Measurement of Limited and Unlimited Emissions during Burning of Alternative Fuels in the Tractor's Engines

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Abstract

This text is aimed at the basic analysis of diesel oil and rapeseed methyl ester and evaluation of limited and unlimited emission produced by their combustion. Thereafter, test results are compared, and the evaluation of emission—greenhouse gases, dangerous exhaust gases and strong carcinogens and their contents during fuel combustion—is done. In this chapter, results obtained from the application of biofuel to the machinery working in conditions sensitive to environmental contamination are presented. At present, our environment is excessively overloaded with all kinds of emission, and the idea of using fuel with a marginal impact on the environment is very important. Based on the evaluation of emission, it can be stated that it is very important to study not only limited but also unlimited emission that can be very dangerous, although in this work it was discovered that values of unlimited emission do not exceed the lethal limit.

Keywords: alternative fuels, exhaust, internal combustion engine, tractor, limited emissions, unlimited emissions

1. Introduction

Developments in the field of technology also bring with their positive impact and increased quality of life undesirable side effects. One of the severe adverse effects of scientific and technical progress is environmental pollution [1–3]. We can now witness the producers' efforts to increase the ecological safety taking place as early as in the combustion engine development for motor vehicles. As a result, vehicles are equipped with exhaust systems supplemented with exhaust gas treatment equipment. Engine developers and producers can also utilize alternative fuels (CNG, LPG, E85, biodiesel) as an energy source for vehicles, as well as transition to hybrid propulsion (combustion and electric motor) and introduction of fuel cells. The authors Vitázek et al. deal with gas emissions resulting from the combustion of biofuels in the environment [4, 5].

With regard to the need for limiting air pollution by combustion engine exhaust gases, the maximum production of pollutants in exhaust gas emissions of all motor vehicles is legally limited. From a legislative point of view are limited emissions of CO, hydrocarbons, volatile organic HC compounds, suspended PM, and NOx oxides. Engine emissions contain hundreds of chemicals with different concentrations, the biological properties (impact on human health) of which have not been exactly determined to date. Combustion engines are responsible for more than 70% of global CO emissions production and 19% of global CO_2 emissions production [6]. In addition to the products of perfect combustion—i.e., CO_2, H_2O, excess oxygen, excess nitrogen—which represent the majority of exhaust products, a wide range of other gases and solids may occur, which tend to receive greater attention: CO, non-combusted hydrocarbons (paraffins, olefins, aromatic hydrocarbons), partially combusted hydrocarbon (aldehydes and ketones), degradation products (acetylene, ethylene, hydrogen, soot), nitrogen oxides NOx (NO—nitrogen monoxide, N_2O—dinitrogen monoxide, NO_2—nitrogen dioxide) and solid particulate matter. It is evident from the operation of a compression ignition engine that the increase in smoke opacity leads to an increase in production of pollutants (CO and HC), the measuring of which is difficult in practice, however. It is therefore vital to observe the value of particulate emissions (PM, particulate matter), the measuring of which is much faster and technologically and economically simple, while simultaneously being sufficient for evaluation of technical condition. Compression ignition engines operate narrowly below the smoke opacity threshold during the maximum performance [7].

One of the ways to comply with the stricter emission regulations is to focus on and search for suitable alternative fuels, as suggested by Ulusoy et al. [8], stating that the main plausible alternative fuels used in car transport are ethanol, hydrogen and biodiesel. A large number of studies have shown that biodiesel could serve as an alternative for compression ignition engines, with small or even no requirements for their adjusting [9]. It was also proven that biodiesel has a great potential for decreasing the CO_2, CO, THC (total hydro carbon) emissions and PM (particulate matter) emissions [10, 11]. In conclusion, alternative fuels and their mixtures with diesel fuel are still a subject of research, focusing primarily on reduction of emission arising from their combustion in engine, and also on the transformation of their heat into mechanical energy.

Agriculture is part of nature and the countryside. Ecological agriculture and environmental protection are the world's global interests [12, 13]. There are a lot of negatives on fossil fuels, on which our society is depending to a high degree. One of the most important disadvantages is fouling the air and causing greenhouse effect, which affects weather with regard to temperature [14, 15]. This work deals with a partial alternate use of diesel oil from a renewable fuel—rapeseed methyl ester (RME). An analysis based on limited and unlimited emission detection was performed.

