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Evaluation of pollutant emissions from a railbus in real operating conditions during transport work

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The article discusses issues related to the assessment of pollutant emissions from a railbus during transport work. The test object was a rail vehicle equipped with two diesel engines with a total power of 780 kW, Stage IIIB homologated. Measurements were carried out on the route Poznań–Wągrowiec in two directions. During the tests, the vehicle performed a transport service, where the number of passengers was counted. For the completed cycles, the average number of people was 82 and 18. Based on the obtained data, the vehicle operating conditions and emission indicators were analyzed, which were related to the number of passengers. A dimensionless toxicity index was also determined.

Key words: *emissions, passenger, PEMS, railbus, toxicity indicator*

1. Introduction

In Poland, 342.23 million passengers traveled by rail vehicles in 2022, and the transport performance amounted to 15,882.97 million pkm [22]. Taking into account the data presented by the UTK (Office of Rail Transport), a systematic increase in the above-mentioned values has been visible since 2012. Following the policy of the European Union, actions are being implemented aimed at introducing ecological drives in means of transport. One of such solutions is hybridization or electrification [2, 11, 12], provided that energy is obtained from ecological sources. In recent years, the rolling stock used for passenger transport has seen an increase in the share and development of electric multiple units [4]. There is still a long way to go before complete electrification.

Due to the significant use of passenger vehicles (including railbuses) equipped with internal combustion engines, it becomes necessary to conduct research and considerations regarding their exact impact on the natural environment. This can significantly affect strategic activities related to the development and modernization of infrastructure, as well as the organization of business activities. At the same time, the assessment of emissions from moving vehicles contributes to a deeper understanding of the problem of knowing the local values of air pollution.

For engine rail vehicles, approval tests in the ecological scope are still valid, only on the engine dynamometer. Stand measurements are to simulate the conditions of real engine operation to some extent, but they are far from the actual parameters of their use. This has been proven in many scientific works for various types of vehicles [1, 17]. As presented in publications [5, 8], to obtain reliable ecological indicators for specific machines and vehicles, it is necessary to perform tests in real operating conditions. Preferably while performing normal machine tasks.

The development of technology and test equipment used for the approval and testing of various types of vehicles (including off-road vehicles) made it possible to test vehicle emissions in real operating conditions. This mainly applies to PC (Passenger Car) and HDV (Heavy Duty Vehicles). In recent years, activities have also been carried out for other types of vehicles, primarily belonging to the NRMM (Non Road Mobile Machinery) group [3, 6, 9, 19]. This is possible, among others, by reducing the size of the measuring equipment and reducing its energy consumption [7, 13, 16, 18]. Such devices belong to the PEMS group (Portable Emission Measurement System).

The aim of the work was to determine and compare the operating parameters of the research facility in two tests and to determine ecological indicators in relation to CO_2 and the average number of traveling passengers. The article presents real research that can complement theoretical considerations and modeling of pollutant emissions [10, 15].

2. Research methodology

The assessment of ecological parameters was carried out on a standard-gauge railbus used for passenger transport in Wielkopolska (Fig. 1). Its construction allows for the simultaneous transport of 246 people. The length of the vehicle is 43.73 m, and the total weight of the object ready to drive is 89,000 kg.

Fig. 1. The research object before the start of measurements at the Poznań Główny station

The research object uses two twin compression ignition engines (Table 1). Each of them is turbocharged, has a displacement of 12.8 dm^3 and develops a power of 390 kW at 1800 rpm and a maximum torque of 2200 Nm at 1300 rpm. The engines were homologated according to the Stage IIIB standard, so they were controlled by the NRSC (Non Road Stationary Cycle) and NRTC (Non Road Transient Cycle) tests.

