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Research Article

Introduction of Blended Pilot Fuel to Enrich the Charge in a CI Engine

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Abstract

This paper aims to study the effect of different fuel blends that were used to enhance combustion of main fuel in a diesel engine. Performance tests were conducted on a four stroke, single cylinder, 3.7 kW/5BHP diesel engine. Pilot fuel blends were directly introduced through a gravimetric fuel introduction system into the intake manifold of the engine. Based on the result obtained, it was found that, pilot fuel blends have resulted in enhanced combustion of diesel fuel. The pilot fuel blends 70 (DEE): 30 (Methyl Alcohol) and 50 (DEE): 50(Ethyl Alcohol) have shown significant increase in performance and hence can be used as effective combustion enhancers. Inferences drawn from the performance graphs shows and validate that using pilot fuel blends significantly improves the performance of the diesel engine.

Keywords: *Pilot Fuel Blends, Gravimetric Fuel Introduction, DEE, Methyl Alcohol, Ethyl Alcohol.*

1. Introduction

Depletion of fossil fuel in the recent times has called for new measures to save fuel. Diesel engines although efficient and gives good power output, suffer from the disadvantage of incomplete combustion of the diesel fuel due to heterogeneous charge. This is the main reason for incomplete combustion of diesel and hence results in wastage of fuel; un-burnt HC's and increased particulate formation. To counter this draw back, many methods have been suggested. One of which is the introduction of a blended pilot fuel through the intake manifold of the engine to enhance combustion of the diesel fuel. Pilot fuels are essentially chemical reagents which are added in minute quantities to enhance combustion and thereby getting more power for less quantity of fuel utilized. Pilot blends like Di-ethyl Ether (DEE) with alcohols like ethanol and methanol are used.

DEE has favorable engine performance characteristics because of its chemical and physical properties such as a low boiling point & high cetane number. It also combusts very clean producing less or no soot/smoke or particulates emitted. Further, it also has projected lower combustion emissions of carbon dioxide, since it has high oxygen content.

Alcohols such as ethanol and methanol are used to improve the stability of DEE. Another important property of alcohols is that they have higher oxygen content in its chemical structure, which enhances combustion of fuels within the engine cylinders and are known to reduce emissions.

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DEE has the required properties like high cetane number, good energy density, reduce emissions etc. Hence, it shows that DEE is highly compatible with diesel. Test results on the effect of DEE on flame speed, ignition delay and emission have also been mentioned. (Brent Bailey *et al* July 2000).

The difficulty in using ethanol with diesel because of its low cetane number, low viscosity and lubricity have been studied and the solution to this problem is using ether-alcohol blends along with diesel. (Eliana Weber *et al* 2005).

Alcohols are good oxygenate and improve thermal efficiency of the engine. Different proportions of alcohol-diesel blends were used and the performance and exhaust emissions were experimentally investigated. The results showed that BSFC and emissions of nitrogen oxides (NO_x) increased while brake thermal efficiency, smoke opacity, emissions of carbon monoxide and total hydrocarbon decreased. (Cenk Sayin *et al* 2009).

The effect of different proportions of orange blends with diesel and its effect on performance and emissions were studied. The utilization of a gravimetric fuel introduction setup for introducing orange oil as a pilot fuel is studied. This technique offers the advantage of easy conversion of the diesel engine to work in the dual fuel mode with volatile fuels and vegetable oils. (Harsha vardhan Reddy *et al* 2012).

Significant reduction of BSFC, increase in BTE and reduction in NO_x formations on using DEE blends. Overall results show a promising characteristics in performance improvement and Emission reduction. (Saravanan *et al* 2012).

The use of Dimethyl ether (DME) and Diethyl ether (DEE) in diesel engines as an alternative fuel. The positives of using DME or DEE were discussed. The study shows improvement in (BTE) brake thermal efficiency and specific fuel consumption (SFC).Oxygen content of these alternative fuels improves the combustion process making it more complete. Thus, generally lower pollutant emissions are emitted with these fuels. (Ismet Sezer *et al* 2010).

