Research of limited and unlimited emission effect on the environment during the burning of alternative fuels in agricultural tractors

Výskum vplyvu limitovaných a nelimitovaných emisií na životné prostredie pri spaľovaní alternatívnych palív v poľnohospodárskych traktoroch

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Abstract

This work 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 there is also done the evaluation of emission – greenhouse gases, dangerous exhaust gases and strong carcinogens and their contents during fuel combustion. These measurements were performed at the Research Station Agroscope ART in Tänikon (AAT) in Switzerland and in cooperation with the Department of Transport and Handling (DTH), Faculty of Engineering, Slovak University of Agriculture in Nitra.

Keywords: alternative fuels, exhaust, internal combustion engine, tractor

Abstrakt

Príspevok je zameraný na sledovanie, porovnávanie a vyhodnocovanie limitovaných a nelimitovaných emisií produkovaných pri spaľovaní motorovej nafty a metylesteru repkového oleja. Z výsledkov nameraných počas skúšok bolo možné vykonať vyhodnotenie emisií skleníkových plynov, nebezpečných výfukových plynov a silných karcinogénov a stanoviť obsah pri ich spaľovaní v motore traktora. Skúšky boli realizované vo výskumnom centre Agroscope ART Tänikon (AAT) Švajčiarsko v spolupráci s Katedrou dopravy a manipulácie Technickej fakulty Slovenskej poľnohospodárskej univerzity v Nitre.

Kľúčové slová: alternatívne palivá, emisie, spaľovací motor, traktor

Introduction

Agriculture is part of nature and the countryside. The major aim of agriculture is to safely secure the self-sufficiency of a region, save the environment, economically utilize energy sources and the maximum recycling of raw materials. Ecological agriculture and environmental protection are the world´s global interests (Cvíčela et al., 2008; Gábriš, 1998). 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 the greenhouse effect, which affects weather in a matter of temperature (Majdan et al., 2008; Semetko et al., 2003).

This work deals with a partial alternate use of diesel oil from a renewable fuel – rapeseed methyl ester (RME). A solution based on limited and unlimited emission detection was performed.

Materials and Methods

The used 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 (Tkáč et al., 2008; Vlk et al. 2004; Šimor, 2008).

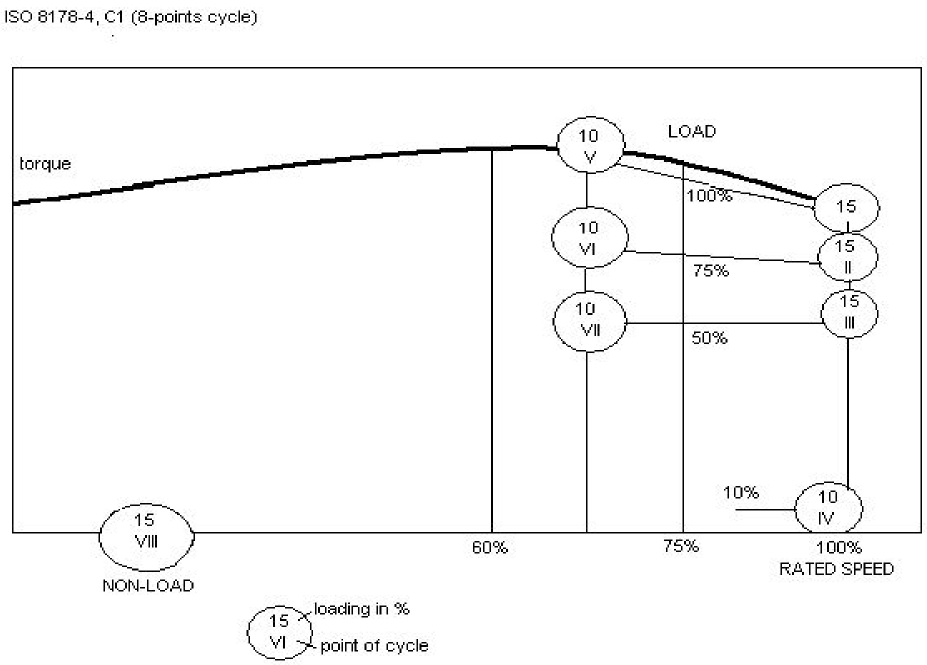

Figure 1: Characteristics of 8-points cycle by ISO 8178-4, C_1

The conversion of individual substances of exhaust gases from ppm to $g*kW^{-1}*h^{-1}$:

