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EXHAUST EMISSION CHARACTERISTICS of WASTE FRYING OIL – DIESEL FUEL BLENDS in a CRDI DIESEL ENGINE

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Abstract— **In this study, waste frying oil (WFO) (without converting biodiesel) was blended with mineral diesel fuel (MDF) in the ratios of 2%, 7%, 15% and 25% (v/v) on condition that the viscosities of all WFO-MDF blends were lower than 5.00 mm^2/s (viscosity upper limit given in European Biodiesel Standard, EN 14214). It was aimed to determine the influences of the direct use of WFO-MDF blends with low viscosity on the exhaust emission characteristics of a modern diesel engine equipped with electronically controlled high pressure fuel injection system which is very susceptible to fuel quality. Test fuels were used in a common rail direct injection (CRDI) diesel engine. Engine tests were performed at constant engine speed of 2000 rpm and five different engine loads (50 Nm, 75 Nm, 100 Nm, 125 Nm, and 150 Nm). Effects of WFO-MDF blends on the exhaust emission characteristics were determined and compared to that of MDF as the reference fuel. WFO usage increased all the emissions types measured. This difference between the emissions of neat MDF and MDF-WFO blends became more pronounced with increasing engine load and WFO percentage in the blend.**

Keywords—biodiesel; direct use; viscosity; waste frying oil; exhaust emission

I. INTRODUCTION

Road transport sector has the deterministic effect on urban air pollution, particularly at roadside locations where people are exposed to highest level of exhaust emission. As a foregone conclusion of the increase in the number of diesel engine vehicles, despite notable improvements in exhaust gas after treatment systems and progressively stricter vehicle tailpipe emission limits, the share of exhaust emissions released from diesel engines in the total atmospheric pollution could not be reduced to the targeted level [1]. Significant reductions in diesel engine emissions are required to improve urban air quality. One way to improve the diesel engine emission characteristic is to use alternative fuels having better exhaust emissions compared with mineral diesel fuel (MDF). It is well known from the literature that biodiesel has better emissions compared to MDF, except for nitrogen oxides (NO_x) emissions [2-5]. Despite environmental advantageous of biodiesel, it cannot economically compete with MDF due to decrease in crude petroleum price and increase in vegetable oil price. In addition to the feedstock cost, transesterification reaction adds extra cost (including chemicals, labor, and time) and inevitably increases the biodiesel break-even price. Because of this, biodiesel usage rate could not be increased as desired amount. This high cost might be alleviated by using waste frying oils (WFO)-MDF blends in diesel engines. Extremely high viscosity of triglycerides, which is the main technical obstacle against the direct use of neat vegetable oils in diesel engines, can be reduced to the acceptable values by blending with MDF. Furthermore, the use of WFOs as fuel in diesel engines prevents the harmful effects against the environment caused by the disposal of these waste materials.

In the literature, there are lots of studies about direct usage of vegetable oils in diesel engines, as neat or blended with MDF. However, when these studies are reviewed, it is realised that the viscosity values of blends are still too high to use in today's modern diesel engines which are very susceptible to fuel quality, especially to fuel viscosity. It is obvious that vegetable oil-MDF blends with high viscosities will cause serious engine failures in long-term usage.

In European Biodiesel Standard (EN 14214), the viscosity upper limit is 5.00 mm^2.s^{-1} (at 40 °C). This is one of the biggest indicators of biodiesel fuel quality. The main purpose of transesterification reaction converting triesters to monoesters is to reduce the high viscosities of triglycerides below this value. Therefore, in this study, WFO was blended with MDF in the ratios of 2%, 7%, 15% and 25% (v/v) without exceeding the viscosity upper limit. With this application it was aimed to determine the technical feasibility of direct use of WFO-MDF blends having viscosities less than 5.00 mm^2.s^{-1} in a modern diesel engine equipped with electronically-controlled high pressure fuel injection system which requires to extremely high fuel quality. According to the authors' knowledge, this is the first study performed with this sense.

II. MATERIALS AND METHODS

WFO used in the engine tests was obtained from a catering facility. It was filtered and heated at 110 °C for 1 hour to remove any food impurities and moisture. MDF was purchased from a local gas station.

Table I. Some key fuel properties of the test fuels.

Test Fuel	Viscosity ($mm^2.s^{-1}$, 40 °C)	Density ($kg.m^{-3}$, 15 °C)	Heating Value ($MJ.kg^{-1}$)	Flash Point (°C)
MDF	2.96	832.6	45951	57.00
WFO-2	3.15	834.7	45796	57.50
WFO-7	3.49	839.1	45226	59.00
WFO-15	4.10	845.2	45064	62.50
WFO-25	4.98	853.0	44321	69.00

Table II. Specifications of the test engine.

