EKSPLOATACJA I NIEZAWODNOŚĆ
MAINTENANCE AND RELIABILITY

Eksploatacja i Niezawodnosc – Maintenance and Reliability

Volume 23 (2021), Issue 4

journal homepage: http://www.ein.org.pl

Article citation info:
Rymaniak Ł, Merkisz J, Szymlet N, Kamińska M, Weymann S. Use of emission indicators related to CO2 emissions in the ecological assessment of an agricultural tractor. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2021; 23 (4): 605–611, http://doi.org/10.17531/ein.2021.4.2.

Use of emission indicators related to CO_2 emissions in the ecological assessment of an agricultural tractor

Indexed by:
Web of Science Group

Łukasz[a] Rymaniak, Jerzy Merkisz[a], Natalia Szymlet[a], Michalina Kamińska[a], Sylwester Weymann[b]

[a]Poznan Univeristy of Technology, Faculty of Civil and Transport Engineering, Institute of Combustion Engines and Powertrains, ul. Piotrowo 3, 61-138 Poznań, Poland
[b]Łukasiewicz Research Network - Industrial Institute of Agricultural Engineering, ul. Starołęcka 31, 60-963 Poznań, Poland

Highlights

- The dimensionlessness of the emission indicator M, it is possible to compare not only vehicles of the same category, but also of objects of different purposes.
- It is necessary to determine the resistances of the internal combustion engine and take into account their values when determining the torque in tests carried out during the vehicle operation and the work performed by the drive system.
- Increasing the driving speed of the tractor during typical field work from 5 km/h to 15 km/h may have a positive impact on the overall exhaust emission results of toxic compounds.

Abstract

The paper presents the proposed proprietary M exhaust emission indicator, which is based on the assumption that CO_2 emissions are a measure of the correctness of the combustion process. The measurements were performed using a farm tractor meeting the Tier 3 emission norm, operated in real conditions during plowing work. The tests were carried out for a given land section at three speeds In the analysis of test results, the net engine work was used, as it is carried out in the type approval procedures. When measuring in real operating conditions, the torque read from the OBD system is overstated because it takes into account the engine's internal resistance. In the analysis of test results, the fuel consumption, emission indicators of gaseous compounds and particulates were determined, and the best conditions for conducting agricultural works were indicated in terms of their impact on the natural environment. The aim of the work is to verify the possibility of determining the emission index for an off-road vehicle and a comparative analysis of its values for various operating parameters of a farm tractor. On this basis, it was found that the lowest values of the M identity were recorded for the test characterized by a vehicle speed of 15 km/h.

Keywords

agricultural machinery, emission of CO_2, emission indicators, PEMS, RDE.

1. Introduction

Manufacturers of agricultural vehicles and machines equipped with internal combustion engines make continuous efforts to reduce the negative impact of their products on the natural environment. It is required both by the legislative guidelines defined in given areas of the world, as well as by the increasing ecological awareness of the human population [2]. The main disadvantages of modern internal combustion engines include noise emission and emission of toxic compounds into the atmosphere. It should be noted, however, that in relation to combustion engines produced even ten years ago, the emission factors decreased by at least several dozen percent. In parallel, considerations are being made to introduce a reduction in CO_2 emissions, which is equivalent to a reduction in fuel consumption.

Agricultural motor vehicles in different regions of the world/countries have to undergo a number of different type approval procedures, including those related to the exhaust emission of pollutants. In the European Union, non-road vehicles must meet the Stage standards, which categorize the engines in terms of their intended use, power and emission indicators as shown, among others, by in the latest regulation of the European Union [20]. Until now, legislative tests have been performed only for the internal combustion engines themselves on engine laboratory dynamometers. These engines, depending on their intended use, are most often tested in two basic types of tests: static (including the *Non-Road Stationary Cycle* NRSC) and dynamic (including the *Non-Road Transient Cycle* NRTC). Currently, since 2019, guidelines for the monitoring of exhaust emissions of gaseous components during real operation also begin to apply for selected NRMM subgroups, but the final limits are still not fully defined.

In the last 20 years (since 1997), the European Commission has presented 7 Directives which include type approval guidelines for off-road vehicles in terms of exhaust emissions. In 2016, Regulation (EU) 2016/1628 was introduced, which presented new exhaust emission limits for off-road vehicles in the Stage V norm, which has been in force since 2019. This document is the same for all EU Member States, as so far specific additional guidance (e.g. on particle number limits) existed only in some countries. The new document also covers a wider range of combustion engines: less than 19 kW and over 560 kW in power. Figure 1 shows Changes in HC + NOx and PM emission limits for Stage I-V standards for an exemplary group of combustion engines of off-road machines. The presented relationships indicate that the PM limit in the Stage V standard is 97% lower than in the Stage I, and the HC + NOx limit has been reduced by 94%.

