Prevention of Hydrosphere’s Pollution by Aluminium

V A Poklonov¹, Yu M Grishaeva¹, I V Spirin², S N Glazachev¹

¹Moscow Region State University – MRSU. Vera Voloshina Str. 24, Mytishchi, 141014, Moscow region, Russian Federation
²Open Joint-Stock Company «Scientific and Research Institute of Motor Transport». Heroev Panfilovtsev Str. 24, 125480, Moscow, Russian Federation

E-mail: j.m.g.@mail.ru

Abstract. The environmental hazard is the transport of toxic ions and aluminium oxides entering the hydrosphere. In addition to solving global issues of maintaining environmental well-being through sustainable development, it is necessary to solve the technological problems of cleaning water bodies from excessive aluminium. One of the effective measures to solve such problems is the use of phytoremediation - a set of methods for treating wastewater and water bodies with the help of aquatic plants. The study of aquatic organisms (hydrobionts) ecology shows how do they affect the physical and chemical parameters of the environment, including the hydrosphere. Our study in measuring the concentration and toxicity of aluminium ions in the aquatic environment based on the results of experiments with aquatic plants (macrophytes) Ceratophyllum and Chara fragilis, as well as with the higher aquatic plant Callitriche palustris Linne showed the possibility in initiating self-purification processes of hydrosphere objects from mentioned pollutants. Another option in preventing hydrosphere pollution by aluminium compounds should be based on implementation the noospheric transformation of the educational system for national economy specialists in accordance with proposals, given in the paper.

1. Introduction

Aluminium (Al) is one of the most frequently occurring chemical elements in nature, as well as the most common metal that forms part of various compounds and minerals. Growth in the turnover of aluminium and its alloys in the economy and in everyday life leads to an advance entry into the natural environment of the by-products of aluminium production and various wastes containing aluminium. The most serious adverse effects due to accelerated aluminization is the impact on hydrosphere.

Due to the lightness of aluminium alloys, they are particularly widely used in transport engineering. They provide a reduction in the total mass of vehicles, which allows to obtain a significant environmental and logistic effect: the energy consumption for traction is largely determined by the mass of the vehicle, which essentially represents a reusable container for the payload carried (passengers and cargo). As a result, energy consumption for transportation is reduced by an average of 20%.

The world reserves of bauxite, the main source of raw materials for the production of aluminium, compared with modern and promising production volumes of this metal can be considered limitless.

The growth dynamics of aluminium production in the world indicates a rapid increase in its production in accordance with the initial phase of the logistics process. The growth rate of aluminium production for the year is about 1.5%. According to the International Aluminium Institute (IAI), in
2019, 63.7 thousand metric tons of aluminium were produced worldwide. Distribution of aluminium production by regions (thousand metric tons): China approximately 36, rest Asian countries 4.40, North America 3.81, South America 1.08, Western Europe 3.45, Central and Eastern Europe 4.16, Gulf countries 5.65, Oceania 1.92, African countries 1.64. The rest (about 1.7 thousand metric tons) not included in the statistics for various reasons (URL: http://www.world-aluminium.org).

The leading buyers of aluminium, produced in the world market, are the EU countries (43%) and the USA (19%). The global volume of the primary aluminium market in terms of value is about $ 60 billion. The main consumers of aluminium are the following industries: transport – 27%; construction – 26%; energy – 14%; mechanical engineering – 9.5%. Studies by environmentalists and other experts show that the aluminization process of natural water is constantly accelerating over time. Acid rains are suppliers of aluminium ions to the soil and water bodies. Getting into the water, aluminium settles on the bottom. There it is absorbed by plants from a mass of silty deposits. Acidic wastewater from coal and other mines contains aluminium in doses that are lethal to aquatic organisms [1, 2].

2. Materials and methods
The scientific apparatus used by the authors in carrying out the research includes the analysis of experience in the areas of the ecology of the hydrosphere, the study of the toxicity of aluminium in relation to living entities, the physical and chemical properties of aluminium as a pollutant of hydrosphere objects, aluminization reduction, carrying out laboratory experiments on Phytoremediation in order to study the mechanisms of action of aluminium ions in the aquatic environment with macrophytes (aquatic plants) Ceratophyllum, Chara fragilis and Callitriche palustris Linne. Laboratory studies of the ability of hydrobionts to adsorb aluminum from water were performed by V. A. Poklonov [1, 3].

