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Emission reduction from a diesel engine fueled by pine oil biofuel using SCR and catalytic converter

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HIGHLIGHTS

- The renewable source of energy has been harnessed from pine oil–diesel blends.
- BTE and heat release rate were increased with the reduction in fuel consumption.
- The NO_X emission is reduced by implementing SCR and catalytic converter.
- Smoke, CO and HC for B50 were reduced by 70.1%, 67.5% and 58.6%.

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ABSTRACT

In this work, we propose pine oil biofuel, a renewable fuel obtained from the resins of pine tree, as a potential substitute fuel for a diesel engine. Pine oil is endowed with enhanced physical and thermal properties such as lower viscosity and boiling point, which enhances the atomization and fuel/air mixing process. However, the lower cetane number of the pine oil hinders its direct use in diesel engine and hence, it is blended in suitable proportions with diesel so that the ignition assistance could be provided by higher cetane diesel. Since lower cetane fuels are prone to more NO_X formation, SCR (selective catalyst reduction), using urea as reducing agent, along with a CC (catalytic converter) has been implemented in the exhaust pipe. From the experimental study, the BTE (brake thermal efficiency) was observed to be increased as the composition of pine oil increases in the blend, with B50 (50% pine oil and 50% diesel) showing 7.5% increase over diesel at full load condition. The major emissions such as smoke, CO, HC and NO_X were reduced by 70.1%, 67.5%, 58.6% and 15.2%, respectively, than diesel. Further, the average emissions of B50 with SCR and CC assembly were observed to be reduced, signifying the positive impact of pine oil biofuel on atmospheric environment. In the combustion characteristics front, peak heat release rate and maximum in-cylinder pressure were observed to be higher with longer ignition delay.

1. Introduction

In recent times, researchers have contemplated on using plant based biofuels such as eucalyptus oil and ethanol as potential substitute for diesel in diesel engine (Anandavelu et al., 2011; Giakoumis et al., 2013; Hansen et al., 2005; Tamilvendhan and Ilangovan, 2011). As opposed to biodiesel, which are synthesized from oil extracted from seeds, these biofuels are synthesized from plant parts and have lower viscosity. In a comparison, the atomization and spray characteristics of these fuels are superior to biodiesel, perhaps even better than diesel. However, despite the advantages of enhanced fuel properties, the cetane number, which characterizes the ignition quality of the fuel, was found to be lower. Often, the lower cetane value fuels cannot be directly used as sole fuel in diesel engine on account of its poor ignition quality and therefore, they entail some engine modifications to combat the above said limitation. Since complete replacement of diesel by these fuels is not possible without any engine modifications, blending of it with either diesel or methyl esters of vegetable oil has been recommended as the possible and easiest option.

The physical and thermal properties of eucalyptus oil are in agreement for its use in diesel engine with its major constituent being identified as cineole, containing in-built oxygen within its structure (Devan and Mahalakshmi, 2010). Based on the

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experimental investigations conducted in a single cylinder DI diesel engine using eucalyptus oil blended diesel fuel, it was reported that the mixing of eucalyptus oil with diesel up to 40% increased BTE (brake thermal efficiency) by 2.5% without affecting the emissions (Tamilvendhan and Ilangovan, 2011). However, lower cetane fuels tend to emit more NO_X (oxides of nitrogen) emission on account of higher peak heat release rate caused by longer ignition delay. In an attempt to reduce NO_X, Anandavelu et al. (2011) implemented EGR to show a 50–60% reduction in NO_X emission without much compromise on engine performance. Further, Devan et al. reported that the blend of 50% eucalyptus oil with methyl ester of paradise oil, which was an attempt to exclude the use of fossil fuel completely, showed better performance and emissions (Devan and Mahalakshmi, 2009). To increase the ignition qualities of eucalyptus oil, a recent study adopted an engine modification technique to preheat the inlet air so as to use it as sole fuel in diesel engine (Tamilvendhan and Ilangovan, 2011). The study revealed a 50% reduction in smoke emission at almost all loading conditions, while the BTE of the engine was observed to be in par with diesel.

In the same note, the use of other plant based fuel, ethanol, in diesel engine requires some modifications with the engine or fuel properties due to its lower cetane number (Guarieiro et al., 2009). The problem with lower ignition quality of ethanol could be remedied by preheating the intake air and consequently, complete combustion can be achieved (Yilmaz, 2007). Moreover, ethanol can also find its use in diesel engine by modifying the engine design, particularly the fuel injection systems (Lawrence et al., 2011). Both these approaches to make ethanol suitable for diesel engine would prove costly and requires lot of efforts, given the diesel engine is standardized for the use of diesel only. To confront this, researchers have suggested using ethanol in blends with diesel, known as diesohol, with an additional intent to lean the air fuel mixture and produce more efficient combustion (Huang et al., 2009; Lapuerta et al., 2008). In addition, several research works reported the engine characterization study on using lower cetane fuels in blends such as ethanol – biodiesel (Park et al., 2009; Shi et al., 2005), methanol – biodiesel (Anand et al., 2011; Cheung et al., 2009), ethanol – diesel – biodiesel (Kannan et al., 2012; Pang et al., 2006), methanol – diesel – biodiesel (Qi et al., 2010; ZHOU et al., 2007) and ethanol – biodiesel – water emulsion (Kannan and Anand, 2011; Qi et al., 2009). From the above studies, it is apparent that less viscous biofuel with lower cetane number and higher self-ignition temperature could also emerge as a potential candidate for diesel engine.