E-mail addresses: Ł. Rymaniak - lukasz.rymaniak@put.poznan.pl, J. Merkisz - jerzy.merkisz@put.poznan.pl, N. Szymlet - natalia.r.szymlet@doctorate.put.poznan.pl, M. Kamińska - michalina.kaminska@put.poznan.pl, S. Weymann - weymann@pimr.poznan.pl

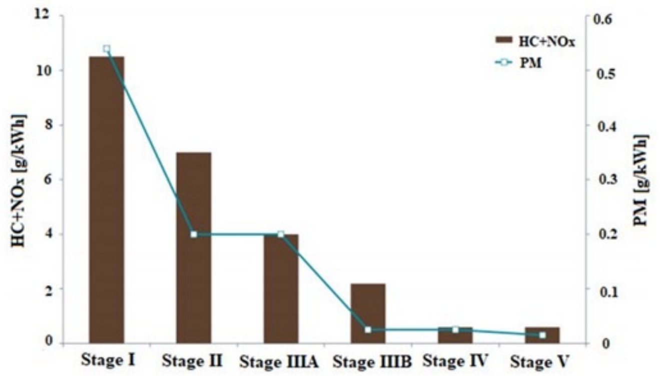


Fig. 1. Exhaust emission limit changes of HC+NO_x and PM for the Stage I–V norms [11]

The development and miniaturization of exhaust measuring equipment belonging to the Portable Emissions Measurement System (*PEMS*) group, which has been progressing in recent years, allows for increasingly more precise tests of the environmental performance of vehicles in real operating conditions to be performed. Currently, these types of testing and research activities are conducted all over the world [1, 3, 4]. They are necessary because, as the studies [12-14] prove, qualitative and quantitative exhaust emission measurements in type-approval tests and in actual operation differ significantly. Road conditions are characterized by an unfavourable effect, primarily on PM and NO_x emissions [9, 10, 21]. Therefore, with Stage V, tests in real operating conditions were to come into force, which have not yet been defined. In terms of particulate emissions, the current limits apply to their mass. Along with the legislative changes, however, limits for the number of particulates are being introduced for the engines of non-road mobile machinery of the NRE category (*Engines for Non-road Mobile Machinery*), as in the case of other passenger and heavy vehicles.

2. Definition of agricultural vehicle emission indicators in relation to CO_2

Agricultural vehicles classified as non-road vehicles are mostly used off public roads in non-urbanized areas. However, due to their overall number, their direct impact on green areas and agricultural crops is significant, as well as on the natural environment. Contemporary agricultural machinery is the result of great technological progress. Currently, their construction uses advanced technologies, safety and comfort systems and non-motor systems that require the use of extensive electronics. This increases the cost of producing the product, but it undoubtedly has a very positive impact on the ecological indicators they currently achieve. Precise control of the fuel supply process enables more efficient use of fuel than in structures based solely on mechanical solutions. This is justified by the fact that in the considered group of machines, despite the increasingly more numerous equipment related to the driver's comfort and greater work efficiency, no significant increase in fuel consumption was observed. All over the world, activities are undertaken by leading scientific and research centers to assess the environmental performance of machines in real operating conditions – in the field. This allows for a broader understanding of the problem of emissivity and allows for the development of new solutions or modification of the existing ones in such a way as to minimize the negative impact of this group of machines on the natural environment as much as possible.

The process of burning fuel in an internal combustion engine is used to generate thermal energy. During its implementation, a number of harmful and toxic chemical compounds are formed. Carbon dioxide CO_2 is produced through complete oxidation. Its emission is not restricted by the current legislative guidelines in terms of a specific vehicle. Existing CO_2 limits in the European Union apply to car manufacturers, but these guidelines take into account the entire range of vehicles produced. The CO_2 emissions of 95 g/km are the average value of the entire model range for each brand. These guidelines were to apply from 2020, but eventually did not enter into force [19]. These types of restrictions apply to passenger cars. Similar ones are introduced for heavy vehicles.

Carbon dioxide is not defined as a toxic exhaust substance, but only as harmful one. It is the main cause of the greenhouse effect and in higher concentrations is poisonous to living organisms. Carbon monoxide CO, hydrocarbons THC and particulates PM (in terms of mass and number) are all formed in the combustion process during partial and incomplete oxidation, while nitrogen oxides NO_x form in the presence of high temperatures. The mentioned combustion products adversely affect the natural environment and it is necessary to introduce solutions limiting their concentration during vehicle operation. They are all undesirable products that significantly contribute to the environmental degradation and pollution.

For working machines, in research works, special units are proposed that refer to the mass of the emitted exhaust component in relation to the work performed (e.g. area of plowed ground, volume of felled tree, etc.). The emission factors developed in this way are sometimes difficult to compare between vehicles (machines), which depends, inter alia, on their intended use, type of drive system used (e.g. hybrid), operating conditions, driving style, etc. For this reason, a new proprietary index was proposed, based on the use of measurements of carbon dioxide parameters (e.g. the emission intensity of this compound, its road or unit emission). The values that are substituted into its structure must be expressed in the same units, which will make it dimensionless.

The physical and chemical processes in the cylinder of an internal combustion engine are complex and very difficult to fully define or simulate. Taking into account the basic combustion equations, it can be assumed that the ratio of CO_2 to the remaining toxic components of the exhaust gas is a measure of the correctness and efficiency of the fuel combustion process. Comparing the emission of toxic compounds with the emission of carbon dioxide, it was proposed to determine the proprietary emission factors M, which characterize a given combustion unit or power unit (if the system will also test non-engine exhaust gas cleaning systems). Such defined ecological indicators allow for the effective comparison of various heat engines with exhaust gas treatment systems. From this perspective, it is a new way to assess the environmental performance of a given vehicle / machine. To achieve this, it is necessary to use the quantitative dimensionless quantitative emission factor M, which is defined by the quotient:

$$M_j = b \cdot \frac{e_{rzecz,\,j}}{e_{CO_2}} \tag{1}$$

where: M – dimensionless emission indicator [–]; j – toxic exhaust component for which the emission indicator was determined; b – universal constant (for CO, THC and $NO_x = 10^3$, for PM = 10^5); $e_{rzecz,\,j}$ – specific emission, road emission or mass of toxic compound j determined during the measurements in the emission test [g/(kW·h); g/(km); g]; e_{CO2} – specific emission, road emission or mass of CO_2 determined during the measurements in the emission test (having the same unit as $e_{rzecz,\,j}$) [g/(kW·h); g/(km); g].

