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# EMISSION AND PERFORMANCE CHARACTERISTICS OF A CI ENGINE FUELLED BY COTTONSEED OIL METHYL ESTER AND DIESEL FUEL BLEND

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**KEYWORDS:** Alternative fuels, cottonseed oil methyl ester, diesel fuel, emission.

## ABSTRACT

Many researches of vegetable oil fuels have investigated that the vegetable oils can be used as an alternative fuel for diesel engines. The viscosity of crude vegetable oils is rather high than diesel fuel. High viscosity has negative effect on atomisation quality, and so engine performance and exhaust emissions are affected badly and become failure on engine parts. To decrease of viscosity of cottonseed oil methyl ester was produced and tested as alternative fuel in a single cylinder, four strokes, air-cooled diesel engine. Engine tests carried out at full load-different speed range, the engine torque and power of cottonseed oil methyl ester with diesel fuel blend was lower than that of diesel fuel in range of 2-3 % and specific fuel consumption was higher than that of diesel fuel of approximately 3 %. $CO_2$, CO and $NO_x$ emissions of cottonseed methyl ester were lower than that of diesel fuel. The cottonseed oil methyl ester fuel was used successfully as alternative fuel in short-term tests.

## INTRODUCTION

The high cost of oil and oil crises have brought much pressure on many countries to re-evaluate their national energy strategies. Ever since the oil crises of the 1970s, 1980s and 1992s, there has been an incentive to increase energy security by seeking substitutes for oil. Thus energy conservation and alternative fuels research are given high priority in energy planing in some countries. In the past, many investigations have been carried out on the use of vegetable oils as diesel fuel. The acceptability of vegetable oils as diesel fuel has been evaluated for the first time in the 70th years because of the well-known energy crises. Several studies conducted world-wide have shown that vegetable oil, without any modification, can give engine performances comparable with those of diesel fuels. In general, it has been reported by most researchers that if crude vegetable oils are used as diesel engine fuel [1-11]. The most important advantage of vegetable oils is that they are renewable energy sources compared to the limited resources of petroleum.

Extensive studies on alternative fuels have been carried out since the fossil based fuels are limited. One of these studies is on vegetable oils to be used in diesel engines. In the researches done so far, some negative sides of using vegetable oils in engines such as carbon deposits in combustion chamber, harmful effects on engine parts, clogged injectors, needle adhesion and the cause a first starting problem have been observed [12-20]. In addition, decrease in combustion efficiency due to poor atomization, thickening of lubricant and piston and ring adhesion has also been reported by some researchers [21-23].

There is always an immixing gap when vegetable oils are mixed with diesel oil due to the difference in densities. The problems due to the viscosity and density of the vegetable oils having different physical and chemical properties from of the diesel fuel should be eliminated to make them less viscous. Although vegetable oils are all virtually sulphur-free, they create other problem in that they are generally too viscous, often acidic, they choke injector nozzles with carbon and leave high carbon residue on burning [24-30]. They have noted some problems as a result of using plants oil and as a fuel blends. One of these problems a thickening of crankcase oil has occurred which is attributed to the contamination of petroleum – based crankcase oil with unburned raw plant oil. Second problem, a build-up of carbon on and in fuel injector nozzles and piston rings was observed. These problems manifest themselves in long-term use and have yet to be solved. However, a great deal of research has been done into blends with petroleum-derived fuel and into the use of vegetable oil esters. With this aim, it is necessary to obtain either esters or emulsions of vegetable oils [31-42]. It had been made short and long term engine performance and emission tests using vegetable oil methyl or ethyl ester fuel for high speed diesel engines. It had been reported that engine performance are no significant changes between rape seed oil methyl ester and diesel fuel.

