Fuel Processing Technology 139 (2015) 100–107

Contents lists available at ScienceDirect

Fuel Processing Technology

journal homepage: www.elsevier.com/locate/fuproc

Examination of the effects of organic based manganese fuel additive on combustion and engine performance

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ARTICLE INFO

Article history:
Received 25 June 2015
Received in revised form 22 July 2015
Accepted 3 August 2015
Available online 11 August 2015

Keywords:
Diesel engines
Fuel additives
Manganese
Combustion characteristics
Exhaust emissions
Motor performance

ABSTRACT

The physical and chemical properties of the fuel used in internal combustion engines affect fuel economy and emission characteristics. Various additives are added into diesel fuel in order to improve fuel quality, achieve better combustion and reduce exhaust emissions. Acting as catalyzers during combustion, additives expedite fuel instability reactions and establish positive effects on engine performance. In the present study organic based manganese additive was added into diesel fuel. Combustion, performance and exhaust emission characteristics of the manganese fuel additives were investigated. The tests were carried out in a single-cylinder diesel engine. Among the fuels supplemented with organic based manganese additive, the best results were obtained from 12 ppm mixture rate. In comparison with diesel fuel, the maximum power of the D0Mn12 fuel increased by 12.48% while the specific fuel consumption was reduced by 8.17%. At fuel load while CO, THC and smoke emissions were determined to remain at the minimum levels in the fuel D0Mn12, NO_x emissions reached the maximum level.

1. Introduction

Diesel engines are widely preferred in industrial and agricultural applications and transportation due to the high levels of efficiency and reliability they provide [1]. The energy demand increases rapidly due to the rapid industrialization and the ever increasing number of vehicles in traffic [2]. The limited nature of energy generation, increasing demand for energy, depletion of fossil fuels, global warming, negative environmental effects and strict emission-related standards brought in have been urging researchers to involve in studies aimed at improving fuel quality and finding alternative and renewable fuels [3–5]. Significant studies are being carried out all around the world in order to limit diesel engine emissions and fuel consumption. Emissions and fuel consumption have been significantly reduced by virtue of the efforts in engine design. However, it is difficult to attain the required emission standards solely through engine design. Alternative methods aimed to obtain lower emission levels, better engine performances and increase fuel durability are tried by mixing different additives within diesel fuel. In recent years additive usage has become the focal point of the studies in this field [6,7]. Various additives are added into diesel fuel in order to improve fuel quality, achieve better combustion and reduce exhaust emissions. These additives create a catalytic action in order to enable better combustion of hydrocarbons [8]. The physical and chemical properties of the fuel used in internal combustion engines affect fuel economy and emission characteristics [9]. With the use of additives, the performance, combustion and emission characteristics of the fuel may be improved. Conducted studies indicate that additives reduce ignition delay and specific fuel consumption while increasing the thermal values of the fuel [10]. In diesel engines, proper fuel atomization enables higher efficiency and significantly reduces exhaust emission generation. Ignition, combustion and pollutant emission generation are affected by atomization properties [11]. Diesel engine performance is closely related with the quality of the injected fuel, the air/fuel mixture in the combustion chamber, the atomization, vaporization, density and viscosity of the fuel [12]. Nitrogen oxides (NO_x) are one of the troublemakers for diesel engines. Especially it is well known that the usage of the biodiesel increases the NO_x level because of its oxygen content and higher cetane number. Higher cetane number reduces the ignition delay period and a shorter ignition delay may result if the initial combustion products are exposed to high temperatures which enable more NO_x formation. However, cetane improving additives can be used sometimes for reducing the NO_x emissions [13]. Keskin et al. mixed tall oil-based methyl ester with diesel fuel (B60) at the rate of 60%, and further added 4 μmol/l, 8 μmol/l and 12 μmol/l magnesium (Mg) and molybdenum (Mo) additives into the fuel. Carbon monoxide (CO) and smoke density emissions were determined to be reduced by 56.42% and 30.43% respectively. It was reported that the reduction of the CO and smoke emissions was highly related to the oxygen content of the biodiesel and the catalyst effect of the metal based fuel additives [14]. A higher viscosity property of biodiesels is the biggest handicap for

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http://dx.doi.org/10.1016/j.fuproc.2015.08.002
0378-3820/

using in engines having advance fuel injection systems such as common rail. In order to improve the performance and emission values of tallow methyl ester Guru et al. added organic-based magnesium additive into biodiesel. With the addition of 12 μmol/l additive into biodiesel, 40 °C viscosity was reduced by 8.33%. Flashpoints of the biodiesel and the fuel supplemented with the additive were determined to be 138 °C and 132 °C respectively [15]. Keskin et al., on the other hand, examined the effects of organic-based metallic fuel additives on diesel engine performance and emissions (smoke, CO, nitrogen oxide (NO_x) and carbon dioxide (CO_2)). Each of MnO_2 and MgO metal additives was added to diesel fuel at the rates of 8 μmol/l and 16 μmol/l in order to prepare a test fuel. The lowest boiling point and pour point were obtained with the addition of the manganese (Mn) based additive. The addition of the 16 μmol/l Mn based additive to diesel fuel reduced pour point to 8 °C and cloud point to 4 °C. The maximum decrease in viscosity was obtained with D-16 Mg [16]. In the study conducted by Caynak et al. it was reported that the viscosity and cold flow properties of fuel were improved with the use of manganese additive. Manganese addition to the biodiesel at a ratio of 12 μmol/l resulted a 20.37% decrease in viscosity. It was also reported that the flash point of the fuel decreased by 7 °C with manganese addition [17]. A supporting study was performed by Guru et al. In this study Mn, Mg, copper (Cu) and calcium (Ca) metals were synthesized and their solutions were used as diesel fuel additives. The cetane number of the pure diesel fuel was increased from 46.22 to 48.24 by using the optimum additive dosage. The freezing point was also reduced about 12.4 °C by using fuel additives [18]. Manganese is an attractive material as fuel additive. In another study it was also used as gasoline fuel additive. Geng and Zhang evaluated Methylcyclopentadienyl Manganese Tricarbonyl (MMT) as gasoline additive to improve octane rating and knocking resistance of the fuel. Test fuels were prepared by doping MMT in a volume of 8, 12 and 18 mg/l to gasoline. Test results showed that the increasing ratios of the MMT caused an increase in cylinder pressure and peak heat release rates. It was also reported that CO, NO_x and particulate matter (PM) emissions increased with the increase of MMT percentage [19].

