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Reduction of Environmental Pollution Generated From a Diesel Engine Using Diesel-Ethanol-Water Micro Emulsion

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ABSTRACT

Alcohol is one of the renewable energy sources that can be locally produced as well as serves as a source that would help in considering the depleting natural petroleum fuel resources. However, its non miscibility with diesel, especially at high alcohol ratios, low cetane number and poor lubricating characteristics have restricted its utilization in diesel engines. Usually, when ethanol contents in the blends reach 20-40%, high concentration of additives are needed to ensure the mixture homogeneity in the presence of high water contents, and to attain the required cetane number for suitable ignition. Therefore, selection of suitable additives plays a vital role for increasing the solubility of ethanol to a larger extent. Similarly, selection of a suitable surfactant is very important for obtaining long lasting emulsions. The surfactant span 20 and tween 20 have been selected here on account of their favourable properties and been focused in this study, as they have been used to stabilize the ethanol diesel and water emulsions and as an alternate fuel. A single-cylinder, air-cooled, direct injection diesel engine that could develop a power output of 5.2 kW at 1500 rev/min was used. Engine performance and emission data were used to optimize the blends for reducing emission and improving performance.

INTRODUCTION

Internal combustion engines generate undesirable emissions during the combustion process. The pollutants that exhaust from the internal combustion engines affect the atmosphere and cause problems such as global warming, smog, acid rain, respiratory hazards, etc. These emissions are mostly due to non-stoichiometric combustion, dissociation of nitrogen and impurities in the fuel and air. Major emissions include nitrogen oxides (NOx), unburnt hydrocarbons (HC), oxides of carbon, oxides of sulphur and other carbon particles or soot. Diesel passenger vehicles will require over a 90 percent reduction in NOx and a 75 percent reduction in particulate matter to meet the new emission standards over the next few years. Such a large technical challenge will require a system-based approach combining water emulsion and additives. The emission improvement achieved by properly designed fuel-water emulsification is universal regardless of engine. The primary benefit of water-fuel emulsions in diesel engines is a notable reduction in NOx emission.

The importance of using emulsified fuel relays, mainly on its ability to reduce unwanted combustion products such oxides of nitrogen and particulate matter from diesel fueled machineries (Anna & Homberg 2006). Injection of water through the engine injector was found to decrease nitrous oxides (NOx) and smoke (Dan Scarpete 2013). Some emulsified fuels were able to reduce the sulphur content in higher sulphur fuels, thus, adding soda ash to the emulsifying water had reduced the smoke emissions by as much as 50% (Fu et al. 2010a)

During the combustion process, water causes the fuel atomization, which results from the occurrence of the micro-explosion, a process through the water droplets, which normally evaporate at 100°C, causes explosion that exceeds the interfacial tension between the fuel and water vapour leading to better fuel air mixture. Water also causes an ignition delay during combustion, which leads to increase in pressure rise within the engine cylinder, increasing thermal efficiency and reduces thermal stress within the engine components. During the combustion process, the elevated level of micro-explosion is witnessed by the reduction of flame height to be more intense around its axis. The NOx reduction process is governed by the elevated local excess air factor due to the manifestation of larger and denser water droplets (Fu et al. 2010b). Micro-explosion occurs because of the differences in boiling points between the continuous phase (oil) and dispersed phase (water). In a typical water-in-oil emulsion fuel sample introduced to a combustor, the oil plus surfactant encapsulated water droplets are heated due to the elevated air temperature (in combustion chamber), and since water has lower boiling point it can be overheated and starts to boil inside the oil capsules, this state is referred to as metastable and water would boil vigorously. Soon after this vigorous boiling, water would cause explosion of the encapsulating parent oil layer of the droplet. This is known as explosive boiling of micro-explosion phenomena which almost always encountered in the combustion of emulsion fuel (Ghannam & Selim 2009).

