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LATEST HARMFUL EXHAUST EMISSION LIMITS FOR NON-ROAD CATEGORY VEHICLES

Non-road vehicles are a large group of machines and a vast majority of them utilize CI engines. This group includes agricultural vehicles, construction machinery, stationary engines, etc. Their regulations are less restrictive compared to vehicles from the HDV category which use similar engine units. For this reason, the Stage V standard will be introduced in 2018, adding reductions in the form of toxic exhaust emissions limits. In addition, retrofitting continues to gain popularity, which means retrofitting older engine designs with more modern exhaust gas after treatment systems. This article reviews also the use of PEMS analyzers to measure the real operation emission.

Keywords: exhaust emission, NRMM, SEMTECH DS, RDE

1. INTRODUCTION

Off-road vehicles are a large group of vehicles using mainly compression ignition engines [Dallmann and Aparna 2016]. These vehicles are not dedicated for use on public roads nor for the transport of people. The engines used in them are usually very similar to those used in HDV vehicles [Merkisz et al. 2016], but the conditions of their operation differ depending on the work for which the machine is designed. In the case of non-road vehicles, the operating conditions are characterized by lower variability primarily in terms of rotational speed. They also have different maximum powers within a single subgroup (Fig. 1).

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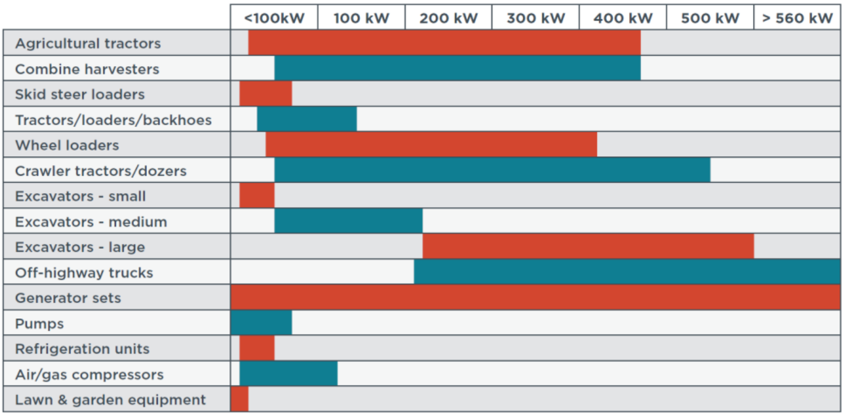

Fig. 1. Range of engine power for various NRMM vehicles [Dallmann and Aparna, 2016]

2. EMISSIVITY EVALUATION PROBLEM

Many modern machines work only within a few load characteristics, where the operator decides on the crankshaft rotation speed depending on the power and torque requirements of the engine from several available values, and then the engine is operating in the load characteristics area. The number of vehicles in the NRMM category is significant, and often the problem is also their age and related technical condition, which is not as often verified as in the case of PC vehicles. [Dallmann and Aparna, 2016] .The same is also true of type approval tests for these vehicle groups. In both cases, this is a stationary test (NRSC for NRMM and WHSC for HDV), and a dynamic test (NRTC and WHTC respectively) (Fig. 2).

