ARTICLE IN PRESS

Alexandria Engineering Journal (2016) xxx, xxx–xxx

HOSTED BY

ELSEVIER

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Experimental investigation on performance characteristics of a diesel engine using diesel-water emulsion with oxygen enriched air

P. Baskar *, **A. Senthil Kumar**

School of Mechanical Engineering, VIT University, Vellore, India

Received 13 May 2016; revised 17 August 2016; accepted 24 September 2016

KEYWORDS

Combustion;
Diesel engine;
Emissions;
Emulsion;
Oxygen enrichment

Abstract Diesel engines occupy a crucial position in automobile industry due to their high thermal efficiency and high power to weight ratio. However, they lag behind in controlling air polluting components coming out of the engine exhaust. Therefore, diesel consumption should be analyzed for future energy consumption and this can be primarily controlled by the petroleum fuel substitution techniques for existing diesel engines, which include biodiesel, alcohol-diesel emulsions and diesel water emulsions. Among them the diesel water emulsion is found to be most suitable fuel due to reduction in particulate matter and NOx emission, besides that it also improves the brake thermal efficiency. But the major problem associated with emulsions is the ignition delay, since this is responsible for the power and torque loss. A reduction in NOx emission was observed due to reduction in combustion chamber temperature as the water concentration increases. However the side effect of emulsified diesel is a reduction in power which can be compensated by oxygen enrichment. The present study investigates the effects of oxygen concentration on the performance characteristics of a diesel engine when the intake air is enriched to 27% of oxygen and fueled by 10% of water diesel emulsion. It was found that the brake thermal efficiency was enhanced, combustion characteristics improved and there is also a reduction in HC emissions.

1. Introduction

Diesel engines are always designed to operate with an excess air in the region of 15–40%, depending upon the application to find the necessary oxygen for combustion. Therefore the engine size becomes bigger for a given output and the air-fuel mixture will be heterogeneous in nature. One of the main aims of the diesel engine designer was that air-fuel ratio should be as close to stoichiometric as possible while operating at full load at the same time giving a better thermal efficiency and mean effective pressure.

The use of water in diesel fuel has numerous benefits. There are four primary methods of introducing water into the diesel engines: water injection into the cylinder using a separate injector, spraying water into the inlet air, intake manifold fumigation and water-diesel emulsions. Although all these methods lead to a reduction in NOx, the use of water-diesel emulsion

* Corresponding author.
E-mail address: pbaskar@vit.ac.in (P. Baskar).
Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2016.09.014
1110-0168 © 2016 Faculty of Engineering, Alexandria University. Production and hosting by Elsevier B.V.

Please cite this article in press as: P. Baskar, A. Senthil Kumar, Experimental investigation on performance characteristics of a diesel engine using diesel-water emulsion with oxygen enriched air, Alexandria Eng. J. (2016), http://dx.doi.org/10.1016/j.aej.2016.09.014

was the most effective technique for the reduction in diesel particulates or smoke and it has been validated by the works of Mello et al. [1].

Diesel emulsion has an influence on reducing the peak flame temperature and hence reducing the NOx emissions. It has also been shown that addition of water may help to improve atomization and mixing, which is attributed to droplet micro-explosions as indicated by Murayama et al. [2]. The improved mixing is due to the increased vaporized fuel jet momentum, giving greater air entertainment into the fuel jet as explained by Kegl and Pehan [3].

Tree and Svensson [4] have seen that improved mixing also assists in the reduction in NOx emissions from the diffusive burning portion of the combustion cycle as well as reducing the carbon formation. This effect, combined with the chemical effect of the water results in an increased ignition delay as noted by Nazha et al. [5]. This in turn promotes an increase in the premixed portion of the combustion process, which decreases the diffusive burning and hence also contributes to the reduction in the NOx emissions and carbon formation as suggested by Subramanian [6].

There are also considerable data that suggest adding water to diesel fuel can reduce the particulate matter or smoke emissions as noted by Alahmer [7]. Liang et al. [8] find that, as the percentage of water in the emulsion increases, a larger amount of diesel is displaced by an equal amount of water, and this means that less diesel fuel is actually contained within each volume of the emulsion thereby decreasing the brake specific fuel consumption of the diesel engine.