The presence of the constant b allows to increase the readability of the results, because the number of decimal places is limited. This has been confirmed on other vehicles that meet various emission standards [16, 17]. Taking into account the internal combustion engine with non-engine exhaust aftertreatment systems, it is possible to consider the environmental impact of vehicles of various categories, especially in the road or field tests. Due to the dimensionless nature of the used indicator, it is also a good method for defining the exhaust emission of toxic compounds in relation to fuel consumption. Therefore, it is possible to ecologically assess the agricultural tractor (which is the subject of this study) and vehicles of other categories based on the proposed M factor in terms of emission tests obtained both in laboratory tests and in real operating conditions. The proprietary M emission index was presented at the Real Driving Emission conference in Berlin in 2017. The idea was approved by the scientific world and representatives of the European Commission. This confirms that the inclusion of the M index in the assessment of the environmental performance of motor vehicles is justified and is characterized by innovation on a global scale. The research carried out so far has not presented the results of work on such defined issues. Thus, an extensive literature review showed that the only publications on this subject belong to the authors of this work [16, 17]. The dissemination of the indicator presented allows for even more precise definition of the environmental performance of the vehicle / machine.

3. Research method

The subject of the pollutant emissions tests in real operating conditions was an agricultural tractor belonging to the NRMM (*Non-Road Mobile Machinery*) vehicle group. The test vehicle was manufactured in 2007 and thus homologated according to the Stage IIIA/ Tier3 norms. The manufacturer equipped the vehicle with a 6.7-liter compression-ignition engine, with a maximum power of 116 kW. The tractor was equipped with a DPF particulate filter, a DOC oxidizing catalytic converter and an EGR exhaust gas recirculation system. Before the tests were performed, the test object was inspected for possible technical defects or damage. In the field work, a cultivating unit was used, which loosened the soil and prepared it for sowing for cultivation. Measurements were made in a field in the town of Borek Wielkopolski. Figure 2 shows the test vehicle along with its technical specification.

Parameter	Value
Displacement:	6,7 dm^3
Driving gear:	4-cylinder, electro-hydraulic clutch
Maximum power:	116 kW/2100 rpm
Maximum torque:	700 Nm/1250-1550 rpm
Equipment:	VGT Turbocharger, EGR, DOC, DPF
EURO standard:	Stage IIIA/Tier 3

Fig. 2. Picture of the tested vehicle and its technical data

The mobile measuring device SEMTECH DS was used in the research, which enables the performance of exhaust emission measurements in real operating conditions [6-8, 22]. It consists of a set of analyzers that allow determining the concentration of the basic gaseous exhaust gas components. The device was designed for use in measuring the exhaust emissions of machines/vehicles with compression ignition and spark ignition engines, compliant with the Stage II and newer emission norms. The device cooperates with the exhaust gas flowmeter, from which the exhaust gas sample is taken. It is transported by a heated line to the inside of the device. The following gaseous components are measured: THC (FID analyzer - *Flame Ionization Detector*), NO_x (NDUV analyzer - *Non-dispersive Detector Ultra Violet*), CO_x (NDIR analyzer - *Non-dispersive Detector Infra Red*), and the oxygen concentration is also measured (using the electrochemical method) [13]. Measurement and data acquisition takes place at a frequency of 1 Hz. The error of the operation of the individual exhaust gas flowmeters and analyzers shall not exceed ±3%. The measuring system also has a GPS device and a weather station (Fig. 3).

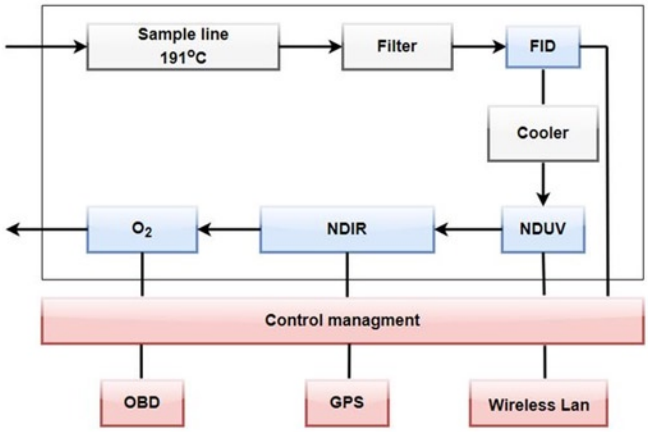


Fig. 3. Diagram of operation of PEMS- SEMTECH DS apparatus [23]

4. Test vehicle operating conditions

The tests of the agricultural tractor were carried out in real operating conditions, while working in the field. The measurements were made in three test cycles divided according to the speed during the work of the tested vehicle – done at 5, 10 and 15 km/h. Using the data recorded from the GPS, the operating parameters of the test vehicle were determined (Fig. 4). The share of operating time was presented relative to the variability of vehicle speed and acceleration. The characteristics include all research tests – for each speed including: acceleration, constant speed operation, and braking. For driving at constant speed (where $a = 0$ m/s^2), the shares of 49%, 24%, and 15.4% were obtained, respectively, for the following value intervals: (1 m/s; 1.5 m/s⟩, (2.5 m/s; 3 m/s⟩ and (4 m/s; 4.5 m/s⟩. In all tests, data was also acquired during stops occurring before and after the performed field work. The total share of time for this point was 3.2%. For all operating points including acceleration or braking (where $a \neq 0$ m/s^2), their share was lower than 0.3%, which proves that the tests were performed correctly, i.e. that the assumed constant velocities were overall maintained during operation.

