Experimental Investigations on Compression Ignition Engine Supplemented with Ethanol and Di-Ethyl–Ether Blends

Ravi.S

Department of Mechanical Engineering, Jeppiaar Maamallan Engineering College, Sriperumbudur, Tamil Nadu, India

Abstract:-**The goal of this research work is to percept the performance and emission characteristics of diesel engine using oxygenated fuels. In view of this, experimental investigations were carried out on a single cylinder four stroke direct injection vertical water cooled diesel engine using Ethanol and Diethyl Ether blended fuels in different volume ratios with Diesel fuel. The experimental investigation was performed with three different blends of Ethanol(E), Diethyl ether(DEE) and Diesel(D) in various ratios (E10% + DEE5% + D85%), (E10% + DEE7.5% + D82.5%) and (E10% + DEE10% + D80%) in comparison with pure diesel (D100%) to assess the impact of using Ethanol and Diethyl Ether-Diesel blends on diesel engine performance. For the same rated speed and compression ratio, various engine parameters such as power, thermal efficiency and fuel consumption, exhaust emissions such as smoke opacity, Hydrocarbon, CO, and NOx, were measured. The results indicate that the fuel blends have higher brake thermal efficiencies at all loading conditions and also the efficiencies increase with the increase of diethyl ether concentration. At full load, E10% + DEE10% + D80% has lower Brake Specific Fuel consumption than diesel. NOx emission and smoke emission also reduced to great extent in fuel blends compared to diesel.**

Keywords: **- Oxygenated fuels- Ethanol - Di-Ethyl-Ether - Performance characteristics - Emission parameters**

Nomenclature

D	**Diesel**
E	**Ethanol**
DEE	**Di-Ethyl-Ether**
NOx	**Nitrogen Oxide**
BP	**Brake Power**
BSFC	**Brake Specific fuel Consumption**
C.I	**Compression Ignition**
CO	**Carbon monoxide**
EGT	**Exhaust gas temperature**
D80%	**Diesel 80%**
E10%	**Ethanol 10%**
DEE10%	**Di-Ethyl-Ether 10%**
HC	**Hydrocarbons**
BTE	**Brake thermal efficiency**
O_2	**Oxygen**
CO_2	**Carbon dioxide**

I. INTRODUCTION

Diesel engine are indispensable equipment in transport, agriculture and power generation sector because of their higher fuel conversion efficiency, higher power output and higher torque capability compared to gasoline engine. Fossil fuel like diesel fuel is fast depleting and their usage in diesel engine cause emissions that affect both environment and human health. Due to high consumption rate of diesel fuel, huge population is constantly exposed to hazarded gaseous emission like NOx, HC, CO, CO_2, and smoke from diesel engine. Particulate matter (PM) emissions from diesel combustion contribute to urban and regional hazards.Particulate matter has been linked to premature death, and increased respiratory symptoms and disease. In view of increased concerns regarding the effects of diesel engine particulate and NOx emissions on human health and the environment and more stringent government regulation on exhaust emissions, reducing the NOx and particulate emission from diesel engines is one of the most significant challenges. The rapid depletion, uneven distribution of petroleum fuels, their ever increasing costs and great concern over pollution led to search for an alternative fuel to replace conventional fuels.The most promising alternative possibility to clear this critical issue is to use the oxygenated fuels either in pure form or blended with diesel to provide sufficient oxygen and promote combustion and reducing PM emission and possibly decreasing NOx emission. Oxygenated fuels are the attractive class of synthetic fuels in which Oxygen atoms are chemically bound within the fuel structure. This Oxygen bond in the oxygenated fuel is energetic and provides a chemical energy that result in no loss of efficiency during combustion. The optimization of oxygenated fuels, to be used either as, neat fuel or as an additive, offers significant potential for reduction in particulate emission. In this study, two oxygenates are tested with diesel in blended form to investigate the performance and emissions of a diesel engine. Ethanol is one of the renewable, bio based and eco-friendly oxygenates for internal combustion engine. Bio-ethanol is a form of renewable energy that can be produced from agricultural feed stocks. It can be made from very common crops such as hemp, sugarcane, potato, cassava and corn. Ethers are a class of organic compounds that contain an ether group, an oxygen atom connected to two alkyl or aryl groups. They have the general formula R–O–R′, where R and R′ represent the alkyl or aryl groups. Ethers can again be classified into two varieties if the alkyl groups are the same on both sides of the oxygen atom, then it is simple or symmetrical ether, whereas if they are different, the ethers are called mixed or unsymmetrical ethers. A typical example of the first group is the solvent and anaesthetic diethyl ether, commonly referred to simply as "Ether" ($CH_3–CH_2–O–CH_2–CH_3$). Ethers are common in organic chemistry and even more prevalent in biochemistry, as they are common linkages in carbohydrates.

