THE IMPACT OF ENGINE COOLING FAN CONFIGURATION ON THE EMISSION OF POLLUTANTS BY VEHICLE EXHAUST SYSTEMS IN CHASSIS DYNAMOMETER TESTS

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Abstract

Reduction of pollutant emission by exhaust systems due to stricter limits has drastically increased the impact of previously ignored factors on the results of emission tests. One such factor is the cooling of the engine by the chassis dynamometer's external fan. Improper cooling can increase the temperature of the engine and the catalytic converter. Preliminary studies conducted by the Motor Transport Institute have confirmed that the configuration of the cooling fan influences exhaust system emissions. This article discusses the results of tests aimed at identifying the cause of changes in emission levels. To achieve this aim, emission levels were measured for various configurations of the chassis dynamometer (including both the fan speed and the distance from the front of the vehicle). During the tests, measurements were taken of temporary pollutant levels in the CVS and of the temperature of exhaust before and after the catalytic converter. The results confirmed the findings of preliminary tests. Increased exhaust emission levels were noted, though not, as anticipated, during the urban driving cycle, but rather during the final phase of the extra-urban driving cycle.

Measurements were taken using a single-roller chassis dynamometer equipped with a cooling fan with a regulated fan speed specified by a second-degree curve.

Keywords: *pollutant emissions, environmental protection*

1. Introduction

Reduction of pollutant emission by exhaust systems due to stricter limits has drastically increased the impact of previously ignored factors on the results of emission tests. One such factor is the cooling of the engine by the chassis dynamometer's external fan. Improper engine cooling during chassis dynamometer tests can lead to an increase in engine operating temperature, and thus to an increase in emission of, e.g. nitrogen oxides. For this reason, in series 06 of amendments to ECE Regulation No. 83 regarding testing of Euro 5 vehicles, changes were made to fan requirements. In series 06 of amendments to ECE Regulation No. 83, no changes were made to the provision requiring that the fan maintain an air cooling speed proportional to the speed of the vehicle, within a range of 10 - 50 km/h and with ± 5 km/h precision. An additional provision was introduced allowing the vehicle manufacturer to request that this range be increased up to the maximum speed of a given cycle, i.e. up to 120 km/h at present. Unlike in 05 series of amendments, in series 06 of amendments the method by which air cooling speed should be measured was specified (Fig. 1), as were requirements regarding that the fan maintain an homogeneous airflow along a cross-section of the fan.

Table 1 compares engine cooling fan requirements from series 05 of amendments to ECE Regulation No. 83 [1] (point 6.1.3, annex 4 for series 05 of amendments) with series 06 of amendments [2] (point 3.4.2 annex 4a for series 06 of amendments).

At present, there are three accepted setting methods, which differ markedly with regard to the velocity of the air used to cool a vehicle. This article discusses results of tests on the impact of these methods on the emission of pollutants by the exhaust system.

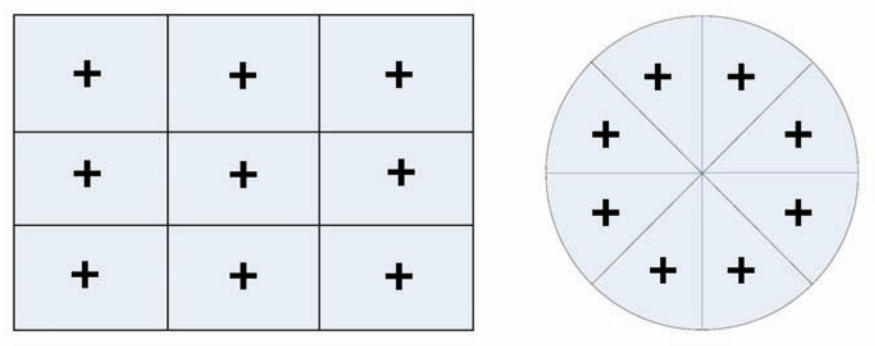

Fig. 1. Points for measuring fan speed for rectangular and circular fans

Tab. 1. Comparison of cooling fan requirements contained in series 05 and 06 of amendments to ECE Regulation 83

