

TECHNO-EVALUATION OF PERFORMANCE, EMISSION AND COMBUSTION CRITERION FOR DIESEL ENGINE WITH VARYING DIESEL - ETHANOL FUEL COMPOSITION AND PROPERTIES

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Abstract— The focus of this study lies on evaluating the performance, emission and combustion characteristics of Di-Diesel Engine for various fuel compositions. A performance window encompassing the core data base is created. The research scheme is framed from the insight of experimental and modeling aspects.

Index Terms—Focus of study, evaluating the performance.

I. INTRODUCTION

Reducing the emissions and fuel consumption are no longer future goals instead they are the demands of the day. Indiscriminate extraction and increased consumption of fossil fuels have led to the reduction in carbon based resources. Alternative fuels promise to harmonize sustainable development, energy conservation, efficiency management and environmental preservation. Diesel engines have the advantages of high thermal efficiency lower emission of CO and HC. However, they have the disadvantage of producing smoke, particulate matter & oxides of nitrogen and it is difficult to reduce both NO_x and smoke density simultaneously in diesel engine due to tradeoff between NO_x and smoke. It follows therefore, that substantial amount of effort has been directed at providing solutions to these problems. Among various developments to reduce emissions, the application of oxygenated fuels to diesel engines is an effective way to reduce smoke emissions. The potentiality of oxygenated fuels to suppress soot precursor formation is dominated by molecular structure as well as fuel oxygen contents [1]. When oxygen content in the fuel reaches approximately 30% by mass, smokeless combustion in diesel engines could be realized [2]. Since ethanol is a widely available oxygenate with a long history of use in gasoline blends it has also been considered as a potential oxygenate for diesel fuel blending. Researchers have investigated the use of ethanol

in diesel engines over the past several decades. The limited miscibility at lower temperature, less heating value, poor lubricating properties and the required minor variations in fuel delivery systems restrict the use of ethanol in diesel fuel [3]. Also the addition of ethanol to diesel fuel decreases the blend's viscosity and causes cetane number of the blends linear reduction at ambient temperature [4]. Usually, when ethanol content in the blends reaches 20–40%, high concentration of additives are needed to ensure the mixture homogeneity in the presence of high water contents, and to attain the required cetane number for suitable ignition [5],[6]. Literary survey revealed that several oxygenated organic compounds (ether, amino alcohols, surfactants etc....) may be used as additives and when the ethanol concentration increases beyond 20%, high concentrations of additives needed to stabilize the mixture. Choosing unsuitable organic additive meets with several difficulties viz; immiscible fuel-alcohol blends, difficulty to handle, high cost etc., [7] [8] [9]. C. Sundar Raj et al investigated the effect of 1, 4 dioxane on ethanol diesel blends and reported even though 10% dioxane is capable to stabilize 30% ethanol with 60% diesel with significant reductions in emissions, 70% diesel- 20% ethanol with 10% dioxane is the optimum mixture [10]. Diesel-ethanol emulsion stabilized by 2% Tetra Methyl Ammonium Bromide is investigated in this study. Each of the different ethanol proportions were mixed with diesel in different percentages by volume (20%, 25%, 30% & 35%). The mixture was then kept for 5 days during which constant stirring were carried out. This was done so as to allow maximum amount of the oil to become dissolved. After this the mixture was thoroughly filtered to remove any undissolved particles. It was absorbed that there is a colour change in the fuel. The above fuel solution was then tested in a CI engine to determine its performance an emission characteristics.

Literary survey revealed that several oxygenated organic compounds (ether, amino alcohols, surfactants, etc.) may be used as additives and when the ethanol concentration increases beyond 20% high concentrations of additives needed to stable the mixture. Choosing unsuitable organic additive meets with several difficulties: immiscible fuel alcohol blends, difficult to handle, very expensive, etc.,

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[7-9].

After sketching through the pros and cons reported in the literatures, an attempt is being made in this research to investigate the emission, combustion and performance characteristics of a Di-Diesel Engine in two phases based on the composition of the fuel viz.,

- 1) Ethanol, Diesel without Water
- 2) Ethanol, Diesel with Water

These studies are further extrapolated for recording observations pertaining to the above said parameters while subjecting the system to with and without thermal barrier coating driven by tetra methyl ammonium bromide-ethanol-diesel emulsion. Besides, Finite Element Analysis is being carried out analyze the heat distribution. The scheme is research is shown in figure 1.

