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An Experimental Investigation of Ethanol Blended Diesel Fuel on Engine Performance and Emission of a Diesel Engine

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ABSTRACT : Improvements in fuel properties is essential for the suppression of diesel pollutant emission along with the optimization of combustion-related design factors and exhaust after treatment equipments like catalytic converter and exhaust gas recirculation. Ethanol is an attractive alternative fuel because *t* is renewable, bio-diesel and is oxygenated thereby providing the potential for the reduction of particulate emission in compression-ignition engines. The effect of ethanol addition on engine performance were evaluated using single cylinder, four stroke, direct injection, Air cooled diesel engine. The experiments were designed to study the effect of their reducing ethanol blended fuel by increasing the fuel temperature and thereby eliminating its effect on combustion and emission characteristics of the engine. The acquired data were analysed for various parameters such as break thermal efficiency, Break specific fuel consumption, break specific energy consumption, exhaust gas temperature. Emission parameters viz. HC, CO, CO_2 and Unburned hydrocarbon are also tabulated. The performance parameters were marginally inferior but the emission is significantly reduced as the blend ratio is increased.

Keywords : Ethanol, blending, oxygenated fuel, engine performance, emission parameters.

I. INTRODUCTION

Recently, diesel engine has received considerable attention because of its high thermal efficiency and low emission; however, The better fuel economy, low green gas emission, much longer life span, less maintenance and reliability are the properties of a diesel engine results in their wide spreads use in transportation, thermal power generation and many more industrial and agricultural application. Despite many advantages, the diesel engine is inherently dirty and is the most significant contributor of pollutant which contributes to serious health problem Particulate matter emission from diesel contributes to urban and regional haze. HC and NOx emission leads to Ozone formation at ground level. With the stringent emission standard and limited petroleum reserve, alternative fuels for diesel engine have been used. As a renewable and oxygen-containing bio-fuel, ethanol is a prospective fuel for vehicle, which can be blended with diesel or be injected into cylinder directly. Studies on the use of ethanol in diesel engines have been continuing since 1970s. The initial investigation were focused on reduction of the smoke and particulate matter in the exhaust gas. Ethanol addition to diesel fuel results in different physical-chemical changes in diesel fuel properties, particularly reductions in cetane number, viscosity and heating value. Ethanol is a promising oxygenated fuel. Pure ethanol with additives such as cetane improver can sharply reduce particulates. Since late 1990s, ethanol blended diesel fuel has been used on heavy-duty and light duty diesel engine in order to modify their emission characteristics. Since ethanol is polar molecule and its solubility in diesel is prone to be affected by temperature and water content, high percentage addition of ethanol to diesel is difficult. In order to mix ethanol and diesel, an emulsifier or co-solvent should be added. Many literatures indicated that aromatic hydrocarbon, middle distillate, and wax content of diesel are important factors of its blend with ethanol [1, 4]. The application techniques of ethanol on diesel engine can be divided into the following four classes: (1) Ethanol-diesel blend by high-pressure pump [9, 18]. (2) ethanol fumigation to the intake air charge by using carburetion or manifold injection, which is associated with limits to the amount of ethanol due to the incipience of engine knock at high loads, and prevention of flame quenching and misfire at low loads. Shen [2, 12, 13, 20, 23]. (3) dual injection system requiring an extra high-pressure injection system and a related major design change of the cylinder head. Satge de Caro [22, 23]. (4) Blends of ethanol and diesel fuel by using an emulsifier or co-solvent to mix the two fuels for preventing their separation, requiring no technical modifications on the engine side [14, 16, 23].