Table 1. Technical data of the powertrain used in the research object

Parameter	Value
Powertrain	2 × CI engines
Layout/number of cylinders	R 6
Displacement volume [dm^3]	12.8
N_{max} [kW] at engine speed [rpm]	390 at 1800
T_{max} [Nm] at engine speed [rpm]	2200 at 1300
Exhaust emission standard	Stage IIIB

In the research work, mobile equipment was used to measure the concentration of harmful compounds from the PEMS group: Axion R/S+. NDIR (Nondispersive Infrared) sensors are used to measure HC, CO and CO_2, E-chem sensors are used to measure NO and O_2, while PM concentration is determined using the Laser Scatter method [20]. The device is characterized by significant miniaturization concerning devices from the PEMS group offered by other manufacturers. It is used e.g. by EPA (Environmental Protection Agency) in the certification process. Information on engine operating parameters and flows in the exhaust system was recorded from the on-board diagnostic system using the Texa Navigator device. The measurement and data acquisition was performed with a frequency of 1 Hz. Based on the recorded data, corrections of the obtained results are made and the road/unit emission of the pollutants tested is calculated.

The tests of the object were carried out on the same route during trips in two directions: Poznań–Wągrowiec (cycle A) and Wągrowiec–Poznań (cycle B, Fig. 2). The total length of individual runs was 56.7 km. The relative height profile varied from 61 to 100 m above sea level, the average slope was 0.7% towards Wągrowiec. In each passage, the rail vehicle served 18 railway stations.

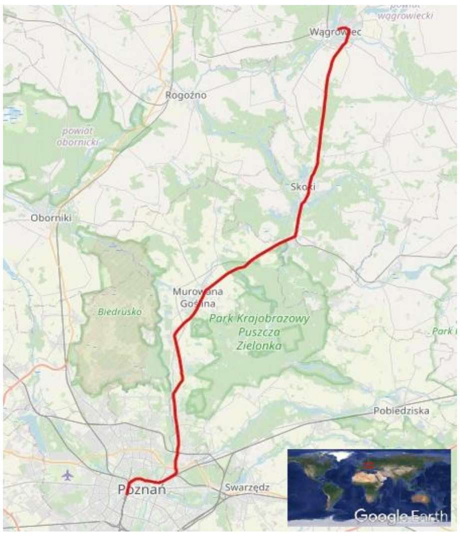

Fig. 2. Research route [21]

The measurements were carried out in real operation, during normal transport service. During the measurements, the number of travelers was acquired based on inspected tickets. In this way, the number of passengers for the Poznań–Wągrowiec route was defined, which was 82. In the second cycle, the value was 18 passengers.

3. Vehicle operating conditions during testing

The tested rail vehicle carried out transport work in real operating conditions. The conditions of its operation are shown in Fig. 3. In both measurement cycles, the object achieved temporary maximum speeds of up to 120 km/h (this is the maximum speed according to the manufacturer). The average speeds were similar and amounted to 43.9 km/h for cycle A and 40.5 km/h for cycle B. Due to the scheduled traffic on the tracks, there was a stoppage of several minutes in each cycle (other rail vehicles were allowed to pass).

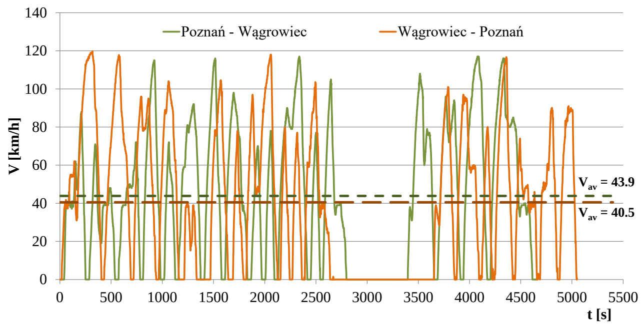

Fig. 3. Velocity characteristics of the research object in cycles A and B

The shares of the working time of the research object in the ranges of speed and acceleration only in cycle A are presented (Fig. 4). This was due to the similar nature of the journeys on the same route in two directions. The largest share of working time, 26.6%, was obtained for standstill. For driving at constant speed ($a = 0$ m/s^2) 19.4% was achieved. The highest shares of accelerations were obtained for the ranges (0 m/s^2; 0.8 m/s^2⟩ – 28.7% and ⟨–0.8 m/s^2; 0 m/s^2) – 17.8%. In the other acceleration ranges, the share for single speed ranges was less than 1%.

