Test Methods and Equipment for Assessment of Passenger Compartment Environmental Parameters of Modern and Advanced Driverless Vehicles

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Abstract. At the moment, no due attention is paid to the problem of ensuring environmental safety of passenger compartments of modern and advanced vehicles, including the driverless ones. The objective of this research is to analyze solutions to this social problem by developing, at this stage, of a new test method and equipment for assessment of parameters of passenger compartments of modern and advanced driverless vehicles.

1. Introduction
The problem of creation and implementation of advanced driverless vehicles (DLV) is one of the most relevant and prioritized ones [1-13]. In 2016, the European Union (EU) adopted Regulations (347/2012 & 351/2012) on traffic safety. The regulations prescribe that all vehicles registered or used within the borders of the EEC shall be equipped with special systems that ensure higher traffic safety level. Those are advanced driver assistance systems (ADAS) ensuring pedestrian recognition, warning the drivers of an emergency, traffic jam and brake assists, systems for vehicle interaction with other road users and road infrastructure.

According to the expert opinion, implementation of DLV and ADAS will allow increasing of traffic safety, efficiency and will allow reducing of cargo and passenger transportation cost, will allow increasing of ride comfort for passengers, will allow reducing of operating fuel consumption and travel time, will allow reducing of emission of hazardous substances (HS) and greenhouse gases into the atmosphere, etc.

One of the unresolved issues in the development and implementation of DLV in the Russian Federation and abroad is the solution of the social problem of ensuring environmental safety of passengers in the passenger compartments, cabins and habitable compartments (hereinafter referred to as "passenger compartments") of modern and advanced vehicles.
2. Main part
Under the operating conditions of modern driver-controlled vehicles and DLV that undergo trial operation, the HS content often exceeds the hygienic standards [14-32]. As a result, modern vehicles continue to have a dangerous influence on life and health of the population in the USA, Germany, Japan, Korea, France, the UK, the Russian Federation and other countries [14-32].

Statistically, the USA had the following negative consequences due to excessive air contamination in passenger compartments: - in the 2000s, about 500 people died each year while driving in cars, and about 1,500 people in garages (not as a result of suicide); - the number of prematurely dying because of the effect of particulate matters (PM) in the air is tens of thousands of people, and the number of poisonings with carbon oxide (CO) reaches 10 thousand cases per year. The US experts have established a connection between the increased mortality and exposure to higher ozone concentrations in the air, especially for people over 65 years old. The number of visits to hospitals due to air contamination in the vehicle passenger compartments is estimated at hundreds of thousands of people, while the majority of the population does not associate their diseases with poisoning by contaminated air.

The air in the modern vehicle passenger compartments contains the following (in the decreasing order of harmful impact on health): ozone, nitrogen dioxide, nitrogen oxide, fine particulate matters, formaldehyde, volatile organic compounds (VOC), aldehydes, carbon oxide and other HS. The solution to the problem of reducing air contamination in the DLV and driver-controlled vehicle passenger compartments to meet the hygienic standards shall begin with the stage of developing test methods and benches for assessment of the environmental safety of DLV passenger compartments and the efficiency of technical and technological solutions to reduce air contamination in the driver-controlled vehicle and DLV passenger compartments.

Both for modern driver-controlled vehicles and advanced vehicles, for example, electric vehicles and driverless electric vehicles which do not emit exhaust gases to the atmosphere, the problem of air contamination in the passenger compartments will remain relevant, as modern cabin air filters of ventilation and air conditioning (HVAC) systems intended for air purification (cleaning) are not actually efficient, especially in relation to such most hazardous HS as nitrogen dioxide, nitrogen oxide, particulate matters (especially the fine ones), ozone, carbon oxide, and are not very efficient in relation to formaldehyde and acrolein. The wear products of road pavement, tyres, brakes and clutch, ozone and other HS contained in the air will keep entering passenger compartments of electric vehicles and advanced electrically driven DLV. Therefore, the problem of improving the quality of air in passenger compartments, cabins and habitable compartments will be relevant for the automotive industry in the long term as well.

