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Performance and Combustion Evaluation of Blends of Pine Oil - Diesel in Single Cylinder CI Engine

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Abstract:
The present study is to seek the prospect of pine oil to be used as a substitute to that of diesel fuel. Pine oil is certainly available in India and it has found to be the least viscous oil due to which it has potential for utility as an alternative fuel may be explored.Therefore, due to low viscosity, no further transformation is done and the study is carried out by its direct blending with diesel fuel in various proportions. In this study, a comparative evaluation and analysis of physio-chemical properties of pine oil, its various blends with diesel has been done. Experimental analysis of performance and combustion of the blended fuels on CI engine has been conducted aiming to maximum substitution of pine oil to diesel in order to reduce emissions and improve quality of exhaust gas without decreasing the performance of the engine.

Introduction
To protect the global environment and support for long-term supplies of conventional fuels, it has become necessary to develop alternative fuels to supplement petroleum fuels.Earlier, research on alternative fuels has been started with the use of straight vegetable oils (SVOs) in place of diesel. But, the viscosity of these oils is significantly higher which restricted the use of SVOs in existing CI engine [1]. The efforts are then shifted to decrease the viscosity of these oils in order to make use of them as alternative to the conventional fuel. The simplest method adopted was to directly blend the oil with diesel.

Many efforts has been made to optimize the blend ratio of SVOs and diesel fuel [2–6]. A chemical transformation process, known as transesterification, separates out the glycerin from fatty acids and hence reduces the viscosity. The final product was named as “Biodiesel” because its properties was in a close agreement with the diesel fuel. From the past few decades, Biodiesel got the maximum popularity among the alternative/biofuels. But still the research is going on to reach up to a general statement regarding prediction of performance of the engine. The major issues with biodiesel are : (a) availability of feedstock; (b) transformation process of biodiesel from raw oil; (c) final properties of the biodiesel depends upon the geographical conditions of the origin of feedstock; (d) Oxidation and storage stability and many more [7]. Scientific community, working on alternative fuels, is now in the search of such a viable fuel which is less or not sensitive to the above said issues.

Comprehensive experimental studies are being done on diesel engines fueled with alcohols along with diesel, ethyl esters, methyl esters and even with SVOs in order to search for viable alternative fuels. H. Yu et al. [8] investigated the characteristics of spray wall – impingement for the various blends on n-butanol and diesel fuel. The investigations were aimed to study the effect of different environmental conditions and various strategies of fuel injection. D.C. Rakopoulos [9] studied the emissions and combustion characteristics with cottonseed oil,its

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biodiesel and blending with n-butanol &diethyl ether. It has been observed that the emissions were more in case of n-butanol and DEE blends with diesel than that of neat cottonseed oil – diesel blends. M. Karabektas et al. [10] investigated performance and emission characteristics of a CI engine using isobutanol–diesel fuel blends. Due to lower calorific value of iso-butanol, the thermal efficiency decreases slightly but there is considerable decrease in CO and NOx emissions for the blends up to 10% of iso –butanol. With the further increase in blend ratio HC emissions get increased.

Recently, some of the studies came up with the use of pine oil with diesel fuel. R. Vallinayagam et al.[11] observed 10% increase in BTE at low load and 5% increase in BTE at high load using pine various blends of pine oil (without transesterification) with diesel. There is 30 – 70% reduction in exhaust emissions (HC and CO) but 25% increase in NOx were observed at high load as compared to diesel. In another study, R. Vallinayagam et al.[12] conducted experiments with fumigation of pine oil in intake air manifold instead of direct blending with diesel. The results revealed that the pine can replace the diesel by 60% at low load and 36% at high load without any modifications. H. Huang et al.[13] investigated the effect of pilot injection strategies as well as EGR on engine performance and emissions using P20 (i.e. 20% Pine oil & 80% diesel) and P40 in comparison with diesel. The pilot injection and EGR along with addition of pine oil in diesel helps in reducing NOx emission without decreasing BTE.

Experimental Methodology

It can be believed that the pine oil addition can be a favourable replacement to diesel fuel. In this study, the experiments were conducted with various pine oil – diesel blends in close interval proportions i.e. P0, P10, P20, P30, P40 and P50 as shown in Figure 1. The physico – chemical of pure pine oil and diesel are shown in Table 1. The engine chosen to carry out experimentation is single cylinder, four stroke, direct injection, compression ignition engine which is widely used for agricultural and domestic electricity generation purposes.The detailed engine specifications for this work are shown inTable 2. The various load conditions taken for engine testing are: 2%, 20%, 40%, 60%, 80% and 100% of full load. The objective here for the substitution of pine oil in diesel fuel without significantly affecting the engine performance and subsequent exhaust emissions reduction.The setup is being equipped with data acquisition system and has capabilities to evaluate combustion and performance parameters. Thermodynamic analysis of measured cylinder pressure data was done for quantifying the various related combustion parameters. In this study the emissions of major concern only i.e. NOx and Smoke were evaluated. AVL Di-Gas 4000 LIGHT analyser is used to take the measurements of NOx and Smoke opacity was taken AVL 437 smoke meter.