Mohammed Yahaya Khan et al. (2014) have studied the effect of ultrasonic emulsification techniques in the stability of water-in-diesel emulsion. They have studied the effect of the ultrasonic horn tip position in the sample, emulsification time (mixing time), and water content by measuring viscosity, droplet sizes and droplet surface area of the produced emulsion. Ethanol-diesel blends (or E-diesel) contain up to 10 volume percent ethanol and an additive known as an emulsifier (Sane et al. 2014). The fuel mixture is known as a micro-emulsion and is prepared by splash blending, a process that requires no special equipment or temperature control. Water-diesel blends have a number of potential advantages including, significant lowering of diesel particulate matter emissions and NOx.

Micro-emulsion is a chemically and thermodynamically stable ultra-fine dispersion of a dispersed liquid phase in an immiscible host phase (Mohammed Yahaya Khan et al. 2014). A micro-emulsion is clear, like a solution, but actually consists of droplets or micelles dispersed in the host phase. The micelle size is roughly one micron. A surfactant additive called an emulsifier and a small amount of water are typically required for the formation of a micro-emulsion. E-diesel formulations are most likely micro-emulsions. Conventional diesel fuel can carry very little water, in the order of 0.1%. Emulsifier manufacturers claim that their products make diesel blends tolerant of reasonable water content without phase separation. For both solubility and water tolerance, a minimum requirement for E-diesel needs to be specified (Hossain et al. 2013).

The blending cetane number of ethanol is 8 and ASTM D975 requires a minimum cetane number of 40 for a diesel fuel (Madhu et al. 2007). There is considerable evidence that cetane numbers below 40 cause poor engine operation and increasing cetane number can improve engine performance and reduce emissions (Song et al. 2002). Adding a cetane-enhancing component is required for E-diesel to retain the performance level of the blending diesel fuel. Because cetane-enhancing additives are expensive, the lowest cost approach is to use only enough cetane additives to bring the cetane number of the E-diesel up to the level of the blending diesel fuel. However, the use of additional cetane additive may be desirable to reduce NOx emissions and to allow marketing as a premium diesel fuel (Miyamoto et al. 1996).

MATERIALS AND METHODS

The major advantage of blending is the absence of modifications in intake and injection systems, and the ease of implementation (Prabhahar et al. 2012a). Therefore, selection of suitable additives play a vital role to increase the solubility of ethanol in larger amount. Similarly, selection of surfactant is very important to obtain long lasting emulsions (Prabhahar et al. 2012b). Tween 20 and Span 20 by virtue of their favourable properties, are focused in this study to stabilize the ethanol diesel and water emulsions and as an alternate fuel (Patricia et al. 2015). Stable emulsion was obtained by mixing ethanol and additive with diesel in the percentage shown in the Table 1. The emulsion was milky white in colour and remained as it is for a very long period of time, which was used in the experiment as the new fuel (Urbina Villalba et al. 2000).

Table 1: Composition (% by weight).

Emulsion	Diesel	Ethanol + Additive
Diesel	100	-
90D:10E	90	9+1
80D:20E	80	19+1
75D:25E	75	24+1
70D:30E	70	29+1

Experimental procedure: A single-cylinder, air-cooled, direct injection diesel engine developing a power output of 5.2 kW at 1500 rev/min is used. The engine was started on neat fuel and warmed up. The test fuel was selected. If the emulsion was used, the emulsified fuel was introduced into the fuel line and another period of time was allowed for the engine to stabilize. Base data are generated with standard diesel fuel, subsequently, four fuel emulsion diesels with tween 20 and span 20 were prepared and tested on a diesel engine. Engine performance and emission data were used to optimize the blends for reducing emission and improving performance.

