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The assessment of the emission level from heavy-duty truck under actual operating conditions

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***Abstract*— The paper presents an analysis of the gaseous exhaust emissions along with an analysis of the size and mass distribution of particulate matter from a Euro V compliant road tractor. The vehicle was fitted with an engine of the displacement of 15,6 dm^3, maximum power output 412 kW generating a maximum torque of 2700 Nm (1991 lb/ft). For the tests the authors used portable exhaust emission analyzers (PEMS: SEMTECH DS and AVL Micro Soot Sensor. The measurements were conducted under actual operating conditions in traffic typical of long distance European haulage.**

The analysis of the obtained results was divided into two parts. The first part was related to the assessment of the influence of the traffic conditions on the exhaust emissions and gas mileage. The second part was related to the assessment of the influence of the engine operating conditions on the said exhaust emissions. The obtained exhaust emission results were compared to the emission limits specified in the Euro 5 standard.

***Keywords*— PEMS, heavy-duty truck, exhaust emissions test**

I. INTRODUCTION

A dynamic development of the road transport market in the European Union causes a constant growth in the number of heavy-duty trucks on our roads [3, 6, 7, 8]. This fact facilitates the phenomenon of road congestion and the time of carriage of goods is extended. The result is a lower quality and an increase in the prices of transport and forwarding services. Apart from the economic aspect we also need to consider the social and ecological aspects. Successive increase in the number of heavy-duty trucks may result in a reduced safety on the roads and a reduced traveling comfort for other road users. This is also related to a negative impact of road transport on the natural environment through increased exhaust emissions [1, 5]. To accommodate these problems, many EU member states such as Sweden, Finland and The Netherlands are seeking new transport solutions. One of these is EMS (European Modular System) whose main postulate is the extension of the maximum admissible length of heavy-duty trucks (in Europe the maximum admissible length of a truck cannot exceed 16.5 and 18.75 m) to 25.25 m (Fig. 1). This solution will allow a transport of larger cargo at a simultaneous reduction of the number of vehicles on the roads. The EMS project also proposes an increase in the gross vehicle weight to 60 000 kg.

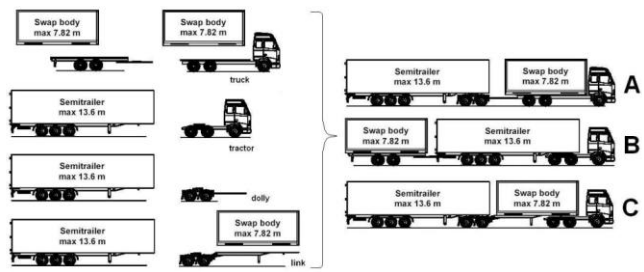

Fig. 1 Possible configurations of vehicles in the EMS system [7]

An increase in the gross vehicle weight of heavy-duty trucks in the EMS system forces vehicle manufacturers to use engines of greater power outputs. Many European manufacturers already fit engines of the power output exceeding 441kW and the maximum torque of 3500 Nm. Volvo is a good example of a manufacturer offering such an engine (power output of 550 kW and the torque of 3500 Nm). Another example may be the engine manufactured by Scania (of the power output of 537 kW) [11]. An increase in the power of combustion engines may lead to difficulties in complying with the exhaust emission standards. This paper analyzes the ecological performance of a Euro V heavy-duty truck based on the exhaust emission tests under actual traffic conditions.

II. THE TEST ROUTE

The selection of the test route was conditional upon the possibility of reflecting the actual conditions of operation of heavy-duty trucks on European roads, particularly stressing the Polish road infrastructure. Today this

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infrastructure contains 1224 km of motorways, 958 km of express roads, which is 12% of the total length of the national roads. A national road network is understood as a network of public roads connecting large cities and generally available border crossings [8, 9]. It does not include provincial, poviat and municipality roads that constitute 90% of the total road infrastructure in Poland [8]. An additional decisive criterion in the selection of the test route was the possibility of reflecting the connection to production and logistic centers to collect or drop the cargo. The authors decided that the test route would go on the national (their maximum share was determined at 30%), provincial and municipality roads. The proposed route has been shown in Figure 2. Its total length was 27 km. It started and ended at a production facility where 50 heavy-duty vehicles were loaded/unloaded daily. The selection of the test route was also conditional upon the applicable gross vehicle weight limits as set by the relevant decision-making body.

