Experimental Investigation on Combustion Characteristics in DI Diesel Engine Using Diethyl Ether Fumigation with Ethanol Blended Diesel

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Abstract - The combustion characteristics of vertical mono cylinder DI diesel engine, while injecting diethyl ether into the inlet manifold at various proportions with the optimum percentage of ethanol blended diesel were experimentally investigated in the present study. Test fuel for secondary injection is diethyl ether and pilot fuel for test rig is E15 (15% bio ethanol blended with 85% diesel). The injected diethyl ether percentage into inlet manifold varied from 0 to 30 with the increment of 10 percent. The injection of diethyl ether into inlet manifold is done by using low pressure injector. The increasing injection percentage of diethyl ether into the inlet manifold raises heat release rate and cylinder pressure of the combustion chamber. Maximum heat release rate increased by 13% for 30 percent injection of diethyl ether. The cylinder pressure was increased by 3 bar when compared to pure diesel operation.

Key Words: Diethyl Ether (DEE), Combustion, Ethanol blend, Ignition Delay, Fumigation.

1. Introduction

The process of combustion can be explained in combustion chamber at two stages, initially the fuels leaves from the injector nozzle mix with air available is known as pre combustion and secondary the fuels starts to burn after the process of collision, minimize in droplet size, evaporation of droplets is known as rapid combustion. When fuel starts to mix with air inside the combustion chamber needs oxygen to initiates the ignition. Hence the oxygenated air quality improves the combustion earlier and short ignition delays. The concept of oxygenated renewable fuel fumigation increases the percentage of available oxygen in inlet air. Thus the study involved with oxygenated renewable fuel diethyl ether fumigation is adopted and experimentally evaluated. Can cinar et al [1] investigated the fumigation of alcohol fuel in HCCI engine with diesel as a pilot fuel and reported that heat release rate and cylinder pressure were increased at earlier combustion process itself. At the end of combustion, those parameters were decreased than diesel fuel. The variations were very small when compared to diesel. When injected diethyl ether percentage increased more than 40 percent, Engine knock is increasing abnormally. Oxides of nitrogen emission controlled marginally. The experimental study carried out by Jothi et al [2] reported the changes on combustion and other parameters in diesel engine using LPG with diethyl ether. The oxides of nitrogen, smoke and particulate matter emissions were decreased but CO and HC emissions were increased than diesel.

Mingfa yao et al [3] investigated in HCCI engine with fumigation of ethanol and found that ethanol fumigation eliminates cold start problems in low temperature of combustion chamber due to its property of ignition and exhaust gas recirculation also improves cylinder operating temperature of diesel engines [4]. The rapid combustion of methanol and higher latent heat helps in improving the combustion and reducing the emissions [5]. Water molecules mix with fuel in very low percentage act as an oxygen supplier at the combustion chamber when fuel is rich. The water molecules decrease the temperature of combustion process. Due to lower temperature, there was decrease in NOx emission. When the amount of water increases, NOx reduces further [6]. The blending of diethyl ether increases the latent heat of vaporization of the fuel mixture. Those properties of diethyl ether plays major role in reducing combustion temperature due to incomplete combustion takes place [8]. The increase in cetane index of fuel mixture while blending diethyl ether reduces the ignition delay period in combustion. The cylinder pressure and maximum heat release were decreased because of minimized ignition delay period [7, 8]. Mohanan et al [9] investigated the effect of 5% diethyl ether blending with diesel, which results in improved efficiency and minimized emission.

2. Materials and Methods

In this experimental study, bio ethanol blended with diesel was subjected to stability test and conducted the experimental evaluation at various proportions. The stability test gave better result for 5% ethanol with 95% diesel due its low miscibility quality. The other parameters like performance, emission and combustion were analyzed and the optimum ethanol blended diesel (E15) had been chosen as pilot fuel. The anhydrous 99.5% pure diethyl ether had been chosen as secondary fuel for injection into inlet manifold. The properties of test fuels were placed in Tab. 1.

The separate secondary fuel injection system was developed to inject the diethyl ether into inlet manifold at various percentages with respect to mass flow rate of air through inlet manifold. The test rig was allowed to run with sole diesel without fumigation, E15 without fumigation, E15D10 (10% fumigation of DEE with E15), E15D20 (20% fumigation of DEE with E15) and E15D30 (30% fumigation of DEE with E15) separately and observations were recorded.