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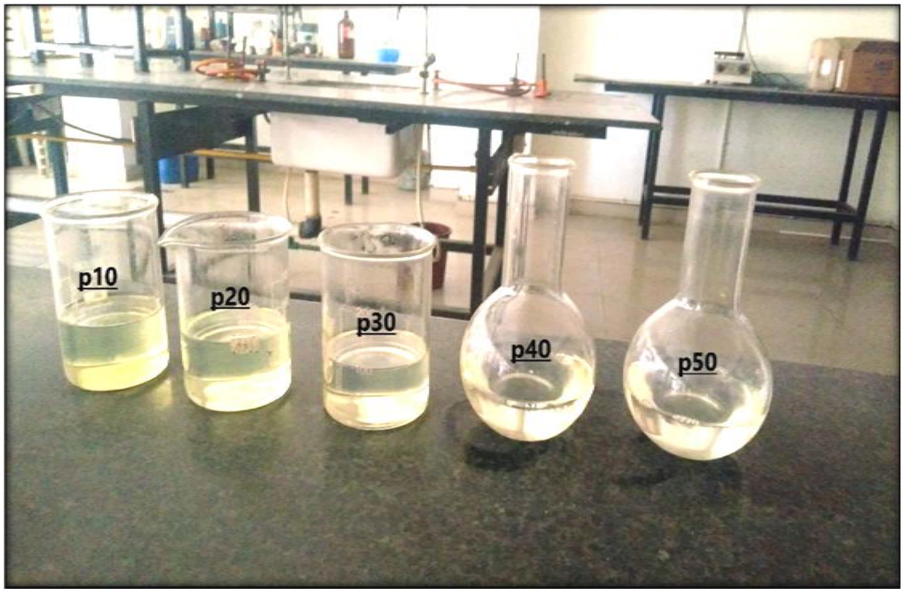

Figure 1. Pine oil- Diesel blends

Table 1. Properties of Diesel and Pine oil.

Property	Standard	Diesel	Pine oil
Density at 15 °C (kg/m^3)	ASTM D 1250	830	890
Kinematic viscosity at 40 °C (cSt)	ASTM D445	2.6	1.7
Flash Point (°C)	ASTM D93	68	56
Net Calorific Value (MJ/kg)	ASTM D240	44	39.9

Table 2. Test engine specifications.

Make	Kirloskar
Model	TV 1
Rated Brake Power (kW)	5.2 kW @ 1500 rpm
Rated Speed (rpm)	1500
Number of Cylinder	One
Bore × Stroke (mm)	87.5 × 110
Displacement volume (cc)	661
Compression Ratio	17.5:1
Cooling System	Water Cooled
Standard Fuel Injection Timing	23° before TDC

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Results and Discussion

Figure 2 shows the variation of brake thermal efficiency (BTE) and brake specific fuel consumption) for various blends at different engine loads in comparison with diesel. It can be observed that the BTE for all the blends is in close agreement with diesel fuel at various load conditions. At low loads BTE of diesel is dominating. But, at high loads, P10 showed slightly higher BTE as compared to all test fuels.

