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A comprehensive assessment on the effect of high octane fuels induction on engine's combustion behaviour of a Mahua oil based dual fuel engine

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HIGHLIGHTS

- Performance, emission and combustion behaviour of Mahua oil was investigated under dual fuel mode.
- Dual fuel mode sufficiently improved the brake thermal efficiency and reduced smoke and NO emissions.
- Cylinder peak pressure increased significantly and reached highest with eucalyptus oil.
- Ignition delay increased in dual fuel operation with eucalyptus oil, ethanol and methanol.
- Significant enhancement in premixed heat release rate was observed in dual fuel mode with all the fuels.

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ABSTRACT

This paper presents a comprehensive study on the influence of different high octane fuels (such as eucalyptus oil, ethanol and methanol) on combustion behaviour of a Mahua oil based dual fuel engine. A single cylinder diesel engine developing a power output of 3.7 kW at 1500 rpm was modified and tested under dual fuel mode of operation. Initially the engine was run using neat diesel (ND), neat Mahua oil (NMO) as fuels. In the second phase, the engine was operated in dual fuel mode by using a specially designed variable jet carburettor to supply the high octane fuels. Engine trials were made at 100% and 40% loads (power outputs) with varying amounts of high octane fuels up to the maximum possible limit. Results indicated significant improvement in combustion pressure and maximum rate of pressure rise in dual fuel operation with all the inducted fuels mainly at 100% load. The ignition delay was found to be higher for all the inducted fuels as compared to single fuel operation for both loads. The combustion duration reduced in dual fuel operation as compared to NMO operation at 100% load but increased at 40% load. Significant improvement in heat release rate was observed in the premixed combustion phase in dual fuel operation as compared to single fuel mode of operation. The optimal energy share for the best combustion behaviour was found to be 44.6%, 27.3% and 23.2% respectively for eucalyptus oil, ethanol and methanol at 100% load. Eucalyptus oil showed the best among the inducted fuels in raising the cylinder peak pressure and heat release rate with reduced ignition delay and combustion duration. In general, dual fuel operation showed inferior combustion behaviour at 40% load for all the inducted fuels.

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1. Introduction

Biomass derived vegetable oils are considered as sustainable alternative fuels to conventional diesel fuel [1–4]. However their direct use in diesel engines results in very high smoke emissions with reduced thermal efficiency [5,6]. Dual fuel operation finds a simple and effective way of reducing smoke and improving thermal efficiency of diesel engines using vegetable oils as fuels [7,8]. Dual fuel engine is a modified diesel engine in which generally a high octane indexed gaseous fuel along with air is supplied during the intake process, compressed and ignited by firing a small amount of liquid fuel injected during the compression stroke. The injected fuel spontaneously auto ignites and initiates combustion of the inducted gaseous air mixture [9]. Diesel engines with appropriate and relatively simple conversion make the engine to accept any fuel to use efficiently in dual fuel mode. This type of engine has the advantage of running in pure diesel/vegetable oil mode also. Enormous work have been carried out on dual fuel engines using gaseous fuels such as natural gas, biogas, liquefied petroleum gas and hydrogen as inducted primary fuels when using diesel and vegetable oil as pilot fuels [7,8,10,11]. However, the

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Table 1
Properties of High Octane Primary fuels [12,13,18–20].

Properties	Gasoline	Methanol	Ethanol	Eucalyptus Oil
Chemical Formula	C_8H_{16}	CH_3OH	C_2H_5OH	$C_{10}H_{18}O$
Molecular Weight (g/mol)	106	32	–	154
Carbon (wt) %	90.56	37.5	52.2 mol%	77.92
Hydrogen %	15.09	12.5	13.1	11.68
Oxygen %	0	50	34.73	10.38
Density (kg/m^3)		790	780	890
Gross calorific value (kJ/kg)	43,900	19,665	27,200	43,270
Self-Ignition Temp. (°C)	520	464	423	300
Stoic. A/F Ratio (Mass)	14.7	6.5	9	12.5
Viscosity @ 40 °C (cSt)		0.65	1.52	2
Cetane Number	2	3	10	15
Octane Number	80	88	110	90
Boiling Point (°C)	30–220	65	78	175
Flash Point (°C)	−42	11	10	54
Heat of Vaporization (kJ/kg)	350	1100	838	320
Flame Velocity (cm/s)	33	40	38.5	40
Reid Vapor Pressure (psi)	9	4.6	2.3	1.6

