EXHAUST EMISSIONS MEASUREMENTS FROM NON-ROAD VEHICLES

The paper is a synthetic approach to exhaust emissions from non-road vehicles measured under actual operating conditions and methods of their measurement. The paper outlines the legislation related to the exhaust emissions from non-road vehicles. Example test results under actual operating conditions have been presented and on this basis, conclusions have been formulated as regards the applicable testing procedures.

Keywords: exhaust emissions, non-road engines, PEMS

1. INTRODUCTION

Beside engines applied in road vehicles, a similarly sizeable group are engines fitted in non-road machinery. This group includes Non-Road Mobile Machinery (NRMM). The engines of these vehicles (out of all non-road vehicles) are characterized by specific conditions of operation, which disqualifies them as traction engines. The prevailing representatives of NRMM are: construction machinery, farm tractors and other farm machinery as well as special purpose machinery.

The sales of construction machinery in recent years have outgrown the sales of Heavy Duty Vehicle [1]. Advancement of transport infrastructure and the ever-growing agglomerations lead to an increasing number of sold and operated construction machinery worldwide. A similar situation is observed in the farm machinery market. Development and modernization of agricultural sector is reflected in an increased number of these vehicles. Europe is a good example where, throughout decades, the number of farm tractors grew almost three times [15]. Developing countries such as China, India and East European states also have a significant impact on the number of NRMM vehicles. It is forecasted that this trend will continue in the future [11, 15].

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In light of the above, it is fully justified to take all necessary steps to reduce the exhaust emissions from engines of non-road vehicles. The main problem in the case of NRMM is the emission of particulate matter (PM) and nitrogen oxides (NO\textsubscript{x}). The scale of the problem can be depicted by the situation in Germany where the share of the emission of PM from non-road vehicle engines has been on a steady level of 50% and the share of NO\textsubscript{x} on the level of approx. 15% [10]. When it comes to the application of diesel engines, an important question is their impact on humans and natural environment. In the report published in 2012, IARC (International Agency for Research of Cancer), one of the divisions of WHO (World Health Organization), informed that the exhaust emissions from diesel engines cause cancer [12]. Earlier, diesel exhaust gas was classified to a group of factors that are only probable to cause cancer. Upon analysis of the results of the latest environmental research, the WHO scientists univocally evaluated diesel exhaust gas as a cancer-causing factor [1, 13, 16].

2. NON-ROAD EXHAUST EMISSIONS LEGISLATION

In Europe, the guidelines for the exhaust emissions testing from NRMM are contained in directive 97/68/EC. Later directives [3, 4, 5, 6–8] introduced changes and supplements that resulted mainly from the technological advancement in engine design and an increasing level of unification of global legislation. Hence, the introduced legislation was a joint product of the European Commission and American Environment Protection Agency [17]. The last directive on exhaust emissions from NRMM was published in December 2012 [4]. This directive drew particular attention to the problem of reduction of the emission of NO\textsubscript{x}. This reduction entails the application of SCR systems. An important and noteworthy part of this directive is the statement on the necessity of incorporating legislation based on directive 595/2009/WE (HDV vehicles) in directive 97/68/EC. This statement has been introduced because tests under actual operating conditions had become part of the homologation procedures.

One of the main aims of European directives is to set the admissible limits of exhaust emissions components. Throughout the years, these limits have become increasingly stringent. Despite the fact that the NRMM and HDV vehicles have similar power outputs and similar properties, the admissible limits for the NRMM are greater [17].

The currently world applicable homologation stationary test for non-road vehicle engine applications is ISO 8178 developed by International Standard Organization [17]. This is an 11-phase test performed on an engine dynamometer. On this basis, the average emissions of individual exhaust components are determined. The characteristic share coefficients in each phase of the test are selected based on the application of a given engine [17].
Ever since Stage III limit was introduced, the measurements of NRMM exhaust emissions are also conducted in the NRTC (Non-Road Transient Cycle) test. The ISO 8178 test was renamed to NRSC (Non-Road Stationary Cycle). The NRTC test has been developed in collaboration with the European and American legislative bodies [17].

The U.S. legislation has also introduced limits on the exhaust emissions from non-road vehicles. In accordance with these regulations, NTE (Not-To-Exceed) test was introduced as an additional tool of exhaust emissions control [17]. According to this procedure, the tests are performed under engine actual operating conditions. NTE was initially introduced for HDV vehicle engines. NTE test procedures are not tied to any particular driving cycle or engine work points. The procedure covers a range of engine operation within the zone of control of the NTE test (NTE zone), including stationary and transient conditions [16].

The analysis of the regulations on the exhaust emissions from NRMM allows formulating the following conclusions:

– Exhaust emissions tests are mainly performed under laboratory conditions on engine dynamometers.

– Exhaust emissions procedures (tests) under actual conditions of operation are currently in the implementation stage. Their final form requires more information and experience.

– There are no procedures and tools allowing the evaluation of exhaust emissions from NRMM. It is to be stated that these vehicles during operation are beyond any control in terms of exhaust emissions.

The performed analysis of literature [14] also allows a statement that there are no clear data and information as to what extent the NRSC and NRTC homologation tests reproduce engine actual operating parameters. In light of the above-formulated conclusions, the authors have undertaken to realize a research task to supplement the state of knowledge.

