Analysis of performance and emissions of diesel engine using sunflower biodiesel

Dragos Tutunea, Ilie Dumitru
University of Craiova, Faculty of Mechanics
dragostutunea@yahoo.com

Abstract. The world consumption of fossil fuels is increasing rapidly and it affects the environment by green house gases causing health hazards. Biodiesel is emerging as an important promising alternative energy resource which can be used to reduce or even replace the usage of petroleum. Since is mainly derived from vegetable oil or animal fats can be produce for large scale by local farmers offering a great choice. However the extensive utilization of the biofuels can lead to shortages in the food chain. This paper analyzed the sunflower methyl ester (SFME) and its blends as an alternate source of fuel for diesel engines. Biodiesel was prepared from sunflower oil in laboratory in a small biodiesel installation (30L) by base transesterification. A 4 cylinder Deutz F4L912 diesel engine was used to perform the tests on various blends of sunflower biodiesel. The emissions of CO, HC were lower than diesel fuel for all blends tested. The NOx emissions were higher due to the high volatility and high viscosity of biodiesel.

1. Introduction

In the past the use of petroleum has led to atmospheric pollution and the global warming. The increase in human population worldwide and industrialization led to depletion of fossil fuel [1]. Gasoline and diesel-driven automobiles are the principal sources of greenhouse gas (GHG) emissions today [2]. Replacing the fossil fuels with biofuels seems to be a viable option because of the scarcity of petroleum reserves and continuously increasing stronger emission regulations [3]. However the fossil fuel cannot be replace in totality especially in transport and power generation because these represent the backbone for the economic growth in a country [4]. Biodiesel can be produced from various feedstock’s (vegetable oils: soyabean, sunflower oil, rapeseed/canola, palm, cottonseed, coconut, peanut, pongamia, karanja, neem; animal fats: usually tallow; or waste oil such as frying oils from food industry) [5]. Due to their high viscosity and density these oils cannot be used in the engines until the glycerol component is removed by a reaction of transesterification [1]. The thermo-physical properties considered important to biofuels are density, viscosity, calorific value, cetane number, flash points, cloud and pour points. Also in several researches has been reported the properties of biofuels depends even by the chemical composition and fatty acid contents. All biofuels must be in the limits specified by ASTM D6751 and EN 14214 standards. High viscosity of biodiesel represents a problem because is directly linked with the injection system and affects fluidity and atomization causing carbon deposits and incomplete combustion in the engine [6]. Raheman and Phadate [7] investigated the performance of karanja methyl ester and various blends (B20, B40, B60 and B80) and found a reduction of CO emissions by 73-94% compared to fossil diesel. Bhupendra Singh et al. [8] tested Karanja biodiesel at different proportions 5%, 10%, 20%, 30% and 100% to evaluate performance and
emissions with diesel fuel. NOX emissions were higher for all the blends and the brake thermal efficiency was lower than neat diesel. Labeckas and Slavinskas [9] tested rapeseed oil methyl esters to evaluate performance and exhaust emissions in direct injection diesel engines and found a reduction in the emissions of HC, CO and CO2. Mohamed F. Al Dawody et al. [10] tested on single cylinder diesel engine different blends of a soybean methyl ester and found a reduction up to 48.23% and an increase in brake specific fuel consumption with 14.65% compared with fossil diesel. The CO emission decreased with 11.36% for B20 and with 41.7% for B100. The NOX emissions were reported higher for all the blends of soybean methyl ester. In a study conducted by Pradhan et al. [11] in a 4 stroke single cylinder diesel engine fueled with biodiesel from waste mustard oil reported a reduction with 7.78% in brake thermal efficiency for B10 blend, higher Brake Specific Fuel Consumption (BFSC) for all biodiesel blends and an increase in NOX emissions. M. Habibullah et al. [12] investigated the effects of two biodiesel blends palm and coconut (PB30, CB30 and PB15CB15) on a single-cylinder, four-stroke, and direct-injection diesel engine under a full load and varying speed conditions. In engine performance PB30, CB30, and PB15CB15 engine brake power was lower by 3.92%, 4.71%, and 4.10%, whereas BSFC values were higher by 8.55–9.03% than diesel fuel. The NOx emissions were increased by 3.13–5.67% for all the tested biodiesel blends. M. Mofijur et al. [13] have reported on the performance and emission characteristics of Moringa oleifera biodiesel (B10 and B20) tested in a multi-cylinder diesel engine at various speeds and full load conditions. They reported that biodiesel blends reduced brake power and increased brake specific fuel consumption. In engine emissions CO was reduced by 10.60-22.93%, HC by 9.21- 23.68% and the NOx increased by 8.46-18.56% compared to diesel fuel. The present study focuses in evaluating the possibility of sunflower biodiesel to become an alternative source for diesel fuel in the existing engine without any modification.

