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Experimental investigation of performance and emissions on low speed diesel engine with dual injection of solar generated steam and pongamia methyl ester

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Abstract

An experimental investigation has been carried out to examine the effects of steam injection into the intake manifold of a single cylinder, low speed, direct injection diesel engine fuelled with biodiesel palm methyl ester. Steam injection is generally carried out by non-conventional energy source. The addition of steam in to the intake manifold of the engine was carried out by vaporizing the water inside a boiler and heat is supplied by the solar concentrated parabolic dish. Biodiesels are known to produce higher NO_x when compared to the neat diesel. Addition of steam to the combustion chamber of diesel engine has known effects of reducing the dangerous emissions of NO_x but it is not clearly known about the engine performance and emissions. To examine this, an experimental investigation has been carried out on a single cylinder low speed diesel engine with steam injection in to the intake manifold during the suction stroke on the performance and engine emissions. Experiment results shows that there is a significant reduction in smoke levels and NO_x during the steam injection both for the diesel fuel and pongamia methyl ester. Also there is a significant improvement of engine performance in terms of specific fuel consumption and brake thermal efficiency with steam injection.

Keywords: Bio-fuels, pongamia methyl ester, thermal efficiency, steam injection, SFC, NO_x.

Introduction

Due to the gradual depletion of petroleum reserves and the impact of environmental pollution of increasing exhaust emissions, there is an urgent need for suitable alternative fuels for use in compression ignition engines (CI). Biodiesel has properties similar to those of traditional fossil diesel fuel which can be directly used in IC engines with little or no engine modifications. Studies clearly indicate that the use of biodiesel may potentially reduce the dependence on petroleum diesel fuel and improve air quality. However, it suffers from higher viscosity, cold starting problems and increased nitrogen oxides (NOx) emissions when compared with diesel oil (Herchel *et al.,* 2001; Silvo *et al.,* 2002; Nwafor, 2004; Agarwal & Agarwal, 2007; Murat & Fikret, 2007). Increased environmental concerns and tougher emission norms have led to the development of advanced engine technologies to reduce NOx and particulate matter (PM) emissions. Modification of diesel engines and fuel to reduce emissions has been a subject of numerous studies over the years. Many such studies have previously focused on fuel changes, such as reduced aromatic content (higher cetane number), reduced fuel sulfur, increased fuel volatility and decreased fuel density. Very low emissions from engines can be achieved with exhaust gas after treatment and optimized combustion processes (Abd-Alla, 2002; Eichlseder & Wimmer, 2003). Oxygenated diesel fuel studies have focused primarily on the possibility of significant emission reductions. It has been concluded from diesel engines combustion that the addition of water in the combustion chamber effectively reduces the NOx emission but there is a concern that it may increase the noise level from such engines. Four major approaches for introducing water into the combustion zone have been reported: 1.Water fumigation in to the inlet manifold of the engine; 2. Direct injection into the engine through separate injectors; 3. In-line mixing of water and fuel prior to injection (Unstabilized emulsion) and 4. Mixtures of stabilized emulsions treatable as a single-phase drop-in replacement fuel. Urbach *et al.* (1997) demonstrated that water mist injection into the bell housing of diesel-fueled turbine engines can lead to promising results. The use of water-fuel emulsion for control NOx emission was described by Nicholls (1969). It was found that 10% water in gasoline caused 10-20% reductions in nitrogen oxides. Bignardi *et al.* (1981) have reported the effects of water presence in fuel on SI engines they indicated that the NOx content in exhaust gas dropped by 1.3% for 1% addition of water to emulsified fuel. The major drawback of water-fuel emulsions is the amount of air bubbles reportedly contained in the emulsion mixture (Iranmanesh *et al.,* 2008; Pugazhvadivu & Rajagopan, 2009) studied the effects of DEE blends with biodiesel and obtained a significant reduction in NOx emissions especially for DEE addition of more than 10% on a volume basis and a little decrease in smoke. NOx reductions in dual fuel engines was studied by Mohamed *et al.* (2009) in which diesel engine is made to run on diesel as pilot fuel and LPG as main fuel. A significant reduction of CO_2 and NOx emissions was noticed along with increase in the specific fuel consumption and decrease in brake thermal effeciency.There have been many solutions to the NOx and smoke emissions problems for diesel engines converted to bio-fuel engines. However, there has not been any work that deals with steam injection for diesel engines converted to bio fuel engines in which steam is generated by means solar concentric dish. Steam generated by means of electrical power adds the running cost of the engine. Therefore, the objective of the present work is to examine the effects of adding steam to the intake manifold air of the engine on the engine performance, and emissions. The steam has been added in the present work to the intake air of the engine in the form of vaporized water produced by a special test rig explained in the next section.

