

Ecological Monitoring of Road Chemistry Materials on Highways

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The use of anti-icing reagents for road maintenance is accompanied by inevitable environmental consequences associated with the release of large amounts of chemicals into the environment. To reduce the negative consequences, environmental monitoring of the state of environmental objects is carried out, which makes it possible to assess the impact of the applied anti-icing reagents for the 4 most important environmental clusters: snow cover and water bodies, soil cover, green spaces and atmospheric air. At the next level of the developed monitoring system, specific geographic objects are shown. Samples were taken on 8 major highways of the city of Moscow. Environmental monitoring was carried out using a computer quality management system developed on the basis of CALS (Continuous Acquisition and Lifecycle Support) information technologies. 6 quality indicators have been added to the system for each geographic object: mass fraction of soluble salts, mass fraction of water-insoluble substances, pH value, specific effective activity of natural radionuclides, mass fraction of impurities and corrosiveness to metal. For each quality indicator, the system contains the most promising methods of analysis and instruments.

1. Introduction

The problem of using effective anti-icing reagents (AIR) in cities is very relevant (Danilov et al., 2019). The processing of the AIR of streets and other objects of road facilities is a necessary and important factor in ensuring road safety in cities and preventing winter injury to citizens. It makes it possible to carry out a system of mechanical cleaning and snow removal with road chemistry facilities, but at the same time, it presupposes a complex of possible (probable) negative impact on the natural environment and engineering infrastructure (Cekstere et al., 2008). However, there is quite contradictory information about the effect of anti-icing reagents on the ecological and geological conditions of the city: on the soil, on motor vehicles, shoes, on living organisms and the health of residents (Makarova et al., 2017). According to the available information, the safest reagents for urbanized ecosystems are friction reagents – sand, crushed stone, granite and marble chips. They are used in advanced countries. Moreover, granite and marble chips are used repeatedly. They are collected at the end of the ice, washed and dried, and then re-applied (Glushko et al., 2018).

The use of anti-icing reagents for the winter maintenance of roads is always accompanied by the inevitable environmental consequences associated with the ingress into the environment of a large number of chemicals (Tian and You, 2020). To reduce the negative effects, environmental monitoring of the state of environmental objects is carried out (Glushko et al., 2018), which allows assessing the impact of applied AIR on the 4 most important ecological clusters (Figure 1): soil cover, water bodies, green spaces and atmospheric AIR.

Environmental monitoring was carried out using a computer-aided quality management system (CQM-system) developed on the basis of the CALS concept (Holden and Schmidt, 2001). In the broad sense of the term, CALS is a methodology creating a common information space, which provides, for industrial products, the interaction of all industrial automation systems (AS) and integration of all persons involved in the life cycle of the products. In this sense, the subjects of CALS are methods and tools for the interaction of both various automation systems and subsystems, including the provision of all types of support. Alongside the CALS, Product Lifecycle Management (PLM) is increasingly used today in the same sense by leading manufacturers of AS (Bessarabov et al., 2016).

