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EXHAUST EMISSION FROM COMBAT VEHICLE ENGINES DURING START AND WARM-UP

Summary. The paper presents the results of the investigations of an armored modular vehicle 8x8 Rosomak fitted with a diesel engine during start and warm-up. For the measurements of the toxic compounds a portable SEMTECH DS analyzer by SENSORS was used. The analyzer allowed a measurement of toxic compounds at the same time measuring the mass flow rate of the exhaust gases. The analysis of the PM emission was performed based on the measurement of the size of the particulate matter (analyzer 3090 EEPS – Engine Exhaust Particle Sizer™ Spectrometer – by TSI Incorporated) and counting of the particles (analyzer Particle Counter by AVL).

The measurements of CO, HC, NO_x, PM and fuel consumption have also been carried out under static conditions, during startup and at constant engine speed without engine load. For the measurement of the engine operating conditions and the fuel consumption a diagnostic vehicle system was used. Based on the obtained results an analysis of the operating conditions of the combat vehicle engine in the emission and fuel economy related aspect has been performed.

EMISJA SZKODLIWYCH SKŁADNIKÓW SPALIN Z SILNIKÓW WOZÓW BOJOWYCH PODCZAS ROZRUCHU

Streszczenie. W artykule przedstawiono rezultaty z badań silnika spalinowego wozu bojowego – kołowego transportera opancerzonego 8x8 Rosomak – podczas rozruchu silnika. Do pomiarów stężenia związków toksycznych wykorzystano mobilny analizator do badań toksyczności SEMTECH DS firmy SENSORS. Analizator umożliwiał pomiar stężenia związków szkodliwych, mierząc jednocześnie masowe natężenie spalin. Analizy emisji cząstek stałych dokonano na podstawie pomiaru wielkości cząstek (analizator 3090 EEPS – Engine Exhaust Particle Sizer™ Spectrometer – firmy TSI Incorporated) oraz pomiaru liczby cząstek stałych (analizator Particle Counter firmy AVL).

Wykonano pomiary CO, HC, NO_x oraz PM i pomiary zużycia paliwa w warunkach statycznych, podczas rozruchu silnika oraz przy ustalonej prędkości obrotowej, bez obciążenia silnika. Do pomiarów warunków pracy silnika oraz do uzyskania informacji o zużyciu paliwa wykorzystano diagnostyczną sieć pokładową pojazdu. Na podstawie uzyskanych wyników dokonano analizy warunków pracy silnika pojazdu bojowego w aspekcie emisji spalin i zużycia paliwa.

1. INTRODUCTION

The reduction of fuel consumption in heavy duty vehicles is a frequently analyzed issue by both engine and vehicle manufacturers. Certification tests performed on an engine test bed pertain to the same engine but they do not present any information on the emissions and fuel consumption under real traffic conditions of this vehicle [1]. The tests on the engine emissions of particulate matter and their size distribution are a topic of many scientific publications [3-4, 8-9]. The use of portable exhaust analyzers resulted in a higher interest in the measurement of real traffic conditions of passenger vehicles [6-7]. When it comes to special applications of vehicles (in this case combat vehicles) there are no investigations in this matter. This paper thus, allows the evaluation of the fuel consumption and the determination of the exhaust emissions and PM during start and warm-up.

2. RESEARCH METHODOLOGY

The object of the investigations was an armored vehicle whose basic technical data and its general overview have been shown in Tab. 1. The characteristics of the time density will serve to determine the mean gas mileage of the vehicle. The characteristics will be a substitute for the whole road cycle with several measuring points on the characteristics of the engine operation and will enable the determining of the average gas mileage.

For the measurements of the exhaust emissions a portable SEMTECH DS analyzer by SENSORS (Tab. 2) was used. The analyzer measured CO, HC, NO_x, CO_2 as well as mass exhaust flow rate.

Table 1

Technical data of the engine and vehicle

Parameter	Value	Photo
Engine	Scania DI1249A03P	
Number of cylinders	6/inline	
Rated power	294 kW @ 2100 rpm	
Maximum torque	1688 N·m @ 1500 rpm	
Maximum power – *overboost*	360 kW @ 2100 rpm	
Maximum torque – *overboost*	1974 N·m @ 1500 rpm	
Vehicle mass	22,000 kg	

Table 2

Characteristics of a mobile exhaust analyzer SEMTECH DS [3, 5]

Parameter	Measurement method	Accuracy	Photo
1. Emission CO HC NO_x CO_2 O_2	 NDIR; range 0–10% FID; range 0–10,000 ppm NDUV; range 0–3000 ppm NDIR; range 0–20% electrochemical; range 0–20%	 ±3% of range ±2% of range ±3% of range ±3% of range ±1% of range	
2. Exhaust flow meter	exhaust temperature < 700oC	±1% of range	
3. Response time	T90 < 3 s		
4. Vehicle interface capacity	SAE J1850/SAE J1979/SAE 15765 (LDV) SAE J1708/SAE J1587/SAE 1939 (HDV)		

For the measurement of the particulate matter a portable Particle Counter analyzer by AVL was used whose basic technical data have been presented in Tab. 3.