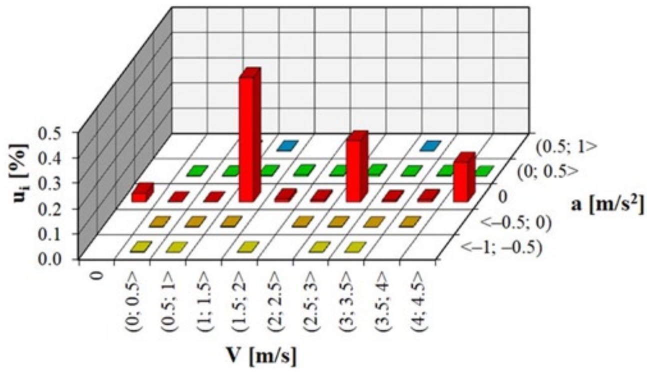


Fig. 4. The area of variability of work parameters of the research object during measurement tests

Based on the information recorded from the on-board diagnostic system, the parameters of the internal combustion engine were also acquired (Fig. 5). In order to determine the actual work performed by the internal combustion engine, when determining the specific exhaust emissions of measured components, it is necessary to take into account the net parameters: power and load, i.e. those obtained at the end of the crankshaft with power used by additional

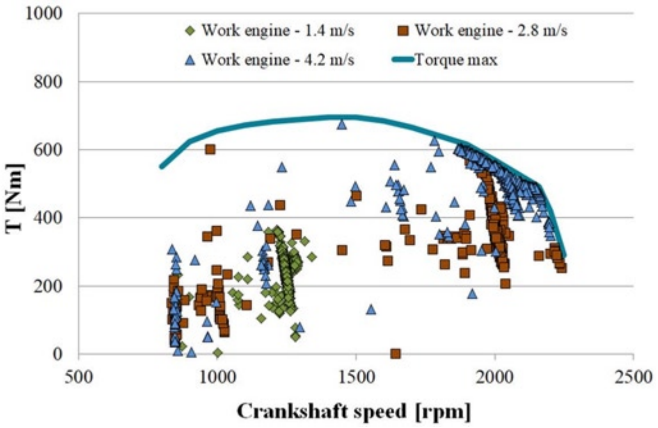


Fig. 5. Internal combustion engine operation parameters

devices already included. Crankshaft speed and generated torque values can be read from on-board diagnostic systems. The first of these parameters is determined directly using induction or Hall effect sensors, and the data obtained by this method is sufficient. However, the torque is determined on the basis of the pressure in the supply system and the injector opening time. However, there are some discrepancies in the real-world values as the readings obtained from the OBD system take into account the internal resistances of the engine. The calculations can address this problem by taking into account the percentage share of the load related to, among others, internal engine friction, however, this is a simplification as the actual internal resistances depend on many factors. As a rule, they are not linear and change depending on the current operating parameters of the engine. In selected areas of its operation, they may constitute up to 40% of the total torque produced. Its inflated value, which is read from the CAN (*Controller Area Network*), causes that the designated work in the test to also be overestimated. This translates into lowering the resulting specific exhaust emissions of pollutants, where the work performed by the drive system is in the denominator. For these reasons, it is necessary to determine the resistances of the internal combustion engine and take into account their values when determining the torque in tests carried out during the vehicle operation. This allows to determine the actual ecological indicators of a given vehicle [5].

For the first measurement test, the highest density of operating points occurred in the area of the load characteristic described by the engine speed interval ⟨1150 rpm; 1245 rpm⟩ and load interval ⟨130 Nm; 358 Nm⟩. During the second run, greater variability of operating parameters was observed. The distribution of work points also shows the greatest share of work in the load characteristic range, especially in the interval ⟨1940 rpm; 2052 rpm⟩ and ⟨254 Nm; 560 Nm⟩. While the highest engine speeds were achieved in the third test run, the engine was operated primarily at engine power band. This is evident for crankshaft speeds above 1,875 rpm. For all tests, there were fragments of operating time spent in the area of load characteristics that showed a lower density of operating points. This was the result of the internal combustion engine cooperation with the mechanical transmission and electro-hydraulic clutch used in the vehicle.

5. Results

In order to perform research on the evaluation of the emission indicators during a typical agrotechnical task performed by a farm tractor, the characteristics of the exhaust emission intensity as a function of engine rotational speed-load (n-T) were analyzed. The distribution of operating points covered the range of operating parameters in one-side closed intervals. The intensity of CO_2 emission increased with the increase of the engine load and rotational speed values (Fig. 6). The maximum CO_2 emission value (20.8 g/s) was recorded at a single operating point within the intervals of rotational speed (1800; 2000 rpm⟩ and load (500; 600 Nm⟩. The area where the highest intensity of carbon dioxide emission was recorded was observed for the ranges (1600; 2200 rpm⟩ and (400–700 Nm⟩. The average emission value for this interval was 19.07 g/s. The lowest emission intensity occurred in the load interval not exceeding 300 Nm. The mean value for the performed test drive was 11.1 g/s.

