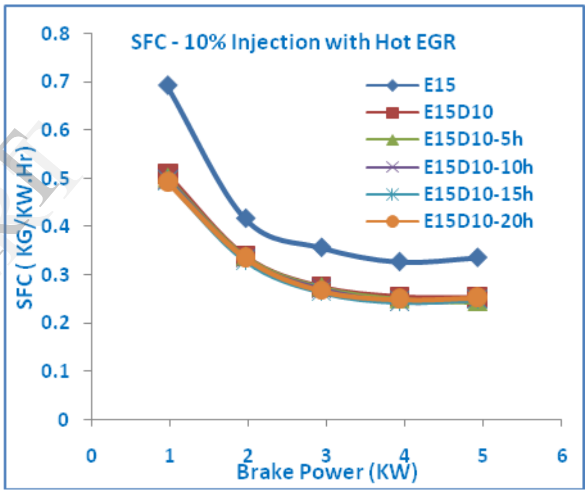

Figure 2: SFC - 10% DEE with Hot EGR.

The figure 6, 7 and 8 shows the comparison of brake thermal efficiency of E15D10, E15D20 and E15D30 respectively for various percentages of hot EGR. The BTE variations at full load for all test fuel are shown in figure 9. The brake thermal efficiency was improved while increase in diethyl ether injection. The brake thermal efficiency was improved further with EGR inclusions for all percentages of Diethyl ether injections.

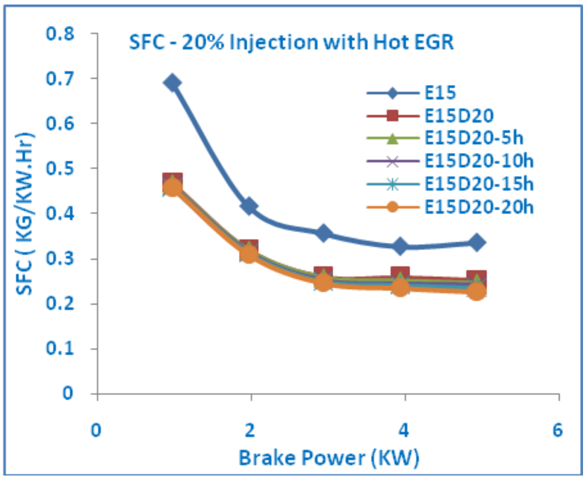

Figure 3: SFC- 20%DEE with Hot EGR.

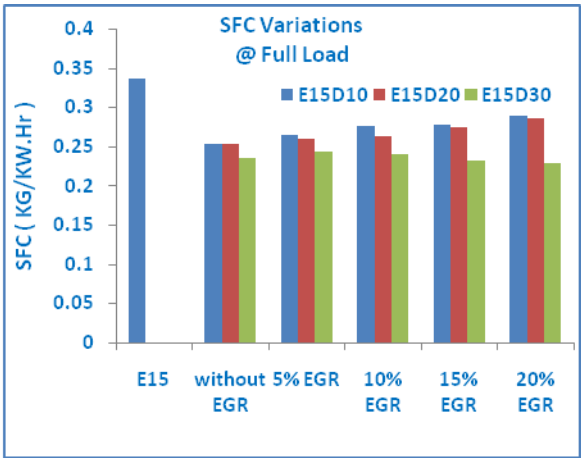

Figure 5: SFC – Comparison at full load for all test fuels with various percentage of Hot EGR.

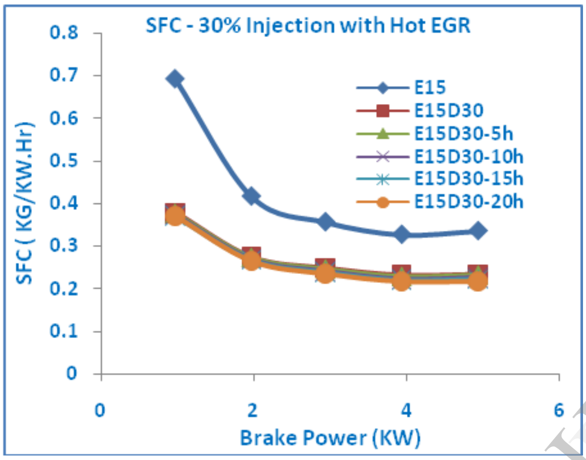

Figure 4: SFC- 30%DEE with Hot EGR.