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2. Materials and methods

The measuring standard was an international standard used for non-road engines. According to International Organization for Standardization (ISO), this standard specifies the test cycles for the measurement and evaluation of gaseous and particulate exhaust emission from reciprocating internal combustion engines, and it is applicable to engines for mobile, transportable and stationary use [16–18]. Characteristics of 8-point cycle by ISO 8178–4, C1 are shown in **Figure 1** [20].

The conversion of individual compounds of exhaust gases from ppm to g.kW^{-1} h^{-1}:

$$ZL_i = EVP_{is} \cdot \frac{Mm_i . t_{vps}}{Mm_{vps} . P_e} = EVP_{iv} \cdot \frac{Mm_i . t_{vpv}}{Mm_{vpv} . P_e}, g.kW^{-1}\, h^{-1} \qquad (1)$$

clarity: ZL_i—concentration of contaminant linked with effective power, g.kW^{-1} h^{-1}, $EVP_{is,id}$—emission of exhaust gases (dry—s, moist—v) of compound i, as volume unit share, ppm; M_{mi}—minor mass of compound i, kg.kmol^{-1}; Mm_{vps}—minor mass of exhaust gases (dry), kg.kmol^{-1}; Mm_{vpv}—minor mass of exhaust gases (moist), kg.kmol^{-1}; t_{vps}—mass flow of exhaust gases (dry) kg.h^{-1}; t_{vpv}—mass flow of exhaust gases (moist), kg.h^{-1}. For the first, second and third points of measurements—0.15; for the fourth, fifth, sixth and seventh points—0.1; for the eighth point—0.15; P_e—effective power, kW.

Needed data for conversion from ppm to g.kW^{-1} h^{-1} are listed in **Table 1** [20].

2.1. Measured objects and measured devices

The technical description of both objects measured is specified in **Table 2** and of measured devices is shown in **Table 3** [20].

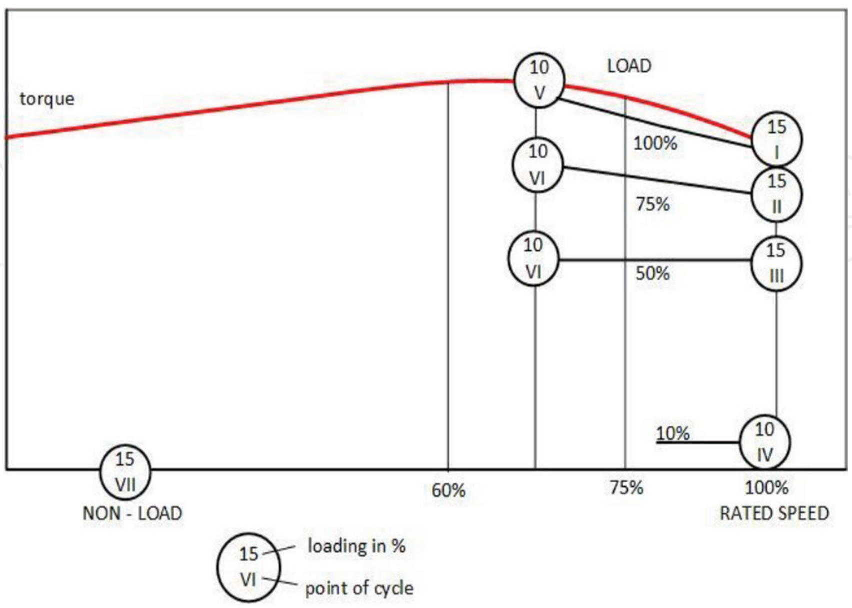

Figure 1. Characteristics of eight-point cycle by ISO 8178–4, C1.

Substance, *i*		Mass ($kg.kmol^{-1}$)	Note
M_{mi}	NO_2	46.0060	NOx process as NO_2
	CO	28.0104	
	HC	13.8760	HC 1
	SO_2	64.0610	
Mm_{vps}	Exhaust gases—dry	30.21/29.84	5% O_2/9.6 O_2
Mm_{vpv}	Exhaust gases—moist	28.84/28.82	5% O_2/9.6 O_2

Table 1. Needed data for conversion from ppm to $g.kW^{-1}\ h^{-1}$.

Tractor 1 (turbocharged)		Tractor 2	
Engine	S. L. H—H 100.4 WT	Engine	Deutz 2012, TCD 2012 L04 2 V
Number of cylinders	4	Number of cylinders	4
Capacity of cylinders	4.00 dm^3	Capacity of cylinders	4.038 dm^3
Cavil/stroke	105 mm/115.5 mm	Cavil/stroke	101 mm/126 mm
Rated revolution	2500 min^{-1}	Rated revolution	2300 min^{-1}
Power	65 kW	Power	72.5 kW
Emission class	Stage I	Emission class	Stage III A

Table 2. Technical data of the tractors.