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

where:

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 substance i, as volume unit share, ppm

M_{mi} – molar mass of substance i, kg*kmol^{-1}

Mm_{vps} – molar mass of exhaust gases (dry), kg*kmol^{-1}

Mm_{vpv} – molar 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 point of measurements – 0.15, for the fourth, fifth, sixth and seventh point – 0.1, for the eighth point – 0.15.

P_e – effective power, kW

Table 1: Data needed for conversion from ppm to g*kW^{-1}*h^{-1}

Substance, i		Mass, kg*kmol^{-1}	Note
M_{mi}	NO_2	46.0060	NO_x 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

Measured objects

Tractor Hürlimann H-488 DT with the following technical parameters:

Producer: Hürlimann/Same (I.)

Engine: S. L. H - H 100.4 WT

Number of cylinders: 4

Capacity of cylinders: 4,000 cm^3

Cylinder bore/stroke: 105 mm / 115.5 mm

Rated speed: 2,500 min^{-1}

Power: 65 kW

Emission class: Stage I.

Tractor Hürlimann XB Max 100 with the following technical parameters:

Producer: Same-Deutz Fahr

Engine: Deutz 2012, TCD 2012 L04 2V

Number of cylinders: 4

Capacity of cylinders: 4,038 cm^3

Cylinder bore/stroke: 101 mm / 126 mm

Rated speed: 2,300 min^{-1}

Power: 72.5 kW

Emission class: Stage III.A

Figure 2: Hürlimann H-488 DT

Figure 3: Hürlimann XB Max 100

Used measuring devices

Dynamometer Schenck W700 with the following technical parameters:

Measuring of power and torque through the output shaft

Maximal power: 700 kW

Maximal speed: 4,000 min^{-1}

Maximal torque: 4,000 min^{-1}

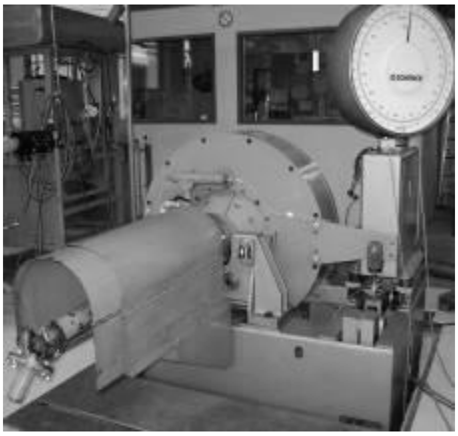

Figure 4: Schenck W700

Figure 5: AVL 733S, consumption (regulation in $kg*h^{-1}$)

Figure 6: Emission testing system AVL – SESAM 4 (FTIR)

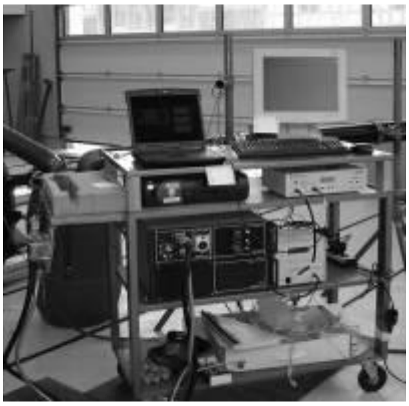

Figure 7: System Matter Engineering with CPS from TSI (particles in number*cm^3)

Results and Discussion

Measurements of limited emission

There were done measurements of limited emission in both tractors, namely CO, HC, NO_x and particle according to the standard ISO 8178-4, C_1 – 8 points (Figure 1). Conversion from ppm to g*kW^{-1}*h^{-1} was made according to Equation (1), by using the values from Table 1. In Table 2, there are figured standard deviations from three repetitions. The graphical representation of limited emission is shown in Figures 8 and 9.