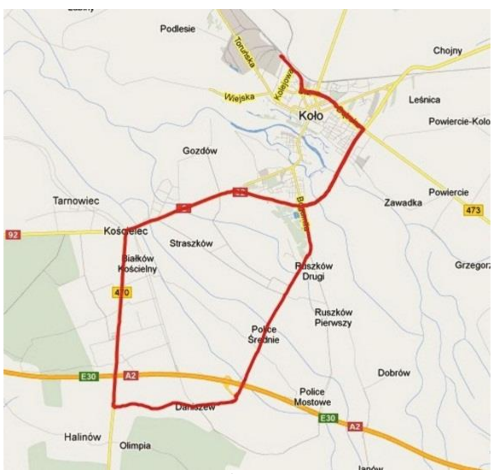

Fig. 2 The test route selected for the exhaust emission tests [10]

III. THE TEST VEHICLE

The tested object was an articulated tractor (Fig. 3-4) – a road tractor with a trailer of the length of 16.5 m. The test vehicle was fitted with a diesel engine of a displacement of 15.6 dm^3 and a maximum power of 412 kW (tab. 1). In order to comply with the exhaust emission limits prescribed in the Euro 5 standard the vehicle was fitted with an SCR system (*Selective Catalytic Reduction*). In order to reflect the conditions of daily operation (carriage of goods) the vehicle was loaded with a weight of 25 000 kg while the vehicle curb weight was 15 000 kg. In the analyzed case 25 000 kg is the maximum weight of cargo – in Europe the gross combined vehicle weight for heavy-duty trucks is 40 000 kg.

Fig. 3 Heavy-duty truck ready for on-road exhaust emission tests

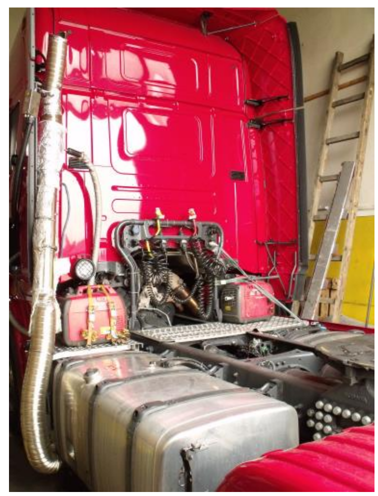

Fig. 4 The view of the exhaust sample uptake

TABLE 1
THE CHARACTERISTICS OF THE TRUCK [11]

Parameter	Value
Engine displacement	15.6 dm^3
Number of cylinders/arrangement	8 / V8
Maximum power	412 kW at 1900 rpm
Maximum torque	2700 Nm at 1000÷1400 rpm
Injection system	PDE unit injectors
Exhaust emissions standard	Euro V
Exhaust gas aftertreatment	SCR
Vehicle curb weight	15 000 kg
Weight of the load	25 000 kg

IV. THE MEASUREMENT EQUIPMENT

The authors used PEMS (*Portable Emission Measurement System*) analyzers for the measurement of the exhaust emissions. The first of the analyzers was SEMTECH DS. measuring the emissions of CO_2, CO, NO_x and the mass flow of the exhaust gas (Fig. 5a). The measurement of the concentration of CO_2 and CO was performed with an NDIR analyzer and the concentration of NO_x with an NDUV analyzer. The devices were equipped with an integrated weather station measuring the ambient temperature, pressure and humidity, which enabled determining of the correction coefficient KH. The analyzer also pulled information on the engine operating parameters from the vehicle OBD system. The measurement of the concentration of PM in diluted exhaust gas was performed with an AVL Micro Soot Sensor (1.5b). Both portable analyzers were controlled by a laptop computer through the Ethernet network. A detailed description of the above-mentioned analyzers has been presented in 2-4.

