Diagnosing Technosphere Pollution to Form Environmental Policy

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Abstract. All The technosphere pollution with various substances has been analyzed considering their impact on human health, depending on the hazard degree. The most frequently occurring in nature hazardous substances have been classified by the degree and class of hazard. The impact of exhaust gases emitted by the recently growing motor vehicle fleet on human health is shown. A new ultrahigh-frequency technique is proposed to monitor the concentration of exhaust gases emitted by vehicles into the atmosphere. Measures are specified that allow reducing the environmental footprint by pursuing a sound environmental policy and introducing innovative technologies.

1. Introduction
The urban population, especially that of industrial centers, lives in a transformed biosphere – the technosphere [1] with the microclimate characterized by a higher temperature and relative humidity, the air polluted with industrial and transport emissions, the water bodies and soil polluted with waste effluents, and the increased level of noise, vibration, and electromagnetic radiation.

The transformed biosphere differs significantly from that in which humanity has evolved, and the changes are so great that the compensatory mechanisms of the human body fail to respond adequately fast enough. Negative consequences for human health occur. However, singling out environmental causes from the totality of factors affecting public health is extremely difficult. This is especially problematic to do in our country, where living conditions and medical preventive measures, and care in the cities and the countryside differ significantly. The ecological component can be justifiably isolated provided that all others are identical for the population living in polluted and conditionally clean zones.

2. Relevance of the issue
There is statistical data on the impact of environmental conditions on human health [2]. It has been established that environmental pollution increases the Russian population morbidity rate by an average of 18 %. In our country, only 15 % of the townspeople live in conditions with permissible air pollution levels [3, 4, 5]. The atmosphere and hydrosphere pollution directly affect the incidence of CNS disease, the occurrence of nephritis, hepatitis, toxicosis, impaired pregnancy, stillbirth, congenital anomalies, and weakening of the immune system.
The situation with endocrine diseases dramatically exacerbated in the areas affected by radiation pollution [6] (accidents at the Fukushima-1 and Chernobyl NPPs, as well as the South Urals). These diseases account for 70% of the population morbidity in these areas.

According to the US Environmental Protection Agency (US EPA), about 170 million Americans live in harsh air environments. In 2017, 1.4 million tons of harmful chemicals, including 169 thousand tons of known carcinogens, were emitted by various US enterprises. One in 1,000 among 250,000 people living around 15 major chemical plants in Virginia is at risk of developing cancerous tumors. Information on a decrease in life expectancy in contaminated areas has been confirmed [7]. Thus, in the chemical industry center Halle (Germany), this index is 5 years less than in other regions of the former GDR. In Bulgaria, in people living near industrial complexes, the incidence of asthma and peptic ulcer is 9, dermatoses 7, and rickets and liver disease 4 times higher than in the population of relatively clean zones. According to the Hungarian National Institute of Health, one in 18 and 25 people dies or becomes disabled, respectively, as a result of exposure to hazardous emissions.

3. Research objective
Recently, many world countries have experienced a sharp spike in the automotive industry development. The increasing number of vehicles has led to the growing concern of both scientists and ordinary people about the impact of fuel combustion products on human health and the entire environment. A significant increase in harmful emissions from vehicles has become a problem, especially in large cities. In megacities, the concentration of substances they contain exceeds the permissible limits and may cause various above-mentioned diseases.

To date, the issue of atmospheric pollution by exhaust gases has not lost its relevance. They contain many toxic components, so exhaust gases are among the main environmental problems of our time. Therefore, the study objectives are analyzing harmful substances and exhaust gases for their composition and toxicity, considering their degree of hazard, diagnosing exhaust gases emitted by the most common diesel ICEs, and developing an environmental policy aimed at protecting and improving the technosphere.