BSFC can be decreased by 10% and diesel fuel consumption can be decreased by 18%. Hydrogen produced in DME or ethanol pyrolysis is considered as the main reason for the excellent fuel saving. (Zhang Bo *et al* 2005)

2. Experimental Set up

The specification of the engine used in this work is given in **Table 1.**

Table 1 Engine Specifications

Manufacturer &Model	Kirloskar, AV1
Type	4 Stroke, CI
No of Cylinders	Single
Fuel Used	Diesel
Rated power	3.7 kW/ 5 Hp
Compression ratio	16.5 : 1
Bore x Stroke	80mm x 110mm
Injection Pressure	175 bar
Pilot Fuel Introduction	Gravimetric

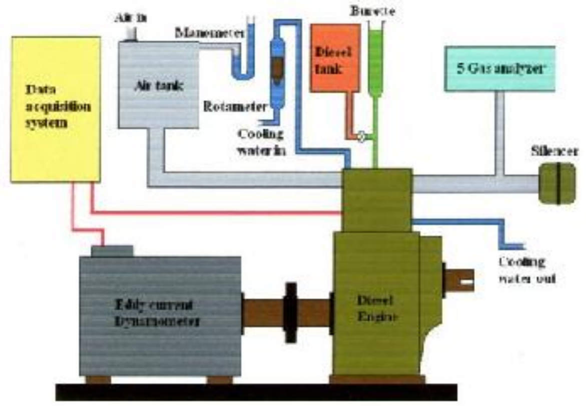

Figure 1 Schematic Sketch of the Experimental Setup

Normally in diesel engines, fuel is often injected into the engine cylinder near the end of the compression stroke, just a few crank angle degrees before top dead center. It atomizes into small droplets and penetrates into the combustion chamber. As the piston continues to move closer to top dead center, the mixture (mostly air) temperature reaches the fuel's ignition temperature. Instantaneous ignition of some premixed fuel and air occurs after the ignition delay period. Increased pressure resulting from the premixed combustion compresses and heats the un-burnt portion of the charge and shortens the delay before its ignition. However, this process does not facilitate complete combustion of the diesel fuel. As a result, some amount of the diesel remains un-burnt and comes out with the exhaust gases; thereby resulting in the wastage of the un-burnt diesel fuel. To facilitate better combustion of diesel and to reduce wastage; the pilot fuel blend is introduced gravimetrically, in low quantities, into the intake manifold.

3. Gravimetric Fuel Introduction Setup

Gravimetric fuel introduction system is commissioned to introduce the pilot blends into the intake air manifold. It consists of Burette, Pilot Fuel Line, Wall mounting pad for Burette and a fuel control knob.

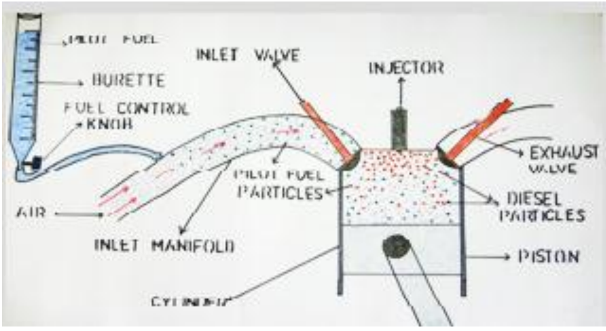

Figure 2 Schematic of the Gravimetric Fuel Setup

Pilot fuel because of its high volatility readily mixes with air. During the suction stroke, this mixture of pilot fuel and air is drawn into the engine cylinder and forms a uniform mixture in the cylinder volume. As the piston rises up during the compression stroke, the uniform charge in the cylinder gets heated. Just before the diesel fuel is injected, the charge which is uniformly distributed throughout the cylinder reaches its auto-ignition temperature and begins to combust at multiple points. During this period diesel fuel is injected. As combustion is initiated at multiple points; the burning of this mixture provides additional heat and oxygen for enhanced combustion of the injected diesel fuel. Also, the prior combustion of this mixture, provides the necessary heat for the pre-flame reactions of the diesel fuel thereby reducing the ignition delay period, which ensures smoother combustion of the diesel fuel. Therefore, this process of introduction of the blended pilot fuel results in enhanced combustion of the diesel fuel thereby producing more power output compared to the normal operation and also reduces the wastage of the un-burnt diesel.