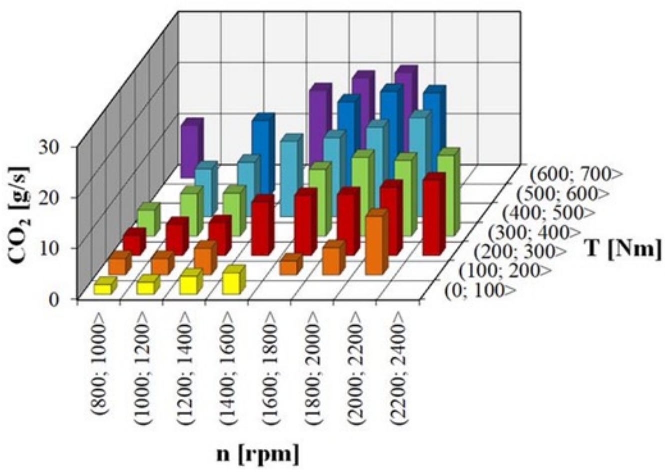
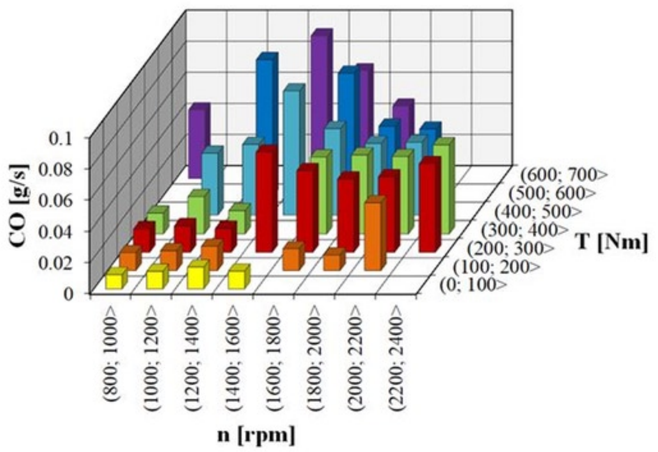


Fig. 6. The CO_2 exhaust emission intensity characteristics in the engine speed-load intervals

For the presented CO emission intensity characteristic (Fig. 7a), the highest values occurred in the interval (1400; 2000 rpm⟩ and (500; 700 Nm⟩, with the local maximum being 0.09 g/s. The average value for this interval was 0.06 g/s. One should also note the rotational speeds interval of (1600; 2400 rpm⟩, in which the mean emission intensity value was 0.05 g/s. The obtained values resulted from the operating conditions during which the fuel dose was increased, which causes global and local oxygen deficiencies closely related to the formation of carbon oxides, their formation was also influenced by the high temperature in the combustion chamber (locally exceeding 2000°C in farm tractors), which was the conditions favouring the thermal dissociation into CO. This reaction occurs at temperatures greater than 2000 K, while above 3000 K 40% of carbon dioxide dissociates into CO.

The mean exhaust emission value for the entire test drive was 0.004 g/s. The values of the M_CO/CO_2 emission indicator were evenly distributed throughout the entire engine operating range and remained in the range between 1.7–6.1 (Fig. 7b). The maximum value of 6.1 was obtained for a single operating point in the intervals of rotational speed (1400; 1600 rpm⟩ and load (200; 300 Nm⟩. The mean emission indicator value was 3.6.

Characterization of the hydrocarbon emission intensity as a function of engine speed and load (Fig. 8a) showed that the highest value was obtained in the area within the rotational speed interval (1600; 2200 rpm⟩ and load interval (400; 700 Nm⟩, for which the average remained at the level of 0.004 g/s. The maximum local value (0.005 g/s) was recorded in a single measurement interval for (1600; 1800 rpm⟩ and (600; 700 Nm⟩. The mean value of hydrocarbon exhaust emission intensity over the entire test drive was 0.003 g/s). The increase in HC emission rate was caused by high rotational speed, at which the injected dose of fuel is not thoroughly mixed with the air, which leads to incomplete combustion. Most of the factors contributing to the formation of an excessive amount of carbon monoxide in the exhaust gas also cause excessive emission of hydrocarbons, hence the local maxima of both compounds were recorded in the same intervals of the engine operating points. The highest values of M_HC/CO_2 emission indicators (0.73) were obtained for the rotational speed range (800; 1000 rpm⟩ at a load of (0; 100 Nm⟩, i.e. for engine idling, where the exhaust aftertreatment systems had not achieved their light-off temperature, and when the overall combustion temperature was low. The a)



b)

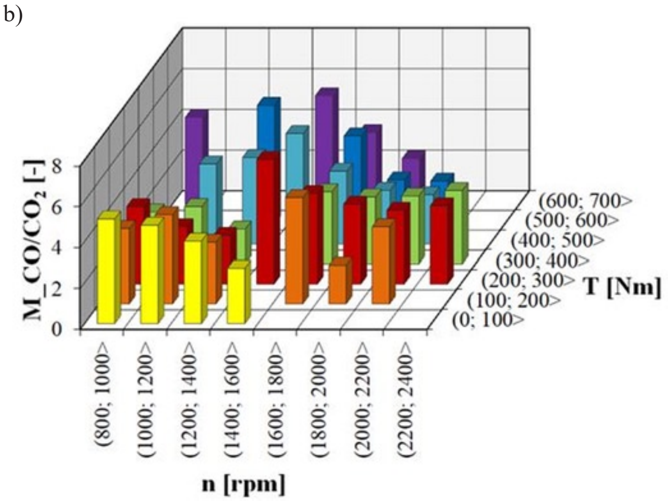
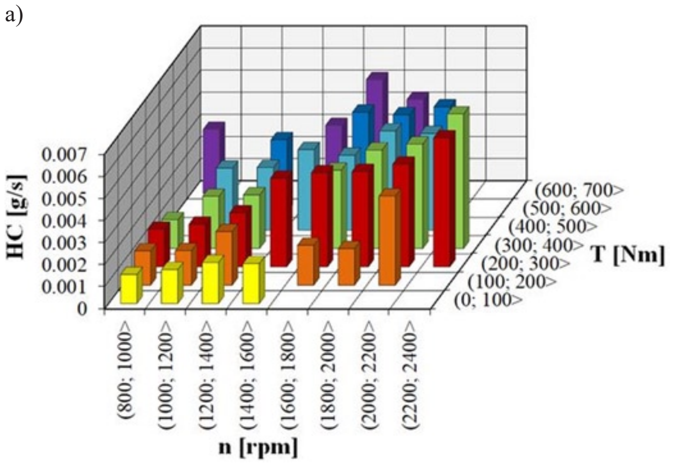