4. Theoretical
By the degree of hazard, all harmful substances are divided into four classes (see Table 1).

### Table 1. Classification of Hazardous Substances.

| Indicator                                      | I          | II         | III        | IV         |
|------------------------------------------------|------------|------------|------------|------------|
| Maximum permissible concentration (MPC) of harmless substances in the working area air, mg/m³ | < 0.1      | 0.1…1.0   | 1.1…10.0  | > 10.0     |
| Average oral LD value, mg/kg                   | < 15       | 15…150    | 151…5000  | > 5,000    |
| Average skin contact LD value, mg/kg           | < 100      | 100…500   | 501…2500  | > 2,500    |
| Average lethal concentration in air, mg/m³     | < 500      | 500…5000  | 5001…5000 | > 50,000   |
| Potential Inhalation Toxicity Index (PITI)    | > 300      | 300…3    | 29…3      | < 3        |
| Acute action zone                              | < 6.0      | 6.0…18   | 18.1…54.0 | > 54       |
| Chronic action zone                            | > 10.0     | 10.5…5.0 | 4.3…2.5   | < 2.5      |
Each chemical hazard class corresponds to a specific lethal dose value causing 50% mortality in those exposed (LD50). The relevant values are given in Table 2.

**Table 2. Airborne Hazard Classes and Relevant Conditional LD50 Values.**

| Hazard Class | LD50 Equivalent |
|--------------|-----------------|
| I            | 15              |
| II           | 150             |
| III          | 5,000           |
| IV           | > 5,000         |

The lower the LD50 value, the more hazardous the chemical is. The chemicals have been classified based on this feature (see Table 3).

**Table 3. The Chemical Hazard Classification According to LD50.**

| K value based on LD50 | Hazard Class | Hazard Degree | Key Parameters | Component Parameters |
|-----------------------|--------------|---------------|----------------|---------------------|
| < 1.2                 | 1            | Extremely hazardous | Mercuric chloride, potassium cyanide, chromium (6) |
| 1.2…2.2              | 2            | Highly hazardous | Copper chloride |
| 2.3…10               | 3            | Moderately hazardous | Acetophenone, carbon tetrachloride |
| > 10                  | 4            | Marginally hazardous | Calcium chloride |

The degree of chemical impact on the human body [8] caused by the intake of harmful substances with air, water, and food is characterized by the real chemical burden index (S):

\[ S = \sum_{i=1}^{n} C_i \ast t_i, \]

where \( C_i \) is the environmental pollution index in specific conditions; \( t_i \) is the exposure duration in fractions of a day; \( i = 1+n \) is different conditions.

Thus, for the air environment, the daily real chemical burden index can be calculated by the equation:

\[ S_{b} = C_{pr} \ast t_{pr} + C_{res} \ast t_{res} + C_{tr} \ast t_{tr} + C_{atm} \ast t_{atm} + \ldots + C_{rec} \ast t_{rec}, \]

where \( C_{pr}, C_{res}, C_{tr}, C_{atm}, \) and \( C_{rec} \) is the air pollution index in production premises, residential and public buildings, transport, atmosphere, and recreational areas, respectively,

\( t_{pr}, t_{res}, t_{tr}, t_{atm}, \) and \( t_{rec} \) is the duration of human exposure to the relevant pollution in fractions of a day.

Chemical substances causing tumors [9] (carcinogens), changes in cellular heredity (mutants), and affecting fetal development (teratogens) are especially dangerous for humans.

Carcinogenic substances include alcohol, asbestos, benzidine, clonofazine, chloromethyl ether, vinyl chloride, arsenic and its compounds, chromium and some of its compounds, soot, resins, mineral oils, yperite, phenacetin, etc. Tumor occurrence is associated with some processes also: tobacco smoking, betel chewing, footwear manufacture and repair, furniture manufacture, nickel enrichment, rubber production, underground work (related to radon impact). Carcinogenic substances have a selective effect on the human organs and tissues. For example, polycyclic aromatic hydrocarbons
occurring at the operation of motor vehicles cause skin cancer, breast and lung cancer; epoxides impact the connective tissue; tetrachloride carbon and chloroform cause hepatomas; heavy metals and their compounds – pulmonary and connective tissue tumors.

