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Vehicle interior air quality standards development

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Abstract. The paper presents results of experiments carried out to refine the procedure for determining the content of harmful substances in the air of vehicle interior coming from the supply system and exhaust system of the vehicle under test, as specified in GOST 33554-2015. Based on the work results proposals were prepared for the working group "Vehicle interior air quality", operating under the auspices of the World Forum for Harmonization of Vehicle Regulations (WP.29) of the United Nations Economic Commission for Europe. Content determination of the air pollutants in the vehicle compartment was carried out under various engine and ventilation system operating conditions when driving along the routes on the testing ground of FSUE "NAMI" and parking in specially selected places with the complete absence of other vehicles in the test area. Based on the test results, a conclusion was made that it is necessary to use a wider range of speed modes and variations in the operation modes of the ventilation system.

1. Introduction

Numerous published studies show that the doses of harmful substances entering the human body during traveling on vehicles significantly increase the daily dose of harmful substances inhaled by humans. For advanced vehicles, including electric vehicles, the problem of air pollution in the cabin will also be relevant while the vehicles with internal combustion engine and tires will continue to move on the roads. Confirming the relevance and importance of current problem, in 2015 the World Forum for Harmonization of Vehicle Regulations (WP.29) established an informal working group "Vehicle Interior Air Quality" (VIAQ). Since July 2017 the work of the group is conducted under the guidance of the Russian State Research Center FSUE "NAMI".

At first, the informal working group VIAQ developed a methodology for determining the volatile organic compounds (VOCs) concentrations emitted from the vehicle interior materials [1].

At present, a technique is being developed for determining the concentrations of harmful substances entering the vehicle interior from the outside. The main sources of air pollution in the vehicle interior are background air pollution measured by monitoring systems; polluted air above the roadway; the exhaust gases of the considered vehicle; exhaust gases of nearby vehicles; tire, roadway cover, clutches and brake mechanisms wear products.

It was decided to use as a basis the standard adopted in the Russian Federation – GOST 33554-2015 "Road vehicles. Pollutants content in the interior of driver cab and passenger compartment. Technical requirements and test methods" [2].

The document requires the determination of formaldehyde (CH_2O), nitrogen dioxide (NO_2), nitrogen oxide (NO), carbon monoxide (CO), saturated hydrocarbons (C_2H_6 – C_7H_{16}) and methane (CH_4) in the vehicle interior. Concentrations of harmful substances should not exceed the maximum single permissible concentrations (MPC_{ms}) established by hygienic standards GN 2.1.6.3492-17 "Maximum permissible concentration (MPC) of harmful substances in the atmospheric air of urban and rural settlements" [3]. MPC_{ms} values of the listed harmful substances are given in Table 1.

Table 1. Regulated harmful substances according to GOST 33554-2015.

Substance	Chemical formula	Hazard Class*	MPC_{ms}, mg/m^3	Engine type**
Formaldehyde	CH_2O	2	0.05	3, 4, 5
Nitrogen dioxide	NO_2	2	0.2	1, 2, 3, 4, 5
Nitrogen oxide	NO	3	0.4	1, 2, 3, 4, 5
Carbon monoxide	CO	4	5	1,2,3,4,5
Saturated hydrocarbons	$C_2H_6 – C_7H_{16}$	4	50	1,2,3
Methane	CH_4	4	50	3,5

Notes: * 1 – extremely dangerous; 2 – highly dangerous; 3 – moderately dangerous; 4 – low-risk
** 1 – spark ignition engines operating on gasoline; 2 – spark ignition engines operating on liquefied petroleum gas (LPG); 3 – spark ignition engines operating on compressed natural gas (CNG); 4 – engines with compression ignition (diesel engines); 5 – compression ignition engines operating on mixed fuel (diesel + CNG).

In accordance with GOST 33554-2015, tests of vehicles are carried out on paved roads with a longitudinal gradient of up to 6%, with a constant speed 50 km/h and idling. The recirculation system must be switched off. The recommended interior temperature is 20 ± 1 °C. Normal climatic factors are ambient air temperature from 15˚C to 30˚C; relative air humidity from 30% to 90%; wind speed 3.5 ± 1.5 m/s; atmospheric pressure from 630 to 800 mm Hg.

The test procedure, taken as a basis is described in the Appendix to GOST 33554-2015, paragraph B 4.2 and B 4.3. In this paper, we investigated the influence of the speed and the ventilation system operating modes on the concentrations of NO, NO_2, CO and total saturated hydrocarbons in the vehicle interior.

2. Test procedure

The test objects were vehicles of M_1 category with a manual transmission: three cars with a gasoline engine, an environmental class 4/5 and two cars with a diesel engine, an environmental class 4/5. The mileage of cars was no more than 30 000 km. The test cars moved along the paved roads of the NAMI Test Center during the "summer-autumn" season.

The tests were carried out in idle mode, at a constant speed, as well as in the drive-coast mode. In each case the influence of ventilation system modes on the concentration of harmful substance in the vehicle interior was investigated. Fan speeds varied from minimum to maximum with air recirculation and air intake from outside.