Experimental test rig and procedure

Biodiesel was prepared from the non-edible oil of *Pongamia pinnata* the crude oil was heated to 100^0C to remove water. Then, the mixture was left to cool to 35^0C. Methanol (8% of the mixture in volume) was added to the mixture at 35^0C and it was stirred for 5 min. One milliliter of 95% H_2SO_4 was added to the mixture. The stirring was continued for 1 hour keeping the temperature constant at 35^0C without any heating. Then, the mixture was settled overnight. In the second stage, 3.5 g NaOH/litre of the mixture was dissolved in methanol (12% of the mixture) to produce methoxide (Freedman *et al.,* 1984; karmee *et al.,* 2004; Veeresh Babu *et al.,* 2009). Half of the prepared methoxide was poured into the unheated mixture and mixed for 5 min. The mixture was heated to 60^0C and the rest of the methoxide was added to the heated mixture. The stirring was continued for approximately 90 min. The mixture was allowed to form 2 layers overnight. The bottom layer was glycerin, while the upper layer was the ester. The glycerin was removed at the end of the settling. The ester was washed with pure water for three times. A small amount of phosphoric acid (2.5 ml/litre of the oil) was used in the first washing. At the end of the process, the oil was heated to 100^0C to remove any water from the oil left in the ester. The pH value of the final methyl ester was measured as 6.8. The properties of the pongamia methyl ester are shown in the Table 1.

Table1. Properties of the Pongamia methyl ester.

Fuel sample properties	PME
Density at 31^0C, (kg/m^3)	881
Gross calorific value, (kJ/kg)	38,850
Viscosity at 31^0C, (cSt.)	4.65
Cetane number	50
Rams bottom, Carbon residue wt%	0.38
Flash point, ^{0}C	180

Reflector: The reflector of our experimental device consists of a parabolic concentrator of 2.2 m opening diameter. Its interior surface is covered with a reflecting layer reflecting the solar rays on the face of a receiver placed at the focal position of the concentric circular dish. The concentrator is posed on a directional support according to 2 axes to ensure the follow-up of the sun. The equation for the parabola in cylindrical coordinates is $Z=r^2/4f$. The boiler was placed at the focal point ‘f’=$d^2/16h$ (ElOuederni & Dahmani, 2008). The boiler was fabricated using copper tubes of 6 mm diameter which are arranged concentrically around the centre of the cylinder. Total 16 numbers of copper tubes were taken due to its higher thermal conductivity when compared to the iron and aluminum. The copper tubes were surrounded by a cylindrical iron surface having a thickness of 5 mm. The base of the copper tubes is placed on a glass plate to reflect the incident light in to the cylindrical copper pipes. The cylinder base diameter is 5 inches and the height was 8 inches. The total surface of the boiler was black coated having a thickness of 3 mm to absorb the maximum incident light. The construction of the boiler was shown in Fig.1.

Methodology

Experiments were conducted on a single cylinder 4 stroke low speed diesel engine fitted with eddy current dynamometer run at rated speed of 650 rpm at 0 kW, 1.357 kW, 2.27 kW, 3.13 kW and 3.67 kW loads with fuel injection pressure of 200 bar. The maximum load on the dynamometer applied is 0 kg, 4.125 kg, 8.25 kg,12.375 kg,16.5 kg respectively and designated as No load, 1/4FL, 1/2FL, 3/4FL, full load respectively. The engine was started with diesel fuel and data was collected after attaining steady state. Then the experiment was switched over to PME fuel. The engine was sufficiently warmed up and stabilized before taking all readings. The technical specifications of the engine are given in Table 2. The steam is generated in the boiler by the concentrated solar dish and it is injected in to the inlet manifold of the engine through the suction end using a bifurcated duct along with air (Fig. 2). Fixed amount of the steam is passed in to the inlet manifold by passing steam through the venturimeter. The experiment was repeated by changing the 5 different speeds 650, 625, 600, 575 & 550 rpm respectively and the performance of the engine were tested by calculating the brake thermal efficiency, specific fuel consumption and brake power. Engine pollution was tested by measuring the smoke HC and NOx levels both at constant speed and variable speed.

Table 2. Engine specifications.

Diameter of the brake drum	0.285 m
Diameter of the orifice	0.02 m
Bore x stroke	0.08 m x 0.11 m
Speed	650 rpm
Rated power output	5 H.P.
Fuel Injection pressure	200 bar

Results and discussion

Fig. 3 shows the effect of steam injection and the engine load on smoke emissions. The smoke emission increased for part and medium loads and decreased by 20% with increase of load for diesel with steam injection. This is because of better combustion due to increase in combustion temperature at higher loads. But there are some fluctuations especially at full load. Smoke density for biodiesel PME is significantly lower than that of diesel

Fig. 2. Combined solar experiment test rig.