Some environmental pollutants are mutagenic [10]. Such substances include radioactive waste, pesticides, intermediate products of organic synthesis, some food additives, some medicines, vinyl chloride, chloroprene, and ethyleneamine.

Teratogens are substances with an embryotrophic effect which have become widely spread in large cities. The research conducted by Saint-Petersburg scientists show that 99.7% of newly born babies suffer from embryogenesis. The history knows the cases of abnormal behavior characteristic for whole ethnic groups (e.g., the Romans affected by lead poisoning caused by lead water pipes). One can assume modern technogenic environment impacts the human evolution. The changes involve people appearance, national characters; the higher nervous function suffers. Some sociological surveys provide dramatic results: 99% of teenagers in big cities think that theft is not a crime while 70% are ready to use violence for reaching their financial goals. Embryogenesis aftermath can manifest itself in 10-20 years after the birth causing immunodeficiency, memory impairment and other diseases. Embryogenesis is influenced by the following chemical substances: ethens, formaldehyde, ethyl carbamate, chloroprene, phenyl alcohol, dimethyl formamide, lead, carbon sulphide, demethyl-dioxap, butyl ether, vinylchloride, dimethyl sulphate, benzene, gasoline, divinyl, tetracycline (severe impact).

Note that some substances have antimutagenic effect (caffeine, polyamides, some aminoacids, antibiotics - actinomycetin, chloramphenicol, ionol, etc.).

As a result of exponential aggravation of the technosphere degradation a snowballing decrease of the human population immune status and intelligence. The destruction of human immunodefence is compared with “environmental” disease by some scientists. The recent research have confirmed a sad trend: environmental pressing on the immune system causes the inherited changes and is one of the causes of moronity growth. According to the WHO data the human health depends on average by 20% on the heredity, by 50% - on the lifestyle, by 20% - on the environmental situation and by 10% - on medical service quality. Some scientists expect these factors to be redistributed in some countries by 2025 as follows: the environmental impact must group up to 40%, heredity – up to 30%, and two remaining factors will have decreased impact (optimal lifestyle – 25% and medical service – 5%).

The problem of finding a way out from the crisis situation is being studied by both national and international organizations. In 2012 at the UN sustainable development conference in Rio de Janeiro (Rio +20), UN dedicated its work to environmental problems. This credible Organization paid more attention to the problems related to operation and use of natural resources, in particular, aspiring the developing countries are to control their own resources. The conference participants delivered their reports mainly on the environmental situation, pointing to, in particular, the transition towards a more environmentally friendly economy, well-minded city planning and provision of more favorable living environment as well as a wider use of renewable energy sources. This will allow significantly reducing carbon emissions and environmental pollution inside and outside simultaneously facilitating the economic growth.

According to many researchers, today two alternative options for the environmental crisis overcoming are considered: sustainable development by self-limitation or civilization combat intended at the development of innovative technology to conduct high-quality environmental monitoring and introducing the idea of the natural protection priority over the human interests into mass consciousness.

The car exhaust components that can be classified as hazardous to human health are carbon monoxide, aldehydes, hydrocarbons, sulfur dioxide, soot, benzpyrene, and carbon dioxide. The harm caused by these substances depends on their airborne concentration. Thus, a low content (up to 0.05 %) of carbon dioxide may cause headaches and nausea, and a higher content (0.5 %) causes asphyxia and death within 15 minutes.

Soot and benzpyrene accumulating in the human body may cause tumors, including malignant ones.
Carbon monoxide is one of the fastest-acting and most dangerous vehicle emission components. It is tasteless and odorless, and its high concentration in a confined space causes nausea, dizziness, asphyxia, faintness, and death.

To date, different techniques are known to detect these substances in the vehicle emission composition and purify the air from various pollutants [11, 12].

