Modern problems of exhaust gases pollution in urban environment

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Abstract. The paper provides materials of Russian and foreign studies showing that the current urban pollution is defined not only by emissions of hazardous particulate matters (PM) with vehicle exhaust gases, but also by particulate matters from other vehicle systems and materials, especially from wear of asphalt roadways. Results of Russian and foreign studies of emissions of a cancerogenic substance which is very hazardous for the health of urban population – benzo(a)pyrene – are presented. Joint studies carried out in the Russian Federation and in the UK are presented regarding comparative determination of the values of particulate matter emissions less than 2.5 microns from different sources of their emissions: with exhaust gases (26%); from wear of brake systems (6%); from wear of tyres (12%) and from wear of roadways (55%). Analysis of potential high-priority investment projects aimed at reduction of urban air pollution with hazardous particulate matters containing cancerogenic substances causing oncological diseases among the population and reduction in their life expectancy is presented.

1. Introduction
The new modern problem of atmospheric pollution in large cities revealed by the Russian studies is not discussed as widely as this much discussed issue in the press and on television coronavirus pandemic having a psychologically terrifying influence on the planet population by an expanding danger. However, on our planet the humankind breathe (9 out of 10 people) the air with a high concentration of pollutants of every kind, including particulate matters, according to the World Health Organization (WHO) data published in 2018 [1]. The WHO states that due to this reason more than 7 million people die each year being in such polluted atmosphere containing particulate matters (PM) able to penetrate deep inside the lungs and cardiovascular system, causing lung cancer, stroke, cardiovascular diseases and pneumonia [1, 2].

2. Results of foreign and Russian studies
Figure 1 shows the studies on the particulate matter (PM) content in the air of our planet within the period from 2008 to 2013 [1, 2].

The ecological and economic efficiency of works performed by the vehicle manufacturers according to the international standard requirements of the UN Regulations (from Euro-0 to Euro-6) phased in since 2000 provided significant reduction of the total damage with the real prevented damage. Figure 2 shows the results using the example of the trucks of the vehicle fleet of the Russian Federation.
Taking into consideration the above-mentioned current state of the issues of concern regarding the global and local urban environment pollution with hazardous substances and highly hazardous particulate matters as well as with the greenhouse gas emissions, the following measures taken by the global society (civilization) to address this complex global ecological and economic issue can be observed:

1. In 2012, due to smog emerging first in European cities, the WHO suggested prohibiting the use of vehicles with diesel engines in the urban automotive transport as it was detected to have the increased emission of PM. This very suggestion of the WHO was accepted by the European Union countries.

2. Due to the increased greenhouse gas – carbon dioxide (CO₂) – emissions resulting from massive fossil fuel (coal, oil, gas) combustion over the past period of time, the global warming of our planet led to a significant increase in the planet temperature, which was reflected by powerful hurricanes and extensive floods with a big number of fatalities in 2019-2020.

3. The issue of the CO₂ greenhouse gas emissions from all sources in general, in particular from the automobile transport operation, has not changed over the last 30 years. Thus, according to the 2017 results, the European Union, Russia, the USA, and Japan decreased CO₂ emissions nearly 2-2.5 times. However, there was also a sharp increase in greenhouse gas emissions – 2.5 times in China, almost 3

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**Figure 1.** Average annual concentrations of PM from 0 to 2.5 and up to 10 µm in the atmosphere of our planet.
times – in India, and almost 1.5 times – in other developing countries, therefore in 2018, total global greenhouse gas emissions counted 33.9 billion tons [3].

![Figure 2](image)

**Figure 2.** Reduction of ecological damage from trucks and buses exhaust gases per 1 mln km against the change in international standards of UNECE Regulation No. 49 from Euro-0 to Euro-6 in rubles.

### 3. Research procedure

Based on results of foreign and domestic investigations on reduction of emissions of hazardous substances, greenhouse gases and particulate matters caused by vehicle operation, one should admit that development of a special procedure by FSUE "NAMI" in 2014 was quite practical for objective evaluation of efficiency of new vehicles being developed and industrialized, as well as design and technological solutions for assessment of various hazardous substance and particulate matter emissions taking into account their relative aggressiveness [4].

Using such concepts as "relative aggressiveness" and "mass emission" of hazardous substances within this procedure allowed assessing not only just cumulative emission toxicity, but also the share of individual components by hazard degree, which additionally allows defining their specific economic damage in rub/km or in rub/kW•h.