Table 1. Properties of test fuels

Properties	Diesel	Bio Ethanol	E15	DEE
Density- Kg/m^3	833	772	821.3	713.4
Specific gravity	0.831	0.769	0.813	0.712
Kinematic Viscosity-cSt (mm^2/s)@40°C	3.0	1.2	2.8	0.23
Cetane number	49	6	41	127
Flash point °C	64	13	59	-40
Auto ignition temperature °C	315	235	306	160
Low calorific value (KJ/KG)	42500	24500	40125	33890
Oxygen percentage - wt%	0	35	--	21

3. Experimental Setup

The experiment is conducted on Kirlosker TV-1 engine. Technical specifications of the kirlosker engine are tabulated in Tab. 2. The engine ran at constant speed at 1500 rpm for different load conditions. The eddy current dynamometer was used for applying loads to the engine. The smoke density was measured using an AVL smoke meter. Combustion parameters like pressure in cylinder, net heat release rate and maximum pressure were measured by AVL combustion analyzer. The AVL combustion analyzer placed with experimental setup was capable to measure the pressure up to 250 bar and capable to capture the heat release rate and cylinder pressure for each crank angle. The arrangement of experimental setup was placed in Fig. 1.

Table 2. Specifications of test engine

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

The inlet air mass flow rate was calculated for each load conditions of test engine. The secondary fuel injection system consists of following setup procedure. The injection of diethyl ether into the inlet manifold is done by low pressure injector which is connected to pressure gauge to maintain the injection pressure. The other end of pressure gauge is connected with fuel pump placed in the diethyl ether fuel tank. The secondary fuel injection system consist a return value to adjust the injection pressure. The power supply to the injectors is connected through a digital counter which is getting continuous signals from the proximity sensor placed in fly wheel of the engine. The interval of injection timing is done by the counts which made from the rpm of test engine. The test engine is set to run for 20 minutes at initial load with test fuels. The observations were recorded two times to derive average value at steady state of engine run. The layout of secondary fuel injection system is shown in Fig. 2