***Table 1. Typical composition ranges of fatty acids of cottonseed oil (%).***

| Component | Carbon bond | Percentage | Chemical equation |
|---|---|---|---|
| Palmitic | 16 | 22,9 | C16H32O2 |
| Stearic | 18 | 2,14 | C18H36O2 |
| Oleic | 18:1 | 24,70 | C18H34O2 |
| Linoleic | 18:2 | 49,70 | C18H32O2 |
| Myristic | 18:3 | 0,56 | C14H28O2 |

Cottonseed oil is attracting considerable attention as diesel fuel extenders of substitutes either in the form of the transesterified-chemically modified cottonseed oil- with various monohydric alcohols. Some vegetable oil contains high concentrations of less common fatty acids [43-46]. Like the others, cottonseed oil includes acids in its content as well. These are palmitic, stearic, oleic, lynoleic, arachidic, and behenic acids. The chemical formulations and the percentage of these acids are given in Table 1. Chemical compositions of cottonseed oil indicate that this is a suitable alternative diesel fuel. Physical properties of cottonseed oil and some other vegetable oils are shown in following Table 2.

***Table 2. Physical properties of cottonseed oil in comparison with other some vegetable oils***

| Properties | Sunflower oil | Cottonseed oil | Corn oil | Soybean oil |
|---|---|---|---|---|
| Calorific value (kJ/kg) | 39500 | 39600 | 37850 | 39620 |
| Density @ 26°C (Kg/lt) | 0.918 | 0.912 | 0.919 | 0.914 |
| Viscosity (mm$^2$/s) at 26°C | 58 | 50 | 39 | 65 |
| Flash point (°C) | 220 | 210 | 277 | 230 |
| Cetan number | 37 | 39 | 38 | 38 |

An oil can be made soapy by removing the last carbon in chain and replacing methyl in the place or in another word the methyl ester of that oil is obtained [47]. Methanol containing 1% sulphuric acid ($H_2SO_4$) can methylise the fatty acids very rapidly. Methanol and oil mixture in a certain proportion can be transformed to a methyl ester by holding at 50°C for 12 hours. In this study also cottonseed oil methyl ester (COME) was obtained in this way. This study was designed to determine utility of the esters of these common fatty acids as diesel fuels. Methyl ester of cottonseed oil was prepared with a four molar excess of the alcohol containing 2% $H_2SO_4$ as catalyst. It was kept in the oil bath for 12 hours at 50°C in laboratory conditions.

***Table 3. Physical properties of crude cottonseed oil (CCO), crude cottonseed oil methyl ester, diesel fuel (No 2 D fuel) and 75%COME+25%DF blend (75/25 fuel).***

| Properties | RCO | COME | No 2 D fuel | 75/25 fuel |
|---|---|---|---|---|
| Density @26°C(Kg/lt) | 0.923 | 0.880 | 0.840 | 0.877 |
| Calorific value (Kj/kg) | 36700 | 40763 | 42902 | 41298 |
| Viscosity @ 26°C(mm$^2$/s) | 34,89 | 4.30 | 3.2 | 4,025 |
| Flash point (°C) | 300 | 70 | 59 | 67,25 |
| Cetane number | 38 | 48 | 46 | 47 |
| Sulphur content | 0.01 | 0.01 | 0.05 | 0.02 |
| Acide value | 0.17 | 0.13 | 0.22 | 0.15 |

There are some differences between the properties of the oil and its own ester. The essential difference is in viscosity. After esterisation the viscosity becomes closer to of the diesel fuel. Higher viscosity causes some problems such as the difficulties in pumping the oil from the tank and injection from the injectors. Due to the high viscosity, large drops are formed and consequently combustion becomes difficult as a result the amount of HC and soot increase [48]. In table 3 are shown different properties of crude cottonseed oil (CSO), cottonseed oil methyl ester (COME), diesel fuel (No 2 D fuel) and 75%COME+25%DF (75/25 fuel).

## EXPERIMENTAL STUDIES

A mixture was prepared in laboratory conditions, 75% cottonseed oil methyl ester with 25% diesel fuel volumetrically (75/25 fuel), and tested in a one cylinder, four-stroke, direct injection, air cooled Lombardini 6LD400 engine with a compression rate of 18:1. Technical specifications of the test engine are shown in Table 4.