2. Materials and methods

2.1. Production of biodiesel

The biodiesel was produced by alkali catalyzed transesterification process from sunflower oil, which was extracted from sunflower seeds. In this process methanol and a base catalyst, NaOH with a purity of 99% was used. Initially, the catalyst is dissolved into methanol and heated to 55°C. The agitation was kept constant at 450 rpm. The reaction time was of 60 minutes. The product separated by gravity into two layers namely ester layer and glycerol layer. The ester layer contains mainly methyl ester and methanol and the glycerol layer contains mainly glycerol and methanol. The mixture was allowed settling for 48 h to allow the separation of biodiesel and glycerin. The biodiesel was then washed with water to remove impurities and heated at 110°C to remove the remaining traces of the catalyst and methanol [14] (Fig.1).

![Biodiesel production scheme](image)

2.2. Characterization of biodiesel

The biodiesel prepared from sunflower oil (SFME) was characterized and tested for the compliance with EN standards. Biodiesel blends of B10 (10% biodiesel, 90% diesel), B20 (20% biodiesel, 80%
diesel), B30 (30% biodiesel, 70% diesel), B40 (40% biodiesel, 60% diesel) and B100 (pure biodiesel) were prepared on volume basis. The physical and chemical properties of SME are listed in Table 1.

Table 1 The physical and chemical properties of blends of SFME and Diesel EN14214

| Property                        | Method          | Specifications | Reference | B10 | B20 | B30 | B40 | B100 |
|---------------------------------|-----------------|----------------|-----------|-----|-----|-----|-----|------|
| Flash point °C                  | EN ISO 3679     | min. 120       | 68        | 75  | 86  | 97  | 110 | 183  |
| Kinematic viscosity 40°C, mm²/s | EN ISO 3104     | 3.5-5          | 3.18      | 3.21| 3.26| 3.31| 3.35| 4.7  |
| Density 15°C, kg/m³             | EN ISO 3675     | 860-900        | 832       | 835 | 839 | 843 | 848 | 868  |
| Calorific value MJ/kg           | -               | -              | 44.8      | 43.6| 42.2| 41.7| 40.3| 33.5 |

2.3. Engine stand
Experiments were conducted on a four cylinder diesel engine with direct injection. The specifications of the engine for the current study are listed in Table 2 and a schematic diagram of the engine with instrumentations is shown in Fig.2.

Table 2 Specifications of Deutz F4L912 diesel engine

| Number of cylinders | 4 |
|---------------------|---|
| Bore/stroke (mm)    | 100/120 |
| Displacement (l)    | 3.770 |
| Compression ratio   | 19 |
| Maximum rated speed (rpm) | 2500 |
| Mean piston speed (m/s) | 10 |
| Power (kW) @ 2350rpm | 51 |
| Mean effective pressure (bar) | 6.9 |
| Maximum torque (Nm) @ 1450rpm | 238 |
| Minimum idle speed (rpm) | 650 |

Fig.2 Schematic diagram of experimental setup

The engine stand is mounted on a chassis which is connected to electronic display and fuel reservoir. Components of testing stand are fuel feeding installation, controller and measuring equipment. Mechanical connection between engine and motor is supported by a shaft fitted with protective
shields. Feeding system has the role to ensure sufficient supply of fuel to the engine by using a fuel tank which stays on electronic balance to measure the fuel consumption. The electric brake is a 110 kW three phase electric motor controlled by the inverter and ordered by the process computer. The feeding system consists of a rack with fuel tank and has separation tap. Controller is equipped with a touch screen which is used to control the engine. The precision of measuring system is given in Table 3. A BEA350 gas analyzer was used to measure engine emissions.