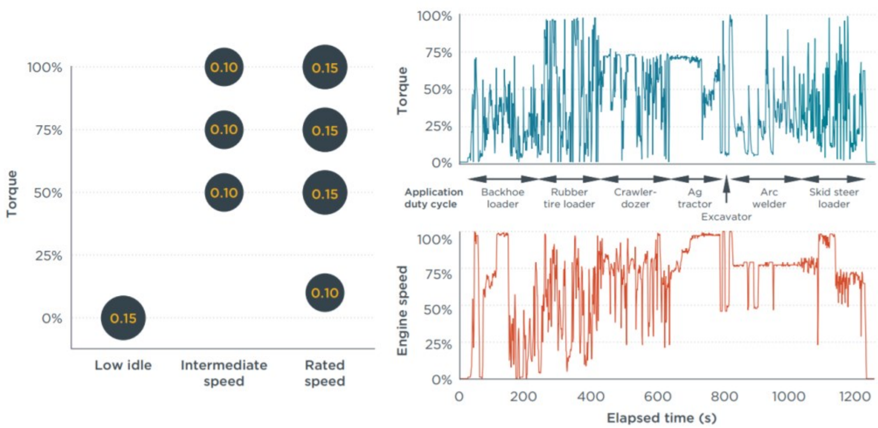

Fig. 2 Type approval tests for NRMM: NRSC and NRTC [European Commission, 2014]

The unit of emissivity is g/kWh, that is, the harmful component weight reference to the unit of energy generated by the engine when operating on the dynamometer. The form of type approval tests has not changed significantly since Stage I [Posada, Yang and Muncrief, 2015]. As has been shown in many scientific papers, these points are not compatible with the actual operating conditions of the vehicle [Lijewski et al., 2017]. These differences also result in other, usually higher values of emissions of harmful compounds to the atmosphere, especially in the case of nitrogen oxides and the mass and number of particles. For example, during field work, the load is approximately constant and varies only with the inclination of the ground and with U-turns [Merkisz et al., 2015], which does not correspond to the NRSC and NRTC tests.

Fig. 3. Example of an electric drive system in an agricultural tractor [John Deere 2016]

At this moment there is no hybrid solution, that is, one that uses a different energy source, usually an electric motor, than an internal combustion engine. These systems result in significant reductions in fuel consumption as well as emissions of harmful compounds in the case of large-scale use of recuperation or recovery braking. Unfortunately, NRMM vehicles either move at low speeds or are stationary and such recovery cannot take place, and the share of recovery itself during idle engine braking results in low energy values with increased mass and complexity caused by electrochemical batteries [John Deere, 2016]. Manufacturers, however, are working on the possibility of using farm vehicles or fully electric vehicles (Fig. 3). The manufacturer determines the battery life at 3100 full charge discharge cycles, but not the capacity. This may change in the future, using modern technologies in batteries by increasing their unit capacity and power.

For the aforementioned reasons, current trends relate to the improvement of the combustion units and the optimization of the operating points so that the engine operates with the highest possible efficiency, i.e. under increased load and avoiding idling. Due to the increasingly stricter emissivity standards and the addition of further constraints (such as the number of particulates in Stage V [European Commission 2014]), vehicle exhaust systems, and more specifically secondary emission reductions, are changing.

3. EMISSION STANDARDS AND METHODS OF EMISSION REDUCTION

The current European standard for off-road vehicles is the Stage IV, which makes the maximum limits dependent on the maximum power of the engine and the engine type (Table 1). The new standard, the Stage V, which will be in effect since 2019, is primarily designed to reduce emission limits with unchanged engine testing. The novelty is the introduction of a limit on the number of solid particles emitted.

Table 1 Emission limits of individual toxic compounds for NRMM depending on power and engine type [EU Regulation, 2016]

Category	Ign.	Net Power	Date	CO	HC	NOx	PM	PN
		kW		*g/kWh*				*1/kWh*
NRE-v/c-1	CI	P < 8	2019	8.00	$7.50^{a,c}$		0.40^{b}	-
NRE-v/c-2	CI	$8 \leq P < 19$	2019	6.60	$7.50^{a,c}$		0.40	-
NRE-v/c-3	CI	$19 \leq P < 37$	2019	5.00	$4.70^{a,c}$		0.015	1×10^{12}
NRE-v/c-4	CI	$37 \leq P < 56$	2019	5.00	$4.70^{a,c}$		0.015	1×10^{12}
NRE-v/c-5	All	$56 \leq P < 130$	2020	5.00	0.19^{c}	0.40	0.015	1×10^{12}
NRE-v/c-6	All	$130 \leq P \leq 560$	2019	3.50	0.19^{c}	0.40	0.015	1×10^{12}
NRE-v/c-7	All	P > 560	2019	3.50	0.19^{d}	3.50	0.045	-