***Table 4. Lombardini Diesel Engine Details.***

| | |
|---|---|
| Type | 6LD 400 Lombardini |
| Number of cylinder | 1 |
| Cylinder diameter | 86 mm |
| Stroke | 68 mm |
| Clearance volume | 395 $cm^3$ |
| Compression ratio | 18:1 |
| Maximum speed | 3600 l/min |
| Maximum power | 6.2 kW @ 3600 l/min |
| Maximum torque | 20 N.m @ 2200 l/min |
| Fuel tank capacity | 4.3 lt |
| Oil consumption | 0.0115 kg/h |
| Cooling | air |
| Injection timing | 30 BTDC |
| Injection opening pressure | 200 $kg/cm^2$ |
| Starting | by dynamometer |
| Dry weight | 45 kg |

The tests were performed with maximum gas and at different engine speeds. The aim of this study was to investigate the effect of cottonseed based oil methyl ester with diesel fuel blend on compression engine performance and exhaust gas emissions. The engine was operated on No 2 D fuel first and then on 75/25 fuel. Tests were held on a laboratory test bed which consisted of an electrical dynometer, an exhaust gas analyzer, a data acquisition system and engine mounting elements, as shown in Fig. 1.

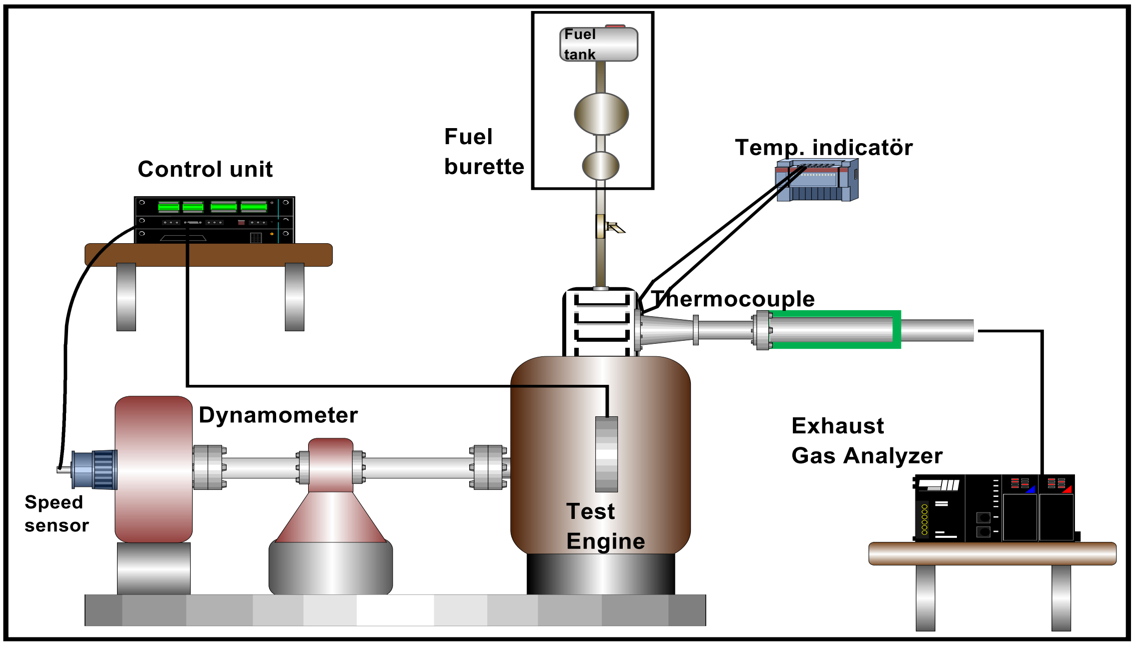

*Figure 1. Schematic layout of the engine test system*

## RESULTS AND DISCUSSION

### Engine torque

Engine speed was firstly adjusted to 3400 rpm and gas spindle was held constant at this speed. Then the speed decreased to 3100 rpm by loading the engine. By continuing loading, engine speed was set at 3100, 2800, 2500, 2200, 1900, 1600 and 1300 rpm sequentially.