Device name	Device producer
Dynamometer	Schenck W700
Emission testing system	AVL—SESAM 4 (FTIR)
Fuel consumption	AVL 733S

Table 3. Used measured devices.

3. Results

3.1. Measurement of technical properties of tractors

Measurement was carried out with the use of two fuels. First type was the diesel fuel, which was used as a reference sample for diesel RME comparisons. Measurements results were evaluated and compared reciprocally. Used measuring devices were connected according to the scheme shown in **Figure 2**. Processed measurement results are shown in **Figure 3**. We can see the appliance connection together with measured parameters. The measurements were repeated three times for both tractors, with each fuel, at full load in accordance to OECD

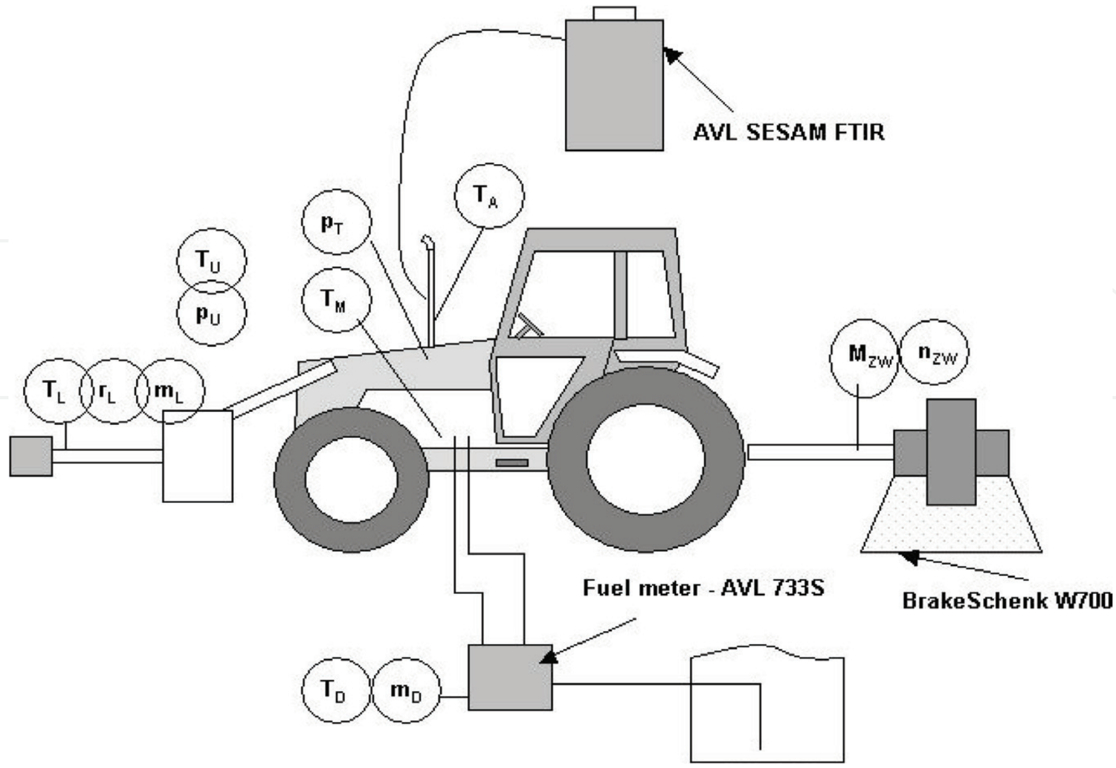

Figure 2. View of test equipment (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra).

Code2 test. Measure points were set at 1000 min^{-1} of PTO revolutions. Based on results curve at full load, the calculation of measure points for emission measurement was processed. These measure points comply with the ISO 8178–4 standard. According to this standard, each measure point lasts for 10 min. Emission test system AVL-SESAMFTIR uses two methods of calculation—diesel and biodiesel. These are set according to the fuel used. The value of smokiness is evaluated at 95% and 70% nominal evolutions and at maximal torque.