The conversion suggested in the procedure significantly changes the view of assessment of individual components into reduction to total toxicity of vehicles with different engines by the maximum allowable concentration (MAC). Thus, when calculating with the 1978 data, over 70% of the reduced emission by gasoline engines was carbon monoxide, while the main toxic component of the diesel engine exhaust gas was nitrogen oxides. Particulate matters in gasoline engines made only ~7% of the total toxicity. Particulate matters in diesel engines belonged to nitrogen oxides and particulate matters, while the share of the latter (PM) in the reduced hazardous emission by diesel engines already amounted to ~45% (Table 1).

| Toxic components of exhaust gases | Basic pollutant | 1978 | 1982 | 1986 | 1999 | 2010 | 2020 |
|----------------------------------|----------------|------|------|------|------|------|------|
| Carbon monoxide                  | Carbon monoxide | 1.0  | 1.0  | 1.0  | 0.09 | 0.09 | 0.09 |
| Sulphur dioxide                  |                | 2.0  | 14.0 | 22.0 | 22.0 | 22.0 | 22.0 |
| Nitrogen oxides                  |                | 3.0  | 18.0 | 41.1 | 3.74 | 3.74 | 3.74 |
| Hydrocarbons                     |                | 2.7  | 2.5  | 3.16 | 1.68 | 1.68 | 1.68 |
| Particulate matters              |                | 1.8  | 120.0| 200.0| 300.0| 300.0| 300.0|

Table 1. Relative aggressiveness (toxicity) of hazardous substances, mg/m³
Based on the above, it can be concluded that the new views require new evaluation methods and ways to improve the economic and environmental parameters of the produced vehicle engines.

Thus, the studies performed in 2013-2019 in FSUE "NAMI" and focused on defining the basic causes of urban atmosphere pollution stated that emissions of particulate matters (less than 10 micron) from wear of tyres and roadway exceed the damage from PM with exhaust gases of passenger cars 60 times and of trucks 300 times respectively. This does not confirm the high-priority need in the ban suggested by the WHO and introduced in Europe on use of diesel-engine vehicles in urban transport [4,5,6].

It should also be noted that as of right now there is no generally accepted measurement system for especially hazardous cancerogenic substances contained in tyres, roadway and fuel and therefore in exhaust gases. For assessment of the current cancerogenic substances emission situation devoid of control at the international level, total masses of hazardous substances emissions $- M_{hs}$ measured by FSUE "NAMI" are shown as an example in Table 2, presently considering only cancerogenic benzo(α)pyrene [3].

### Table 2. Total mass of hazardous substance emissions considering a higher hazard degree of cancerogenic benzo(a)pyrene

| Euro standard | Euro-1 | Euro-2 | Euro-3 | Euro-4 | Euro-5 | Euro-6 |
|---------------|--------|--------|--------|--------|--------|--------|
| $M_{hs}$ gasoline engine | 613.6 | 612.5 | 607.8 | 605.5 | 604.9 | 602.0 |
| $M_{hs}$ diesel engine | $1.2 \cdot 10^5$ | $1.2 \cdot 10^5$ | $1.1 \cdot 10^5$ | $1.1 \cdot 10^5$ | $1.1 \cdot 10^5$ | $1.1 \cdot 10^5$ |

### Table 3. Values of PAH emissions in µg/km

| Chemical substances | Vehicle engines | Liquefied-gas (propane-butane) |
|--------------------|----------------|-------------------------------|
|                    | Gasoline       | Diesel                        |                               |
|                    | Passenger car  | Light truck                   | Passenger car                 | Light truck |
| benzo(a)pyrene     | 0.48           | 0.32                          | 0.63                          | 2.85        | 0.01 |
| indeno(1,2,3-cd)pyrene | 1.03         | 0.39                          | 0.70                          | 2.54        | 0.01 |
| benzo(k)fluoranthene | 0.30          | 0.26                          | 0.19                          | 2.87        | 0.01 |
| benzo(b)fluoranthene | 0.88          | 0.36                          | 0.60                          | 3.30        | 0.02 |
| benzo(ghi)perylene | 2.90           | 0.56                          | 0.95                          | 6.00        | 0.02 |
| fluoranthene       | 18.22          | 2.80                          | 18.00                         | 38.32       | 1.36 |
| pyrene             | 5.78           | 1.8                           | 12.3                          | 38.9        | 1.06 |
| phenanthrene       | 61.72          | 4.68                          | 85.50                         | 27.65       | 4.91 |
| anthracene         | 7.66           | 0.80                          | 3.40                          | 1.37        | 0.38 |

Table 3 provides information on the polycyclic aromatic hydrocarbons (PAH) content in the mix of particulate matters from exhaust gases, from wear of tyres and roadway collected after a moving passenger car and light truck (according to the results of foreign studies). The values are expressed in parts per million (ppm) [8].