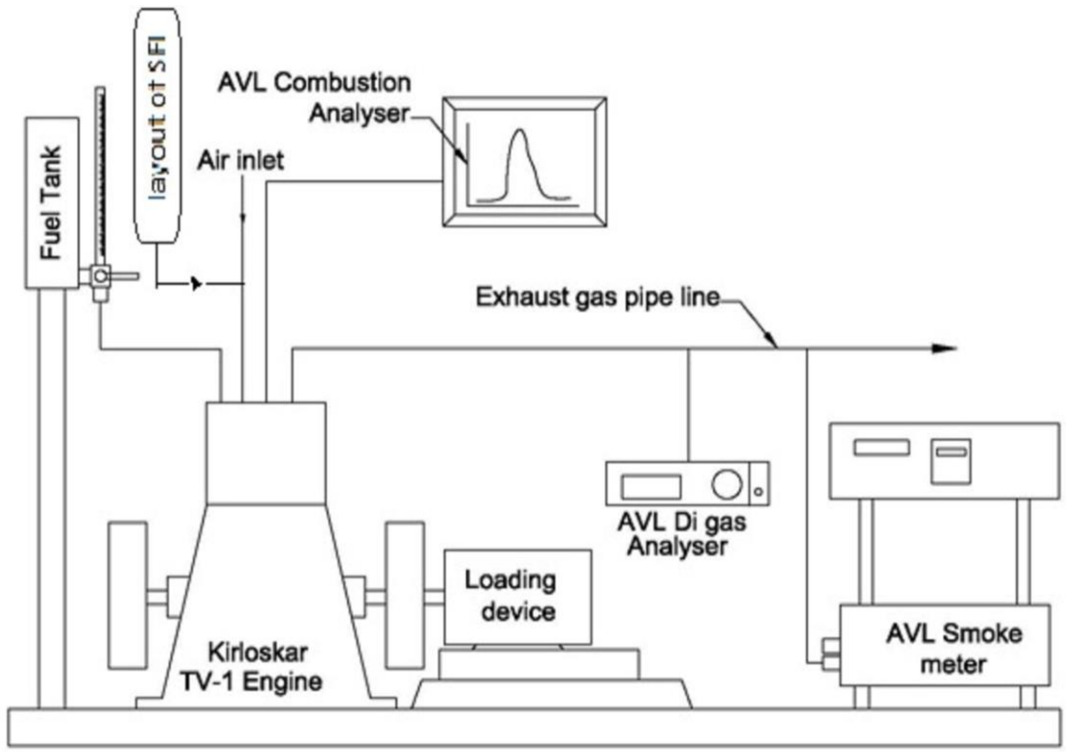

Figure 1. Experimental setup

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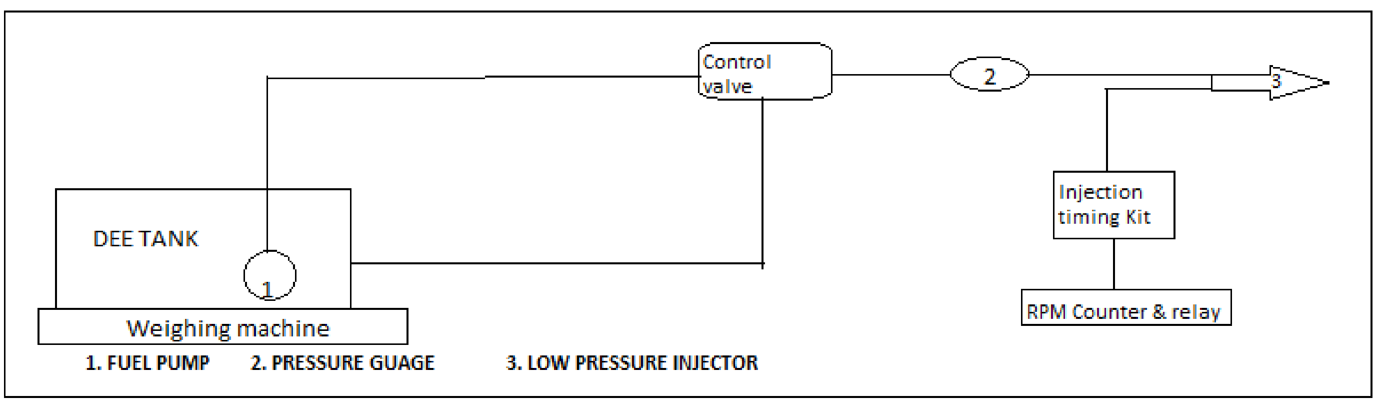

Figure 2: Layout of SFI (Secondary Fuel Injection).

4. Result and Discussion

The stability test gave better result for 5% ethanol with 95% diesel due to its low miscibility quality. The other parameters like performance, emission and combustion were analyzed and the optimum ethanol blended diesel (E15) had been chosen as pilot fuel. The specific fuel consumptions were decreased for increased percentages of DEE injections by 25%, 33% and 45% respectively for 10%, 20% and 30% injection of diethyl ether due to the increased calorific value of combustible mixtures. The brake thermal efficiency was improved for increased percentages of DEE fumigation.

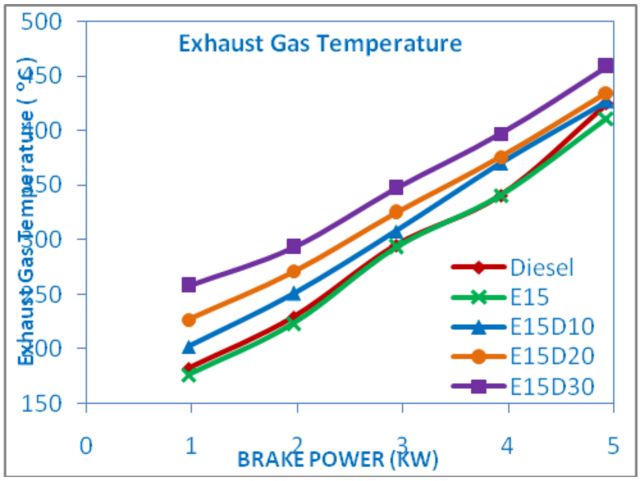

Figure 3. Exhaust gas temperature plots

The exhaust gas temperature for above mentioned test fuels at each load conditions were placed in Figure 3 and the percentage increase in exhaust gas temperature with respect to diesel without fumigation were placed in Figure 4. The increased injection percentage of DEE increases the exhaust gas temperature by 0.5%, 3% and 8% respectively. The oxygenated fuel addition leads to rapid combustion process which increases the temperature inside the combustion chamber. It was clearly proven by the exhaust temperature shown in Figure 3. The same was experienced by mohanan et al [9] and he reported increased exhaust gas temperature due to oxygenated additives.

