Fuel 236 (2019) 666–676

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

A novel fuel containing glycerol triacetate additive, biodiesel and diesel blends to improve dual-fuelled diesel engines performance and exhaust emissions

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ARTICLE INFO

Keywords:
Dual fuel diesel engine
Glycerol triacetate
Diesel/biodiesel fuel blend
Engine performance and emissions
Fuel additive

ABSTRACT

Declining petroleum sources and increasing demands for energy and emissions characteristics of fossil fuels combustion lead investigations to clean, available and low-cost energy resources. Dual-fuelled diesel engine by NG as main fuel and biodiesel blend as pilot fuel can be an appreciate idea to reduce engine emissions and using renewable source of fuel. The main aim of present study is to use the blend of glycerol triacetate (GT) additive and biodiesel to reduce emissions and to improve fuel cost of dual-fuelled diesel engine by natural gas as main fuel. Tests performed on dual fueled, constant speed (1500 rpm) diesel engine by two levels of biodiesels (B5, B20) with three levels of GT additives (3%, 5%, 7%) and neat diesel fuel as pilot fuel and four levels of pilot fuel to gaseous fuel (20%, 30%, 40%, 50%). Based on results, using B5A3 as pilot fuel decreased NOx emission by 24% in pilot-to-gaseous (P/G) fuel ratio of 50%. Using B20A3 as pilot fuel significantly reduced PM emission, such that in P/G ratio of 20% it was 85% lower than that of diesel as pilot fuel. CO emission was found to be 72% lower than that of diesel as pilot fuel in case of using B5A7 as pilot fuel in P/G ratio of 20%. Using B5 as pilot fuel in P/G ratio of 20% reduced CO_2 emission by about 8% compared to that of diesel as pilot fuel. UHC emission had been increased slightly using biodiesel and GT additive rather than diesel pilot fuel. It was also observed that in the P/G ratio of 40% using B5 fuel, the GP cost was 0.22 $/kWh which is about 15% lower than that for diesel pilot fuel.

1. Introduction

The global increase in demand for energy consumption and reduction of fossil fuel resources and the increase of pollutions caused by the combustion of these fuels, especially diesel fuel, is growing, quickly [1–3]. In order to reduce the air pollutant and greenhouse gases emission and also due to the reduction of petroleum resources, in recent decades alternative fuels for internal combustion engines (such as diesel engines) have been widely discussed [4]. In the meantime, the supply of energy by using renewable energy resources with low emissions and cost is today's study of researchers [5].

Diesel engines are widely used in transportation, agricultural and industrial equipment, and the developed researches focus on reducing emissions, increasing thermal efficiency and using of alternative fuels in these engines [6–10].

Compared to other combustion engines, diesel engines have a high thermal efficiency and low greenhouse gases emission, but according to its shortage of energy resources (fuel) and environmental pollutions, the use of these engines is limited [6]. The need for clean and low-cost fuels lead to use the dual-fuelled Diesel-Natural gas engines all over the world [7–9]. Using dual-fuelled engine (diesel-natural gas) is a good solution to reduce emissions compared to that of diesel engine [10].

Dual Combustion includes entering air-natural gas pre-mixed into the combustion chamber and its ignition when the pilot fuel injection is fired [11,12].

The compression-ignition (CI) engines which are converted to dual-fuelled engine generate less soot and NOx pollutants, but emit more unburned hydrocarbons and CO due to their incomplete combustion

Abbreviations: B5A3, Biodiesel 5% with additive 3%; B5A5, Biodiesel 5% with additive 5%; B5A7, Biodiesel 5% with additive 7%; B20A3, Biodiesel 20% with additive 3%; B20A5, Biodiesel 20% with additive 5%; B20A7, Biodiesel 20% with additive 7%; CO, Carbon monoxide; CO_2, Carbon dioxide; GP, Generated power; GT, Glycerol triacetate; UHC, Unburned Hydrocarbon; NOx, Nitrogen Oxide; NG, Natural gas; PM, Particle material; P/G, Pilot to gaseous fuel; Z, Pilot to gaseous fuel ratio

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https://doi.org/10.1016/j.fuel.2018.08.142
Received 24 November 2017; Received in revised form 12 March 2018; Accepted 30 August 2018

process compared to that of a diesel engine [13,14] and they also have low engine power due to high content of unburned hydrocarbons (HC) which cause high brake specific fuel consumption (BSFC) [15].

