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Research Paper

Effect of emulsified fuels based on fatty acid distillates on single cylinder diesel engine performance and exhaust emissions

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HIGHLIGHTS

- Discussion of various issues with regard to formulation of emulsions containing FAD.
- Stable emulsions were produced using FAD, diesel fuel and a mixture of surfactants.
- The effect of emulsions on engine performance and exhaust emissions were studied.
- Emulsions containing FAD and water lead to higher BSFC and delayed start of combustion.
- Emulsions were found as an effective way to reduce the nitrogen oxides emissions.

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ABSTRACT

In this contribution an experimental investigation concerning the effect of emulsified fuels based on fatty acid distillates (FAD) on a single cylinder diesel engine performance and exhaust emissions was investigated. The single cylinder diesel engine assessment was conducted under selected test conditions, fixing the engine speed and varying the load. Emulsified fuels were formulated using blends of fatty acid distillates in diesel fuel as continuous phase, as well as deionized water as dispersed phase and Nonyl phenol with 8 mol of ethylene oxide as surfactant. Over these conditions the brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), ignition delay (ID), rate of heat release (ROHR), cumulative heat release, nitrogen oxides (NOx), carbon monoxide (CO) and unburned hydrocarbons (HC) were analyzed. The results indicate that the use of emulsified fuels produce increases in the specific fuel consumption and decreases in the brake thermal efficiency for emulsions compared to diesel fuel and a blend of 30% FAD in diesel. On the other hand, later starts of combustion and retarded ROHR for emulsified fuels compared to diesel fuel and a blend of 30% FAD in diesel were obtained. Further, lower NOx and higher HC and CO emissions for emulsified fuels were reported.

1. Introduction

Biofuel production from vegetable oils is widely considered one of the most sustainable alternatives to diesel fuel. However, they are not economically competitive as yet due to their current production and supply chain (i.e.: price, manufacturing, supply and distribution). In this context, biofuels production based on waste and residual by-products represents an attractive alternative due to low waste product costs.

The fatty acid distillates (FAD) are a low-value by-product obtained from the vegetable oil refining industry generated during the physical refining in the fatty acid stripping and deodorization stages [1]. It is a well-known fact that several metric tons of fatty acid distillates are produced around the world annually from different feedstock (e.g. palm oil, rapeseed and soybean oil). Particularly, Malaysia has one of the largest refining palm oil industries in the world [2] and hundreds of thousands of metric tons of fatty acid distillates are annually generated according to Malaysian Oil Palm Statistics [3].

According to the fatty acid distillates' composition they are suitable as a feedstock for biofuel production [1,4–9]. This element might enhance the refining industry efficiency; contributing to the concept of zero-waste through recycling, generating energy

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and reducing the environmental degradation. However, fatty acid distillates have not been researched thoroughly and they are not widely applied as diesel engine fuel.

The direct use of vegetable oils, animal fats or waste by-products such as FAD as diesel engine fuel affects the engine performance and component wear. To obtain an economic and environmentally-friendly engine fuel from fatty acid distillates, it is necessary to change their physicochemical properties for which there are different methods (preheating, blending, trans/esterification, cracking/pyrolysis and emulsification). Even, it is also possible to use an additive as fuel improver to enhance the engine performance and emissions [10–13].

Among these methods the transesterification is one of the most popular methods. However, because of the high free fatty acid (FFA) content of FAD, this feedstock cannot be converted directly to biodiesel via alkaline transesterification [14]. Although different methods to decrease the FFA content are reported [15,9,16] for enhancing the transesterification efficiency, biodiesel production is not economically profitable until now. In addition, depending on the quality of the FAD feedstock, additional steps are necessary to remove the water content and free fatty acids.

The combination of different methods previously mentioned might represent an alternative. The use of blend of fatty acids distillates in diesel fuel can leads to a reduction of viscosity to within biodiesel and diesel fuel standards. Thereupon, the emulsification technique has an additional attraction linked to the emulsified fuel capacity of decreasing diesel engine exhaust emissions such as nitrogen oxides (NOx). Both methods are not sophisticated because modifications of the original engine design and special equipment are not necessary.

The formulation of an emulsion involves no complex chemical reactions [17]. In addition, due to the micro-explosion phenomenon as a consequence of the dispersed water into emulsified fuel, it is also possible to improve the atomization process and recover in part the combustion efficiency when it is used as diesel engine fuel.