Fig. 7. Characteristics of a) CO emission per second; b) CO emissivity in the torque ranges of the engine speed

a)



b)

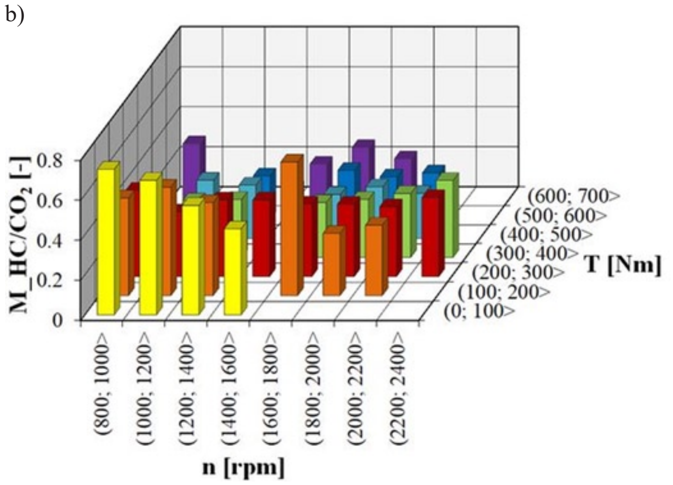


Fig. 8. Characteristics of a) second HC emission rate; b) HC emissivity in the torque ranges of the engine speed

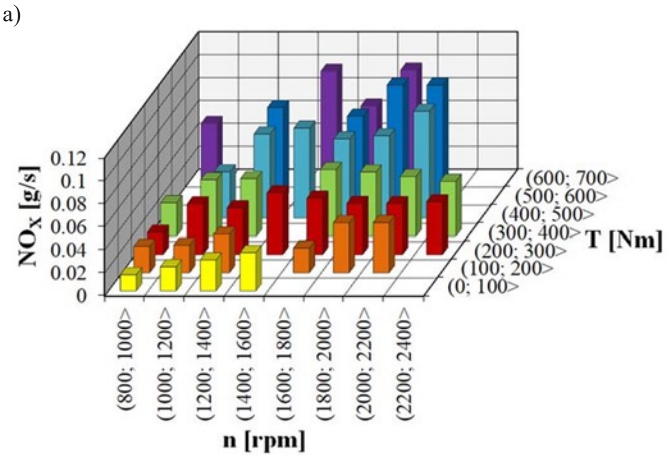
mean value of the emission values for the entire test was 0.035 g/s. The values of the discussed exhaust compound were evenly distributed throughout the engine operation area, similarly to CO emission indicators (Fig. 8b).

The highest NO_x emission intensity was recorded for the engine rotational speed interval (1600; 2200 rpm⟩ and load interval (400; 700 Nm⟩ - Fig. 9a, for which the mean value was 0.053 g/s. The maximum value of 0.1 g/s) occurred in two separate measurement intervals (1800; 2000 rpm⟩ and (500; 600 Nm⟩ as well as for (2000; 2200 rpm⟩ and (500; 600 Nm⟩.

At significant engine speeds, above 800 rpm, the engine generates a higher cylinder temperature, which directly promotes the formation of nitrogen oxides. Distribution of the exhaust emission characteristics is similar to the distribution of the previously described exhaust compounds, and therefore uniform in the entire range of the engine operation. The emission indicator values varied in the range of 3–8.8, with the local maximum 8.8 being recorded for engine parameters enclosed in the intervals of rotational speed (100; 1200 rpm⟩ and load (0; 100 Nm⟩. The mean value for the entire operating area of parameter variability was 5.4 (Fig. 9b).

Based on the determined masses of individual emitted gaseous compounds, a comparison of their emission indicators was made for

a)



b)

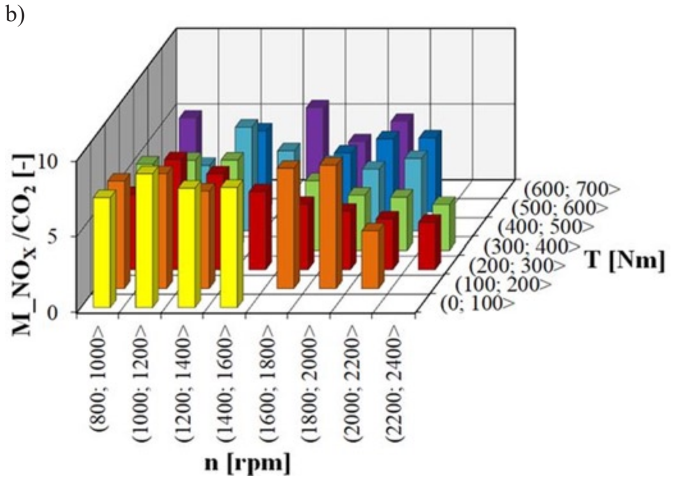


Fig. 9. Characteristics of a) second NO_x emission rate b) NO_x toxicity in the torque ranges of the engine speed