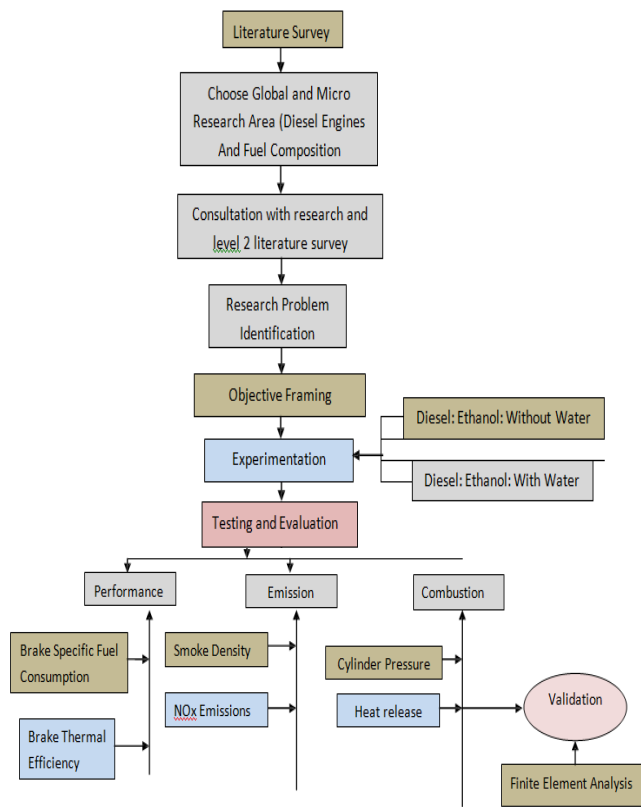


Figure 1 : Scheme of research

II. EXPERIMENTATION

A. Experimental Set Up

Experiments were conducted on Kirloskar TV1, Four stroke, single cylinder, and air cooled diesel engine. The rated power of the engine was 5.2kw at 1500 rpm. The engine was operated at a constant speed of 1500 rpm and standard injection pressure of 200 bars. The fuel flow rate was measured on volume basis using a burette and a stop watch. K-type thermocouple and a digital display were employed to note the exhaust gas temperature. AVL smoke meter was used for measurement of smoke density. NOx emission was measured by AVL digas analyzer. In cylinder pressure was

measured with help of AVL combustion analyzer. The experimental set up employed for this investigation is shown in figure 2.

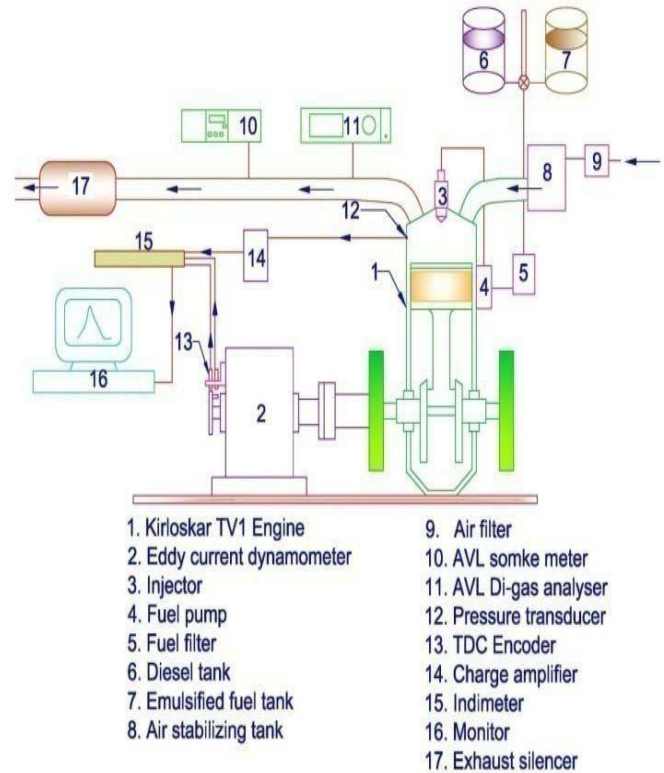


Figure2. Experimental Set Up

B. Experimental Study: Phase I:

- a) Analysis for Ethanol and Diesel fuel mixture without water- Fuel Composition/ Properties and Parametric Analysis

The fuel components and their individual properties are presented in table1.