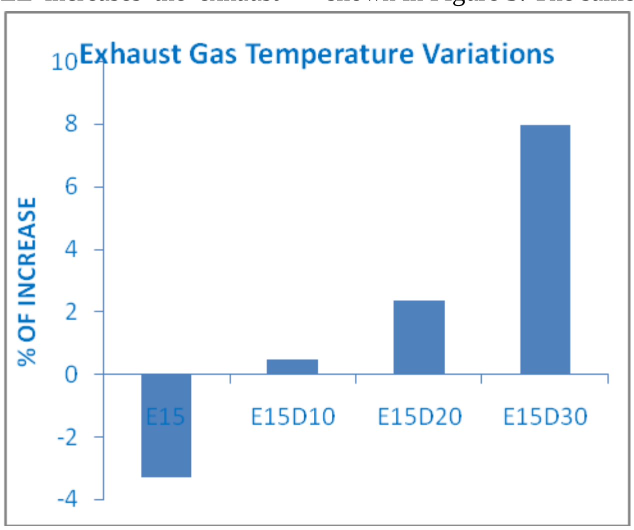

Figure 4. % Variations of EGT.

The heat release rate for each test fuel with respect to each crank angle at full load conditions were plotted in Figure 5. The maximum heat release rate for each test fuels were 117, 97, 112, 121 and 132 KJ/m3.deg respectively for pure diesel, E15, E15D10, E15D20 and E15D30. From the observations it was clear that blending of alcohol fuel with diesel reduces heat release rate and cylinder pressure in combustion chamber. The auto ignition temperatures of alcohol fuel had initiated the combustion process earlier than pure diesel and lead to complete combustion [8]. In the case study of ethanol blend, the reduction in calorific value of combustible mixture and reduced cetane index lead to reduction in maximum heat release rate.

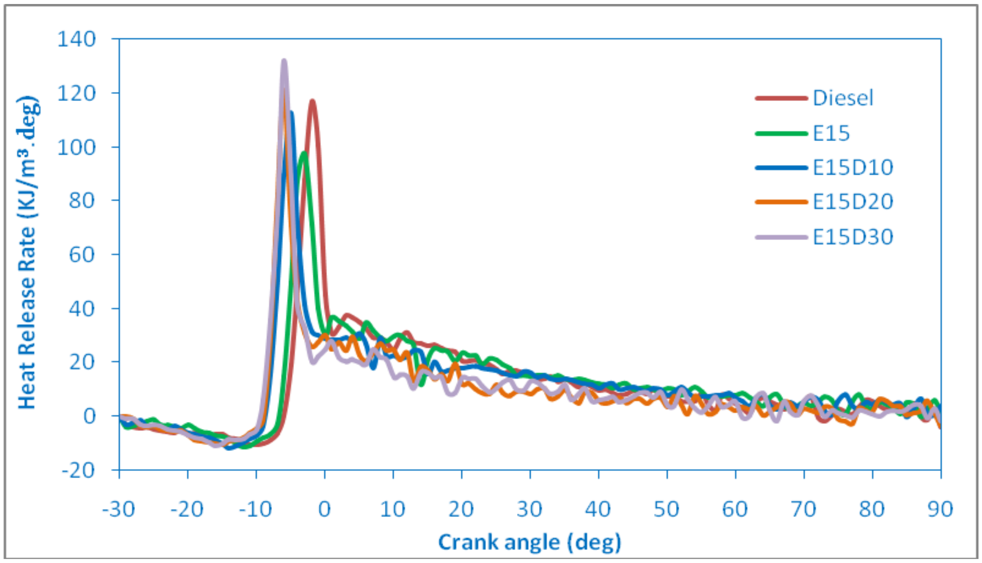

Figure 5. Heat release rate for each crank angle**.**

When inlet air was oxygenated through fumigation of diethyl ether, it improved the quality of inlet air and initiated pre combustion process immediately after the pilot fuel injected into combustion chamber. The ionization of diethyl ether in inlet air was improved through the process of pressurized injection, which induced the pre combustion earlier. That was clearly evident from the observations shown in Figure 7.