Parameter	revision series 05	revision series 06
fan speed	- proportional to vehicle speed within a range of 10 - 50 km/h or - constant, not less than 6 m/s	- proportional to vehicle speed within a range of 10 - 50 km/h or - constant, not less than 6 m/s or - **proportional to vehicle speed within a range of 10 km/h to the maximum speed occurring in the cycle**
precision in generating fan speed	- at linear roller speed < 10 km/h, fan speed may approach zero, - 10 - 50 km/h: ± 5 km/h in relation to vehicle speed	- at linear roller speed < 10 km/h, fan speed may approach zero, - 10 - 50 km/h: ± 5 km/h in relation to vehicle speed - **at linear roller speed >50km/h: ± 10 km/h in relation to vehicle speed**
method for measuring air speed	not specified	speed at measuring points may not differ from the mean value by more than 10%
Placement of fan in relation to vehicle	The bottom rim of the fan around 0.2 m from the floor, distance between air outlet from the fan and front of vehicle: around 0.3 m	no change

2. Testing methodology

Measurements were taken using a single-roller chassis dynamometer equipped with a cooling fan with a regulated fan speed (photo 1) specified by a second-degree curve based on the following equation (1):

$$n = F_0 + F_1 \cdot v + F_2 \cdot v^2 \,, \tag{1}$$

where:
n - rotational velocity of the fan expressed in a percentage of its maximum rotational velocity,
v - linear velocity of the chassis dynamometer rollers
F0, F1, F2 - coefficients.

Photo 1. Chassis dynamometer fan

For testing, a vehicle was selected which met Euro 4 and was equipped with a spark ignition engine. Temperature sensors were installed before and after the catalytic converter, and the temperature of the converter at these points was recorded during the driving cycle. The measurements were taken on an NEDC cycle (after the start of cold engine). Three variants were chosen for analysis of the impact of the fan settings on exhaust emission of pollutants:

- used by the MTI for emission testing: velocity of air on the vehicle in proportion to the linear velocity of the rollers within a range of 0 - 120 km/h, distance of the air outlet from the fan to the front of the vehicle L = 0.3 m (W1);
- constant velocity of air on the vehicle v = 6 m/s, distance from the air outlet from the fan to the front of the vehicle L = 0.3 m (W2);
- velocity of air on the vehicle in proportion to the linear velocity of the rollers within a range of 0 - 120 km/h, and the distance from the air outlet from the fan to the front of the vehicle L = 1.1 m (W3);

Configuration of the chassis dynamometer as in W1 and W2 is permitted by Regulation 83. Configuration W3 is inconsistent with the requirements of Regulation 83. It was nevertheless analysed as an example of erroneous placement of the fan too far from the front of the vehicle.

Table 2 presents the coefficients used for the chassis dynamometer's fan as well as the distance between the air outlet from the fan and the front of the vehicle (L).

Tab. 2. Coefficients for the chassis dynamometer and its positioning with regard to the vehicle

Indicator	F_0	F_1	F_2	L [m]
W1	0	0.875	0	0.30
W2	20	0	0	0.30
W3	0	0.875	0	1.10

In order to minimize the impact of other factors on the uncertainty of the measurement results:

- prior to beginning a series of emissions measurements, 5 NEDC cycles were conducted without emission measurement in order to stabilize the engine's operational parameters,
- before each measurement, the vehicle was conditioned at a temperature of 23 ± 2° for at least 16 hours,
- during driving cycles, an ambient temperature of 23 ± 2°C and a relative humidity of 40 ± 3% were maintained,

- the cycles were run by the same driver,
- nine emissions measurements were taken, three for each set of fan parameters: W1, W2 and W3.
- after each measurement, fan settings were changed as follows: W1, W2, W3, W1, W2, etc.
- the vehicle remained mounted on the dynamometer throughout the series of measurements.

3. Test results

Table 3 presents average exhaust emissions measured for each fan configuration.