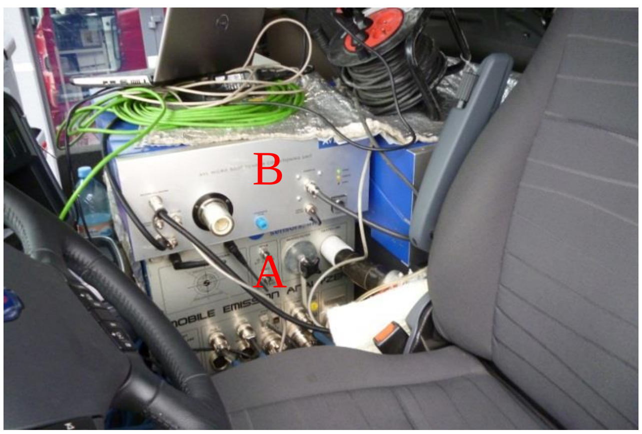

Fig. 5 Portable exhaust emission analyzers fitted in the vehicle cab: a) Semtech DS, b) AVL MSS

V. THE TEST RESULTS AND THE VEHICLE

Vehicle acceleration was determined in the first place based on the data obtained during the tests. The next step was the determination of the operating time share distribution of the vehicle in the speed and acceleration intervals (Fig. 6). Analyzing the distribution the authors observed that the vehicle operated in the acceleration interval of 0÷0.6 m/s^2 for half of its operating time – its share was 54%, 3% of which the vehicle was stationary. Another significant acceleration interval of the vehicle (on the level of 37%) was 0.6÷1.2 m/s^2. As for the vehicle speeds its maximum value was 24 m/s (approximately 86 km/h). The greatest operating time share in terms of the vehicle speed fell in the interval of 16÷20 m/s and constituted 35%. The obtainment of such an operating time share distribution indicates that during the exhaust emissions tests the vehicle operated mainly in the range of medium and high speeds at small changes of acceleration.

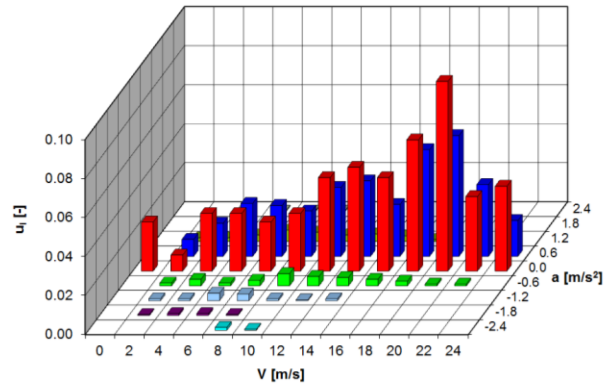

Fig. 6 Characteristics of the operating time share in the speed and acceleration intervals

Figure 7 presents the emission rates of CO, PM and the tracking of the vehicle speeds during the tests. The authors observed that the greatest increases in the emission of CO and PM occurred in the initial phases of the vehicle acceleration (high acceleration rate). The exception is the first 250 seconds of the test (circled) during which no significant emission increase of CO and PM was observed. Such a course of the emission of both exhaust components resulted directly from the amount of injected fuel and the excess air coefficient (λ).