Oxygen enriched air has been tried by the researchers over the years with the aim of reducing HC, CO, smoke, and particulate levels and improving the brake thermal efficiency in diesel engines. The major drawback of OEA technique is increasing NOx emissions; however, Virk et al. [9] conducted test on a single cylinder diesel engine to reduce the NOx emissions caused by the OEA and achieved it by low levels of enrichment along with retardation of injection timing. By using these optimized conditions, NOx levels were kept at the same value as the unenriched-air, while particulates and smoke emissions were reduced.

Donahue et al. [10] found that oxygen enhancement, whether it is from intake air enrichment or via oxygenated fuels, reduces particulate matter, the effectiveness depending on the local concentration of oxygen in the fuel plume. Oxygen-enriched intake air significantly reduces all the exhaust emissions except NOx; however, it improves the power density, lessens ignition delay, and allows the use of lower-grade fuels as reported by Poola et al. [11].

Cammarota et al. [12] and later Salzano et al. [15] proved that the OEA results in increased flame velocity and flame temperature, and this can lead to a flame propagation which is not deflagration but it is combustion induced rapid phase transition. It has also been noted by Rakopoulos et al. [13] that post treatment of the exhaust may be needed to control NOx levels when oxygen enriched air is used. Perez and Boehman [14] report that the oxygen enhancement helps to avoid a decrease in brake specific fuel consumption values at high altitude conditions and also maintains power output constant.

Lu et al. [16] studied the effect of lower oxygen concentration and found that 17% OEA causes an increase in soot and CO exhaust because of lower temperature in the later stages of combustion. Mohsen et al. [18] illustrate that oxygen enrichment is an effective way to reduce the knock tendency of pilot ignited natural gas- diesel engine at maximum load.

NOx emissions are generally increasing with OEA due to increased availability of atomic oxygen and also due to attainment of higher temperature during lean operation which enhances the kinetics for thermal NOx formation. This was clearly observed in the works of Jianxi et al. [17] and Baskar et al. [19].

The increase in NOx emissions is a key issue for further development and application of oxygen-enriched combustion in internal combustion engine. Earlier studies [16–22] have shown that oxygen-enriched combustion can greatly reduce particulate matter and soot significantly; however, NOx emissions will significantly increase if no special measure was applied. The harmful NOx emissions and PM purification methods of diesel engine contradict with each other, which makes it difficult to fully meet future stringent emission regulations.

In this research, the above two methods were combined in experimental tests to explore the coupling effects of oxygen enrichment and water contents of emulsified diesel fuel on NO emissions, cylinder pressure, heat release rate and brake thermal efficiency. A single cylinder, air cooled, four stroke cycle compression ignition engine was used for the above purpose.

2. Experimental method

To study the effect of oxygen concentration in the intake air and diesel-water emulsion as fuel for combustion, performance and emission characteristics a direct injection diesel engine is selected. A single cylinder constant speed diesel engine was run under variable load conditions. Experiments were conducted in four different phases. In the first phase the engine was run with neat diesel and 21% of atmospheric air and then in the second phase engine was fueled by 10% of water diesel emulsion. In the third phase the intake air was enriched with 27% of oxygen and neat diesel as fuel. Final phase consists of an engine was fueled by 10% diesel-water emulsion and 27% of oxygen enriched intake air in volume basis was used. The diesel-water emulsion prepared was obtained by adding 10% water (v/v) to the diesel fuel with the aid of surfactants that enabled the mixing of water and diesel.

2.1. Preparation of emulsion

Emulsification is the process of mixing the two immiscible phases by reducing the stress between these phases. It can be formed by the addition of water as the dispersed phase within a continuous diesel fuel phase leading to the formation of diesel water emulsion with the addition of surfactants. The addition of surfactants combines the different phases to form a single phase and its presence is very much essential in the formation of diesel-water emulsion. Surfactants' primary role was to lower the interfacial tension between the water phase and the diesel fuel phase. The secondary role was to stabilize the water droplet phase within the diesel fuel phase to avoid the coalescence mechanism of the water phase. Surface active material accumulates at the interfacial film between the water droplet phase and the diesel fuel continuous phase to stabilize the water droplet phase and thus, consequently stabilize the

Please cite this article in press as: P. Baskar, A. Senthil Kumar, Experimental investigation on performance characteristics of a diesel engine using diesel-water emulsion with oxygen enriched air, Alexandria Eng. J. (2016), http://dx.doi.org/10.1016/j.aej.2016.09.014