Tab. 3. Average exhaust emissions [mg/km] ([g/km] for CO_2) and fuel consumption [dm^3/100 km] in type I tests for ECE Regulation No. 83

Cycle	fan conFig.	CO	NO_x	THC	CO_2	fuel consumed
urban	W1	1344.6	46.5	85.6	270.6	11.63
	W2	1328.9	50.6	97.0	269.0	11.57
	W3	1487.1	50.7	85.1	268.5	11.35
extra-urban	W1	0.6	3.7	4.5	165.9	7.07
	W2	16.0	6.2	6.4	173.8	7.41
	W3	7.9	5.8	7.1	164.2	7.00
weighted average	W1	494.5	19.4	34.4	204.4	8.75
	W2	499.1	22.5	39.7	208.9	8.94
	W3	548.7	22.3	35.6	202.3	8.66

Figures 2 and 3 indicate average exhaust emissions for the urban cycle following a cold start and for the extra-urban cycle, including the values obtained

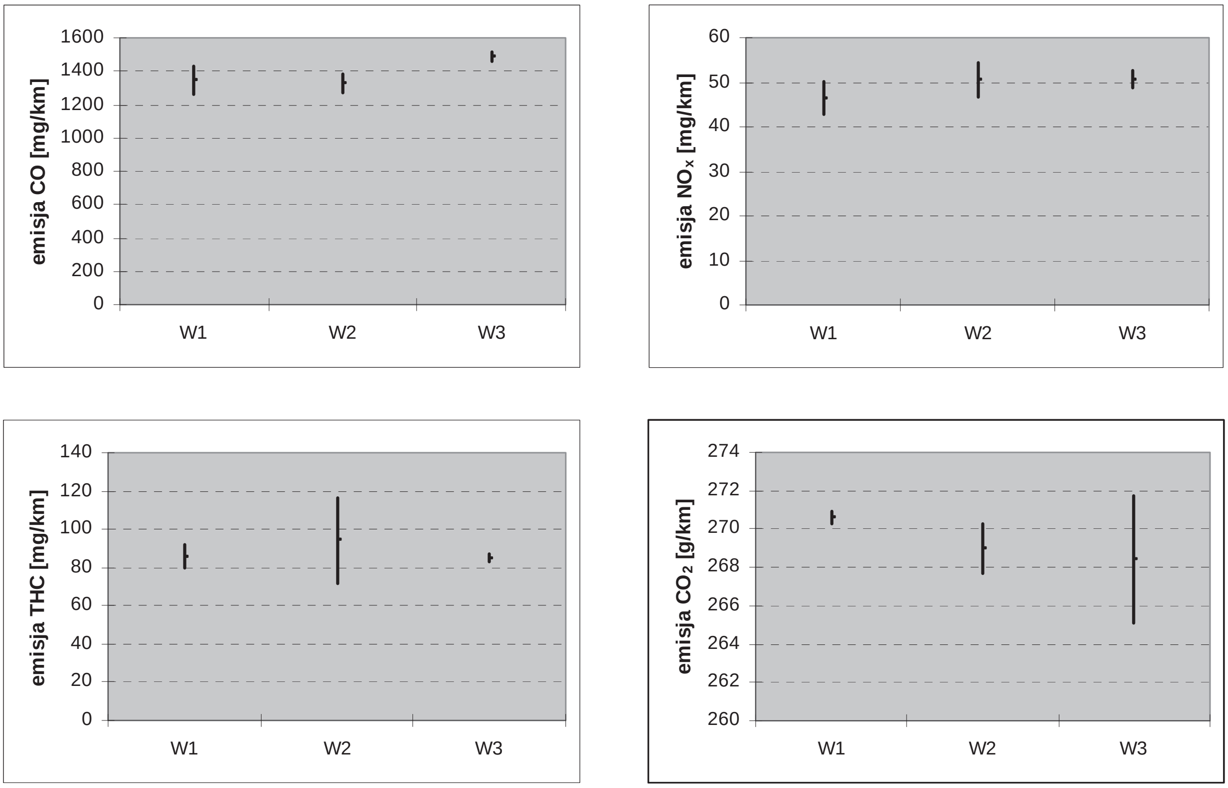

Fig. 2. Average exhaust emissions for the urban cycle following a cold start, with various dynamometer fan configurations

