Problem of Hazardous Substances Content Reduction in Habitable Compartments of Driverless Vehicles

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Abstract. Nowadays, road and environmental safety of people during vehicle operation is one of the most important problems. One of the main ways to solve this problem is development and implementation of driverless vehicles, start of operation of which on public roads is expected since 2020-2025. In the process of development, no due attention is paid to addressing the social problem of ensuring passengers' environmental safety in habitable compartments of driverless vehicles (DLV) and modern driver-controlled vehicles. This fact may lead to the DLV implementation process restraint and negative consequences in the process of their operation as a result of harmful exposure of people's life and health to hazardous substances in the air of habitable compartments. The objective of this research is analysis of the solutions for this social problem.

1. Introduction

Global modern automobile transport development is significantly connected with the toughening of requirements for safety and economic efficiency of cargo and passenger transportation as well as for reduction of vehicle negative impact on human and environment. The priority automobile transport development field is considered to be the driverless vehicles (hereinafter referred to as "DLV") development, which is carried out by all leading automobile manufacturers planning to start the DLV implementation in 2020-2025 [1-6].

It is assumed that the DLV implementation would allow raising the efficiency and reducing the cargo and passenger transportation cost, ensuring traffic safety, using the road capacity more effectively, extending the possibility to use vehicles for people with reduced capabilities, ensuring cargo transportation possibility in danger areas, during natural and technogenic disasters or military operations, raising passengers' comfort and safety, reducing operating fuel consumption and travel time, reducing emissions of hazardous substances (hereinafter referred to as "HS") and greenhouse gases into the atmosphere.

Compared to other vehicle development fields, the DLV, active safety systems (ADAS) and DLV components are evolving at a higher rate. As an illustration of that, the foreign development patenting dynamics for the ground DLV, ADAS systems and DLV components is given in Figure 1.
As it appears from Figure 1, the issue of creation and implementation of the advanced DLV is one of the most relevant and prioritized issues of foreign and Russian automobile manufacturers. Nowadays, in the DLV development, one of the most important issues is addressing the social problem of ensuring the environmental safety for the DLV and modern driver-controlled vehicle passengers in terms of harmful impact of the excessively contaminated air in the habitable compartments.

2. Main part

The lack of solution for this social problem will constrain the DLV implementation process and keep the negative consequences during their operation due to harmful impact on people's health and life. In addressing this problem, it is necessary to consider two circumstances.

The first circumstance is that nowadays the problem of excluding the environmental hazard for the passengers is not solved not only for the advanced DLV, but also for the modern and newly developed driver-controlled vehicles, as the HS content may be hazardous to health under the operating conditions in their passenger compartments, cabins and habitable compartments (hereinafter referred to as "HC"). According to publications in the USA, Germany, Japan, Korea, France, the UK, the Russian Federation and other countries [7-20], the consequences of air contamination in the modern vehicle HC may be premature mortality, common diseases of the whole population, feeling unwell, headache, confusion of consciousness when driving and hence a big number of road traffic accidents.
Nowadays the reduction in average life expectancy (premature mortality) due to vehicle negative impact on human is as follows: 1) about 9 months in the EU countries; 2) 1-2 years in the USA; 3) 25-28 thousand people per year in the Russian Federation [13, 16, 17].

The HS in the HC air are especially dangerous for children, aged people, pregnant women, disabled people, asthmatics, people with bronchopulmonary and cardiovascular diseases. Even small HS concentrations in the air have cumulative toxic effect having an impact on passengers' and drivers' health for all their subsequent life.

Environmentally friendly transport technical regulation and development started about 40 years ago. It related only to the HS specific emissions in exhaust gases (hereinafter referred to as "EG") into the atmosphere and did not provide for elimination of the harmful impact of contaminated air in the vehicle HC on drivers and passengers. However, the actual HS content in the atmospheric air, on the sidewalks and in the modern vehicle HC, especially in traffic jams, heavy traffic flows, tunnels, parking and garages may exceed the hygiene standards from 2-4 up to 10-20 times. In megalopolises, drivers and passengers spend from 0.5 to 1.5 hour on average per day in traffic jams and during this time, being in the HC, they inhale more HS, than during the rest of the day and few times more than people who do not use vehicles [7, 9-13]. As a result, until the considered problem is solved, the negative impact of HS in the driver-controlled vehicle and DLV HC on the population will remain and hold true.