Fig.3. Smoke Vs Load.

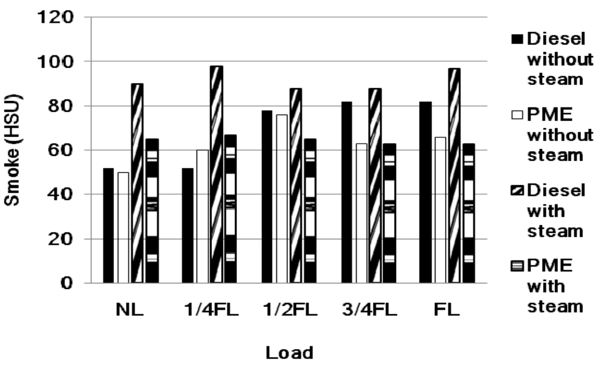


Fig .4. NO Vs Load

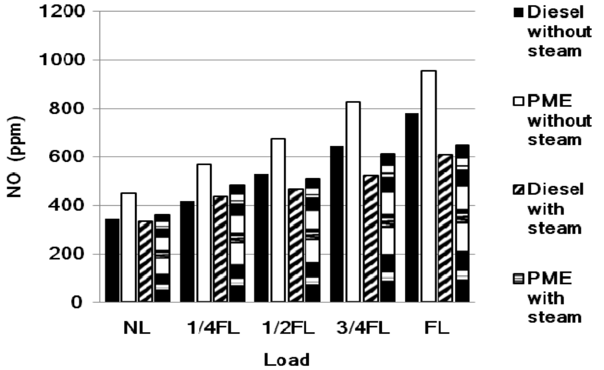


Fig.5. Exhaust Gas Temperature Vs Load

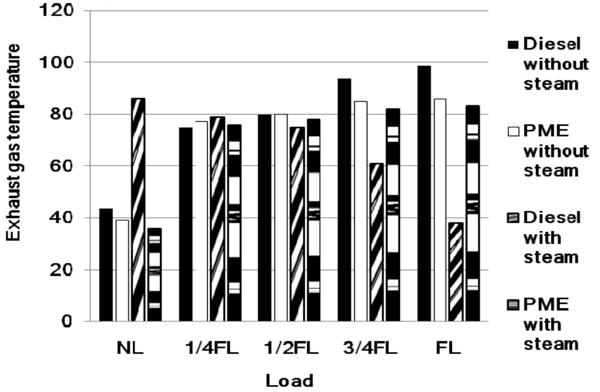


Fig.6. Brake Thermal Effeciency Vs B.P.

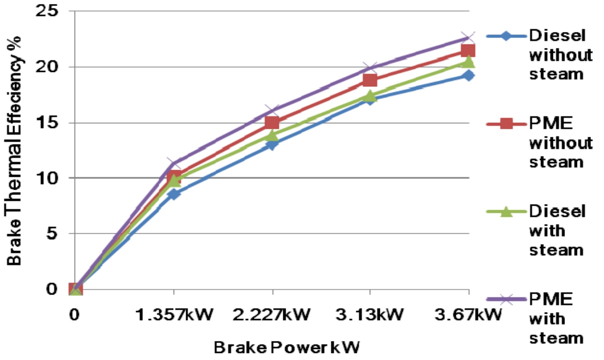


Fig.7. Brake power Vs Speed

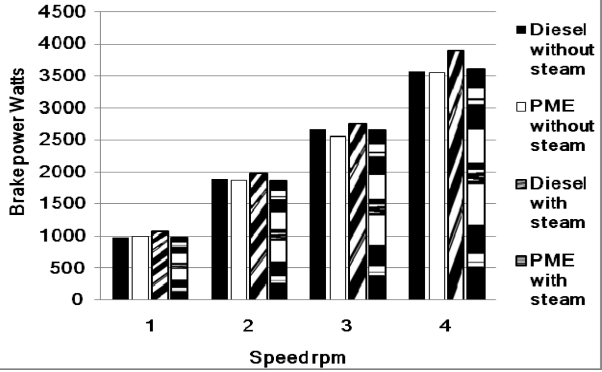
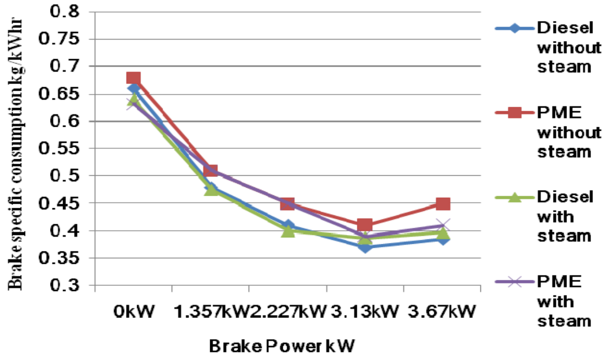