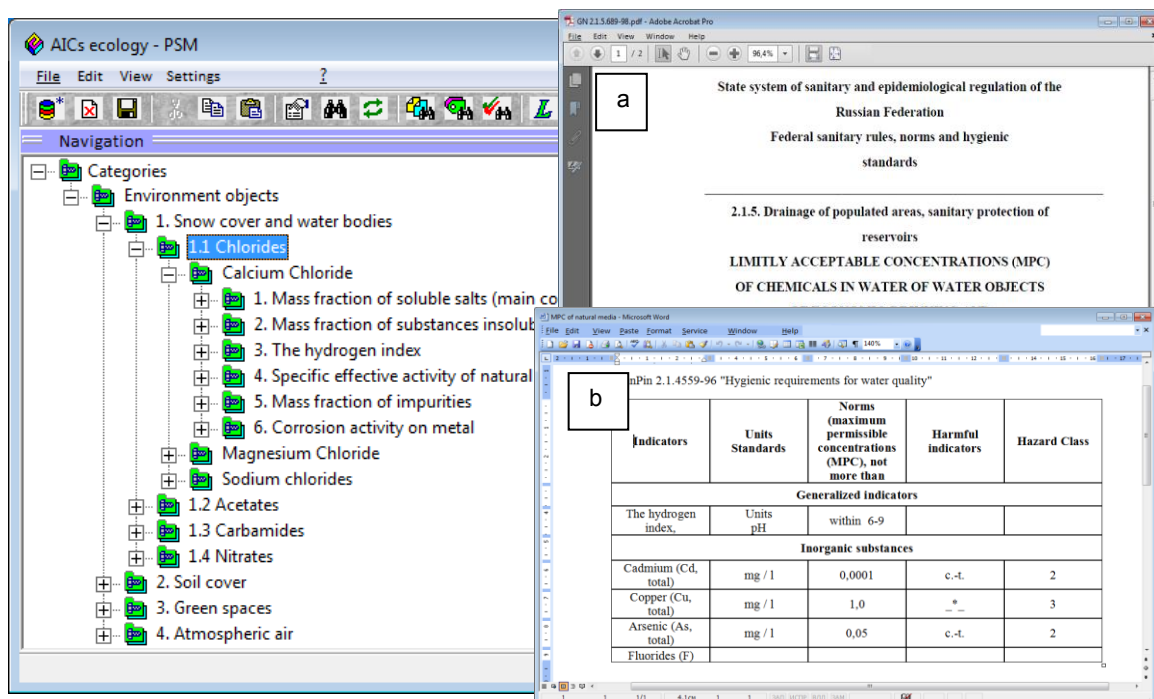


Figure 1: CALS-project "Environmental Impact of AIR". Snow, water bodies - Chlorides (a - hygienic standards 2.1.5.689-98, b - table of maximum permissible concentrations for water)

This work is devoted to the creation of a fundamentally new computer quality management system based on geo-environmental monitoring of the influence of anti-icing reagents on environmental objects. The results of experimental studies were used as fundamental data of employees of the Lomonosov Moscow State University (Nikiforova et al., 2017). For research, samples were taken of a mixture of snow mass or road slurry with remnants of AIR from the main roads of Moscow. All analyzes were performed using the latest analytical equipment.

2. Geoecological monitoring of impurity components

The system of geo-ecological monitoring of AIR (Figure 2) was developed on the basis of the information CALS-standard ISO-10303 STEP in the software package PSS Lite (Bessarabov et al., 2016). PDM STEP Suite configuration has a two-tier client-server architecture. Configuration PSS Lite has a two-tier client-server architecture. The server is the Local Database Server module, which is part of the PSS client module distribution. Any computer on which the PSS client is installed can act as a Lite database server.

At the top level of the CQM-system, specific geographical objects of the city of Moscow are shown. Samples were taken from Leninsky Prospekt, Vernadsky Avenue, Lomonosovsky Prospekt, on the streets of Profsoyuznaya, Krupskaya, Academician Bakulev, Lebedev (on the territory of Moscow State University). The samples taken were placed in containers of neutral material, sealed and stored in a refrigerator at a temperature of +4 °C.

It is necessary to separately consider the environmental impact of a large volume of the main components of the AIR and potentially dangerous impurities. To this end, at the second level of the developed CQM system, the main groups of physicochemical indicators of the AIR are considered (Figure 2): pH value (the hydrogen index), mass fraction of water-insoluble substances, mass fraction of impurities, mass fraction of soluble salts, index impact aggressiveness (corrosivity with respect to steel of AIR sediments), specific effective activity of natural radionuclides.

The first element of the CALS project (Figure 2) considers the indicator "mass fraction of impurities". This indicator is considered in two subcategories: "Maximum concentration limit in soil" and "Content in a draft." The content in the sediment is considered for three clusters of impurity components: "Cd, Pb, Mg, As, Hg, Se", "Co, Ni, Zn, Cu, Cr" and "F". For each cluster, various methods for their determination are presented. For cluster "Cd", the method of mass spectrometry with inductively coupled plasma (ISP-MS) is used. Three models of spectrometers for this method are listed in the CQM system. For the cluster "Co", the method of atomic emission spectrometry using inductively coupled plasma (AES-ICP) is used. Three ISP spectrometers

have been added to the system. For cluster “F” and determination of the mass fraction of fluorine impurities, the method of potentiometric titration is used. This method is based on measuring the potential of an electrode immersed in a solution. The magnitude of the potential depends on the concentration of the corresponding ions in the solution. When using the potentiometric method, instruments such as ion meter or ion meter conductometer are used.

