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EMISSION OF PARTICULATES AND CHOSEN GASEOUS EXHAUSTS COMPONENTS DURING A DIESEL ENGINE STARTING PROCESS

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ABSTRACT

It is very important to reduce harmful emissions in rural areas. One of the ways is to replace old tractors and farm machinery with the modern, equipped with engines of the highest standards. However, the cost of such replacement is very high and not always acceptable, especially for smaller farmers, nevertheless, due to the needs of sustainable agriculture it should be kept up. This work focuses on exhaust harmful emission during a start-up of a diesel engine installed in a small agricultural tractor. Based on measurements and recorded data, calculations of exhaust gas emission were carried out. The results indicate that the engine starting process, and its initial temperature, have a considerable impact on the emissions during the analyzed operation period. The most important is cold start process which is responsible for most harmful pollutants emission during the initial period of engine work. The temperature of cold start is also noticeable for cold starts and for worm starts as well.

INTRODUCTION

The growing problem of increasing air pollution is more and more the outstanding issue in the agrarian areas. Tractors and agricultural machinery used for the field work and transport purposes constitute one of the emission sources. This paper regards ecological aspect of operating a tractor concerned with its engine start-up and its work right after the start. Engine start-up is especially significant in terms of reliability (Droździel & Krzywonos, 2009). On the other hand it is an extremely hazardous process in terms of emission of toxic substances (Fan, Bian, Lu, Li, & Deng, 2012; Kuranc, 2008; Kuranc & Tarasińska, 2009). Emission of exhaust gases is influenced by a number of construction design-related factors that are also very important operation-related factors (Mysłowski, 1996). Fuel and engine oils as well as engine wear-and-tear (Ambrozik, Ambrozik, & Lagowski, 2015; Wolak & Zając, 2017; Zając & Węgrzyn, 2008) are extremely significant for efficiency of the engine start-up, and in particular for preparation of proper air/fuel mixture as well as airtightness of combustion chamber of a cold engine and minimize resistances during the start-up. A tractor or machinery wear-and-tear as well as its technical advancement related to exhaust gas after treatment methods used for neutralization purposes matter, too (Merkisz, Lijewski, & Walasik, 2010; Sarkan, Stopka, Gnap, & Caban, 2017). Although a successive replacement of agricultural machinery with new and more ecological one has been being observed for several years now, numerous farmsteads still use machinery and equipment that is obsolete in terms of construction (Lorencowicz, 2016; Skudlarski, 2017). URSUS 2812 agricultural tractor, very popular in the 80s and 90s of the 20th century, still manufactured until 2009, is an example of quite simple construction that was examined.

STUDY OBJECTIVE, OBJECT AND SUBJECT MATTER

The aim of the study was to measure the emission of particulate matter and some of the gas components emitted during the engine start-up and right after the start when the engine was idling. For the purpose of the study the instruments such as the MPM4 particulate matter measuring instrument and the MGT5 exhaust gas analyser had been adjusted for continual analysis, and equipped with a computer hardware and software for recording data purposes.

The study covered measurements and analysis as well as track recording of the following parameters:

- engine rotational speed – RPM, (min^{-1}),
- engine oil temperature – T, (°C),
- emission of particulate matter – PM (Particle Matter), ($mg \cdot m^{-3}$),
- volumetric shares of chosen gas components – CO carbon oxide, CO_2 carbon dioxide , O_2 oxygen, (%), and HC unburned hydrocarbons, NO_X nitrogen oxides, (ppm),
- λ air excess coefficient computed by the analyser.

The measurement results were recorded at the frequency of 1Hz.

Next, the emissions of the distinguished exhaust gas components were computed.

METHODS

URSUS 2812 (MF235) agricultural tractor equipped with Perkins AD3.152 self-ignition engine was the object of the study (ZPC URSUS, 1987). Before the study was commenced, the tractor and its engine alongside power supply system, intake system, cooling system, lubrication system, start-up system, and the battery had undergone check-up procedures. Filters and exploitation fluids had been replaced and the injection pump and the fuel injectors had been checked and regulated. After having completed the check-up procedures, the engine load tests were conducted by means of the dynamometer stand to assess whether the condition of the engine was good.

For the purpose of the exhaust gas study, the 5-component gas analyser of „0" class - type MGT5 (MAHA, 1999) was used, additionally measuring the rotational speed and engine oil temperature. The MPM4 particulate matter measuring instrument was aligned with the exhaust gas analyser (MAHA, 2008). The aforementioned instruments, including the PC and dedicated software, made up the measuring-and-recording system. The research stand was located outside the laboratory in order to take advantage of natural temperature conditions.