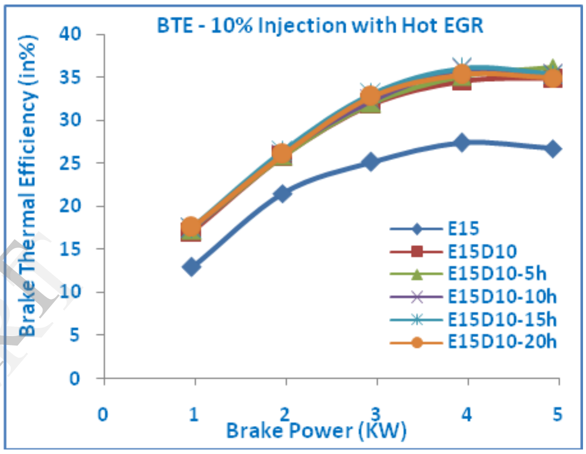

Figure 6: BTE - 10% DEE with Hot EGR.

The E15 blend shows the poor brake thermal efficiency due to the lower calorific value of ethanol. However the brake thermal efficiency is the reciprocal effect with respect to specific fuel consumptions. The engine exhaust temperature for E15 is slightly decreased than neat diesel due to slight enhance in oxygen content of combustible mixture leads to good combustion. The addition of Diethyl ether through fumigation increases the engine exhaust temperature with respect to the increasing injection percentages. In the cases with hot EGR increases the engine exhaust temperature. The enrichment of oxygen in inlet air by diethyl ether influences the combustion in rapid manner, may be the cause for increased engine exhaust temperature.

The figure 10, 11 and 12 shows the comparison of oxides of nitrogen emission of E15D10, E15D20 and E15D30 respectively for various percentages of hot EGR. The variations of oxides of nitrogen emission at full load for all test fuel are shown in figure 13. The fumigation of Diethyl ether in large quantity increases the oxides of nitrogen emission by 49%. The increasing percentage of Diethyl ether injection marginally increases the NOx emission. However the EGR reveals the good control over the NOx emission reduction.

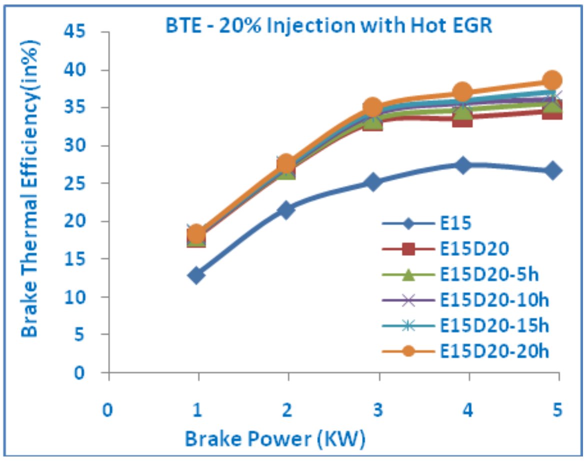

Figure 7: BTE - 20% DEE with Hot EGR.

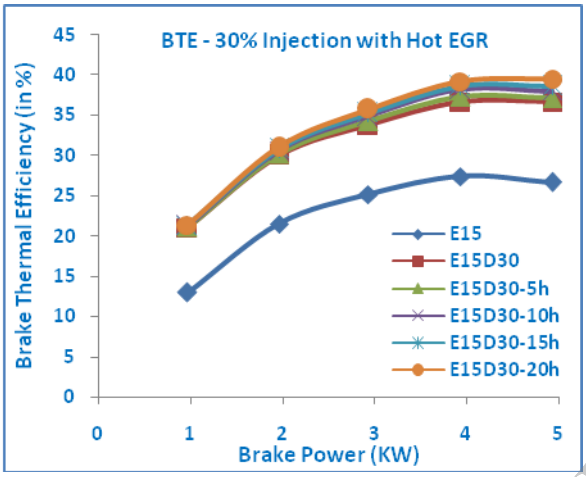

Figure 8: BTE - 30% DEE with Hot EGR.

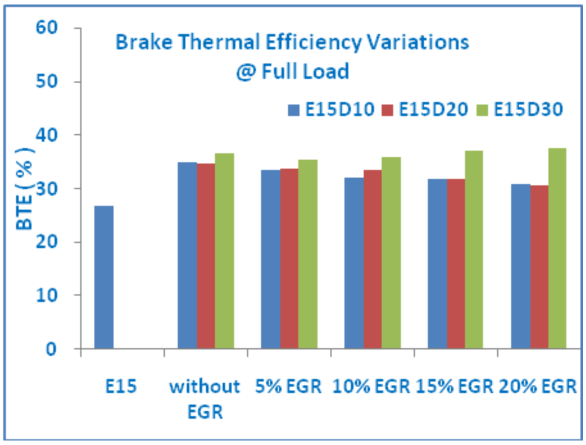

Figure 9: BTE – Comparison at full load for all test fuels with various percentage of Hot EGR.

The maximum percentage reduction of NOx emission with hot EGR is 51 % while compare without EGR. The kinematic viscosity of diethyl ether and ethanol decreases the viscosity of combustible mixture. The excess oxygen and reduction in viscosity induces the rapid combustion and leads to temperature rise in combustion chamber. This may cause the formation and increased emissions of oxides of nitrogen.