3.2. Measurements of limited emission

Measurement of CO, HC, NOx and particulate emissions on both tractors were done according to ISO 8178-4, C_1 - 8 points (**Figures 4** and **5**), [20]. The conversion from *ppm* to $g.kW^{-1}\,h^{-1}$ was made by pattern (1) using the values from **Table 1**. In **Table 4**, there are figured standard deviations from three repetitions. The graphic description of limited emission is represented in **Figures 6–11**.

Based on measured values of limited emission, average value by the next pattern was calculated:

- the average value of sign in a subgroup [19]:

$$\overline{x}_i = \frac{1}{n} \tag{2}$$

clarity: *i = 1,2,...., k* and *j = 1,2,....n.*

- the standard deviation in a subgroup [19]:

$$s_i = \sqrt{\frac{1}{n-1} \sum_{j=1}^{n} x_{ij}} \quad (3)$$

clarity: $i = 1,2,...,k$ and $j = 1,2,..., n$; i—marking of a subgroup; j—numerical order of measured value in a subgroup, n—range of subgroup, X_{ij}—measured value in a i–subgroup.

- the average value X:

$$\overline{\overline{x}} = \frac{1}{k} \quad (4)$$

- the average of standard deviations of individual subgroups [19]:

$$\overline{s} = \frac{1}{k} \quad (5)$$

Based on the patterns above, the standard deviations of limited emission measured on Tractor 1 with turbo and Tractor 2 were determined. The standard deviations of individual emissions

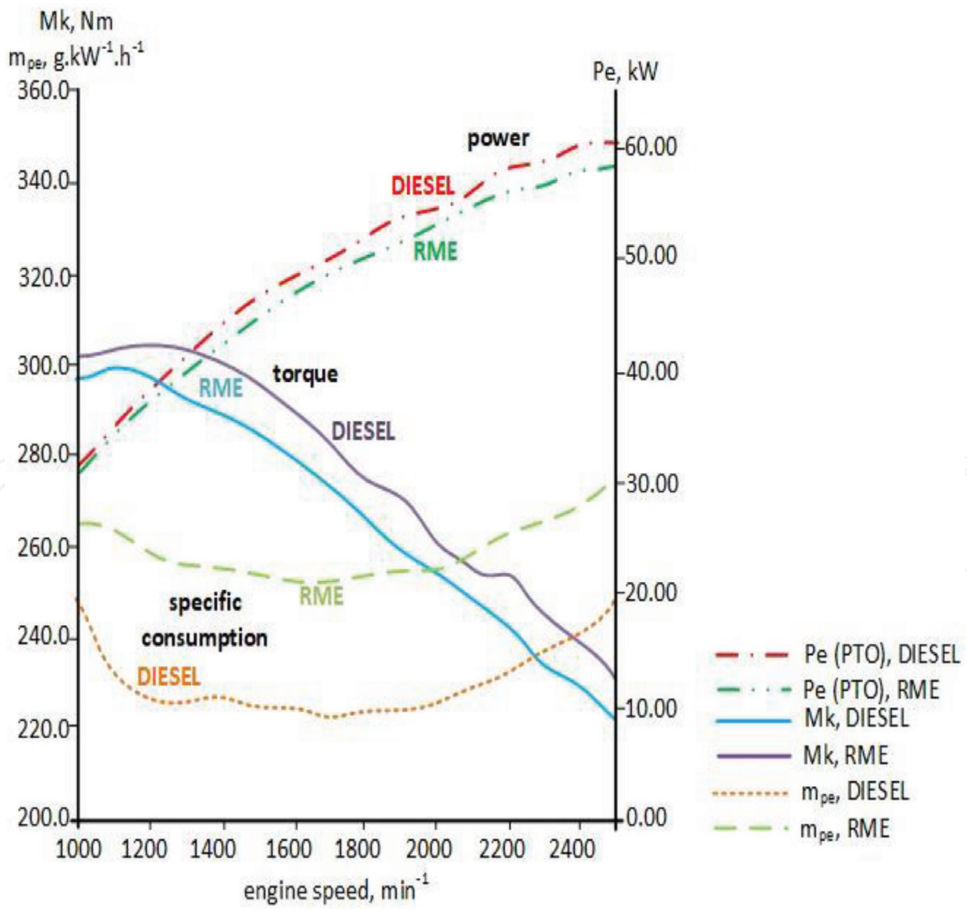

Figure 3. Engine-speed map of Tractor 1 (turbocharged) with fuels—diesel and biofuel RME (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra).