Due to importance and relevance of the discussed problem solution, 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. This group developed draft Mutual Resolution No.3 (M.R.3) concerning the vehicle interior air quality, which was adopted at session 173 of the World Forum WP29 in November, 2017. However, this resolution includes provisions and harmonized test procedure for the measurement of HS emissions into the HC air from the internal trimming materials only and only for a new vehicle, which came off the assembly line, with the run of at most 80 km provided that the HS entering the vehicle HC from the ambient air are excluded.

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

At present, the VIAQ Informal Working Group started the work on the second stage of development of the requirements for the air contamination by HS entering the HC through the ventilation and conditioning systems, as well as due to vehicle bodies nonhermeticity. At the same time, the EG and fuel and lubrication system evaporations from the test vehicle only are considered to be the contamination sources. The informal working group plans to start developing the requirements for HC air cleaning devices and on-board air quality monitoring systems for the vehicles only [7] from 2021.

It follows that the work plan of the VIAQ group is not aimed at the general solution of the considered problem in the coming years. It is also important to note that the international informal working group focuses only on piloted vehicles controlled by drivers and is not involved in solving the problem regarding passengers and operating personnel in the DLV HC.

Considering the fundamental shortcomings of the test procedures established in the Mutual Resolution M.R.3, the obtained test results when using them are not representative, as they do not allow estimating the air quality in the DLV and driver-controlled vehicle HC, estimating the efficiency of technical and technological solutions for air quality improvement in the HC under vehicle operating conditions at various speeds with excessive atmospheric air contamination, especially in cities.

It is important to note that for modern piloted and advanced vehicles, for instance, electric vehicles and electrically driven DLV that do not emit EG into the atmosphere, the solution of the social problem under discussion is also relevant. Without additional technical solutions, the wear products of road pavement, tyres, brakes and clutch (including PM2.5, PM10, CH2O, VOC, etc.) as well as O3 and other
substances hazardous for health contained in the atmospheric air, will keep entering the HC of electric vehicles and advanced DLV.

Table 1 provides general information about the efficiency of removing HS (nitrogen dioxide (NO2), nitrogen oxide (NO), particulate matters (PM10), extra fine particulate matters (PM2.5), ozone (O3), carbon oxide (CO), formaldehyde (CH2O), Volatile Organic Compounds (VOC)) by means of modern air cleaners in the vehicle HC [23-32].

**Table 1. Efficiency of modern cabin air cleaners.**

| Air cleaning methods and systems | Hazardous substances to be removed | Disadvantages of cabin air cleaners |
|---------------------------------|-----------------------------------|-----------------------------------|
|                                 | PM10  | PM2.5 | NOx | CO | VOC | CH2O | Soot |                  |
| Cabin air filter (paper)        | +     | -     | -   | -  | -   | -    | -    | Removes only coarse particulate matters (PM), does not remove NOx, CO, CH, formaldehyde |
| Cabin air filter (paper + carbon)| +     | -     | -   | -  | -   | -    | -    | Does not remove fine PM, as well as NOx, CO |
| Air ionizing air cleaner        | -     | -     | -   | +  | +   | -    | -    | Does not remove NOx, dust; emits O3 - the HS of hazard class 1 - into the air of habitable compartments |
| Ozonizer                        | -     | -     | -   | +  | +   | -    | -    | Does not remove NOx, PM; emits O3 - the HS of hazard class 1 - into the air of habitable compartments |
| Photocatalytic purifier         | -     | -     | -   | +  | +   | -    | -    | Does not remove NOx, PM, large weight and overall dimensions |
| Pulsed corona discharge air cleaner | -     | -     | -   | +  | +   | -    | +    | Unacceptably high energy costs, weight, overall dimensions, no PM removal |

Remark: + - air cleaning; - - no air cleaning; ⊥ - partial air cleaning; NI - no info.

The most commonly used for air cleaning in the vehicle HC are the **cabin air filters** installed in conditioning systems. The majority of population, and even specialists, have an erroneous idea that they effectively clean the contaminated air in the vehicle HC, ensuring the environmental safety of drivers and passengers.