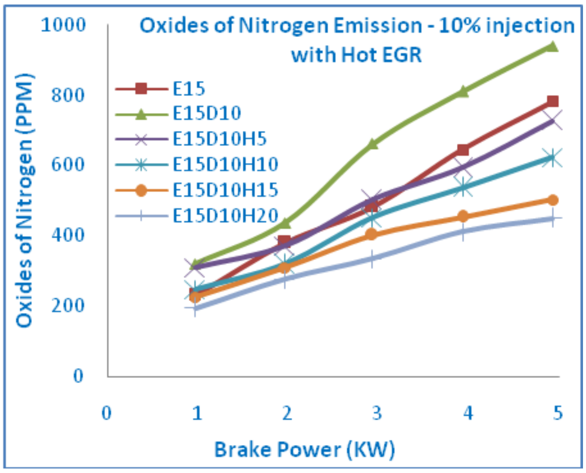

Figure 10:NO_x emission- 10% DEE with Hot EGR.

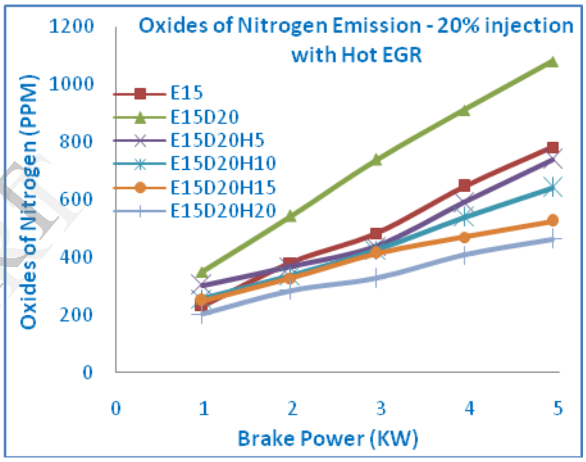

Figure 11:NO_x emission - 20% DEE with Hot EGR.

The figure 14, 15 and 16 shows the comparison of smoke density of E15D10, E15D20 and E15D30 respectively for various percentages of hot EGR. The variations of smoke density at full load for each test case are shown in figure 17. The smoke density of E15 decreased. The increasing percentage of Diethyl ether injection without EGR decreases the smoke density. However the increasing percentage of hot EGR was resulted increased smoke density than in the case of without EGR.

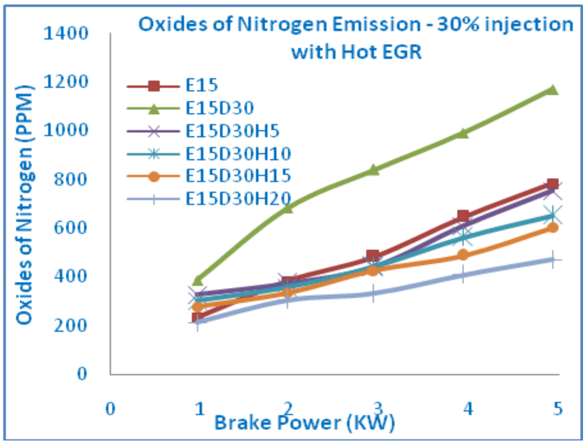

Figure 12:NO_x emission - 30% DEE with Hot EGR.

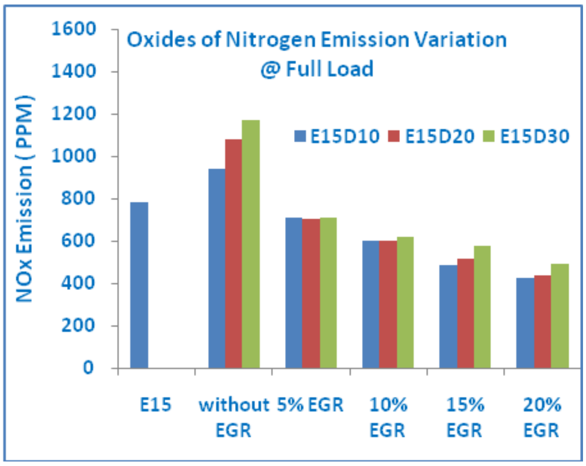

Figure 13: NO_x emission – Comparison at full load for all test fuels with various percentage of Hot EGR.

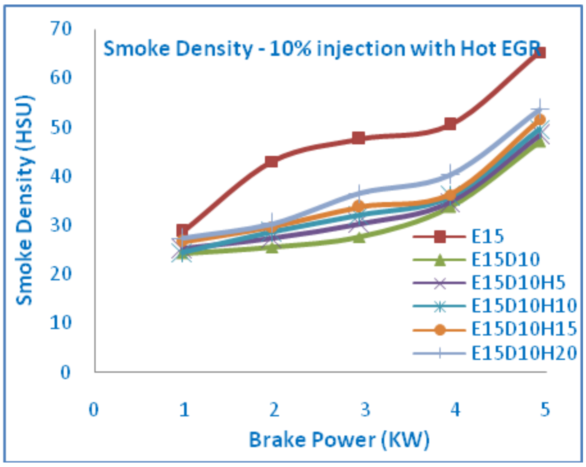

Figure 14: Smoke Density- 10% DEE with Hot EGR.