Natural gas (methane) is the simplest hydrocarbon and has no carbon-carbon (C-C) bonding and has lower carbon-to-hydrogen (C/H) ratio compared to those of diesel engines which causes a clean combustion compared to use of other fossil fuels. NG is an inexpensive and available fuel in most countries, so that it can be considered as a suitable fuel for using in internal combustion engines to reduce emissions [5,16]. Therefore, the use of methane fuel along with diesel fuel in a dual-fuelled engine can be a good idea for reducing emissions in urban and industrial areas [17].

Dual combustion provides good conditions for reducing NOx and PM emissions in compression to ignition engines [18,19]. Also, the amount of CO_2 pollutant can be reduced in dual fuel engine [20]. Unburned hydrocarbons do not cause photochemical fog, but its effect in global warming is 30 times greater than that of CO_2 [16]. In order to overcome the problem of high CO and UHC contamination in dual-fuelled engines, many solutions are suggested such as using EGR [21–24], adjusting the engine throttle [25], change in the combustion chamber geometry [26], the opening and closing timing of the intake valves [27], advancing of pilot fuel injection [28,29], using biodiesel [1,30] and various additives in pilot fuels [31].

Previous works on dual-fuelled engines revealed higher amount of UHC and CO emissions in dual-fuelled engine in comparison with diesel engine, especially at low loads [32,33]. Dual-fuelled compression ignition (CI) engines are a good approach to reduce diesel engine emissions, especially NOx and PM [34]. Most of the tests results have shown that the diesel engine has a better performance than dual-fuelled engines. NOx and CO emissions in the diesel engine are more than that of the dual-fuelled engine. However, an increase in engine speed reduces these emissions in both reported modes. Increasing the load and engine speed increases the engine thermal efficiency and increasing the amount of pilot fuel in the dual-fuelled engine increases the engine output torque and reduces the engine noise and probability of its knocking [7,35–43].

Using various biodiesels with different ratios in diesel and dual-fuelled (as pilot fuel) engines is a suitable solution to use of renewable fuels and reducing emissions [31,44–46]. However, in some cases results were opposite and increased the emissions.

Biodiesel is a renewable energy source and has the similar characteristics to diesel fuel, and in proper ratios it can improve the diesel engine performance in different operating conditions and modes [47,48]. Biodiesel can be obtained from waste vegetable or animal oils [49,50]. Biodiesel can be used in diesel engine blended with diesel fuel [51]. Biodiesels have a high viscosity and cannot be used directly as a fuel in a diesel engine. It is necessary to reduce its viscosity by lowering glycerin and ester [52].

In order to reduce the UHC and CO emissions in a dual-fuelled engine, alternative pilot fuel fuels needed to be introduced [13]. Biodiesels can be used as renewable and clean fuels in dual-fuelled engines as pilot fuel. The use of biodiesel as a renewable fuel has been investigated in past work.

Tartab et al. [53] experimentally investigated the effect of using biodiesel and natural gas on the performance and emissions of a single-cylinder direct injection (DI) engine, and compared the results of using natural gas with results of using diesel as pilot fuel. Research has shown that in case of using biodiesel as a pilot fuel, pressure variations of the cylinder are similar to that of using diesel fuel as a pilot fuel. Also, the use of Eucalyptus Biodiesel as a pilot fuel reduces the emissions of UHC, CO and CO_2 at full loads in engine, but increases BSFC and nitrogen oxide (NOx). They justified this result with low thermal value in the presence of oxygen in biodiesel fuel.

Ryu [54] used vegetable oil biodiesel as pilot fuel in a dual-fuelled diesel engine with compressed natural gas (CNG). The results showed that the engine has lower CO_2 emission compared to that of a diesel engine, but in low loads, increases UHC and CO emissions due to low temperatures of combustion.