In this work, we selected pine oil as a renewable fuel for diesel engine in the lines of plant based fuels such as ethanol and eucalyptus oil as discussed above. Rare attention has been paid to use pine oil in diesel engine and hence significant endeavors have been made to test the characteristics of a diesel engine using this unutilized pine oil. Pine oil has lower viscosity and boiling point, which is deemed to enhance the fuel atomization and it's mixing with air. Despite this advantage, pine oil suffers a disadvantage of having lower cetane number, which prevents its direct use in diesel engine. Therefore, the present study has focused on using pine oil in blends with diesel and herein, the ignition assistance is provided by high cetane diesel fuel. For the current study, the pine oil being used has been procured from the commercial store and various blend composition such as B10 (Pine oil – 10% and diesel – 90%), B20 (Pine oil – 20% and diesel – 80%), B30 (Pine oil – 30% and diesel – 70%), B40 (Pine oil – 40% and diesel – 60%) and B50 (Pine oil – 50% and diesel – 50%) were prepared and tested for their performance, emission and combustion characteristics in a single cylinder diesel engine. Since lower cetane value fuels are prone to more NO_X formation, SCR (selective catalyst reduction) and CC (catalytic converter) assembly, which is regarded as an effective after treatment process, has been incorporated in the exhaust pipe.

2. Pine oil biofuel – composition and attributes

Pine oil is obtained from oleoresin of pine tree and contains terpineol, which is a tertiary alcohol, along with pinene. The oleoresins, collected from the pine trees, were subjected to steam distillation process to condense out pinene. The pinene was then treated with orthophosphoric acid to generate terpineol, an essential component of pine oil, leaving behind pinene. Finally, the produced pine oil was found to contain lower boiling fractions such as pinene ($C_{10}H_{16}$) and terpineol ($C_{10}H_{18}O$) as its two major constituents. Significantly, the molecular formula of pine oil clearly indicates that it is a hydrocarbon with inherent oxygen in its structure. Unlike biodiesel, which are synthesized from triglycerides, pine oil is extracted from the plant based source and hence its composition is quite distinct. Evidently, ester based fuels are reported to have longer carbon chain length, whereas, plant based fuels have shorter carbon chain length. Thus, the carbon to hydrogen ratio of these plant based fuels is lower, which does have an effect on engine soot and particulate emissions. In general, the characteristics of plant based fuels are antagonistic with the characteristics of biodiesel in respect of thermal and physical properties. Notably, biodiesel tend to have higher viscosity, boiling point, flash point and cetane number than pine oil.

A comprehensive comparison of various properties of eucalyptus oil and ethanol, as collected from open literature, is made with pine oil, as shown in Table 1. Incidentally, the physical – thermal properties of pine oil, as determined by ASTM standards, have close resemblance with the properties of eucalyptus oil and ethanol. However, contrary to ethanol, pine oil has higher calorific value, which makes it as one of the appropriate biofuel to be used in diesel engine. When compared to conventional petroleum diesel, pine oil has lower viscosity, boiling point, flash point and cetane number, while the calorific value of it is noted to be comparable. However, the self-ignition temperature of pine oil was observed to be slightly higher than diesel, affecting its auto-ignition characteristics. Therefore, it is required to provide some ignition support for the successful operation of it in a diesel engine like blending them with higher cetane fuel, preheating the inlet air or by adding ignition promoters with the blend.

3. Experimental setup and arrangement

3.1. Engine setup

Kirloskar stationary diesel engine has been used for the investigation of pine oil blends and the engine is loaded by a water

Table 1
Property comparison of pine oil with other fuels.

Property	Measurement standards	Pine oil	Diesel	Ethanol	Eucalyptus oil
Density at 15 °C in kg m^{-3}	ASTM D1298	875.1	822	789	890
Kinematic viscosity at 40 °C in 10^{-6} m^2 s^{-1}	ASTM D445	1.3	3.6	1.2	2
Flash point in °C	ASTM D92	52	74	13	54
Boiling point in °C	ASTM D1160	150–180	180–340	78	175
Gross calorific value in kJ kg^{-1}	ASTM D240	42,800	42,700	26,800	43,270
Sulfur content in %	ASTM D5453	Less than 0.005	Less than 0.005	–	–
Calculated cetane index	ASTM D976	11	52	5–8	Less than 15
Self-ignition temperature °C	ASTM G72	300	250	425	300–330