Energy Conversion and Management 123 (2016) 372–380

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

An assessment on performance, combustion and emission behavior of a diesel engine powered by ceria nanoparticle blended emulsified biofuel

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A R T I C L E I N F O

Article history:
Received 22 April 2016
Received in revised form 21 June 2016
Accepted 22 June 2016
Available online 27 June 2016

Keywords:
Lemongrass oil
Lemongrass oil emulsion
Cerium oxide nanoparticle
Emission
Diesel engine

A B S T R A C T

The consequence of using cerium oxide (CeO_2) nanoparticle as additive in Lemongrass Oil (LGO) emulsion fuel was experimentally investigated in a single cylinder, constant speed diesel engine. A novel biofuel plant was introduced in this project, namely lemongrass whose binomial name is *Cymbopogon flexuosus*. The main objective of the project is to reduce the level of harmful pollutants in the exhaust such as unburned hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_X), and smoke. The engine performance could also be increased due to the addition of CeO_2 nanoparticle. The LGO emulsion fuel was prepared in the proportion of 5% of water, 93% of LGO and 2% of span80 by volume basis. Span80 acted as surfactant and it would reduce surface tension between the liquids with a hydrophilic-lipophilic balance (HLB) value of 4.2. The ceria nanoparticle was dispersed with the LGO emulsion fuel in the dosage of 30 ppm (ppm). The diesel engine performance, combustion behavior and emission magnitude were compared with diesel and LGO as the base fuels. The whole investigation was conducted with a single cylinder diesel engine using the following fuels, namely neat diesel, neat LGO, LGO emulsion and LGO nano emulsion fuels respectively. The LGO emulsion fuel could reduce smoke and NO_X emissions and could improve Brake Thermal Efficiency (BTE), Brake Specific Energy Consumption (BSEC) compared with neat LGO despite the marginal increase in HC and CO emissions. For ceria nanoparticle blended test fuel, the drastic reduction of carbon monoxide (CO), unburned hydrocarbon (HC), oxides of nitrogen (NO_X) and marginal decrease of smoke opacity emission could be achieved compared with the LGO emulsion and diesel fuel at various power outputs. Improvement in BTE was also observed for LGO nano emulsion test fuel compared to neat LGO and LGO emulsion fuels due to improved atomization and rapid evaporation rate of fuel owing to large surface area to volume ratio of CeO_2 nanoparticle.

1. Introduction

In the recent era, there exists an urge to find an alternative, biodegradable and environmental friendly fuel to meet the energy demands. One such positive alternative is the biodiesel which may replace the energy demand of the future generation with much greener and cleaner environmental impacts [1]. But the limitations with biodiesel fuel are NO_x and particulate emissions and these concerns should be properly addressed before implementing real time practical applications. Over the past three decades, many analyses have been examined across the globe in order to reduce the NO_X and particulate emissions [2]. In this regard, the recirculation of exhaust gas, retardation of injection timing, oxygen enrichment, emulsification of biodiesel and addition of nanoparticle in biodiesel are the various possible methods that are available for NOx reduction in biodiesel fuelled diesel engine. Among these possible methods, emulsification of fuel is the viable and modest technique which improves the fuel efficiency and reduces the engine emissions [3,4]. Debnath et al. [5] evaluated the performance and emission behavior of a compression ignition engine fuelled with emulsified palm biodiesel under different operating conditions. It was suggested that the evaporation of water from emulsified palm biodiesel reduced the NOx emissions inside the cylinder during combustion process.

The effect of various parameters such as stability, fluidity, fat content on emulsion characteristics of animal fat was experimentally studied by Kerihuel et al. [6]. They concluded that 50% of

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http://dx.doi.org/10.1016/j.enconman.2016.06.062
0196-8904/

Nomenclature

ASTM	American Society for Testing and Materials	*Ppm*	parts per million
LGO	Lemongrass Oil	*TDC*	top dead centre
CeO_2	cerium oxide	*bTDC*	before top dead centre
Ce_2O_3	cerous oxide	*CNT*	carbon nano tubes
BTE	Brake Thermal Efficiency	*HRR*	heat release rate
BSEC	Brake Specific Energy Consumption	*DICI*	direct injection compression ignition
BSFC	brake specific fuel consumption	*XRD*	X-ray diffraction
CA	crank angle	*SEM*	Scanning Electron Microscope
CI	compression ignition	*HLB*	hydrophilic–lipophilic balance
CO	carbon monoxide	*WCO*	waste cooking oil
HC	hydrocarbon	*JCPDS*	Joint Committee on Powder Diffraction Standards
NO_x	oxides of nitrogen		

animal fat with 36.4% of ethanol, 3.6% of SPAN 83 and 10% of water produced best emulsion in terms of stability and fat content. In another investigation, ethanol-animal fat emulsion was used as fuel in single cylinder diesel engine and results were compared with neat animal fat and diesel fuels [7]. The ethanol-animal fat emulsified fuel showed significant reductions in smoke content, NO_X, HC and CO emissions at higher loads. A comparative study on performance and combustion characteristics of diesel engine fuelled with biodiesel and bio-oil based emulsified fuels were performed by Prakash et al. [8]. The study reveals that the brake thermal efficiency of both biodiesel and bio-oil based emulsified fuels was higher than that of diesel at 100% load. This is because of the combustion kinetic rate is faster and the presence of oxygen content in the emulsified fuel resulted in higher positive work done on the piston.