A significant number of investigations on emulsified fuels formulation and engine performance using vegetable oil sourced fuels as feedstock have been conducted since the 20th century to the present [18–35]. However, emulsified fuels containing fatty acid distillates as alternative fuels have not been reported. Therefore, in the present work we aimed for the formulation of emulsified fuels containing diesel fuel and fatty acid distillates from the local refining oil industry in order to analyze their effect on diesel engine performance and exhaust emissions.

2. Materials and methods

2.1. Emulsified fuels formulation

The emulsified systems were formulated based on stabilization zone reported in our previous experiments [36] using blends of rapeseed oil in diesel fuel as continuous phase. Additional components such as deionized water as dispersed phase and Nonyl phenol (NP) + 8 mol of ethylene oxide (8MOE) as surfactant were used. The fatty acid distillates (FAD) were collected from the Cuban vegetable oil refining industry. The physicochemical properties of diesel fuel and fatty acid distillates are shown in Table 1.

The fatty acid distillates were filtered to remove impurities. For this purpose a vacuum pump coupled to a Kitasato flask attached to a Büchner porcelain funnel through a rubber adapter was used. The filter paper had a medium filtered speed. The vacuum pump was a rotary vane pump MLW DSE2 with a pressure of 5.7 Pa and pumping rate of 2 m^3/h.

The emulsification was conducted using a sonicator lab device (i.e.: Soniprep 120) with a frequency of 14 Hz. The volume prepared was 250 mL with continuous sonication during 15 min. The required amount of surfactant was added into the continuous phase (blends of FAD in diesel fuel); then the deionized water was slowly added. After each addition, the dispersed systems were vigorously sonicated.

Table 1
Physicochemical properties of diesel fuel and fatty acid distillates.

Properties	Unit	Diesel fuel	Fatty acid distillates
Viscosity	mm^2/s	5	28.6
Density	g/cm^3	0.818	0.908
Lower heating value	MJ/kg	42.5	36.3
Water content	%	< 0.05	0.387
Cetane number	–	45	40*

* Prediction using Sánchez' model [37].

The stability assessment of emulsified fuels was analyzed through a direct method like the visual observation, keeping the samples in glass test tubes with stopper after their preparation, aging at ambient laboratory conditions. The main criterion for stable emulsified fuels was the preservation of only one phase [38].

Physicochemical properties such as density, dynamic viscosity and lower heating value were evaluated. The density was measured using a pycnometer of 25 mL. On the other hand, the dynamic viscosity was evaluated using a viscometer RION VT-03F, with a measurement accuracy of ±5%. The measurements were repeated thrice and the averages of the replicates were used in the analysis. The lower heating value of fuels was performed through a bomb calorimeter according to ASTM D 240.

2.2. Experimental engine set-up and procedures

The engine used for the research was a Lister Petter diesel engine PH1 W. This is a four-stroke single cylinder engine with direct injection. The main engine characteristics are shown in Table 2.

The schematic diagram of the experimental setup used for the engine tests is shown in Fig. 1. The engine was equipped with load cell, Froude hydraulic brake DPX 2, four K-type thermocouples and a tachometer (Radio energy). A piezoelectric relative pressure sensor (Kistler; model: 6067C, water-cooled) mounted directly on the cylinder head was used to measure the cylinder pressure. A piezoresistive absolute pressure sensor (4075A10) mounted in the admission duct was used to register the intake air pressure.

The engine was also equipped with a data acquisition system, a Kistler signal conditioning platform with a charge amplifier (model 5064); a piezoresistive amplifier (model 4665), a module NI 9401 (digital) and a module NI 9215-BNC (analog) were used. On the other hand, a Kistler system 2614 A to measure the crank angle position was used, with a resolution of 0.2 crank angle degrees

Table 2
Characteristics of the Lister Petter diesel engine PH1 W.

Item	Value
Bore	87.3 mm
Stroke	110 mm
Compression ratio	16.5:1
Cubic capacity per cylinder	659 cm^3
Fuel injection timing	24° before TDC (up to 1650 rpm) 28° before TDC (1651–2000 rpm)
Inlet valve opens	4.5° before TDC
Inlet valve closes	35.5° after BDC
Exhaust valve opens	35.5° before BDC
Exhaust valve closes	4.5° after TDC

TDC: Top dead center.
BDC: Bottom dead center.