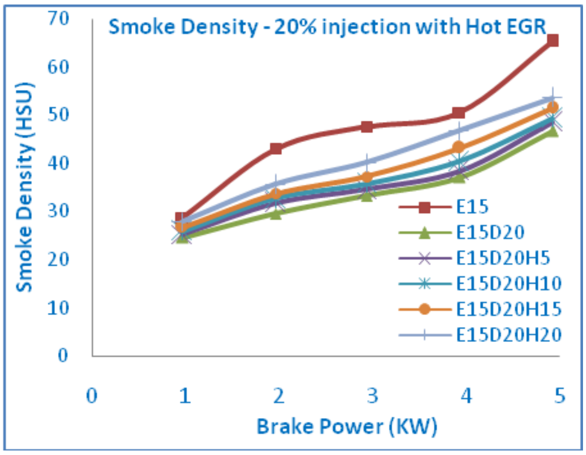

Figure 15: Smoke Density-20% DEE with Hot EGR.

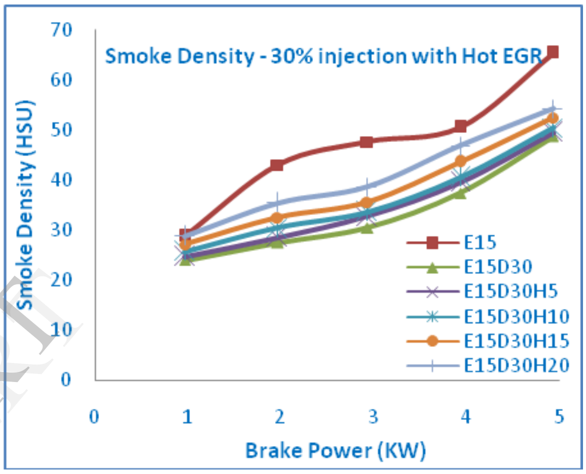

Figure 16: Smoke Density - 30% DEE with Hot EGR.

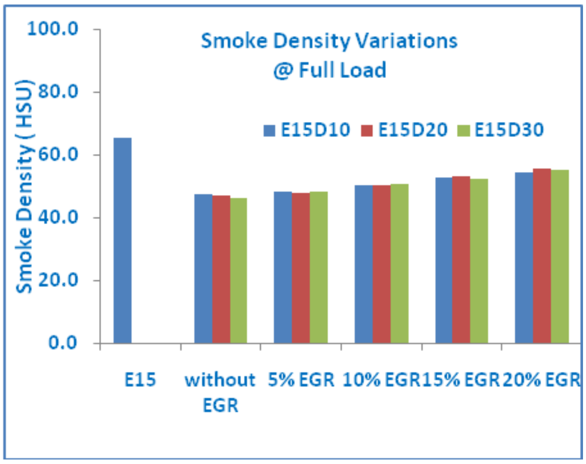

Figure 17: Smoke Density – Comparison at full load for all test fuels with various percentage of Hot EGR.

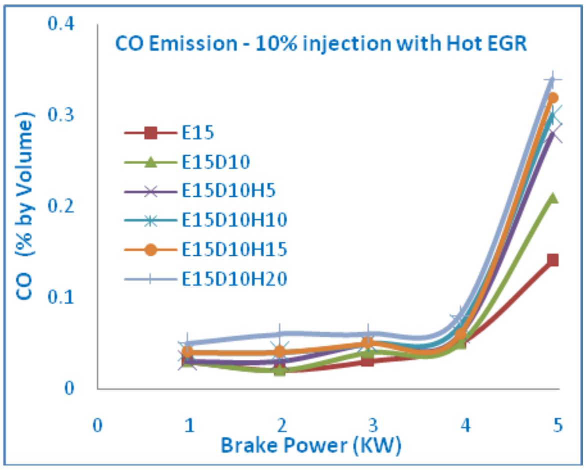

Figure 18: CO Emission - 10% DEE with Hot EGR.

Figure from 18 to 25 shows the CO and HC emissions respectively as said in above manner. The unburned hydrocarbon and CO emissions were increased compare with diesel and E15. The increasing percentage of Diethyl ether injection results marginal increase in HC and CO emission. The Exhaust Gas Recirculation system further increases the HC emissions marginally at low level load conditions and increases the CO emission at full load conditions.

