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Investigation of the effects of organic based manganese addition to biodiesel on combustion and exhaust emissions

Mehmet Celik [a,*], H.Serdar Yucesu [b], Metin Guru [c]

[a] Nigde Vocational High School, Nigde University, Nigde, Turkey
[b] Faculty of Technology, Gazi University, Ankara, Turkey
[c] Faculty of Engineering, Gazi University, Ankara, Turkey

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ABSTRACT

The use of biofuel as an energy alternative has gain continuous increase over the years; this is due to their advantage in limiting global warming and harmful emissions arising from diesel engines; this couple with the fast dwindling rate of fossil fuels has increased attention towards their uses. Studies have been conducted in recent years to analyze different energy sources and fuel additives for diesel engines. In this study, the combustion and emission characteristics were investigated by adding organic based manganese additive into rapeseed methyl ester (R0) in four (4) different loads. The results showed that there was a decrease in the viscosity, density, and flash point of fuels treated with additives while the calorific value of the treated fuel was increased. These improvements in the fuel features enhanced the fuel atomization. A minimum ignition delay was obtained in the R0Mn12 fuel for all the loads. A fuel ignition delay of 13.21 °CA occurred in the maximum load, while the maximum cylinder pressure of 62.76 bar was recorded. As a result of enhancing the fuel characteristics, analysis of the combustion emission revealed a reduction of 25.28% in carbon monoxide (CO), 6.64% in total hydrocarbon (THC), 6.5% in smoke emission and 25.52% increase of nitrogen oxides (NO_x) were recorded in the R0Mn12 fuel compared to the R0 fuel.

1. Introduction

Diesel engines are the most commonly used engines in the world today [1], they are used in various industries, including manufacturing, construction, transportation, and for agricultural purposes due to their high efficiency and reliability [2]. Diesel engines are preferable to their gasoline counterparts due to their high thermal efficiency and lower emission of carbon dioxide (CO_2). However, the two major obstacles of the use of diesel engines are high NO_x and particulate matter emissions. Any improvement in the fuel characteristics and the engine system will be a welcome idea to ensure the necessary strict emission standards. Emission standards are an unattainable target for controlling the combustion in the cylinder only. Furthermore, additional systems will be required to reduce NO_x emissions in the exhaust fume [40–41]. There is vast and rapid development in automobile technologies with view to improving on the fuel economy and emissions standards. Because of the high NO_x emissions from diesel engines, an international acceptable standard was adopted for diesel engines [42]. The growing environmental and health concerns towards the consumption of petroleum resources has necessitated the development of alternative from renewable resources that are cheaper and acceptable with respect to the environment [3].

These alternative sources should be renewable, environmentally-friendly, and easily obtainable; in addition, they should be capable of been used for internal combustion in engines through a few modifications [4]. The use of biodiesel -as an energy alternative has rapidly increased in the world due to its superior exhaust emission properties and renewability compared to the use of automotive gas oil (AGO) or diesel fuel [5]. Today, about 10% of the AGO requirement in the world is being covered by biodiesel [6]. Biodiesel which is biodegradable, non-toxic and eco-friendly, with approximately 10–12% oxygen- demand, is a significant alternative to diesel [7]. The source of biodiesel may be from raw materials of plant origin (such as palm, soybean, peanut, cottonseed, sunflower, rapeseed, and coconut) and animal fats (e.g. tallow) from which oil can be extracted [8].

The combustion in diesel engines is a complex fact; the fuel-air mixture, the temperature of cylinder wall, oxidation, the transfer of heat to the walls of the cylinder from the exhaust gases and the atomization etc. affects the fuel combustion [9]. It is worthy to note that the properties (such as viscosity, density, flash point etc.) of the fuel affect the performance of the engine and its combustion characteristics. The combustion

* Corresponding author.
E-mail address: mehmetcelik@nigde.edu.tr (M. Celik).

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Table 1
Summary of different types of additives used in various biodiesel-diesel blends.

Yakıtlar	Viscosity at 40 °C (mm^2/s)	Density at 15 °C (kg/m^3)	Lower heating value (MJ/kg)	Flash point (°C)	Cetane number	References
Pomace biodiesel (B25) 12 μmol/l manganese additives	2,9	828	43,540	76	49	[49]
Tall biodiesel (B60) 8 μmol/l manganese additives	4,8	–	–	81	–	[50]
Tall biodiesel (B60) 12 μmol/l manganese additives	4,3	–	–	80,5	–	[50]
Canola biodiesel (B20) 100 ppm BHA (butylated hydroxyanisole) additives	3,94	0.8495	–	–	48.35	[51]
Canola biodiesel (B20) 500 ppm BHA additives	4,45	0.849	–	–	49.57	[51]
Canola biodiesel (B20) 1000 ppm BHA additives	4,23	0.849	–	–	53.45	[51]
Jatropha biodiesel	5,25	0.895	38.88	85	53	[52]
Jatropha biodiesel 25 ppm alumina	5,31	0.896	39.22	84	54	[52]
Jatropha biodiesel 50 ppm alumina	5,35	0.897	39.53	82	56	[52]
Waste cooking palm biodiesel (WCPBD)	4,56	0.866	38.03	107	66	[53]
WCPBD 5 μmol FBC (fuel borne catalyst)	4,55	0.865	38.1	170	67.4	[53]
WCPBD 10 μmol FBC	4,52	0.865	38.14	168	67.9*	[53]
WCPBD 15 μmol FBC	4,52	0.865	38.21	167	68.1	[53]

* Cetane Index.

properties of an engine are very important in reading the engine's performance and its exhaust emissions as well as to determine the engine's design and the optimum operation parameters [10].