Table 2: Values of limited emission *

Hürliman H-488 DT	CO	NO_x	HC	Particles
	g*kW^{-1}*h^{-1}			number*kW^{-1}*h^{-1}
Diesel	1.80	11.13	0.77	3.93E+14
RME	1.61	12.42	0.60	3.33E+14
Hürliman XB Max 100	CO	NO_x	HC	Particles
	g*kW^{-1}*h^{-1}			number*kW^{-1}*h^{-1}
Diesel	1.05	5.90	0.19	4.31E+14
Engine	0.91	5.92	0.13	2.66+E14

* average value, based on PTO power

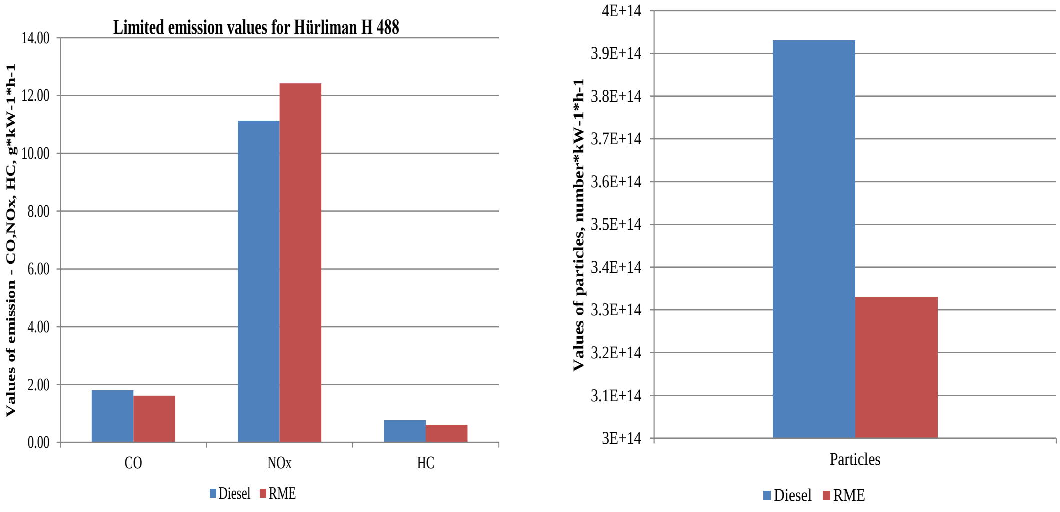

Figure 8: Values of limited emission for the tractor Hürlimann H-488 DT (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra)

