Fuel 212 (2018) 256–267

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

Combustion, performance and emission characteristics of a DI diesel engine fueled with mustard oil biodiesel fuel blends at different engine loads

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ARTICLE INFO

Keywords:
Mustard oil biodiesel
Engine load
Performance
Combustion
Exhaust emission

ABSTRACT

This study highlights the effects of mustard oil biodiesel fuel blends on combustion, performance and emission characteristics in depth. For this purpose, a single cylinder DI diesel engine was run with mustard oil biodiesel-diesel fuel blends (M10, M20, M30) and standard diesel fuel (D100) at maximum brake torque speed of 2200 rpm and different engine loads of 3.75, 7.5, 11.25, 15 Nm and full load conditions in this study. It was seen that indicated thermal efficiency (ITE) decreased 6.8% with M10 while BSFC increased 4.8% with M10 compared to D100 at full load condition. Moreover, no huge differences were seen on cylinder pressure between mustard oil biodiesel-diesel fuel blends and diesel fuel. Remarkable reductions were seen on CO and smoke emissions with the usage of mustard oil biodiesel-diesel fuel blends compared to diesel. However, NO_x emissions increased in case mustard oil biodiesel fuel blends are used. NO_x emissions were determined 582 ppm with D100 while increased by about 22.1% and it was obtained 711 ppm with M30 test fuel. The test results also showed that low levels of mustard oil biodiesel-diesel fuel blends seems to be optimum fuel when the engine is operated at part engine loads. As a result, mustard oil biodiesel-diesel fuel blends can be used efficiently in CI engines without modifications.

1. Introduction

Researchers focused on renewable energy sources since oil reserves have been consumed and exhaust gases from motor vehicles damage the environment, atmosphere and human health. Not only the price of fossil based sources have increased day by day but also the depleting of coal, natural gases and oil reserves have increased due to the increase of number of motor vehicles dramatically in the world [1–10]. This overexploitation usage of fossil fuels causes global warming and reducing oil reserves each passing day. One of the most important handicap is that the biggest source of green house gases is motor vehicles. So, investigation of the new form of energy have become essential for internal combustion engines (ICE). Diesel engines have some advantages for lower specific fuel consumption and HC formation compared to spark ignition engines. Furthermore, they have been widely used in transportation, electric generation and for heavy duty. However, emitting high amount of NO, CO_2 and soot emissions of diesel engines should be reduced. At this point, biodiesel fuels based on vegetable oils are easily available, non toxic, environmentally friendly, low-sulfur, oxygenated and alternative energy source for diesel engines [6–13]. Usage of biodiesel is considered to be one of the best method in order to reduce noises and air pollutant levels of diesel engines due to its potential. Moreover, the utilization of biodiesel is significant because tremendous energy demand is required for transportation technologies and to preserve fossil fuel reserves. For this reason, production and utilization of biodiesel is attractive way to overcome all these difficulties with vegetable oils [14–21]. Another concern regarding the use of biodiesel based on vegetable oil is that diesel engine can operate well with biodiesel-diesel fuel blends and it is suggested to balance combustion stability in compression ignition (CI) engines. The production process of biodiesel significantly affects fuel properties such as cetane number, calorific value, density, viscosity etc. As chain length increases cetane number, heating value and viscosity increase in transesterification reactions that is known as the reaction of vegetable oil with alcohol in order to obtain esters. Conversely, cetane number, heating value and viscosity decrease with the increase of unsaturation. Also high degree of unsaturation of biodiesel causes to release more NO_x emissions [22–33]. One drawback of usage of biodiesel is that oxidation properties and cold flow properties resulting in decrease on engine performance. Among the liquid biofuels, mustard oil have played important role as a remarkable alternative fuel and prevented to oil crisis [16–19]. Widespread acceptance has been gained by mustard oil biodiesel as biodiesel feedstock that belongs to the Brassicaceae plant family. It is mentioned that mustard oil can be produced with lower price than canola and rapeseed. Furthermore, food chain is not deteriorated when mustard oil is used as a biodiesel feedstock. In addition, three of the

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http://dx.doi.org/10.1016/j.fuel.2017.09.005
Received 4 August 2016; Received in revised form 4 September 2017; Accepted 5 September 2017

Nomenclature

A	combustion chamber surface area
ABDC	after bottom dead center
ASTM	American society for testing and materials
ATDC	after top dead center
BBDC	before bottom dead center
BSFC	brake specific fuel consumption
BTDC	before top dead center
BTE	brake thermal efficiency
CA	crank angle
CI	compression ignition
CO	carbon monoxide
CO_2	carbon dioxide
COV_{imep}	cyclic variation of imep
dQ	heat release rate
dQ_{heat}	transferred heat to the cylinder wall
$d\theta$	crank angle
$\left(\frac{dP}{dt}\right)_{max}$	maximum pressure rise rate
D100	100% No. 2 diesel fuel
DC	direct current
DI	direct injection
EGR	exhaust gas recirculation
EN	European norm
EVC	exhaust valve closing
EVO	exhaust valve opening
h	heat transfer coefficient
HC	hydrocarbon
ICE	internal combustion engine
ID	ignition delay
ITE	internal combustion engine
IVO	intake valve opening
IVC	intake valve closing
imep	indicated mean effective pressure
k	The ratio of specific heat values
MPRR	maximum pressure rise rate
M10	(10% Mustard oil biodiesel + 90% No.2 diesel fuel in vol)
M20	(20% Mustard oil biodiesel + 80% No.2 diesel fuel in vol)
M30	(30% Mustard oil biodiesel + 70% No.2 diesel fuel in vol)
n	engine speed
NO_x	nitrogen oxides
P_{max}	maximum in-cylinder pressure
RI	ringing intensity
ROME	rapeseed oil methyl ester
SFC	specific fuel consumption
SOC	start of combustion
SOI	start of injection
T_g	mean gas temperature
T_W	cylinder wall temperature
T_{max}	maximum in-cylinder gas temperature
TDC	top dead center
ULSD	ultra-low sulphur diesel
γ	polytropic index
σ_{imep}	standard deviation of imep values of 50 consecutive cycles
$\overline{X}$	averaged imep values of 50 consecutive cycles