In this study, organic based manganese additive was added into diesel fuel. During the preparation of test fuels 4 ppm (D0Mn4), 8 ppm (D0Mn8), 12 ppm (D0Mn12) and 16 ppm (D0Mn16) organic-based manganese additive was added into diesel fuel (D0). The properties of the used fuels are presented in Table 1. The tests were carried out in a single-cylinder diesel engine. Engine tests were conducted at 2200 1/min fixed engine speed where the maximum torque is obtained and at 5 different loads. By establishing stable operation conditions, the tests were conducted at fixed engine operating temperature.

2. Experimental setup and procedure

In the study a Cussons P8160 engine test mechanism and a single-cylinder diesel engine were used. The technical properties of the test engine are presented in Table 2. The indicator system consisted of a Cussons brand P4100 model combustion analysis device, an AVL brand 3009 model charge amplifier, a water-cooled piezoelectric AVL8QP500c cylinder pressure sensor and National Instruments' USB 6259 data transfer card and an encoder. THC, NO_x, CO_2 and CO emission measurements from exhaust gases were carried out through an EGAS-2M model analytical exhaust gas measurement system produced by the Environnement SA Company. Smoke measurement was made through the use of an AVL 4000 DiSmoke model partial-flow opacimeter. Technical specifications of the gas analyzer and opacimeter were given in Tables 3 and 4 respectively. The schematic figure of the experimental setup is presented in Fig. 1. Uncertainties were given in Table 5.

Table 2
Technical specifications of the test engine.

Make/model		Antor/6LD400
Engine type		DI-Diesel engine, natural aspirated, air cooled
Cylinder number		1
Bore × stroke [mm]		86 × 68
Displacement [cm^3]		395
Compression ratio		18:1
Maximum power [kW]		5.4 @ 3000 rpm
Maximum torque [Nm]		19.6 @ 2200 rpm
Combustion chamber geometry		ω type
Fuel injection system		PF Jerk-type fuel pump
Injection nozzle		0.24 [mm] × 4 holes × 160°
Nozzle opening pressure [bar]		180
Fuel delivery advance angle [°KA]		24 BTDC
Valve timings	IVO/IVC [°KA]	7.5 BTDC/25.5 ABDC
	EVO/EVC [°KA]	21 BBDC/3 ATDC

During the experimental measurement, the constant variation of the data obtained from cylinder pressure sensor due to the instantaneous change of cylinder volume, combustion and heat transfer to the cylinder wall are the most significant factors acting upon the graphic [20]. In each cycle 2000 raw in-cylinder pressure data are received at intervals of 0.36 °CA. For the purpose of negating the effect of cyclic differences, corrections were made on 50 consecutive cycles and their average was calculated for analyses. During a cycle the cylinder pressure corresponding to each °CA in compression and extension time provide quantitative information on the combustion. These data consist of the energy released during the transformation of the fuel's chemical energy into heat energy. In-cylinder pressure data were used to calculate heat distribution rates [17–23]. Noise is generated in consequence of the numeric operations conducted with cylinder pressure data in heat dissipation analysis. In order to reduce these noises, the filtering operation presented in Eq. (1) was implemented.

$$P_i = \frac{1}{x^2}\left[\begin{matrix} P_{i-(x-1)} + 2P_{i-(x-2)} + 3P_{i-(x-3)} + \ldots + xP_i + \ldots + 3P_{i+(x-3)} + \\ 2P_{i+(x-2)} + P_{i+(x-1)} \end{matrix}\right] \tag{1}$$

where P_i functions indicate the cylinder pressure signals and i indicates the certain crankshaft interval.

Heat dissipation was calculated from Eq. (2) by making certain assumptions and implementing the first law of thermodynamics with single zone combustion model.

$$\frac{dQ_{net}}{dt} = \frac{k}{k-1}P\frac{dV}{dt} + \frac{1}{k-1}V\frac{dP}{dt} \tag{2}$$

The variation of the mixture composition within the cylinder along with the temperature and pressure differences in the cylinder causes cyclic differences. The sudden and rapid heat dissipation that occurs in the whole combustion chamber causes the cyclic differences to increase.

Table 1
Characteristics of test fuels.

Parameter	Method	D0	D0Mn4	D0Mn8	D0Mn12	D0Mn16
Viscosity (mm^2/s, 40 °C)	ASTM D 445	2.5	2.4	2.34	2.25	2.18
Density (kg/m^3, 15 °C)	ASTM D 1298	0.838	0.833	0.830	0.828	0.827
Flash point (°C)	ASTM D 93	64	62	59	58	57
Lower heating value (MJ/kg)	ASTM D 2015	41.13	41.19	41.22	41.24	41.25