The ultrahigh-frequency technique for monitoring the concentration of exhaust gases emitted by diesel vehicles can be considered one of the promising ways to detect vehicle emissions into the atmosphere. This technique involves sounding the medium monitored in the tailpipe with electromagnetic oscillations of different frequencies and powers. This technique is based on the fact that when entering the tailpipe, the electromagnetic wave with, e.g., millimeter length interacts with soot particles settling on the filter and then passes through the particulate filter.

Fig. 1 shows a functional block diagram of the device.

**Figure 1.** A functional block diagram for determination of exhaust gases concentration in the gas pipe.

The device contains the first power block 1, the first UHF-generator 2 connected by the outlet to the first element of the UHF energy input 3, the second power block 4, the second UHF-generator 5, comparator 6, the second element of the UHF-energy input 7, the element of the UHF-energy output 8,
an amplitude detector 9, an amplifier 10, a computing device 11, a particulate filter 12 and a metal net 13. 14 indicates a gas pipe in the Figure.

The device has the following operating principle. The first power block 1 is intended to supply power to the first UHF-generator 2, for example, in the wave millimeter range. The electromagnetic power from the generator outlet 2 is delivered to the first element of the UHF-energy input 3 located on the external gas pipe surface 14 where exhaust gas flows. To get power into the gas pipe, a “dielectric window” is designed under the first input element; it allows electromagnetic oscillations passing into the gas pipe with exhaust gases. The oscillations delivered into the gas pipe spread along the exhaust gas and further pass through the particulate filter 12, fixed on the surface of the metal net 13. After this the electromagnetic signal that passed through the filter is caught by the element of the UHF-energy output 8 installed on the gas pipe external surface in front of (diametrically) of the first input element. Here a “dielectric window” is also designed under the output element to take electromagnetic oscillations out of the gas pipe.

In the case under consideration, the amplitude of the electromagnetic signal passing through the filter [13] and interacting with the soot particles deposited on it can be expressed as follows:

\[ I = I_0 e^{-\mu d} \]

where \( I \) is the amplitude of the signal passing through the filter, \( I_0 \) is the amplitude of the electromagnetic signal incident on the filter, \( \mu \) is the soot absorption coefficient, \( d \) is the soot layer thickness.

The above formula shows that at the constant frequency of electromagnetic oscillations sounding the particulate filter, the soot absorption coefficient, and the amplitude of the millimeter-wavelength electromagnetic signal incident on the filter, the intensity of the signal passing through the particulate filter can indicate the thickness of the soot layer on the filter, i.e., the concentration of soot particles on the filter surface.

As it is known, a maximum permissible concentration (MPC) is set for exhaust gases. Thus, in case the measured soot concentration does not exceed the MPC value, the particulate filter is considered to operate well. The particulate filter can be made of a dielectric material with lesser losses.

When the soot concentration at the particulate filter outlet exceeds the maximum permissible concentration, the soot particles on the filter are automatically sounded with centimeter electromagnetic waves having a radiation power higher than that of millimeter ones used to determine the soot concentration at the filter outlet. Here UHF oscillations simultaneously received from two generators have double impact on soot. Meanwhile, taking into account that the frequency and power of the first UHF-generator are different from those of the second generator, the signals passing through the filter have no mutual impact. The operating principle of this device stipulates that a lower power (not causing soot burning) of the first generator is used to assess soot concentration while a higher power of the second generator (facilitating soot burning) is used to heat a filter with soot, i.e. to burn out the soot.