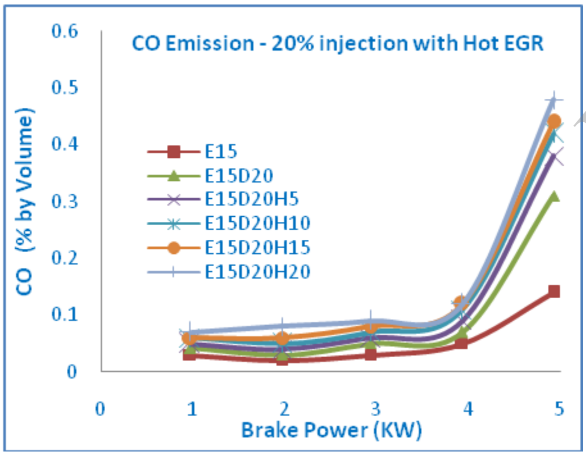

Figure 19: CO emission - 20% DEE with Hot EGR.

The combustion parameters like maximum cylinder pressure and heat release rate are shown in figures from 26 to 31 as said in above manner. The comparison chart clearly reveals that the ignition delay period was shortened while the percentage of Diethyl ether injection increases. The enriched oxygenated fuels ethanol and diethyl ether plays a vital role in pre combustion of combustible mixture and initiated the ignition little bit earlier results the shortened ignition delay period compare with ethanol blended diesel.

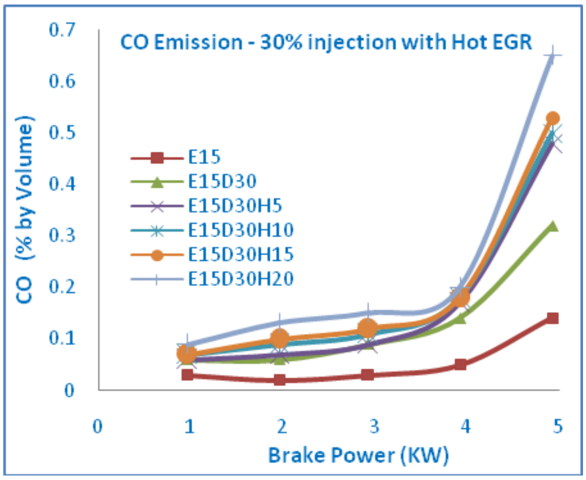

Figure 20: CO emission - 30% DEE with Hot EGR.

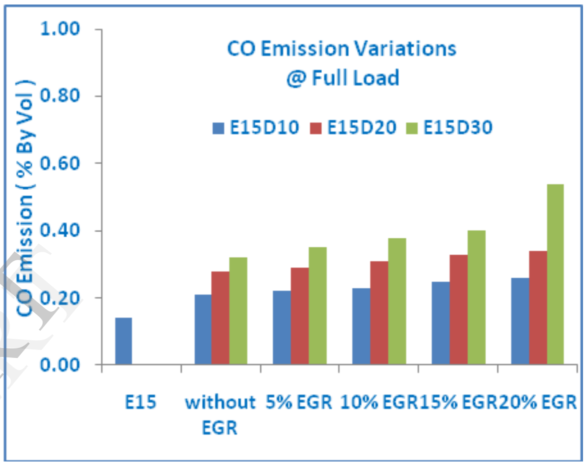

Figure 21: CO emission – Comparison at full load for all test fuels with various percentages of Hot EGR.

The maximum heat release rate decreased for E15 compare with neat diesel due to decrease in cetane index of ethanol and oxygen content of ethanol leads to complete combustion. However the increasing percentage of diethyl ether injection further improves the cetane index of combustible mixture and increase in the percentage of oxygen leads to increase in maximum heat release rate respectively and shortened diffusion phase combustion were recorded.

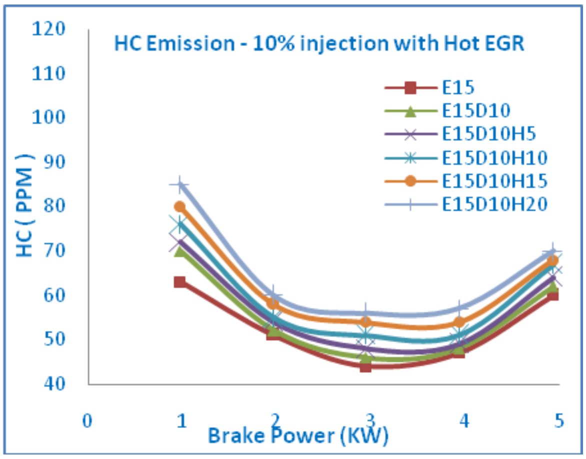

Figure 22: HC emission - 10% DEE with Hot EGR.