Within the start-up time limits, engine stabilisation time before start ranges from 6 hours to 12 hours (Mysłowski, 1996). During the aforementioned measurements and analyses, before every measurement for the cold start-up, the tractor had been pre-conditioned in ambient conditions for approximately 20 hours. The temperature of respective parts and exploitation fluids at the moment of the cold start-up was assumed to be equal to the ambient temperature. Measurements during the so called warm start-up were conducted after the measurements for the cold start-up, given the same surrounding, had been completed.

The recorded results in relation to the data on air composition and fuel combustion process formula have allowed to define the composition of exhaust gases for the engine under consideration under the specific conditions. Details on the method of computing the mass volume of emission of respective components had already been elaborated upon (Kuranc, 2015).

RESULTS

Phenomena occurring in the course of starting a combustion engine are complicated and depend on a sequence of factors. The thorough analysis of the impact of the first fuel injection upon emission during the start-up has been presented (Fan et al., 2012). Our analyses refer to a longer period of time. In the Figure 1 the print screen of recorded parameters for the cold start-up in the ambient temperature of 5°C has been presented. Upon the first fuel injections, unburned hydrocarbons (HC), being the proof of misfiring fuel during first cycles of turning the engine shaft, are first to appear. The maximum value of their concentration stands approximately at 55ppm for 5°C. Next we have observed the decrease in the concentration of oxygen (O_2) in exhaust gases and appearance of carbon dioxide (CO_2) and carbon oxide (CO), which is the proof for the combustion process. Carbon oxide alike hydrocarbons prove imperfection of the combustion process and local lack of oxygen. It is evident within seconds after the start-up when its emission volume reaches the peak value of 0.64%. Later on, during the idling, the concentration of CO is stabilised at 0.05%.

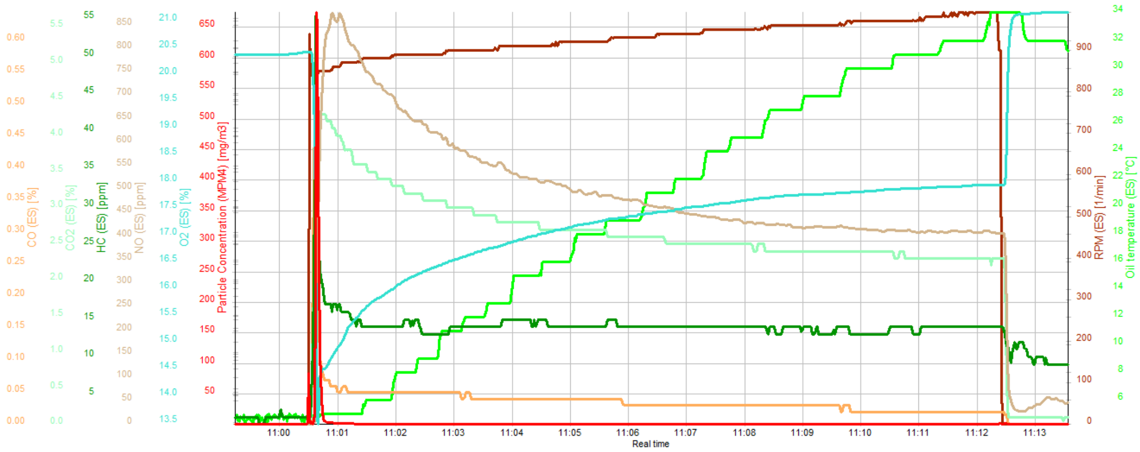

Figure 1. AD3.152 engine fumes composition changes after a cold start at ambient temperature 5°C – software print screen MAHA EmissionViewer Version 1.0.4.380

At the start-up the emission of particulate matter (PM) is also pretty evident and its peak value reaches 670 $mg \cdot m^{-3}$. Emission of PM and observed smokiness mainly result from high temperature deterioration of fuel particles and local unburning and then coagulation and conglomeration of PM. In the absence of external engine load, such a situation is limited to first cycles of operations. In subsequent seconds, PM emission decreases and after a dozen of seconds after having started the engine, its value does not, exceed 10 $mg \cdot m^{-3}$.