3. Result of research

3.1. Aluminium in the ecosystem: theoretical studies and experimental results
About 250 minerals are known to contain aluminium. Aluminium is the third most abundant after oxygen and silicon. The mass concentration of aluminium in the earth's crust is estimated at 7.45 - 8.14% [4, 5].

The concentration of aluminium in soils is 150–600 mg / kg of mass. The aluminium content in natural water is 2.5 - 121 mg/l, in groundwater - 14 - 290 mg/l, and in surface water - 16 - 1170 mg/l. Human technogenic activity leads to violations of the natural «aluminium background» in the hydrosphere, in connection with which these limits may be exceeded many times. So, if we take the natural concentration of aluminium in the atmosphere of a rural area (about 0.5 μg/m³), then in cities this indicator is 20 or more times more! The aluminium content in the sources of water used for drinking, according to monitoring data, has a steady tendency to increase [5, 6].

The result of technological activity is the emergence of new ways for aluminium compounds to enter the ecosystem in suspended forms, ions and colloids. Aluminium enters water bodies primarily when industrial and domestic water is discharged. The study of the dynamics of river pollution minus Al-ions according to the monitoring data of 2003–2017 showed the joint influence of natural and anthropogenic factors on the annual variations in the concentration of this metal in water. The main influence is made by anthropogenic factors caused by metallurgical production [7].

Since the effluent water has an increased acidity, aluminium compounds enter the natural water bodies in a «finished form», being already dissolved. It has been established that any production that technologically provides for a spillway, results in an increase in the aluminium concentration in natural objects that receive drains by at least 2 to 5 times [2].

3.2. The negative impact of aluminium on wildlife
Aluminium compounds in their natural environment, have a harmful effect on plants when the concentration of this metal is 1 mg/l of water and more. Aluminium in the soil has insoluble compounds with
phosphates, which leads to a violation of the absorption of phosphates by the roots of plants, deprives them of food. Aluminium disease, in which the structure of plant tissues is disturbed, is fatal for them.

Aluminium enters the human body with food products consumed with non-normalized water, using aluminium utensils, as well as in the composition of certain medical preparations and cosmetics. The human body usually receives up to 50 mg of aluminium daily. The gastrointestinal tract absorbs 2 to 4% of the incoming aluminium, mainly from water-soluble moles, for example, AlCl₃. The concentration of aluminium in human tissues ranges from 0.2 to 0.6 µg / g. The average aluminium content is highest in the lymph nodes 32.5 µg/g, lungs 18.2 µg/g and liver 2.6 µg/g (URL: https://www.smed.ru/guides/221).

The human body begins to have a serious toxic effect when the following concentrations are exceeded (expressed in mg / kg of human body weight): ammonium acetate - 0.2; aluminium hydroxide - 3.7; aluminium alum - 2.9.

No organisms were found that would use aluminium to perform their biological functions. Aluminium causes diseases of the blood, nervous and bone systems. Aluminium has a high neurotoxicity, which is confirmed by numerous studies [8]. By European standards, the permissible weekly consumption of aluminium by people should not exceed 1 mg per kg of body weight [9]. Italian researchers note the effect of exceeding allowable concentrations of aluminium on the occurrence of human neurodegenerative diseases [10]. The review of T. Stahl et al. [11] shows that aluminium contamination has detrimental consequences for the nervous, bone and hematopoietic system of living organisms. Experiments with the use of aluminium compounds as part of an adjuvant vaccine have revealed the appearance of changes in some organs of experimental fish. The research team of Spanish scientists recommends to provide more detailed study concerning effects of aluminium on fish species [12]. Experiments with Allium cepa showed that onion cells underwent changes when grown using water that was previously boiled in aluminium vessels [13].

The review [14] summarizes the hypotheses according to which aluminium is considered to be the cause of neurodegenerative diseases of the brain. The entry of aluminium into the human body is due to harmful occupations, its presence in food and water, and general pollution of the environment. The reviewers believe that it is necessary to continue in-depth studies in the main risk groups (children, the elderly and those with kidney diseases, carriers of occupational risks living in disadvantaged areas. The review of Klotz et al. [15] showed the scientifically based proofs of aluminium effects on the human body that come in some dietary products, antiperspirants, and as an adjuvant during vaccination. Data on the carcinogenicity of aluminium, as well as its association with the use of aluminium-containing antiperspirants, with breast cancer require further confirmation.

