The Technological Solution for Management of Toxic Wastes Accumulated in the Last Century (on the Example of the Closed Mining Enterprise in the Primorsky Krai)

IOP Conf. Series: Earth and Environmental Science **272** (2019) 032014 doi:10.1088/1755-1315/272/3/032014

The Technological Solution for Management of Toxic Wastes Accumulated in the Last Century (on the Example of the Closed Mining Enterprise in the Primorsky Krai)

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Abstract. Natural-mining technogenic systems formed within the boundaries of the tailings toxic waste impact of the closed Khrustalnensky GOK mining enterprise (the Primorsky Krai) were the object of research. The article presents the data of the long-term researches of the problem for development of technological solution of the accumulated mineral processing toxic wastes management. Exposed to weathering and transformation into new forms, they migrate with groundwater and air flows, having negative impact on ecosphere and human being. Considering this, the aim of the research was to substantiate the need to develop a technological solution for the management of toxic wastes based on the assessment of the present state of the technogenic system and modeling to develop a new technology of liquidation of accumulated environmental damage of the past operation of the former Khrustalnenskiy GOK mining enterprise. Based on the aim of the study, a fundamental research task was established. It includes the scientific basis of assessment and prognosis of environment situation adverse changes. It is established that the technological solution of toxic mining wastes management is based on the results of experimental researches, proposed criteria and principles of ecological rehabilitation of the tailings surface, mining-environmental monitoring of environment objects changes, mathematical modeling of transfer and accumulation of toxic waste technogenic pollution, based on the fundamental principles of hydraulics and engineering hydrology, updating and developing the database of mining and environmental monitoring of ecosystems within the tailings impact boundaries, with regard to the calculation of the pollutants dispersion in the biosphere in the GIS MapInfo-6.0 format.

1. Introduction

It is known that a mining enterprise provides its existence by destruction the lithosphere areas and further use of efficient product. The ecological situation is worsened here by high carrying capacity of wastes in the process of mineral development, low complexity of useful components extraction and inefficient use of mineral reserves of the deposits under development, a low level of mining greening, the problems connected with development of technogenic deposits and tailing dumps, an obsolete system of ecological norms and necessity of its reformation. The consequence of this is the environment deterioration due to harmful emissions into the atmosphere and water objects, soil and vegetation cover destruction, a large amount of wastes, including tailings stored in ponds, sludge dumps, occupying huge areas of productive land. Under the conditions of mining enterprises of the Far

Eastern Federal District (FEFD), according to the Russian legislation, conservation and reclamation of these hydraulic facilities were not carried out, which contributed to a large-scale technogenic pollution of environment objects. In fact, the wastes of mineral processing contain toxic compounds of chemical elements in a considerable amount, having negative impact on ecosphere. After the analysis of the literature data, it should be noted that there are almost no publications considering the information about mining toxic wastes management and choice of sustainable technological solution for their ecological and social safety in the region under study. **The relevance to study** this problem is obvious. Hence, the **aim of research** was the substantiation of necessity to develop the technological solution of toxic waste management on the basis of the technogenic system current state to develop new technology of clean-up of the past environmental damage of the Khrustalnensky GOK former mining enterprise. Proceeding from the aim, the fundamental scientific task was defined. It includes scientific base of assessment and prognosis of ecological situation adverse change under a technogenic system impact using mathematical modeling. The practical task is to develop a technological solution for the last century toxic waste management (on the example of a closed Khrustalnensky GOK mining enterprise, the Primorsky Krai).

2. Objects and methods of research

The objects of the study were natural-mining technogenic systems, formed in the last century during tin development by the mining enterprise Khrustalnensky GOK (closed at present). They include the processing wastes, stored in the tailings in the form of pulp, overburden dumps, dumps of substandard ores and barren rocks, considered by the authors as ecological damage of the Khrustaknensky GOK past activity. Modern instrumental, traditional physico-chemical and biological methods were used, as well as atomic emission spectroscopy, cartographic modeling, scientific forecasting, systematization and scientific classification, zoning (metallogenic, landscape-geochemical), statistical data processing using the computer programs. The forecast of the environment components pollution was based on the methods of mathematical modeling.

3. Results and discussion

Virtually, the analysis, generalization and systematization of literature sources are indicative of the absence of publications on the toxic waste management and the choice of a sound technological solution to ensure environmental and social security in the FEFD (Far Eastern Federal District) and, in particular, in the Kavalerovsky District of the Primorsky Krai [1, 2, 7, etc.]. There is only limited experience in solving the problem of waste management, including the organization of mining and environmental monitoring at the mining enterprises of the Far Eastern Federal District [1-3, etc.]. However, the development of the principles of its organization under the conditions of closed mining enterprises hasn't yet been worked out.

