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Full Length Article

Experimental investigation of the effects of turkey rendering fat biodiesel on combustion, performance and exhaust emissions of a diesel engine

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A R T I C L E I N F O

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A B S T R A C T

In this study, turkey rendering fat biodiesel (TRFB) was produced by two-step reactions (esterification and transesterification). Fatty acid ester content and yield in methyl ester were found 96.7% and 88.5% respectively. TRFB was blended with diesel fuel (DF) at 10%, 20%, and 50% (v/v) proportion to obtain fuel blends named TRFB10, TRFB20 and TRFB50, respectively. The effects of TRFB blends on the combustion, performance and exhaust emissions of a direct injection single cylinder diesel engine were systematically investigated under different engine loads, at the constant engine speed of 2000 rpm. The results show that the maximum cylinder pressure (CP_{max}) and maximum heat release rate (HRR_{max}) values of the TRFB blends were higher than those of DF for all engine loads because of the low cetane number of the TRFB and the rapid burning of the fuel accumulated in the combustion chamber during the long ignition delay. It was observed that the DF has a higher exhaust gas temperature than the biodiesel blends at high loads because of the longer combustion duration of the DF. The brake thermal efficiency (BTE) values of the TRFB blends were found to be lower than those of DF at all loads. Since the heating value of the biodiesel is lower than that of DF, it was observed that the brake specific fuel consumption (BSFC) values of TRFB blends are higher compared to those of DF. In addition, TRFB10, TRFB20 and TRFB50 blends reduce smoke opacity approximately 20%, 25% and, 40%, respectively, and cause a slight increase in nitrogen oxide (NO_x) emissions.

1. Introduction

Investigations on alternative fuels are continuing extensively due to the decline of oil reserves and the increase in oil costs as well as the increase in environmental pollution. Biodiesel is considered the most promising alternative fuel for diesel engines. Biodiesel containing approximately 10–15% oxygen by weight is a biodegradable, non-toxic and renewable fuel and has similar combustion behavior to DF. For this reason, it can be used in modern diesel engines directly or blended with DF [1].

During the biodiesel production, oils or fats react with alcohols (commonly ethyl or methyl alcohol). This chemical reaction which requires alkali or acid catalysts is called as esterification (the reaction of the free fatty acids with an alcohol to produce an ester of a fatty acid) or transesterification (the reaction of the triglyceride with an alcohol to produce a mixture of fatty acid alcohol ester). However, mostly alkaline catalysts such as potassium hydroxide and sodium hydroxide are preferred. Because, in the case of using alkali catalysis, the transesterification process is much faster than the acid catalyzed transesterification process. Following the transesterification reaction, the glycerin, a by-product of the reaction, is separated from the sample by centrifugation or using a precipitation tank.

The reaction temperature, type and amount of alcohols and catalysts, free fatty acid (FFA) content, time and pressure, and water content in oil or fat are the main factors affecting the transesterification reaction [2]. In selecting feedstock for biodiesel production, two crucial factors must be taken into account, namely the amount of the raw material and the cost of production [3]. Biodiesel production can be carried out using different feedstock such as edible [4] or non-edible vegetable oils [5], waste oils [6], poultry fats [7] and animal fats [8]. The main reason why the commercial application of biodiesel is limited is high production cost. The raw material price accounts for 70–95% of the total biodiesel cost [9]. Since biodiesel produced from expensive edible oils cannot compete financially with DF, low-cost fatty feedstocks should be used in biodiesel production. In order to reduce the production cost of ecologically acceptable and sustainable biodiesel fuel, cheap waste oils, inedible oils, wastes of the edible oil refinery, and waste animal oils can be used. Animal fat based biodiesel has

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Nomenclature

ACP_{max}	location of maximum cylinder pressure
BSFC	brake specific fuel consumption
BTE	brake thermal efficiency
CD	combustion duration
CO	carbon monoxide
CP_{max}	maximum cylinder pressure
DF	diesel fuel
EGT	exhaust gas temperature
EOC	end of combustion
FFA	free fatty acid
HC	hydrocarbon
HRR	heat release rate
HRR_{max}	maximum heat release rate
ID	ignition delay
LHV	lower heating value
NO_x	nitrogen oxide
SOC	start of combustion
SOI	start of injection
TRFB	turkey rendering fat biodiesel
TRFB10	10% (v/v) biodiesel proportion
TRFB20	20% (v/v) biodiesel proportion
TRFB50	50% (v/v) biodiesel proportion

sustainable feedstock sources and its fuel properties are very similar to vegetable based biodiesel [10].