Table 3

Technical data of AVL Particle Counter [10]

Parameter	Value	Photo
Measuring range	0÷10,000 cm^{-3}	
PNC (t_{90}) rise time	≤ 5 s	
Sample flow rate	1÷5 dm^3/min; adjustable	
Operating temperature	5÷45^oC	
Exhaust temperature (inlet)	< 200^oC	

For the measurement of the size of the particulate matter a portable analyzer 3090 EEPS (*Engine Exhaust Particle Sizer™ Spectrometer*) by TSI Incorporated was used, whose basic technical data have been presented in Tab. 4. The analyzer measured the particle sizes of the tested vehicle on a continuous basis. The measurement of the particle sizes was in the range of 5.6 to 560 nm, with the measuring frequency of 10 Hz. Diluted exhaust gases of a proper temperature were at the same time directed to a particle counter and mass spectrometer. Hence, two quantities were given at the same time – overall particle number and the size distribution in each size range.

Table 4

Specification of a portable analyzer 3090 EEPS by TSI [11]

Parameter	Value	Photo
Particle size range	5.6–560 nm	
Particle size resolution	16 channels per decade	
Electrometer channels	22	
Time resolution	10 Hz	
Sample flow rates	10 dm^3/min	
Sheath air flow rate	40 dm^3/min	
Inlet sample temperature	10–52°C	
Operating temperature	0–40°C	

For the measurement of the engine operating conditions and information on the fuel consumption a vehicle onboard diagnostic system (CAN J1939) was used.

3. GASEOUS AND PARTICULATE MATTER EMISSION FROM THE COMBAT VEHICLE

3.1. Research methodology

The characteristics of the gaseous and PM emission was performed taking the gaseous emission and PM number and their size distribution into account. The measurement of PM aimed at determining of the PM number released at a given point of engine work. The measurements (gaseous and PM emission) were performed with no load on a warmed up engine and steady engine speeds – 1000, 1500 and 2000 rpm. This resulted in graphs of ongoing gaseous and PM number measurements and average values obtained from the measurements with admissible errors overlain (marked as a standard deviation).

The PM size distribution was determined for individual points of engine work. The measurements were performed with no load on a warmed up engine and steady engine speeds – 1000, 1500 and 2000 rpm. The results have been presented as spectrum characteristics of the PM size distribution and the averaged values (during the measurement) of the individual distributions of the PM size (their area, volume and mass). The PM mass was calculated according to the relation that the density of the PM is independent of its characteristic diameter (aerodynamic) and amounts to 1 g/cm^3.

3.2. Emission during engine start and variable engine speeds

A diesel engine cold start is the main reason for high gaseous emission and high mass PM emission. In this paper the results of investigations performed on a warmed up engine have been presented. The CO and HC concentrations are the smallest during the engine start (which results from the exhaust gas flow rate) but almost steady for high engine speeds (Fig. 1a, b). The NO_x concentration is the highest during the start-up but decrease for high engine speed (Fig. 1c). Fuel consumption is the smallest during the start-up but increase for high engine speed (Fig. 1d).

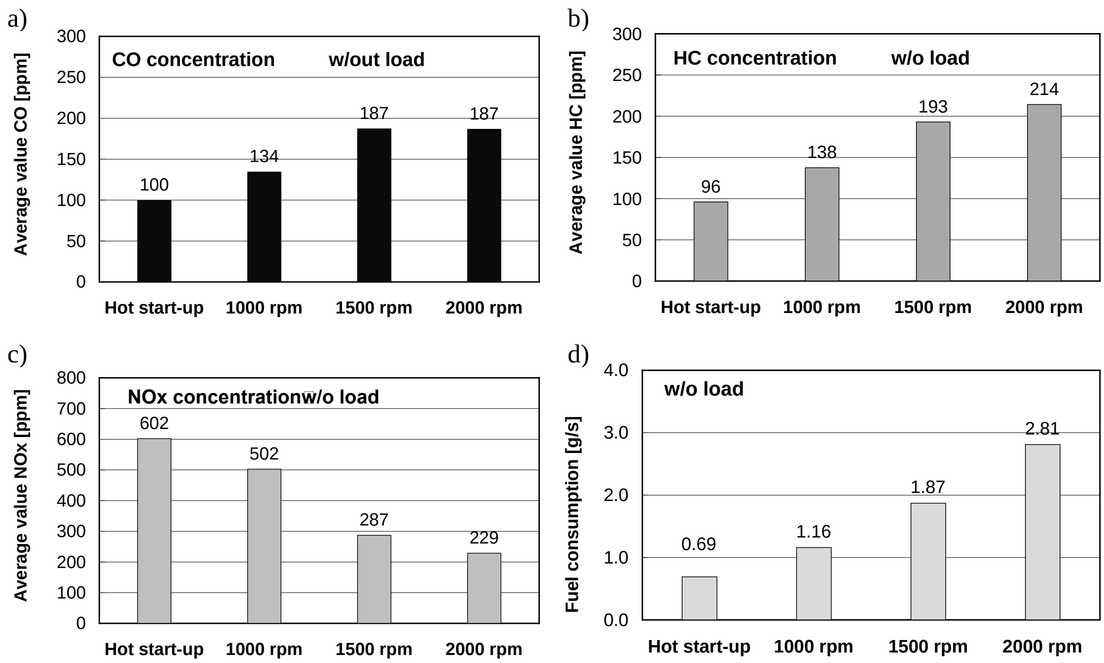
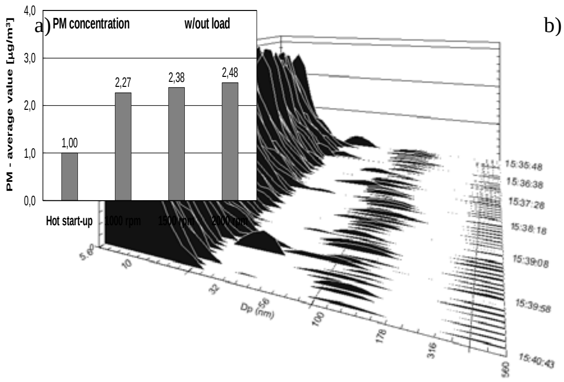