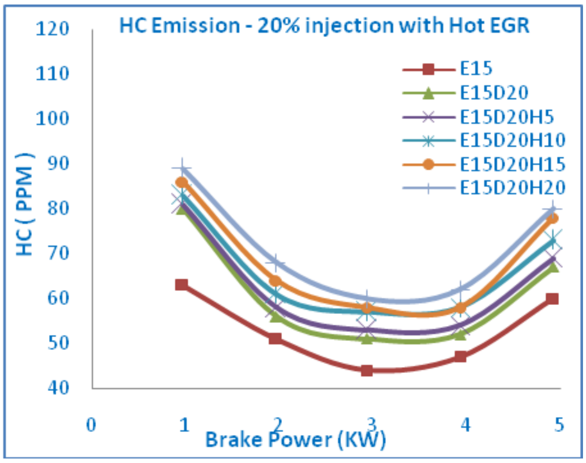

Figure 23: HC emission - 20% DEE with Hot EGR.

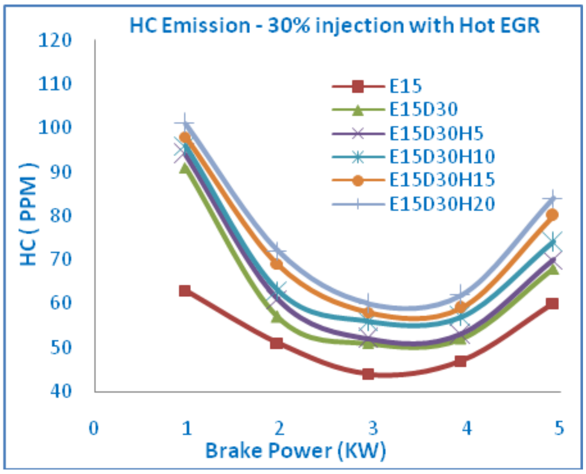

Figure 24: HC emission - 30% DEE with Hot EGR.

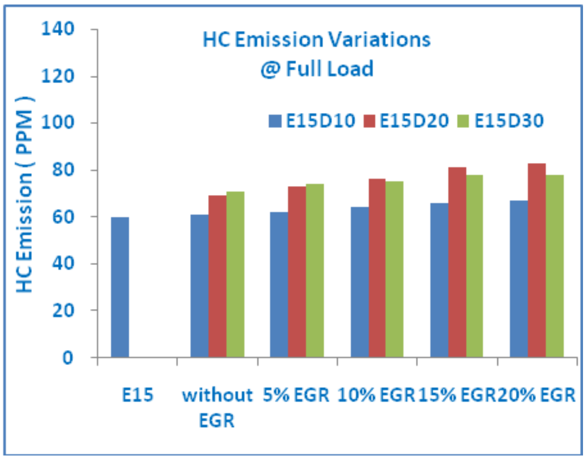

Figure 25: HC emission – Comparison at full load for all test fuels with various percentage of Hot EGR.

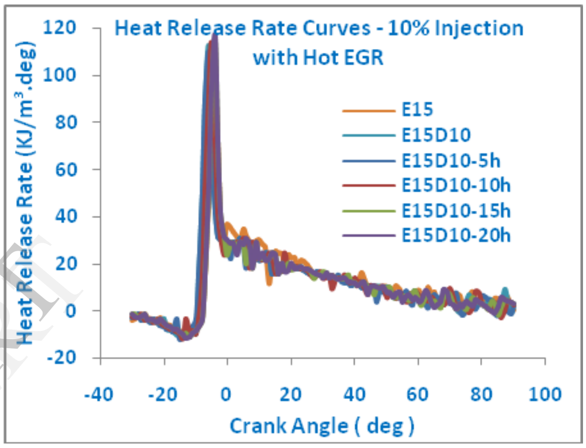

Figure 26: Heat Release Rate plots for 10% DEE with Hot EGR.

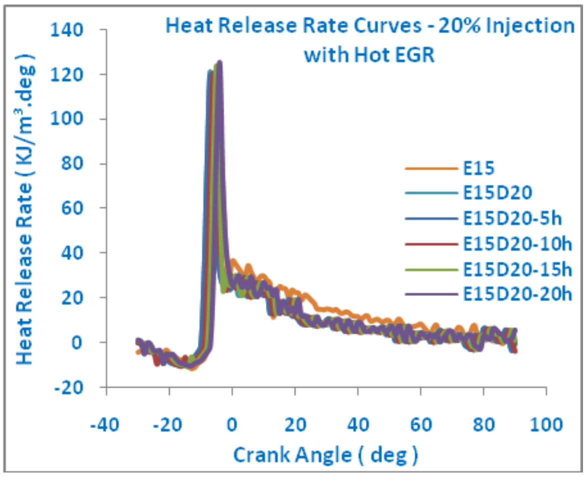

Figure 27: Heat Release Rate plots for 20% DEE with Hot EGR.

