Scientific problems in the field of research of non-exhaust particulate matter emissions formed during the movement of wheeled vehicles

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Abstract. Emissions of non-exhaust particulate matter are among the most dangerous emissions of pollutants generated by the movement of wheeled vehicles. At the same time, scientific research and legal regulation in this area are insufficient for making informed decisions on the real reduction of the impact of these emissions on the environment and public health. The article presents an overview and analysis of domestic and foreign scientific research, as well as the regulatory framework in the field of emissions of non-exhaust solid particles formed during the operation of wheeled vehicles. Priority directions of scientific research and development of the regulatory framework for limiting emissions of particulate matter especially hazardous to public health have been formed.

1. Introduction
Currently, in large megacities of the world, road transport accounts for 50 to 80% of all anthropogenic emissions of air pollutants [1–3]. In view of the above, the United Nations (UN), government, scientific and public organizations, as well as business are taking coordinated measures to reduce the negative impact of wheeled vehicles on the environment and public health.

2. Legal regulation in the field of emissions of pollutants generated during the movement of wheeled vehicles
In the current period of time, the negative impact of wheeled vehicles on the environment (exhaust emissions, noise and electromagnetic pollution, etc.) is limited by the relevant international and national regulatory legal documents (international agreements, technical regulations, UN rules, standards, directives, etc.). These documents are reviewed periodically, amended and supplemented, as well as new documents are created aimed at tightening restrictions on environmental pollution by wheeled vehicles.

In the Russian Federation, the environmental safety of wheeled vehicles is directly or indirectly regulated by 7 international agreements, the technical regulations of the Customs Union "On the Safety of Wheeled Vehicles", the technical regulations of the Customs Union "On requirements for automobile and Aviation gasoline, diesel and marine fuel, jet fuel and fuel oil", 6 federal laws, 4 decrees of the President of the Russian Federation, 15 resolutions and 3 orders of the Government of the Russian Federation, 15 UN regulations and a number of other regulatory legal documents.

At the same time, there are no regulatory legal acts that limit environmental pollution by emissions of non-exhaust particulate matter (wear of brakes, tires and roadway), the share of which is constantly
Growing due to the global increasing of the world vehicle fleet. Moreover, there are no generally accepted methods for studying such emissions. The results of emission estimates obtained by different methods may differ tenfold [4].

3. Modern methods of research of non-exhaust particulate matter emissions

Currently, three approaches are usually used in the study of non-exhaust particulate matter emissions – direct measurement in the conditions of bench or road tests, computational studies and mixed studies (experimental and computational).

The direct measurement on the bench allows the emissions from tire wear and brake wear to be determined separately. Direct measurement in road test conditions allows to define emissions from wear of brakes, tires and the roadway. However, in this case, there is uncertainty associated with the separation of emissions from tire wear and from roadbed wear, as well as from the resuspension of existing road dust [5].

Estimates are usually based on data from manufacturers on the service life or wear rates of tires and brakes, wear rates and roadway repair times.

Most of the current methods for estimating non-exhaust particulate matter emissions are mainly related to obtaining data on gross emissions of pollutants from vehicles obtained from stationary measurement sources located along highways and motorways. This data is used to compile national and international inventories of air pollutants. The estimation and forecasting of emissions in this case is usually carried out by an experimental calculation method without breaking down by source of origin.

At the same time, in some cases it is necessary to assess the actual contribution of individual sources of pollutant emissions in order to take appropriate regulatory or design and technological measures that reduce the negative impact of these emissions on the environment and public health.

The methodologies for estimating emissions of exhaust origin are sufficiently developed and formalized by the relevant UN regulations, while there are no generally accepted methodologies for estimating emissions of non-exhaust origin.

In different countries, different researchers in each specific case apply their own methods for measuring the amount and composition of non-exhaust particulate matter emissions. Review and analysis of domestic and foreign scientific research in this area has revealed a wide variety of these methodologies.