But the modern **cabin air filters** containing paper (item 1, Table 1) and, at best, carbon filtering material (item 2, Table 1) do not remove nitrogen oxide and dioxide, ozone and carbon oxide from the air. This is their fundamental disadvantage. The cabin air filters are also not very effective regarding other priority HS. Due to the absence of standards for the fineness of air cleaning, paper filtering
materials in them remove only coarse PM – larger than 2-5 microns [16] that are much less toxic than finer PM$_{2.5}$ [22, 26-29].

**Air ionizing air cleaners** (item 3, Table 1) and **ozonizers** (item 4, Table 1) partially remove only CO, some groups of hydrocarbons and soot from the air and reduce the air smell in the HC. However, they do not remove NO$_2$, NO and dust from the air and are not very effective against formaldehyde. Their major disadvantage is also that they generate and deliver ozone into the air of the cabins, the content of which in the air higher than the hygiene standard is more dangerous than any of the HS, such as NO$_x$, PM, CH$_2$O, CO.

In the Russian Federation, vehicle owners widely use air ionizing air cleaners (for instance, automobile air ionizers XJ-801, 802, "Fresh Air To Go", etc.) which are prohibited in the USA. The ozone content in urban atmosphere is typically at the level of or exceeds hygiene standards [24, 31, 32]. For this reason, additional emission of ozone into the air of the vehicle HC by ionizers without using means for diagnosing its content in the air (gas analyzers) is extremely hazardous and is not allowed in accordance with the current sanitary regulations of the Russian Federation. At the same time, air ionizing air cleaners are being successfully certified, which proves the shortcomings of the regulatory framework for vehicle environmental safety.

**Photocatalytic purifiers** (item 5, Table 1) ensure CO removal up to 70%, are less effective in relation to individual hydrocarbons, formaldehyde and do not remove NO$_2$, NO and dust from the air, and have a large weight and overall dimensions [25]. For these reasons, photocatalytic air purifiers are not widely used in the vehicle HC.

**Pulsed corona discharge installations** (item 6, Table 1) [27] along with little knowledge of them, design complexity, large overall dimensions and weight, excessively high power consumption, and limited number of HS that they remove, generate and deliver ozone into the HC air. Therefore, the use of these setups in the vehicle is not promising.

Thus, none of the means presented in items 1 to 6 of Table 1 provides effective air purification in terms of all priority HS. Given this, the world's leading automakers are developing their own technical solutions to reduce air contamination in vehicle HC, however, they are not effective enough. Tesla, for example, applies the control of vehicle HC air bioprotection using HEPA filters; BMW, Toyota and Volvo an apply air recirculation mode in HVAC systems in order to prevent ingress of HS into the vehicle HC from the ambient air [21-23].

Taking into account Russian and foreign experience in solving the social problem under consideration, we can conclude that at present the international community is still far from developing efficient technical and technological solutions to eliminate excessive air contamination in the driver-controlled vehicle and DLV HC.

The second fundamentally important circumstance is that there is no driver in the DLV. Therefore, maintenance of comfortable and safe conditions in terms of air contamination in the DLV HC shall be carried out automatically, regardless of the level of environmental pollution, DLV driving modes, operation parameters of air conditioning systems and applied means to reduce air contamination.

### 3. Conclusion

Note should be made of the lack of unified standardized assessment methods for the vehicle HC environmental safety and for assessment of technical and technological solutions for its improvement as well as of fragmentary nature of results of investigation of ventilation, conditioning and climate control system operation mode impact on the air quality in the vehicle HC depending on the air contamination level in the habitable compartment air and ambient air, and on the vehicle speed for the whole range of the most dangerous HS as well as CO$_2$.

If using a comprehensive approach, solving the considered problem in the first stage shall begin from the development of an intelligent automatic control system for the HC environmental safety systems and tools operation, which will allow reducing the air contamination levels in the HC of not only DLV but also modern driver-controlled vehicles significantly.
Such control system, based on the gas analyzers and particulate matter counter data on the ambient and HC air contamination during the vehicle operation under the conditions of excessively contaminated air, will allow activating the conditioning system in recirculation mode automatically, thus reducing the HS entering the DLV and driver-controlled vehicle HC from the ambient air, and allow additional automatic activation of autonomous air cleaners to provide auxiliary air cleaning up to the safe levels.

Acknowledgments
This scientific paper was prepared based on the results of the applied scientific research performed with governmental financial support from the Ministry of Education and Science of the Russian Federation, Agreement No. 14.625.21.0043, Unique Project ID RFMEFI62517X0043.

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