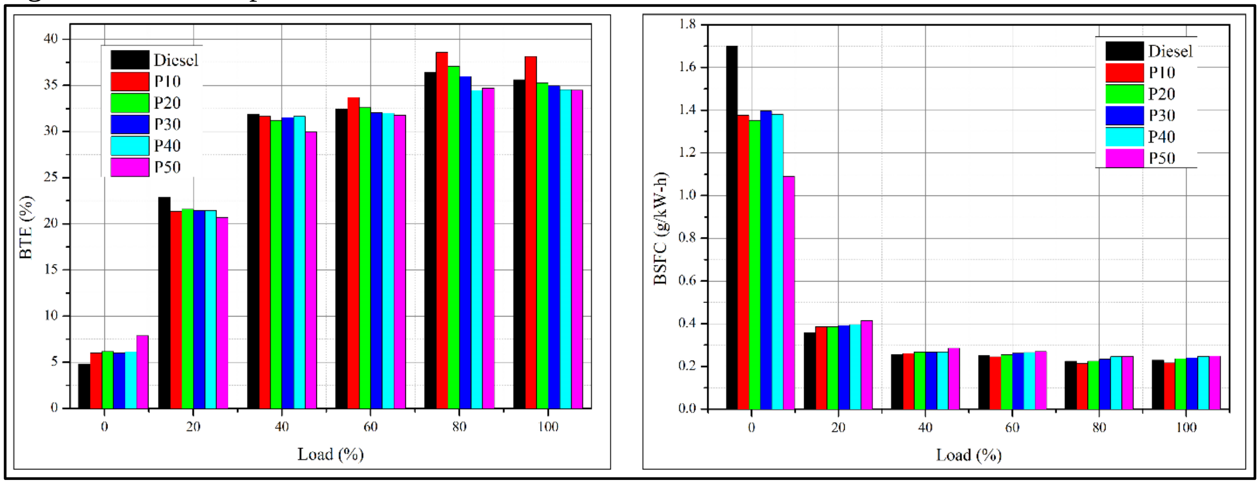

Figure 2. Variation of BTE and BSFC w.r.t. engine load.

A sharp decrease in BSFC is observed from 2 – 20% load but further it decreased gradually with the increase in load. This is due to the fact that the proportion of fuel required to drive the engine is less than the proportion of increase in brake power due to relatively less heat losses at higher loads [14]. It is interesting to note that at 2% load BTE is higher and consequently the BSFC is lower in case of all blended fuels as compared to diesel even having lower calorific values. It may be due to lower viscosity and better atomization at lower load requirements [11]. At higher loads there is slight increase in BSFC, special for P40 and P50 fuels, due to lower calorific value but still the values are almost identical.

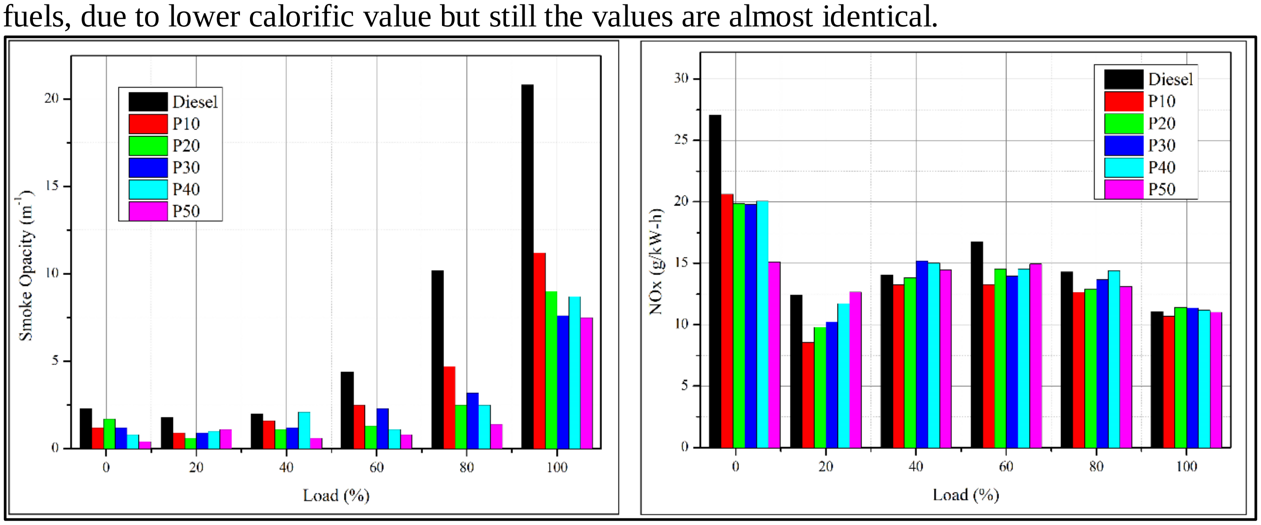

Figure 3. Variation of smoke opacity and NOx w.r.t. engine load.