II. LITERATURE REVIEW

Several researchers have conducted experimental investigation on the diesel engine fuelled with diesel blended fuels. Some of them are briefly highlighted in the following section.

Dinesh Kumar Soni , Rajesh Gupta [1] observed that as the percentage of methanol increases in diesel from 10% to 30%, significant reduction has achieved 65%, 68% and56% in NO, CO and HC emission respectively with respect to diesel alone. Therefore, D+M30 blend may be considered as optimum blend in terms of emission reduction. **Pragyan. P. Patnaik, Shakti P[2]** investigated the effect of $FeCl_3$ and diethyl ether as additives on compression ignition engine emissions. They observed decreased CO, HC, O_2 emissions and smoke generations accompanied with an increase in the N_O and CO_2 emission with $FeCl_3$ additions. The diesel and DEE15 combination showed the highest BTE and lowest BSFC, HC, CO, CO_2 emissions and smoke generation as compared to $FeCl_3$ diesel and standard diesel mode. **Loannis Kalargaris, Guohong Tian, SaiGu [3]** concluded that the engine was able to operate stably on low density polyethylene oil produced at 700^{o}C[LDPE700] and ethylene-vinyl acetate oil[EVA] produced at 900^{o}C blends. LDPE700 has very similar combustion characteristics with diesel, while EVA blends have slightly longer ignition delay period, lower cylinder peak pressures and longer combustion period. The brake thermal efficiency of engine is marginally reduced when LDPE700 was used in comparison with diesel and decreased by 1.5–2 % when EVA blends were used. LDPE700 produced lower NOx, CO and CO_2 emissions than diesel and higher UHC, while EVA blends produced higher NOx and UHC emissions and lower CO and CO_2 in comparison to diesel. **Pinzi.S and Dorado.M.P[4]** observed the Influence of Ethanol/Diesel fuel and Propanol/Diesel fuel blends over exhaust and noise emissions. They concluded that the presence of short chain alcohols in the blend increases sound pressure level, probably due to a reduction of the blend cetane number. Exhaust emissions show a low reduction of soot emissions when the presence of alcohol in the blend increases, probably due to the increase of oxygen in the fuel. On the other hand, oxygenated alcohol/diesel fuel blends show an increase of HC and CO emissions, as a result of incomplete combustion. This trend can be probably due to the low homogeneity of the blends or the thermal decomposition of the alcohol. **Yanuandri Putrasari, Arifin Nur, Aam Muharam[5]** analysed Performance and emission characteristic on a two cylinder DI diesel engine fuelled with ethanol-diesel blends. The results indicate that the engine power and the indicated mean effective pressure increase with increasing of ethanol percentage, brake specific fuel consumption and exhaust gas temperature decrease. From the experiments, as the increase of ethanol percentage content, the emission of CO, HC and smoke decrease. **Ethanol is an excellent alternative to partially substitute fossil fuels, due to its renewable and oxygenated nature, which is responsible of particulate emissions reduction when used to fuel compression-ignition engines. The main drawback of its use as fuel is its poor solubility when it is blended with diesel fuel. Additives can be used to improve its miscibility with diesel. Some of the diesel additives are Ethylhexyl Nitrate, Castor oil, Butanol and Di Ethyl Ether**. **M.D Redel-macis and S.Pinzi[6]** analysed the Ternary blends of diesel fuel oxygenated with ethanol and castor oil for diesel engines. They concluded that the use of castor oil improves miscibility of ethanol with Diesel blends. Sandip S. Jawre and Amit Bhagat conducted the experiment on Diethyl Ether as Additive and its Effect on Diesel Engine Performance. They concluded that the presence of oxygen in the DEE blend helps in complete combustion of the fuel raising the BTE. When small quantities of additives like DEE is started adding the NOx content started reducing. With increasing DEE percentage in the blend, CO emission level is decreased for 5% DEE. **Ahmad Fitri Yusop, Mohd Hafizil Mat Yasina[7]** analysed particulate matter emission of diesel engines using ester-ethanol-diesel blended fuel. The results show that increasing ethanol in blended fuel will decrease the particulate matter. **Pappula Bridjesh, Pitchaipillai Periyasamy[8]** analysed Methoxy Ethyl Acetate and DEE as additives on diesel engine using waste plastic oil diesel blends. The test results are compared with diesel. An increase in brake thermal efficiency and abatement in brake specific fuel consumption are seen with 50D+40W+10MEA, as well as reduction in hydro carbon, carbon monoxide and smoke emissions. 50D+40W+10DEE showed reduced NOx emission.