The physical and chemical characteristics of ethanol-diesel blends are very important to its application on diesel engine. The stability, density, viscosity, surface tension, specific heat, heat value, and cetane number of blends have great impact on the injection, atomization, ignition, and combustion properties, as well as cold start, power, fuel consumption, and emission characteristics of engine. Additionally, the poking and leakage of conventional tank, fuel pipe, and sealing part can be rendered. The cetane number (CN) of a diesel fuel is a measure of the ignition quality of the fuel and affects cold starting, combustion and emissions. This cetane number varies systematically with hydrocarbon structure. Molecules with many short side chains have low cetane numbers; whereas those with one side chain of four or more carbons have high cetane numbers. The cetane number is an important fuel property for diesel engines. It has an influence on engine start ability, emissions, peak cylinder pressure, and combustion noise. According to research carried out by Li *et al*. (2005), for each 10% addition of ethanol by volume to the diesel fuel, results in a 7.1-unit reduction in cetane number of the resulting blend [11]. Ethanol has a very low cetane number (around 8) and once it is mixed with diesel fuel, the CN of the blend is reduced significantly [17]. According to research carried out by Corkwell, each 10% volume ethanol added to the diesel fuel, results in a 7.1-unit reduction in cetane number of the resulting blend [8]. The addition of ethanol resulted in increased ignition delay, reduced combustion duration, high maximum pressure rates, and slightly decreased gas temperature because of its low cetane number and high/low heat value. With the addition of cetane number improver, the combustion properties can reach the level of prototype at middle-high load. Without modification, the ethanol-diesel blends decreased the power of diesel engine and increased the brake-specific fuel consumption; however, the performance of prototype can be rehabilitated after adjusting the fuel delivery and injection timing of engine [4, 9, 22]. Brake-specific fuel consumption increased by up to 9% as compared to diesel alone. The exhaust gas temperature and lubricating oil temperatures were lower with operations on ethanol-diesel blends as compared to operation on diesel. Ethanol-diesel blends can reduce the smoke and PM emissions of diesel engine. The higher this reduction is, the higher the percentage of ethanol is in the blends. The reason is that the oxygen content in blends can promote the combination of fuel and oxygen, even in fuel-rich region [5, 15, 21]. The NOx emissions remained the same or very slightly reduced with the use of the ethanol-diesel fuel blends with respect to those of the diesel; however, the NOx emissions can be reduced by other techniques, such as EGR and SCR. Xing Cai (2004) investigated that the influence of cetane number improver on heat release rate and emission of a high speed diesel engine fueled with ethanol diesel blended fuel [27]. They added different percentage of cetane number enhancer to blends, and the engine were tested and found that the break thermal efficiency improved remarkably and NOx and smoke emission were reduced, BSEC increased but BSFC was reduced.

The energy content of ethanol-diesel blends is lower than a typical diesel fuel. Indeed, ethanol contains about 42% less energy than diesel fuel on a volumetric basis. As a consequence, a higher fraction of ethanol implies a blend with lower energy content (Table-1). The energy content of ethanol-diesel decreases around 2% for each 5% of ethanol volume considering that any additive included has the same energy content as typical diesel fuel [1]. In terms of engine performance, due to the lower energy content there is a reduction of the engine power. Accordingly to the loss of heating value, the brake specific fuel consumption of ethanol-diesel blends increases with respect to the reference diesel. However, the increase becomes smaller as the torque is increased, leading to an increase in brake thermal efficiency [1, 12, 18, 21, 27]. This affects the overall economic and environmental effects.

Table 1. Lower heating value of ethanol, diesel and theoretical ethanol diesel blends.

Fuel	LHV(btu/ gal)	(MJ/L)	% Decrease from Dieseal
Typical diesel	132, 000	(36.6)	—
5 % Ethanol-diesel	129,222	(36.8)	21
10 % Ethanol-diesel	126,443	(35.1)	42
15 % Ethanol-diesel	123,665	(34.3)	63
Ethanol	76,431	(21.3)	42

Hansen *et al*.(2001) reviewed work on durability. Studies from early 80’s blends containing 10-15% ethanol indicated no abnormal wear in engines correctly adjusted for injection timing [1]. Some engines showed increased piston erosion due to low cetane number, thus a small retardation of injection timing was recommended. In one durability test no abnormal deterioration of the engine or fuel injection system was detected after 1000 hours of operation on a blend containing diesel fuel, 30% dry ethanol, octyl nitrate ignition improver and ethyl acetate phase separation inhibitor. The performance of ethanol-diesel was evaluated by Waterland *et al*. (2003) and concluded that the loss of engine maximum power was the most significant adverse performance effect [25]. This was followed by possible fuel pump cavitations causing vapour lock or fuel vaporization in injectors and potential fuel filter clogging problems. Recommended actions to address these possible adverse effects included:

- Increasing the capacity of the fuel injection pump(s) on a case-by-case basis.
- Installing an electric fuel pump at the vehicle fuel tank and adding a restrictor fitting to the fuel return line.
- Ensuring that all fuel handing system and vehicle engine fuel system components are of ethanol-diesel compatible materials

Bilgin *et al*. (2002) evaluated the performance of a variable compression ratio compression-ignition engine operating with ethanol-diesel fuel, the experimental results indicated the 4 % ethanol blend to increase power output and efficiency of the engine while it decreased specific fuel consumption [3]. Kass *et al*. (2001) measured the torque output from the same model engine with two blends containing 10 % and 15 % ethanol (Betz-Dearborn additive), respectively, and reported an approximate 8 % reduction for both fuel blends [17]. Lapuerta et al (2005) reported slight improvements in the engine effective efficiency with respect to that obtained with commercial diesel, as a consequence of an increase in the diffusion flame speed [21]. The detailed study of the combustion timing from the cylinder pressure signal shows that no modifications are needed in the injection system tuning, at least when blends contain less than 10% bioethanol.