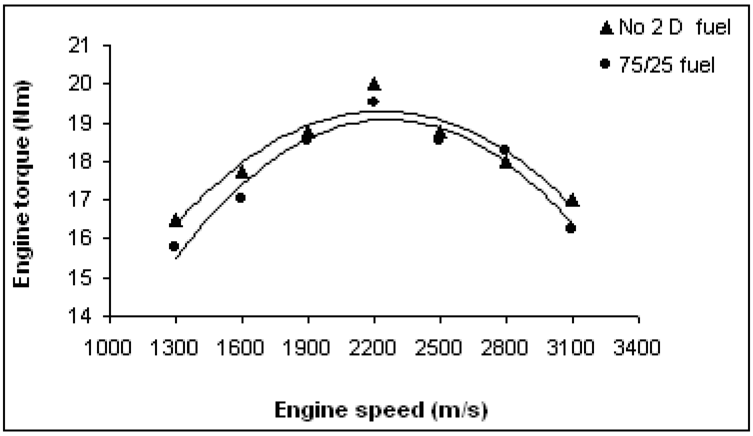

*Figure 2. Engine torque variation with No 2 D fuel and 75/25 fuel at various engine speeds*

Maximum engine torque was obtained at 2200 rpm. It was the same value stated in the engine's catalogue. In Figure 2, the variation of engine torque versus engine speed is given. A torque of 20 Nm was obtained with No 2 D fuel at 2200 rpm while with 75/25 fuel a torque of 19.75 Nm was obtained. The decrease rate in the torque at 2200 rpm was 2 %. The torque of 17 Nm and 16.25 Nm were obtained with No 2 D fuel and 75/25 fuel respectively at 3100 rpm at maximum power. The drop in the torque is 5 % at the minimum speed. At 1300 rpm, the torque was 16.5 Nm in case of No 2 D and 15.75 Nm with 75/25 fuel with a drop of 5%. The engine was trembling at

1300 rpm with 75/25 fuel. The engine was stable with No 2 D at the same speed. These results may be due to the higher viscosity and lower heating value of 75/25 fuel.

### Engine power

The variation of engine power versus engine speed is seen in Figure 3.

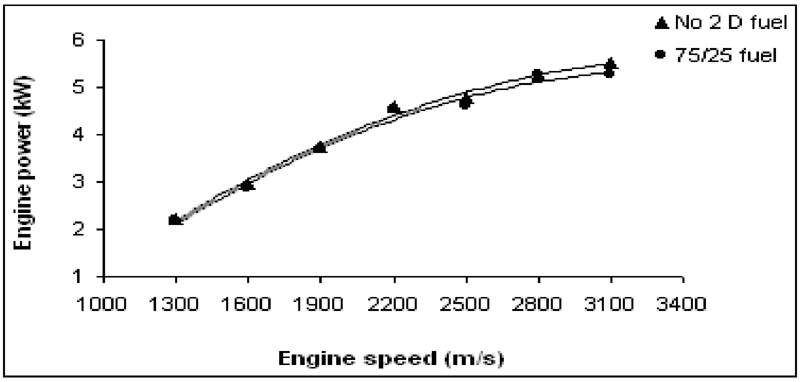

*Figure 3. Engine power variation with No 2 D fuel and 75/25 fuel at various engine speeds.*