Table 1. General fuel properties of diesel and ethanol

Chemical Property of Diesel and Ethanol	Molecular Formula	Molecular Weight	Density at 20°C (×103kg/m ³)	Boiling point (°C)	Flash point (°C)	Viscosity (mPa s)	Cetane Number	% of oxygen by weight
Diesela	C _x H _y	190-220	0.829	180-360	65-88	3.35	45-50	0
Ethanolb	C ₂ H ₆ O	46.07	0.789	78.4	13	1.20	8	35

- b) Evaluation and Testing

It is imperative to assess the system with respect to three prominent factors that significantly govern the overall behavior and performance viz., Performance, Emission and

Combustion. The results are briefly presented in the following section:

Performance Assessment

Fig. 3 shows the brake specific fuel consumption for different ethanol additions at peak load. Among the blends 10% ethanol shows minimum brake specific fuel consumption to other blends.

Increase in BSFC at higher blends indicates that there are no cavitation's due to ethanol additions.

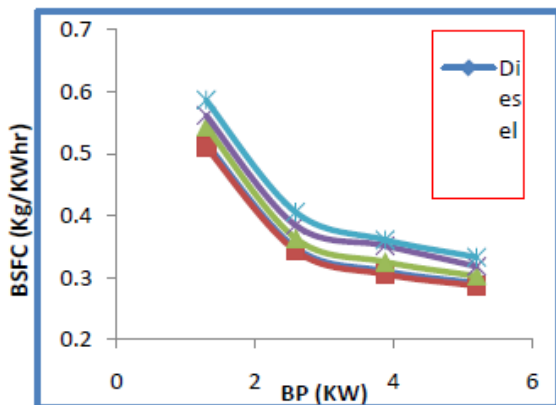


Figure 3. Brake Specific Fuel Consumption for various ethanol concentrations

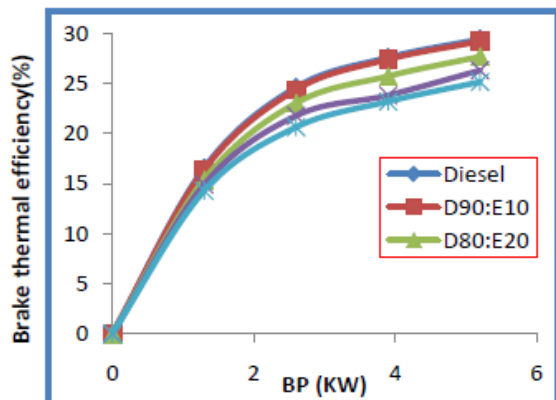


Figure 4 Brake Thermal Efficiency for Different Ethanol Consumption

Fig. 4 shows the brake thermal efficiency for different ethanol additions. From the figure it is observed that the brake thermal efficiency of 10% ethanol blends recorded a maximum of 30.5% efficiency. Improvement in combustion, especially diffusion combustion due to the increase in oxygen concentration from ethanol in the fuel is the reason for this increase in brake thermal efficiency. However, decrease in heat value of the blend makes the efficiency to decrease for higher blends.

Emission Behavior

The variation of smoke density with respective engine brake power is shown in Fig. 5. The addition of ethanol, decrease the smoke density especially between part loads to peak load. Addition of ethanol reduces smoke density

uniformly at peak load because of the decreased quenching distance and the increased lean flammability limit due to the high combustion temperature. The presence of oxygen in the fuel assists in permitting the oxidation reactions to proceed close to completion. The results reveal that the tendency to generate soot from the fuel-rich regions inside diesel diffusion flame is decreased by ethanol in the blends. 16% reduction of smoke was observed for 90D: 10E blend ratio

Compared with the neat fuel.