In the same period when carbon oxide and particles appear, nitrogen oxides (NOx) appear, too, and prove the combustion since they appear exclusively when there is high pressure and high temperature that accompany the burning process. However, the peak value of NOx emission (approximately 650ppm) is reached approximately 15 seconds later than that for hydrocarbons, carbon oxide or particles. This is caused by a very large influence of low temperature of the cylinder walls that absorb substantial quantity of heat and, in this way, hamper the process of creation of nitrogen oxides. However, their later decrease in concentration may be explained by means of diminishing resistance of motion of the engine being warmed up and thus diminishing fuel dose indispensable for keeping it in motion, which contributes to the decrease in maximum temperature and pressure, responsible for creation of NOx, in the cylinder.

Due to the emission of exhaust gases, it is worth comparing the cold and warm start-up of the engine (Figure 2). In the case of the warm start-up, the period, during which the emission of HC, CO, NOx and PM is higher, is shortened to last for a dozen of seconds. Therefore, the peak values of their concentration multiply. In the case of PM, they are ten times lower.

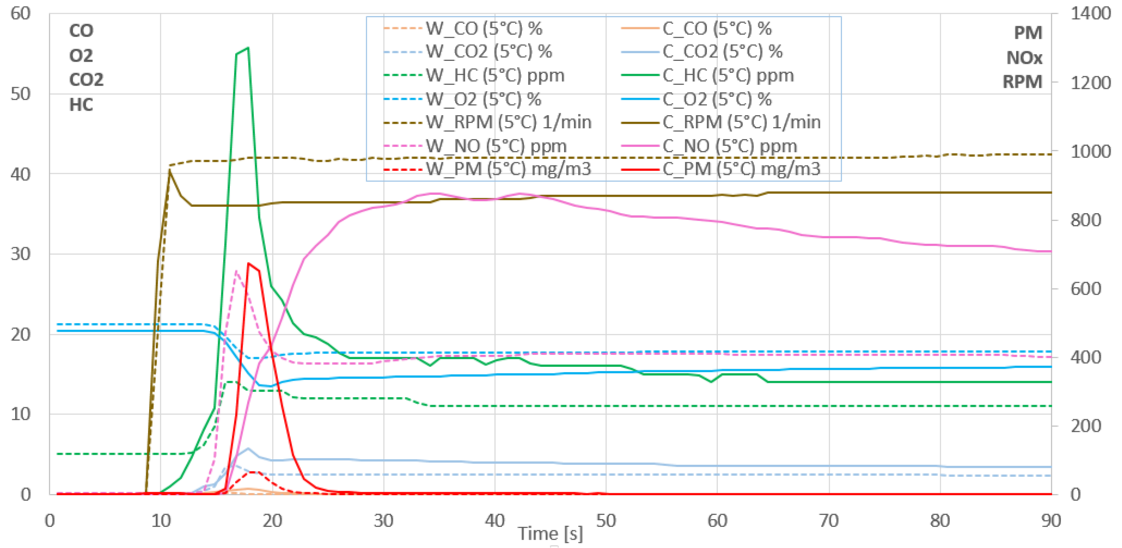

Figure 2. Volumetric shares of chosen fumes compounds at cold (C) and warm (W) startups within the first 90 seconds of work at ambient temperature 5°C for engine AD 3.152

Summing up the emission in the beginning of operations of the engine, the table (Table 1) of mass emission of gas exhaust components for cold and warm start-ups in ambient temperature of 0°C and 5°C has been presented. The table has been drawn up in respect of first 90 seconds following the start-up on the basis of computations referring to the flow of exhaust gases and their composition.

Table 1. Emissions and fuel consumption at cold and warm startups within the first 90 seconds of work at ambient temperatures 0°C i 5°C for engine AD 3.152

	Total	CO_2	O_2	CO	HC	NOx	PM	Fuel
	[kg]	[kg]	[kg]	[g]	[g]	[g]	$[g]*10^{-1}$	$[kg]*10^{-1}$
Cold 0	1.6454	0.0917	0.2967	1.5921	0.1054	1.3992	1.0507	0.2839
Cold 5	1.6453	0.0897	0.2886	1.3141	0.0797	1.4731	0.3751	0.2833
Warm 0	1.4339	0.0544	0.2877	0.4659	0.0454	0.9014	0.0317	0.1664
Warm 5	1.4330	0.0512	0.2888	0.4175	0.0477	0.7247	0.0408	0.1576

The analysis of the figures (Figure 3) indicates that cold start-ups in temperature 0°C and 5°C are similar in terms of emission, which is also the case with warm start-ups. For cold start-ups largest differences may be spotted in the case of emission of particles of 105.07 mg and 37.51 mg (64%), respectively, carbon oxide of 1592.1 mg and 1314.1 mg (17%), respectively, and hydrocarbons of 105.4 mg and 79.7 mg (24%).
In the case of warm start-ups, emission of hazardous substances is much lower than that for cold start-ups. The comparison of warm and cold start-up in temperature of 5°C for

the period of 90 seconds indicates the reduction in the emission of PM by 89%, CO by 68% and HC by 40%, NO_X by 51%.