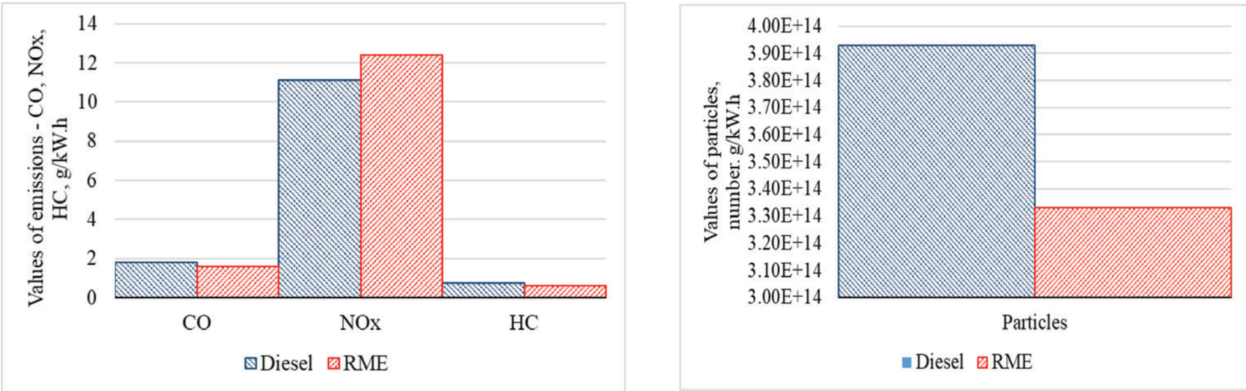

Figure 4. Values of limited emission for Tractor 1 (turbocharged).

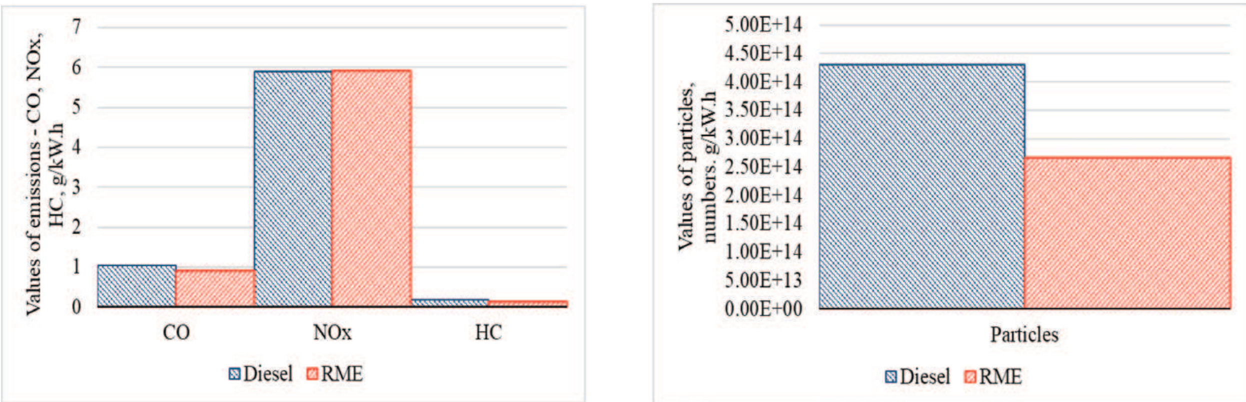

Figure 5. Values of limited emission for Tractor 2.

	CO	NOx	HC	Particles
	(g.kW^{-1}.h^{-1})			(Number. kW^{-1}.h^{-1})
Tractor 1 (turbocharged)				
Diesel	1.80	11.13	0.77	3.93E + 14
RME	1.61	12.42	0.60	3.33E + 14
Tractor 2				
Diesel	1.05	5.90	0.19	4.31E + 14
RME	0.91	5.92	0.13	2.66 + E14

*Average value, based on PTO power.

Table 4. Values of limited emission*.

are demonstrated in **Figures 6–11**. In **Figures 6–11**, reciprocally compared standard deviations of limited emission measured using diesel oil and RME are given [20].