Najafi et al. [3] carried out the empirical experiments on the emissions and performance of a dual-fuelled engine with natural gas and biodiesel (as pilot fuel). In this research, it was investigated the possibility of using biodiesel of sunflower oil instead of diesel fuel in a low-speed engine (Lister M8/1) in both neat diesel and dual-fuelled (diesel-gas) modes. Performance parameters and engine exhaust emissions were studied in various volumetric blends of biodiesel and diesel fuel (B10, B20, B30, and B40), diesel (B00) and biodiesel fuel (B100). Results indicated the decrease of CO and NOx emissions by 67% and 2%, respectively, compared to that of using the diesel as a pilot fuel.

Yoon et al. [55] experimentally studied the combustion and emissions of a dual-fuelled engine with biogas as gaseous fuel and biodiesel as pilot fuel. Results showed that combustion characteristics of neat biodiesel and neat diesel follow a similar pattern at different loads. Also, NOx emission in the dual-fuelled engine was significantly lower than that of neat diesel engine, in both biogas-biodiesel and biogas-diesel. Due to the absence of aromatic substances and the presence of oxygen in the biodiesel, the biogas-biodiesel mode had lower soot emission than that of other modes.

Wang et al. [56] investigated the effect of dimethyl ether on a dual-fuelled (LPG-diesel) engine. In their research, liquid petroleum gas (LPG) was mixed with dimethyl ether in the air manifold, and then the mixture was forced into the combustion chamber and then combustion started by diesel fuel injection. The results showed that the use of dimethyl ether increases the ignition delay and slightly reduces the NOx emission.

Mohsin et al. examined the effects of various blends of biodiesel fuel (waste cooking oil) as a pilot fuel on the performance and emissions of a dual-fuelled engine with CNG. In their study, the B20 pilot fuel increased 30% of CO and 7% of NOx, but reduced 6% of UHC and 0.5% of CO_2 emissions [44].

Namasivayam et al. [13] used biodiesel, emulsified biodiesel, and dimethyl ether as a pilot fuel in a dual-fuelled engine. The results showed that the presence of water in the biodiesel did not have much effect on reducing the emissions of the dual-fuelled engine, and increases the emissions of UHC and CO. Dimethyl ether causes high emissions of UHC and CO in a dual-fuelled engine compared to that of other fuels, but instead, almost reduces the NOx emission compared to that of other fuels.

Sunmeet and Subramanian [57] discussed the effects of using biogas (simulated with natural gas by introducing various percentages of CO_2 into the air intake manifold) as main fuel and biodiesel (pongamia pinaata) as pilot fuel on the performance and emissions of a dual-fuelled diesel engine. They found that running diesel engine in dual-fuelled mode reduces the NOx emission but increases the CO and UHC emissions, significantly compared to that of using single-fuelled diesel engine.

Using of various additives such as Al, Mg, Zi, Ti, Boron, Silicon powder in diesel fuel has been suggested as an approach to reduce engine emissions [31,58–61]. Using Zink Nano oxide additive blended with jetropha methyl ester biodiesel, reduced NOx emission [2]. Although in some ratios this additive increased UHC emission. Using a little water in the waste cooking oil biodiesel reduces the emissions of CO, UHC, CO_2, and NOx in the diesel engine [31]. Copper nanoparticles in Soya bean biodiesel reduces the NOx emission in diesel engine [62]. Aghbashlo et al. Used aqueous nano-emulsion of cerium oxide as additive in diesel fuel blended with biodiesel and examined the performance and emissions of the engine. Finally, they found a proper combination of biodiesel and additive to reduce engine emissions [63].

Karabektas et al. used the blend of dimethyl ether and diesel fuel (as pilot fuel) in dual-fuelled (diesel-natural gas) engine. In their study, the ratio of fuel gas was about 40%, and the results showed that the use of dimethyl ether additive in diesel fuel as a pilot fuel reduced the CO and NOx emissions compared to that of the dual-fuelled engine in presence