most produced vegetable oil produced in the world are rapeseed, palm and mustard oil. Mustard is grown in dry and hot areas. It also includes more than 50% erucic acid which makes it non-edible. Mustard can be defined as hard, round and the color of mustard seeds changes from yellow to light brown [21–29]. The price of mustard oil biodiesel production is lower than untaxed diesel fuel which seems to be economical for biodiesel feedstock [26,28]. For diesel engines, several investigations have been performed towards vegetable oils and its blends on engine performance and exhaust emissions. Maiti et al. [34] investigated the pyrolysis of mustard straw and stalk at different heating rates in a 40 cc/min nitrogen flow. They have seen that kinetics of pyrolysis of biomass was helpful for the improving thermochemical conversion process. Fadhil et al., [35] produced liquid bio-fuels and activated carbons from non-edible fish waste. They have determined that fuel properties have met the ASTM D 6751 specifications. They have also mentioned that 500 °C activation temperature, 60 min activation time and 60 mesh particle size were found as optimal conditions for best activated carbon sample. Çelebi et al. [36] investigated the vibration and acoustic effect of sunflower and canola biodiesel blends. Moreover the effects of addition of natural gas were researched. They showed that artificial neural network model presented good results. Valente et al. [37] evaluated the properties of waste cooking oil biodiesel and castor oil biodiesel. They have mentioned that cetane index decreased with higher biodiesel content in diesel. Maximum biodiesel concentration in diesel met the fuel characteristics of internal combustion engine. Uddin et al. [38] proposed to determine the effets of pure mustard oil kerosene fuel blends (m20, m30, m40, m50 and M100) at different load conditions on performance. They observed that m20 and m30 showed minimum brake specific fuel consumption (BSFC) at 12.5 kg load. Singh et al. [39] explored the mustard oil in biodiesel production and engine performance. Test results showed that 8% fuel blend presented good efficiency without modifications. Tesfaye and Katiyar [40] evaluated the effect of poly (lactic acid)-oligomer (OLLA) on engine performance and exhaust emissions with the usage of microwave synthesized soybean oil biodiesel. They stated that lower CO and HC were determined with the comparative utilization. Furthermore the usage of OLLA improved the cold properties of biodiesel. Sanjid et al. [41] researched the effects of mustard biodiesel on engine performance and exhaust emissions. They have found that MB10 and MB20 showed higher BSFC of 8–13% and lower brake thermal efficiency (BTE) of 5–6% compared to B0. Pradhan et al. [42] developed fast, energy efficient biodiesel production from waste mustard oil with infrared radiated reactor. Produced optimal biodiesel fuel blends showed promising engine performance compared to diesel. Fathil et al. [43] investigated the effects of ethanol to oil molar ratio, reaction temperature, reaction duration, the catalyst type and catalyst concentration through transesterification in case of biodesel production from mustard seed oil ethyl ester. They have found that 0.90% KOH wt/wt of oil, 8:1 ethanol to oil molar ratio, a reaction temperature of 60 °C, and a reaction time of 60 min were optimum conditions. Tulip and Radha [44] analyzed the physical and chemical properties of mustard oil biodiesel and experimented mustard oil biodiesel blends in a diesel engine at different engine loads in view of performance and emissions. HC decreased with the blends of biodiesel compared to diesel. Singh et al. [45] presented the characteristics of waste cotton seed oil and mustard oil with the blends of B10, B15, B20. The results showed that characteristics of B10 (waste cotton seed oil and mustard oil methyl esters) were more optimized according to B15 and B20. Sharma et al. [46] researched the effects of mustard oil biodiesel in a single cylinder diesel engine. They have reported that BSFC of biodiesel blends (BB10 and BB20) were closer to diesel than other test fuels. SenthilKumar and Gopalakrishnan [47] evaluated the effects of jatropha and mustard oil methyl esters from 0 to 80% engine load. They have seen that brake thermal efficiency was higher with diesel for all engine loads. Aysal et al. [48] have performed the optimization of mustard oil. Parameters such as methanol/oil ratio, catalyst concentration, reaction duration and temperature were investigated. They found that brake power and torque decreased while BSFC increased with biodiesel fuel blends (B50, B100) compared that diesel fuel. Nalgundwar et al. [49] investigated the effects of palm, jatropha biodiesel and diesel fuel blends on engine