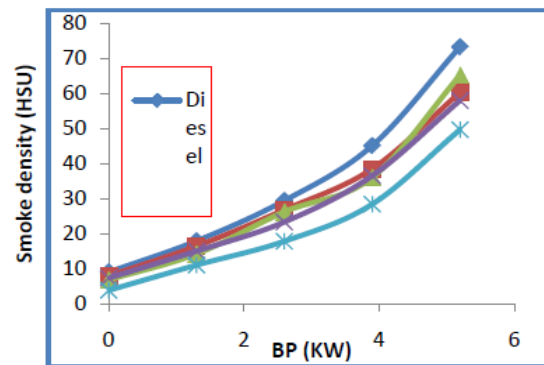


Figure 5. Variation of smoke density for different ethanol concentration

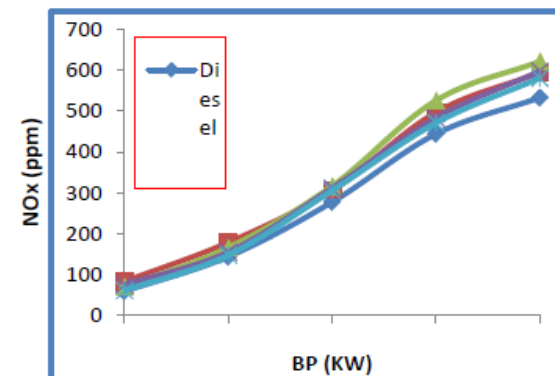


Figure 6. Variation of NOx emissions for different ethanol concentration

The presence of oxygen increases the heat release rate for the oxygenated fuel and hence the NOx emission will be high. The anticipated increase in NOx emissions as a function of increasing ethanol concentration is apparent in Fig. 6. Nitrogen oxides emissions are predominately temperature phenomena. It can be seen that NOx emissions of all blends increase more rapidly than those of neat fuel as ethanol proportion and load increase at medium and high loads. The maximum increase in NOx emissions occur at 80~100% full load conditions because of long ignition delay and rich oxygen circumstance from ethanol in the mixture.

Combustion Factor Analysis

Oxygen molecules presented in ethanol increase the spray optimization and evaporation and hence the combustion process of the engine.

Fig. 7 illustrates cylinder pressure traces for different ethanol blended diesel fuels for various conditions of the engine. A peak pressure of 74 bars for 10% ethanol blend was recorded while it was 68 bars for neat fuel. The oxygenated fuel engine has longer delay period compared to neat fuel.

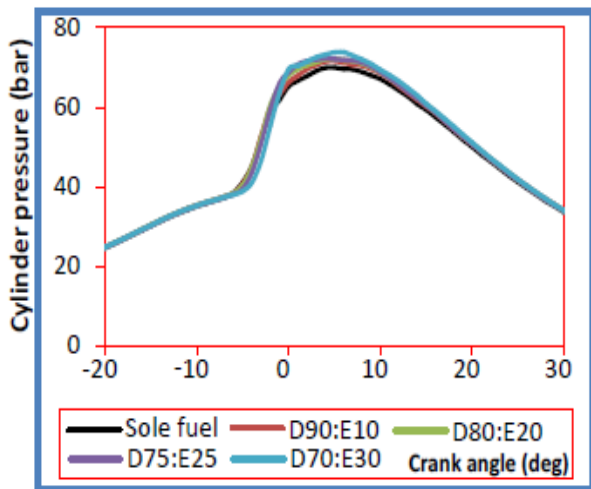


Figure 7. Cylinder pressure for different crank angle

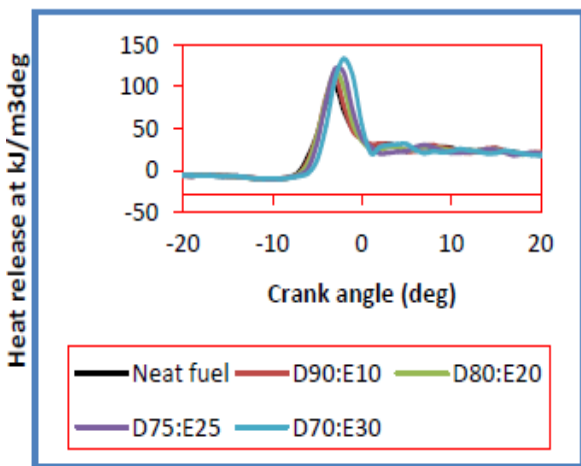


Figure 8. Heat release rate for different crank angle

Fig.8 illustrates heat release rate of the oxygenated fuel blends and neat fuel at different crank angle. The heat release rate is high for oxygenated fuels due to the longer duration of the combustion. It can be seen that heat release rate curves of the oxygenated fuel blends and neat fuel show similar pattern. The reason is the rate of diffusion combustion of the oxygenated fuel increases the heat release rate and consequently oxygenated fuel has controlled rate of pre-mixed combustion.

Experimental Study: Phase 2:

1.2 b) Analysis for Ethanol and Diesel fuel mixture with Water- Fuel Composition/ Properties and Parametric Analysis

The fuel components and their individual properties are presented in table2.