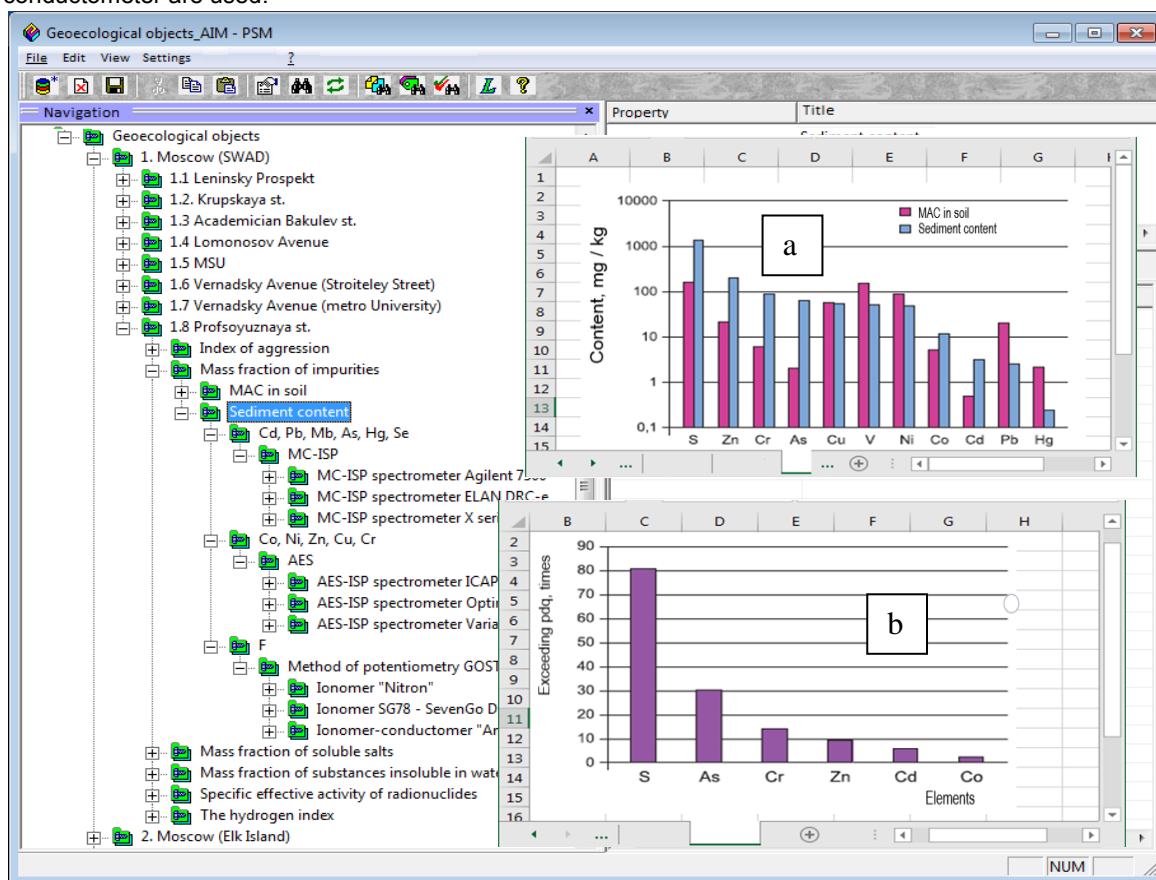


Figure 2. CALS-system of geoeological monitoring AIR. Mass fraction of impurities. (a – is the concentration of impurities in the soil and sediment; b – is the fraction of the excess of the AIR)

In the CALS-element of the CQM system of geo-ecological monitoring (Figure 1), geo-referencing to specific streets of Moscow is considered with an example of an analysis of impurities of the 2nd hazard class in soil and sediment. Road precipitation with remnants of the AIR contains a complex of substances and elements that are harmful to humans and animals. Spectral analysis showed that they contain many toxic elements and heavy metals (Nikiforova et al., 2017).

Of the elements of the 2nd hazard class, road sediments after the use of the AIR contain As, Sr, Rb, Co, Cd, Pb, Mo (Figure 1a). The concentration of heavy metals and other elements in them exceeds the maximum permissible concentration (MAC) for soils many times (Figure 1b).

3. Geoeological monitoring of hydrogen index

For the analysis of the pH in the CQM-system (Figure 3), 3 research methods were entered: the indicator method, the ionometric method and the acid-base method. The system contains devices and apparatus corresponding to the specified method. For example, a “pH recording / ion meter HI 2216” is used for the indictoric determination of pH. For the “ionometric method” cluster, the “pH meter HI-2020” is added to the CQM system, and for the acid-base method, the microprocessor “pH-meter HI 991000” is added.