[a] HC+NOx
[b] 0.60 for hand-startable, air-cooled direct injection engines
[c] A = 1.10 for gas engines
[d] A = 6.00 for gas engines

Current technologies used in the construction of internal combustion engines are not sufficient to meet emission limits. To meet their needs new methods of reducing emissions have been developed that work in two ways: reduction of emissions in the cylinder, as well as purification of exhaust gases from the engine. The first of these can include modern injection systems that allow for fuel dispersion and independent of injection from the crankshaft position (Table 2).

It can be seen that the limits depend on the maximum engine power and its type. Engines of lower power have limits at a higher level than the unit of power produced. It should be emphasized that motors with power of over 56 kW have significantly reduced hydrocarbon and nitrogen oxide limits. The emission limit will again increase by more than eight times for motors above 560 kW, the particulate mass may also be three times higher and no particle size limit.

Table 2. A summary of each emissivity method together with a description [Dallmann and Aparna 2016]

Design strategy/ technology	Pollutants targeted	Description
In-cylinder—fuel injection system		
Fuel injection pressure	PM, NO_x, HC, CO	Increased injection pressure promotes fuel atomization and better air and fuel mixing, resulting in improved combustion efficiency.
Rate of fuel injection, multiple injections	NO_x	Fine tuning of fuel injection during single combustion event by varying rate of injection or using multiple injections. Multiple injection strategies require electronically controlled high-pressure unit injectors or common rail injection systems.
Fuel injection timing	Advanced: PM, CO, HC Delayed: NO_x	Advanced or delayed fuel injection to tune combustion process. Advanced timing increases combustion pressures and temperatures resulting in improved fuel efficiency, reduced PM emissions, and increased NO_x formation. Delayed fuel injection timing reduces NO_x emissions at the expense of fuel economy and PM emission penalties.
In-cylinder—air handling technology		
Turbocharger	PM, CO, HC	Compressor used to boost intake air pressure. Wastegated, multiple-stage, and variable geometry turbochargers developed to improve turbocharger performance over a broad range of engine operating conditions.
Charge air cooling	NO_x	Heat exchanger used to lower temperature of gases entering combustion chamber to reduce peak combustion temperatures. Air-to-air systems can achieve lower temperatures and thereby better NO_x control than air-to-water systems.
Exhaust gas circulation (EGR)	NO_x	Portion of exhaust gas mixed with intake air to serve as diluent and reduce peak combustion temperatures. EGR systems used in non-road engines include internal EGR in which residual exhaust is retained within the combustion chamber, and external high pressure loop systems where exhaust gas is routed from upstream of the turbocharger exhaust turbine to the intake manifold. Cooled EGR systems incorporate a cooler to increase system NO_x reduction efficiencies.
Aftertreatment devices		
Diesel oxidation catalyst (DOC)	PM[1], HC, CO	Flow-through catalytic converter composed of a monolith honeycomb substrate coated with a platinum group metal catalyst.
Diesel particulate filter (DPF)	PM	Wall-flow filtration device. Filters are regenerated using active and/or passive regeneration methods to oxidize and remove collected particles.
Selective catalytic reduction (SCR)	NO_x	Catalytic reduction of NO and NO_2 to N_2 and H_2O using ammonia as reducing agent. Catalysts types include vanadium, iron-exchanged zeolite, and copper-exchanged zeolite. Catalysts vary in effective temperature ranges, exhaust NO_2/NO_x sensitivity, and sulfur tolerance. Ammonia is generated from the decomposition of a urea solution, which is referred to as diesel exhaust fluid in the United States and by the brand name AdBlue in Europe.
Ammonia slip catalyst (ASC)	NH_3	Oxidation catalyst used for the control of ammonia passing through the SCR system.