Several attempts made by researchers to reduce diesel emission, one such method is blending diesel with alternate fuel like alcohol, ether, to get the desired properties. With reference to the literature survey, no considerable experimental studies have been made on the effect of Di Ethyl Ether additives to Ethanol/Diesel blends. In our experiment, we have used ethanol and diethyl ether in various ratios to blend with diesel, to reduce diesel emission without compromising the engine performance and the readings are generated. In this work, the use of Di Ethyl Ether as additive to increase the miscibility of ethanol/diesel fuel blend is proposed. Performance and emission characteristics are tested for various Ethanol, Di-Ethyl-Ether and Diesel blends and also we have compared the result with diesel (100%) reading for better understanding of various performance. The investigations shows the ternary blend has improved engine performance and emission characteristics to a greater extent as comparable to that of diesel.

For our experiment, the normal diesel supplied by Indian Oil Corporation was procured from the local market. The Ethanol and Diethyl Ether supplied by Sri Venkateswara Engineering Consultancy Services, Kanchipuram was taken for blending with diesel. The readings were generated for the following fuel blends and various Performance characteristics and Emission characteristics of diesel blends were studied.

BLEND 1- Ethanol (E) 10% +Diethyl Ether (DEE) 5%+ Diesel (D) 85%

BLEND 2- Ethanol (E) 10% + Diethyl Ether (DEE) 7.5% + Diesel (D) 82.5%

BLEND 3- Ethanol (E) 10% + Diethyl Ether (DEE)10% + Diesel (D) 80%

Preparation of test fuels

For our research work, three test fuels were prepared. Ethanol (E) 10% +Diethyl Ether (DEE) 5%+ Diesel (D) 85% , Ethanol (E) 10% + Diethyl Ether (DEE) 7.5% + Diesel (D) 82.5%,Ethanol (E) 10% + Diethyl Ether (DEE) 10% + Diesel (D) 80%. The complete mixing of ethanol and diethyl ether with diesel was done with the help of a mechanical stirrer for 45minutes.The physical properties of the fuels were determined as per ASTM standards.

Properties of test fuels

The properties of Diesel, Di-Ethyl-Ether and Ethanol were measured and compared with ASTM standard. The properties were found to be having coincidence with the ASTM standards.

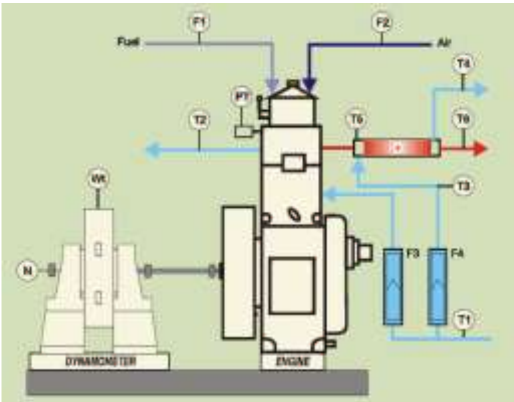
III. EXPERIMENTAL INVESTIGATION

The experimental was carried out on a vertical four stroke single cylinder naturally aspirated engine. The specifications of the engine are given below.

Properties of test fuels

Properties	Diesel	Ethanol	DEE	Blend-1	Blend-II	Blend-III
Molecular formula	$C_{12}H_{26}$- $C_{14}H_{30}$	C_2H_6O	$C_4H_{10}O$	-	-	-
Higher calorific value at 15°C Kj/kg	45600	29700	36840	35000	37800	39200
Density Kg/m^3	847	785	713	750	790	820
Specific gravity at 15°C	0.88 - 0.82	0.794	0.714	0.72	0.75	0.79
Kinematic viscosity at 40°C cSt	3.9	0.795	0.223	1.8	1.85	2
Latent heat of vaporization Kj/kg	250	846	377	300	350	365
Cetane number	45	5	125	30	32	35
Carbon content % Weight	84 - 87	52.2	64.86	75	79	82
Oxygen content % Weight	0	34.7	21	5	7	9
Flash point ^{o}C (closed cup)	66	16	-45	58	60	61
Boiling point ^{o}C	188	78	35	178	185	189
Auto-ignition temperature ^{o}C	315	422	160	300	325	340

Experimental Investigation setup



LEGEND

T1	- Engine cooling water inlet	F1	- Fuel line
T2	- Engine cooling water inlet	F2	- Air inlet
T3	- Calorimeter water inlet	F3	- Engine cooling water
T4	- Calorimeter water outlet	F4	- Calorimeter water
T5	- Calorimeter exhaust gas in	PT	- Pressure transmitter
T6	- Calorimeter exhaust gas out	N	- Crank angle encoder