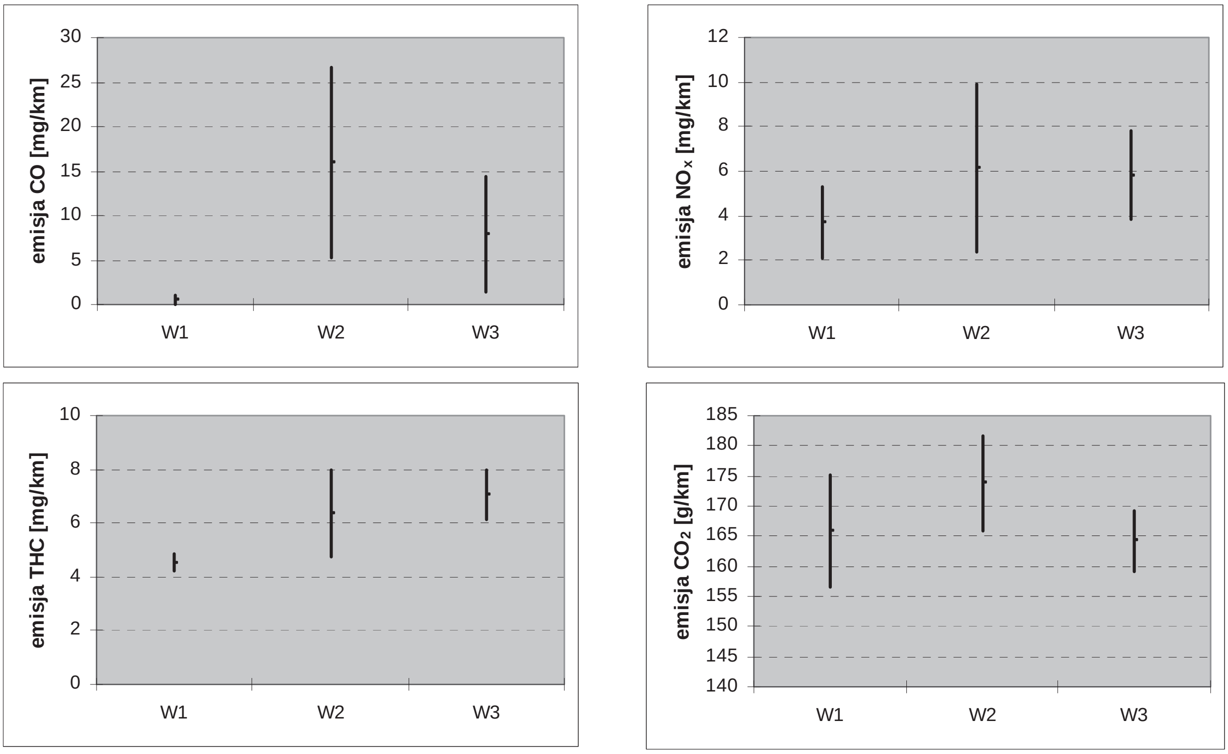

Fig. 3. Average exhaust emissions for the extra-urban cycle, with various dynamometer fan configurations

On the basis of the results obtained, it has been determined that with regard to configuration W1:

1. for the urban cycle:

- emission of carbon monoxide increased when the fan was placed at a distance of L = 110 cm from the front of the vehicle (W3); this increase does not significantly exceed 10%. To statistically confirm the impact of such a fan configuration on the emission of carbon monoxide for the urban cycle, a greater number of measurements would have to be taken,
- in configurations W2 and W3 emission of nitrogen oxides increased 9% in comparison with the average results obtained for configuration W1; this change fits within the range of measurement results obtained in testing. As with CO emission, a greater number of measurements would have to be taken to confirm this influence,
- hydrocarbon emissions did not change; the increase in hydrocarbon emissions observed in configuration W2 may result from incidental errors; three emission measurements were taken for this configuration, and widely disparate results were obtained: 74.8 - 119.1 mg/km, whereas remaining measurements fell within a range of 81 - 93 mg/km,
- in configurations W2 and W3, fuel consumption and CO_2 emission decreased slightly in comparison to the average value obtained for configuration W1; this is probably because the engine warmed up quickly due to weaker airflow cooling the vehicle;

2. for the extra-urban cycle:

- carbon monoxide emission increased from 0.6 mg/km (W1) to 7.9 - 16.0 mg/km (W3 and W2),
- a minor increase was noted for emission of hydrocarbons, from 4.5 mg/km (W1) to 6.4-7.1 mg/km (W2 and W3),
- a minor increase was noted for nitrogen oxides; from 3.7 mg/km (W1) to 5.8-6.2 mg/km (W2 and W3); this change fits within the range of measurement results obtained in testing. To statistically confirm this change, a greater number of measurements would have to be taken,
- changes to CO_2 emissions and fuel consumption fall within the range of measurement errors typical for measurement of these types of parameters.

