Reducing NO$_x$ emissions from tractor engines by using the diesel fuel and rapeseed oil blend

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Abstract. The paper presents the influence of the use of rapeseed oil and diesel mixture on diesel engine performance and pollutant emissions. The main focus of the study is to identify the possibility of using rapeseed oil mixed with diesel at tractor engines. The fuel mix used consists of 50% diesel with cetane number (CC) 51 and 50% refined rapeseed oil. The experimental results have led to the conclusion that, in the case of tractor engines, NO and NO$_x$ emissions can be substantially reduced compared to the situation when diesel fuel is used. Following the experimental determinations carried out and presented in the paper, both in load and idle operation, by using a fuel mixture consisting of diesel and rapeseed oil, a NO$_x$ and NO emission reduction of up to 25% was achieved. Such a reduction in NO and NO$_x$ emissions is important to emphasize precisely because of the fact that at the moment there is still a large number of U650 tractors in agriculture.

1. Introduction

The purity and quality of air is vitally important to the health of the population. Climate change is a global challenge which demands collective action and international cooperation. The main legislative instrument to achieve the 2030 objectives of the Clean Air Programme is Directive 2016/2284/EU on the reduction of national emissions of certain atmospheric pollutants which entered into force on 31 December 2016 [1]. The usage of biofuels is increasing yearly due to their lower environmental impacts compared to fossil fuels. Besides the minimal impact on the environment, the interest in using biofuels has also increased due to the high price of diesel [2]. Today, there are some 6.5 million trucks in circulation throughout the EU and the average age of Europe’s trucks is 12 years [3]. An important sector in which diesel engines are used is agriculture. In recent years, the development of agriculture in Romania has led to the renewal of the agricultural machinery park. However, a very large number of old-generation agricultural machinery, equipped with diesel engines are still used, which has a negative impact on the environment. A possibility to reduce the emissions generated by these engines is the use of rapeseed oil and diesel blends [4]. The physical and chemical properties of biofuels highly depend on the raw materials used for biofuel production and have a significant influence on combustion and emission formation processes [5]. In the EU, biofuel production has largely been focused on biodiesel, and its constituent is chiefly rapeseed oil [6]. Worldwide, there is a tendency to increase the area planted with rape. In the European Union, rapeseed oil represents approximately 77% of the total biodiesel [7]. There are many studies on the use of rapeseed oil and rapeseed oil blends in diesel engines. Thus, the influence of biodiesel properties on engine operating parameters and the amount of pollutant emissions is studied in [8,9]. Qi et al. [10], studied how the use of rapeseed oil
biodiesel fuel blended with conventional diesel fuel influences the combustion and emission characteristics in two-cylinder agricultural diesel engines. Due to the viscosity and high density of crude rapeseed oil, depending on the amount of rapeseed oil in the fuel mixture, modifications to the diesel engine feed system are required [11]. Labeckas et al. [12] investigated the effect of rapeseed oil blending with ethanol on engine performance and exhaust emissions. Thus are presented the testing results of a four stroke, four cylinder, direct injection, unmodified, naturally aspirated diesel engine operating on neat rapeseed oil (RO) and its 2.5 vol% (ERO 2.5) and 7.5 vol% (ERO 7.5) blends with ethanol [12].

2. Equipment used for experimental studies
All the experimental measurements presented in this study were performed on a 4 cylinder, naturally aspirated, water-cooled, D103, four-stroke diesel engine. This diesel engine equips U 650 tractors and has a power output of 65 HP at 1800 rpm. Although they are older generation, U 650 tractors are still widely used in agriculture in Romania. The engine laboratory equipment (Figures 1 and 2) was equipped with a Froude hydraulic brake. The coupling between hydraulic brake and diesel engine is directly, without transmission gear.

Figure 1. The scheme of experimental laboratory equipment.

The elements specified in figure 1 are: 1 – diesel engine D103; 2 - fuel tank; 3 - fuel supply pipe; 4 - three-way valve; 5 - calibrated fuel consumption measurement; 6 - electronic weighing; 7 - flue gas outlet pipe; 8 - expansion tank for coolant; 9 - oil cooler; 10 - coolant cooler; 11 - fuel filter battery; 12 - injection pump with speed regulator; 13 - fuel pump; 14 - cooling liquid pump; 15 - hydraulic brake; 16 - coupling; 17 - signaling and warning panel; 18 - suction air tank; 19 - air filter; 20 - diaphragm used for measuring air flow; 21 - diaphragm used for measuring the flow rate of the coolant.

The fuels used in experimental research was mixture of 50% refined rapeseed oil - 50% diesel fuel and 100% diesel fuel as reference fuel.

In the Table 1 are presented the main physical chemical properties of refined rapeseed oil and diesel fuel.

In the present case, no modifications have been made to the diesel fuel injection system and no equipment has been installed to correct the viscosity of the fuel mixture. The viscosity of the fuel mixture (diesel and refined rapeseed oil at 50%) measured with the Hoppler viscometer was 18.4 mm²/s at 20 °C, about 3.8 times higher than diesel fuel and 3.5 or less than refined rapeseed oil. The values measured with the Hoppler viscometer at 20 °C were for diesel fuel of 4.8 mm²/s respectively for the refined rapeseed oil of 64.5 mm²/s.
Table 1. Physical and chemical properties of refined rapeseed oil and diesel fuel.

| Parameter                        | Rapeseed oil | Diesel fuel |
|----------------------------------|--------------|-------------|
| Kinematic viscosity, 20°C [mm²/s] | 60-72        | 4-6         |
| Lower Calorific value -LCV [ MJ/kg] | 37.4-38      | 41.5-42     |
| Density, 20 °C [kg/dm³]          | 0.91-0.92    | 0.82-0.84   |
| Cetane number                     | 40           | 51          |
| Flash point, [°C]                | 270-321      | 65-80       |
| Freezing point [°C]              | -18…0       | -12…0      |

The amounts nitric oxide NO (%vol), the total emission of nitrogen oxides NOₓ (%vol) and the residual content of oxygen O₂(vol%) in the exhausts were measured with the Multilyzer STx gas analyser. The measurement of the flue gas temperature was carried out on the exhaust pipe at a distance of about 1.5 [m] from the engine exhaust manifold, that is to say, at a distance similar to the displacement of the U650 on the exhaust of the tractor engine.