Since 2009, the specialists of FSUE "NAMI" have repeatedly noted the importance and necessity of studying the non-exhaust particulate matter emissions formed during the movement of wheeled vehicles [1, 2]. They also raised this issue on behalf of the Russian Federation at the meetings of the working groups of the World Forum for Harmonization of rules in the field of Vehicles (the World Forum). Finally, in June 2013, within the framework of the Working Group on Energy and Environmental Pollution (GRPE) at the World Forum, an informal Expert Working group (PMPgroup) was formed and studies of particulate matter emissions from brake wear were initiated.

3.1. Studies of emissions from brake wear

The development of an international brake cycle for the study of particulate matter emissions from brake wear is currently being finalized within the framework of the PMPgroup. The cycle is based on the reference driving cycle database - WLTP (Worldwide Harmonized Light-Duty Vehicles Test Procedure), which includes driving data in five different regions of the world (EU, USA, India, Korea and Japan) with a total mileage of 743,694 km. The cycle duration is 4 hours 24 minutes, with the length of 192 km, average speed of 44 km/h maximum speed – 133 km/h, slowing to 0.49-2.18 m/s² (mean value of 0.97 m/s²). During the cycle, 303 stops are simulated. The cycle is repeatable and reproducible on a dynamometer bench and on a real car during testing at the test site. An important condition of the cycle is maintaining adequate temperature conditions for testing, ensuring the same level of temperature of the brake discs on the road and in the laboratory, necessary for the correct assessment of the amount and composition of solid particles released by the brakes. The specified
brake cycle is the first step in starting the regulatory work on particulate emissions from brake wear. Illustration of the braking cycle on the vehicle and on the bench is shown in Figure 1.

Figure 1. WLTP brake cycle on the vehicle and on the brake bench.

Figure 2 shows an example of synchronization of temperature conditions during tests on a vehicle and on a bench [6].

Figure 2. Temperature of the brake disc on the vehicle and on the bench.

The final completion of the methodology for measuring particulate emissions from brake wear and its presentation for discussion at GRPE and the World Forum is planned for the 4th quarter of 2021.

3.2 Studies of emissions from tire and roadway wear

Review and analysis of the literature has shown that the results of scientific studies of particulate emissions from tire and roadway wear are often not comparable due to various factors: the material of tires from different manufacturers, the composition of the roadway in different regions, the conditions of testing and sampling, as well as the equipment and measurement methods used.
In 2017-2018, ISO standards were issued, which can serve as a basis for creating a unified methodology for estimating particulate emissions from tire and road wear, as well as determining their physical and chemical properties (Table 1).

Table 1. ISO standards

| №   | ISO/TS standard | Note                                                                 |
|-----|----------------|----------------------------------------------------------------------|
| 1   | ISO/TS 20593: 2017. Ambient air – Determination of the mass concentration of tire and road wear particles (TRWP) – Pyrolysis-GC-MS method | Describes method for determining the mass concentration (mcg/g) and mass fraction (%) of tire and road wear particles in air by pyrolysis and gas chromatography-mass spectrometry |
| 2   | ISO/TS 21396: 2017. Rubber – Determination of mass concentration of tire and road wear particles (TRWP) in soil and sediments – Pyrolysis-GC/MS method | Establishes the principles of collecting soil or sediment samples and determining the mass concentration (mcg/g) of tire and road wear particles by pyrolysis and gas chromatography-mass spectrometry |
| 3   | Section 1.01 ISO/TS 22638:2018. Rubber – Generation and collection of tyre and road wear particles (TRWP) – Road simulator laboratory method | Defines the method for measuring tire and road wear particles on the bench |
| 4   | Article II. ISO/TS 22640:2018. Rubber – Framework for physical and chemical characterization of tyre and road wear particles (TRWP) | Provides a basis for characterizing the physical and chemical properties of tire and road wear particles using published ISO, ASTM and AFNOR standards, etc. |
| 5   | Article III. ISO/TS 22687:2018. Rubber – Framework for assessing the environmental fate of tyre and road wear particles (TRWP) | Sets out general guidelines for evaluating the transformation of chemical additives in tire tread during polymer curing, as well as tire particles and road wear throughout the tire life cycle |

In roadside TRWP emission studies, sampling is usually performed at the wheel of the vehicle using a vacuum device. In this case, the emission of solid particles can be read directly during sampling (determination of the number and dispersion of particles) or undergo a rather complex procedure of pyrolysis, gas chromatography and mass spectrometry (determination of the chemical composition of particles).