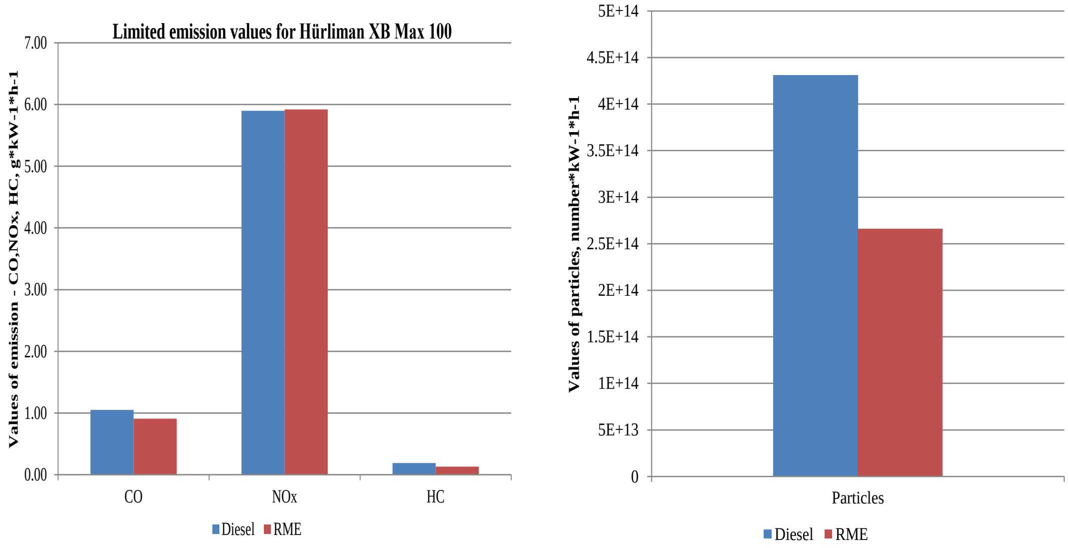

Figure 9: Values of limited emission for the tractor Hürlimann XB Max 100 (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra)

Based on measured values of limited emission, the average value was calculated according to the following equation:

- average value of attribute in a subgroup (Hrubec, 2001):

$$\overline{x}_i = \frac{1}{n} \qquad (2)$$

where: i = 1,2,..., k and j = 1,2,... n

- standard deviation in the subgroup (Hrubec, 2001):

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

where:

i = 1,2,..., k and j = 1,2,..., n

i – marking of subgroup

j – serial number of measured value in the subgroup

n – subgroup size

X_{ij} – measured value in the i-th subgroup

- average value:

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

- average value of standard deviations of individual subgroups (Hrubec, 2001):

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

Based on the equations above, the standard deviations of limited emission measured on the tractors Hürlimann H-488 Turbo and Hürlimann XB Max 100 were determined. Standard deviations of individual emission are demonstrated in Figures 10 and 15.

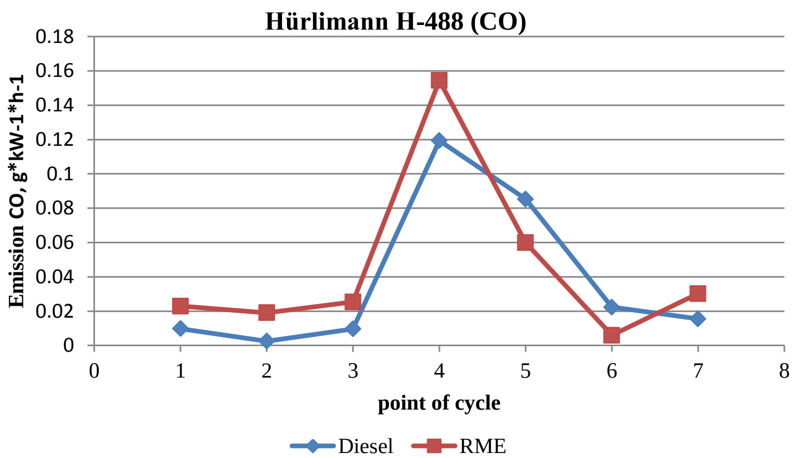

Figure 10: Standard deviation values of limited emission – Hürlimann H-488 (CO) (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra)

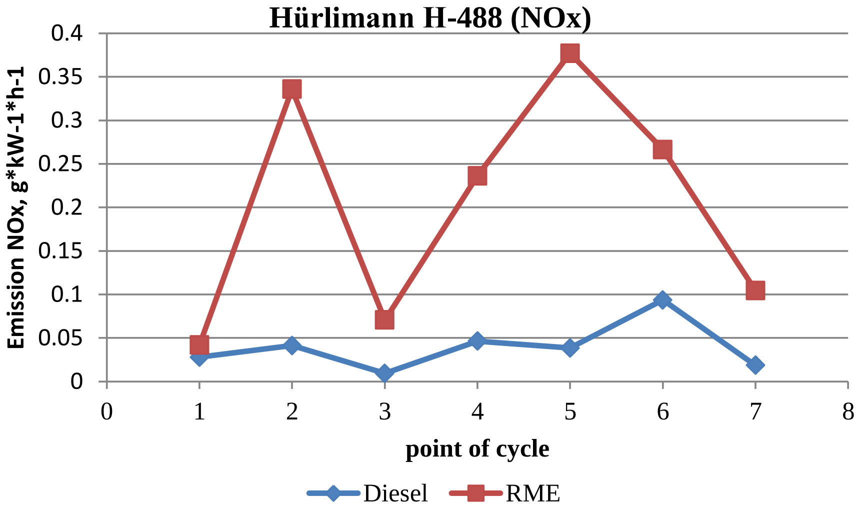

Figure 11: Standard deviation values of limited emission – Hürlimann H-488 (NO_x) (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra)