Specifications of the Engine

Parameter	Specification
Engine Model	Vertical 4S-engine
NumberOf Cylinder	Single cylinder
Rated Power	4.4Kw
Rated Speed	1500 rpm
Bore Diameter	87.50mm
Swept Volume	661.45cc
Stroke Length	110mm
ConnectingRod Length	234mm
Compression Ratio	17.50
Orifice Diameter	20.00mm
Fuel Pipe Diameter	12.40mm
Cooling System	Water cooled

IV. EXPERIMENTAL PROCEDURE

Initially at no load condition the engine was started using normal diesel as fuel with the experimental setup engine as shown in the diagram. After getting warm-up, nil load was applied and the engine was allowed to run for a while. After the engine reaches the equilibrium condition, performance and emission characteristics parameters were observed and recorded by using AVL DiGas 444 N Gas Analyzer, AVL 437 C Smoke Meter and other performance measuring sensors. Now, load of 25% is added by using eddy current type dynamometer and the above procedure is repeated by varying the load until 100% step-by-step of 25%. After the checking of various performance and emission characteristics for diesel fuel the engine was shutdown. Now diesel fuel was replaced by fuel blend consisting of Ethanol 10%, Diethyl Ether 5% & Diesel 85%, then the performance and emissioncharacteristic for the same is measured and recorded by the same procedure done for diesel by varying the load.The same procedure is followed for other two fuel blends consisting of Ethanol 10%, Diethyl Ether 7.5% & Diesel 82.5% and Ethanol 10%, Diethyl Ether 10%, Diesel 80% and then various performance and emission characteristics are observed and recorded. From the observed, recorded and generated values, the various performance, combustion and emission characteristics of the engine using diesel and different blended fuels at different loading condition were presented in the form of graph.

V. PERFORMANCE CHARACTERISTICS

Brake Specific Fuel Consumption: Brake Specific fuel consumption is the amount of fuel consumed by a vehicle for each unit of Brake power output. Brake Specific Fuel Consumption by the engine using diesel and ethanol - diethyl ether – diesel blends at various loading conditions is presented in bar graph as shown in figure 3. At loading condition of 25%, the fuel blend consisting of E10%, DEE5% and D85% has more BSFC value than the diesel. It may be due to lowest energy content, high viscosity of the blend Ethanol and Diesel. The BSFC for Diesel,E10%, DEE5% and D85%,E10%, DEE7.5% and D82.5% and E10%, DEE10% and D80% at full load are 264g/kWh 265g/kwh, 266g/kWh and 254g/kWh respectively. The fuel blend consisting of E10%, DEE10% and D80% has the lower BSFC value than neat diesel. The decrease in BSFC may be due to less kinematic viscosity, lower calorific value and the higher latent heat of evaporation of Ethanol and Di-Ethyl-Ether blends when compared to Diesel.[28]

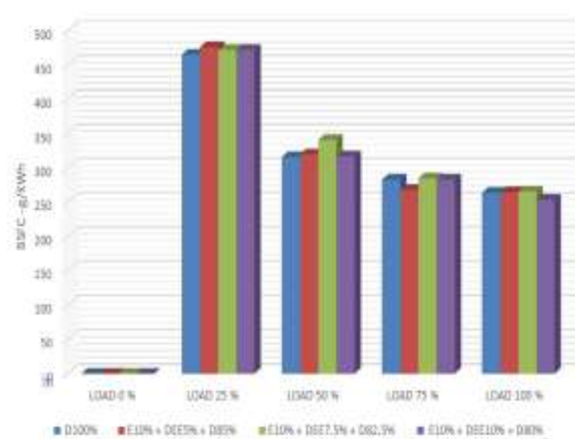
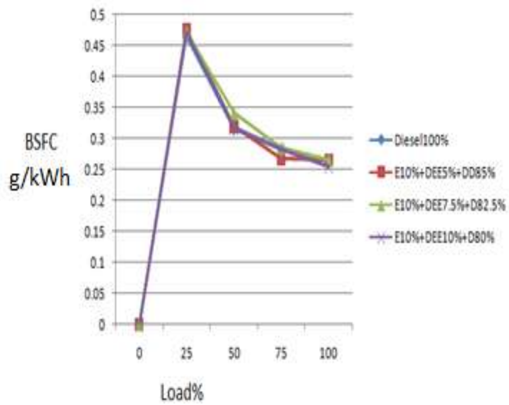


Fig 3: Brake Specific Fuel Consumption Vs Load



Brake Thermal Efficiency: Brake thermal efficiency is the ratio between thepower output and the energy of the fuel. It is used to evaluate how well an engine converts the heat from the fuel to mechanical energy. Brake Thermalefficiency of the engine using Diesel and Ethanol - Diethyl Ether – Diesel blends at various loading conditions is presented by bar graph as shown in figure 5. From the graph, Ethanol - Diethyl Ether – Diesel blends have higher brake thermal efficiency at all loading conditions and also the efficiencies increases with the increase of Ethanol and Diethyl ether concentrations.This is due to reduction in viscosity which leads to improved atomization, vaporization and combustion. Due to a faster burning of Ethanol and DEE in the Diesel blend, the thermal efficiency improved.[27]