Engine	1.9 liter, Fiat JTD
Type	Direct Injection, turbocharged-intercooled, four stroke, water cooled, common rail
Number of Cylinder	4
Bore – Stroke	82 mm – 90.4 mm
Compression Ratio	18.45:1
Maximum Power	77 kW (4000 rpm)
Maximum Brake Torque	205 Nm (1750 rpm)

WFO was blended with MDF in the ratios of 2%, 7%, 15% and 25% (v/v). Test fuels were coded as following: Mineral diesel fuel (MDF) as reference fuel, 2%WFO - %98 MDF (WFO-2), 7%WFO – 93%MDF (WFO-7), 15%WFO – 85% MDF (WFO-15) and 25%WFO – 75%MDF (WFO-25). Some key fuel properties of the test fuels were given in Table 1.

Engine tests were performed in four-cylinder, four-stroke, water-cooled, turbocharged-intercooled, common rail direct injection (CRDI) diesel engine Specifications of the test engine can be seen in Table 2. A hydraulic dynamometer was used to load the engine. The crank shaft position was determined by a crank angle encoder fixed over the engine crank shaft pulley. The temperatures of the intake air, fuel, engine oil and engine coolant were measured by using K type thermocouples with a digital display. The fuel temperature was controlled by a heat exchanger and kept around 40 °C±3 °C to avoid the viscosity change of test fuels caused by temperature increase. Intake air mass flow was measured by AVL Flowsonix-Air product. Fuel consumption was determined by weighing fuel used for a period of time on an electronic scale. The measurement of the emissions was carried out by AVL SESAM FITR exhaust emission analyzer.

III. RESULTS AND DISCUSSION

The influences of the engine load and the WFO percentage in the fuel blend on the exhaust emission characteristics were evaluated by comparing the carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbon (THC) and nitrogen oxides (NO_x) emissions.

A. CO Emissions

The changes of CO emissions of test fuels were given in Fig.1. Compared to MDF, WFO mixtures caused to increase in CO emissions. This increase became more apparent with increasing WFO percentage and engine load. Highest difference in the CO emissions was 13.93% at 125 Nm for WFO-2 (on average 5.65% increase), 13.62% at 125 Nm for WFO-7 (on average 7.58% increase), 24.89% at 150 Nm for WFO-15 (on average 11.95% increase) and 40.58% at 150 Nm for WFO-25 (on average 16.65% increase).

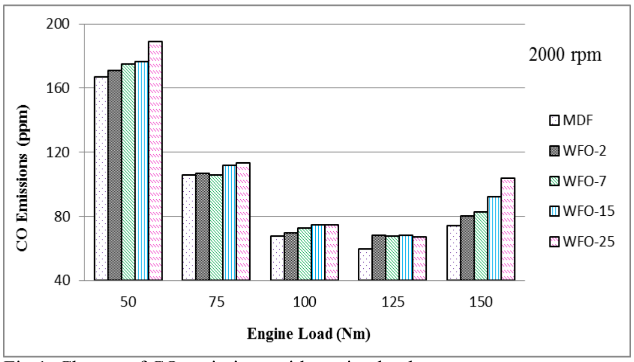

Fig.1. Change of CO emissions with engine load

The viscosity of the blends increased with WFO content. Relatively high viscosities of the mixtures deteriorate the atomization quality and cause to large fuel droplets from the injectors. Long penetrations of the large fuel droplets inside the combustion chamber lead to locally fuel-rich zones, increasing CO emission.

B. CO_2 Emissions

As shown in Fig. 2, CO_2 emissions of all test fuels increased as the engine load was increased. This upward trend may be explained with the increase in combustion temperatures, air and fuel charge to the engine. In addition, higher fuel injection pressures (better atomization) with increasing engine load may enhance the combustion efficiency and so increase the CO_2 emissions.

WFO blends increased the CO_2 compared with MDF, but not as much as seen in the other emission types. In comparison to MDF as reference fuel, the increase in CO_2 emissions was on average 1.66%, 2.89%, 2.84% and 4.10% for WFO-2, WFO-7, WFO-15, WFO-25 fuels, respectively. The carbon content of the blends increased with WFO percentage and this could lead to CO_2 emission increase. Also, the higher CO_2 emissions of WFO-MDF blends may be interpreted with higher fuel consumptions of the blends. The fuel consumption difference between the MDF and MDF-WFO blends increased with increasing engine load and WFO content.