Fig. 1. Average values of emission and fuel consumption: a) CO, b) HC, c) NO_x, d) fuel consumption
Rys. 1. Średnie wartości emisji i zużycia paliwa: a) CO, b) HC, c) NO_x, d) zużycia paliwa

From these investigations the results were that the dominant number of PM falls in the range of 20 nm (Fig. 2a). The PM concentrations are the smallest during the engine start (which results from the exhaust gas flow rate) but almost steady for variable engine speeds (Fig. 2b).

Taking the distributions of PM size into account we should note that changes in the engine operating conditions (from engine start to higher engine speeds) do not result in a change of the PM size distribution. The highest number of PM falls within the size range of approximately 10 nm and amounts to 14,000 cm^{-3}. The influence of the changes in engine speed is noticeable only at n = 2000 rpm: the PM number in the range of 50-100 nm becomes significant (Fig. 3a). The influence of the engine operating conditions on the distribution according to their areas is rather classic i.e. the area grows with the diameter reaching its maximum for PM above 500 nm. Yet, we need to note that as the engine speed grows the PM area (of diameter of 100 nm) begins to grow too (Fig. 3b). Such a high dependence has not been recorded in this size range. The difference between the PM size distribution during engine start and engine speed n = 1000 rpm has not been recorded. In all other cases the growth of the engine speed by 50% (e.g. from 1000 to 1500 rpm) causes the PM area to grow by approximately 160% at a steady diameter in the range of 100 nm. At larger PM diameters the changes do not occur. Much smaller changes occur in the PM volumetric and mass distributions in various engine operating conditions (Fig. 3c-d). Noticeable changes (several per cent) pertain only to PM diameters of 100 nm. In the other ranges no changes in the distributions were recorded at variable engine operating conditions of the armored combat vehicle (Rosomak).

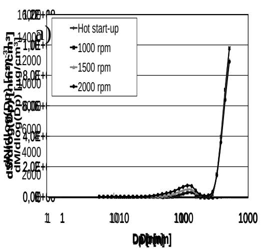
A growth in the exhaust flow rate at higher engine speeds causes a growth in the mass PM emission (Fig. 4a). The PM number grows almost proportionally to the mass PM emission (Fig. 4b).



b)

Fig. 2. PM emission: a) PM size distribution during engine start, b) average densities of PM in various measuring points

Rys. 2. Emisja cząstek stałych: a) rozkład PM podczas rozruchu silnika, b) średnie wartości koncentracji PM w punktach pomiarowych



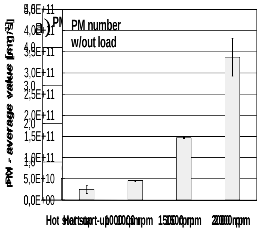
b)

c)

d)

Fig. 3. Distributions of PM size: a) number vs. diameter, b) surface vs. diameter, c) volume vs. diameter, d) mass vs. diameter

Rys. 3. Rozkłady cząstek stałych: a) średnic, b) powierzchni, c) objętości, d) masy



b)

Fig. 4. Average values of PM: a) mass PM emissions in different measuring points, b) values of PM number
Rys. 4. Średnie wartości PM: a) masa cząstek stałych, b) liczba cząstek stałych

4. CONCLUSIONS

A change in the engine speed at small loads significantly influences the concentrations of the exhaust toxic compounds but it does not cause a change in the concentration of the PM (the emission of PM changes though).

The analysis of the PM number in the aspect of changing engine speeds at small loads indicates an occurrence of a maximum PM number of the size of 10 nm for each investigated engine speed.

The characteristics of the PM size distribution indicates an existence of a maximum PM number of a diameter of 100 nm, yet the maximum areas, volume and mass pertain to PM of a diameter of over 500 nm.

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