In order to identify the causes of increases in emissions, analysis was conducted of the concentrations of individual pollutants over time. A significant increase in concentrations of pollutants was noted in the final cycle of the NEDC extra-urban test (from the acceleration phase to 100 km/h). This phenomenon was observed for all pollutants (CO, THC, NO_x). Fig. 4 and 5 indicate the average concentration over time for the sum of hydrocarbons and nitrogen oxides for each fan configuration.

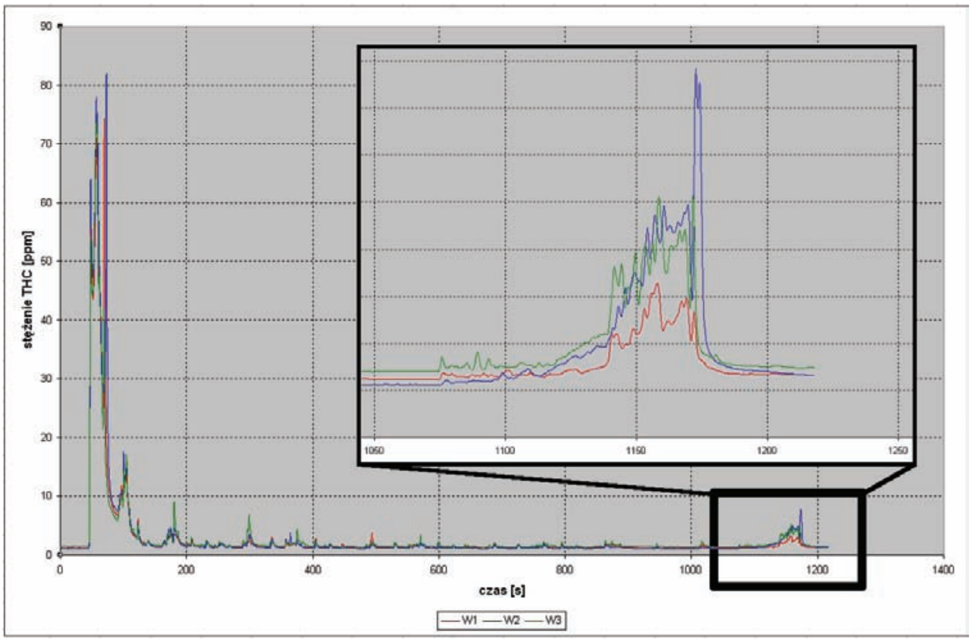

Fig. 4. Concentration of hydrocarbons (THC) over time in the exhaust system for various chassis fan settings

