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Glycerine emulsions of diesel-biodiesel blends and their performance and emissions in a diesel engine

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HIGHLIGHTS

- Glycerine emulsions of diesel-biodiesel blends are tested in a modern diesel engine.
- Glycerine from biodiesel production is purified and used in making glycerine emulsions.
- Lower temperatures and emissions of oxides of nitrogen were observed with glycerine emulsions.
- Lower smoke with glycerine emulsions was also obtained.

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ABSTRACT

The extensive use of biodiesel as an alternate fuel has resulted in the oversupply of glycerine, leading to an increased demand to look for the use of glycerine as an alternate fuel. In this paper, multiple blends of diesel-biodiesel and their glycerine emulsions were compared to investigate the performance and emissions in a modern small diesel engine. A direct injection diesel engine was tested at different loads and speed conditions. Biodiesel was produced onsite and crude glycerine obtained as a by-product was purified using an orthogonal test method. Hydrophilic-lipophilic balance was formulated using two surfactants: Polyoxyethylene Sorbitan Monooleate and Sorbitan Monooleate, which were used in the emulsification process to attain desired stability of glycerin emulsion.

Emulsion stability, mean particle droplet size, fuel properties, engine performance, and emissions were examined. Test results show that with the increase in glycerine concentration, brake-specific fuel consumption and brake-thermal efficiency increased. In terms of emissions, it was seen that carbon monoxide and unburned hydrocarbon increased, and reductions in exhaust gas temperature and oxides of nitrogen were observed. In addition, there was a significant decrease in smoke (approximately 80%) with an increased concentration of glycerine at 3000 rpm, at high load.

1. Introduction

Emergence in technology has led to the increase in the use of fossil fuels, such as diesel and gasoline, because of their high thermal productivity in various areas such as agriculture and transportation, as well as to generate electricity. However, these fuels have been labeled as being responsible for climate change and environmental pollution. There is a greater demand in the search for alternative methods of energy production such as biodiesel fuels [1]. Biodiesel can be defined as a mono alkyl ester that is obtained from animal or vegetable fat through transesterification with methanol [2]. The primary molecule in biodiesel, known as fatty acid methyl esters (FAME), has been proven to be effective in reducing environmental pollution and improving energy efficiency in transportation sector [3], which can be seen as a step towards sustainable energy [4]. Although biodiesel can effectively reduce harmful exhaust emissions including particulate matter (PM), carbon monoxide (CO), and unburnt hydrocarbons (HC), it generates higher nitrogen oxides (NO_x) due to the presence of oxygen, which is otherwise helpful for proper fuel combustion. Roy et al. [5] investigated engine performance and emissions at rated engine speed of 1800 rpm under three different loading conditions (low, medium and high) for three fuel series: biodiesel–diesel, biodiesel–diesel-additive and kerosene–biodiesel. The results showed that the average reductions in CO and HC are 20% and 35%, respectively, whereas average increase in NOx is 13% with B100 than neat diesel. In a recent research by Elsanusi et al. [6], a small diesel engine was investigated with diesel-biodiesel emulsion

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Nomenclature

BSFC	brake-specific fuel consumption
BTDC	before top dead center
BTE	brake thermal efficiency
CO	carbon monoxide
CO_2	carbon dioxide
cP	centipoise
cSt	centistokes
EGT	exhaust gas temperature
FAME	fatty acid methyl esters
HC	hydrocarbon
HLB	hydrophilic-lipophilic balance
MPa	mega pascal
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	oxides of nitrogen
O_2	oxygen
pH	potential of hydrogen
PM	particulate matter
RL	rhamnolipid biosurfactant
Span 80	sorbitan monooleate
Tween 80	polyoxyethylene sorbitan monooleate
US EPA	United States Environmental Protection Agency

fuels at different speed and load conditions, and it was noticed that there was approximate 7–8% average CO reduction, more than 50% average HC reduction and about 7% average NOx increase with B40 than diesel. US EPA has done a comprehensive analysis of biodiesel impacts on exhaust emissions [7] mentioning that pure biodiesel can reduce HC about 70% and particulate matter (PM) and CO about 50% when compared with diesel fuel. Engine performance and emissions were analyzed for different biodiesels and an ultra-low sulphur diesel fuel at high load [8]. Compared to the diesel fuel engine-out emissions of NO_x, a high-cetane number (CN) biodiesel fuel produced comparable NO_x while the biodiesel with a CN similar to the diesel fuel produced relatively higher (about 8% higher) NO_x at a fixed start of injection.