each test sample, which differed in the vehicle speed value (5 km/h, 10 km/h, 15 km/h). For each exhaust compound, the lowest emission rates were found for the test characterized by the highest speed of 15 km/h. These values were 2.42, 0.31, 4.86 for CO, HC and NO_x respectively. In the first test, there was an almost 70% difference in the HC emission indicator value (compared to the third trial) and a 30% difference in the indicator for NO_x. The second test (at 10 km/h) was characterized by the highest emission indicator for CO, and the differences in the values were 34% and 32% respectively when compared to the tests performed at 5 km/h and 15 km/h (Fig. 10). The measurement results presented in [15] showed that increasing the vehicle speed when performing field work may contribute to the reduction of fuel consumption. During the tests described in [15], an 18% reduction in fuel consumption was achieved as a result of increasing the drive speed with the field cultivator from 5 km/h to 15 km/h. Fuel consumption tests were carried out in the same field in successive cycles, i.e. the measurements were made for the same type of soil and for the same weather conditions. Fuel consumption is closely related to the emission of harmful CO_2 and other toxic exhaust gas compounds, hence it confirms that the lowest emission indicators were recorded in the third measurement test.

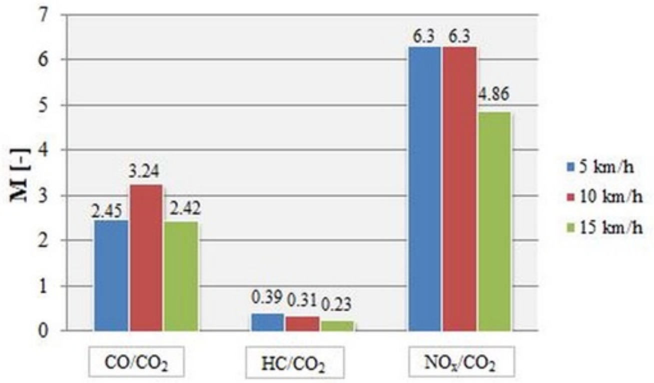


Fig. 10. Comparizon of M emission indicators for CO, HC and NO_x obtained during the three test drives

6. Conclusion

General conclusion:

- The paper proposes a new proprietary emission factor M, based on the use of measurements of carbon dioxide parameters (e.g. the emission intensity of this compound, its road or unit emission). The values that are substituted into its structure must be expressed in the same units, which will make it dimensionless.
- The conducted analyzes, in particular the introduced emission indicator, are a novelty in the aspect of emissivity analysis.

Detailed conclusions:

- On this basis of reserach, it was found that the lowest values of the emission indicators M were recorded for the test characterized by the highest vehicle speed of 15 km/h. Therefore, increasing the driving speed of the tractor during typical field work from 5 km/h to 15 km/h may have a positive impact on the overall exhaust emission results of toxic compounds.
- In the previous work of the authors [17], considerations were made in terms of the possible applications of the emission indicator for conventional, hybrid and alternative fuel urban buses. Measurements were made in accordance with the SORT 2 drive test procedure and on the test route in the Poznań agglomeration. The comparison of the emission indicators from both studies shows that the NRMM vehicle at a speed of 10 km/h is characterized by similar trends in the values of the M indicators as the hybrid bus. In the case of CO/CO_2, the vehicle achieved exactly the same value (3.24) as the hybrid bus during road tests on the city line and 3.44 for a trip in the standardized SORT 2 test. This is due to the similar performance characteristics of the engines of both these vehicles, namely the engine operating at higher loads (above 50%). The comparison of the values of the remaining emission indicators for the NRMM vehicle (during the 10 km/h test) with the hybrid bus results in the following values:
- M_{HC_NRMM} – 0.31; $M_{HC\_urban\ route}$ – 0.24; $M_{HC\_SORT\ 2}$ – 0.2,
- M_{NOx_NRMM} – 6.3; $M_{NOx\_\ urban\ route}$ – 9.63; $M_{NOx\_SORT\ 2}$ – 6.97.

The comparative analysis of the agricultural tractor and the hybrid bus also showed that in both cases the highest values of the M_{NOx} indicator were achieved, which, as already mentioned, results from the operation of the engines in the higher efficiency range of operating points. It should be noted that the drives of the test vehicles had different rated parameters, and the hybrid vehicle was equipped with an SCR aftertreatment system. Similar considerations were also carried out in [16], where a comparative analysis of the emission indicator for two passenger cars and a city bus was performed. Therefore, this analysis confirms the universality of the M indicator as a tool for comparizon of overall engine.

Methodological conclusions:

- It is necessary to determine the resistances of the internal combustion engine and take into account their values when determining the torque in tests carried out during the vehicle operation and the work performed by the drive system.
- Many studies have shown [13] that the current type approval tests (static - NRSC and dynamic - NRTC) do not fully reflect both the actual engine operation parameters and the emission of toxic exhaust compounds. Therefore, it is necessary to continue work on testing the exhaust emission of toxic compounds from this group of vehicles and changing the regulations regarding emission control strategies. In addition, an important aspect in relation to the vehicles in the NRMM group is also work on the improvement of mobile exhaust emission measuring equipment in order to optimize the research process itself with this type of machines.