3. THE RESEARCH

3.1. Research methodology and objects

Within the research tasks 24 vehicles from the NRMM group were tested. These were: farm tractors and farm machinery, construction machinery and machines used in forestry. The investigations were conducted under actual conditions of operation. During the tests, exhaust emissions were measured and parameters of engines and vehicles were recorded. An example vehicle has been shown in Fig. 1. The tested vehicles complied with the emission standard of Stage II or higher.

The measurement of the concentrations of exhaust components was performed with the use of Semtech DS by Sensors Inc (Fig. 2). The analyzer allows a meas-
urement of the concentrations of exhaust components and a simultaneous measurement of the mass flow of the exhaust gas along with the engine parameters. All flow of the exhaust gas is directed to the mass flow and a sample of the exhaust gas is fed to the analyzer through a heated line (191 °C). In the analyzer, the exhaust gas is filtered and then concentration of HC is measured in the FID (Flame-Ionization Detector). Later, the exhaust gas is chilled to the temperature of 4 °C and the non-dispersive analyzer utilizing the ultraviolet (NDUV – Non-Dispersive Ultra Violet) measures the concentration of NO\textsubscript{x}. The NDIR (Non-Dispersive Infrared) analyzer utilizing infrared radiation measures the concentration of CO and CO\textsubscript{2}. Together with the data related to the exhaust gas measurement, engine and vehicle parameters are pulled and recorded (engine speed, load, coolant temperature etc.) directly from the vehicle OBD system. That includes the GPS information. For some of the tested vehicles, the use of in-service diagnostic tools was necessary to measure the engine operating parameters. For the measurement of the mass flow of the exhaust gas, mass flow meters integrated with the Semtech DS analyzer were used.

Fig. 1. View of the tested vehicles with the measurement equipment
Exhaust emissions measurements from non-road vehicles

For the measurement of the PM emissions the authors used Semtech LAM (Laser Aerosol Monitor) by Sensors Inc. The analyzer’s principle of operation is based on laser beam dispersion by the particles contained in the exhaust gas. Semtech LAM allows determining real time concentration of the PM in the exhaust gas. It can be used as stationary or portable (actual traffic conditions) equipment. The analyzer’s basic parameters have been presented in the table.

3.2. Results

The analysis of the emission from all the tested vehicles was performed in the entire measurement cycle, i.e. measurements began when the machine started operation and ended when the machine stopped operation. Example results of the relative emission of PM, NO\textsubscript{x}+HC and CO referred to the limits for a given engine have been presented in Fig. 3 and 4. From the figures it results that for all tested vehicles the emission of PM and NO\textsubscript{x}+HC was greater under actual operation than the admissible emission determined in the homologation tests. The only exception was the emission of NO\textsubscript{x} for the forest harvester. The emission of CO from all tested vehicles was lower than the admissible one (Fig. 3).

The engine parameters during actual operation were also subjected to analysis. This analysis was performed mainly in the aspect of engine operating conditions under the NRSC, NRTC and NTE tests. Example analyses for a farm tractor operating in the field have been presented in Fig. 5–7. It is noteworthy that they are representative of all the tested vehicles. As far as the NRSC stationary test is concerned, it was observed that actual engine work points do not converge with those of this test (Fig. 5).
Differences in the engine parameters in the transient test and the test performed under actual operation were also observed. The key parameter for all tested vehicles that differed significantly in the transient test and under actual operation was the engine speed (Fig. 6). For most of the tested engines, the engine speed under actual operation was characterized by a narrower range of changes and their lower frequency.
The points of work recorded during the tests under actual operation were referred to the NTE test. For the farm tractor the engine work area only partly lied in the NTE zone (Fig. 7). The operating time share of the engine in the NTE test was the 37% engine operating time.
4. CONCLUSIONS

The performed tests covering a large group of non-road vehicles justify a formulation of conclusions on the current situation in exhaust emission test procedures. The obtained results and their analysis confirm the imperfections in the applicable methodology. This remark pertains to both laboratory engine tests (NRSC and NRTC tests) and the tests performed under actual operating conditions (NTE test). Currently applicable tests do not reflect the conditions that occur under actual operation of a given group of vehicles. It is thus necessary to introduce changes in the applicable procedures so that they could better reflect the actual engine parameters. Based on the performed tests, it has been observed that the emission of the key diesel exhaust gas components (PM and NOx) under actual operating conditions is much higher than the admissible limits determined in the homologation tests.

REFERENCES

Exhaust emissions measurements from non-road vehicles

Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery.


POMIARY EMISJI ZWIĄZKÓW TOKSYCZNYCH SPALIN
Z SILNIKÓW NON-ROAD

Streszczenie

Artykuł jest syntetycznym ujęciem problemu emisji związków toksycznych spalin z silników o zastosowaniach pozadrogowych w rzeczywistych warunkach eksploatacji oraz metod ich badań. W artykule przedstawiono zarys ustawodawstwa dotyczącego emisji związków toksycznych spalin z silników o zastosowaniach pozadrogowych. Przedstawiono także przykładowe wyniki badań emisji związków toksycznych w rzeczywistych warunkach eksploatacji i na tej podstawie sformułowano wnioski dotyczące obowiązujących procedur badawczych.