The engine power increases with the engine speed. Maximum power was obtained at 3100 rpm. The engine powers obtained at this speed were 5.51 and 5.27 kW with No 2 D fuel and 75/25 fuel respectively. The drop in engine powers between these two kinds of fuels was 5%. 4.60 kW and 4.51 kW of power were obtained with No 2 D fuel and 75/25 fuel respectively at 2200 rpm. The drop in engine power was 2%. 2.24 kW and 1.17 kW of power were obtained with No 2 D fuel and 75/25 fuel respectively at the minimum engine speed, 1300 rpm. The drop in engine the power was 3 % in this case. The powers obtained are related to the burning and heat capacities of the oils. The heat capacity of No 2 D is 42902 KJ/kg while of 75/25 fuel is 41298 kJ/kg. The difference between them is approximately 3 %. Under the same circumstances in case of 75/25 fuel the power decreases by 5 % at the maximum power speed. These results may be due to the higher viscosity and lower heating value of 75/25 fuel.

### Specific fuel consumption (SFC)

Spesific fuel consumption of the engine changes depending on the engine speed and loading. Although the amount of the fuel in volume taken into the combustion chamber in every cycle at a specific throttle valve position and engine speed are same, the difference in density of the fuels affects the amount of the fuel intake. SFC is defined as the consumed fuel in mass per unit power. In figure 4, the change in SFC with the engine speed is given.

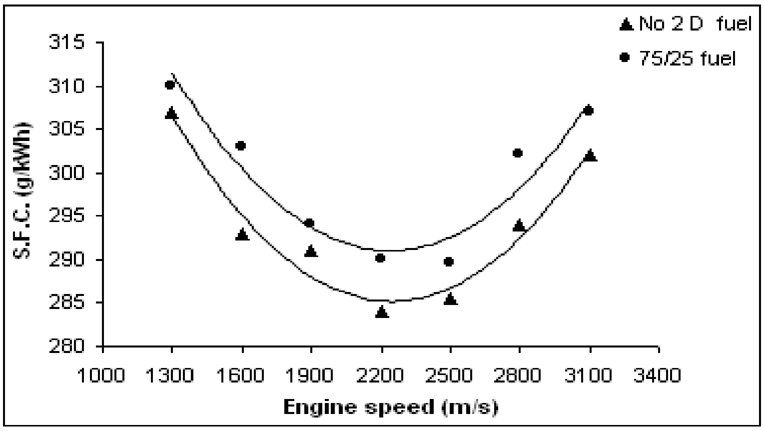

*Figure 4. Engine specific fuel consumption variation of No 2 D fuel and 75/25 fuel at various engine speeds.*

SFC for No 2 D fuel and 75/25 fuel were found to be 302 g/kWh and 308 g/kWh respectively at an engine speed of 3100 rpm. The increase in 75/25 fuel is 2 % with respect to No 2 D fuel. At the maximum torque speed, the SFC were 289 g/kWh for No 2 D fuel and 296 g/kWh for 75/25 fuel. The minimum SFC was obtained at this speed for both fuels. That is, test results showed that minimum SFC values obtained were in the vicinity of the engine's maximum torque speed. The difference between No 2 D fuel and 75/25 fuel is 3 %. At the minimum engine speed, 1300 rpm, the SFC is 307 g/kWh for No 2 D fuel and 312 g/kWh for 75/25 fuel.

SFC is higher at all engine speeds for 75/25 fuel. Even if the volumetric fuel amount sent to the combustion chamber is same, since the mass of ester is higher and heat capacity is lower due to the density difference, SFC is higher in case of 75/25 fuel. The higher SFC values in the case of 75/25 fuel are due to its lower energy content than No 2 D fuel.

**Carbon dioxide (CO2) emissions**

The variations of CO2 emissions related with two fuels are shown in Fig. 5.