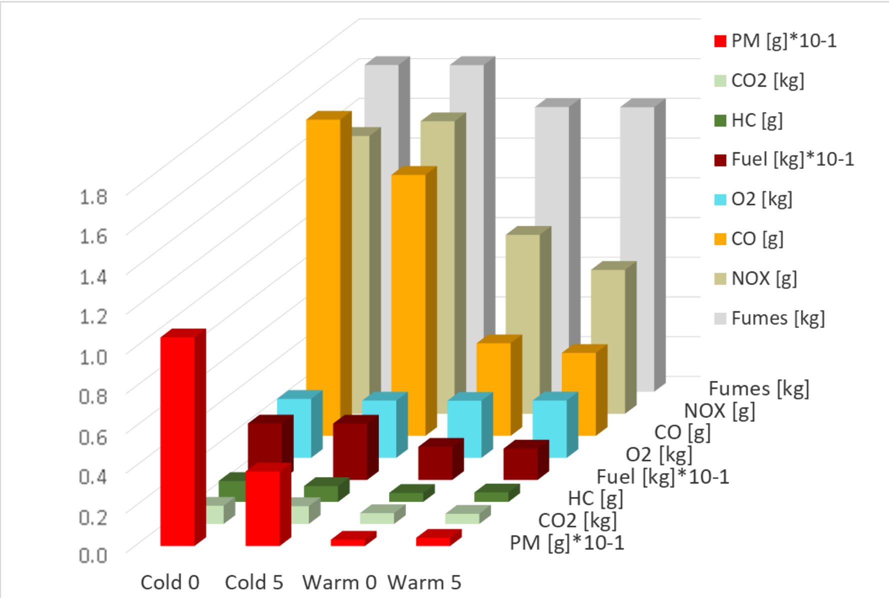

Figure 3. Emissions and fuel consumption at cold and warm startups within the first 90 seconds of work at ambient temperatures 0°C and 5°C for engine AD 3.152

In the case of fuel consumption and emission of carbon dioxide, differences have also been considerable and have amounted to 44% and 43%, respectively.

CONCLUSIONS

On the basis of the results, regarding the composition of exhaust gases during the start-up and the following warming up period, the temperature of the engine at the start-up proves to substantially influence the emission of hazardous components of exhaust gases. As far as the period of 90 seconds is concerned, the differences in the emission for the cold and warm start-up have been extremely evident and have reached the value of 89% for particulate matter, 68% for carbon oxide, 40% for hydrocarbons and 51% for nitrogen oxides.

Due to the higher internal resistance of the cold engine that inter alia results from higher viscosity of lubricant, the start-up process may happen to be a very energy-consuming process (Mysłowski, 1996). In our study the aforementioned cold start has manifested itself by approximately 44% higher fuel consumption and related approximately 43% higher emission of carbon dioxide than the warm one.

The comparison sets of cold start-ups as well as the sets of warm start-ups have not indicated such considerable differences as it has been the case with the comparison of the cold and warm start-up, however such differences also occur and the impact of ambient temperature upon the emission and composition of exhaust gases is evident. Lower temperature of the cold start-up increases the emission of particles, carbon oxide and hydrocarbons whereas it doesn't increase the creation of nitrogen oxides, which can also be observed in this case. In the case of warm start-ups, differences are noticeable, however, they are not that considerable as in the case of cold start-ups.

Taking into consideration the above, it is plausible to aim at reducing the emission and shortening idleness of the engine being warmed up as much as possible and at the same time one should pay attention to the manufacturer's recommendations in respect of the engine load when it is being warmed up.

Another way to reduce harmful emissions in rural areas is to replace old tractors and farm machinery with the new ones equipped with engines of the highest standards. However, the cost of such replacement is very high and is not always acceptable, especially for smaller farms. It is a long-lasting process requiring generations to be done, however, due to the needs of sustainable agriculture it should be kept.

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