3. Experimental determinations and results

There was a significant reduction in the effective engine power at loads greater than 0.75. According to the results presented in figure 3 the reduction is between (6-20)%, the higher values being at the full load and close to the nominal speed, and the lower values at lower loads and revolutions ranging between (1200-1700) rpm.

The reduction in power is mainly due to the lower calorific value of the fuel mixture by about (8-12)%, but this can be accepted under conditions where a reduction in pollutant emissions is found when using the indicated fuel mixture, considering that most of the time of use, we do not exceed 0.8 of the full load.

For the idle regimes, there is a clear NO and NOₓ emission reduction, which is a positive aspect, especially that it will also be confirmed in the case of medium and high load operation. NO and NOₓ emissions are reduced by (10-20)% for idling, with higher cuts at lower engine speeds, according to the variations shown in Figure 4 and 5.
For load performance, at least for loads ranging from 0.6 to 0.9, the NO and NO$_x$ emission reduction is noteworthy and it ranges from 8 to 25%, with higher values for loads of 0.6-0.7 and lower values at loads above 0.8, as shown in figure 6 and figure 7.
Figure 5. Emissions of NO\textsubscript{x} for idling regimes

Figure 6. Emissions of NO depend on load and rotation.
Figure 7. Emissions of NO\textsubscript{x} depend of load and rotation.

Figure 8. The temperature of the exhaust gases depends of load and rotation.
Figure 9. Oxygen in the exhaust gases depends on load and rotation.

This reduction of NO and NO\textsubscript{x} emissions occurs even when the exhaust gas temperature is slightly increased by up to 10\% (especially at lower loads), as shown in figure 8, as the combustion moves to detention, the mixture has the cetane number diminished as compared to classic diesel. There would certainly be a reduction in the temperature of the gas in the situation of increasing the injection advance when using the fuel mixture and possibly a further reduction of the pollutant emissions with this, which will be verified in the framework of extensive experimental determinations.

In principle, the use of the fuel mixture increases the amount of O\textsubscript{2} in the flue gas due to the presence of the oxygenated compounds in the rapeseed oil, the amount of O\textsubscript{2} in the combustion gases being anyway higher at partial loads regardless of the type of fuel according to Figure 9.

In constant load and variable speed regimes, the major influence on NO and NO\textsubscript{x} emissions reduction with the increase in engine speed is the decrease in the amount of O\textsubscript{2} in the combustion gases according to Figure 9.

The experimental results, carried out on the laboratory stand (within the Department of Thermal Systems and Automotive Engineering at the Galati Engineering Faculty) with diesel engine D103, which equips the U650 tractors, led to the following positive results regarding the reduction of the NO and NO\textsubscript{x} emissions in the case of using a fuel mixture made up of diesel oil and refined rapeseed oil in a 50\% ratio, compared to normal diesel fuel with a cetane number of 51:

- for idling regimes, NO and NO\textsubscript{x} emissions are reduced by 10-20\%, with higher cuts at lower engine speeds.
- for operation regimes at average loads of 0.6-0.7, the NO and NO\textsubscript{x} emission reduction reaches 20-25\% and drops to 8-10\% at loads above 0.8.
- taking into account the price of refined rapeseed oil of about 0.9 Euro/litre compared to that of diesel fuel which is of 1.24 Euro/litre, the authors recommend the use of this fuel mixture consisting of 50\% diesel with CC 51 and 50\% refined rape seed oil, as there was no noticeable
decrease in power in the average 0.6-0.8 load range, which was most frequently encountered in operation.

- in constant speed and variable load modes, the increase in the gas temperature has a major influence on the increase in NO and NO\textsubscript{x} emissions with increasing engine load.
- for constant load and variable speed regimes, a major influence on the NO and NO\textsubscript{x} emissions reduction with increasing engine speed has the decrease of O\textsubscript{2} in the flue gas.
- regardless of the type of fuel used, 100% diesel or mixed fuel with 50% refined rapeseed oil, according to experimental results it is recommended that at loads above 0.6 the engine should operate at higher rpm, ie in the range (1500-1800) rpm because the NO and NO\textsubscript{x} emissions will be reduced by up to (10-25)%.

4. Conclusion

Following the experimental determinations carried out and presented in the paper, both in load and idle modes, using a fuel mixture consisting of diesel and refined rapeseed oil in a ratio of 50%, a decrease of up to 25% of NO and NO\textsubscript{x} emissions was noticed, with higher values at loads of 0.6-0.7 and lower values at loads of the engine over 0.8. Such a reduction in NO and NO\textsubscript{x} emissions is important to emphasize precisely because of the fact that at the moment there is still a large number of U650 tractors in Romania's agriculture. At the same time, regardless of the type of fuel used, 100% diesel or 50% rape oil mixture, according to the experimental results, it is recommended that at loads above 0.6 the engine should operate at higher rpm, ie in the range (1500-1800) rpm as NO and NO\textsubscript{x} emissions will be reduced by up to 25%.

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