II. EXPERIMENTAL SETUP AND PROCEDURE

The present study was conducted on a single cylinder four stroke direct injection diesel engine of Kirloskar make, which is primarily used for agricultural purpose and house hold electricity generation as shown on Fig.1.

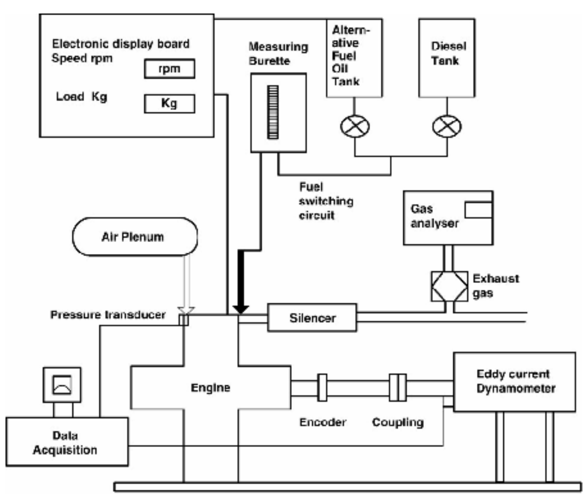

Fig. 1. Experimental set up.

Engine was chosen as single cylinder because it was light and easy to maintain. Being air cooled means absence of radiator and water body and pump, made the system more suitable for the hot and arid conditions. The objective is to replace diesel fuel to the maximum without much loss of performance and significant reduction in emission. The compression ratio of 17: 1 and was normally aspirated and air cooled. The shaft of the diesel engine was coupled to generator set of 3 kW capacity. A load bank was made using three numbers of 1 kW electric heaters. The emission data were recorded with the help of automotive emission analyser AIRREX HG 540 and Gas Composition was measured from NAMTECH SM054. A calibrated burette and a stop watch were used to measure the volumetric flow rate of fuel. The schematic diagram of the experimental setup along with all instrumentation is shown in Fig 1.

Table 2. Engine Specifications.

Manufacturer	Kirloskar
Engine Type	Single cylinder, four stroke, air cooled, diesel engine
Bore/ Stroke	87.5/110
Rated Speed	1500 rpm
Rated Power	4hp
Inlet valve opens/ Inlet valve closes	4° BTDC/ 35.5° ABDC
Exhaust V/v opens/ Exhuast V/v closes	35.5° BBDC/4.5° ATDC

The emission analyser was calibrated for standard diesel engine and set to zero before each experiment. The general specification of engine is given in table 2.

The fuels used in this study are standard diesel and ethanol which was purchased off the shelf form the market. The blending was done on volume basis. With three blend ratio of 0 %, 5 %, 10 % and 20 % of ethanol with 100 %, 95 %, 90 % and 80 % of diesel respectively. The commercial diesel fuel and anhydrous ethanol were used for the preparation of different blends. Pure diesel fuel was used as base fuel for ethanol diesel blends in this study. Different diesel- ethanol fuel blends were kept for 24 hours and they showed some sort of phase separation in the blends which had more than 5 % ethanol, by volume. Separation of ethanol-diesel blended fuel is achieved by using emulsifier which can suspend small droplets of ethanol within diesel. We have used ethyl acetate as emulsifier to prevent phase separation problem. For 10 % blended ethanol diesel 7 % ethanol and 3 % ethyl acetate are mixed whereas for 20 % blending of ethanol blending, 13 % ethanol and 7 % ethyl acetate was added by volume. These were designated as E0, E5, E10 and E20. The experiments were conducted under steady state for four different load (No Load, 1 kW, 2 kW and 3 kW load) conditions and three different proportions of blends. All data were collected after the engine was stabilized. All the gaseous emissions were measured after 20 minutes of running of engine so that the stable conditions were achieved and average result could be evaluated. The steady state tests were repeated to ensure that the results are repeatable.

III. RESULT AND DISCUSSION

Results which are engine performance parameters such as brake thermal efficiency, brake specific fuel consumption, brake specific energy consumption and exhaust gas temperature and exhaust emission parameters such as unburned hydrocarbons, carbon mono-oxides, carbon dioxide and particulate matter were recorded. The brake thermal efficiency with different load is presented in Fig. 2.