Graphical changes of the limits over the years and the introduction of further norms are shown in Fig. 4. The limits for hydrocarbons and nitrogen oxides as well as particulates are reduced. Limits of these components are today the most difficult to meet when testing internal combustion engines.

These changes are dictated by new research into the effect of particle diameter on human health, which shows that the most dangerous to humans are the smallest particles, a few nanometers in diameter that can pass directly to the lungs. For this reason, it would be very beneficial to evaluate the introduction of a particle number limit, i.e. to limit not only the unit mass but also the diameters.

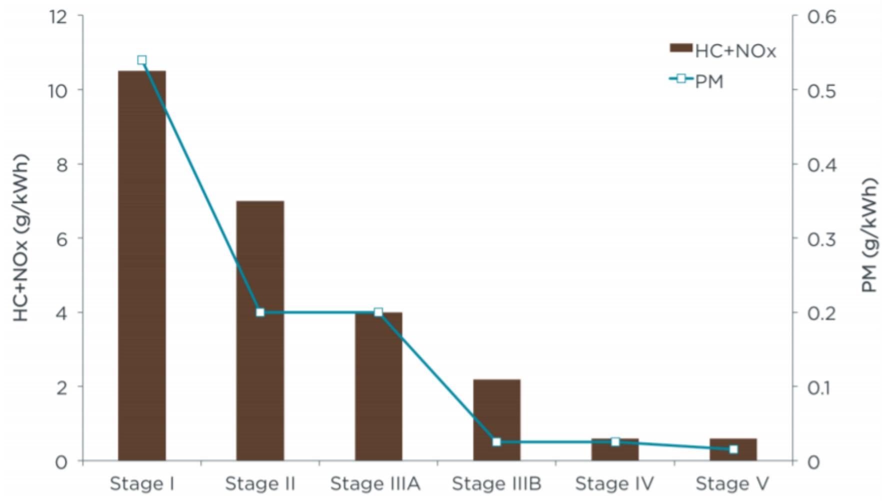

Fig. 4. Change of the specific emissions limit of $NC+NO_x$ and pm depending on the standard [EU Regulation, 2016]

It is possible to gradually reduce the admissible values of compounds such as CO, HC, NO_x, and particulate matter in mass and number. The carbon dioxide emissions directly related to fuel consumption are not limited in any way, and all fuel consumption data comes from the manufacturers themselves.

4. MODERN MEASUREMENT METHODS

Due to the broadly understood digitization and, above all, the miniaturization and reduction of prices of electronic equipment, the measurement possibilities are also changing. One of the possibilities that has developed very strongly in recent years especially for PC vehicles is the use of PEMS equipment. This is a set of mobile exhaust gas analyzers that, in real time through sample analysis, determines the concentration of a particular harmful component contained in the exhaust gases. Intermediate methods are used. utilizing radiation absorption of a given wavelength, acoustic and electrostatic methods. Determining the concentration is not sufficient to assess the impact on the environment, therefore an exhaust gas flow meter is used which allows the measurement of the volume flow rate of the exhaust gases or its mass over time. After multiplying the two values, it is possible to obtain the emission per second result. In order to finally receive the result of the specific emission, the momentary power generated by the engine is required, and this is recorded by the on-board diagnostic system. An example of a farm tractor test using PEMS is shown in Fig. 5.

Fig. 5. Example of using PEMS during farm tractor test

The main problem of this type of research is the placement of PEMS on the vehicle. NRMM vehicles are large in size, but they do not provide space for mounting the equipment. Especially problematic are the harvesters, which are characterized by considerable height and often the assembly of the equipment is impossible due to high-voltage lines above. In the case of agricultural tractors, the use of plastic bodywork is often a problem, which prevents any installment of such a structure outside the designated areas. It should be noted that a set of analyzers with the required wires and power generators is about 150–170 kg. The second problem is the high price of the apparatus. There are not many companies offering this type of device, which, through lack of strong competition, does not reduce the price of devices. Also usage is related to costs such as the calibration process is carried out by means of gas mixtures of strictly defined composition, the cost of which is considerable.