Many researchers attributed the emergence of neurodegenerative conditions of the body to the ingestion of aluminium into organisms [16]. Colleagues from the UK reviewed the environmental risk factors for the occurrence of senile dementia in publications from databases up to 2016. 60 articles were reviewed that demonstrated the impact of environmental factors on dementia. [17].

A. Mirshafa, et al. conducted experimental studies of aluminium-containing nanoparticles effects on rat brain tissue [18]. The high toxicity of Al-nanoparticles on brain tissue has been established. It is noted that the high toxicity of these nanoparticles seems to be related to their intensive penetration into the cortical areas of the brain.

The study of serum obtained from the blood of the fetus umbilical cord in experimental animals showed that an increase in aluminium concentration is associated with an increased risk of coronary heart disease [19]. Experimental studies of aluminium chloride effects on zebra fish larvae have shown that aluminium is cardiotoxic. In 50% of cases, pericardial edema and cardiac arrhythmias were observed [20].

From a human body, up to 15 mg of aluminium can be released per day with urine. But due to the heightened sensitivity to an excess of the usual aluminium background, the kidneys often become affected by aluminium intoxication and lose their cleansing capability.

Experimental studies of the effects of aluminium intoxication on animals showed the presence of pathological changes in virtually all-important organs: the heart, lungs, kidneys, liver, intestines, pan-
creases and thyroid, nervous system, etc. In chronic aluminium hydroxide intoxication, frequent cases of urolithiasis, nephro-hepatosis, and gastro-enterocolitis have been observed [14, 15].

Some researchers have indicated that aluminium compounds contained in deodorants and antiperspirants can stimulate breast cancer, but this information requires further testing [21].

Thus, intoxication with aluminium compounds, both representatives of the flora and fauna, especially in water, leads to serious and even catastrophic states of organisms.

3.3. Sustainable development as a strategic direction for the formation of environmental well-being
The concept of Sustainable Development (SD) is a vector of civilization development in modern conditions, characterized by increasing environmental threats in combination with the exacerbation of social, economic, energy and a number of other problems and contradictions. The carrier of the noospheric perception of the surrounding reality is the cognitariat, which has become the leading class of modern society. In the modern post-industrial world, cognitariat replaced the proletariat due to the transformation of scientific knowledge into the main productive force of society.

The cognitive society understands the prevalence of environmental threats over all other contradictions and mercantile interests of people and classes.

In the modern economy, a mercantile approach to production is used. In contrast, SD is based on a comprehensive approach to assessing the effectiveness of any projects for the social and economic development. It takes into account not only the economic results, but also the environmental, social, geological, climatic, urban planning, political and other consequences of the proposed solutions. SD aims to achieve a high quality of life for present and future generations [22, 23].

The SD concept is fully applied to prevent pollution of the hydrosphere and excessive aluminization of natural objects. The transport complex is the main consumer of aluminium. In its production activities, it uses a lot of process water. Urban Public Transport (UPT) is currently leading the way in implementing the SD concept, which is explained by environmental, social, demographic and economic factors:

Therefore, research and development are currently underway, a methodological basis is being developed for the implementation of the SD concept in urban settlements [23, 24].

3.4. The use of phytoremediation to clean water from excessive aluminium
One of the modern and promising methods of biotechnology is phytoremediation - the use of aquatic plants for binding and removing pollutants.

To remove aluminium from water, the possibility of using some aquatic plants has been experimentally studied. Two experiments were carried out, during which a comparative study of changes in the concentration of aluminium salts with time was carried out. In each experiment, microcosms were compared (experimental systems in which plants) and the contents of control vessels in which these plants were not. At the beginning of the experiments, the same primary concentration of aluminium ions was established in each of the vessels being compared. In the course of the experiment, measurements of the concentration of aluminium ions in the working and control vessels were carried out periodically. The ion concentration was measured by the fluorescence method in accordance with using the Fluorat-02-5m analyzer.

The first experiment involved the macrophytes Ceratophyllum demersum (dark green rombolica) and Chara fragilis (hara fragilis). It should be emphasized that the hydrobiont Ceratophyllum fragilis for carrying out such experiments in scientific circulation was used for the first time [1].