Fig.8. Brake Specific Consumption Vs B.P.



since bio-fuels are oxygenated fuels (Venkanna *et al.,* 2009).The inherent oxygen molecule in the fuel, which helps to promote stable and complete combustion by delivering oxygen and results in lower smoke emissions. These results agree with the results of Herchel *et al.,* (2001) but the degree of reduction is not same. The intensity of smoke for PME with steam injection is still lower than that of diesel and PME without steam injection due to the presence of oxygen in steam. Better combustion is observed due to preheating of inlet air due to the steam injection for PME which can be observed from the graphs that smoke intensity decreased continuously from medium to full load operation. The NOx emission from the engine using PME and diesel with steam injection is shown in Fig. 4. It shows that with increase in load there is an increase in NOx emissions for PME when compared to that of the diesel. The NOx formation depends on the availability of oxygen and combustion temperature (Md Nurun Nabi *et al.,* 2005). Without steam injection for PME operation NO_x emissions increased from 400ppm to 990ppm.When steam is injected along with PME the NO_x emissions reduced to 720ppm at full load. This decrease in NO_x emissions may be due to cooler combustion and better air fuel entrainment in the presence of water vapor. Less intense premixed burning and slower combustion rate helped in reducing the particulate matter. Steam injection improved the combustion and a new mode of combustion has taken place at due to better toque conversion which can be evident from the brake power. Fig. 5 shows that the exhaust gas temperatures increases with increase of load for all tested fuels without steam injection (Ramadhas *et al.,* 2005).Steam injection certainly reduced the exhaust gas temperatures of diesel at medium and full loads. The nitrogen oxides emission is directly related to the engine combustion chamber temperatures which in turn indicated by the prevailing exhaust gas temperatures. With increase in the value of exhaust gas temperature, NOx emission also increases the same is reflected in NO_x graphs (Fig. 4). But without steam injection PME is exhibiting higher exhaust temperatures when compared to diesel due to high combustion temperatures and peak pressures. Hence, steam injection certainly reduced the exhaust gas temperatures for all tested fuels. The reason for this is that steam injection provides better turbulence for the incoming fuel particles and latent heat of steam provides cooler combustion. The variation of brake thermal efficiency with steam injection is shown in Fig. 6. The thermal efficiency of PME has improved by 2% with steam injection at full load. At part loads there is no much variation in brake thermal efficiency for all fuels without steam injection. Fig. 7 shows the experimental results of the brake power output of the engine as a function of the engine speed and water vapour addition. The engine speed is varied from 575 rpm to 650 rpm keeping the same compression ratio. It can be seen that increasing the engine speed in this range generally increases the volumetric efficiency of the engine followed by an increase in the fuel rate which increases the brake power output of the engine. It may be seen from Fig. 7 that there is no much change in brake power with steam injection at low and medium speeds this may be attributed to the charge dilution at lower speeds. However, the benefits of using steam injection are more effective at full loads. The variation of brake specific fuel consumption with load for different fuels is presented in fig. 8. For all fuels tested, brake specific fuel consumption is found to decrease with increase in the load. This is due to the higher percentage increase in brake power with load as compared to the increase in fuel consumption. At maximum load condition, without steam injection the specific fuel consumption of PME is more than 14% than that of diesel. It may be noted that the calorific value of PME is 16% lower than that of diesel. At medium loads the specific fuel consumption of PME with steam injection is almost equal to that of without steam injection .At full loads the specific fuel consumption of PME without steam injection is 0.45 kg/kWhr where as with steam injection SFC is decreased to 0.42kg/kWhr. This is due to the better torque conversion and improvement in combustion at higher loads which is reflected in brake thermal efficiency graphs.

Conclusion

Pongamia methyl ester is generally tends to produce more amount of NO_x when compared to the neat diesel at all loads. But however steam injection reduced the NO_x emissions. At part loads the reduction of NOx is not so high for both PME and diesel fuel. But with increase of loads particularly for PME with steam the NO_x was reduced to a tune of 720 ppm and almost equal to that of diesel fuel. Specific fuel consumption decreases with increase of load for all fuels .Steam injection certainly increased the specific fuel consumption for all fuels. With steam injection SFC was slightly decreased for PME at full load when compared to without steam injection. However, compared to neat diesel fuel the SFC of PME in both the techniques is still higher due to higher calorific value of diesel fuel. The brake thermal efficiency of PME with steam injection was increased by 2%. With steam injection there is a significant reduction of smoke levels at full load. Smoke levels are still higher at low and medium loads. There is no much change in exhaust gas temperatures at medium loads for all fuels both with and without steam injections. Combustion is improved in the case of palm methyl ester with steam injection when compared to the neat diesel.

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