In the course of the research, it was found that, along with the general high mineralization of road sediments with AIR residues, their aggressiveness is largely due to an elevated pH (Figure 3), the value of which reaches 8.2 (the pH of the initial AIR is 8.5). Due to the increased alkalinity, the salt solution of AIR residues dissolves many organic compounds, including technical oils and other petroleum products (Voronina et al., 2019).

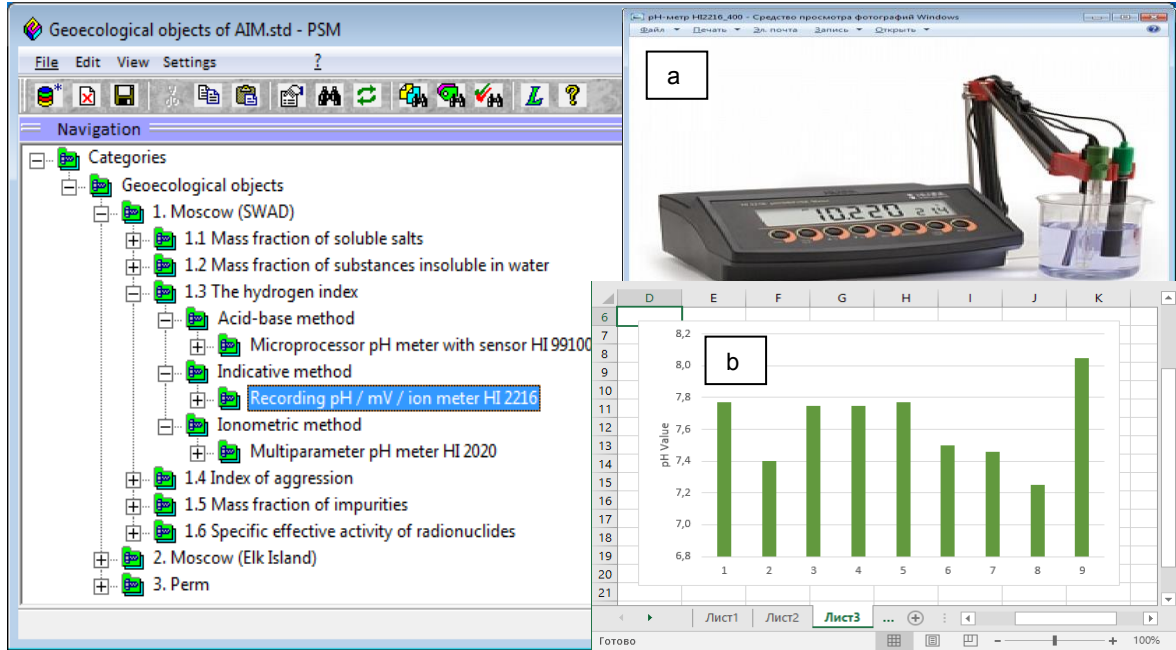


Figure 3. Element of the CALS-project "Hydrogen indicator". Indicative method (a – device "pH / ion meter HI 2216"; b - PH value for 9 geographic objects of the South-Western district)

The total mineralization of the original AIR used in Moscow is 30 g/l. When diluted with ice and snow, their mineralization decreases, but still remains high, reaching 25–26 g/l. High mineralization causes aggressive road precipitation with remnants of AIR in relation to many materials, as well as to living organisms. In the remaining saline solution on the road, the main cations are Na^+ and Ca^{2+} with a slight admixture of Mg^{2+} ions (Figure 4). Of the anions in the saline solution, Cl^- predominates, and there is also an insignificant impurity of HCO_3^- . The mass fraction of the technical salt used as AIR (the main component is NaCl) still remains relatively high (up to 50 %). This is despite the refusal of the city authorities to use it in its pure form. Especially dangerous for many living organisms is the high content of chlorine in road sediments with the remnants of the AIR (3rd hazard class).

