Current challenges and innovations in environmental safety of vehicles

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Abstract. The automobile is one of the mass industrial products. The article analyzes its environmentally harmful effects on the environment. The current environmental safety of vehicles is analyzed and changes in the structure and volumes of harmful emissions caused by innovative design changes are justified. The destructive effect of the wheel propulsion on the soil cover in natural landscapes is described. The current state of the car recycling system is analyzed and some promising technologies for its implementation are described.

1. Introduction
At present, the number of vehicles is 800 million [1]. By 2035, there will have been 3 billion vehicles [2]. It is obvious that the automobile as one of the mass industrial products is a vivid representative of the large-scale negative impact on the environment (exhaust emissions, noise and vibration [3, 4], the destructive effect of the propulsion device on the road and soil [5–9], products of operational wear of automotive components [10], products of car recycling and special operational technical fluids [10–12], etc.). The maximum permissible norms of this negative impact are scientifically substantiated and regulated by federal and industrial acts [12–18]. They aim to reduce environmental pollution and ensure safety of roads and landscapes. But they do not regulate waste management, sources of secondary materials and energy resources. As a result, complex multicomponent automobile waste is not recycled due to the high cost of collecting and separating it. The availability of primary raw materials and its relatively low cost make the use of waste unprofitable. In addition, the existing regulatory mechanisms do not contribute to their involvement in economic activities. However, evaluating environment development forecasts in the automotive sector, one cannot but take into account current design trends whose implementation can significantly affect priorities in the fight for the environmental safety of the automobile [19, 20].

Thus, the need for a comprehensive synthesis of domestic and foreign experience in reducing environmentally harmful consequences of mass motorization in conditions of stringent international restrictions and regulations, is obvious.
2. Justification of the object, subject, tasks and methods of research

The research object is the state of the human environment in conditions of mass motorization. The research subject is environmental safety of the car at all stages of its life cycle. The research objective is to assess the impact of innovative design changes on environmental safety of the car. The research methods are statistical analysis and forecasting.

2.1 The state of human environment in conditions of mass motorization

**Engine exhaust emissions**: Cars emit more than 4 billion tons of carbon dioxide (CO2) into the air. By 2030, this figure can reach 7 billion tons and increase the average air temperature by 4 °C compared with the pre-industrial level. The exhaust gases of internal combustion engines (ICE) contain more than 200 toxic substances. The most carcinogenic ones are carbon monoxide, oxides of nitrogen and sulfur, soot, aldehydes, compounds of lead and other heavy metals [3, 21]. Legislative requirements for emissions of harmful substances determine the environmental class of a car (for example, EURO 2, EURO 3, EURO 4, EURO 5, EURO 6) characterized by an acceptable content of harmful substances in the exhaust gases of its engine. The issues of reducing emissions of harmful substances into the atmosphere are described in literature. These processes are caused by the design of the internal combustion engine whose effectiveness is limited by the efficiency of the Carnot cycle.

**Environmental emissions of carcinogenic wear products**: In addition to indicators of atmospheric emissions of harmful substances in the exhaust gas, indicators of automobile emissions into the environment of all other types of carcinogens are crucial. These data make it possible to evaluate the effect of vehicles on the level of total carcinogen pollution in the human environment. This issue refers to the least studied system "man – car – environment". There have been attempts to solve it. Table 1 presents data by I.P. Ksenevich who evaluated these indicators for the entire Soviet fleet of trucks and wheeled agricultural machines as of 1987. It was assumed that the life cycle of the machine was 10 years (older machines were excluded from the calculation).