3.1 Specifications of the Gravimetric Fuel Setup

Table 2 Specifications of Gravimetric Fuel Setup

Height of the Burette	0.65m
Diameter of the Burette	0.015m
Volume	50ml
Length of the Pilot Fuel Line	1m
Diameter of the Pilot Fuel Line	0.005m

4. Blended Pilot Fuels

To achieve the objective of enhanced combustion of diesel in the engine; DEE has been identified as a viable pilot fuel from the Literatures available. Diethyl ether has high cetane number and it is a very good oxygenate. It has relatively good energy density, it is volatile and hence mixes easily, but, it has a major disadvantage of low auto ignition point when compared to that of diesel. As a result, if only neat DEE is introduced into the intake manifold, because of its low auto ignition point, it will combust in the intake manifold itself or just as it enters the engine cylinder due to the prevailing high temperatures, prior to when it is actually required to combust, hence, it becomes necessary to raise it's auto ignition temperature close to that of diesel but slightly lower than it. This is achieved by blending DEE with suitable alcohols like ethanol and methanol in suitable proportions.

Table 3 Pilot Fuels and their Blends

Properties	Ethanol	Methanol
Density (Kg/m^3)	789	791.3
Flash Point (^{O}C)	14	12
Cetane Number	5	0-1
Boiling Point (^{O}C)	78.4	64.7
Auto Ignition Temperature (^{O}C)	363	385
Calorific Value (kJ/Kg)	30000	23000

5. Experimentation

The engine is setup as per standard experimentation procedure. A set quantity of a pilot fuel blend (at the rate of 1.5cc/min) from the burette in the gravimetric pilot fuel introduction set up is introduced into the intake manifold; The same procedure is repeated for various blends of pilot fuel mentioned above. The results are tabulated for varying loads.

From experimentation, it can be determined that pilot fuel blends within the proportion ranges of 70 (DEE): 30 (Alcohol) and 50 (DEE): 50 (Alcohol) function effectively as combustion enhancers. In this present investigation, the following blends have been used for combustion enhancement. The Proportions of the pilot fuel blends are:

- 50 (DEE) : 50 (Ethyl Alcohol)
- 50 (DEE) : 50 (Methyl Alcohol)
- 70 (DEE) : 30 (Ethyl Alcohol)
- 70 (DEE) : 30 (Methyl Alcohol)

If blends outside the proportion ranges are used, then the efficiency of the blends decreases leading to unsatisfactory results such as the tendency of the engine to knock increases. Also, the calorific value of the entire fuel decreases and it may sometimes lead to corrosion of internal parts. It is also inferred that the auto ignition temperature of the blend will drop below the required value. Hence, the proportions of 70 (DEE): 30 (Alcohol) and 50 (DEE): 50 (Alcohol) serve as the borderline for the effective functioning of the blended pilot fuel.

6. Results and Discussions

Based on the above experimentation results, performance curves are drawn as shown below.

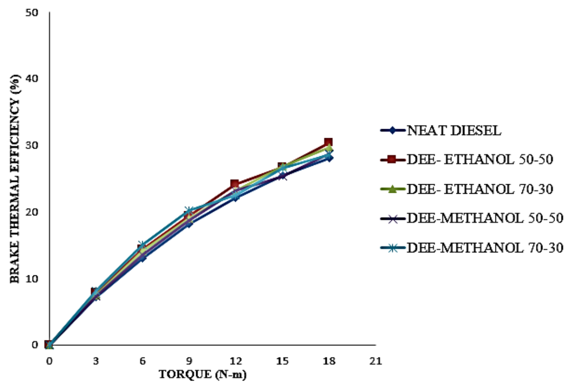

Figure 3 Brake Thermal Efficiency vs Torque

From the figure-3, it is inferred that neat diesel has produced low BTE at most loads, than, when blends are used. When pilot fuel blend is introduced into the intake air manifold, they vaporize, mix with air and enter the cylinder as a mixture. These blends, as they contain oxygen in them, provide additional oxygen for combustion, apart from the usual air intake. Due to this, combustion of diesel improves. As combustion is enhanced, the thermal efficiency increases, hence BTE increases. DEE - Ethanol taken in ratio of 50:50 has produced the best result here.