When injected diethyl ether percentage increased more than 30 percent, engine knock increased abnormally. Thus the study was limited to 30% injection of DEE in inlet manifold due to audible knocking occurred [1]. Immoderate heat release rate and oscillations in cylinder pressure were observed in 30 percent injection of DEE. This is mainly due to rich oxygenated fuel mixture with high cetane index in combustion chamber leads to rapid combustion [10].

The cylinder pressure for each test fuels at full load conditions were shown in Figure 6. The increased percentage injection of DEE increased heat release rate inside combustion chamber lead to increase in cylinder pressure also. It was observed that cylinder pressure was increased 3 bar for 30 percent injection of DEE. While blending alcohol fuel with diesel, cylinder pressure was reduced by 13.8% than diesel. This was due to decreased calorific value of E15, which leads to poor diffusion combustion phase.

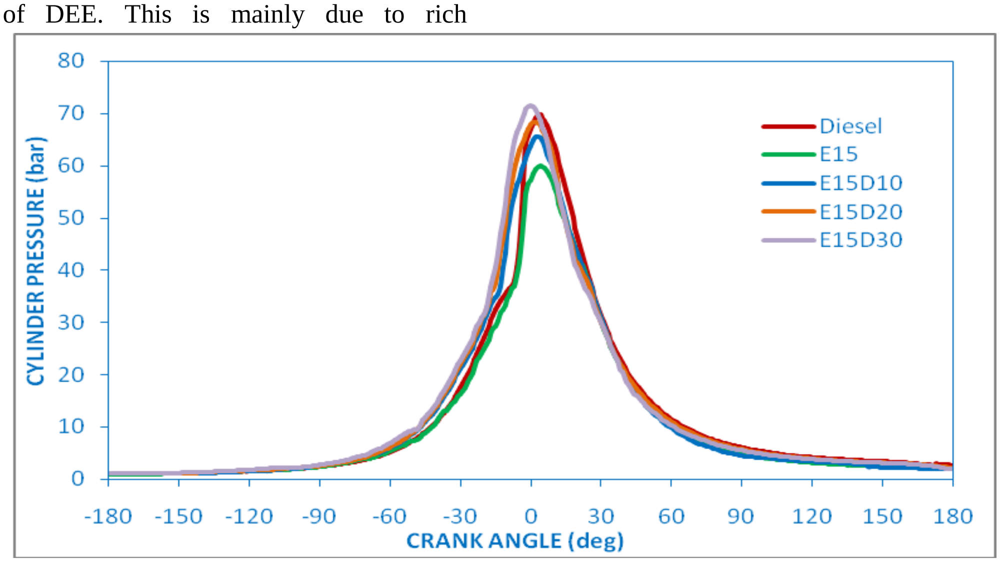

Figure 6. Cylinder pressure for each crank angle

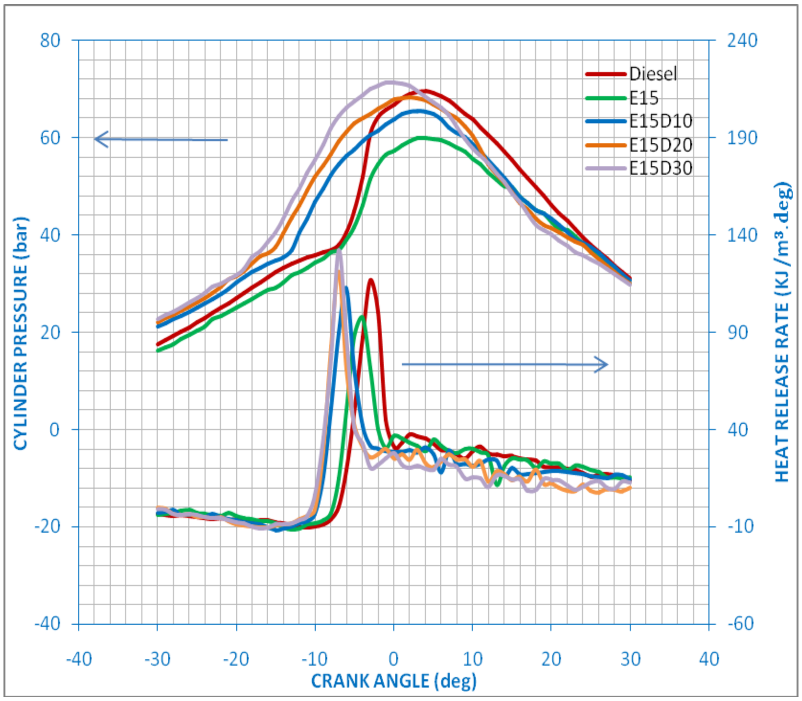

Figure 7. Comparison curves of heat release rate and cylinder pressure

The ignition delay shortened for all percentages of DEE injection were clearly evident from the plots of combustion characteristics. The 10% injection of diethyl ether shortened the delay by 2 crank angles and 30% injection shortened the delay by 4 crank angles. The shorter delay period was achieved by using high cetane index fuel diethyl ether [7]. Earlier combustion of DEE increased the combustion temperature in combustion chamber.

5. Conclusion

Results from the experimental investigation of fumigative diethyl ether into inlet manifold concludes the following points

- Blending of ethanol with diesel at 5, 10, 15 and 20 percentages were subjected to experimental investigation on performance, emission and combustion characteristics. The E15 was producing the viable results among those blends. The maximum heat release rate and cylinder pressure for E15 (pilot fuel for this study) were decreased than diesel.

- The exhaust gas temperature increases with respect to increase in injection percentage of diethyl ether. The maximum exhaust gas temperature 459°c was recorded for 30% injection at full load of test rig.