The main causes of air contamination in the passenger compartments (in the decreasing order of significance) are as follows:

- Low efficiency of air cleaning by means of cabin air filters of ventilation and conditioning systems.
- Passenger compartment nonhermeticity.
- Absence of control systems for the HVAC systems operation modes depending on the air contamination level in the passenger compartments.
- Absence of diagnostic systems as to the level of air contamination in the passenger compartments.
- Absence of a systematic approach when developing ecological regulations for passenger compartment environmental safety. In particular, no comprehensive work is being done on developing standards for the range of Restricted Hazardous Substances (RHS), their limit content in passenger compartment air, requirements for air cleaning efficiency of cabin air filters and cleaners, requirements for body habitable compartment nonhermeticity, HVAC, HS content diagnostics systems for passenger compartment air, testing methods, etc.
- Lack of public awareness of the problem and of actions to be made in case of excessive air pollution.
Taking into account the importance and relevance of the discussed problem solution regarding the vehicle drivers and passengers, creation of international Vehicle Interior Air Quality (VIAQ) Informal Working Group was approved at the 70th session of the Working Party on Pollution and Energy (GRPE) of the World Forum for Harmonization of Vehicle Regulations (WP29) of the United Nations Economic Commission for Europe in 2015. For two years, this group had been developing draft Mutual Resolution No.3 (M.R.3) concerning the vehicle interior air quality, which was approved and adopted at session 173 of the World Forum WP29 in November, 2017. This resolution includes provisions and harmonized test procedure for the measurement of HS emissions into the passenger compartment air only from the internal trimming materials of a new vehicle, which came off the assembly line, with the run of at most 80 km provided that the contamination of the vehicle passenger compartment air from outside is excluded.

The tests according to this procedure shall be carried out on a static vehicle in a special chamber (box) with measurement of the content of carbonyl compounds, volatile organic compounds including formaldehyde and acrolein in the vehicle passenger compartment air and in the chamber air. However, the listed HS are not the priority ones in terms of the hazard of the harmful impact on the population's health. Their share in the general air toxicity in the vehicle passenger compartment and vehicle chamber does not exceed 10-20%.

At present, the VIAQ Informal Working Group has started working on the second stage of development of the requirements for the air quality in the vehicle passenger compartments regarding the passenger compartment contamination by the substances coming through the ventilation and air conditioning systems, as well as due to vehicle body nonhermeticity. Only the exhaust gases and evaporation from the fuel and lubrication system of the test vehicle are considered the contamination sources. The informal working group plans to start developing the requirements for air cleaning devices and on-board air quality monitoring systems in the piloted vehicles [14] beginning in 2021.

Thus, the VIAQ Informal Working Group formed a limited work plan for the considered problem solution and did not even start developing the test procedure (methodology) for the environmental safety assessment of the vehicle passenger compartments. It is important to note that the international VIAQ Informal Working Group considers only the piloted vehicles controlled by the drivers and does not plan to solve the same problem for the driverless vehicles.

The basic and main drawbacks of the VIAQ group work are as follows:

- the tests according to the adopted test procedure are carried out only on a static vehicle, i.e. they do not include simulation (modeling) of the vehicle motion, which makes the main contribution to the air contamination in the driver-controlled vehicle passenger compartments and cabins;
- the tests are carried out on a test vehicle under the clean air conditions, i.e. they do not include simulation (modeling) of the traffic flow and contaminated urban atmosphere, which make the main contribution to the air contamination in modern driver-controlled vehicle passenger compartments;
- the tests are carried out measuring the following contaminating HS: carbonyl compounds, volatile organic compounds, including formaldehyde and acrolein, while the most dangerous passenger compartment contaminants are particulate matters, nitrogen dioxide, nitrogen oxide, ozone, carbon oxide; the total hazard of the last-named ones exceeds 90% of the total air toxicity in the driver-controlled vehicle passenger compartments and cabins.

The current standard of the Customs Union, GOST 33554-2015, developed in the Russian Federation and compulsory in the countries of the Customs Union, being an integral part of the Technical Regulation On Wheeled Vehicles Safety, practically duplicates the test procedure of the UNECE Regulations and has the same drawbacks. The test procedures applied according to Mutual Resolution No.3 (M.R.3) and Customs Union standard GOST 33554-2015 regarding the vehicle passenger compartment air quality shall be designated as the static ones, which may be conducted under the standard conditions with the specified parameters of the environment and the test vehicle, which may be performed and reproduced by various test laboratories, and that is their advantage.

However, taking into account the basic drawbacks of the test procedures adopted in Mutual Resolution M.R.3 and in the Customs Union standard, the obtained test results are not representative, as
they provide assessment of the vehicle passenger compartment environmental safety only at idle and do not allow assessing the air quality in the passenger compartments of intelligent driverless and driver-controlled vehicles as well as the efficiency of technical and technological solutions for the air quality improvement in the passenger compartments under all vehicle operating conditions at different speeds with the excessive atmospheric air contamination, especially in cities and traffic jams.

There are dynamic (road) methods of testing the passenger compartments for environmental safety in the process of vehicle motion on public roads, which are used by foreign test subdivisions, in particular, by Emissions Analytics (Great Britain) with subdivisions in the United States, Germany and South Korea. However, the known dynamic test methods for assessment of the environmental safety of vehicle passenger compartments and impact of the ventilation and conditioning system operation modes on the environmental safety [28-32] allow obtaining only qualitative results due to incommensurable test conditions (different climatic conditions (air temperature and humidity, wind, pressure, etc.), road parameters, vehicle speed, ambient air contamination, etc.).