The tin ore processing wastes of the closed Khrustalnensky GOK tailings, being a source of environment pollution, contribute to technogenic pollution of ecosphere. The main pollutant is dust containing increased concentrations of heavy metals compounds (Pb, Mn, Cu, Zn, Hg, As, Cr, Co, Ni, Cd). The calculation showed that the wastes belong to the second class of hazard (highly hazardous). It has been experimentally proved that pollution of the air basin by heavy metals, sulfate-ion aerosols, dust containing carcinogenic compounds of chemical elements (arsenic, chromium and antimony), refers to an extremely high level. The established high ecological toxicity of tin ore processing waste, undoubtedly, contributes to pollution of environment objects. The experimental researches within the limits of technogenic system (tailing) impact allow speaking about deep involvement of toxic chemical elements in a geochemical circulation. It is revealed that the HM ions content in snow cover is 2 - 7 times higher than the background values.

In technogenic soils and vegetation within the impact boundaries of the Khrustalnensky GOK former mining enterprise tailings, there were local foci with increased concentrations of such HM compounds as: copper, zinc lead, cobalt, nickel, chromium, etc., that is an evidence of technogenic origin of environmental objects pollution. It was found that the gross content of lead, zinc, copper, arsenic

compounds in soils and vegetation exceeds MAC (maximum allowable concentration) and background values, respectively: up to 23 and 5-7 times in all experimental areas. The content of heavy metal compounds in water reservoirs within the limits of the investigated tailings impact is considerably above background values. For example, Sn - almost in 40 times, and Mn, Cu, Pb, Zn in 15-40 times are higher than the background values. In this regard, in the water samples from the wells located near a source of pollution (tailings waste in Fabrichnoe settlement), the 1.5 to 7 and more times excess of background values was revealed. A complex of physico-chemical, chemical and biological methods, including bioindication, allowed to estimate ecological state of the studied region as critical at the 10 km distance from the tailings dumps, as unsatisfactory – at 15 km, partially satisfactory – at 20-22 km distance. High level of technogenic pollution of biosphere components contributes to the formation of environment-related human diseases. The population in the area of study is living under conditions of constant exceeding of normative pollutant parameters in soil, vegetation, water and air.Our experimental researches have allowed us, on the basis of the proposed principles of recycling, secondary use and processing, to define the concept of the management of toxic wastes system accumulated by the last business activities of closed mining enterprises (tailing dump wastes). It is a complex of measures for processing, recycling or waste disposal, based on the principles of: 1) ensuring environmental safety and mining and environmental monitoring of these processes and change of environment objects and 2) forecast of the environmental situation. On the basis of the of academician V.V. Vernadsky theory on the biosphere and noosphere [5], taking into account the biogenic principles of J. M. Andersen [6] and the concept of sustainable development, [7] we suggest the following principles of ecological safety of mineral processing waste: 1. Priority of environmental requirements, taking into account technological, biological, informational, legislative and moral solutions; 2. The necessity of the waste treatment closed cycle; 3. Complex development of the technogenic deposit (tailing dumps of the former Khrustalnensky GOK; 4. Minimum level of technogenic impact. This principle should be within the range of autochthonous species tolerance – edificators of phytocenosis of the ecosystem within which the mining enterprise is located; 5. Development of methodological approaches to the creation of a system of biologically significant restrictions on the technogenic ecosystem impact levels and compliance of these changes in accordance with their biologically permissible values; 6. Protection of the genetic fund (biota and human population); 7. Overcoming ecological illiteracy, introducing in school the Ecology subject; 8. Organization of mining and environmental monitoring of environmental changes within the boundaries of the technogenic impact, taking into account the basin, not administrative principle; 9. Improvement of legal and regulatory framework, development of environmental regulations.

Thus, the formulated principles of ensuring the ecological safety of tin processing wastes, accumulated in the last century, determine such directions of technogenic system development, implementation of which, will reduce its impact on the environment to a permissible level of its inevitable impact, caused by the fact of artificial removal of a part of lithosphere for mining purposes.

In recent years, to assess the technogenic object (wastes) impact on ecosphere and forecasting the more innovative methods are used, namely: computer modeling with GIS-technologies [8], allowing not only quantitatively describe the processes in complex eco- and geosystems, but also, through modeling process, scientifically substantiate the methods of assessment of the various environment components state [1, 3, etc.]. In this regard, based on the results of the research by B. G. Saksin and M. B. Bubnova [2, 9-10 etc.] and our own [1-2, 3, 7], the following principles of mining and ecological monitoring of ecosystem change are proposed: 1. To raise a level of exploration of the territory under research; 2. Minimization of work volume (minimum number of observation points), targeting of recommended researches on a certain type of technogenic pollution; 3. Reasoning of composition and observations frequency, a spectrum of typomorphic chemical elements characterizing techno-geochemical flows of pollutants, their specifics, as well as recommended testing media and types of analytical studies; 4. Necessity of environmental awareness, probable and future ecological problems of the region, connected with all sources of environment pollution, and also forecast of possible changes of the biosphere components state on the basis of the revealed trends [1, 6]; 5.