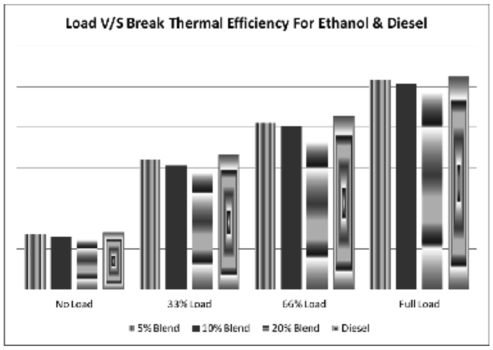

Fig. 2. Variation between load and brake thermal efficiency.

The efficiency of all three proportions of blends was found to be less than pure diesel. At full load, break thermal efficiency reduced by 13 % for the 20 % methanol blended diesel than pure diesel at no load condition and difference was reduced to 6 % for the full load condition. The reason being the specific gravity of the methanol blended fuel is less than diesel. As the blend percentage increases the specific gravity and the Lower Heating Value keeps on reducing.

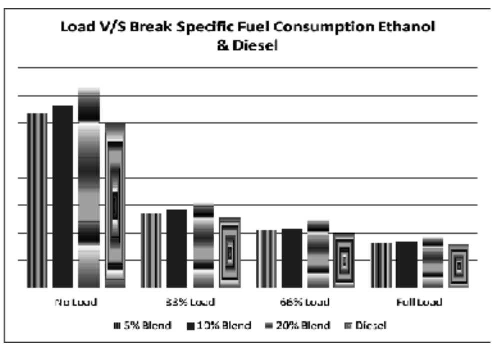

Fig. 3. Variation between laod and brake specific fuel consumption.

The brake Specific Fuel Consumption of the given blends depends upon the quality of combustion process. Fig. 3., shows the variation of BSFC v/s load. The reason being specific gravity of the fuel is reduced which has led to more amount of fuel to be burnt and ultimately causing the increase in BSFC value. The range of variation lies between 22 % to 4 % from 20 % blend ratio to 5 % blends No load to full load conditions respectively.

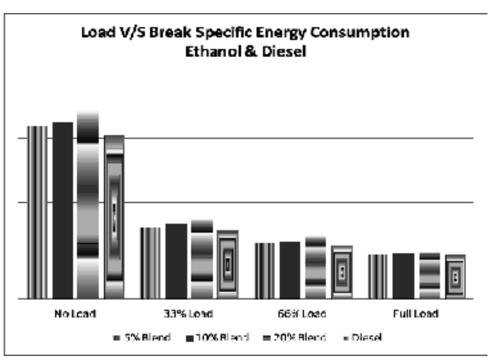

Fig. 4. Variation btween load and brake specific energy consumption

Brake Specific Energy Consumption is also more than the neat diesel as the specific gravity of the blend as well as lower heating value is reduced with increase in blend ratio which causes mass of fuel consumption to increase. Figure 4 shows the variation of load v/s BSEC.

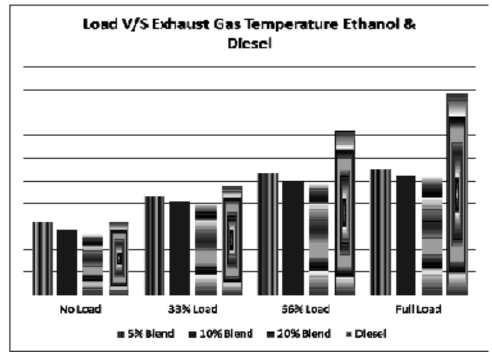

Fig. 5. Variation between load and exhaust gas temperature.

The engine is found to run cooler across the range of fuel proportions and load conditions. The reason being, lower calorific value of the fuel used. The same is indicated in the Fig.5. As the load is increased the exhaust gas temperature is also increased which means the engine is consuming more amount of fuel and same is translated in the BSEC and BSFC curve as well.

Emission characteristics of the methanol blended fuel are also evaluated and same is presented in Fig. 6.

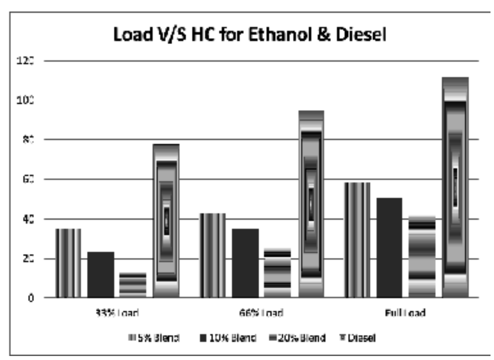

Fig. 6. Variation between load and unburned hydrocarbons.