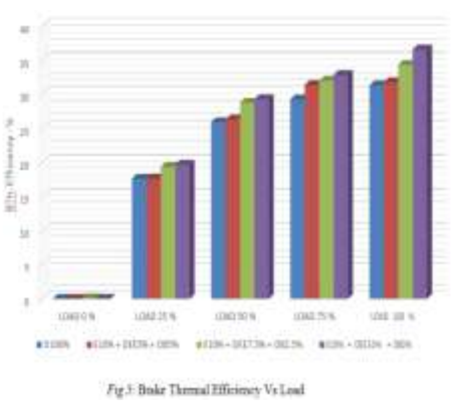
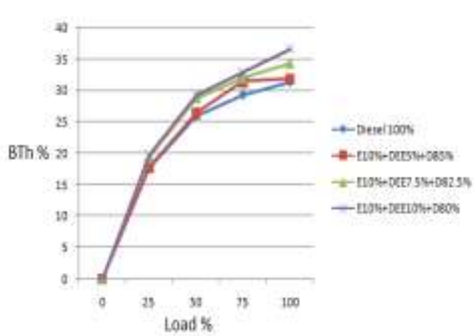


Fig.5



VI. EMISSION CHARACTERISTICS

Carbon Monoxide: Carbon monoxide emission by the engine using Diesel and Ethanol - Diethyl Ether – Diesel blends at various loading conditions is recorded and from that data, graph is generated as shown in figure 7. From the graph , it is known that, at nil loading condition fuel blends are having less CO emission compared to diesel and also at maximum loading condition fuel blend consisting of E10%, DEE7.5% and D82.5% has recorded the lowest percentage of CO emission.This mixture of E10%, DEE7.5% and D82.5% combination indicates reduction in CO emission less than diesel at full load. This can be achieved by addition of optimum DEE which improves the start of ignition and suppresses the ignition delay due to its low boiling point and viscosity that helps in proper mixing with air leading to early burning and allows more time for oxidation of the fuel. The molecular oxygen in DEE also improves the combustion that can leads to better oxidation of the fuel air mixture [13]. The higher cetane number of DEE acts as an ignition enhancer and reduces the combustion duration indicating improved rate of combustion, resulting in a reduced CO emission [25, 16]

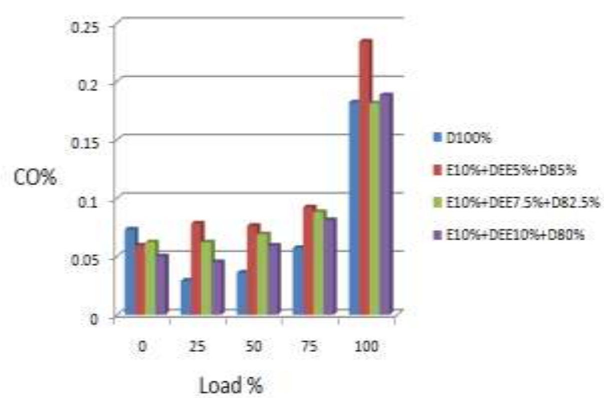


Figure.*7*

Hydro Carbon: Hydro Carbon emission by the engine using Diesel and Ethanol - Diethyl Ether – Diesel blends at various loading conditions is recorded and from that data, graph is generated as shown in figure 8. At nil loading condition fuel blend consisting of E10%, DEE5% and D85% has lower HC emission.A reduction of HCemission was observed by adding Ethanol and DEE in diesel at zero load ascompared to diesel at full load. The catalytic effect Ethanol and DEE improvesthe combustion leading to oxidation of unburnt hydrocarbon into CO_2 eventually resulting in decrease of HC emission. In E10%, DEE5% and D85% combination, HC emission was found to be lowered compared to that with diesel alone. The low boiling point and high cetane number of DEE give an advanced start of combustion which can leads to increase in combustion gas temperatureat earlier stage of combustion and rapidly reaches the activation temperature of carbon combustion. This can improve the oxidization of hydrocarbon fuels, leading to better combustion with a reduction in HC emission [12,14].