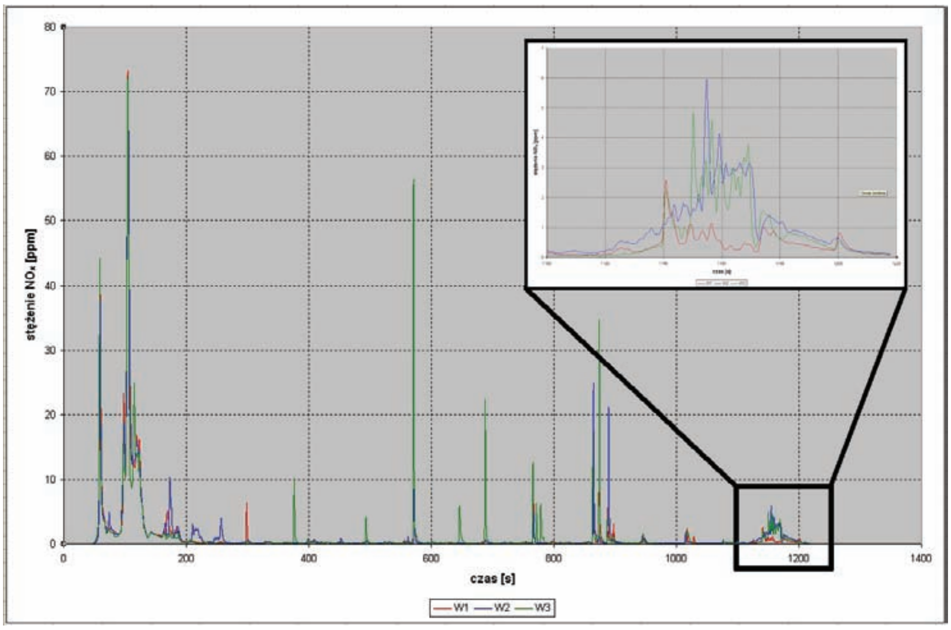

Fig. 5. Concentration of nitrogen oxides (NOx) over time in the exhaust system for various chassis fan settings

Figures 6 and 7 present the concentration of hydrocarbons (THC), carbon monoxide (CO) and nitrogen oxides (NO_x) in the CVS over time, as well as exhaust temperature before and after the catalytic converter in configurations W1 and W2 in the final phase of the urban cycle for the type I test pursuant to ECE Regulation No. 83 (900 - 1180 s. of the test).

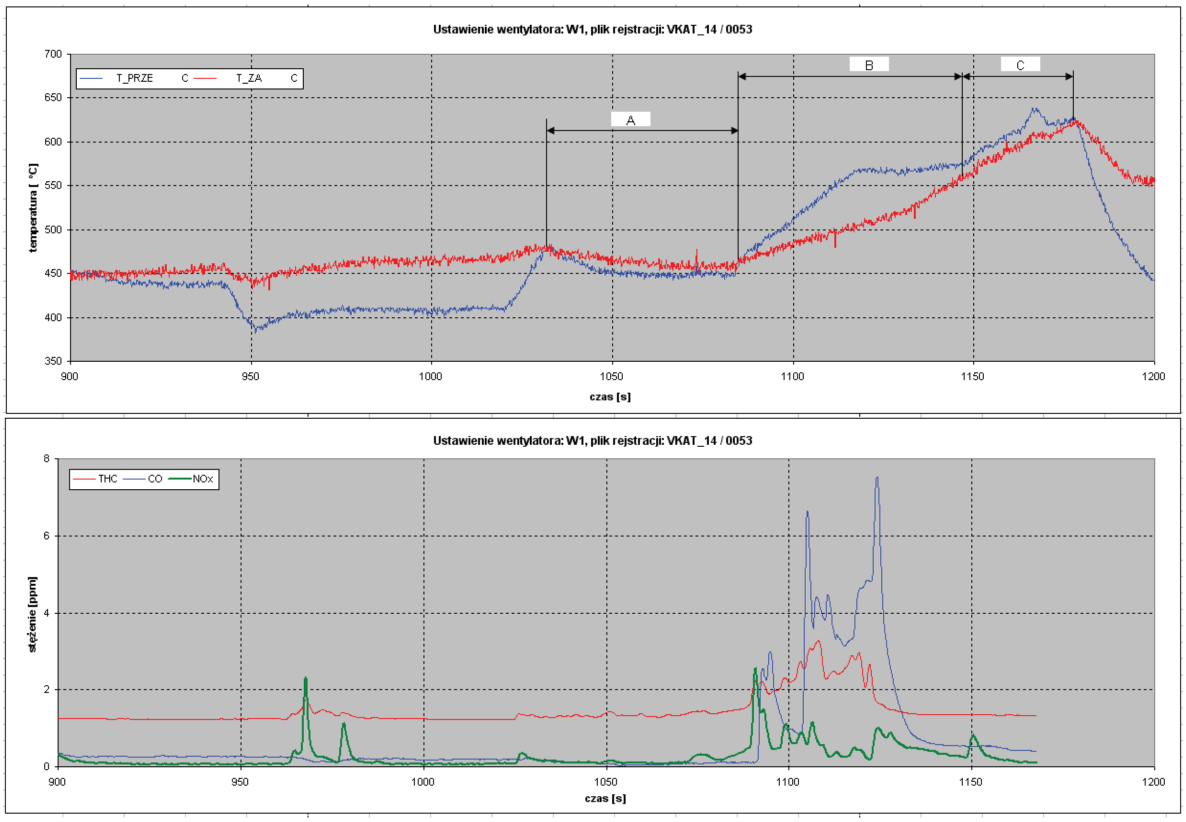

Fig. 6. The average concentration of hydrocarbons, carbon monoxide and nitrogen oxides in the CVS over time, as well as exhaust temperature before and after the catalytic converter in chassis fan configuration W1