According to the observations of the dynamics of the concentration of aluminium ions, it turned out that the concentrations of these ions decreased significantly faster compared to the control vessels without plants. After 28 days after the start of the experiment, the following results were obtained:

in the vessels containing Ceratophyllum demersum, the concentration of aluminium ions decreased to a level of 0.23 - 0.19 mg/l. 90.7% of aluminium was removed from the water. However, for the period of the experiment «on the battlefield», 3–5% of Ceratophyllum demersum shoots died for clean water, which should be considered good result;
in vessels containing *Chara fragilis*, the results were more modest. The concentration of aluminium ions decreased to a level of 0.39 - 0.47 mg/l, and there was observed a multiple phytotoxicity of plants - up to 55 - 77% of their shoots died. 80.9% of aluminium was removed from the water.

The second experiment was performed using *Callitriche palustris Linne*. This plant was also used for the first time in a phytoremediation experiment. The method of measuring the concentration of aluminium ions and the apparatus corresponded to those described for the first experiment [3].

As a result of this experiment, it turned out that the decrease in the concentration of aluminium occurred much faster, compared with the control vessels. In total, about 70% of aluminium ions were removed. The plant *Callitriche palustris Linne* reduced the concentration of aluminium ions to 0.93 - 0.89 mg/l, in other words, to the level of 4.5 TLV. However, on the 17th day, the complete plant death was recorded, and therefore further observations were discontinued.

### 4. Discussion and conclusions

Excessive aluminization has recently become a serious environmental problem. However, the use of aluminum will increase in the future. This is due to the transition to reuse of wastewater and, consequently, the concentration in them of pollutants (including aluminium). There is a problem with the operation of biological treatment facilities and the maintenance of satisfactory oxidative and sedimentation properties of activated sludge to help purify water. Pollutants accumulate in the mud, and under their influence, wastewater treatment is disturbed, activated sludge is dispersed. Therefore, there is the task of finding ways to preserve uncontrolled spread of aluminum in the environment, primarily in water.

The general methodological direction of solving problems of excessive aluminization of natural objects is the practical implementation of Sustainable Development concept, developed and supported by the world community.

Experimental studies have shown the possibility of using hydrobionts for the purification of water from aluminium. In the experiments, the macrophytes *Ceratophyllum demersum* (dark green rombolica), *Chara fragilis* (hara fragile) and *Callitriche palustris Linne* (marsh bog, otherwise a water star) were used. Obtained significant for the practice of the results, indicating the possibility of using biotechnology based on the use of these plants.

The system of education should be aimed at acquiring environmental-oriented knowledge by students. It is necessary to move from a passive understanding of environmental problems to the development of active skills by them in the implementation of future environmental-oriented professional activities. Important condition in implementing a set of measures aimed at protecting the hydrosphere from aluminium compounds pollution is the training of specialists for industry with the necessary competencies.

### 5. References

[1] Poklonov V A 2016 Removal of aluminium water plants of Ceratophyllum Demersum and Chara Fragilis from water of experimental ecosystems *Ecological Chemistry* 25(2) 79-85

[2] Emeh C, Igwe O and Onwo E S 2019 Potential effect of environmental pollution on the degree of dissolution of iron and aluminium oxides in lateritic soil *Environ Earth Sci* 78 256

[3] Poklonov V A 2019 Research of the interaction of aluminium with Callitriche palustris in the conditions of freshwater experimental systems Yu A Ovchinnikov bulletin of biotechnology and physical and chemical biology 15(1) 17-21

[4] Shugalei I V, Garabadzhiu AV, Ilyushin M A and Sudarikov A M 2012 Some aspects of effect of aluminium and its compounds on living organisms *Ecological Chemistry* 21(3) 172-185

[5] Drozdov A 2007 *Aluminium. Thirteenth element* (Moscow: Rusal Library) p 122

[6] Lopez F F, Cabrera C, Lorenzo M L and Lopez M C 2002 Aluminium content of drinking waters, fruit juices and soft drinks: Contribution to dietary intake *Sci Total Environ* 26 202(3) 205-13
Acknowledgements
This work has been supported in part by Russian Foundation for Basic Research (RFBR), Project 19-013-00322 A «Multicultural design of ecological development of personality in digital education». 