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Experimental investigation of performance, exhaust emission and combustion parameters of stationary compression ignition engine using ethanol fumigation in dual fuel mode

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ABSTRACT

Dwindling reserves and steeply increasing prices of the fossil-fuels, concern over climatic change due to release of anthropogenic greenhouse gases and the strict environmental regulations have motivated the researchers for the search for renewable alternative fuel that has clean burning characteristics and may be produced indigenously. Alcohols, being oxygenated fuel improve the combustion and reduce greenhouse gas emissions, thus enhancing agrarian economies and encouraging national economy as a whole. The objective of this paper is to investigate the thermal performance, exhaust emissions and combustion behaviour of small capacity compression ignition engine using fumigated ethanol. Fumigated ethanol at different flow rates is supplied to the cylinder during suction with the help of a simplified low cost ethanol fuelling system. With ethanol fumigation, brake thermal efficiency decreased upto 11.2% at low loads due to deteriorated combustion, whereas improved combustion increased efficiency up to 6% at higher loads, as compared to pure diesel. Maximum reduction of 22%, 41% and 27% respectively in nitrogen oxide, smoke and carbon-di-oxide emissions with simultaneous increase in hydrocarbon and carbon-mono-oxide emissions upto maximum of 144% and 139% respectively for different rates of ethanol fumigation have been observed, when compared to pure diesel operation. This is due to the changes in physico-chemical properties of air fuel mixture, viz combustion temperature, oxygen concentration, latent heat of vaporisation, fuel distribution, cetane number and ignition delay, that occurred with addition of ethanol content. The rise in peak pressure of cycle, heat release rate and ignition delay along with decrease in combustion duration for different rates of ethanol fumigation have been observed. The increasing fumigation levels of ethanol results in the increase of maximum rate of pressure rise by 0.3–0.5 bar/°crank angle and the crank angle after top dead centre, where peak pressure occurs, shifts by 1–4° of crank angle. It is also observed that maximum heat release rate increases by 2–9 J/°crank angle as compared to baseline diesel case. Coefficient of Variance of indicated mean effective pressure increases with ethanol fumigation.

1. Introduction

Diesel engines that are widely used in transportation, agrarian and industrial equipments, etc. plays an important role in enhancing the energy-economy and reducing the exhaust emissions significantly. The objective to develop the engines with high efficiency and specific power output, obligation to comply with stringent emissions regulations and concern over dwindling crude oil reserves are the significant factors that have encouraged the engine manufacturers world wide to focus their attention on the use of renewable and cleaner alternative fuels [1–5].

The use of alternative fuels in CI engines that are produced from non-petroleum resources is suggested as one of the promising methods for improving their performance and emissions. These fuels include alcohols (such as ethanol and methanol), ethers, vegetable oils, animal fats, gaseous fuels (hydrogen, natural gas, liquefied petroleum gas) and bio-diesel [6–14]. The use of biogas in automobiles is restrained due to the requirement of high storage pressure and the lethal effects in case of leakage. Hence, the use of biogas as a substitute fuel for automobile is subjected to the development of the facilities for the safe storage and handling of the fuel. The exceedingly large demand for edible vegetable oil,

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Nomenclature

Symbols
AFR stoichiometric air fuel ratio (–)
$\dot{E}x_w$ net exergy work rate (kJ/s)
$\dot{E}x_{in}$ kJ/s input exergy rate
P_b brake power (kW)
q_m mass flow rate (kg/h)
Q_{LHV} lower heating value (kJ/kg)

Greek symbols
ε specific exergy of ethanol (kJ/kg)
φ chemical energy factor (–)
ψ exegy efficiency (–)

Abbreviations
aTDC after top dead centre
BTE brake thermal efficiency
CI compression ignition
CO carbon monoxide
CO_2 carbon dioxide
CoV Coefficient of Variance
°CA degree crank angle
HC hydrocarbons
HRR heat release rate
IMEP indicated mean effective pressure
NO_x nitric oxides of nitrogen
O_2 oxygen

Subscripts
air air
d diesel
e ethanol
st stoichiometric

greater than its supply, in India has restrained its use and has compelled to use non-edible oil. To initiate biodiesel program at large-scale cultivation may result in decreased production of food crops. Therefore, in the present scenario, alcohols seem to be the most attractive alternate fuel from the view-point of availability, storage and handling. Two alcohols commonly considered for automotive application are methanol and ethanol. Methanol has certain disadvantages, such as its low calorific value and toxic effects.

