Possibilities of Using Higher Aquatic Vegetation in the Process of Treatment of Industrial Wastewater from Mining Enterprises

K E Gula¹, D A Golubev¹-², K A Kolobanov¹-²

¹Department of Ecology, Resource Use and Life Safety, Pacific National University, 136 Tihookeanskaya Street, Khabarovsk 680035, Russian Federation
²Department of Forest Protection and Forest Ecology, Far East Scientific Research Institute of Forestry, 71 Volochaevskaya street, Khabarovsk 680030, Russian Federation

E-mail: ecologiya2010@yandex.ru

Abstract. The paper analyzes the possibility of using different higher aquatic vegetation (HAV) and its effectiveness in the treatment of industrial effluents of mining enterprises. The influence of various factors on phytoremediation processes is assessed: natural and climatic (ambient temperature, air humidity, illumination, water temperature) and chemical (pH of water, content of dissolved oxygen in water, concentration of pollutants in water, presence or absence of organic compounds). The cleaning efficiency of both one and several species of hydrophytes, both semi-submersible and free-floating, was analyzed. It was found that the greatest effect of phytoremediation is manifested with the complex use of groups of higher aquatic plants different in their species composition and place of growth.

1. Introduction
Surface water, and the Earth's hydrosphere as a whole, is an extremely important and valuable resource. Water is the basis of life on Earth. The hydrosphere is interconnected with other spheres of the planet: atmosphere, lithosphere, biosphere. Water sources are influenced by natural processes, as well as human daily living and economic activities. In the modern world, when the rate of growth in water consumption is extremely high and some countries are already experiencing a deficit of fresh water, the problem of reducing fresh water pollution is particularly acute.

Active development of mining raw materials in the Far Eastern Federal District (FEFD) of Russia forms extensive technogenic mining systems and contributes to the input of a large amount of various chemicals into the environment, including the water environment, which leads to pollution of natural spheres. Modern mining methods of mining enterprises allow to increase significantly the yield of the useful product, but the measures taken to reduce the pollution of the natural environment are not effective enough. [1-3].

The aim of the work is to assess the ability of higher aquatic plants to purify industrial wastewater from mining enterprises in the climatic conditions of the Far Eastern Federal District.
2. Characteristics of industrial wastewater as a source of technogenic impact

Pollution of water bodies occurs both naturally and artificially [4]. For example, compounds of chemical elements present in the soil get into the water through natural chemical reactions. But, mainly, water bodies are polluted by industrial and domestic wastewater [5].

Wastewater discharged into natural water bodies have a significant impact on intra-water body processes, disturb the biological equilibrium and thereby complicate the rational use of water, and in some cases completely disable water bodies.

The discharge of untreated wastewater negatively affects the oxygen regime, water transparency and color, its acidity. In this case, the productivity of water bodies decreases and self-purification processes are disrupted.

The most important indicators of water quality in water bodies mixing wastewater with natural water are:
- content of dissolved oxygen;
- content of suspended solids;
- mineral residue;
- content of toxic substances;
- absence of odors and flavors.

Consequently, the chemical composition, acidity and temperature regime of water bodies are violated when they get into water bodies, which leads to changes in both its physical and biological components (death of some plants and organisms and mutation of others occur).

Waters become unsuitable for domestic use.

The same changes take place in the near-water area (the flora and fauna are changing).

Like any other biological environment, water bodies have their own protective systems and are capable of self-purification.

Self-purification is a set of all natural (hydrodynamic, chemical, microbiological, hydrobiological) processes in natural waters, aimed at restoring the original properties and composition of water bodies [6]. Among other things, self-purification occurs through higher aquatic vegetation.

3. Characterization of higher aquatic vegetation as an object of industrial wastewater treatment

Aquatic plants (hydrophytes) in water bodies perform the following main functions:
- filtration (they contribute to the deposition of suspended matter);
- absorption (they absorb nutrients and some organic substances);
- accumulation (they can accumulate some metals and hardly decomposable organic compounds);
- sanitary (they have bactericidal properties);
- oxidative (they enrich water with oxygen during photosynthesis);
- detoxification (they can accumulate toxic substances and transform them into non-toxic ones).

The dominance of one or another function in plants depends on its species, belonging to different ecological groups, the stage of vegetation, the nature of pollution, etc. [7-9].

Hydrophytes have a beneficial effect on the processes of water quality formation, and the thickets of air-water plants forming along the banks protect the slopes from destruction. Higher aquatic plants are capable of removing various pollutants from water, such as biogenic elements (potassium, calcium, nitrogen, magnesium, manganese, phosphorus, sulfur) [10, 11], heavy metals (nickel, chromium, molybdenum, vanadium, lead, strontium, barium, iron, aluminum, and others) [12-20], phenols, sulfates - and reduce its pollution by petroleum products, synthetic surfactants, which is controlled by such indicators of organic pollution as biological oxygen demand (BOD) and chemical oxygen demand (COD) [21, 22], which allows to consider their use in practice of cleaning industrial, domestic waste water and surface runoff.

Submerged aquatic plants accumulate heavy metals 4-9 times more than coastal water plants. The most complete purification of polluted water occurs when it is passed through thickets of semi-submerged water plants, then plants with floating leaves and, finally, submerged plants.
It was established by many researchers that hydrophytes (Acorus calamus, Scirpus Tabernemontanus, Typha angustifolia, Phragmites australis, Nymphaea tetragona, Ceratophyllum demersum etc.) accumulate heavy metals mainly in their roots but not in their stems and leaves [23-25].