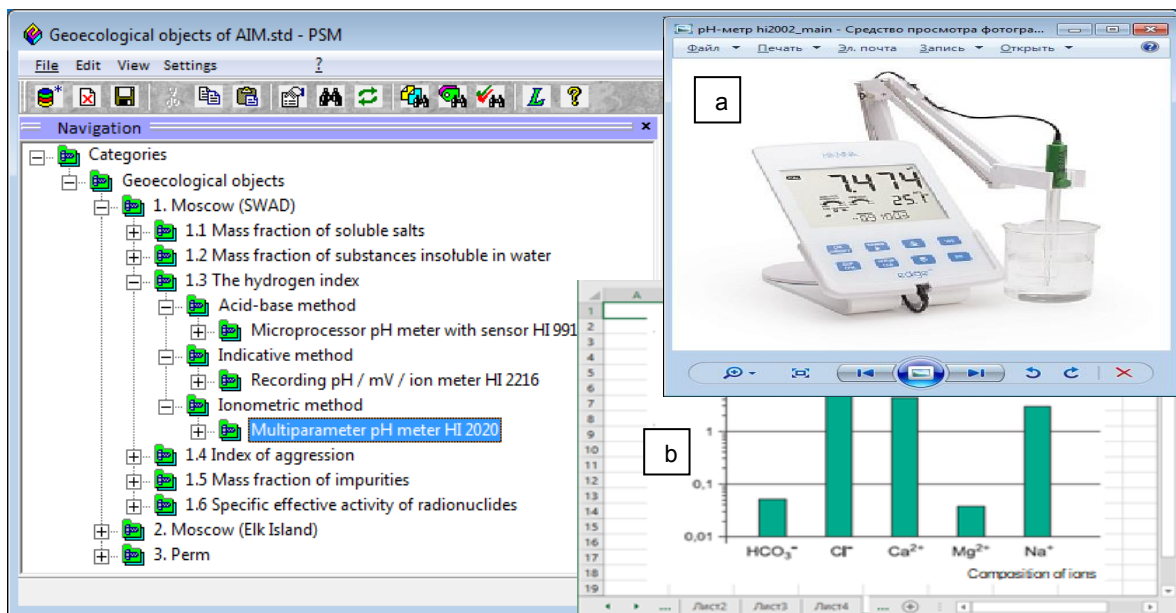


Figure 4. Element of the CALS-project "Hydrogen indicator". Multimethod method (a – device pH meter "HI 2020"; b – concentrations of cations and anions)

The hazard class of the waste is established based on the results of a set of studies, taking into account the limiting hazard indicator, which is taken as the indicator that revealed the greatest degree of hazard. In this case, priority is given to toxicological indicators.

The data on the justification of the hazard class of waste are submitted for approval to institutions that carry out state sanitary and epidemiological supervision in the relevant territory of the Russian Federation

Compliance with the proposed new "Technology" and control over the implementation of the requirements for it, eliminates the possibility of a negative impact of AIR on the environment and human health. Manifestations of any significant effect from the effects of reagents are possible only: directly on the roads or near the streets and highways at a distance of no more than 5-15 m from the borders of the zone of traffic.

To determine the pH of the AIR using the multimetric method (Figure 4), the pH meter "HI 2020" is used. This analytical instrument is also listed in the CQM system and belongs to the corresponding cluster.

The ionometric method for determining pH is based on measuring with a multimeter pH meter (Figure 4a) the electromotive voltage of a galvanic circuit including a special glass electrode, the potential of which depends on the concentration of H⁺ ions in the surrounding solution. The method is convenient and highly accurate, especially after calibration of the indicator electrode in the selected pH range, allows you to measure the pH of opaque and coloured solutions and therefore is widely used.

The glass electrode is a glass tube with a ball with a very thin wall, blown out at its end, into which AgCl suspension is poured in HCl solution, and silver wire is immersed. Thus, inside the tube with a ball is silver chloride electrode. To measure the pH, the glass electrode is immersed in the test solution (thereby not contributing to it any foreign matter). In the same solution, directly or via an electrolytic key, immerse the reference electrode. In the resulting system, the transfer of electrons from the silver chloride electrode to the reference electrode, which occurs under the action of a directly measured potential difference, is inevitably accompanied by the transfer of an equivalent number of protons from the inside of the glass electrode to the test solution. If we assume that the concentration of H⁺ ions inside the glass electrode is constant, then the measured EMF is a function only of the activity of hydrogen ions, i.e. pH of the test solution.

4. Geoeological monitoring of corrosion activity on metal

To analyse the corrosivity of the metal (steel), the KMC system (Figure 5) included 3 research methods: the gravimetric method, the optical method, and the electronic method. For each method in the CQM-system the corresponding devices are entered. When using the gravimetric method, the system suggests using measuring instruments "Vibra AJ 8200CE" or "Sartorius R200D". In the case of optical measurement of corrosion activity, devices such as the Olympus IPLEX FX video endoscope and the A99 720P endoscope are used.