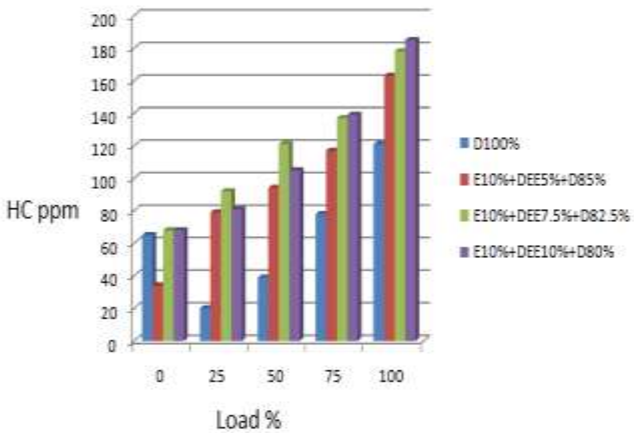


Figure.8

NOx: NOx emission by the engine using Diesel and Ethanol - Diethyl Ether – Diesel blends at various loading conditions is recorded and from that data, graph is generated as shown in figure 9. From the graph, it is clear that at all loading conditions the fuel blends are having lesser NOx emission than diesel. There are three main NOx formation mechanisms (a)Thermal mechanism (b) Prompt mechanism (c) Fuel mechanism [21,22]. The Thermal mechanism produces the majority of the NOx emissions in diesel engines because of the increased in-cylinder temperatures and availabilityof oxygen. The fuel blends produces lesser NOx emissions in comparison to diesel probably because of the lower in-cylinder temperatures and heat release rates.

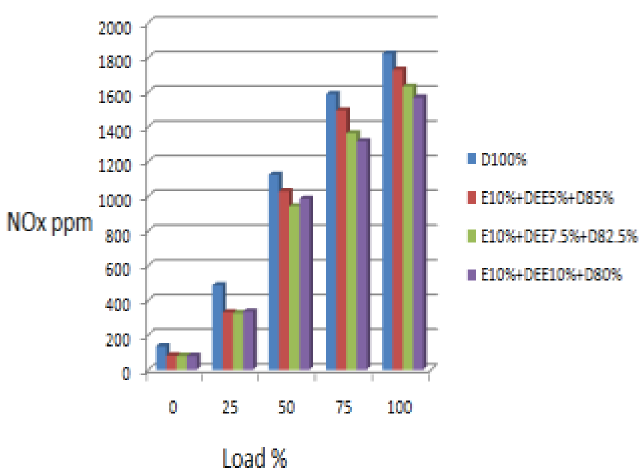


Figure.9

Smoke: Smoke emission by the engine using Diesel and Ethanol - Diethyl Ether – Diesel blends at various loading conditions is recorded and from that data, graph is generated as shown in figure10. Comparing the graph it is noted that smoke emissions were reduced in a large extent with the increase of percentage of diethyl ether in blended fuels. By E10%+DEE10%+D80% blend combination, the smoke opacity is reduced when compared when only diesel was used, at all engine load. The blend of DEE advances the combustion by reducing ignition delay which leads to increase in combustion time resulting in the reduction of soot formation. The molecular oxygencontent of DEE depromotes the formation of smoke during the diffusion phase of combustion [16]. The mixture of E10%+DEE10%+D80% showed reduction in smoke opacity emission as compared to diesel alone at all loading condition.

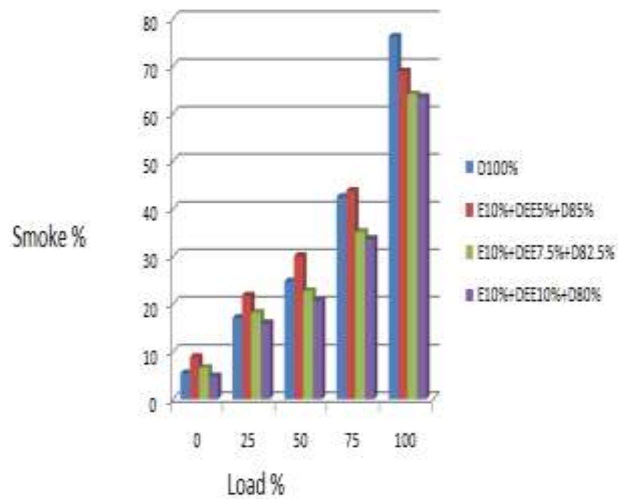


Figure 10

Exhaust Temperature: Exhaust temperature by the engine using Diesel and Ethanol - Diethyl Ether – Diesel blends at various loading conditions is recorded and from that data, graph is generated as shown in figure 11. Comparing the graph it is noted that at all fuel blends have low exhaust temperature than diesel in all loading conditions except the zero loading condition. Exhaust gas temperature decreases with the increase in percentage of DEE in the blend when compared with diesel alone.This may be due to better combustion process initiated by DEE which reduces the heat loss in the combustion chamber during after burning stage, leading to decreases in EGT. At full load EGT of E10%+DEE10%+D80% shows 312^{o}C as compared to 343 ^{o}C of diesel. The mixture of diesel blend exhibits a gradual increase in the EGT at increasing loading conditions. This may be due tolow boiling point of DEE with high cetane number, its blend reduces the ignition delay with short ignition time and its high heat of vaporization also reduces the in-cylinder temperature, resulting in EGT decreases as compared to standard diesel [5,10].

