Experimental investigation on the usage of ethanol and DEE as additives in a CI engine

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Abstract: Mankind has been trying to find alternate fuels for centuries now and the developments made in the field of Bio-diesels have been extensive. As the world calls for a more sustainable approach to fuel procurement, processes of agricultural fermentation with homegrown yields such as wheat and sugarcane have opened up the potential for producing ethanol in a cost-effective, sustainable and efficient manner. Our investigation dives into integrating ethanol with traditional diesel to study its merits and demerits. To overcome some inherent flaws of ethanol, we invite another potent contender to the mix, Di-ethyl ether, which acts as a cetane booster. Blends of different proportions are mixed and tested before it undergoes the usual string of performance, combustion and emission tests. Graphs were plotted, outcomes were studied and a comprehensive conclusion was made, covering the positive and negative effects of the blends created.

1. Introduction

The inception of biofuels came as a desperate attempt to avoid the dependence on the highly diminishing prospect of fossil fuels and to reduce the emissions of traditional gasoline and diesel. While several advancements have been made in tackling both these issues, the CI engine has proven itself as a more approachable and flexible option to try new varieties of fuels. The term Bio-fuels does include a biological factor, which means a naturally occurring form of fuel that can be harnessed in a sustainable, economical and efficient manner. And with more and more vehicles on the road being designed from the factory to run on biofuels, it has opened up a world of opportunities for innovative blends and mixtures.

With CI engines, the potential for an alternative/sustainable fuel is endless. People have been experimenting with plant and harvest based fuel sources for more than a century. The ease of procuring and producing an alternative fuel with their limited resources has encouraged people to experiment with several combinations of blends. Fermentation processes of agricultural products like wheat and sugarcane have opened up the potential for producing methanol and ethanol and enabled us to attempt alcohol inclusion in diesel. And thanks to fruitful results, methods like Alcohol fumigation, Dual fuel injection and Alcohol-diesel emulsions were developed to induce alcohol in the most effective manner. The easiest method of this inclusion would be alcohol-diesel blend in appropriate ratios. With our experiment, we have chosen ethanol as a rightful candidate to help us understand the role and effect of alcohol addition [1] uses DEE as an ignition enhancing agent in CI engines. The reference fuel is diesel, which is being compared to ethanol blended with biodiesels and regular diesel with ratios 20:40:40 with 5 per cent DEE, methanol with biodiesels and regular diesel of ratio 20:40:40 with 5 per cent DEE with an additional 5 per cent DEE added to both of the blends. The results for the ethanol blend favours DEE as there is an improvement in cylinder pressure combustion duration and it helped to decrease NOx, PM and smoke emissions. Banupurmath [2] in his experiment saw a decrease in CO values when exposed to higher loads with ethanol and DEE blends.
HC was found to be higher while on the other hand, the NOx values came down drastically.[3] This investigation dives into finding the results of adding a known cetane improver, DEE, in this case, oxygenated. DEE is added in the volume percentages 5, 8, 10 and 15 per cent respectively to a 10 per cent blend of ethanol in diesel. [4] There have also been studies showing the effects of adding diethyl ether and ethanol to a single-cylinder compression ignition engine and studying engine characteristics.[5] Some have even done experiments in Understanding the role of Oxygenated Diesel in enhancing emissions and performance characteristics of CI Engines.[6] Takes a deep insight into the particulate emissions of CI engines powered by Biodiesel. [7] Understanding the role of alcohol content (ethanol and methanol) for different direct injection diesel engine parameters have been explored.[8] and [9] Study the role of ethanol on the combustion and performance of a CI engine.[9] Blending ethanol into diesel and investigating the effects.[10] Experimental trials of using oxygenated fuels with various injection methods have been attempted to reduce emissions here.

2. Experimental Investigation

Ethanol certainly has certain noticeable drawbacks and as evidence suggests, ethanol, while still effective, shows better results with SI engines more than CI engines. The main factor here is the low cetane number of ethanol. This brings down the cetane number of diesel when blended. Research papers suggest a number below 40 would make the operation of CI engines inefficient. To combat this issue, we have introduced a known cetane enhancer, Di-ethyl ether. With a cetane number of 125, this should certainly help in improving engine performance under various loads. After determining appropriate blends, we evaluated these mentioned blends for their performance, emission and combustion characteristics.