In the recent times, light biofuels derivative from woods, leaves, biomass and other parts of plants are being considered as alternative source for diesel fuel by many scientists and researchers across the globe [9]. These biofuels are completely differing from vegetable oil based biodiesel that are not in need of transesterification process. The preferable types of biofuels are lemongrass oil, eucalyptus oil, pine oil and ethers [10]. The better atomization and complete mixing of fuel with air are significant merits of these low viscous biofuels over vegetable oil based biodiesel [11].

Fewer researchers made significant contributions in the field of low viscous biofuel applications in diesel engine under different operating conditions. Alagumalai [12] studied the combustion behavior of partially pre-mixed charge compression ignition engine using lemongrass (*Cymbopogon flexuosus*) oil. It was pointed out that the neat LGO can be used as a sole fuel in compression ignition engine without any pre-treatment processes such as pyrolysis and transesterification. Dhinesh et al. [13] investigated the performance, combustion behavior and emission magnitude of diesel engine with *C. flexuosus* as fuel. The *C. flexuosus* biofuel was blended with diesel under different proportions of 10%, 20%, 30% and 40% on volume basis and the results indicated that 20% raw *C. flexuosus* biofuel-diesel blend shown better performance and lower emissions compared to other blended fuels. Sathiyamoorthi and Sankaranarayanan [17] studied the effect of two antioxidant additives, namely butylated hydroxyanisole and butylated hydroxytoluene on the performance and emission behavior of direct injection compression ignition (DICI) engine fuelled with lemongrass oil-diesel blend. The addition of the antioxidant additives was carried out for the concentration of 500 ppm, 1000 ppm and 2000 ppm in the blend of 25% lemongrass oil and 75% diesel. Higher brake thermal efficiency and lower brake specific fuel consumption were observed for the addition of antioxidant additives with the lemongrass oil-diesel blend.

New approaches of introducing fuel additive of nano dimension have been the critical area of research to bring down the NO_X emissions in biofuel operated diesel engine. Several attempts have been made to improve the quality of diesel, biodiesel and other biofuels through doping of nanocatalyst. The recent research work suggested that the addition of nanoparticles with diesel engine fuels would reduce the delay period and auto-ignition temperature and evaporation time, enhancement of dispersion rate and minimize the fuel clogging in the fuel injector [18,19]. It was also stated that the doping a small amount of nano based additives such as alumina, ceria and carbon nanotubes in biodiesel and emulsified fuel would act as catalyst and would strengthen the bonding of water and diesel or biodiesel mixture [20,21].

A comparative study on performance, combustion and emission characteristics of single cylinder diesel engine for diesel, diesel-water emulsion and diesel-water emulsion with nanoparticle additive was performed by Basha and Anand [22]. Higher brake thermal efficiency was noted for nanoparticle addition in diesel-waster emulsion compared to other fuels due to catalytic action of alumina nanoparticle in the fuel that increases the combustion efficiency of the fuel. Prabhu and Anand [23] examined the influence of 10, 30 and 60 ppm of alumina and ceria nanoparticle in Jatropha oil methyl ester on performance and emission behavior of diesel engine. The experimental results showed that the brake thermal efficiency of nanoparticle addition in biodiesel was comparable to diesel fuel. In addition, it resulted in 13% reduction of NO_X and 60% reduction of CO emission when nanoparticle was added to Jatropha biodiesel.

Basha and Anand [24] investigated the performance and combustion behavior of compression ignition engine using carbon nanotubes (CNT) blended Jatropha methyl ester emulsion. The brake thermal efficiency of Jatropha biodiesel, Jatropha biodiesel with 5% water emulsion, and 5% water with 100 ppm carbon nano tubes (CNT) blended Jatropha biodiesel emulsion fuels was found to be 24.80%, 26.34%, and 28.45% respectively. It was observed that the addition of CNT to the emulsion fuel resulted in drastic reduction of smoke and oxides of nitrogen emissions. Arulmozhiselvan et al. [25] investigated the performance and emission behavior of diesel engine using ceria nanoparticle additive in diesel and diesel-biodiesel-ethanol blended fuels. The tested results proved that ceria nanoparticle could be used as fuel additive for the improvement of combustion rate and exhaust emission reductions. In addition, the deposition of non-polar compounds on the wall of the engine cylinder was prevented by the CeO_2 nanoparticle and its activation energy burns off the deposited carbon particles at the combustion chamber wall temperature which results in lower HC emission.

Dhinesh et al. [26] studied the influence of cerium oxide nanoparticle addition in *C. flexuosus* biofuel in direct injection