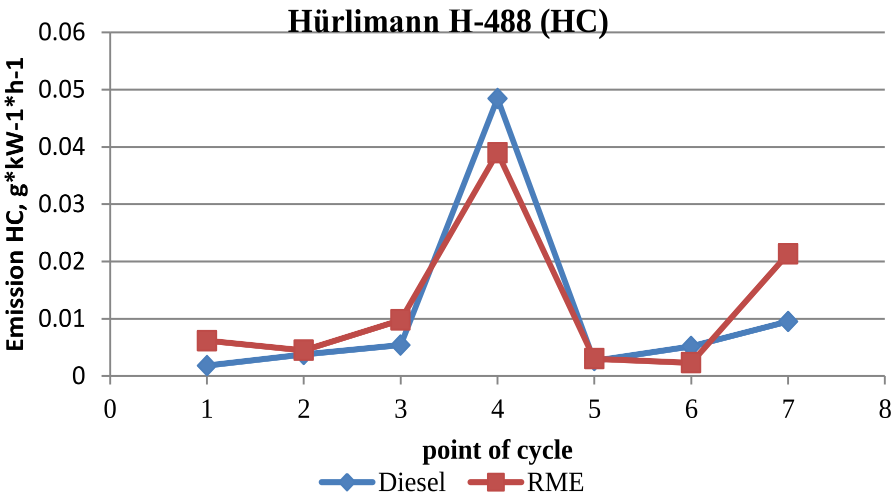

Figure 12: Standard deviation values of limited emission – Hürlimann H-488 (HC) (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra)

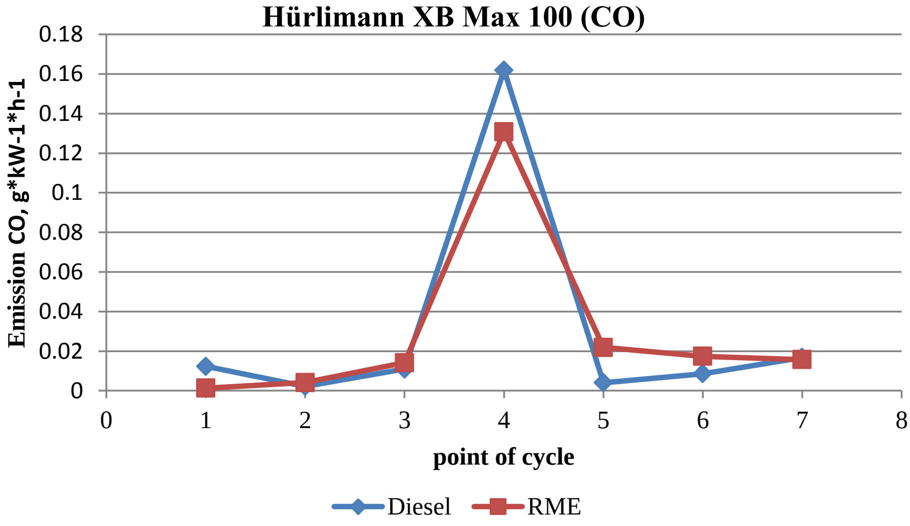

Figure 13: Standard deviation values of limited emission – Hürlimann XB Max (CO) (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra)