RESULTS AND DISCUSSION

Fig. 1 shows the specific fuel consumption for different ethanol additions. All the blend specific fuel consumption is lower than sole fuel. Among the blends, 90D:10E ratio shows minimum specific fuel consumption in the middle load conditions compared to other blends and sole fuel. Fig. 2 shows the effect of oxygenated fuel blend on the brake thermal efficiency. The maximum brake thermal efficiency occurs for 90D:10E ratios and hence is considered as optimum emulsion ratio. Fig. 3 depicts that the average brake thermal efficiency for 90D:10E ratio is approximately 2% over diesel for the maximum load of the engine. Improvement in combustion, especially diffusion combustion, as the oxygen concentration increase by surfactant in the fuel may be the reason for the increase in

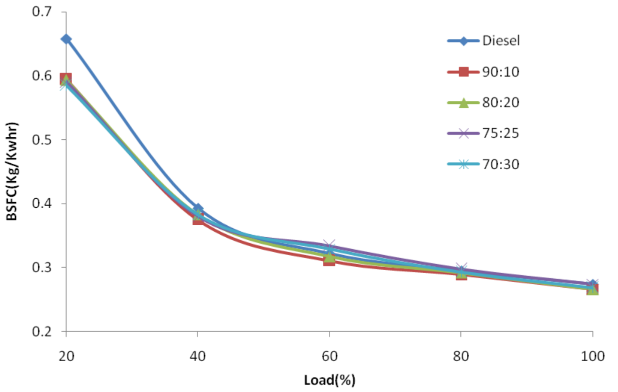

Fig. 1: Variation of BSFC with load.

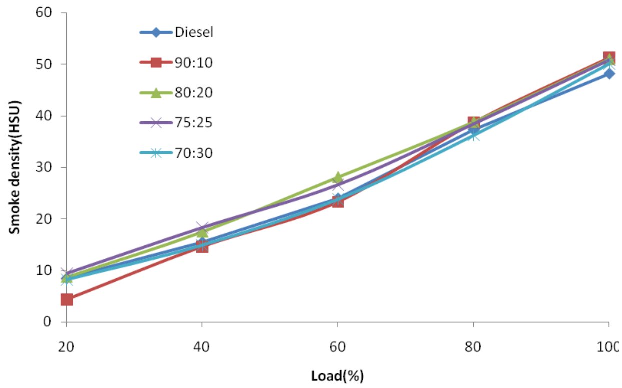

Fig. 4: Variation of smoke density with load.

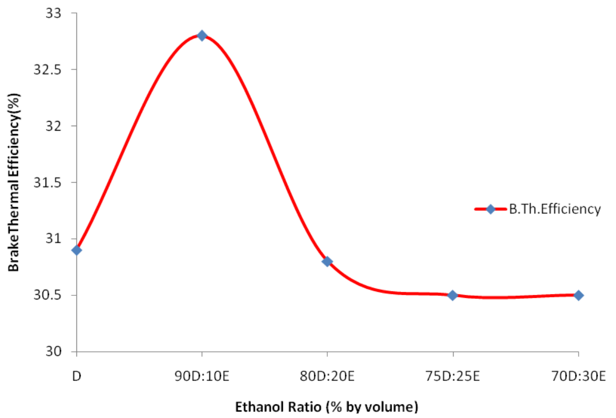

Fig. 2: Variations of brake thermal efficiency with ethanol ratio.

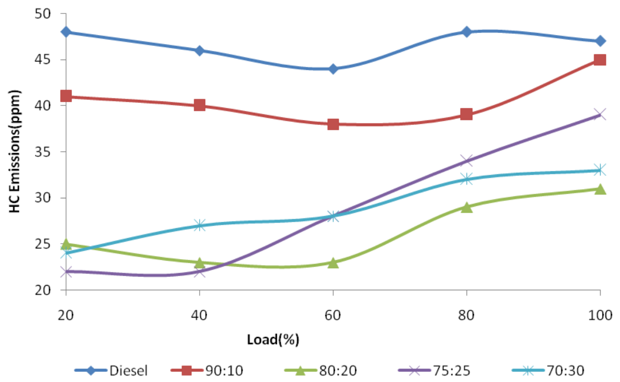

Fig. 5: HC emission with load.