Ethanol is a biomass based renewable fuel that can be produced by alcoholic fermentation of sugar from vegetable materials, such as corn, sugar cane, sugar beets, barley, sweet sorghum, cassava and molasses. It can also be produced by agricultural residues, feedstock and waste woods using modern and commercially viable technologies [15]. Complete substitution of diesel with alcohol is very difficult, but in recent years, various researchers have carried out certain investigations using the lower alcohols such as methanol and ethanol, employing different techniques with varying amounts of alcohols in dual fuel mode. These techniques involves alcohol–diesel blends [16–28], alcohol fumigation [29–34] and alcohol–diesel fuel emulsification [35].

Sahin et al. [36] investigated experimentally the effects of 2%, 4%, 6%, 8% and 10% (by vol.) gasoline fumigation in a single cylinder direct injection (DI) Diesel engine at the speed of 900–1600 rpm and at the selected compression ratios of 18–23. The study with objective of comparing the effect of applying a biodiesel with either 10% blended methanol or 10% fumigation methanol was carried out by Cheng et al. [37]. The biodiesel used in this study was converted from waste cooking oil. Experiments were performed on a 4-cylinder naturally aspirated direct injection diesel engine operating at a constant speed of 1800 rev/min with five different engine loads. Zhang et al. [38] conducted the experiments on a four-cylinder direct-injection diesel engine with methanol or ethanol injected into the air intake of each cylinder, to compare their effect on the engine performance, gaseous emissions and particulate emissions at various loads at the maximum torque speed of 1800 rev/min. In another experimental study, Zhang et al. [39] conducted the experiments on same engine with methanol fumigation to investigate performance parameters and emissions of the engine at engine speed of 1920 rpm. Further, Zhang et al. [40] investigated the combined application of fumigation methanol and a diesel oxidation catalyst for reducing emissions of an in-use diesel engine. Experiments were performed on a 4 cylinder naturally aspirated direct-injection diesel engine operating at a constant speed of 1800 rev/min at various engine load. Hansdah and Murugan [41] investigated the influence of bioethanol fumigation on the performance, emission and combustion characteristics of single cylinder, four stroke, air cooled diesel engine. Bioethanol produced by the fermentation of Madhuca indica flower was used as an alternative fuel in this investigation. Bioethanol was fumigated at four different flow rates in the suction, with the help of a vaporiser and a microprocessor controlled injector. The results of the combustion, performance and emissions of the engine, running with the bioethanol fumigation, were compared with those of the diesel operation.

Sudheesh and Mallikarjuna [42] carried out experimental investigations of a homogeneous charge compression ignition engine using biogas as a primary fuel and diethyl ether as an ignition improver. The results obtained in this study were compared with those of the available biogas–diesel dual–fuel and biogas spark ignition modes. In another study, Can et al. [43] studied the effects of premixed ratio of diethyl ether on the combustion and exhaust emissions of a single-cylinder, homogeneous charge compression ignition direct injection engine. The amount of the premixed diethyl ether was controlled by a programmable electronic control unit. The effect of the variation of energy ratio of premixed DEE fuel on various performance, emission and combustion parameters was investigated and the results obtained were compared to neat diesel operation. Hou et al. [44] modified two-cylinder direct injection diesel engine for a homogeneous charge compression ignition–direct injection engine fuelled with dimethyl ether and investigated experimentally the effects of premixed ratio on various combustion characteristics.

From above, it is clear that numerous studies have been carried out to determine performance and exhaust emission parameters of CI engine using ethanol in fumigation mode for multi cylinder CI engines, but only a small quantum of work has been undertaken to study the performance, exhaust emissions and combustion characteristics of small capacity single cylinder four stroke water cooled CI engine fuelled with ethanol. The studies reported included expensive micro controller operated device for supply of ethanol whereas in the present study simplified low cost ethanol fuelling system was developed.

The engine used in this investigation is the most versatile engine that is widely used in diesel gensets in the urban areas and to power agricultural pump-sets in rural areas. Owing to their widespread use, there is a need to explore ways of making them more efficient, less polluting, less expensive, and more eco-friendly. The relevance of this study lies in the fact that it facilitates