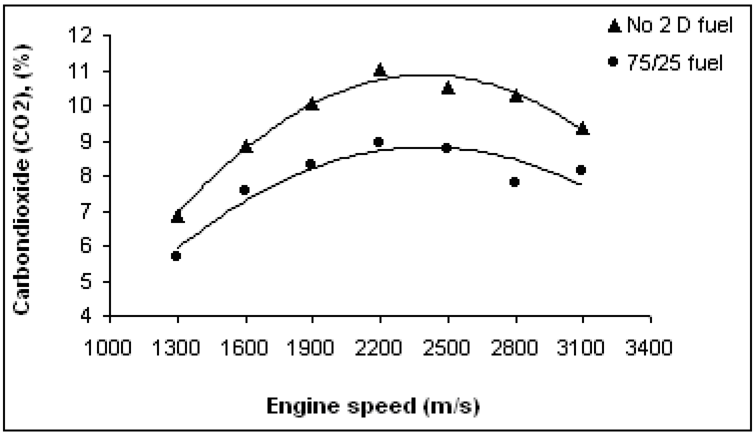

*Figure 5. The variation of the carbondioxide with No 2 D fuel and 75/25 fuel at various engine speeds.*

Carbon dioxide emission is an emission product related to the entire combustion of the fuel. High post-combustion temperature and existence of enough oxygen for an exact burning increase the amount of CO2. It is seen from CO2 amount – engine speed graphics that CO2 amount is higher around maximum torque speed for both fuels. It is also understood that the best burning occurred around this speed. The CO2 emission is 9.85 for No 2 D fuel and 8.12% for 75/25 fuel at 3100 rpm, the maximum power speed. CO2 emission is seen to be 11.08 % for No 2 D fuel and 8.94 for 75/25 fuel at the maximum torque speed. In case of diesel fuel it is seen that CO2 emission is higher at all engine speeds (Figure 5). This means that the quality of combustion for No 2 D fuel is higher than 75/25 fuel. This is an expected result of relatively better spraying qualities and more uniform mixture prepation of air and No 2 D fuel

**Carbon monoxide (CO) emissions**

In figure 6, CO emission – engine speed curve is seen. Carbon monoxide is exerted as a result of inadequate burning and partial oxidation of carbon atoms in fuel. This emission changes depending on the air/fuel ratio in cylinder. When this ratio is small, the amount of CO increases. NO emission, on the other hand, is at the lowest level. When the air is insufficient, CO transforms to CO2 after a certain amount of air. As can be seen from CO2 – engine speed relationship, CO emission tends to decrease with the increase in engine speed. When OH radical which transforms CO to CO2 decreases below 1500 K, burning deteriorates and consequently, amount of CO increases due to the lower temperature [Police, Prati, Auriemma, Alfuso, 1993].

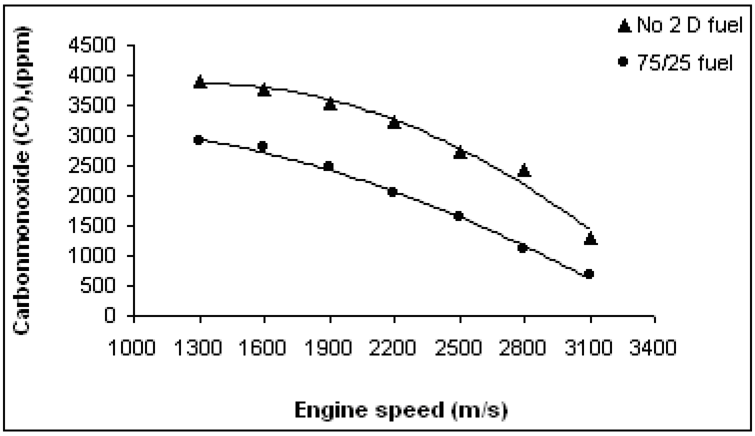

*Figure 6. The variation of the carbonmonoxide with No 2 D fuel and 75/25 fuel at various engine speeds.*

Comparing No 2 D fuel and 75/25 fuel, relatively lower CO emissions were obtained with 75/25 fuel. Since turbulence occurs in the combustion chamber at higher speeds, burning improves, and due to the increase of the temperature of the mixture, CO emission decreases. When the engine speed decreases and the loading increases, the quality of burning gets worse and CO emission rises. The partial oxidation of 75/25 fuel causes CO emission to be relatively lower than of the No 2 D fuel. In the experiments performed with 75/25 fuel, CO emissions were determined to have decreased by 36 - 67 %.