5. CONCLUSIONS

Lawmakers largely focus on limiting the emissivity of toxic components to the atmosphere resulting from the combustion process. Further standards reduce the limits that must be met by ever more perfect engines used in machines. NRMM is a broad group of vehicles whose limits are less restrictive than those of HDV vehicles. The introduction of Stage V in 2019 introduces a limit on the number of permanent constants, which is particularly important for human health. Unfortunately, type approval tests are unchanged, and they have little in common with the actual operation of agricultural and building vehicles. At this moment, the only possibility to check for real emissions is the use of PEMS equipment. In NRMM vehicles it is problematic to mount it, despite the considerable reduction in its size over the years. At this moment there is no possibility of effective use of a hybrid or electrical drive system.

REFERENCES

Dallmann T., Aparna M., 2016, Technology pathways for diesel engines used I non-road vehicles and equipment, International Council on Clean Transportation.

European Commission, 2014, Impact assessment accompanying the document review of Directive 97/68/EC on emissions from engines in non-road mobile machinery in view of establishing a new legislative instrument.

EU Regulation 2016/1628, 2016, of the European Parliament and of the Council of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) No. 1024/2012 and (EU) No. 167/2013, and amending and repealing Directive 97/68/EC (Text with EEA relevance).

Fuc P., Rymaniak L., Ziolkowski A., 2017, The correlation of distribution of PM number emitted under actual conditions of operation by PC and HDV vehicles, Air Pollut t. 21/174, p. 207-213.

John Deere materials, 2006.

Lijewski P., Merkisz J., Fuć P., Ziółkowski A., Rymaniak Ł., Kusiak W., 2017, Fuel consumption and exhaust emissions in the process of mechanized timber extraction and transport, European Journal of Forest Research, No. 136/1, p. 153-160.

Merkisz J., Lijewski P., Fuc P., Siedlecki M., Ziolkowski A., 2016, Development of the methodology of exhaust emissions measurement under RDE (Real Driving Emissions) conditions for non-road mobile machinery (NRMM) vehicles, IOP Conference Series: Materials Science and Engineering, Vol. 148, No. 1.

Merkisz J., Lijewski P., Fuc P., Siedlecki M., Weymann S., 2015, The Use Of The PEMS Equipment For The Assessment Of Farm Fieldwork Energy Consumption, Applied Engineering In Agriculture, Vol. 31, Iss. 6, p. 875-879.

Posada, F., Yang, Z., & Muncrief, R. 2015, Review of current practices and new developments in heavy-duty vehicle inspection and maintenance programs. International Council on Clean Transportation.

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Streszczenie

Pojazdy o zastosowaniu pozadrogowym to szeroka grupa maszyn, w których wykorzystywane są głównie silniki o zapłonie samoczynnym. Należą do niej maszyny rolnicze, budowlane, silniki stacjonarne itp. W porównaniu do pojazdów ciężkich, w których używane są zbliżone konstrukcyjnie silniki spalinowe, przepisy dotyczące ich emisyjności są mniej restrykcyjne. Norma Stage V, która wejdzie w życie z rokiem 2018 ma zmniejszyć ta dysproporcję zmniejszając obowiązujące limity, a także wprowadzając ograniczenie liczby cząstek stałych. Dodatkowo, coraz większą rolę odgrywa retrofitting, czyli doposażanie starszych silników w nowoczesne układy oczyszczania gazów wylotowych, a także badania w rzeczywistych warunkach eksploatacji przy użyciu aparatury z grupy PEMS.

Słowa kluczowe: emisja, pojazdy non-road, przepisy