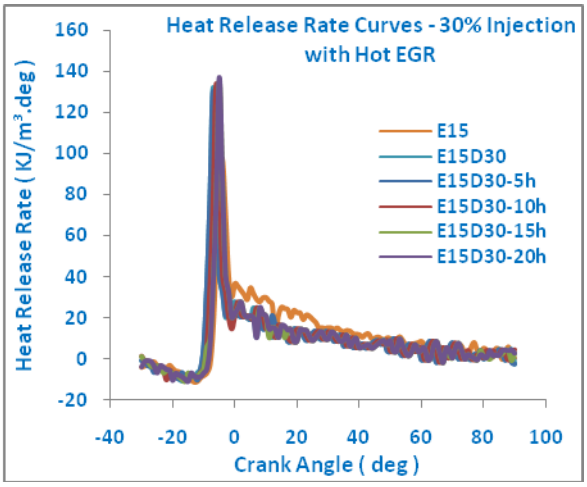

Figure 28: Heat Release Rate plots for 30% DEE with Hot EGR.

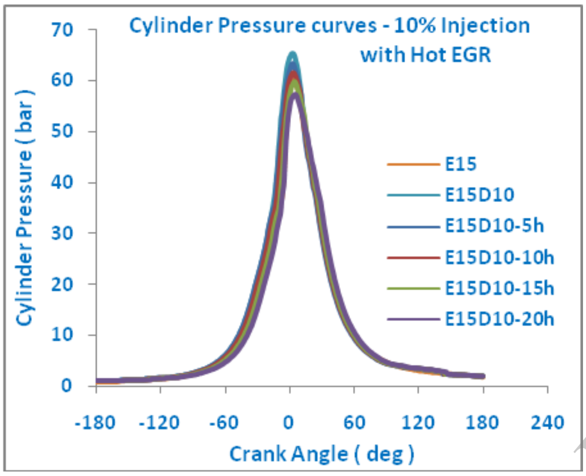

Figure 29: Cylinder Pressure Plots for 10% DEE with Hot EGR.

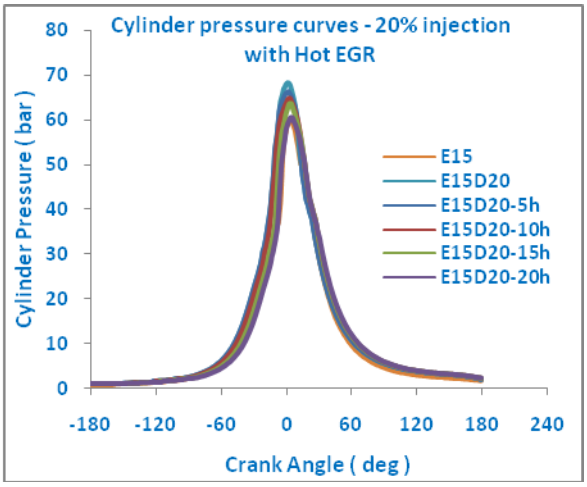

Figure 30: Cylinder Pressure Plots for 20% DEE with Hot EGR.

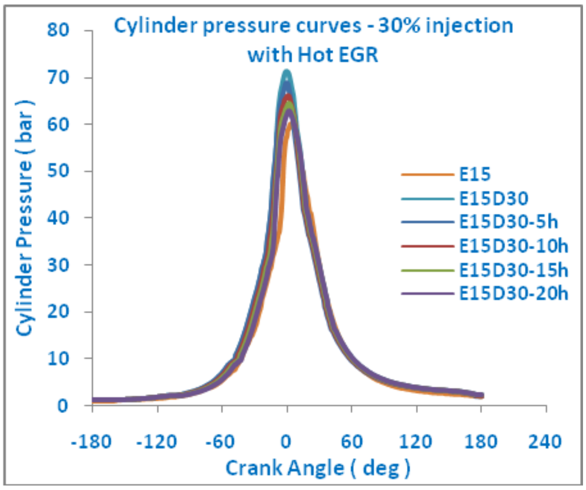

Figure 31: Cylinder Pressure Plots for 30% DEE with Hot EGR.

The cylinder pressure was decreased for E15, further inclusion of diethyl ether increases the maximum cylinder pressure while compare with E15. The EGR effect decreases the maximum heat release rate by 10 % due to the reduction in quality of combustible mixture while compare without EGR.