The tables above show the increased hazard degree of SO$_2$, NO$_x$, and PM emissions within the total emissions of hazardous substances, and considering the concentration of the cancerogenic substances in the exhaust gases and in particulate matters from wear of tyres and roadway. Their hazard degree exceeds that of other hazardous substances more than $10^2$ - $10^4$ times for the gasoline engines and $10^5$ - $10^8$ times for the diesel ones.

It is important to highlight the order of the Deputy Prime Minister of the Russian Federation, Victoria Abramchenko, dated July 27, 2020 for the Ministry of Natural Resources and Environment of the Russian Federation and Federal Service for Supervision of Natural Resources. It aims to update the current calculation methodologies for environmental damage due to breach of legislation concerning the environmental protection and the Subsoil Law by October 1, 2020. Besides, the instruction prescribes
that by this time a procedure to calculate the atmospheric air damage because of man-made accidents and industrial impact shall be created from scratch.

4. Results of comprehensive research carried out in the Russian Federation and Great Britain
Summarizing the more and more complex issue of air pollution due to operation of about 2 mln vehicles already within the current period, improvement of the urban living environment for people cannot be expected. Figure 3 gives the results of the investigations performed by the FSUE "NAMI" specialists based on the example of the Russian Federation vehicle fleet operation, which were presented within the World Forums on the development of the international UN Regulations with the requirements for vehicle design (WP-29) of the UNECE Inland Transport Committee (ITC) in 2017-2018 [4-7].

![Figure 3](image_url)

Figure 3. Dynamics and forecast of annual PM emissions from wear of tyres, braking mechanisms and asphalt roadway in the Russian Federation, in tons, compared to the emissions and emissions limits (standards) for PM with EG.

In 2018, these results of investigations by the Russian Federation were confirmed by Great Britain in their report [9].

Figure 4 provides the comparative results of the research on PM emissions during vehicle operation according to the materials from the Russian Federation and the United Kingdom (UK) [6, 9, 10].
The range of research works on real PM emissions evaluation conducted in the Russian Federation and in the UK was presented within the Working Party on Pollution and Energy (GRPE) of the World Forum (WP-29). It allowed objective evaluation of the current level of PM emissions into the urban air environment reflected in the following % ratio: with exhaust gases – from 25 to 30%, from brake systems – from 2 to 10%, from wear of tyres – from 9 to 17%, and from roadway – from 42 to 63%. This does not match the WHO position relating to prohibition of use of vehicles with ICEs in the cities.

During the UNECE ITC World Forum (WP-29) session in November 2019, representatives from more than 100 countries concluded that UNECE Regulations should legally control not only emissions of hazardous substances and PM with vehicle exhaust gases, but also those from wear of tyres and brake mechanisms.

5. Conclusion
Based on the performed studies of current issues of complex environmental safety of the existing and new vehicle designs, it is necessary to draw the following conclusions:

1. The main international legal regulation of emissions of hazardous substances from vehicles that started in the 70s of the past century has led to a significant reduction in emissions of hazardous substances and particulate matters. However, as demonstrated by the example of vehicle fleet expansion in the Russian Federation (Figure 3) and vehicle fleet expansion in developing countries, it will not lead to a considerable reduction in emissions volume, especially in urban areas.

2. The progress & success that have been made by the world scientific and industrial community, the results on reduction in emissions of hazardous substances and particulate matters with exhaust gases over the past 30 years still do not permit creation of "pollutant-free" (green) vehicles for the urban environment. Thus includes the people in the coming decades, even with the expansion of production and operation of electric vehicles in urban areas, as well as future mastering of production of vehicles operating on environmentally friendly hydrogen fuel. This happens because of the increased emissions from these new vehicles of highly hazardous particulate matters and hazardous cancerogenic substances from tyre and asphalt roadway wear.
3. The above-mentioned present-day state of addressing the issues, as well as all that is currently happening show the need to re-define the opinion and attitude of governmental bodies regarding speed-up of investment of necessary funds in more efficient (not only electric vehicle) areas (programs) for real reduction of PM emissions and of their content of cancerogenic substances. That today causes silent deaths of more than 7 million people on our planet, which is out of mass media line compared to the coronavirus fatalities amounting to 3 million people that have been happening in 2020-2021.

Proceeding from the above results of research on current civilization development, satisfaction of humanity's needs intensively leads to increased pollution of our planet, while no in-depth comprehensive research is carried out when implementing new materials, mechanisms and designs of moving objects.

In our opinion, to optimize targeted investments in new technologies, it is necessary to determine comparative characteristics of complex environmental friendliness of the existing vehicles and new vehicles under development according to a comprehensive parameter determined in conformity with the full life cycle method with assessment of their cost in production and in operation.

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