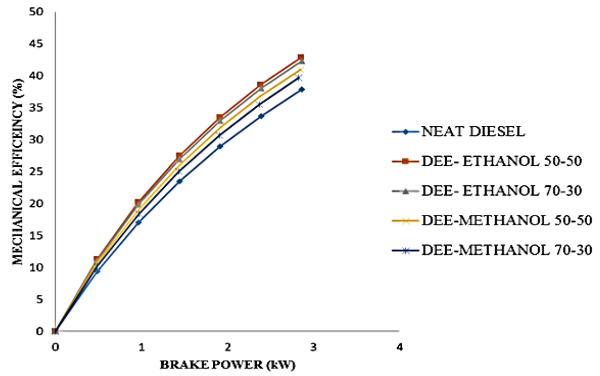

Figure 4 Mechanical Efficiency vs Brake Power

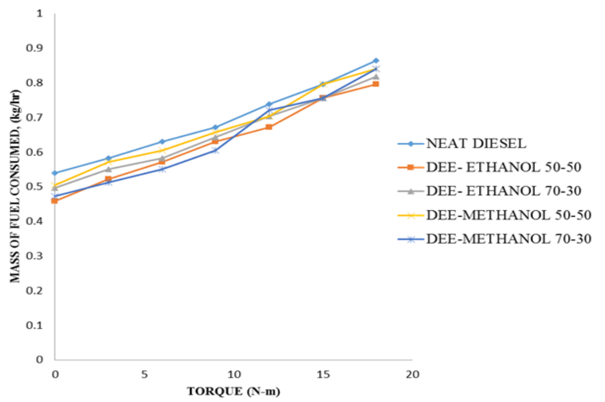

Figure 5 Mass of fuel consumed vs Torque

From the figure-4, it is inferred that Mechanical efficiency has increased with the use of blends than with NEAT

DIESEL. Addition of blends has resulted in smoother combustion due to reduction in friction losses, producing more power output. As power output is BP and it is increasing with the addition of blend and FP being constant for each blend and neat diesel, mechanical efficiency increases.

From the figure-5, it is inferred that the use of blends reduces the mass fuel consumption of diesel. Blends enhance combustion of diesel fuels, thereby producing higher power output for the same quantity of the diesel fuel, compared to the normal combustion of diesel fuel where only neat diesel is used without the blend.

Conversely, to produce a given power output, the required quantity of diesel fuel (with blend) is much lesser compared to neat diesel. Hence the mass of fuel consumed for a particular load is higher in case of 'neat diesel' than 'diesel with blend'.

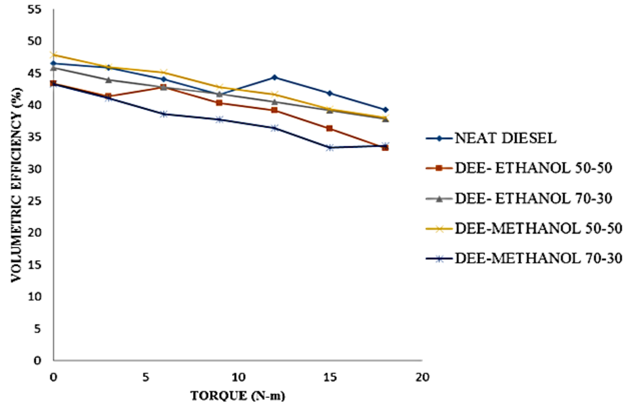

Figure 6 Volumetric Efficiency vs Torque

From the figure 6, it is inferred that use of blends reduces the volumetric efficiency of the engine. As blends enhance combustion of diesel fuels, higher heat release takes place in the engine cylinder resulting in higher temperatures inside the cylinder. Therefore the temperature of the residual gases will also be higher. During the succeeding suction stroke when the charge is drawn in, this excessive heat of the residual gases is transferred to the incoming charge thereby reducing charge density.

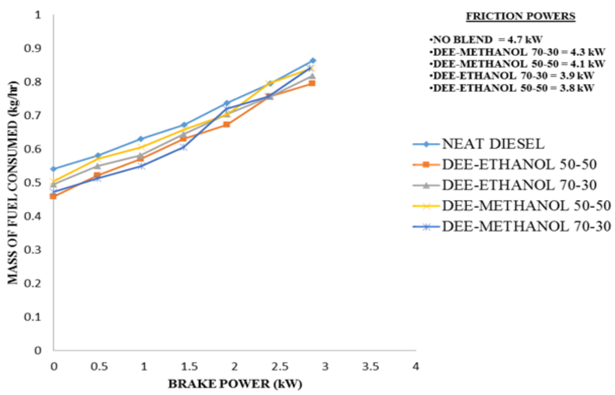

Figure 7 Willian's Line

Hence lesser volume of the charge enters the cylinder leading to lower volumetric efficiencies (when blends are used).