**Nitrogen oxide (NOx) emissions**

Nitrogen oxide is the generalized term for NO and NO2 given with the formula of NOx. Nitrogen oxide is formed as a result of the oxidation of nitrogen in the air during burning of the air-fuel mixture in the combustion chamber. NOx emissions are usually a result in higher combustion temperatures. Its formation is dependent on the duration of the flame temperature in the combustion chamber above 1800°K. In the formation of nitrogen oxides, the prodominant factors are the air/fuel ratio and the environment temperature. In case of adequate burning the temperature rises and consequently more free oxygen atoms combine nitrogen; this, in turn, increases the formation rate of nitrogen oxide. When the burning temperature is above 1800°K, NOx formation considerably accelerates. NOx formation changes as dependent upon the air surplus coefficient.

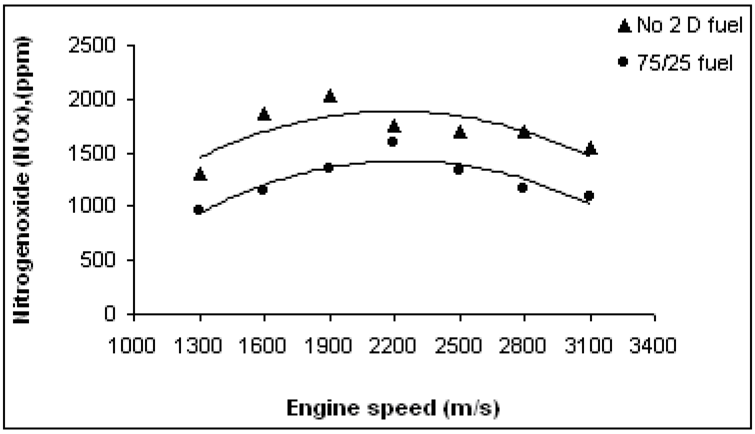

*Figure 7. The variation of the nitrogen oxide with No 2 D fuel and 75/25 fuel at the various engine speeds.*

When air surplus coefficient is higher, the cooling rate of engine decreases and the exhaust system remains hot. In poor mixtures, first O2 is decomposed to 2O. It is then accepted that NO forms with free radicals. Since the activation energies of these reactions are high, both reactions in lower temperatures are very slow [49]. Regarding this, the amount of oxygen, which determines the reaction rate at lower temperatures, can be neglected. As can be seen from Figure 7, initially the increase in NOx emission is, for both fuels, with the increase in engine speed and then decrease after the maximum torque speed. From both graphics of emissions, it is seen that the best burning is in the maximum torque range. This also means that the maximum temperature is reached in this range and NOx emissions are higher. In Figure 7, NOx emissions and engine speed graphics are seen. NOx emissions are lower for all engine speeds in case of 75/25 fuel. The decrease in NOx emission is 10 – 36 %. NOx emission reaches a maximum at the maximum torque speed. It is 1492 rpm with No 2 D fuel, whereas 1300 rpm for 75/25 fuel.

**Exhaust gas temperature**

The exhaust gas temperature (EGT) was measured at a distance 1 m away from the engine outlet. The variation of the exhaust gas temperatures of the test fuels were evaluated on a graph. From Fig. 8, it is seen that exhaust gas temperatures are maximum around the maximum torque speeds.