| Name of waste and emissions | Mass of carcinogenic emissions |
|----------------------------|--------------------------------|
|                            | Per one wheeled vehicle for the entire life cycle, kg | For the entire fleet of wheeled vehicles, million tons |
| Rubber (tires)            | 734.35                          | 1.15                      |
| Oil                       | 859.30                          | 1.349                     |
| Antifreeze                | 20.05                           | 0.317                     |
| Lead (battery)            | 80.00                           | 0.258                     |
| Filters                   | 244.75                          | 0.334                     |
| Debris, cullet            | 1529.06                         | 2.401                     |
| Asbestos                  | 49.10                           | 0.077                     |
| Lead                      | 61.25                           | 0.096                     |
| NOx                       | 6126.70                         | 9.619                     |
| CO                        | 24508.80                        | 38.479                    |
| Hydrocarbons              | 3675.80                         | 5.77                      |
| Sulfur Oxides             | 183.32                          | 0.288                     |

The data presented in Table 1 confirm the need to expand research on environmentally friendly materials applied in the design of vehicles and develop efficient technologies for the disposal of automotive components.

**External noise of the main units**: International European standards for permissible levels of external noise are reflected in the UNECE Regulation No. 6 and in the national standards of most European countries. In Russia, the document was adopted in 1974. At present, the noise level is measured in
decibels (dB) on the A scale (GOST 17187, GOST 27435 and GOST 27436) which corresponds to sensitivity of the human ear. The importance of this indicator is due to the fact that in 1974, the EEC (EEC Directive 70/157) permissible level of external noise decreased from 91 to 84 dBA. The West European companies producing long-haul road trains managed to bring this level to 65...68 dBA.

**The impact of vibrations on the driver and passengers.** One of the main features of vehicles is their frequent movement with a high speed along rough and broken roads. This puts forward special requirements for limiting acceleration regulated by the federal standards. To reduce the effects of vibrations, it is necessary to implement mechatronic modules into the suspension design based on long-stroke pneumatic or hydropneumatic springs [22].

**Destructive effects of the propulsion system on the soil surface.** The destructive effects of the propulsion system of self-propelled vehicles on the soil are studied by scientists working in the agricultural field. However, the problem of the destructive effect of the propulsion system on the soil is of more global importance [5]. When wheeled vehicles move outside paved roads, the non-rational “ICE – transmission – propulsion” system destroys the support surface of the soil due to its compaction and milling with skid wheels. To assess an environmental damage, gauge dimensions (depth and width) and soil compaction are assessed [23]. The elimination of the damage requires a long time or it is almost impossible. This fact must be taken into account when designing vehicles for specialized areas, for example, forestry, agriculture, exploration, oil and gas, etc.

**Problems of car recycling.** Car recycling is developing in two directions: the restoration and reuse of components, assemblies and other automotive components that have retained their resources and the processing of components and assemblies that cannot be restored, with a view to their use in the production of new materials. This approach is being implemented by countries with developed automobile industries. For example, in the European Union, there are acts that are obligatory for all EU countries. These documents prescribe [24]: a sharp reduction of non-recyclable waste at the end of the vehicle’s life cycle; reuse of parts and components; production of worn-out parts; burning of non-recyclable waste.

The adopted acts are as follows: Directive 2000/53 / EC ”Out of service vehicles” (July 2007) defines the requirements for preventing waste production during the decommissioning of a vehicle; Directive 2005/64 / EC prescribes the reuse of components suitable for further use, as well as the disposal of remaining parts of the vehicle; Directive 2000/53 / EC (2006) obliges all EU countries to ensure the deep recycling of cars, including burning by 95%, and recycling of 85 % of their mass in the form of secondary material resources; Directive 2005/64 / EC establishes a list of documents for obtaining the right to sell cars: documentary evidence of exclusion of the use of toxic heavy metals in the components; marking polymeric products; control over the use of secondary material resources by suppliers of used automotive components and materials; availability of technological regulations for the disposal of vehicles. Cars that do not meet the EU requirements cannot be sold in the EU countries. The European Commission for the Environment controls the implementation of these requirements. Responsibility for the disposal of decommissioned vehicles is allocated to the manufacturers. In 2005, Japan developed similar requirements (The Act on the disposal of automobiles). Some Japanese companies increased the sale of remanufactured units and parts 10 times. Thus, the laws of the industrialized countries consider a used car as a large source of secondary components and material resources.

3. Results and discussion

The article aims to predict long-term changes in the structure of carcinogenic risks of mass motorization.