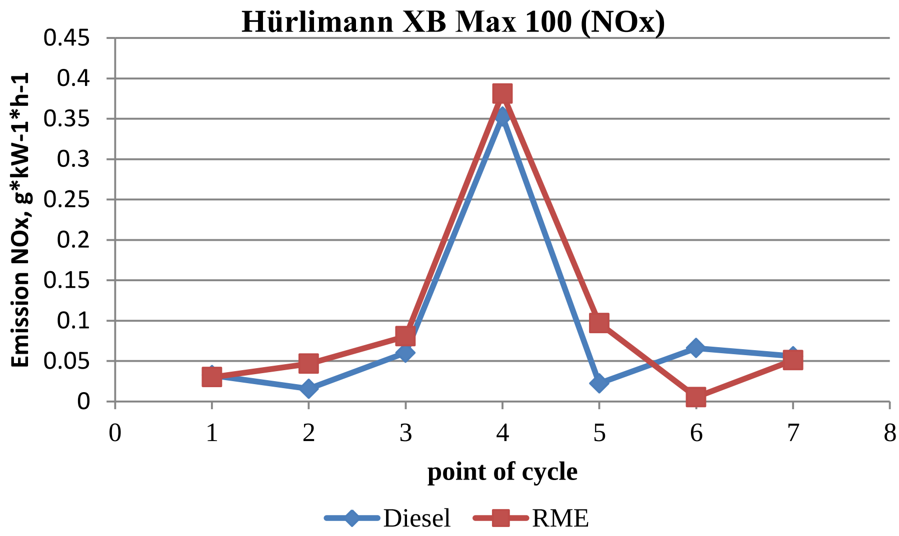

Figure 14: Standard deviation values of limited emission – Hürlimann XB Max (NO) (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra)

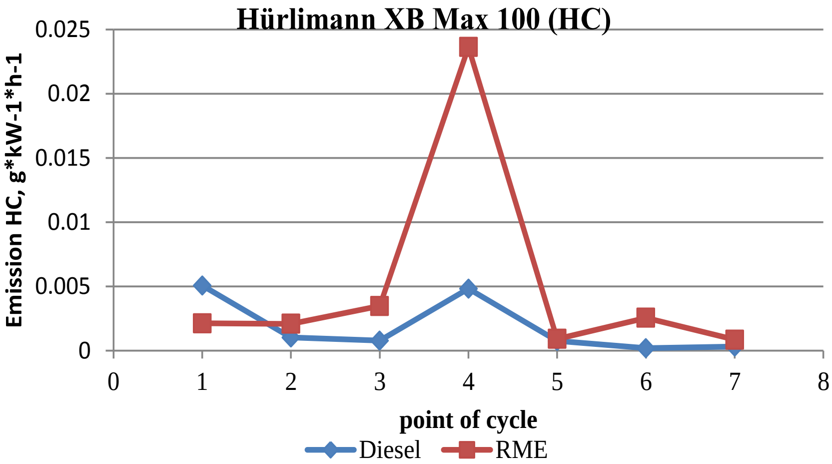

Figure 15: Standard deviation values of limited emission – Hürlimann XB Max (HC) (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra)

The values of CO and HC as well as of particulate matter are lower for RME. However, the values of NO_x are lower for diesel oil. It is evident that a newer engine of Hürlimann XB Max 100 decreases emission significantly. Measured values are based on PTO power and cannot be evaluated by Emission Standards for Off-Road Vehicles. If these measurements were done on the vehicle's engine, both tractors would meet the requirements of standard for CO and HC emission in case of using RME and diesel. For both fuels, the values of NO_x are higher than the values determined by the emission limit by about 21 % in Hürlimann H-488 and by about 25 % in Hürlimann XB Max 100.

Measurements of unlimited emission

There were also done measurements of unlimited emission, which are possible to be measured 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, there are figured average values from three repetitions for each fuel (diesel oil, RME). 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. In the newer tractor Hürlimann XB Max 100, there are higher values of NO_x, acetaldehyde and 1.3-butadiene for RME, but the difference is not so high.

On the other side, lower values are with RME for sulphur dioxide and acetaldehyde for Hürlimann H-488 and for sulphur dioxide, hydrogen cyanide and formaldehyde for Hürlimann XB Max 100. Nevertheless, the values of unlimited emission are negligible, except carbon dioxide where can be seen higher values of RME in both tractors.