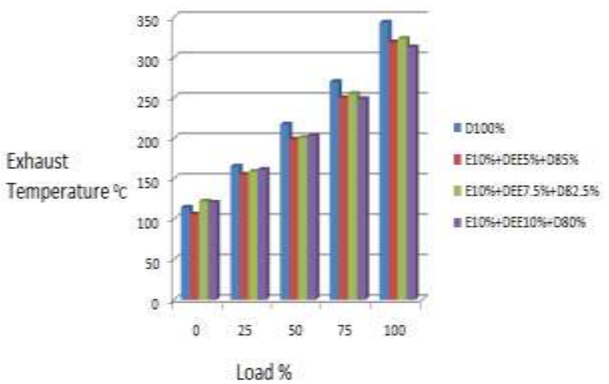


Figure.11

VII. CONCLUSION

This experimental investigation aimed to enhance the performance of diesel engine with the blend of Ethanol and Diethyl Ether at different proportions by volume is attainable. In addition to this, within the scope of study, the NOx and smoke emission from the engine could be minimized appreciably is another objective. Comparing to remaining blends and diesel, blend consisting of E10%, DEE5% and D85%, has the highest mechanical efficiency at 25% loading condition and indicated thermal efficiency at 75% loading condition. Brake Specific Fuel Consumption has recorded lower value at 75% loading condition. It also has lower HC emission at zero loading condition. Upto 50% of loading it has lowest exhaust temperature too. However one drawback of this blend is, it contributes the peak CO emission at maximum loading condition. Comparing to remaining blends and diesel, blend consisting of E10%, DEE7.5% and D82.5%, has the highest mechanical efficiency at 50%loading condition. It has lower CO emission at 100% loading condition. At 75% loading condition it has low CO_2 emission. Considering NOx emission it has lower values upto 50% loading conditions. Considering these facts, this blend is best suited for application that requires low NOx emission upto medium loading conditions.Comparing to remaining blends and diesel, blend consisting of E10%, DEE10% and D80%, has the highest mechanical efficiency at higher loading condition. Mostly at all loading condition it has the maximum brake thermal efficiency and indicated thermal efficiency. In addition to this it has low Brake Specific fuel Consumption value at Maximumloading condition. Also it has minimum CO_2 emission at all loading condition except 75% loading condition. At higher loading condition it has minimum NOx emission, at all loading condition it produces less smoke emission and also it has low exhaust temperature at higher loading condition. Overall, this blend has excellent performance and emission characteristics at higher loading conditions.From the results it can be conclude that the fuel blend consisting of E10%, DEE10% and D80% can replace diesel in heavy duty diesel engine without any modifications thereby reducing the dependency of fossil fuel. Further research for varying parameters can be done for the improvement of performance of the blends.