Hydrophytes accumulate different pollutants in different ways. Phragmites australis (Fig. 1) extracts from water: nitrogen, phosphorus, potassium, calcium, chlorine; Medicago sativa, Acorus calamus, Typha angustifolia, Bidens tripartita: silicon and other minerals, destroy sulfur compounds (sulfates) and delay their reduction.

Zinc is accumulated by: Scirpus Tabernemontanus, Potamogeton lucens, filamentous algae, phytoplankton, Lemna minor (Fig. 2), Charophyceae; manganese: Najas; copper: Elodea; cobalt: Charophyceae; mercury: Myriophyllum aquaticum.

Free-floating aquatic plants also better concentrate: nickel, chromium, molybdenum, vanadium, strontium, barium, iron, aluminum, etc. [26-30].

Figure 1. Phragmites australis. Figure 2. Lemna minor in a pond.

There is also a suggestion to use not living plants but their dead parts (leaf litter) or plant cuttings [31]. The author bases his proposal on the fact that plant materials contain a large number of sulfhydryl and disulfide groups due to chemical interaction with which heavy metals are chemisorbed. The amount of sorbed metals is equivalent to the content of these groups in plant tissues.

Plants used for water purification have the following requirements:
- maximum resistance to heavy pollution;
- the ability to grow well in polluted water bodies;
- an extensive, strong root system;
- the ability to accumulate and recycle many pollutants;
- the becoming of thick and dense thickets;
- formation, growth of large biomass and abundance;
- easy removal and renewal after removal [32, 33].

Many countries around the world widely use mine water treatment systems in shallow ponds planted with Scirpus Tabernemontanus and Phragmites australis [34].

Scirpus Tabernemontanus is used for domestic wastewater treatment in China, Holland and Japan. Since Scirpus Tabernemontanus is resistant to the influence of high concentrations of pollutants, it is successfully used in Great Britain on pig farms. In Australia, Norway and many other countries it is used for treatment of surface effluents [35-40].

In the USA and Ireland shallow ponds with Scirpus Tabernemontanus, Typha angustifolia, Phragmites australis, as well as with free-floating plants (Lemna minor, Lilium and Eichhornia crassipes) are used for joint treatment of surface and domestic effluents [41].
As a result of many years of industrial and experimental studies, many authors have established a high efficiency of wastewater (industrial and domestic) purification by higher water plants from pollutants, both heavy metals and organic origin [42-51].

It is also noted that temperature is an important abiotic factor that determines all aspects of life activity of hydrobionts [52].

The plants we analyzed, which are able to adapt to industrial wastewater and absorb heavy metals, can be divided by the minimum temperature values for their comfortable growth: 8 °C (Scirpus Tabernemontanus, Phragmites australis, Lemna minor), 17 °C (Acorus calamus, Ceratophyllum demersum, Najas, Elodea, Myriophyllum aquaticum), 20 °C (Potamogeton lucens, Charophyceae).

Fig. 3-18 present a comparative characterization of the growth potential of hydrophytes relative to the average temperature conditions of the subjects of the Far Eastern Federal District.

**Figure 3.** Comparative characteristics of temperatures for the studied vegetation in the Chukotka Autonomous District

**Figure 4.** Comparative characteristics of temperatures for the studied vegetation in the Amur region.

**Figure 5.** Comparative characteristics of temperatures for the studied vegetation in Khabarovsk Krai (south of 55°N).

**Figure 6.** Comparative characteristics of temperatures for the studied vegetation in Khabarovsk Krai (north of 55°N).
Figure 7. Comparative characteristics of temperatures for the studied vegetation in the Jewish Autonomous Region.

Figure 8. Comparative characteristics of temperatures for the studied vegetation in the Republic of Buryatia.

Figure 9. Comparative characteristics of temperatures for the studied vegetation in the Sakhalin region (south of 55°N).

Figure 10. Comparative characteristics of temperatures for the studied vegetation in the Sakhalin region (north of 55°N).

Figure 11. Comparative characteristics of temperatures for the studied vegetation in the Republic of Sakha (Yakutia) (south of 60°N).

Figure 12. Comparative characteristics of temperatures for the studied vegetation in the Republic of Sakha (Yakutia) (north of 60°N).
According to the obtained data on the comfortable growing temperatures of Scirpus Tabernemontanus, Phragmites australis, and Lemna minor, these plants are more adapted and suitable for bioremediation of tailings waste water from most mining enterprises in the Far Eastern Federal
District, except for the Chukotka Autonomous District and the north of the Sakha (Yakutia) Republic and the Magadan region.

4. Conclusion
Phytoremediation of wastewater in the natural environment has proven itself in warm and humid climates. Implementation of this method in the Far Eastern Federal District of Russia is not yet optimistic enough. This is because the number of days a year with average daily temperature above 16°C (at which the higher aquatic vegetation actively grows and develops) is very small, so there is a need to adapt the cleaning technology. Only a small part of the plant community is adapted to the climatic conditions of the FEFD and has not yet been sufficiently studied. As such it is necessary, in the future, to develop specific technological and technical solutions to ensure sustainable and effective operation of biological treatment systems using higher aquatic vegetation.

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