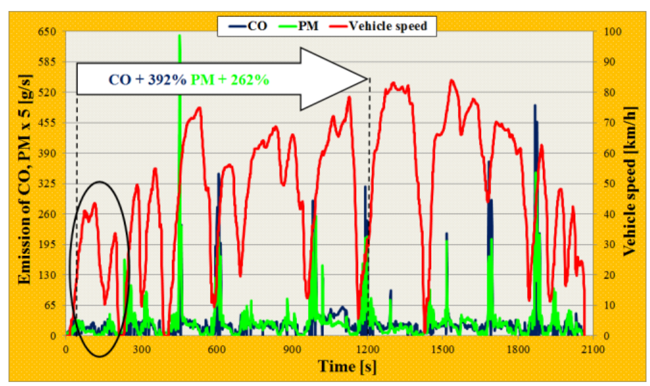

Fig. 7 The trackings of the second-by-second emission of CO, PM and the vehicle speed

The fact was confirmed by determining of the second-by-second fuel consumption based on the information pulled from the vehicle OBD system (data transmission protocol SAE J1939) on the instantaneous fuel injection rate expressed in dm^3/s (Fig. 8). In the first 250 seconds of the tests the highest second-by-second fuel consumption was 7 g/s – for this value the emission of CO was 27 mg/s and PM – 16 mg/s. For instance, in the 1200th second of the test the second-by-second fuel consumption was 15 g/s. At this point an increase in the emission of CO and PM occurred (in relation to the value of the fuel consumption of 7 g/s) by 392 and 262% respectively. In the analyzed case the increase in the second-by-second fuel consumption by 214% resulted in an enrichment of the air-fuel mixture from λ=2.15 to 1.33. Such conditions facilitate the formation of CO and PM as the global amount of O_2 necessary to oxidize the injected fuel is reduced, which results in the occurrence of the combustion zones of local oxygen deficiency (λ<1).

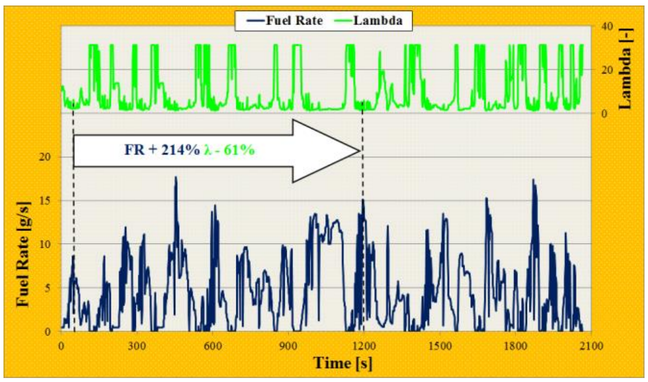

Fig. 8 The trackings of the fuel consumption and the excess air coefficient

VI. THE TEST RESULTS AND THE ENGINE

Using the values of the engine speed and load pulled from the vehicle OBD, the distribution of the engine work fields was determined (Fig. 9). The authors observed that the engine operated mostly at 1200 rpm – the time share for this range was 60%. Analyzing the load generated by the engine the authors also observed that the greatest share occurred for the interval of 1200÷2400 Nm, which was 40%. The operating time share for the idling speed did not exceed 4%. For high idle – 800÷1200 rpm, the operating time share was 12% of the total time of engine operation.

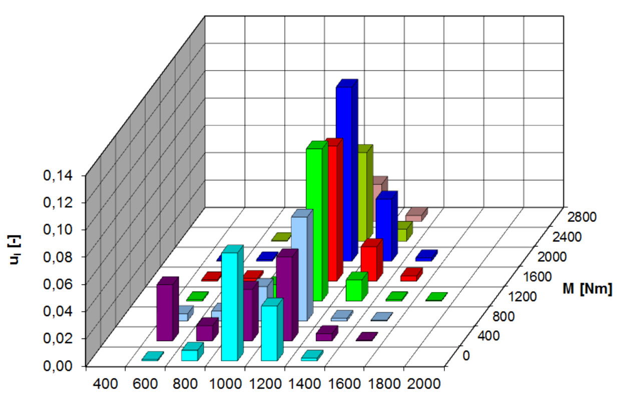

Fig. 9 Characteristics of the operating time share in the engine speed and torque intervals

In the initial stage of the test an increased second-by-second emission of NO_x was observed at a lower load generated by the engine as compared to the rest of the test (Fig. 10 – circled). The main reason for this situation was a low temperature of the exhaust gas that reduced the conversion rate of the SCR fitted in the vehicle exhaust system. In order for the SCR system to obtain a high conversion rate, high temperature exceeding 300^{o}C must be maintained. This is confirmed by the results obtained in the rest of the test– from the 500th second onwards a significant drop in the second-by-second emission of NO_x was observed.