V. CONCLUSIONS

From the obtained results leads to the following conclusions that

1. Diethyl ether and ethanol may be a good partial substitute for the fossil fuel. Method of fumigation does not require any major modifications of the engine design. Blending of these fuels into diesel in large quantity is not stable for long periods. The optimum injection of diethyl ether into the inlet manifold is up to 30 percentages.
2. The brake thermal efficiency was increased 15% while compare with ethanol blended diesel. The decrease in the calorific value of ethanol while blending is compensated when the percentage of Diethyl ether injected. The effects of EGR improve the brake thermal efficiency slightly while compare the case of without EGR.
3. The increasing percentage of diethyl ether increases the NOx emission by 49%, The EGR inclusion reduces the NOx emission by 51%. The oxygen available in Diethyl ether induces the combustion rapidly leads to high temperature rise in combustion chamber is the basic cause for higher NOx emission. However the HC emissions were increased 33% at initial level load conditions and CO emissions were increased 65% at full load condition of the test rig. The smoke density decreases for initial load conditions at constant speed. The EGR develops the smoke density at initial run of test engine due to minimized ignition quality of combustible mixture.

4. The combustion parameters like maximum cylinder pressure and heat release rate were producing the promising results without EGR. When the inclusion of EGR with 20% of diethyl ether injection, the heat release rate and maximum cylinder pressure were decreased 4%. Above 30 percentage Diethyl ether injection through inlet manifold produces the audible knocking at full load conditions.

5. The maximum cylinder pressures were almost similar, when the engine runs with 20 percent EGR for all percentages of diethyl ether injection while compare E15.

6. The ignition delay period is decreased while increasing the percentages of Diethyl ether injection. The 20 and 30 percentage DEE injections shortened the delay about 3 crank angles. The EGR again increases the ignition delay about 2 crank angles. So the 20 percentage of Diethyl ether fumigation through inlet manifold with up to 15% EGR is the optimum percentage while E15 is the pilot fuel.

REFERENCES

[1] Alan C. Hansen, Qin Zhang and Peter W.L. Lyne,. “Ethanol–diesel fuel blends—a review”. Bioresource Technology, 2005, vol 96, pp: 277–285.

[2] B. Bailey, J. Eberhardt, S. Goguen and J. Erwin, “Diethyl ether (DEE) as a renewable diesel fuel”, SAE Paper No. 972978, 2011.

[3] Bang-Quan He, Shi-Jin Shuai, Jian-Xin Wang and Hong He, “The effect of ethanol blended diesel fuels on emissions from a diesel engine”, Atmospheric Environment 2006. 37; pp. 4965–4971.

[4] C.D. Rakopoulos, K.A. Antonopoulos, D.C. Rakopoulos, D.T. Hountalas and E.C. Andritsakis, “Study of the performance and emissions of a high-speed direct injection diesel engine operating on ethanol–diesel fuel blends”, Int. J. Alternative Propulsion, 2007., Vol. 1, No. 2/3, pp: 309 -324.

[5] D.H. Qi, H. Chen, L.M. Geng and Y.Z. Bian, “Effect of diethyl ether and ethanol additives on the combustion and emission characteristics of biodiesel-diesel blended fuel engine”, Renewable Energy 2011,vol: 36, pp 1252 – 1258.

[6] E. W. De Menezes, R. da Silva, R. Cataluna, and R. J. C. Ortega, “Effect of ethers and ether/ethanol additives on the physicochemical properties of diesel fuel and on engine tests”. Fuels, 2006, vol. 85, no. 5-6, pp. 815–822.

[7] Gurumoorthy s hebbar and Anantha krishna bhat, “Control of NOx from a DI diesel engine with Hot EGR and Ethanol Fumigation: An Experimental Investigation”. IOSR Journal of Engineering, 2012, ISSN: 2250-3021 Volume 2, Issue 7, PP 45-53.

[8] Heywood JB., Internal Combustion Engine Fundamentals. 1988, New York: McGraw Hill. 491- 514, 676-82.

[9] M. Ghazikhani, M. R. Kalateh, Y. K. Toroghi and M. Dehnavi, “An Experimental Study on the Effect of EGR and Engine Speed on CO and HC Emissions of Dual Fuel HCCI Engine”. Proceedings of world academy of science, engineering and technology, 2009, volume 40, pp – 136 – 141; ISSN: 2070-3740.

[10] Mack John Hunter, Buchholz Bruce A Flowers, Daniel L and Dibble Robert W, “The Effect of the Di-Tertiary Butyl Peroxide (DTBP) additive on HCCI Combustion of Fuel Blends of Ethanol and Diethyl Ether”. SAE International 2005-01-2135.

[11] Magın Lapuerta, Octavio Armas and Reyes Garcıa-Contreras, “Stability of diesel–bioethanol blends for use in diesel engines”. Fuels vol: 2007, 86, pp: 1351–1357.

[12] Mohamed Y.E. Selim, “Effect of exhaust gas recirculation on some combustion characteristics of dual fuel engine”, Energy Conversion and Management, 2003, vol 44, pp - 707–721.

[13] Masoud Iranmanesh, “Experimental Investigations about the Effect of New Combination of Biofuels on Simultaneous Reduction of NOx and Smoke Emissions in DI-Diesel Engine”, International Journal of Automotive Engineering 2013,Vol. 3, Number 2, pp: 379-392.