The values of CO and HC and also particle emission are lower for RME as in **Table 4**, but the values of NO_x are lower for diesel oil. It is evident that the newer engine of Tractor 1 decreases

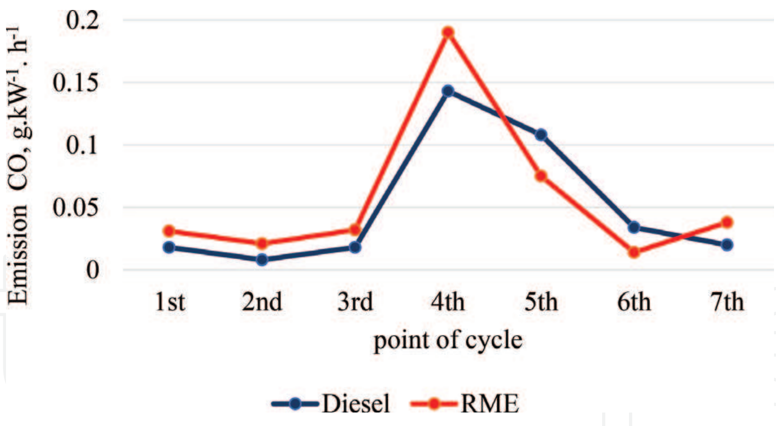

Figure 6. Standard deviation values of limited emission—CO for Tractor 1 (turbocharged) (Müllerová, Landis, Schiess,: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra).

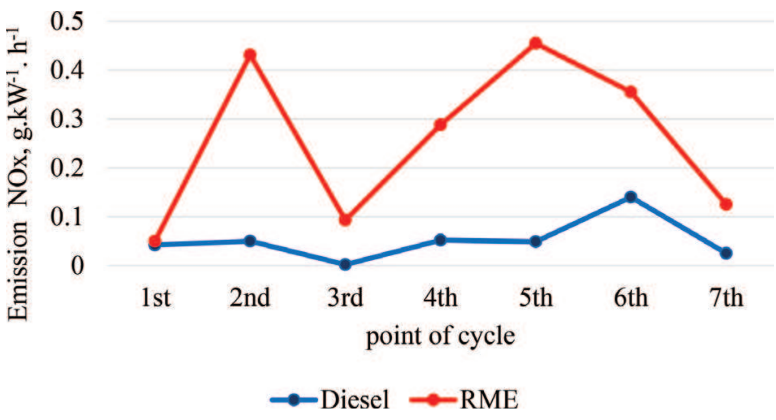

Figure 7. Standard deviation values of limited emission—NOx for Tractor 1 (turbocharged) (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra).

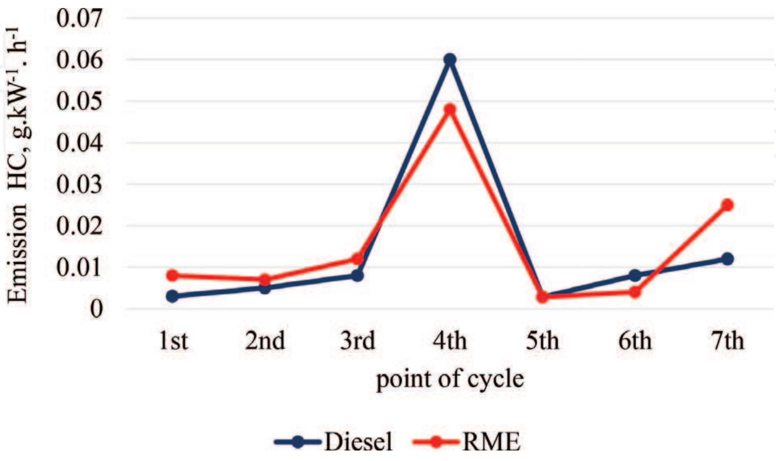

Figure 8. Standard deviation values of limited emission—HC for Tractor 1 (turbocharged) (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra).

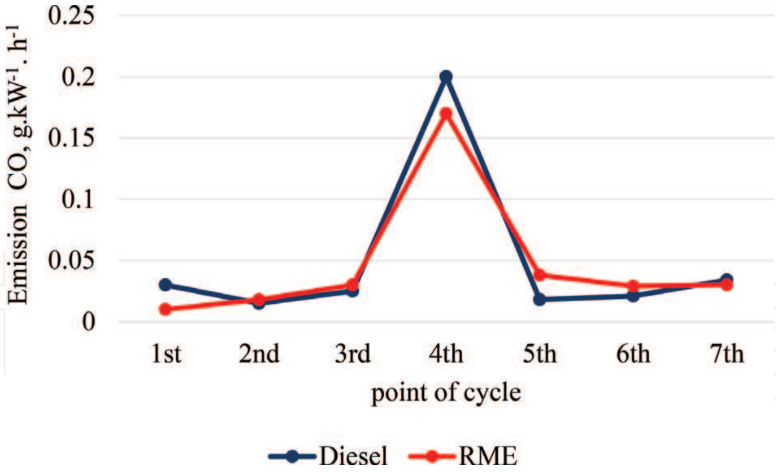

Figure 9. Standard deviation values of limited emission—CO for Tractor 2 (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra).