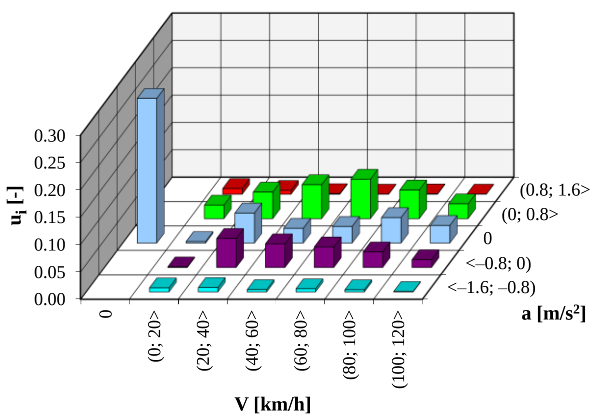

Fig. 4. Shares of research object work time in the speed and acceleration ranges during tests in cycle A

The shares of working time in the speed and acceleration ranges recorded during the tests in cycles A and B were compared (Fig. 5).

This was a supplement to the analyzes of vehicle operation conditions. The characteristics show the differences between route A (minuend) and route B (subtrahend). The size of the circles refers to the obtained difference, for positive values they are full, while for negative results they have not been filled in. This allowed to indicate how the characteristics obtained in subsequent cycles differ.

The greatest differences occurred during standstill 4.69% and driving at constant speed, e.g. in the range (20 km/h; 40 km/h⟩, where 4.04% was obtained. For the considered accelerations and decelerations ($a \neq 0$ m/s^2) in the individual speed ranges, the differences were less than 1% (excluding one point for V ∈ (80 km/h; 100 km/h⟩). The obtained results prove that the trips were similar, especially in terms of driving style. Therefore, the parameter of a different mode of operation in individual cycles is excluded.

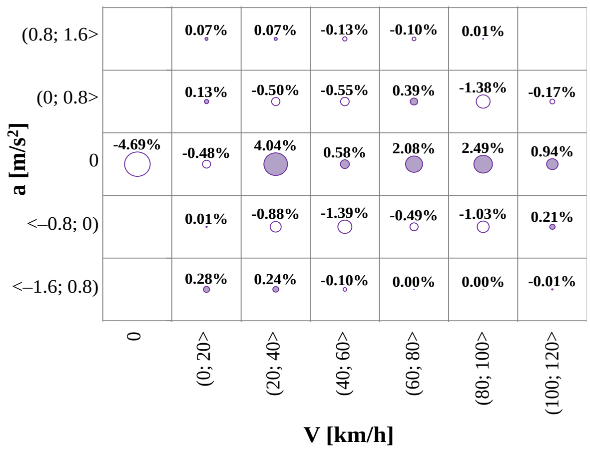

Fig. 5. The difference in the share of the research object's working time during measurements in the speed and acceleration ranges

4. Analysis of test results

Based on recorded data on the vehicle operating conditions and the concentrations of chemical compounds in the exhaust system, the emission intensity of individual harmful compounds was determined. On this basis, it was possible to integrate CO_2 emissions during the implementation of cycles A and B (Fig. 6).