2.1. Test fuel

With our literature surveys, we’ve come to the conclusion that any percentage of ethanol addition over 20 would lead the homogeneous mixture to become unstable and separate. To be on the safer side, we restricted our max ethanol content to 15 per cent. Our first blend will contain 5 per cent of ethanol to determine the effect of ethanol introduction. This content is increased to 15 per cent in the subsequent blend to observe the changes of utilizing additional ethanol. We aim to differentiate the values of E5 D95 and E15 D85 for various parameters. For our third and final blend, we add DEE to the mixture containing 15 per cent ethanol. The DEE content would be 10 per cent by volume. This would give us an idea of the effect of the addition of Di-ethyl ether.

Blend 1 - D95 E5
Blend 2 - D85 E15
Blend 3 - D75 E15 DE10
Reference fuel - Diesel

Table 1. Properties of fuel

| Fuel Property                     | Diesel | Di-ethyl Ether | Ethanol | D75 E15 DE10 Blend |
|-----------------------------------|--------|----------------|---------|-------------------|
| Density (kg/m³) at 15°C           | 820    | 713.4          | 789     | 801               |
| Kinematic Viscosity (cSt) at 40°C | 3.11   | 0.233          | 0.795   | 2.1               |
| Gross Calorific Value (MJ/kg)     | 41.58  | 33.8           | 29.89   | 37.65             |
2.2. Experimental setup and procedure

| Make and Model   | Kirloskar TV1 engine |
|------------------|----------------------|
| Product          | DI VCR               |
| No of cylinders  | Single cylinder      |
| No of strokes    | 4                    |
| Power            | 7.5 kW               |
| Bore length      | 87.5 mm              |
| Stroke length    | 110 mm               |
| Speed            | 1500 rpm             |
| Cooling system   | Water-cooled         |
| Dynamometer      | Eddy current type    |

The engine is a four-stroke, single-cylinder CI unit made by Kirloskar with a power output of 5.2 kW@1500rpm. This has a compression ratio of 17:5:1. This unit is linked to an eddy dynamometer for various loads. Moreover, this engine is equipped with the necessary instruments to measure combustion pressure and crank-angle. A standalone panel board is also provided to the test rig which consists of the fuel tank, airbox, fuel measurement tool, manometer, air and fuel transmitter which measure flow and engine speed indicator. Figure 1 shows the schematic of the experimental set up used for performing experiments. This setup allows us to study multiple engine performance characteristics such as Indicated and Brake mean effective pressure, brake power, indicated power, frictional power, BTE, BSFC, Air/Fuel ratio and finally, heat balance. For analyzing and evaluating the performance of the engine, an engine performance analyzing software named “Engine soft” is used.

![Figure 1. Schematic of Experimental set-up](image)

3. Results and Discussion

3.1. Performance Analysis

Brake thermal efficiency (BTE) determines the probability of reaching complete combustion. It mainly depends on the calorific value of the test engine fuels. Figure 2 shows that BTE increases with an increase in brake power. The brake thermal efficiency of both the ethanol blends seems to be on par with the values of Diesel. The addition of DEE has brought down the value of BTE marginally. Engine knocking was observed during combustion which means this blend is not burning as efficiently as Diesel, which is our reference fuel.
The BSFC values are more or less the same for all the blends. E15DE10D75 has a 5 per cent decrease in BSFC which means the consumption is lower for higher loads which is definitely a positive factor. The BSFC graph varies very linearly which stays true to its diesel consumption characteristics.

3.2. Combustion Analysis

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**Figure 2.** Variation of brake thermal efficiency under varying loads

**Figure 3.** Variation of Brake Specific Fuel Consumption with load

**Figure 4.** Variation of cylinder pressure with crank angle
Figure 4. shows that there is no significant change between the blends in different Crank angles. Pressure rises up with increasing crank angle and we are able to find the maximum pressure of each blend. Diesel, as seen from the graph shows the highest values of Cylinder pressure. The difference in cylinder pressures of the ethanol and diesel blends are marginally lesser than the values of Diesel.