During the entire test the engine generated a torque of the average value of 1060 Nm. Compared to the maximum engine torque it is only 40%. This directly translates into the obtained values of the second-by-second emission of CO_2. Its highest values were recorded for the maximum values of the engine torque. In relation to earlier research works carried out by the authors [4] the tested vehicle had lower values of the second-by-second CO_2 emission (the fuel consumption) than the 309 kW vehicle tested on the same route carrying a smaller load (20 000 kg).

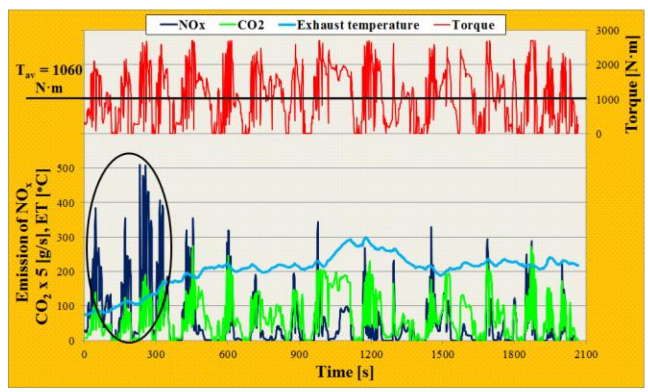

Fig. 10 The trackings of the second-by-second emissions of NO_x, CO_2, the temperatures of the exhaust gas and the engine torque

VII. CONCLUSIONS

The tests conducted under actual vehicle operating conditions allowed determining of the influence of the engine parameters of the tested vehicle on the exhaust emissions. Additionally, the authors performed an analysis of the measurement conditions – the vehicle speed and acceleration during the test. In the paper the authors also analyzed determining of the unit emission of CO_2, CO, NO_x and PM. The authors decided to compare the emission values obtained in the test with the limits prescribed in the Euro V standard that the engine of the test vehicle complied with (Fig. 11). As for the unit emission of CO and NO_x much lower values were obtained than those prescribed in the standard. Only the values of PM were more than 8 times higher. This was caused by a lack of a DPF filter in the vehicle exhaust system.

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Future research works related to the exhaust emission compliance of heavy-duty vehicles operating under actual traffic conditions should aim at a development of procedures whose research methodology will reflect the actual daily operation of these vehicles. In this case a vehicle type will be necessary to take into account. For example, the operating mode of heavy-duty delivery trucks is characterized by a great variability of accelerations, which translates into a varied operation of the powertrains. In the case of long-haul heavy-duty trucks we may observe a prevalence of steady conditions of operation of both the vehicle and its engine. The above confirms the need to develop separate tests.

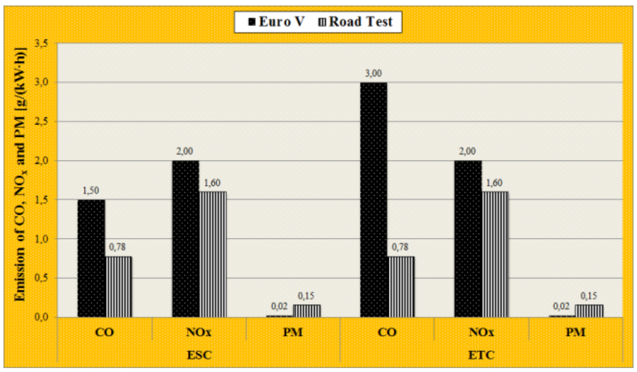

Fig. 11 Comparison of the unit emissions of CO, NOx and PM obtained during the on-road tests with the Euro V emission standard

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