Fig. 6 represents the variation of HC emission with loads. The Unburned hydrocarbons are reduced and it may be due to lower carbon/ hydrogen ratio of throughout the engine operation. Another reason is oxygenated in nature of blended fuel. The hydrocarbon level is reduced by as much as 35 % at full load for 20 % blend. Result showed athe falling trend of CO as the methanol ratio in the blends increased, the CO concentration in the exhaust emission were decreased. This was the result of improving combustion process since oxygen content in the methanol caused better combustion.Comparing with the standard diesel maximum reduction is achieved for 20 % at full load condition to the extent of 41%. Since methanol has lower carbon and higher oxygen content more methanol in the blend result in less CO in exhaust emission.

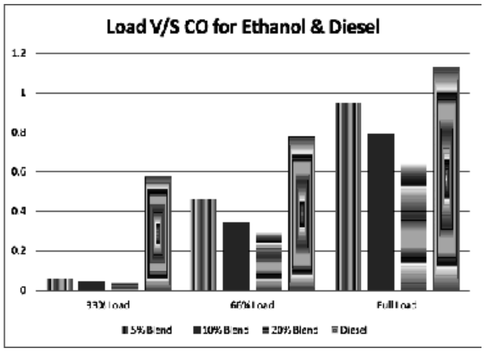

Fig. 7. Variation between load and carbon mono-oxide.

Fig. 7., represents the variation of CO emisison with loads. Carbon dioxide is normal product of combustion. Ideally combustion of htdrocarbon fuel should produce only CO_2 and water. Fig. 8 represents the variation of CO_2 emisison with loads. Hence CO_2 amounts increased while HC and CO emission amounts decreasing and this is an indication of a successful combustion. Maximum of 38% was achieved for 66% load for 20% blend.

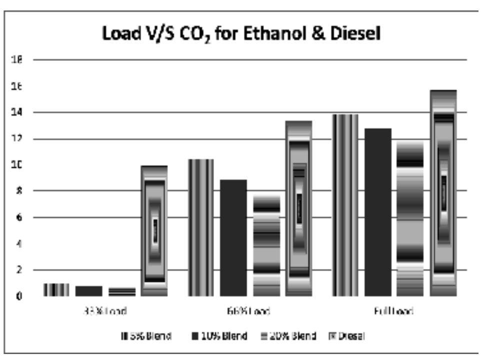

Fig. 8. Variation between load and CO_2.

Most of the UHC are caused by unburned fuel air mixture, whereas the other sources are the engine lubricant and incomplete combustion. The term UHC means organic compounds in the gaseous state, solid means organic compounds in the gaseous state, solid HCs are the part of the particulate matter. It can be named as total hydrocarbon emission (THC) here. Typically, HC are a serious prolem at low loads in CI engine. At low loads , the fuel is apt to impinge on the surfaces, but because of poor fuel distribution, large amounts of excess air and low exhaust temperature, lean air mixture regions may survive to escape into the exhaust.

When methane is added to the diesel fuel, it provides more oxygen for the combustion process and leads to the improved combustion. Improved combustion is rich mixture areas leads to higher temperature which in turn affects.

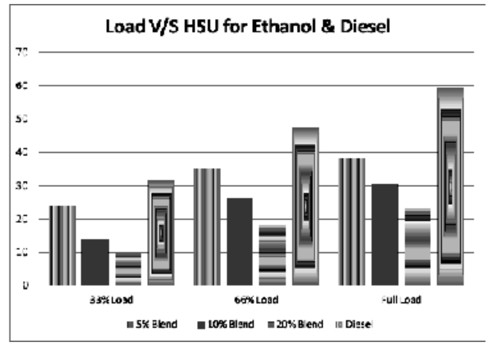

Fig. 9. Variation between load and smoke capacity.

IV. CONCLUSION

Ethanol diesel blends are in early stage of development compared to other alternatives as CNG or LPG. These blends can also reduce green house gas emissions. On an energy basis, ethanol has lower calorific value than diesel hence it will consume more amount of fuel. It also has lower cetance number so the blends of ethanol & diesel require cetane improver. To pevent phase separation at higher percentage of blend ratio we require emulsifier. The main result of this experimental investigation leads to following conclusions:

- The total fuel consumption and break specific fuel consumption of ethanol diesel blended fuel increased for the reason that low heating value of ethanol is about half of that of diesel, and it is increasing with increase in blend ratio.
- The break thermal efficiency of ethanol blend is lower and as the load is increased the difference in efficiency also increases.
- In the emission front, the significant reduction of CO with increase in blend ratio, the same pattern is followed in particulate matter as well. It is attributed to the same physical and chemical characteristic
- The HC emissions were reduced with the use of the ethanol-diesel fuel blends with respect to that of neat diesel.

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