![Heat release rate VS Crank Angle](image)

**Figure 5. HRR VS Crank Angle**

HRR or Heat release rate indicates the pace at which energy is transferred in heat in the cylinder. This entire process can be divided into 4 segments.
1. Ignition delay
2. Uncontrolled combustion
3. Controlled combustion
4. Delayed combustion

The negative side of the x-axis is extended well beyond the Y-axis representing HRR. This is because liquid fuels get heated and evaporate. After sufficient heat been released by the entire combustion process, it produces a positive net heat release rate. The HRR for diesel is highest compared to the other blends. This indicates it is more effective in dissipating that heat as the graph suggests. This would also mean it has a Higher BTE value. The blends having 5 and 15 per cent ethanol have the lowest rates of HR. DEE helps increase that value by a small margin.

![Mass Fraction Burned VS Crank Angle](image)

**Figure 6. Variation of Mass Fraction Burnt with varying crank angles**
MFB or Mass fraction burnt helps in determining the duration of the total combustion process taking place. The rate of combustion inside the combustion chamber is very important for finding the best engine thermal efficiency and peak temperature and pressure. MFB depends on Air/Fuel ratio. The amount of air and fuel to be burned should be done in a very stage which will ensure sufficient time for the rest of the process to be executed quicker. As we can observe from Figure 6, The blend containing DEE completes combustion in 25 deg crank angle compared to 26 deg for other blends. This leaves more time for the next combustion, aiding in a small improvement in performance.

3.3. Emission Analysis

At lower BP we can find that the values of D95 E5 and D85 D15 are closely similar to that of diesel but when the BP increases the HC emission varies between the two ethanol blends, having a difference of about 15 PPM, with diesel values in between. The HC values are highest for the Blend containing DEE and Ethanol. The rise in HC emission values is primarily due to the higher heat of evaporation of the DEE which causes slow evaporation and poor fuel-air mixing.

Here we can notice as the load is increased, the blends having additives added to it produce lower Carbon Monoxide values. At full load, D75 E15 DE10 produces the same percentage as diesel. But the values at intermittent loads are much lower than diesel. This graph is evidence of additives like ethanol and DEE helping to reduce CO emissions.
The amount of smoke formation depends mainly on the oil quality used for lubrication and the oxygen participation in the combustion process. The Smoke values are lower for all three blends when compared to diesel, having the highest percentage.

The rate of formation of NOx emission largely depends on the oxygen content and composition of the fuel used and the adiabatic gas temperature inside the combustion chamber during the combustion process. D75 E15 DE10 drastically reduces NOx emissions here (25% decrease). This reduction in NOx can be attributed to three factors such as DEE lowering the combustion temperature, engine running overall leaner due to lower oxygen concentration and the reduction in reaction time.

4. Conclusion

After successful completion of combustion, performance and emission tests, we can surely draw a few conclusions with our investigation involving ethanol and DEE addition in diesel. To begin with, the prepared blends do not impact the combustion process in the scale one would expect when using ethanol and DEE. Lower HRR and cylinder pressure values equate to a lower thermal efficiency value when compared to the reference fuel fuel diesel. However, as a silver lining, there is a slight advantage in MFB rates
with the addition of DEE. The story is more or less the same when we shift focus to the performance side of things. Blends prepared perform very similar to diesel under most conditions. A slightly lower BSFC value with the addition of DEE is certainly a positive. The real impact of additives is noticeable when we tilt focus to emissions. Lower CO and smoke values are an apparent gain over the standard fuel here, diesel. Although the HC emissions are drastically higher with D75 E15 DE10, that seems justifiable with a significant NOx emission reduction. All of the blends created to aid in lower emissions more than an outright performance enhancer. The blend containing 5 per cent ethanol (D95 E5) gives us an optimum balance with its results all across.

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