Production of turkey meat in Turkey was 47 thousand tons in 2016 [11]. Since turkey feathers contain approximately 6.7% fat, rendering fats obtained from turkey slaughterhouses provide an important potential for biodiesel production [12]. The turkey rendering fat is obtained by pressing the flour obtained as a result of boiling the wastes (blood, feathers, meat particles, internal organs, feet, and heads) separated during cutting and processing of turkeys in the rendering facilities and it is cheaper compared to high-quality vegetable oils [13]. However, low cost raw materials generally have high free fatty acid content. FFA and moisture content have a significant effect on the transesterification of glycerides with alcohol. The high FFA content (> 1% w/w) causes soap formation and the reaction makes it difficult to separate the products from each other, resulting in biodiesel production at low efficiency. Therefore, it is preferable to use a two-step process as an alternative method, in the production of biodiesel from raw materials having high FFA content [14].

The researchers have recently conducted a number of studies on the production of biodiesel from various animal fats and their use as fuel in diesel engines. Mata et al. [15] used poultry, lard, and tallow fats to produce biodiesel by two-step process and found that at same operation conditions lard and tallow fats converted to biodiesel with a yield above 90% while chicken fat remained at 77%. Rao et al. [16] investigated the emission and performance of single cylinder diesel engine fueled with chicken fat methyl ester and diesel blends under full load at 1500 rpm. They founded that BSFC and NO_x emissions increase while BTE, exhaust temperature, carbon monoxide (CO) and hydrocarbon (HC) emissions decrease as the amount of biodiesel increases. In another publication of this working group [17], they analyzed the performance, combustion and emission characteristics of the same engine under four different load at 1500 rpm. According to the results, depending on low heat value of the chicken biodiesel, as the amount of biodiesel in the mixture and load increase the BTE and BSFC decrease. Increasing the percentage of the chicken biodiesel in the blends causes the low CO, HC and high NO_x due to the high oxygen content of the biodiesel. Also heat release rate (HRR) and pressure rise of the chicken biodiesel are very similar to diesel fuel at all loads. Behçet [18] produced methyl esters from fish and chicken fats and used these methyl esters in a single-cylinder diesel engine and compared with diesel fuel. The test results showed that the brake power, torque values do not change greatly and CO and HC of methyl esters are lower than those resulting from diesel fuel. Gürü et al. [19] studied the engine performance and exhaust emissions of 10% chicken fat biodiesel and diesel blend and concluded that because of low lower heating value of biodiesel BSFC increases 5.2% while NO_x increases by 5%, smoke emissions and CO decreases by 9% and 13% respectively. Oner and Altun [20] examined the effect of animal tallow methyl ester and different proportion (5, 10 and 50%) diesel blends on performance and emissions of a diesel engine. In this study the engine performance and the exhaust emissions (CO, NO_x, and smoke opacity) of tallow methyl ester were found lower than those of diesel fuel. Thus they concluded that tallow methyl ester is an alternative fuel for diesel and can help in controlling air pollution.

Table 1
Main properties of the test engine.

Items	Specifications
Model	Lombardini 15 LD 350
Engine type	Naturally-aspirated, air-cooled, DI diesel engine
Cylinder number	1
Maximum power	7.5 HP/3600 rpm
Maximum torque	16.6 Nm/2400 rpm
Displacement	349 cm^3
Compression ratio	20.3/1
Bore × stroke	82 mm × 66 mm
Injection pump type	QLC type
Injection nozzle	0.22 × 4 holes × 160°
Nozzle opening pressure	207 bar
Fuel delivery advance (°CA)	20 BTDC
Intake valve open/close (°CA)	10 BTDC/42 ABDC

A number of studies on biodiesel production from various animal-based raw materials and their effects on engine performance and exhaust emissions have been mentioned above. However, to the best of authors' knowledge, there is no research in the literature, about the production of biodiesel from turkey rendering fat and the determination of its effects on the performance, emissions and combustion characteristics of diesel engines. In this experimental study, low cost turkey rendering fat obtained from a rendering facility of turkey slaughterhouse was used as feedstocks for biodiesel production. Because the free fatty acid content of the turkey rendering fat is over 1%, biodiesel production is carried out in two-step process. The fuel properties of the produced methyl ester were detected by standard test methods and compared with biodiesel standards. Later, the effects of the different TRFB blends on the combustion behavior, engine performance and exhaust emissions of a direct-injection single-cylinder diesel engine were systematically investigated and compared with those of DF.

2. Materials and methods

2.1. Production of biodiesel

The turkey rendering fat was obtained from Bolca Hindi Slaughterhouse in Bolu, Turkey. It was filtered to remove solid residues and it was then heated at 110 °C for one hour in order to remove residual water. The two-step process was preferred because the content of free fatty acid in the turkey rendering fat was high. In all stages of production, the laboratory-scale devices were used and all chemicals used in the biodiesel production were purchased from Merck and were of analytical grade.

In the first step of the biodiesel production, the solution was prepared by using methanol as the alcohol and sulfuric acid as the catalyst, stirring at 40 °C for 30 min. The turkey rendering fat was placed into the