Table 2. Fuel composition/properties used for the study

Properties	Diesel: ethanol: Water Ratio			
	90D:10E:5W	90D:10E:5W	75D:25E:5W	70D:30E:5W
Density @ 15°C in gm./cc	0.8363	0.8394	0.8412	0.8286
Flash Point	53°C	52°C	50°C	49°C
Pour Point	-15°C	-15°C	-14°C	-14°C
Kinetic Viscosity at 40°C in CST	3.29	3.18	2.51	2.46
Specific Gravity@15°C/15°C	0.836	0.839	0.841	0.8293
Sulphur %	0.024	0.024	0.024	0.024
Gross Calorific value KJ/Kg	43900	44112	44238	44293
Ash Content %	0.00076	0.00076	0.00076	0.00076
Cetane Number	54	54	53	53

2.2. b) 1 Evaluation and Testing

The objective of this investigation was to first create a stable ethanol-diesel – water emulsion fuel with the help of TMAB additive, and then to generate performance, emissions and combustion data for an evaluation of different oxygen content based on ethanol content on a single cylinder DI diesel engine.

Performance Assessment

The Fig 9 shows the specific fuel consumption for different ethanol additions. The specific fuel consumption is increase with increases in the ethanol percentage in the diesel fuel. All the blend specific fuel consumption is lower than sole fuel. Among the blends 90D: 10E: 5W ratio shows minimum specific fuel consumption to other blends and sole fuel.

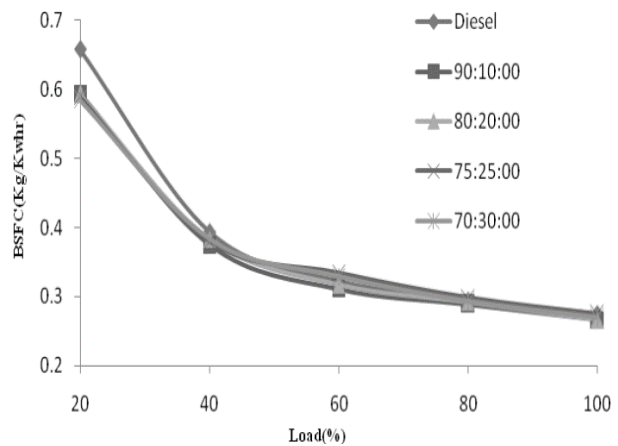


Figure 9: Variation of BSFC with Load

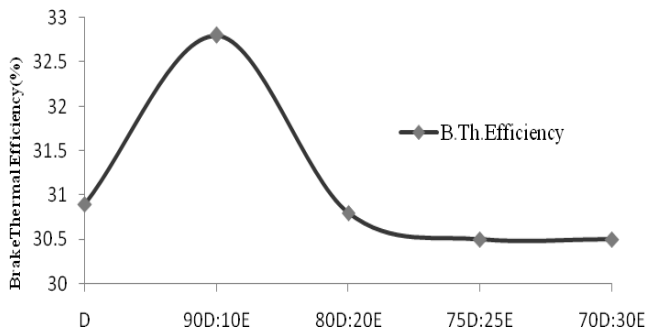


Figure 10: Variation of brake thermal efficiency with ethanol addition

The Fig 10 shows the effect of oxygenated fuel blend on the brake thermal efficiency. The maximum brake thermal efficiency maximum brake thermal efficiency occurs for 90:10:5 ratios and hence is 90:10:5 ratios and hence is considered as optimum emulsion ratio. The Fig 4 depicts that the average break thermal efficiency for 90:10:5 ratio is approximately 2% over sole diesel for the maximum load of the engine. Improvement in Combustion, especially diffusion combustion as the oxygen concentration increases by surfactant in the fuel may be the reason for the increase in efficiency. The brake thermal efficiency generally increases up to 10% ethanol addition but slightly decrease for further additions as the combustion temperature drops due to the increased amount of ethanol