Figure 3 shows a bench with a running drum for measuring particulate emissions from tire wear, which meets the requirements of ISO/TS 22638 [7].

Figure 4 shows the laboratory and road complex of the Japan Automobile Standards Internationalization Center (JASIC) for TRWP research [8].

Emissions from tire and roadway wear are sampled from the "fifth wheel" located in the base of the complex. After sampling and filtration, solid particles are studied using thermal cracking, gas chromatography, and mass spectrometry. In this case, there is some uncertainty due to the difference between the rolling process of the "fifth wheel" and the rolling process of the real wheels of the car.

In contrast to the Japanese method, the methods of FSUE "NAMI" and a number of other research centers provide for the sampling of TRWP directly from the wheels of the tested car. In this case, the particulate emission samples correspond to the actual rolling process of the wheel of a particular vehicle.

Figure 5 shows the installation of a receiving pipe for the sampling of solid particle emissions from the tire contact with the roadbed according to the method of FSUE "NAMI". The amount and dispersion of solid particle emissions are measured directly using the Lighthouse HENDFELD 3016 laser particle counter manufactured in the USA (Fig. 6), which has 6 counting channels showing the number of particles of six size ranges in the selected sample [9].
Figure 3. Test bench according to ISO/TS22638 standard.

Figure 4. Diagram and photo of the laboratory and road complex of the JASIC company [7].

Figure 5. Installation of a receiving pipe for the sampling of solid particle emissions from the tire contact with the roadbed according to the method of FSUE "NAMI".
Figure 6. Lighthouse HANDHELD 3016 Laser Particle Counter.

Figure 7 shows the location of the sampling sites directly inside the wheel arch when measuring particulate emissions carried out by specialists from the Ford Aachen GmbH Research Center (Germany) and the German university Bergische Universität Wuppertal. The particle size distribution of solid particles was analyzed using the TSI Engine Exhaust Particle instrument. Sizer (EEPS) [10].

Figure 7. Sampling points (aligned with the middle line of the wheel): 1 – at the junction of the tire with the road; 2–4 - vertically relative to the tire tread; 5 – the initial position of the background in front of the car; B – at the brake disc.

Currently, according to the European research and innovation program "SHARE: Sustainable Holistic Approach to Road Emissions and noise" (Horizon 2020), the French research center Utac Ceram intends to conduct scientific research on the assessment of particulate emissions from tire wear, roadbed, tire noise and their impact on human health and the environment. As a result of the research, it is planned to create test methods for assessing tire and roadway wear, as well as to provide recommendations for the European tire industry to reduce the harmful effects of tire wear products on human health. The work is planned to be carried out in the period from 2021 to 2024. In August 2020, FSUE “NAMI” supported this work and expressed interest in receiving information about the non-
confidential results of this project and participating in meetings/seminars that will be organized within the framework of the project.

4. Conclusion

1. Based on Russian studies, the international community, within the framework of the World Forum in 2019, recognized the significant role of non-exhaust emissions generated by the movement of wheeled vehicles in environmental pollution and the lack of generally accepted methods for studying such emissions.

2. As a priority, it is planned to complete the development of methodology for measuring particulate emissions from brake wear and present it for discussion at the GRPE and World Forum sites in the 4th quarter of 2021.

3. For an objective assessment and analysis of non-exhaust emissions generated by the movement of wheeled vehicles, it seems appropriate to primarily develop generally recognized standardized methods for assessing the wear of tires and roadbed in real operation, broken down by source.

4. The French research center Utac Ceram plans to conduct work on the study of emissions from tire wear and roadway in the period from 2021 to 2024. It is assumed, that FSUE "NAMI" will receive non-confidential results of this work.

5. Considering the above and the experience of FSUE "NAMI" researches in the period from 2009 to 2019 in the field of particulate emissions from wear of tires and of the roadway, research on these emissions needs to be expanded and continue to actively participate in the discussion of standardized test methods of non-exhaust emissions, formed during the movement of wheeled vehicles.

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