The direct use of biodiesel (without enhancing their properties) in engines generates various problems due to its weak chemical and physical properties compared to diesel fuel [11]. The physical properties such as high viscosity and density constitute the barrier to the use of unaided biodiesel; a high level of viscosity and density may cause injection problems, weak atomization, and deficient combustion [11,12]. The ignition, combustion, and formation of the contaminant emissions are affected by the atomization properties [13]. Density is a significant property of fuel that directly affects the performance of the engine. Properties such as the cetane number and calorific value are affected by density. The viscosity determined the spray properties, size of fuel droplet, atomization, and the amount of combustion. A high viscosity will increase the droplet size of fuel during spraying, and increase the exhaust emission [14]. The cetane number of fuel used in diesel engines plays an important role; fuel with a low cetane number will have a ignition delayed. Hence in this research we explored the use of organic based additives to improve the fuel quality [43]. Biodiesel has a high viscosity and density compared to AGO; through research conducted, it has been specified that high viscosity and density reduces spraying quality and as a result, the average droplet diameter and disintegration period of the fuel spraying increases [9].

Different additives were added to the fuel to aid the physical properties of the fuel, improve the combustion, and decrease the emission of harmful exhaust gases. The additives used in petroleum product are usually obtained from petroleum based raw materials and these additives form a catalytic effect which enhances the combustion of the hydrocarbons [15]. The type and structure of the additives, and the quantity required varies according to the products in which they will be used. The application of additives is necessary in order to reduce the level of emission and guarantee the efficiency of the engine using biodiesel as energy source [16]. With the use of additives, the performance, combustion, and emission characteristics of the biodiesel can be improved [17]. Products such as oxygenated additives, antioxidants, cetane number improvers, lubricants improvers, cold flow properties improvers are few examples of additives that improve the combustion properties of biodiesel [44].

The effects of the use of fuel additives on the performance of the diesel engine have been studied by many researchers, and promising results had been obtained [9]; and parameters such as cylinder pressure, heat dissipation rate, ignition delay, and the combustion period are used to investigate the quality of the combustion in diesel engines [18]. Keskin et al. examined the engine's performance and its emissions by adding metal based palladium and nickel as additives to diesel fuel. The result showed that there was an increase in the maximum moment in fuels aided with additive; a 7.75% decrease resulted in the brake specific fuel consumption when compared to unaided diesel fuel. The analysis of the exhaust emission showed a decrease of 50.24% CO, 34.96% of NO_x and 39.64% of smoke respectively in the additive aided fuels [45]. A similar study by Silva et al., examined the engine performance and emissions by adding titanium dioxide (TiO_2) nanoparticles into diesel fuel. The result showed that at the maximum load an increase of 0.9% occurred in the brake thermal efficiency of the fuel aided with TiO_2 and a 21.28% decrease in the brake specific fuel consumption. The exhaust emissions analysis showed that at the maximum load an increase of 32.2% NO_x and 16% of CO_2 resulted while a decrease of 18.36% hydrocarbon (HC) and 25% CO resulted in the fuel aided with TiO_2 [46]. Keskin et al. in their study examined the engine performance and emissions by adding 4 μmol/l, 8 μmol/l and 12 μmol/l magnesium (Mg) and molybdenum (Mo) additive to the mixture of the biodiesel produced of the tall oil and diesel fuel (B60). Their result indicated a decrease of 3.08% in the brake specific fuel consumption, in the fuel aided with 8 μmol/l Mo additive. The emission analysis revealed a maximum decrease of 36.21% and 24.12% CO occurred in fuel aided with 12 μmol/l additive of Mg and Mo, a maximum decrease of 23.19% in the NO_x emissions occurred when the fuel was aided with 8 μmol/l Mo, and a decrease of 8.82% in CO_2 emission resulted when aided with an additive of 12 μmol/l Mg [47]. The characteristics of fuel aided with the additives are shown in Table 1.

The aim of this study is to improve the negative properties of fuel such as the density, viscosity, flash point, and calorific value which affect the quality of the combustion and limits their usage as alternative energy source or biodiesel. We sought to improve these fuel properties and the quality of emission by adding an organic based manganese additive into methyl esters.

Table 2
Characteristics of test fuels.

Parameter	Method	R0	R0Mn4	R0Mn8	R0Mn12	R0Mn16
Viscosity (mm^2/s, 40 °C)	ASTM D 445	4.44	4.32	4.19	4.15	4.03
Density (kg/m^3, 15 °C)	ASTM D 1298	0.881	0.873	0.864	0.860	0.855
Flash point (°C)	ASTM D 93	167	161	157	155	152
Lower heating value (MJ/kg)	ASTM D 2015	39.08	39.22	39.37	39.43	39.50