Therefore, after passing through the particulate filter, centimeter waves ensure burning the soot at the filter outlet out (exothermic soot combustion due to an increase in the filter surface temperature). Simultaneously with the soot combustion on the filter, the changes in the soot concentration on the filter are monitored (tracked). At the allowable soot concentration on the filter, sounding soot particles with centimeter waves stops automatically. At this, air delivered to the filter facilitates soot inflammation with increase of the filter temperature. This initiates an active heat-generating process of soot burning. This allows concluding that the use of two different (millimeter and centimeter) ultrahigh frequencies allows monitoring the soot concentration at the particulate filter outlet and reducing it by burning out. Thus, the first cycle of concentration monitoring and filter cleaning has finished. The second and subsequent cycles for the same operations will be similar to the first cycle.

The considered high-frequency method for controlling the content of exhaust gases concentration emitted by diesel vehicles can be successfully applied for resolving other problems as well, e.g., to
diagnose exhaust gases emitted into atmosphere at the gas pipes of heat power plants operated on coal dust.

As practice shows, the total pollutant emissions from motor vehicles moving near regulated intersections are determined considering the total pollution from moving cars and those standing in line at the red traffic light, but for the urban areas, the pollution degree should be determined considering the layout of the road network elements [14, 15]. One of the most effective ways to reduce total air emissions under urban conditions may be the decreased number of traffic lights at intersections by building underground crossings rather than a subway in large cities. Another important factor should be adjusting the carburetor and timely replacing the old air filters or adjusting the injection valves.

In recent years, both supporters and opponents of transferring vehicles to gas fuel and electric traction have appeared [16]. It is noted that electric traction is strategically more promising than gas fuel. Data have been obtained showing that already today, electric vehicles are more cost-effective than those with ICEs. In the last decade, the world has seen an electric vehicle boom. As part of this innovation, the appearance of electric buses in Moscow in 2019 can be considered timely for this metropolis. According to statistics, due to the development of the electric bus network, emissions of exhaust gases into the air in Moscow in 2020 were reduced by 400 tons. Replacing one diesel bus with an electric one reduces carbon dioxide emissions into the environment by 60, 7 tons per year.

To ensure a safe technosphere, one of the topical issues is pursuing a balanced and scientifically justified environmental policy concerning the impact of society on nature. By definition [17], environmental policy is a set of intentions and principles defined by an entity regarding its environmental performance, which creates the basis for the development of specific goals and objectives.

When, e.g., implementing local environmental policy concerning the safety of the technosphere, municipal authorities definitely direct all available resources to perform local and objective monitoring, implement the state control over compliance with environmental legislation, and arrange the development of local environmental programs and projects. Also, all industrial enterprises that are potential environmental pollution sources [18] should implement the principles of sustainable development, consider the interests of all parties, including residents of the territories where they operate, ensure the maximum efficiency of all business processes, while paying attention to the development of the social sphere, preservation of the environment, and saving resources. As for the vehicle owners, they should undergo the MOT test in the prescribed manner and adhere to the regulatory requirements for the concentration of harmful (polluting) substances in the vehicle emissions [19].

5. Experimental part
A device for determining the concentration of harmful substances in the tailpipes of diesel vehicles and cleaning them was built based on the above ultrahigh-frequency technique for diagnosing exhaust gases. The laboratory prototype of this device comprises a millimeter-wave generator based on a Gunn diode [20] with a frequency and output power of 34 GHz and 50 mW, respectively; a centimeter wave generator of an avalanche-diode oscillator type [21] with a frequency and output power of 9.6 GHz and 90 mW, respectively; segments of rectangular waveguides to induce oscillations in the tailpipe and obtain millimeter waves at the output; amplitude detectors of high-frequency signals; other elements required for the device operation.

The device has been tested on a laboratory bench. In the experiments, the medium monitored was ash transported through a vertical pipe 10 cm in diameter, made of a dielectric material. The ash concentration varied within 0.1 to 0.5 %. Tests have shown the device's efficiency and good prospects of using it in natural conditions as an innovative gas analyzer.
6. Conclusion
The study results allow concluding that permanent and qualified monitoring of the urban technosphere with more advanced tools will minimize the ecological burden on the air and thereby ensure optimal living conditions for the population of the region concerned.

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