However this reduction in volumetric efficiency will not serve as a drawback because although lesser charge enters the cylinder, due to higher heat release, the required power output is obtained.

From figure 7 shows the Willian's line plot (without extrapolation). Willian's line plot gives the Friction Power. As the blends are oxygenates, they aid in better and smoother combustion. Thereby, reducing friction losses and hence friction power reduces. From the graph it is evident that all blends will definitely give less friction power than NEAT DIESEL. Thus addition of blend reduces friction power.

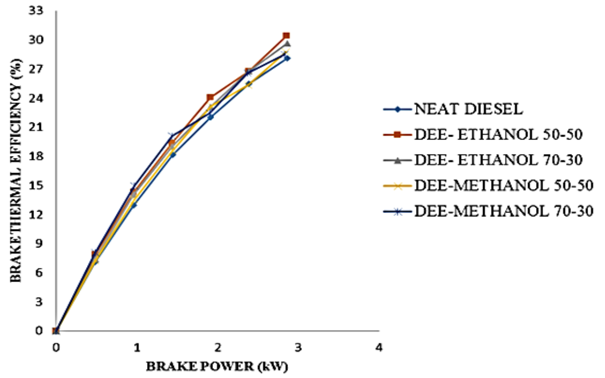

Figure 8 BTE vsBP

From the figure-8, it is inferred that with the use of blend, BP obtained is more compared to NEAT DIESEL and hence the BTE is more.

Blends being oxygenates, result in better combustion of diesel fuel. Better Combustion leads to higher power output. BTE is the percentage ratio of BP to Heat Input. So, as BP Increases, BTE also increases.

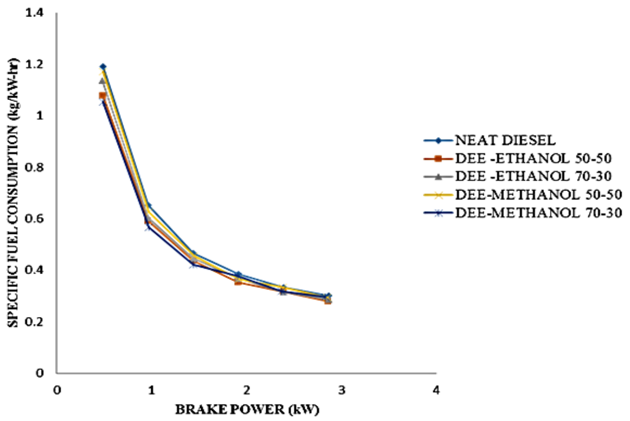

Figure 9 SFC vs BP

From the figure 9, it is inferred that use of blends reduce the specific fuel consumption of the engine. As blends results in better combustion, an effective utilization of diesel fuel is made. Therefore specific fuel consumption reduces with blends for a given output.

From the figure 10, it is inferred that use of blends reduces SFC than when compared with NEAT DIESEL. As Blends result in better combustion, diesel consumed to produce 1kW for 1hr reduces. Therefore for a given output, Specific fuel consumption reduces with blend.