The same drawbacks are also characteristic of the stage of dynamic (road) tests set forth in GOST 33554-2015, which are used only for vehicle certification testing and not suitable for scientific research when addressing the discussed social problem.

Summing up the domestic and foreign experience related to the status of solving the social problem of ensuring the population's environmental safety, the following conclusions can be made.

The problem of creating modern driver-controlled vehicles and advanced DLV passenger compartments safe for human health has not received adequate attention and thus the solution thereof for the advanced DLV is of top priority and relevancy.

Nowadays there are no test methods for quantitative assessment of the vehicle passenger compartment environmental safety, for studying the causes of air contamination in the DLV and driver-controlled vehicle passenger compartments as well as for assessment of the technical and technological means and methods to reduce the air contamination level in the passenger compartments to meet the hygiene and health standards.

The solution for the considered problem regarding the driver-controlled vehicles and, in particular, driverless vehicles shall be comprehensive and shall include development of:

Test methods for assessment of harmless content of HS in the driver-controlled vehicle and DLV passenger compartment air.

Unique experimental setups and facilities to test the technical and technological solutions being developed for the guaranteed compliance with the hygienic requirements for the HS content in the driver-controlled vehicle and DLV passenger compartment air.

Standards for the range and maximum allowable concentration of the most hazardous substances that shall ensure environmental safety of the driver and passengers in the driver-controlled vehicle and DLV passenger compartments.

Environmental safety assessment criteria for the driver-controlled vehicle and DLV passenger compartments.

Technical specifications:

- for instrument and equipment to measure the HS content in the air of driver-controlled vehicle and DLV passenger compartments;
- for the nonhermeticity level of driver-controlled vehicle and DLV passenger compartments;
- for emissions of HS in exhaust gases to the atmosphere;
- for the design and health-safe operating modes of the driver-controlled vehicle and DLV passenger compartment HVAC;
- for the design of cabin air filters and air cleaners including autonomous ones, for efficiency of air cleaning by means of these systems and devices in the driver-controlled vehicle and DLV passenger compartments;
- for materials applied for tyres, clutches, brake systems and road pavement, as well as for the amount of their wear products;
for methods and means of diagnostics of air quality in the driver-controlled vehicle and DLV passenger compartments;
for test equipment and measuring instrumentation.

Due to the absence of a driver in a driverless vehicle, maintenance of comfortable and safe conditions in terms of air contamination in the DLV passenger compartments shall be ensured automatically under any driving conditions of the DLV, regardless of the environmental pollution, DLV driving modes, operation parameters of air conditioning systems (climate control) and means to reduce air contamination in the DLV passenger compartments.

Compared to the well-known methods, the test method being developed shall provide testing under stationary conditions with simulation of operating conditions such as excessive contamination of the air over the traffic way, especially in cities, driver-controlled vehicle and DLV speed, and shall ensure measurement of priority HS content (nitrogen oxide and dioxide, particulate matters, ozone, formaldehyde, carbon oxide and other HS) in the DLV passenger compartment air and ambient air during testing.

3. Conclusion
The test method being developed shall provide simulation of operating conditions (ambient air contamination, vehicle motion speed) by contaminating ambient air in a new specially created unique experimental facility performed in a controlled way by DLV exhaust gases (or by supplying corresponding HS to the test facility air from vessels), as well as by simulating vehicle motion speed, which can be performed by means of a fan blowing air at the DLV with a set or specified speed. In the course of testing, the content of priority HS shall be measured in the DLV passenger compartment air and in ambient air.

The results obtained in the course of the testing can form a basis for the following:
- identification assessment of the environmental safety parameters of intelligent DLV and driver-controlled vehicle passenger compartments;
- development of effective technical and technological solutions to ensure environmental safety of the intelligent DLV and driver-controlled vehicle passenger compartments;
- benchmarking or comparative testing of DLV and driver-controlled vehicle passenger compartments regarding their environmental safety parameter;
- benchmarking or comparative testing of technical and technological solutions to remove HS from the air in DLV and driver-controlled vehicle passenger compartments;
- certification testing of DLV and driver-controlled vehicles regarding their environmental safety parameter.
- The creation of integrated intelligent traffic control systems based on new principles opens the possibility to implement the projects, starting with the operation of unmanned cargo vehicles with electric drive in limited areas and their subsequent introduction to public roads, including the northern regions and the Arctic zone of the Russian Federation. The conceptual core of such systems is mathematics and software, which requires concentration of the developers’ efforts in this area.

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