The variations of smoke opacity and NOx of all the blends in comparison to mineral diesel with respect to engine load are presented inFigure 3. The trends of smoke opacity shows that it is increase with increase in engine load. It is a well-established fact that the smoke is generated during diffusion combustion zone[15,16]. Figure *4* shows that diesel is having more residual energy during diffusion combustion and late combustion relative to other blends. Due to this fact,the smoke opacity for diesel in considerably higher than all the blended fuels The smoke opacity is slightly on higher side at lower engine loads for P30, P40 and P50 fuels than that of diesel, B10 and B20. Anextensive difference can be witnessed for the smoke opacity for diesel and all blended fuels at 80% and 100% load. The reduction in smoke can also be explained by the presence of less carbon [terpineol ($C_{10}H_{18}O$) and pinene ($C_{10}H_{16}$)] as compared to diesel ($C_{12}H_{23}$) and absence of aromatics compounds as compared to diesel. Moreover, terpineol component itself contains an oxygen molecule which ensures faster oxidation rate during the combustion. More the carbon in a fuel molecule, more likely it is to produce the soot [17].At lower engine loads, the tested fuels showed higher brake specific NOx. However, at higher engine loads, the magnitude of brake specific NOx get reduced. This may be due to the fact that increase in NOx concentration in exhaust was smaller than increase in engine brake power. In the present study, blends of blended fuels do not show any significant differences in NOx trends of when comared to diesel. In the literature, the increase in NOx emissions have been reported using biodiesel as fuel in comparison to diesel [14,18,19].The effect of oxygen content of biodiesel on increase in NOx emissions has also been discarded in some other similar studies [20,21].

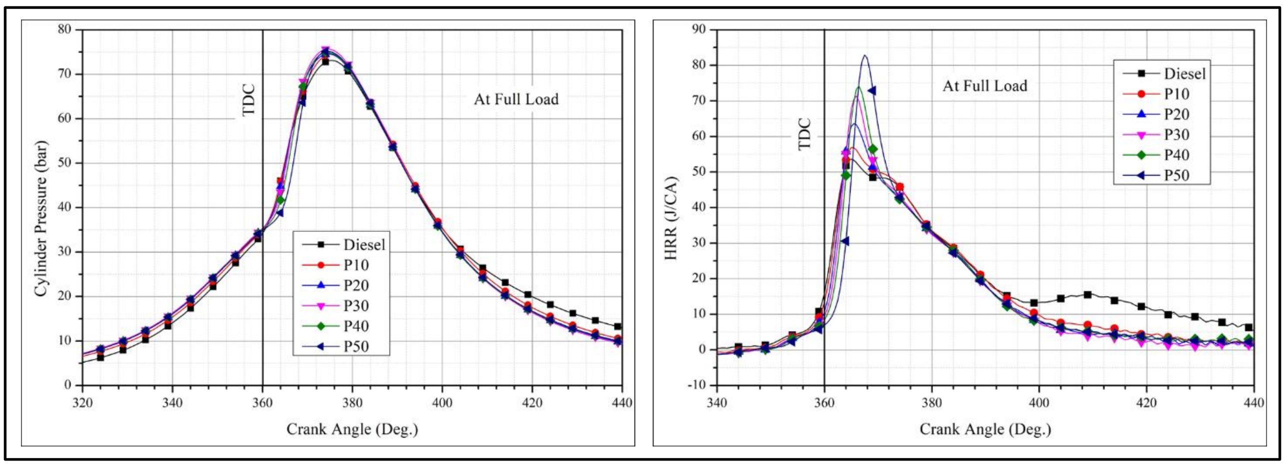

Figure 4. Variation of Cylinder Pressure and Heat release rate w.r.t. crank angle at full load.

Figure 4 shows the in-cylinder gas pressure history and heat release rate (HRR)with respect to the crank angle at fullload for all the tested fuels. The overall cylinder pressure (CP) history in each case indicates the smooth combustion from the point of fuel injection till the late combustion phase. Throughout the experimentation, no undesirable operational indications have been observed with any of the fuel blends which could have been harmful for the engine. The peak CP was observed to be slightly higher for blends as compared to diesel. It may be attributed lower viscosity due to which the rate of combustion is relatively faster. The faster rate of combustion can also be observed from the early rise of pressure curves for blended fuels which are slightly closer to TDC as compared to diesel. On the other hand, the rise HRR curves for blended fuels are also closer to TDC than diesel which also confirms the improved rate of combustion. Also, peaks of HRR for blended fuel are on higher side than that of diesel. The same reason may quoted for not having much difference in BTE of blended fuels even with lower calorific values. In late combustion phase, diesel is showing higher residual energy due to which high smoke is observed at full load as compared to blended fuels.

Conclusion

An experimental investigation has been presented with the objective the substitution of pine oil in diesel fuel without significantly affecting the performance of the engine and subsequent decrease in exhaust emissions. All the blended fuels have shown a close agreement in terms of BTE and BSFC of the engine instead of lower calorific values. It also shows that the maximum temperature of combustion for blended fuel may also be identical to diesel and hence NOx emissions are not increased. The lower kinematic viscosity of pine oil helps in improving the atomization of the blended fuel and hence improved the combustion rate. The lower smoke opacity for blended fuel, as compared to diesel, are the result of the improved combustion process.

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