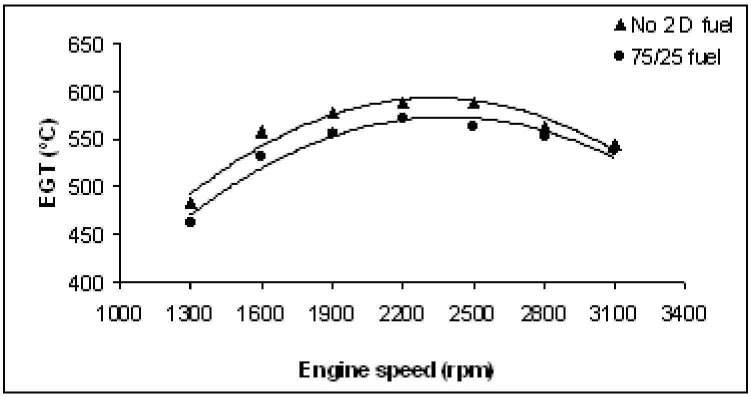

*Figure 8. The variation of the exhaust gas temperature (EGT) with 75/25 fuel and diesel fuel at various engine speeds.*

Exhaust gas outlet temperature is 588°C-483°C and 572°C-462°C for No 2 D and 75/25 fuel respectively. Exhaust gas temperatures of the fuels changes change with the factors such as viscosity, heat capacity and flame velocity during burning. Low viscosity causes poor atomization which leads to the longer ignition times and continuation of burning in the expansion stroke. Consequently, post burning pressure and temperature become lower. At higher engine speeds, spreading of the burning in the exhaust system causes the temperature of the exhaust gases to rise. If the heat capacity of the fuel is high, the energy exerted during combustion gets higher and subsequently the energy of the exhaust gas is higher. The temperatures of exhaust gas at 2200 rpm are 588°C and 572°C for No 2 D fuel and 75/25 fuel respectively.

## CONCLUSIONS

In this study, cottonseed oil methyl ester, produced from the cottonseed oil, was mixed volumetrically 75% with 25% diesel fuel and used as 75/25 fuel in a four-stroke diesel engine in order to determine if it could be used as an alternative fuel. The following results were obtained from the experiments:

1. While the density and viscosity of 75/25 fuel decreased from 0.92 kg/l to 0.88 kg/l and from 34.89 $mm^2/s$ to 4.30 $mm^2/s$ respectively at 26°C, the heat capacity increased from 36700 kJ/kg up to 40763 kJ/kg. SOME produced has more similar properties to No 2 D fuel compared with raw cottonseed oil. Especially viscosity decreased considerably as a result of esterification and mixed with No 2 D.
2. When the engine performance is considered, there were slight decreases in the engine torque and power with respect to No 2 D fuel. These decreases are 2 – 5 %, at maximum torque speed (2200 rpm) and maximum power speed (3100 rpm). The main reason of this decrease is poor atomization or inadequate burning due to the lower heat capacity and high viscosity. In case of 75/25 fuel, specific fuel consumption is higher than No 2 D fuel. The difference is about 3 % for all engine speeds. This is because of the lower heat capacity and higher density of 75/25 fuel.

3. CO2 emissions measured in the experiments with No 2 D fuel were higher than of 75/25 fuel for all the engine speeds. Maximum CO2 emission was measured at the engine speed (2100 rpm) for the maximum engine torque for both fuels. The same results are valid for NOx emission, as well. NOx and CO2 emissions are maximum in the range of maximum burning efficiency. The exhaust gas temperatures are also maximum in the same range. Considering exhaust emissions it can be concluded that 75/25 fuel is superior to No 2 D fuel.
4. Results of performance and exhaust emission sunflower oil methyl ester blend with diesel fuel is presented. CO, CO2, NOx, O2 of the exhaust gas and the exhaust gas temperature are also measured. It is observed that sunflower oil methyl ester blend have great potential as alternative diesel fuel.
5. Vegetable oil methyl ester cuts down on targeted emissions and used in a 20 percent blend with diesel fuel and a catalytic converter will reduce air pollution. Particulate matter is reduced 31 percent, carbon monoxide by 21 percent and total hydrocarbons by 47 percent. Vegetable oil methyl ester used in a blend will also reduce sulfur emissions and aromatics. Using 100% vegetable oil methyl ester further reduces emissions and harmful compounds.

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