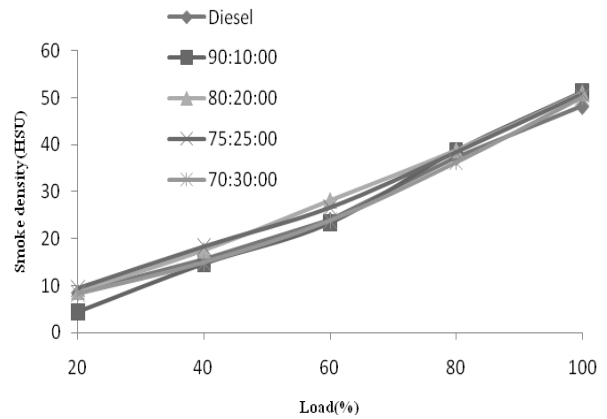


Figure 12. Variation of Smoke density with load

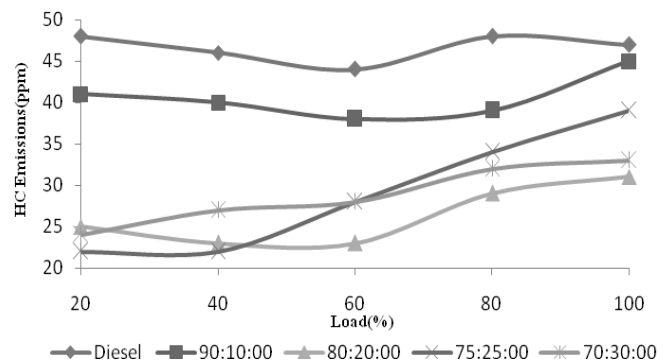


Figure 13. HC Emission with Load

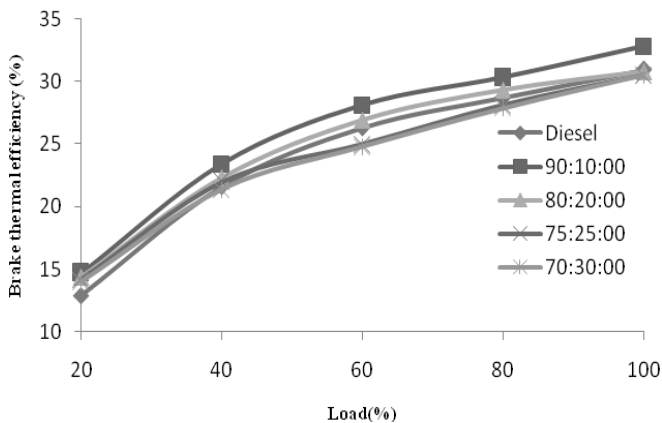


Figure11. Variations of Brake thermal efficiency with load

Emission Characteristics

The variation of smoke density with respective engine brake power is shown in Fig 11. From the figure it is observed that the addition of ethanol, decreasing the smoke density slightly at maximum load. Ethanol has less carbon than diesel fuel and also having oxygen content and thereby increasing the oxygen fuel ratio at rich fuel region. Therefore ethanol addition to diesel fuel is more effective reduction of smoke density in diesel engine. But the presence of surfactant acted in the opposite way and hence the smoke is maintained.

The Fig 12 gives the HC emission with different ethanol additions. It is observed that HC emission for emulsions are lower than neat diesel fuel. This is due to the presence of oxygen in ethanol and water which enhances complete combustion. The Fig 13 illustrates the NOx emission with brake power of the engine. Nitrogen oxides emissions are predominately temperature phenomena, local counteraction of oxygen and duration of combustion. It is found that initially all the emulsions NOx emission was reduced after the part load the NOx emission was increased gradually. It can be seen that NOx emissions of all blends increase more rapidly than those of sole fuel as ethanol proportion and load increase at medium and high loads. The maximum increase in NOx emissions occur at 80~100% full load conditions because of long ignition delay and rich oxygen circumstance from ethanol in the mixture.

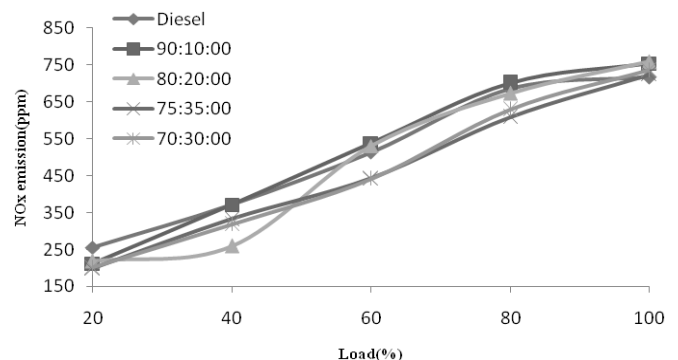


Figure 14. Variation of NOx emission with load

Combustion Factor Analysis

The presence of oxygen molecules increases the spray optimization and evaporation. Hence it improves the combustion process of the engine. The Fig 14 & 15 illustrates cylinder pressure traces of ethanol emulsified diesel fuels. It is found that at the same engine speed and maximum load, the cylinder pressure shows greater differences for sole fuel and oxygenated fuel. The peak pressure is 75.5 bars for 75D: 25E:5W emulsion against 74.4 bars for sole fuel. It can also be seen that the pressure variations of oxygenated fuel engine higher pressure region will change sharply as with diesel engine, but the durations of the higher pressure period is shorter than that of diesel engine. The oxygenated fuel engine are having longer delay period compared to sole fuel.