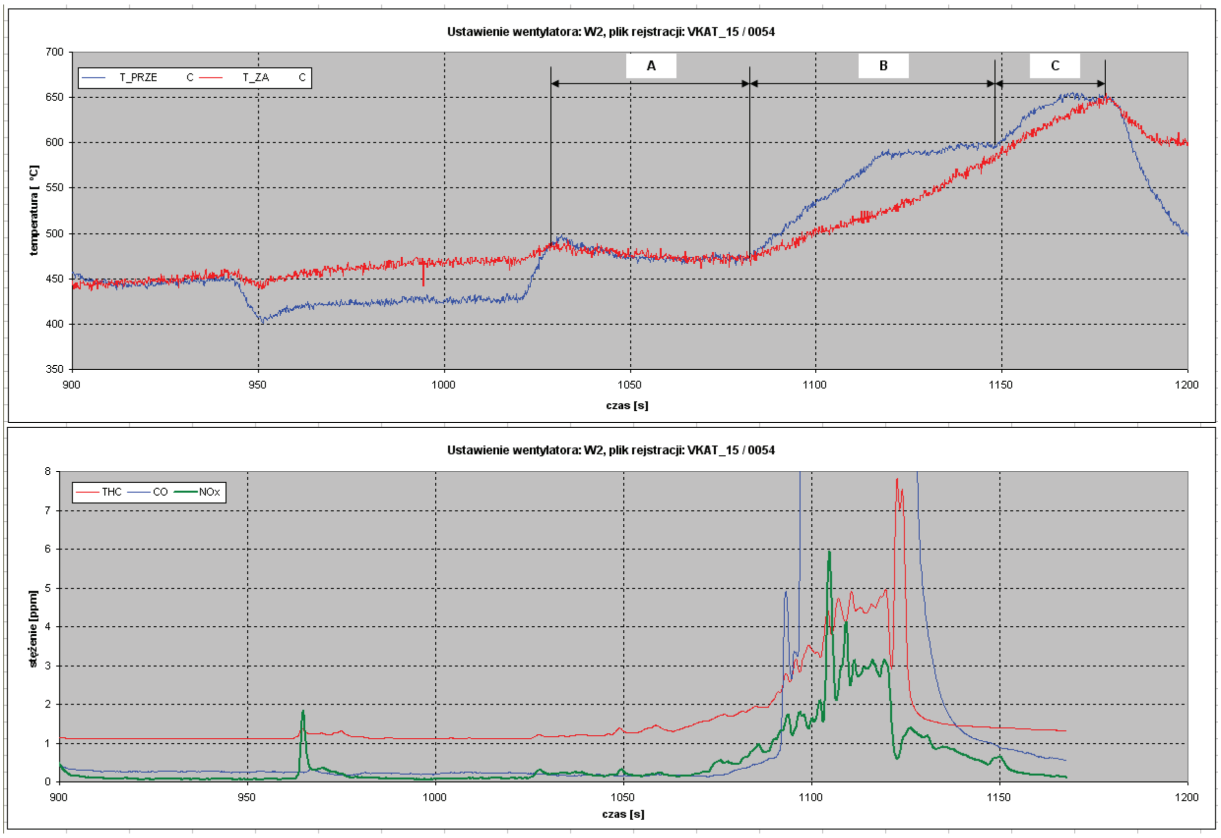

Fig. 7. The average concentration of hydrocarbons, carbon monoxide and nitrogen oxides in the CVS over time, as well as exhaust temperature before and after the catalytic converter in chassis fan configuration W2

The abovementioned time periods can be divided into three characteristic phases:

- **phase A**, lasting from around second 1030 of the test to around second 1083, during which exhaust temperature before the catalytic converter is almost constant and slightly (around 10°C) lower than the value of the temperature after the catalytic converter (configuration W1) or nearly equal (configuration W2),
- **phase B**, lasting from around second 1083 to around second 1150 of the driving test, during which exhaust temperature after the catalytic converter increases evenly, but the temperature before the catalytic converter at the beginning of the phase increases faster than the temperature after the catalytic converter, and then stabilizes; at the end of the phase, both temperatures approach the same value (the difference is around 15°C),
- **phase C**, lasting from around second 1150 to the end of the driving test, in which both temperatures are observed to increase evenly, and the temperature before the catalytic converter is around 20°C higher than the temperature after the catalytic converter.