information indicates that the engine with gaseous fuel supply needs sophisticated fuel flow control meters, special gas carburettor, safety devices such as flame trap, flame arrester, gas cylinder which make the intake system a very complex one when using gaseous primary fuels. On the other hand liquid fuels are potential candidates to overcome the above said problem. High octane liquid fuels like ethanol and methanol look very attractive to use as primary fuels in dual fuel engines as their properties such as high octane number, self ignition temperature, low viscosity and good vaporization characteristics. The important properties of methanol and ethanol were compared with gasoline and presented in Table1. Studies on the use of alcohols in diesel engines reported significant results on engine's performance and smoke reduction [12,13]. Alberto Boretti investigated the performance of a diesel ethanol dual fuel engine and reported that the thermal efficiency was superior with dual fuel mode as compared to neat diesel mode [14]. Wang et al., studied the combustion characteristics of a methanol diesel dual fuel engine extensively [15]. They observed the heat release rate of the dual fuel engine moved very close to TDC under high loads. They further noted simultaneous reduction of smoke and NOx in dual fuel operation with methanol injection. Jamuwa et al. investigated the effect of fumigated ethanol on engine's performance [16]. With ethanol fumigation, improvement in brake thermal efficiency and reduction in smoke and NOx emissions were reported. They further noted deterioration in engines performance at low loads with ethanol fumigation. Wojciech performed a study on using E85 (85% ethanol and 15% gasoline) as primary fuel in a three cylinder diesel engine with diesel as pilot fuel [17]. He noted that the cylinder pressure was significant in dual fuel mode at high power outputs with reduced soot and NOx emissions. It is evident from the above studies that dual fuel operation can be effective in reducing smoke emissions with alcohols while using diesel as pilot fuel with improved brake thermal efficiency and heat release rates.

Mahua oil (MO) is a non edible vegetable oil which appears to be a very promising fuel for diesel engines due to its easy availability (particularly in south India) and properties very close to diesel as seen in Table 2. Methanol and ethanol were recommended by most of the researchers in the past for dual fuel operation as primary liquid fuels. Past studies also reported successful engine results on methanol and ethanol as primary fuels using diesel as pilot fuel. Eucalyptus oil is an another biomass derived liquid fuel looks very attractive to use as primary fuel for dual fuel operation due to its unique properties very close to gasoline [18–20]. It has superior energy content as compared to other biomass derived hydrocarbon fuels. Though a number of studies have been carried out on dual fuel diesel engines using various liquid and gaseous fuels, information indicated no engine analysis on using Mahua oil dual fuel operation with alcohols as fuel supplement for enhancing engine's performance behaviour. In addition detailed analysis on combustion behaviour of a dual fuel engine with Mahua oil as pilot fuel with alcohols (methanol and ethanol) and eucalyptus oil as primary fuels was not studied in detail.

Table 2
Properties of Mahua Oil and Diesel.

Properties	Diesel	Mahua oil
Density (kg/m^3)	850	960
Low Heating Value (kJ/kg)	42,490	36,000
Viscosity (cSt) @ 40 °C	4.59	24.6
Flash Point (°C)	68	232
Pour Point (°C)	15	−20
Water content (%)	1.6	0.02
Ash Content (%)	0.9	0.01
Carbon Residue (%)	3.7	0.17
Cetane Number	45	46
Auto ignition Temperature (°C)	260	300

In view of the above it was decided to use methanol, ethanol and eucalyptus oil as primary fuels for dual fuel operation for improving the combustion behaviour of the MO based diesel engine. The influence of eucalyptus oil, ethanol and methanol induction on combustion characteristics of a Mahua oil based dual fuel engine was studied experimentally. In the first phase of the work the engine was operated on ND and NMO at two different loads such as 40% (part load) and 100% load (peak load) for baseline data generation. For this present work the load of the engine represents the brake power output from the crank shaft at the dynamometer side. 100% and 40% loads represent 3.7 kW and 1.48 kW power output of the engine. In the second phase the engine intake system was modified to supply primary fuels (eucalyptus oil, ethanol and methanol) by incorporating a vaporizer arrangement. A modified carburetor system was used to supply varying amount of primary fuels along with air by fumigation technique. The amount of fuel delivered was varied by adjusting the jet opening path. Experiments were carried out using MO as pilot fuel with eucalyptus oil, ethanol and methanol being used as primary fuels at 100% and 40% loading conditions. The amount of primary fuel induction was varied from 0% to the maximum possible energy limits where knock or misfire occurs. The primary fuel energy share was calculated as the ratio of total energy consumed from the primary fuel to the sum of total energy consumed (TEC) from both primary and pilot fuels. i.e.

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