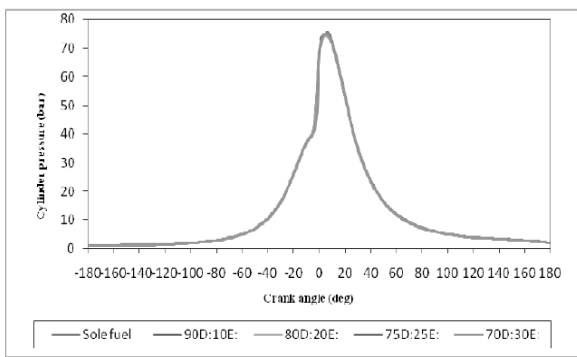


Figure 15. Variation of Cylinder pressure with crank angle

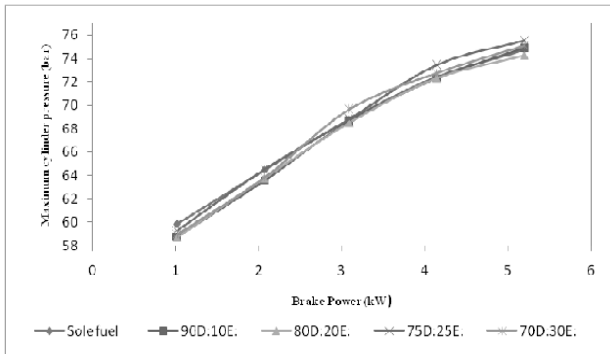


Figure 16: Variation of Maximum Cylinder pressure with BP

The Fig 16 shows the rate of heat release rate for oxygenated fuel blends and sole fuel for different crank angle. It can be seen that heat release rate curves of the oxygenated fuel blends and sole fuel shows similar curve pattern although the rate of heat release for the 75D:25E:5W shows higher heat release than sole fuel. The reason is the rate of diffusion combustion of the oxygenated fuel increasing the heat release rate – consequently oxygenated fuel has controlled rate of pre-mixed combustion. The rate of heat release rate of oxygenated fuel is slightly shifted to the top dead centre due to increased

pre-mixed combustion.

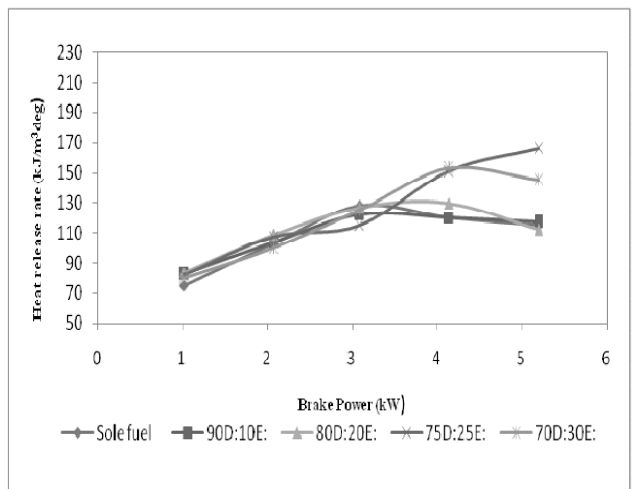
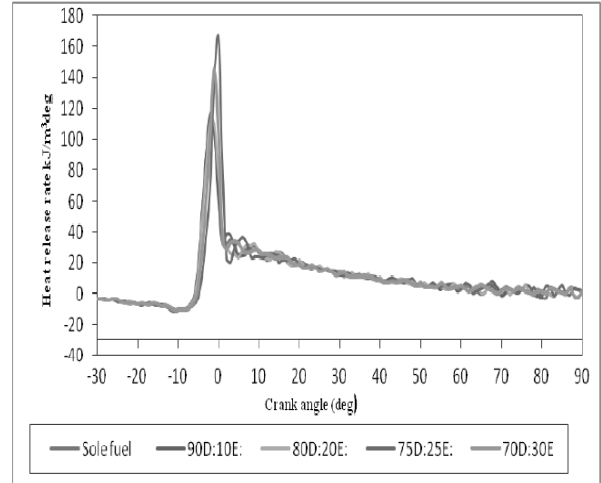


Figure 17. Heat Release Rate with different crank angle/ Maximum heat release rate with BP

The Fig 17 shows that increase in load and ethanol addition improve the heat release rate Results show that ethanol emulsions increases the brake thermal efficiency. Higher ethanol ratio reduces the efficiency but, still better than neat diesel. 90D: 10E:5W ratio shows highest efficiency with less smoke density. NOx emissions and peak heat release rate are high for blends than neat diesel.