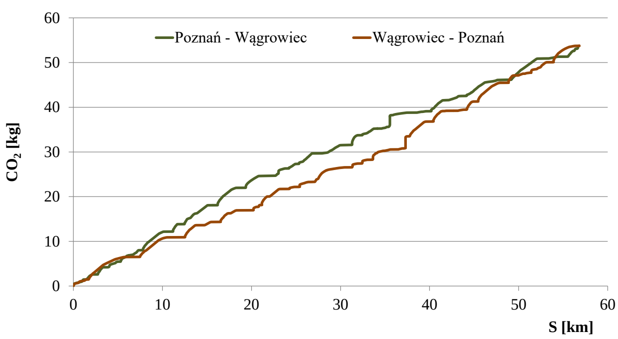

Fig. 6. Total CO_2 emissions during tests in cycles A (Poznań–Wągrowiec) and B (Wągrowiec–Poznań)

The presented characteristics about the speed of the vehicle indicate that the greatest increase of the considered harmful compound occurs during acceleration. Due to the implementation of the same driving style by the driver and driving on the same route, very similar results of the total CO_2 emissions were obtained. It was 53.5 kg for the A cycle and 56.8 kg for the B cycle. The cumulative emissions from two internal combustion engines downstream of the after-treatment systems were taken into account.

Taking into account all the analyzed harmful components, the road emission in cycles A and B was determined (Fig. 7). The obtained results indicate that similar values were achieved during the measurements, the largest differences occurred for CO – respectively 6.46 g/km (cycle A) and 5.22 g/km (cycle B). For CO_2 and NO_x, the determined values differ by less than 1%. Specific emissions are used to assess rail vehicles, but for the purposes of the article reference was made to the cited indicators. It also did not affect the determination of toxicity indicators presented in the further part of the paper.

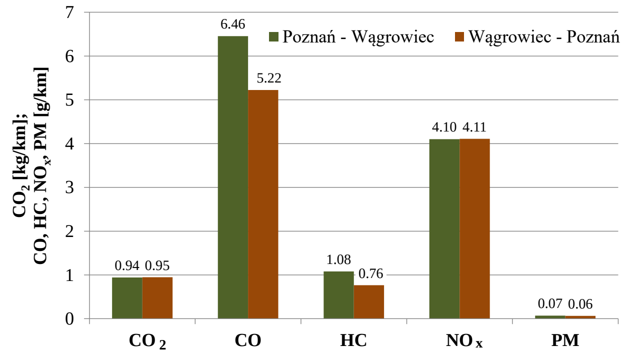

Fig. 7. Summary of road emissions during tests in cycles A (Poznań–Wągrowiec) and B (Wągrowiec–Poznań)

Based on the collected data, fuel consumption was determined using the carbon balance method. Road emission of CO_2 has the greatest impact on the results of calculations, because it has the largest mass in harmful gases. Therefore, fuel consumption reached similar values: 35.49 dm^3/100 km was obtained in cycle A and 35.57 dm^3/100 km in cycle B.

Comparing road emission or unit emission indicators for different groups of vehicles can be difficult. This is related to the nature of the work of the facility and its intended use. This is especially true for the NRMM vehicle group. The basic combustion product in engines is CO_2. Its weight is directly related to fuel consumption, but also to the quality of the combustion process and the operation of engine exhaust gas treatment systems.

Toxic compounds such as CO, HC, NO_x or PM are products of incomplete or imperfect combustion and combustion at high temperature and pressure. It is therefore possible to compare CO_2 emission to other emitted toxic compounds and on this basis to determine the toxicity indicator M_j. Index j means the toxic compound to which it relates [14]. The structure of the M_j indicator allows for dimensionless expression of values, described e.g. in [14]. Its structure is as follows:

$$M_j = b \cdot \frac{e_{real,j}}{e_{CO_2}} \quad (1)$$

The universal constant b makes it possible to reduce the results to a range of quantities greater than hundredths or thousandths (CO, HC, $NO_x = 10^3$, $PM = 10^5$). Whereas the $e_{real,}$j and e_{CO2} components mean the specific emission, road emission or mass of the compound j determined during the tests [g/kWh; g/km; g]. The numerator and denominator units must always be the same. According to the recommendations of the European Commission, such an indicator should be introduced into the emission assessment of vehicles and work should be conducted on its recognition.