Table 3: Values of unlimited emission (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra)

Hürlimann H-488 Turbo	CO_2	NO	NO_2	N_2O	NH_3	CH_4
ppm	carbon dioxide	nitric oxide	nitrogen dioxide	nitrous oxide	ammonia	methane
DIESEL	55867	845	40	0.5	0.13	0.52
RME	56769	890	43	0.66	0.21	1.27
	C_4H_6	HCN	AHC	SO_2	HCHO	MECHO
	1,3 butadiene	hydrogen cyanide	aromatic HC	sulphur dioxide	formaldehyd e	acetaldehyd e
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
Hürlimann XB Max 100	CO_2	NO	NO_2	N_2O	NH_3	CH_4
ppm	carbon dioxide	nitric oxide	nitrogen dioxide	nitrous oxide	ammonia	methane
DIESEL	64426	378	16.9	0.43	0.12	0.1
RME	66040	431	16.8	0.57	0.13	0.1
	C_4H_6	HCN	AHC	SO_2	HCHO	MECHO
	1,3 butadiene	hydrogen cyanide	aromatic HC	sulphur dioxide	formaldehyd e	acetaldehyd e
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

Measurements of emitted smoke

The values of smoke in exhaust gases are usually significantly lower with RME than diesel oil. For the older tractor Hürlimann H-488, the value of smoke was more than 50 % lower with RME than diesel oil. From Figure 16, it is evident that the newer tractor Hürlimann XB Max 100 had much lower value of smoke. These values went near to zero and it does not matter if RME or diesel oil is used.

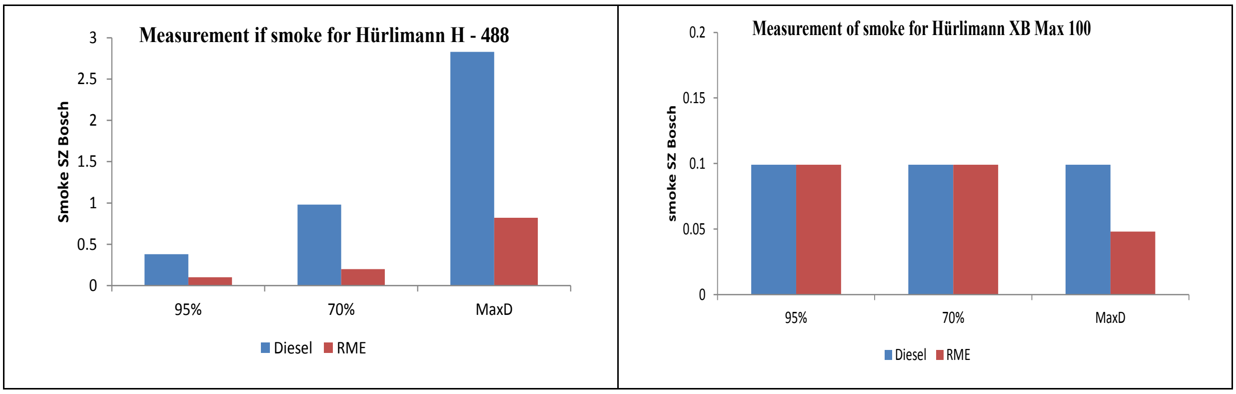

Figure 16: Measurement of smoke (Müllerová, Landis, Schiess: Agroscope Reckenholz-Tänikon Research Station ART and SUA in Nitra)

Conclusion

In this paper, there are presented results obtained from application of biofuel into the machinery working in conditions sensitive to environmental contamination. At present, our environment is excessively overloaded by all kinds of emission and the idea of fuel using with a marginal impact on the environment is very important. It is possible to state that the differences of these two tractors are peculiar to their engines' structure, the year of production and specification (Hürlimann XB Max 100 is specified as 100 % biodiesel). Based on the evaluation of emission (GHG, dangerous exhaust gases and carcinogens), 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, there was discovered that values of unlimited emission do not exceed the lethal limit.

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