III. FINITE ELEMENT ANALYSIS

Numerical modeling and simulations are carried out using finite element analysis technique to determine the temperature distribution. Meshing with 25,400 elements and

80,265 nodes are used for this study in order to increase the accuracy. ANSYS software is used for this analysis. Suitable boundary conditions and assumptions are considered for this study. Figure 18 shows the meshing of the model and the corresponding results obtained after running the simulation iterations.

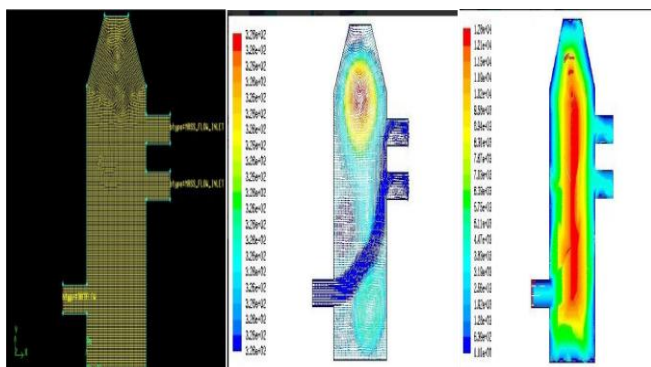


Figure 18. FEA model: Meshed Model and Heat Distribution

IV. CONCLUSIONS

Important conclusions are summarized in this section:

- The brake specific fuel consumption increase with increase in ethanol blend in diesel fuel but less than sole fuel. 90D: 10E shows lower specific fuel consumption, and is further decreased for coated engines.
- The brake thermal efficiency for 90D: 10E blend is almost same when compared to sole fuel, whereas the increase is 8% for TBC engines.
- Smoke reduction is 8 HSU for 80D: 20E at peak load for the normal engine and is decreased to 8 HSU for the coated engines.
- All blends shows increase in NO_x emission when compared to sole fuel at all engine conditions. Cylinder pressure is higher for 90D: 10E blends than other blends with and without thermal barrier coating.
- The CO emissions were reduced with the use of the ethanol-diesel fuel blends with respect to that of the neat diesel fuel, with this reduction being higher the higher the percentage of ethanol in the blend. Further reduction was observed for TBC engine.
- The unburned HC emissions were increased with the use of the ethanol-diesel fuel blends with respect to that of the neat diesel fuel, with this increase being higher the higher the percentage of ethanol in the blend. TBC increased the HC emissions for sole fuel; on the other hand it decreased the HC emissions for the oxygenated fuels.
- The peak pressure and heat release rate for blends are higher than sole fuel and is maximum for coated engines. On the whole it is concluded that 90D:10E with 2% TMAB as surfactant can be used as fuel in a compression ignition engine with improved performance and significant reduction in exhaust emissions except NO_x as compared to neat diesel and that can be controlled by other techniques like turbo charging, exhaust gas recirculation, etc. The ethanol ratio can further be improved in thermally insulated conditions.

SCOPE FOR FUTURE STUDIES

- 1) The experimental investigations may be extended to analyze the vibration patterns
- 2) Finite Element Analysis may be employed to assess the distribution of heat and stress for corresponding fuel concentration/compositions.

- 3) To identify a suitable tool/ technique to optimize the fuel compositions to yield the most efficient performance.

OVERVIEW OF THE RESEARCH

Chapter 1 presents an introduction on the engines, fuels with various compositions typically being employed in existing systems, the factors/parameters influencing the performance, combustion and emission aspects and the interdisciplinary dependency of governing phenomenon's.

Chapter 2 presents an elaborate literature survey that highlights the challenges posed by fuel factors on engine performance. It also explains the limitations of existing works based on which the objectives and framework for this study was evolved.

Chapter 3 reports the experimental investigations carried out for conceptual understanding and to clarify and confirm the phenomenal terminologies based on literatures. The experimental set up and the trials carried out for various fuel composition percentages are documented.

Chapter 4 records the results. Inferences derived from various results are discussed. A comparative chart emphasizing the impact on system, with and without the addition of water is clearly presented.

Chapter 5 presents the preliminary attempts made to investigate temperature distribution using finite element method. Ansys is being used as the software. Results of simulation

being favorable provided a platform to extrapolate the method for any fuel with varying content percentages.

Chapter 6 documents the overall conclusion. This chapter further provides the scope for future studies.

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