| Table 3 Precision of parameters by measuring system |
|-----------------------------------------------|
| Parameter              | Precision value     |
| Speed (rpm)           | 0…6000±2%          |
| Torque (Nm)           | 0…1000±2%          |
| Fuel consumption (kg/h)| 0…50±2%            |
| Intake air temperature (°C) | 0…50 ±5%         |
| Inlet pressure (kPa)   | -50…300±5%         |
| Exhaust temperature (°C) | 0…800±5           |

3. Results and discussion

EGT (exhaust gas temperature) is an indicator of the heat release rate of the fuels tested during combustion period. In generally the combustion in the case of biodiesel is improved due to the presence of excess oxygen in the fuel itself. It is observed that EGT increase with the increase in load for all blends of SFME (Fig.3). These findings are in accordance with several researches; Godiganur et al. [15] on a six cylinder turbocharged diesel engine fueled with mahua biodiesel blends observed an increase in EGT with the increase in engine load (about 12% higher than diesel in the case of B100); Datta et al. [16] on a double cylinder, four stroke, diesel engine fueled with jatropha biodiesel blends observed an increase in EGT due to the higher flame temperature of biodiesel.

![Fig.3 Variation in exhaust gas temperature with load](image)

Carbon monoxide (CO) in the engine is produced by incomplete combustion of the fuel. It is observed that CO emissions decrease at lower loads due to the presence of oxygen (almost 11%) at lower loads and then increase sharply for all fuels tested (Fig.4). Other researchers found similar results; Nabi et al. [17] on a single cylinder fueled with cotton biodiesel the CO emissions were reduced with 24% in comparison with diesel; Çelikten et al. [18] on a four cylinder diesel engine fueled with soybean...
biodiesel found a decrease of 28% of CO emissions; Anand et al. [19] observed a reduction with 46.5% of CO emissions at higher load for karanja biodiesel.

Complete combustion inside the combustion chamber increase carbon dioxide (CO$_2$) emissions. It is observed that CO$_2$ emissions increase at all the loads for the tested fuels (Fig.5). Huzayyin et al. [20] found a increase in CO$_2$ emissions for jojoba biodiesel blends for all engine loads. Fontaras et al. [21] for blends of soybean the CO$_2$ emissions increase by 14% for B100 and 9% for B50. Aydin and İlkılıç [22] found a reduction by 16% of CO$_2$ emissions of rapeseed biodiesel compared with diesel.

In general the emission of hydrocarbons (HC) depends mainly by compositions and combustion characteristics of the fuels tested. If combustion is improved the HC emissions decrease and vice versa. Because of the high content of oxygen in the biodiesel it is expected that HC emission will
decrease for blends of SFME and diesel. It is observed that the decrease of HC emissions depends on the percentage of biodiesel in the blend (Fig.6). Sahoo et al. [23] found a reduction in HC emissions by 20.64%, 20.73% and 6.75% using biodiesel of karanja, jathropa and polanga. Tsolakis et al. [24] observed a reduction of nearly 50% for rapeseed biodiesel compared with low sulfur diesel.

Nitric oxide (NO) and nitrogen dioxide (NO$_2$) are formed in the process of oxidation of the nitrogen during combustion and depend on the combustion temperature and oxygen content. The tests show an increase in NOx emissions with the increase in engine load for all blends (Fig.7). It is found highest for SFME because of high oxygen content which results in complete combustion causing high combustion temperature. Gumus M. [25] found an increase of NOx emissions for apricot seed kernel oil methyl ester by 10% compared to diesel fuel. Aydin and İlkiliç [22] reported an increase of NOx emissions 16.7% with B20 blend and 11.8% with B100 for biodiesel of rapeseed.
Conclusion
The 4 cylinder diesel engine runs successfully during tests on biodiesel of sunflower oil and its blends. The blends were characterized for their various physical chemical properties. The EGT was found highest for pure biodiesel. The availability of extra oxygen enhanced the temperature of combustion resulting in higher temperature for all the blends tested. CO and HC emissions are highest for the diesel fuel and lower for the blends of SFME. The NOx were found highest for pure SFME and its blends because of high volatility, low heat content and high viscosity compared with diesel fuel.

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