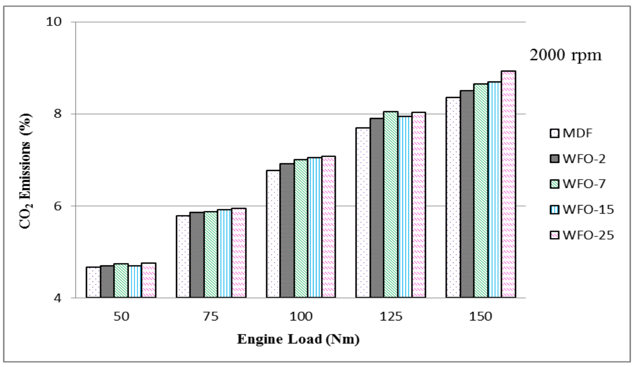

Fig.2. Change of CO_2 emissions with engine load.

C. THC Emissions

The change of THC emissions of test fuels were plotted in Fig. 3.

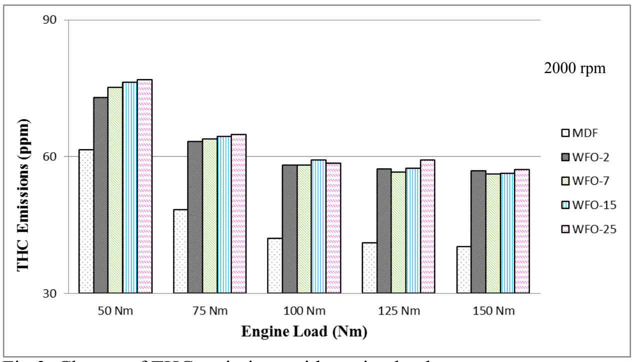

Fig.3. Change of THC emissions with engine load.

As seen, THC emissions of all test fuels decreased with engine load, but this decrease was more obvious between 50 Nm and 100 Nm. Increasing combustion temperatures and fuel injection pressures could be effective in this decline period.

In proportion to neat MDF, WFO blends emitted more THC emissions. The average difference compared to THC emissions of MDF was 33.66% for WFO-2, 33.95% for WFO-7, 35.51% for WFO-15 and 36.88% for WFO-25. Lower volatility of WFO in the blends compared to MDF may contribute to larger difference in THC emissions of test fuels. Also, the glycerol ingredient of WFO (since WFO was used directly without converting biodiesel) which is a highly viscous, having very high boiling temperatures and difficult to ignite may have a vital influence on this high THC emissions.

D. NO_x Emissions

The change of NO_x emissions emitted from the test fuels was illustrated in Fig. 4. NO_x emissions of all test fuels significantly increased with engine load. In the literature, there are many studies reporting that air induction into the engine, injection pressures, injection timing advance and so in-cylinder temperatures and pressures increase with engine load [6-8]. These factors could enhance the NO_x formation.

WFO blends produced more NO_x emissions than MDF. This difference steadily grew with increasing WFO content and engine load. On average, the NO_x emissions increased by 2.96%, 5.85%, 8.79% and 10.71% for WFO-2, WFO-7, WFO-15, and WFO-25, respectively. The less cetane numbers of WFO blends compared with MDF may be effective in this NO_x rise. In addition, in the literature, it is known that fuels with high viscosity, density, iodine number and bulk modulus (less compressibility) lead to increase in NO_x emissions [9, 10].

Despite it is not in many amounts, the oxygen content of WFO might enhance the NO_x formation. Also, there are studies have found that triglycerides cause to high fuel injection pressures and advanced injection timings, leading to high NO_x emissions [11-14].

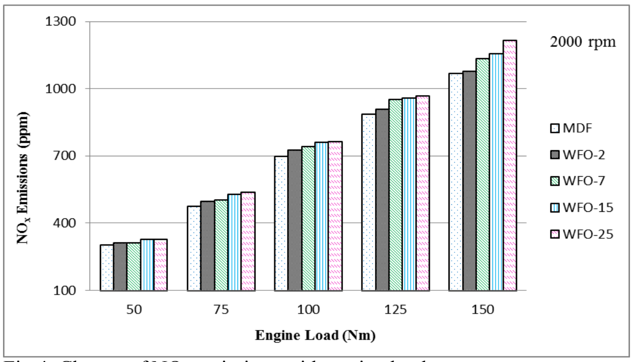

Fig.4. Change of NO_x emissions with engine load.

IV. CONCLUSIONS

WFO was blended with MDF in small amounts in order not to exceed the viscosity upper limit given in EN 14214. Although there was not any problem in terms of viscosity which was the biggest parameter deteriorating the atomization quality, WFO blends emitted more exhaust emissions compared with neat MDF. NO_x and CO_2 emissions of all the test fuels were not much different from each other. But, in terms of CO and THC emissions, the differences were more distinct. This should be emphasized that up to 7% blend ratio, the difference between the exhaust emissions were tolerable. However, long-term engine endurance tests must be performed to determine the suitability of these blends as fuel in diesel engines.

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