In Russia, the total number of vehicles is 49 million, which is slightly more than 6 % of the world number [2]. If in the long term, the share between different types of vehicles and the share of Russia in the global car fleet are maintained, their total number can reach 180 million units by 2035 (of which about 162 million units will be passenger and commercial vehicles and about 18 million units will be medium- and large-capacity trucks, special vehicles and large-capacity buses). This structure confirms the continued massive use of vehicles both in the urban and rural environments.
The design trends give reason to believe that by 2035 cars equipped with internal combustion engines will have been replaced by hybrid cars and electric vehicles. As for heavy vehicles, this trend is unlikely. The mass use of gas engine fuels and hybrid power drives is more probable [20].

The use of clean electric vehicles will completely eliminate emissions of NO, CO, hydrocarbons, sulfur oxides, lead and reduce negligible carcinogenic emissions from oils, coolants, fuel and oil filters. The absence of friction clutches and the use of electromagnetic brake mechanisms exclude emissions of friction materials. In addition, the massive electromobilization of vehicles contributes to the implementation of intelligent transmissions which reduce damage to the soil cover [22]. However, the number of recoverable current sources - batteries - will increase significantly, which will affect the total amount of lead waste to be recycled.

The use of gas engines for heavy vehicles can significantly reduce the content of carcinogens in exhaust gases. Figure 1 shows (according to the research by D.Kh. Valeev and V.Yu. Kulemin, PJSC "KAMAZ") the ratio of the components of harmful emissions of gasoline, diesel and gas ICE. All major types of carcinogens, except soot, were taken as 100%. For soot, its content in the emissions is taken as 100%, since soot is the main carcinogen.

An analysis of the ratios shown in Fig. 1 gives reason to believe that the massive use of natural gas as a fuel for medium and large trucks makes it possible to reduce the amount of harmful emissions by 1.25 times (CO), by 1.7. times (NOx), by 1.4. times (hydrocarbons), by 8.3. times (benz (a) pyrene), by 100 times (soot) and eliminate sulfur and lead oxides.

Comparative calculations of the predicted values of total carcinogenic emissions over the 10-year service life of cars of traditional and innovative designs were carried out. According to the calculation results, the total amount of harmful substances emitted by cars with promising designs (based on the data in Table 1) will be no more than 18-20% for cars and light vehicles, and about 77-80% for heavy vehicles. The environmental impact of cars and light vehicles will be caused by the wear of rubber (tires), debris and cullet, as well as battery components. The names of carcinogenic substances emitted by heavy vehicles will not change much; in quantitative terms, the changes will reduce the content of harmful emissions of exhaust gases.

**Figure 1.** The ratio of main components in the exhaust gases for various internal combustion engines (according to the research by PJSC KAMAZ)
Thus, even taking into account the estimated four-fold increase in the number of vehicles by 2035, the problem of air pollution can be solved. The same is not true for soil and water pollution with solid waste products of wear and disposal of components.

For the efficient utilization of solid waste, it is necessary to develop new technologies for crushing rubber products, triplex cullet and separating frame materials [25]. One of the directions may be the use of the electro-hydraulic effect [26]. The authors developed a laboratory plant based on the use of this effect for the disposal of tires, cullet and electronic components, as well as its application technology for crushing rubber products, triplex cullet and separating frame materials. This plant affect the material being processed selectively, destroying one (rubber or glass) and not affecting the other (frame products, for example, car tire cord). The destroyed material is recycled. The electro-hydraulic technology for the disposal of batteries and electronic components based on the selective destruction of plastic enclosures isolates pure noble, rare earth and other metals and their alloys.

4. Conclusion
Forecasts of changes in the number and composition of the vehicle fleet and implementation of innovative design solutions give reason to believe that the main emphasis will be on reduction of wear products and recycling of automobile components. The priority measures in solving the problems of recycling should be development of new technologies for crushing rubber products, triplex cullet, separating frame materials, recycling electronic devices and batteries based on the selective destruction of components of these structures.

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