Prognostic conclusions:

- The literature review allows the authors of this work to state that its subject matter is consistent with the direction of research carried out around the world, and the presented emission index M met with the approval of the scientific world and representatives of the European Commission at numerous industry conferences.
- In the longer term, taking into account the dimensionlessness of the M emission indicator, it is possible to compare not only vehicles of the same category, but also objects belonging to different groups, from LDV to NRMM vehicles. Thus, the dissemination of the indicator presented allows for even more precise definition of the environmental performance of a vehicle / machine.

References

1. Almén J. Swedish In-Service Testing Programme on Emissions from Heavy-Duty Vehicles. AVL Sweden Certification & Regulation Compliance. 2010.
2. Anser MK, Apergis N, Syed QR. Impact of economic policy uncertainty on CO2 emissions: evidence from top ten carbon emitter countries. Environmental Science and Pollution Research 2021; 1-10, https://doi.org/10.1007/s11356-021-12782-4.
3. Association for Emissions Control by Catalyst (AECC). Workshop on Clean Air and Real Driving Emissions. Conference materials of: Motor Transport Institute in Warsaw 2010.

4. Barlow TJ, Latham S, McCrae IS, Boulter PG. A reference book of driving cycles for use in the measurement of road vehicle emissions. TRL Published Project Report. 2009.
5. Čupera J, Sedlák P. Design and verification of engine power calculation model using the data of a digital bus built into an agricultural tractor. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 2014; 59(6): 111-120, https://doi.org/10.11118/actaun201159060111.
6. Daszkiewicz P, Andrzejewski M. Preliminary analyzes in terms of the possibility of reducing energy consumption by the SM42 locomotive used in track works. MATEC Web of Conferences. 2017; 118(00014), https://doi.org/10.1051/matecconf/201711800014.
7. Fuc P, Lijewski P, Kurczewski P, Ziolkowski A, Dobrzynski M. The analysis of fuel consumption and exhaust emissions from forklifts fueled by diesel fuel and liquefied petroleum gas (LPG) obtained under real driving conditions. ASME International Mechanical Engineering Congress and Exposition 2017. American Society of Mechanical Engineers Digital Collection, https://doi.org/10.1115/IMECE2017-70158.
8. Fuc P, Lijewski P, Ziolkowski A, Dobrzynski M. Development of a method of calculation of energy balance in exhaust systems in terms of energy recovery. ASME International Mechanical Engineering Congress and Exposition 2017; 58431(V008T10A047), https://doi.org/10.1115/IMECE2017-70159.
9. Fuc P, Lijewski P, Ziolkowski A. Analysis of the CO2, NOx emission and fuel consumption from a heavy-duty vehicle designed for carriage of timber. IOP Conference Series: Materials Science and Engineering 2016; 148 (1): 012065, https://doi.org/10.1088/1757-899X/148/1/012065.
10. Giechaskiel B, Lähde T, Gandi S, Keller S, Kreutziger P, Mamakos A. Assessment of 10-nm particle number (PN) portable emissions measurement systems (PEMS) for future regulations. International Journal of Environmental Research and Public Health 2020; 17(11): 3878, https://doi.org/10.3390/ijerph17113878.
11. International Council on Clean Transportation. European Stage V non-road emission standards. 2016;1-8.
12. Kuranc A. Exhaust emission test performance with the use of the signal from air flow meter, Eksploatacja i Niezawodnosc - Maintenance and Reliability 2015; 17 (1): 129-134, https://doi.org/10.17531/ein.2015.1.17.
13. Lijewski P. Study of exhaust emission from non-road engines. Dissertation, Poznan Univeristy of Technology 2013.
14. Lijewski P, Fuc P, Dobrzynski M, Markiewicz F. Exhaust emissions from small engines in handheld devices. MATEC Web of Conferences 2017; 118(00016), https://doi.org/10.1051/matecconf/201711800016.
15. Merkisz J, Lijewski P, Fuc P, Siedlecki M, Weymann S. The use of the PEMS equipment for the assessment of farm fieldwork energy consumption. Applied Engineering in Agriculture 2015; 31(6), https://doi.org/10.13031/aea.31.11225.
16. Merkisz J, Rymaniak Ł. Determining the environmental indicators for vehicles of different categories in relation to CO2 emission based on road tests. Combustion Engines 2017; 56, https://doi.org/10.19206/CE-2017-310.
17. Merkisz J, Rymaniak L. The assessment of vehicle exhaust emissions referred to CO2 based on the investigations of city buses under actual conditions of operation. Eksploatacja i Niezawodność - Maintenance and Reliability 2017; 19(4): 522-529, https://doi.org/10.17531/ein.2017.4.5.
18. Merkisz J, Waligorski M, Bajerlein M, Markowski J. Application of the Frequency and JTFA Analyses of the Accompanying Processes for OBD Combustion Process Monitor Design in Turbocharged CI Direct Injection Engines of HDV Non-Road Vehicles. SAE Technical Paper 2011, https://doi.org/10.17531/ein.2017.4.5.
19. Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles and repealing Regulations (EC) No 443/2009 and (EU) No 510/2011.
20. Regulation (EU) 2016/1628 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.
21. Siedlecki M, Lijewski P, Weymann S. Analysis of tractor particulate emissions in a modified NRSC test after implementing a particulate filter in the exhaust system. MATEC Web of Conferences 2017; 118(00028), https://doi.org/10.1051/matecconf/201711800028.
22. Warguła Ł, Kukla M, Lijewski P, Dobrzyński M, Markiewicz F. Influence of Innovative Woodchipper Speed Control Systems on Exhaust Gas Emissions and Fuel Consumption in Urban Areas. Energies 2020; 13(13): 3330, https://doi.org/10.3390/en13133330.
23. www.semtech.com