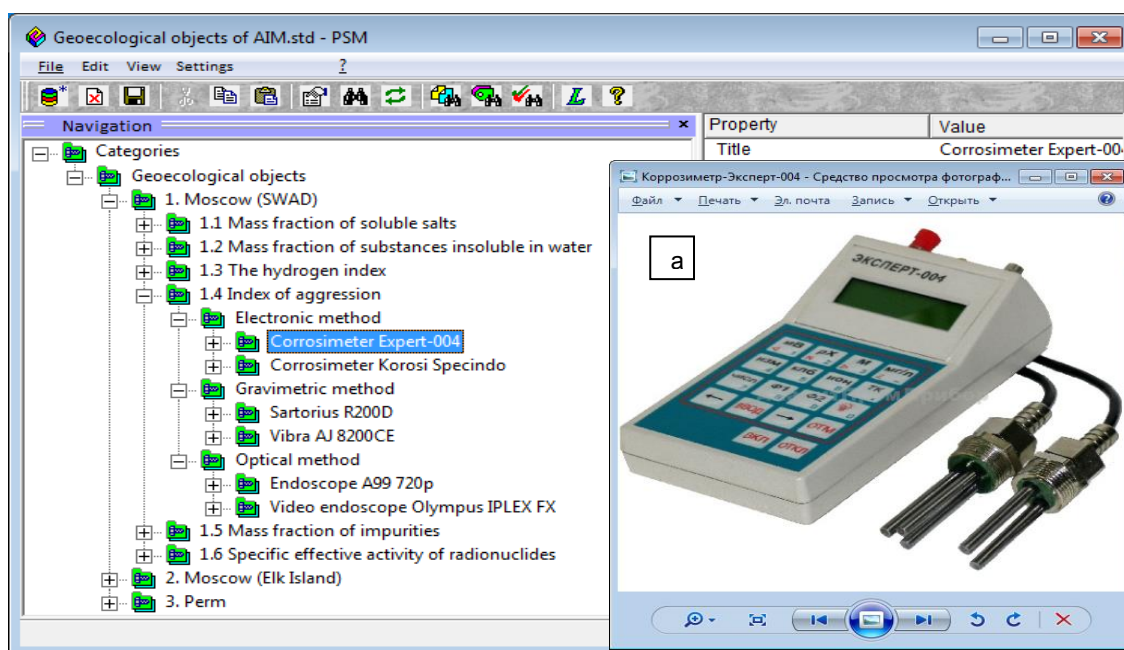


Figure 5. The element of the CALS-project "Corrosion activity on metal" (a – corrosion meter "Expert-004")

For the electronic determination of the corrosion activity of AIR on a metal (steel), two analytical instruments were added to the system: an imported corrosion meter Korosi Specindo and a corrosion meter made in Russia, Expert-004.

Expert-004 is a universal corrosion meter, which is used in the production laboratory monitoring of corrosion, as well as for a comprehensive assessment of the effectiveness of protective anti-corrosion measures. The device automatically determines the indicators of general and pitting corrosion, the potential for corrosion of metals, their alloys and coatings in liquid media. The device also determines the parameters of metal etching processes and the protective properties of anodic, chromate and other conversion coatings. Corrosimeter is used in energy and utilities, in the oil, gas, chemical, metallurgical and food industries; in machine building and instrument making; in scientific and educational organizations.

The obtained data indicate that, despite the anti-corrosion additives used in the AIR, their corrosivity in road sediments is rather high (Figure 5). At the same time, dilution of AIR with melted snow and ice does not significantly affect their corrosivity. If for the initial AIR, the corrosivity with respect to steel is about 0.35 mg/cm² per day, for residues of the reagent on the roads this value is 0.2–0.33 mg/cm² per day, i.e. remains quite high (compared to the corrosive activity of thawed snow water, for which it is less than 0.2 mg/cm² per day).

Thus, the complex impact of AIR residues on motor vehicles can, of course, be considered only negative, increasing the wear and tear of vehicles and their accident rate, as well as the material costs of their maintenance.

5. Conclusions

On the basis of informational CALS technologies, for the first time, a system of geo-ecological monitoring of the effect of anti-icing reagents on the main components of the environment has been developed. In the created systems, the territorial binding of environmental monitoring to the most important urban sites is carried out. The CQM-system for all environmental indicators listed the main methods of analysis and analytical devices. The use of computer support in geoecological monitoring of the CALS-system allows unifying comprehensive studies aimed at reducing the negative impact of anti-icing reagents on the environment.

The use of CALS technology will help reduce the time required to complete all monitoring work by 15-20%. For the road services of the city of Moscow, this makes it possible to improve the quality and reduce the time required for research and development work during the geoecological monitoring of anti-icing reagents.

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