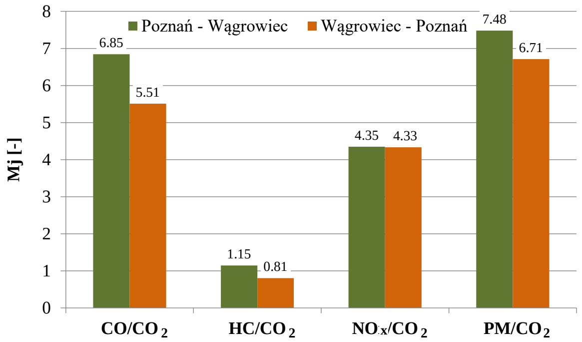

Fig. 8. Summary of dimensionless toxicity indicators during tests in cycles A (Poznań–Wągrowiec) and B (Wągrowiec–Poznań)

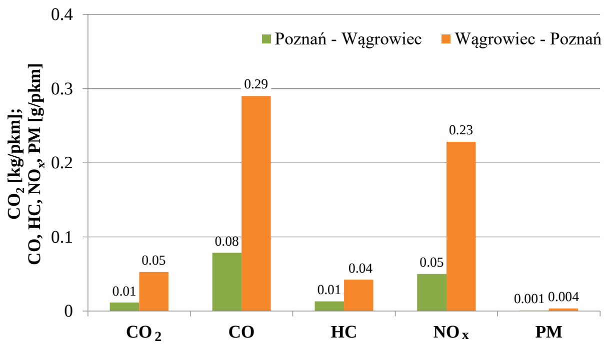

Fig. 9. Summary of road emissions per passenger during tests in cycles A (Poznań–Wągrowiec) and B (Wągrowiec–Poznań)

Values ranging from 0.81 to 7.48 were obtained for the defined dimensionless toxicity indicators (Fig. 8). The highest indices were obtained for CO and PM. This means that greater efforts must be made to reduce emissions of this compound, e.g. by improving fuel atomization during injection, changing the fuel injection strategy, or improving off-engine exhaust aftertreatment systems. Based on the data collected in work [14], it can be concluded that the obtained indicators are the closest to those of a small passenger car equipped with a petrol engine (CO and HC). However, in the NO_x range, the greatest similarity was obtained to an off-road vehicle with a CI engine.

The last stage of the evaluation of pollutant emission results is to compare them per 1 passenger (Fig. 9). The most favorable values were obtained for cycle A, where a larger number of passengers traveled.

Based on such a shape of the results, it can be concluded that the mass of the traveling passengers has little impact on the emission of toxic compounds during transport work. Assuming that each passenger weighs 70 kg (there were also children on board), the difference in subsequent cycles was about 4500 kg. This accounted for 5% of the total weight of the facility ready for service.

5. Summary

The assessment of the real emission of pollutants from vehicles is very important for the implementation of remedial actions in the field of environmental degradation. In rail vehicles used for passenger transport, more and more new solutions in drive systems are used – engines with newer emission standards, electrification, as well as the introduction of hydrogen structures. However, a significant group of about 25% is still combustion engines traction units.

The article presents the results of pollutant emission tests from a rail vehicle in real operating conditions. Tests carried out on the same route in two directions, show very similar results. However, during the implementation of individual cycles, a different number of passengers traveled. Calculated per person, it was proven that the emissions are much lower in the A cycle. This was mainly due to the low weight of these passengers in relation to the total weight of the vehicle.

The obtained values of toxicity indicators M prove the validity of its use to assess vehicles with internal combustion engines. It makes it possible to compare various groups of vehicles, regardless of the type of emissions taken into account for the calculations. In the next stage of scientific work, it is expected that rail vehicles of other emission standards will be subjected to the emission assessment, rather than greater diversification of the load using the principles of ecodriving.

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Nomenclature

a	acceleration
CI	compression ignition
EPA	Environmental Protection Agency
HDV	heavy duty vehicles
M	toxicity indicator
NDIR	nondispersive infrared
NRMM	Non Road Mobile Machinery
NRSC	Non Road Stationary Cycle
NRTC	Non Road Transient Cycle
PC	passenger cars
PEMS	Portable Emission Measurement System
V	velocity

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