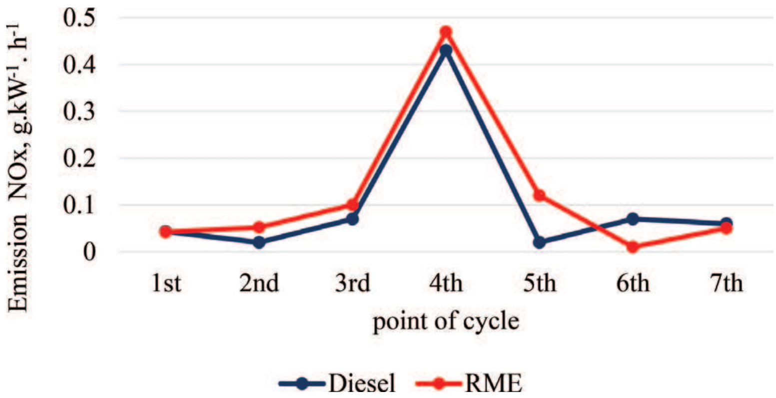

Figure 10. Standard deviation values of limited emission—NOx for Tractor 2 (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra).

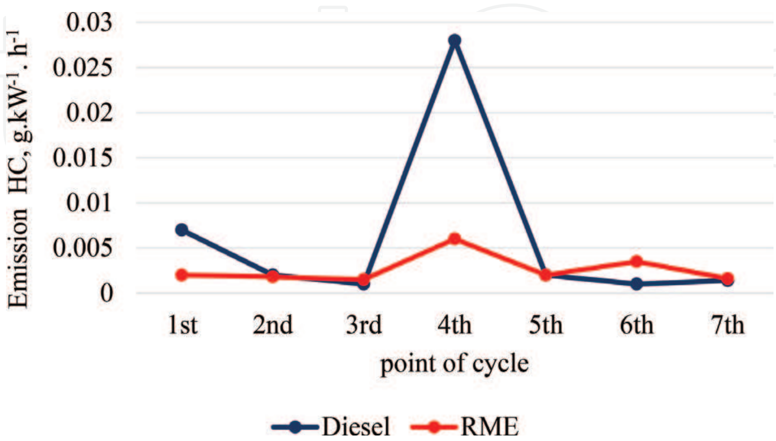

Figure 11. Standard deviation values of limited emission—HC for Tractor 2 (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra).

Tractor 1 turbocharged	CO2	NO	NO2	N2O	NH3	CH4
ppm	Carbon dioxide	Nitric oxide	Nitrogen dioxide	Nitrous oxide	Ammonia	Methane
Diesel	55,867	845	40	0.5	0.13	0.52
RME	56,769	890	43	0.66	0.21	1.27
	C4H6	HCN	AHC	SO2	HCHO	MECHO
	1,3 Butadiene	Hydrogen cyanide	Aromatic HC	Sulfur dioxide	Formaldehyde	Acetaldehyde
Diesel	0.97	0.57	2.1	4.6	8.1	2.7
RME	1.98	0.57	1.19	1.40	9.95	0.57
Tractor 2	**CO2**	**NO**	**NO2**	**N2O**	**NH3**	**CH4**
ppm	**Carbon dioxide**	**Nitric oxide**	**Nitrogen dioxide**	**Nitrous oxide**	**Ammonia**	**Methane**
Diesel	64,426	378	16.9	0.43	0.12	0.1
RME	66,040	431	16.8	0.57	0.13	0.1
	C4H6	**HCN**	**AHC**	**SO2**	**HCHO**	**MECHO**
	1,3 Butadiene	**Hydrogen cyanide**	**Aromatic HC**	**Sulfur dioxide**	**Formaldehyde**	**Acetaldehyde**
Diesel	0.44	0.59	0.77	5.0	2.23	0.49
RME	0.90	0.45	1.19	2.9	2.08	0.73

Table 5. Values of unlimited emission (Müllerová, Landis, Schiess,: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra).

emission significantly. Measured values are based on PTO power, so cannot be evaluated by emission standards for off-road vehicles. If these measurements were done on engine, both tractors will meet the emission norm for CO and HC of RME and diesel. The values of NO_x are higher about 21% for both fuels tested in agricultural Tractor 1 (turbocharged) and about 25% for fuels tested in agricultural Tractor 2.