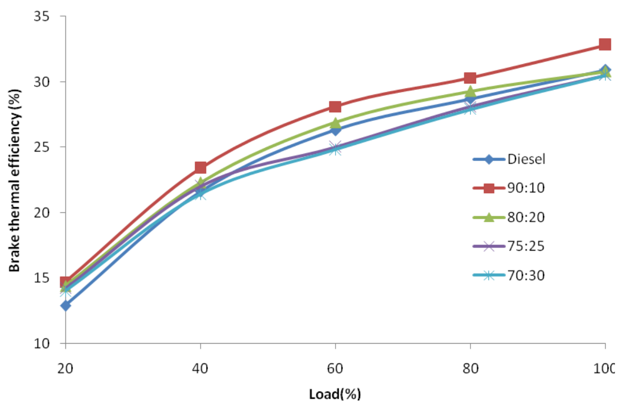

Fig. 3: Variation of brake thermal efficiency with load.

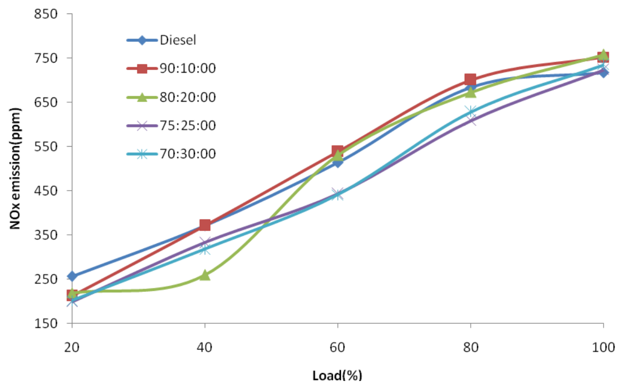

Fig. 6: Variation of NOx emission with load.

efficiency. The brake thermal efficiency generally increases up to 10% ethanol addition, but slightly decrease for further additions as the combustion temperature drops due to the increased amount of ethanol.

Emission parameters: The variation of smoke density with respective engine brake power is shown in Fig. 4. From the figure it is observed that the addition of 10% ethanol, decreased the smoke density slightly at minimum load. Ethanol has less carbon than diesel fuel and also having oxygen content and thereby increasing the oxygen fuel ratio at rich fuel region.

Fig. 5 gives the HC emission with different ethanol ad-

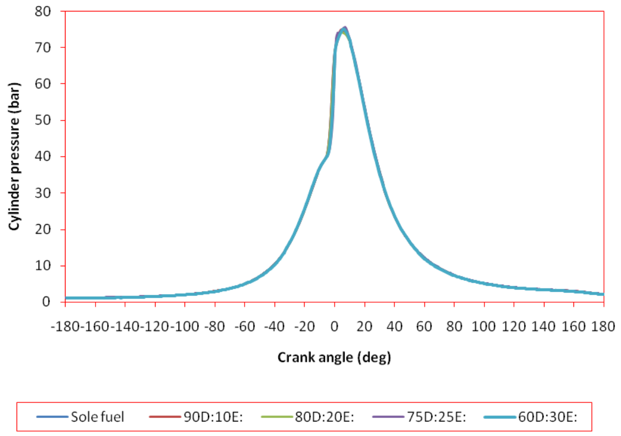

Fig. 7: Variation of cylinder pressure with crank angle.

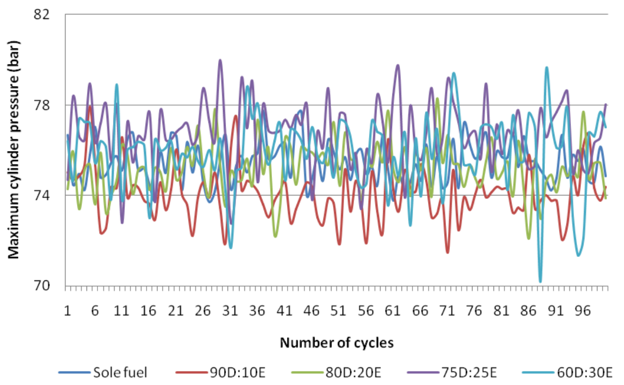

Fig. 8: Variation of cylinder pressure with number of cycles.