REFERENCES

[1]. Dinesh Kumar Soni, Rajesh Gupta Numerical investigation of emission reduction techniques applied on methanol blended diesel engine Alexandria Engineering Journal (2016) 55, 1867–1879
[2]. Pragyan P. Patnaik, Shakti P. Jena, Saroj K. Acharya, Harish C. Das Effect of $FeCl_3$ and diethyl ether as additives on compression ignition engine emissions. Sustainable Environment Research 27 (2017) 154-161
[3]. Ioannis Kalargaris, GuohongTian, SaiGu Experimental evaluation of a diesel engine fuelled by pyrolysis oils produced from low-density polyethylene and ethylene–vinyl acetate plastics Fuel Processing Technology 161 (2017) 125–131
[4]. Pinzi.S and Dorado.M.P Influence of ethanol/diesel fuel and propanol/diesel fuel blends over exhaust and noise emissions Energy Procedia 142 (2017) 849–854
[5]. Hariharan S, Murugan S, Nagarajan G. Effect of diethyl ether on Tyre pyrolysis oil fueled diesel engine. Fuel 2013;104:109-15.
[6]. Yanuandri Putrasari, Arifin Nur, Aam Muharam Performance and emission characteristic on a two cylinder DI diesel engine fuelled with ethanol-diesel blends Energy Procedia 32 (2013) 21 – 30
[7]. M.D Redel-macis and S.Pinzi Ternary blends of diesel fuel oxygenated with ethanol and castor oil for diesel engines. Energy Procedia 142 (2017) 855–860
[8]. Ahmad Fitri Yusop, Mohd Hafizil Mat Yasina Particulate matter emission of diesel engines using ester-ethanol-diesel blended fuel. Procedia Engineering 53 (2013) 530 – 535
[9]. Pappula Bridjesh, Pitchaipillai Periyasamy Methoxy Ethyl Acetate and DEE as additives on diesel engine using waste plastic oil diesel blends. Sustainable Environment Research 28 (2018) 142e147
[10]. Sudheesh K, Mallikarjuna JM. Diethyl ether as an ignition improver for biogas homogeneous charge compression ignition (HCCI) operation-An experimental investigation. Energy 2010;35:3614-22
[11]. Gnanamoorthi V, Devaradjane V (2013) Effect of Diesel-Ethanol Blendson Performance, Combustion and Exhaust Emission of a Diesel Engine.International Journal of Current Engineering and Technology 3.
[12]. Venu H, Madhavan V. Influence of diethyl ether (DEE) addition in ethanol biodiesel-diesel (EBD) and methanol-biodiesel-diesel (MBD) blends in a diesel engine. Fuel 2017;189:377-90
[13]. Sachuthananthan B, Jeyachandran K. Combustion, performance and emission characteristics of water-biodiesel emulsion as fuel with DEE as ignition improver in a DI diesel engine. J Environ Res Dev 2007;2:164-72
[14]. Navaneethakrishnan P, Vasudevan D. Experimental study on performance and exhaust emission characteristics of a C.I. engine fuelled with tri compound oxygenated diesel fuel blends. Ind J SciTechnol 2015;8:96-102
[15]. Nurun MN, Dhandapani K, EinarHustad J, Rahman MM (2009) Role of oxygenated fuel to reduce diesel emissions: A Review. Proceedings of theInternational Conference on Mechanical Engineering 26-28.
[16]. Devaraj J, Robinson Y, Ganapathi P. Experimental investigation of performance, emission and combustion characteristics of waste plastic pyrolysis oil blended with diethyl ether used as fuel for diesel engine. Energy 2015;85: 304-9
[17]. Manuel AG, William Piel, Tom Asmus, Wendy Clark, John Garbak, (2001)Oxygenates screening for advanced Petroleum- based Diesel Fuels: Part 2.The Effect of Oxygenate Blending Compounds on Exhaust Emissions. Societyof Automotive Engineers.

[18]. David LH, John CE, Leslie RW (2001) The Emissions Performance ofOxygenated Diesel Fuels in a Prototype DI Diesel Engine. Society of Automotive Engineers.
[19]. Labeckas G, Slavinskas S, Mazeika M (2014) The effect of ethanol-diesel-biodiesel blends on combustion, performance and emissions of a directinjection diesel engine. Energy Conversion and Management 79: 698-720.
[20]. Armas O, Reyes GC, Ramos A (2014) Pollutant emissions from New EuropeanDriving Cycle with ethanol and butanol diesel blends. Fuel ProcessingTechnology 122: 64-71.
[21]. J.B. Heywood, Internal Combustion Engine Fundamentals, McGraw-Hill Inc. 1988
[22]. H. Semerjian, A.Vranos, NOx formation in premixed turbulent flames, Symp.(Int.) Combust. 16 (1) (1977) 166–179
[23]. SayiLikhitha SS, Durga Prasad Ch, Vikram Kumar R (2014) Investigation on theEffect of Diethyl Ether Additive on the Performance of Variable CompressionRatio Diesel Engine. International Journal of Engineering Research 3: 11-15.
[24]. Omran H R, Ashour F H , Abdir E F (2017), Economic evaluation of aromatic production, a case study for financial model in petrochemical properties‘, Egyptian journal of petroleum.
[25]. Karabektas M, Ergen G, Hosoz M. The effects of using diethyl ether as additive on the performance and emissions of a diesel engine fuelled with CNG. Fuel 2014;115:855-60
[26]. Swamy R L, chandrasekar T K, banapurnath N R, Khandal S V (2015), Impact of Diesel-Butanol blends on performance and emission of Diesel engine research article‘, Oil and Gas Research – journal.
[27]. B. Prbakaran, DinoopViswanathan Experimental investigation of effects of additionof ethanol to bio-diesel on performance, combustionand emission characteristics in CI engine. Alexandria Engineering Journal (2018) 57, 383–389
[28]. Aly M. Elzahaby, MedhatElkelawy, Hagar Alm-EldinBastawissi, SaadMostafaEl_Malla,Abdel Moneim M. NacebKinetic modeling and experimental study on the combustion,performance and emission characteristics of a PCCI engine fueled with ethanol-diesel blends Egyptian Journal of Petroleum (2008)