In constant speed mode, the cars moved with the speeds 50, 90, 110 and 130 km/h. In drive-coast mode, acceleration was made to the speed of 60 km/h, after 15 minutes the vehicle accelerated to 130 km/h with a fully open throttle and then the vehicle was slowed down by engine brake to the speed of 60 km/h. From six to eight "acceleration-deceleration" cycles were made. In all modes, the engine was started from a cold state (20-30 °C).

Measurements of pollutant concentrations were carried out in the express mode (direct measurement in the interior of the test object) during the driving modes. The measured harmful substances are carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO_2), total hydrocarbons (C_mH_n).

Quantitative measurements of substances at idle and during driving with constant speed were carried out in accordance with GOST 33554-2015. At the drive-coast mode, the gas analyzer readings were recorded each time when a vehicle had reached the maximum speed (6 – 8 times).

The gas analytical equipment complex used in tests is "P-310A" with a chemiluminescent detector for measuring nitrogen oxide and nitrogen dioxide (NO, NO_2), "Colion-1B" with a photo-ionization detector for measuring gasoline vapor (in terms of benzene C_6H_6), "Optogaz 500.4.CO" with an electrochemical detector for measurement of carbon monoxide (CO).

The final results were calculated by averaging the obtained data for the engine type, recirculation mode and fan speed of the ventilation system.

3. Test results

At idle, the excess of the standardized concentration value was detected only for nitrogen oxide (NO). This concentration was observed in case of diesel cars with recirculation switched on, at the maximum fan speed. For nitrogen dioxide (NO_2), the maximum concentration was also observed at testing of diesel vehicles with the same ventilation system operating mode. High concentrations of nitrogen oxides in exhaust gases of diesel engines caused by the peculiarities of fuel combustion. The maximum concentration of carbon monoxide (CO) was obtained for gasoline vehicles, but the ventilation mode coincided with the previous one (Table 2).

Table 2. Harmful substance concentrations at idle.

Substance	MPC_{ms}, mg/m^3	MPC_{ad}, mg/m^3	Max. value	Engine type*	Recirculation	Fan speed
NO	0.4	0.06	**0.498**	D	Enabled	max
NO_2	0.2	0.04	0.072	D	Enabled	max
CO	5	3	0.53	P	Enabled	max

Notes: P - petrol engine, D - diesel engine

When moving at a constant speed, the results were ambiguous. For cars with a gasoline engine, the maximum concentrations of harmful substances occurred when driving at speed 90 km/h (for NO) and at speed 130 km/h (for NO_2 and CO). Most maximum concentrations of harmful substances were found in the air recirculation mode and maximum fan speed.

In the case of diesel cars, the maximum concentrations of harmful substances were achieved at three different speeds: 50, 90 and 110 km/h. The operating mode of the ventilation system corresponded to the results obtained for diesel cars – with recirculation switched on and fan operation at maximum speed (Table 3).

Table 3. Concentrations of harmful substance when moving at a constant speed.

Substance	MPC_{ms}, mg/m^3	MPC_{ad}, mg/m^3	Max. value	Speed, km/h	Engine type*	Recirculation	Fan speed
NO	0.4	0.06	0.031	90	P	Enabled	max
NO_2	0.2	0.04	0.013	130	P	Disabled	0
CO	5	3	1.01	130	P	Enabled	max
NO	0.4	0.06	0.021	50	D	Enabled	max
NO_2	0.2	0.04	0.031	110	D	Disabled	max
CO	5	3	0.42	90	D	Enabled	max

Notes: P - petrol engine, D - diesel engine

When driving in the acceleration-deceleration mode, the maximum concentrations of harmful substances are obtained for the recirculation and fan operation at medium and maximum speed (Table 4).

Table 4. Concentration of harmful substances in the acceleration-deceleration mode.

Substance	MPCms, mg/m^3	MPC_{ad}, mg/m^3	Max. value	Engine type*	Recirculation	Fan speed
NO	0.4	0.06	0.081	D	Enabled	med
NO_2	0.2	0.04	0.03	P	Enabled	med
CO	5	3	1.16	P	Enabled	max

Notes: B - petrol engine, D - diesel engine

For total hydrocarbons at all speeds and ventilation modes observed concentrations were 0 mg/m^3.

4. Conclusions

The tests helped to identify the ventilation system modes, which provide the maximum concentrations values of harmful substances. For idling and driving at a constant speed the mode of ventilation system providing maximum harmful substance concentrations is recirculation and fan operating at maximum speed.

A particular speed mode at which the concentrations of all harmful substances were the highest failed to be detected, but it was possible to show that higher concentrations of harmful substances in the vehicle interior are observed when the vehicles moved at higher speeds than required by GOST 33554-2015, specifically, at speeds of 90, 110 and 130 km/h.

It is also worth noting that the concentrations of harmful substances in the vehicle interior air were very low – an excess of MPC_{ms} was obtained only for nitrogen oxide at idle. Such concentrations do not correspond to concentrations detected in vehicle interior while travelling along the carriageway [4]. It indicates that the movement of a single car does not reflect the real situation and it is worthwhile to consider other methods of conducting similar studies that take into account the real conditions of traffic movement in the traffic flow.

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