- The increased injection percentage of diethyl ether increases the cylinder pressure respectively. The maximum cylinder pressure 72 bar was observed for E15D30 and which was three bar higher than diesel. The ignition delay shortened for fumigation of DEE by two, three and four crank angles respectively.

- Heat release rate for all percentages of diethyl ether injection were increased than E15. The maximum heat release rate 132 KJ/m³.deg was derived for 30% injection of diethyl ether into inlet manifold. The maximum heat release rate for E15D20 is almost equal to the heat release rate of diesel.

References

[1] Can Cinar, Ozer Can, Fatih Sahin and H.Serdar Yucesu, “Effects of premixed diethyl ether (DEE) on combustion and exhaust emissions in a HCCI-DI diesel engine”, Applied Thermal Engineering 30 (2010) 360–365.

[2] N.K.M. Jothi, G. Nagarajan and S. Renganarayanan, “Experimental studies on homogeneous charge CI engine fueled with LPG using DEE as an ignition enhancer”, Renewable Energy 32 (9) (2007) 1581–1593.

[3] Mingfa Yao, Zhaolei Zheng and Haifeng Liu, “Progress and recent trends in homogeneous charge compression ignition (HCCI) engines”, Progress in Energy and Combustion Science 35 (2009) 398–437.

[4] B. Bailey, J. Eberhardt, S. Goguen and J. Erwin, "Diethly ether (DEE) as a renewable diesel fuel", SAE Paper No. 972978.

[5] V. Manente, P. Tunestal and B. Johansson, "Influence of the compression ratio on the performance and emissions of a mini HCCI engine fuelled with diethyl ether", SAE Paper No. 2007-01-4075.

[6] J.H. Mack, D.L. Flowers, B.A. Buchholz and R.W. Dibble, "Investigation of HCCI combustion of diethyl ether and ethanol mixtures using carbon 14 tracing and numerical simulations", Proceedings of the Combustion Institute 30 (2005) 2693–2700.

[7] Oda, Y.Osafune, S.Ueda and Fujimura. K., "Clean combustion technology in diesel engines operated with dimethyl ether". Mitsubishi Heavy Industries, Technical Review, 40(6) (2003) Advanced Technologies, 1-5.

[8] Kannan T.K. and Marappan R, " Comparative study of performance and emission characteristics of a diesel engine fuelled by emulsified biodiesel/diethyl ether blended biodiesel", Journal of Applied Science, 11(16), (2011) 2961-2967.

[9] Mohanan.P, Kapilan.N and Reddy.R.P., " Effect of diethyl ether on the performance and emission of a 4-S Di diesel Engine". SAE Technical Paper 2003-01-0760.

[10] Heywood, J.B., 1988, Internal Combustion Engines fundamentals, Mc Graw Hill, New york.