The renewable quality of biodiesel has led to an increase in its production and an oversupply of glycerine in the market which has not only caused the difficulty of its disposal which has become an environmental concern but has also negatively impacted the prices of glycerine [9]. Therefore, in future, there will be a need to contemplate strategies to counter the surplus supply of glycerine. Glycerine is produced through the transesterification process as a by-product of biodiesel, which has recently emerged as a possible alternative in energy production [10]. There are many researches of additive use in diesel and biodiesel to improve the combustion and emissions [11–13]. In [11], it is mentioned that a large pentanol volume blending ratio up to 40% is able to enhance thermal efficiency and reduce soot emissions in most engine conditions. The influence of methanol on the blend of diethyl ether, biodiesel and diesel at different engine speed and load conditions with blends of B20, B50 and B100 with EGR was conducted [12]. As the percentage of biodiesel in diesel increased, NOx emission also increased. By adding methanol and diethyl ether, it was observed that it exhibited lower NOx at all engine speeds and loads. In Ref. [13], ternary blends of diesel, biodiesel and 10% *iso*-butanol were investigated for their characteristics and performance and emissions in a modern small diesel engine at different load and speed conditions. The most important conclusion of this investigation was that blend IBU10B90, which contains 90% biodiesel and 10% *iso*-butanol, can effectively be used in a diesel engine with much improved engine performance and emissions than pure diesel.

The use of glycerine as an additive in the production of fuel is also a proposed solution to neutralizing its excessive supply [14]. Crude glycerine is comprised of several contaminants such as soap, methanol, catalyst, and other organic compounds [15]. However, glycerine has a low auto-ignition quality, high ignition temperature, and low heating value, which makes it unfeasible for use in combustion engines because burning it can emit carcinogenic acrolein [16]. Consequently, the emulsification process is used to blend glycerine with diesel/gasoline or biodiesel to reduce the problems related to stand-alone use of glycerine fuel [15]; it can also be used as an alternative fuel [17] that would reduce transportation costs compared to fossil fuels. Emulsification has also been shown to enhance combustion efficiency and to reduce NO_x and smoke levels [18–20].

In [18], engine performance, emissions and combustion characteristics of a diesel engine fueled with biodiesel and ethanol biodiesel micro-emulsions is compared experimentally. The micro-emulsions tend to improve combustion and hence have lower brake specific energy consumption. NOx emissions are slightly decreased for the micro-emulsions, whereas there was no significant change in CO and HC. Up to 30% reduction in NO_x and 60% reduction in PM can be achieved by emulsifying up to 15% water in diesel [19]. Micro-explosion mechanism of water–diesel emulsions leads to NOx–PM trade-off [20].

Emulsion is termed as a mixture of two immiscible liquids (polar and non-polar), which are thermodynamically stable [21] in the presence of a surfactant [22] that can reduce and stabilize the interfacial tension. Polar liquids (e.g., water and glycerine) have molecules that contain an unequal charge distribution due to the presence of a highly negative charge in their oxygen atoms. In non-polar liquids (e.g., oils), molecules have an even charge distribution, which do not allow them to blend properly [21]. The emulsifier has the quality of amphipathy, which contains both polar and non-polar molecules to create a stable blend [20]. Each emulsifier is assigned an HLB (hydrophilic-lipophilic balance) value that ranges from 1 to 20. A low HLB value (1–8) tends to be more attracted to non-polar liquids (known as lipophilic or oil-loving), whereas a high HLB value (12–20) is more attracted to polar liquids (called hydrophilic or water-loving) [23]. The values between 9 and 11 are known as intermediate. Emulsion can be categorized into micro-emulsions, macro-emulsions, and nano-emulsions, depending on the droplet size of the particles, as well as on the phase [24]: two-phase (water-in-oil and oil-in-water) and three-phase (oil-in-water-in-oil and water-in-oil-in-water). Two-phase emulsion has been effectively used to produce combustion fuels because of its smaller mean droplet size and higher heating value than three-phase emulsion [25], which is used mostly in food, medicine, and cosmetics industries [26]. Emulsion can be prepared using ultrasonic [27], mechanical, electronic and magnetic forces [28].

Many researchers have investigated the role of a glycerine-water mixture with diesel. Quispe et al. [9] investigated the production, consumption, and characteristics of glycerine and recommended that it can be used in combustion owing to its heating value, but due to the presence of salts, it may cause corrosion problems in combustion system which makes combustion difficult. Leng et al. [10] found that glycerine in diesel micro-emulsion fuels using bio-surfactant rhamnolipid (HLB = 22–24) remained stable over six months when stored at 4 °C, and the fuel properties were found comparable to that of diesel. They also discovered that glycerine, through this micro-emulsion technology, can also be used as a cold flow improver. Oprescu et al. [29] compared diesel, diesel-glycerol ketal blends and diesel-glycerol ketal ester blends which are two different derivatives of glycerol as additives for diesel fuel on a diesel engine and noted a decrease with diesel-glycerol ketal ester blends in the level of HC, CO, and smoke emissions and a slight increase in NOx emission. Lapuerta et al. [30] tested FAGE (fatty acid formal glycerol ester) which is produced from crude glycerol and is then blended with diesel fuel on the automotive engine and found out

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