3.3. Measurements of unlimited emission

Measurements of unlimited emission were also done, which are possible to measure by AVL SESAM FTIR 4—CO_2, NO, NO_2, N_2O, NH_3, CH_4, C_4H_6, HCN, AHC, SO_2, HCHO and MECHO. In **Table 3**, average values from three repetitions for each fuel (diesel oil, RME) are figured. The tractor that used RME had not only higher values of NO_x (NO, NO_2 and N_2O) but also almost 50% higher values of ammonia, methane and 1.3-butadiene, which are considered to be dangerous substances. The newer engine of Tractor 2 had higher values of NO_x, acetaldehyde and 1.3-butadiene for RME but the difference was not so big.

On the other side, lower values with RME for sulfur dioxide and acetaldehyde were obtained for Tractor 1 (turbocharged) and for sulfur dioxide, hydrogen cyanide and formaldehyde for

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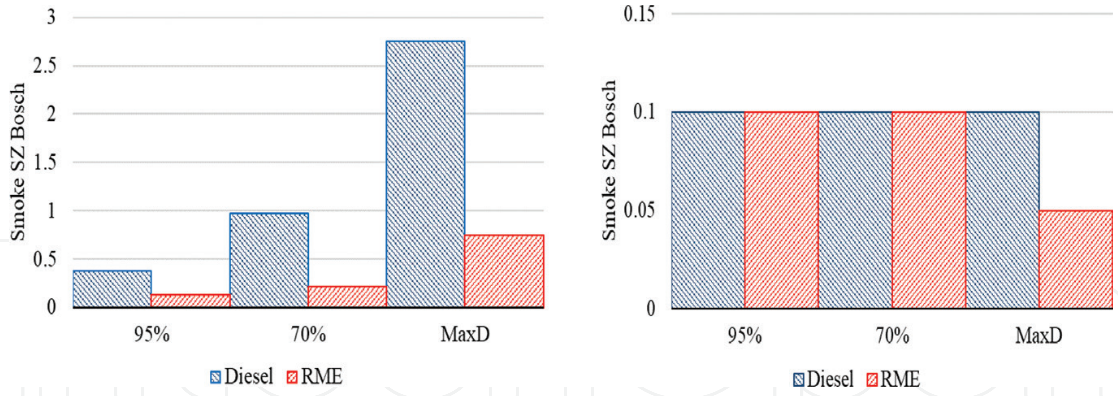

Figure 12. Measurement of smoke (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SPU Nitra).

Tractor 2. Nevertheless, the values of unlimited emission are negligible, except carbon dioxide whose values were higher with RME for both tractors.

Values of unlimited emission are shown in **Table 5**.

3.4. Measurements of emitted smoke

The values of smoke in exhaust gases are usually a lot lower with RME than diesel oil. For Tractor 1 (turbocharged), the value of smoke was more than 50% lower with RME than diesel oil. From **Figure 12**, it is evident that Tractor 2 had much lower value of smoke. These values were near zero and it did not matter whether RME or diesel oil was used.

4. Conclusion

At present, when our environment is overburdened with emissions of all kinds, the idea of using fuels with minimal impact on the environment is of great importance. Fuel produced from methyl ester of vegetable oils can be considered advantageous in that almost every diesel engine is in principle capable of combusting such fuels. Taking into account the fact that up to 90% of the transport of passenger and cargo transport is provided by diesel fuel vehicles (trucks, buses, locomotives, ships, tractors) at the present, fuels made from methyl ester of vegetable oils represent a huge potential for their use in the diesel combustion engines. Very often, the emphasis is on the contribution of fuels of plant origin in terms of creating a carbon balance in nature. The production of carbon dioxide during combustion corresponds to its consumption during photosynthesis. Biodegradability, for example, rapeseed oil methyl ester after its release into the environment, is approximately 95%.

In this chapter, the results reached from application of biofuel to the machinery working in condition that are sensitive to environment contamination are presented. At present, our environment is excessively overloaded with all kinds of emission and the idea of using fuel with marginal impact on environment is very important. It is possible to state that the differences of these two tractors are peculiar to their engines’ construction, the year of production and specification (Tractor 2 is specified as 100% biodiesel). By evaluation of emission (GHG, dangerous exhaust gases and carcinogens) it can be declared that it is very important to study not just limited but also unlimited emissions, which can be very dangerous, although in this work it was discovered that values of unlimited emission do not exceed lethal limits.

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