In fan configuration W2, temperatures for phases A, B and C are around 50°C higher than for corresponding measurement conditions in fan configuration W1. During phase A, in configuration W2, a minor increase in nitrogen oxides is observable in comparison to configuration W1. The start of the increase coincides with the start of the rise in temperature before and after the catalytic converter in this phase for configuration W2. In this configuration, an increase in the levels of hydrocarbons and carbon monoxide occurs earlier than in W1, starting around 10 seconds before the end of the phase. However, the increase in concentrations for setting W1 begins at the start of phase B. In phase B, in both of the cases described (W1 and W2), increased emission of pollutants is noted in comparison to the remainder of the extra-urban cycle. However, in phase C a drop in all of the pollutants measured is observed.

4. Conclusions

The tests revealed that the configuration of the chassis cooling fan impacts the emission of pollutants by the exhaust system. The increase in emissions noted in the test vehicle took place during the final phase of the extra-urban cycle, test type I pursuant to ECE regulation No. 83. In comparison with the average emission level measured for the extra-urban cycle in configuration W1, in configuration W2 a 27-fold increase in emission of carbon monoxide (CO) was observed, together with a 1.5-fold increase in hydrocarbons (THC). This increase does not have a significant impact on the average level for the entire test because most of the emissions of these pollutants take place during cold engine start-up (for the test vehicle, emissions in the urban cycle accounted for 98.0 - 99.9% of total CO and 87.4 - 91.7% of total THC emissions). The increase in emission levels in the extra-urban cycle led to an increase in the average emission for the test as a whole by around 1% for CO and 3.5% for THC. However, this influence could not be overlooked in the case of nitrogen oxides (NOx). In the test vehicle, an increase in emission of NOx in the extra-urban cycle led to an increase in average emission for this pollutant over the entire test, by around 15 - 16%, depending on fan settings.

Consequently, it is clear that reductions in permissible pollutant levels should be correlated to increased precision in the measurement procedure. The results obtained from the tests prove that, within the framework of the methodology currently in use, the results of measurements of nitrogen oxides can be changed by around 15% simply by modifying a factor as seemingly insignificant as the positioning of the fan vent in accordance with a defined measurement procedure. Results obtained for one vehicle should not be treated as representative for the entire population of test vehicles. Nevertheless, these results constitute proof that procedures are not being adapted to increasing demand for creation of measurement conditions.

The impact of chassis fan configuration on emissions will be more noticeable for vehicles characterized by low emission levels, i.e. vehicles meeting EURO 5 requirements and higher, because in order to meet increasingly strict emission requirements, it will be necessary to lower emissions that occur during the initial phase of the NEDC cycle (after cold engine start-up). This will lead to an increase in the percentage of emissions in the extra-urban cycle as compared to the average emissions for the entire cycle and hence to an increase in the impact of fan configuration on the average emission level. Consequently, efforts should be made to ensure that the provisions of ECE Regulation No. 83 permit only those chassis fan configurations in which the velocity of the air cooling the vehicle is proportional to the linear velocity of the rollers within a range of 0-120 km/h.

References

[1] ECE Regulation No. 83, *Uniform provisions concerning the approval of vehicles with regard to the emission of pollutants according to engine fuel requirements,* Revision 3 (doc. E/ECE/324, E/ECE/TRANS/505, Rev.1/Add.82/Rev.3 of April 2005).

[2] ECE Regulation No. 83, *Uniform provisions concerning the approval of vehicles with regard to the emission of pollutants according to engine fuel requirements,* Revision 4 (doc. E/ECE/324, E/ECE/TRANS/505, Rev.1/Add.82/Rev.4 of April 2005).