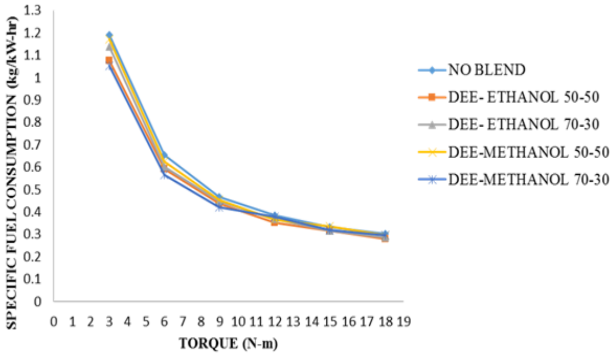

Figure 10 SFC vs Torque

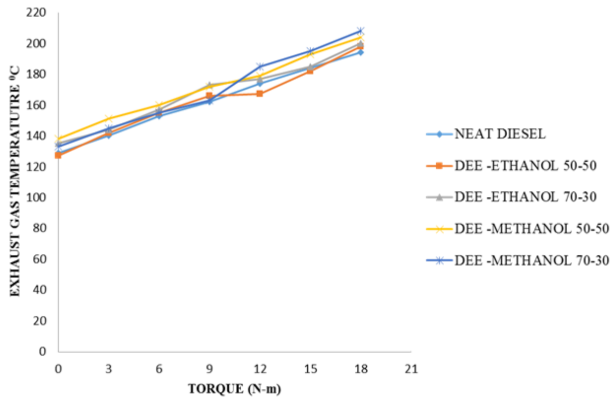

Figure11 Exhaust Gas Temperature vs Torque

From the figure 11, it is inferred that exhaust gas temperatures increases with use of blends when compared to that of neat diesel. As blends result in better combustion, higher heat release is obtained. As a result combustion temperatures increases and therefore exhaust gas temperatures also increases.

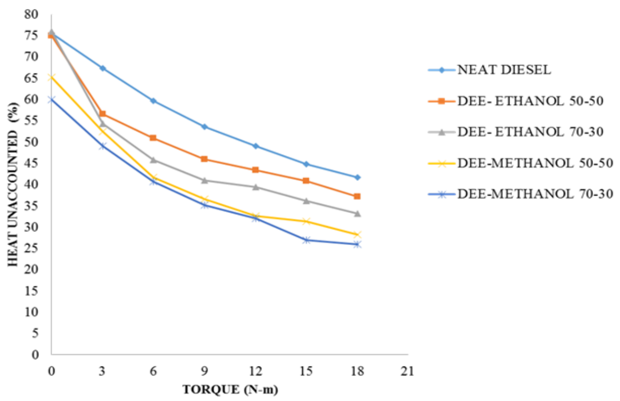

Figure 12 Heat Unaccounted vs Torque

From figure 12, is an inference from heat balance sheet, and it points out that most of the heat unaccounted is reducing for a given torque with the use of blend. This is due to increase in engine exhaust gas temperature which ultimately results in higher heat exchange between exhaust gases and cooling waters,(engine cooling water and calorimeter cooling water). Previously unaccounted heat is now accounted as cooling effect on the engine test rig and the source of the heat lost is now known. Thus engine is cooled more efficiently.

Conclusions

From the experiments that was carried out on a 4 stroke, single cylinder diesel engine using the following blends

50 (DEE) : 50 (Ethyl Alcohol),
50 (DEE) : 50 (Methyl Alcohol),
70 (DEE) : 30 (Ethyl Alcohol),
70 (DEE) : 30 (Methyl Alcohol).

Table 4 Comparison between both fuels

Graph	Neat Diesel	Diesel + Blend
BTE VS TORQ	26	31
MECH VS BP	37	43
VOL VS TORQ	39	33
FUEL CON VS TORQ	0.86	0.7
FP	4.7	3.8
BTE VS BP	27	31
SFC vs TORQ	1.2	1.05
SFC vs BP	1.2	1.05
$T_{Exhaust\ Gas}$ vs TORQ	194	216
Qunacc vs TORQ	42	26

From all the above figures and table it is clearly evident that, pilot fuel blends have resulted in enhanced combustion of the diesel fuel. The blends 70 (DEE) : 30 (Methyl Alcohol) and 50 (DEE) : 50 (Ethyl Alcohol) have shown significant increase in performance and hence can be used as effective combustion enhancers.

With large scale implementation of the above system, a solution can be obtained for the current energy crisis and the longevity of the fossil fuels can be increased…

Future Scope of Work

There is lot of potential for further research on this topic. Some of which are:

- Using other pilot fuels like Dimethyl ether, Ethylene glycol, ethers blended with peroxides etc. Different blends can be used at various proportions for further study.
- Emission study for the above work. Effect of pilot fuel blends on combustion products like CO, CO_2, NO_x, UBHC's and other particulates can be studied.
- Using pilot fuels along with EGR and pre-heater systems. Both EGR and pre heater systems result in better vaporization of the pilot fuel particles; hence, their effect can be studied.
- Changing the injector pressure of diesel injection. Increasing injector pressure helps distribute fuel particles in the cylinder more uniformly. The effect of this can be studied.

Currently the gravimetric system is feasible only for stationary diesel engines; with modification in the method of introduction of blended pilot fuels, enhanced performance can be obtained in mobile engines also.

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