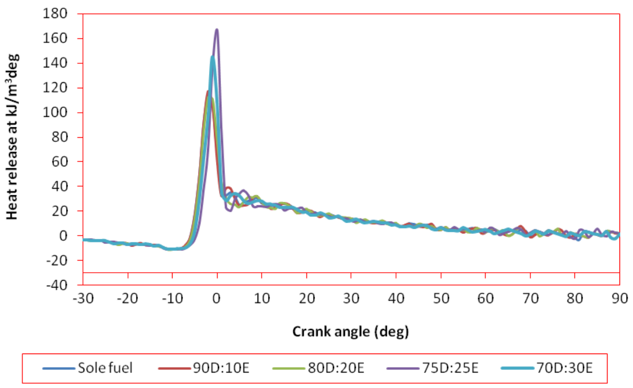

Fig. 9: Variation of heat release with crank angle.

ditions. It is observed that HC emission for emulsions are lower than neat diesel fuel. This is due to the presence of oxygen in ethanol and water which enhances the complete combustion.

Fig. 6 illustrates the NOx emission with brake power of the engine. Nitrogen oxides emission are predominately temperature phenomena, local counteraction of oxygen and duration of combustion. It is found that initially in all the emulsions, NOx emission was reduced, but after the part load the NOx emission was increased gradually.

It can be seen that NOx emissions of all blends increased more rapidly than those of sole fuel as ethanol proportion and load increase at medium and high loads. The maximum increase in NOx emissions occur at 80~100% full load conditions because of long ignition delay and rich oxygen circumstance from ethanol in the mixture.

Combustion parameters: The presence of oxygen molecules increases the spray optimization and evaporation. Hence, it improves the combustion process of the engine. Figs. 7 and 8 illustrate the cylinder pressure traces of ethanol emulsified diesel fuels. It is found that at the same engine speed and maximum load, the cylinder pressure shows greater differences for sole fuel and oxygenated fuel. The peak pressure is 75.5 bar for 75D:25E emulsion against 74.4 bar for sole fuel.

It can also be seen that due to the pressure variations of oxygenated fuel engine, higher pressure region will change sharply as with diesel engine, but the durations of the higher pressure period is shorter than that of diesel engine. The oxygenated fuel engine is having longer delay period, compared to sole fuel.

Fig. 9 shows the rate of heat release for oxygenated fuel blends and sole fuel for different crank angle. It can be seen that heat release rate curves of the oxygenated fuel blends and sole fuel show similar curve pattern although the rate of heat release for the 75D:25E is higher than the sole fuel. The reason is that the rate of diffusion combustion of the oxygenated fuel increase the heat release rate, consequently oxygenated fuel has controlled the rate of pre-mixed combustion. The rate of heat release rate of oxygenated fuel is slightly shifted to the top dead centre due to increased premixed combustion.

Results show that ethanol emulsions increase the brake thermal efficiency. Higher ethanol ratio reduces the efficiency but, still better than neat diesel. 90D:10E ratio shows highest efficiency with less smoke density.

CONCLUSION

The present work can be considered as a development of E-diesel fuels. From the study made from the experimental investigation it was found that influence of ethanol-diesel emulsifying on the main pollutant emissions, namely both oxides of nitrogen and hydrocarbon emissions in single cylinder four stroke cycle diesel engines could be controlled. The emulsion used here achieved significant reduction in the NOx emissions from diesel engines without requiring substantial retrofitting of the engines, nor an increase in emission of other pollutants. Though higher ethanol ratio reduces the efficiency it was better than neat diesel. 90D: 10E ratio shows highest efficiency with less smoke density. It was also found that NOx emissions and peak heat release rate are high with blends than neat diesel.

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