Allocation of the site contours due to the boundaries of the basin [2, 9]. The boundaries of the sites are the watersheds, which are uniquely interpreted on the topographic maps [10]; 6. The studies should include a definition of not only integral content of chemical compounds in dissolved, but also in suspended form. Therefore, it is recommended to provide: 1) analysis of dry water residue; 2) Analysis of the solid precipitation of snow water; 3) Calculation of indicators of habitats ecological state: concentration coefficients (Kc), and biological accumulation (CBA), as well as total pollution indicator (Zc).

An important aspect of the toxic waste management system is the forecast of the ecological situation, mathematical modeling of the processes of pollutants distribution in atmosphere and soils. An attempt was made to create a model built on the mathematical description of physical processes that occur in soils. Pollutants (P), migrating within the allocated area by air flows, will be deposited in soil and accumulate in it. The role of soil in the processes of migration of toxic heavy metals compounds - pollutants in natural, in particular, soil systems, is great and is explained by several reasons. First, its organic horizons are a place of interaction between various components, ecosystem "blocks", supplying organic matter and retrieve mineral compounds from the mineral substrate. Secondly, the soil, due to its central position in the landscape, is an arena of active chemical transformations of both autochthonous and allochthonous substances, as a result, it is possible to expect the transformation of metal chemical forms in it. Third, the soil is the main factor in the formation of the chemical composition of local runoff water. Its properties and characteristics determine the possibility to reach, (with atmospheric moisture), a groundwater level, and in the place of their discharge – the local runoff waters. In this regard, consider a negative form of relief (river valley, intermountain basin), where a tailing dump is located (natural-mining system), not protected by forests, with poorly outlined borders (Fig.). The abstract problem of accumulation of toxic element compounds in soils both in soluble and insoluble forms was formulated and solved for the specified area.

Pollutant flows will be through — penetrating with partial discharge regarding the environmentally tense area. And if the disperse structure is considered as some basin – a capacity with poorly outlined borders, it is possible to introduce concepts of recharge and discharge.

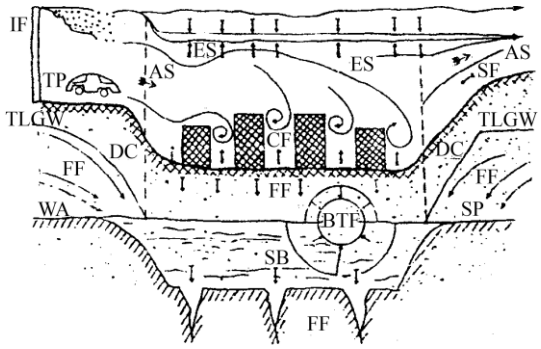

Figure 1. A model of soil technogenic pollution migration
Note: **IF** - industrial facilities; **TP** - pollutant streams from transport; **AS** - air streams; **APS** - atmospheric precipitation streams; **ES** - evaporation streams; **SF** - storm flows; **CF** - civil facilities; **TLGW** - technogenic level of ground waters; **SP** - saturation plane; **DC** - drawdown curve; **FF** - filtration flows; **SB** - soil block; **WA** - waterproof aquifer; **BTF** - biological treatment flow (→water flow→air flow).

Naturally, flooded ground - soil with the ability to accumulate technogenic pollutants - is a repository in this flow process. Natural purification is classified as discharge, thus, it is impossible to forget about other examples of impurities discharge, for example, with outgoing transport streams. The most important reason of the pollution concentration growth in flooded soils is water evaporation from the ground surface. Water pollutant solutions, which concentration as a result of water evaporation grows, become stronger reagents than flows entering the basin.To derive the differential equation of pollution kinetics, we turn to the notions of the yield of water supply source S_0q_n and the flow of Sq_c of harmful impurity:

$$\left| \begin{array}{l} S_0 q_n = \sum_{i=1}^{n} S_i q_i \\ q_c = \sum_{j=1}^{m} q_j, \end{array} \right. \quad (1)$$

So – weighted average content of harmful impurity in dropping and gaseous liquid of recharge;
q_n – total recharge flow; S – current value of harmful impurity content in flooded soils;
q_c – total drain flow.

From the equation of harmful impurity mass balance it can be seen

$$S_0 q_n dt - S q_c dt = V dS, \quad (2)$$

dt – elementary time interval;
V – basin volume;
dS – concentration change.

Using P (pollutants) material balance equation after rearrangement we get the following:

$$S = S_0 [1 + (q_n - q_c) \frac{t}{V}] \quad (3)$$

Consequently, the P (pollutants) concentration is unstable and linearly depends on time. According to the experimental calculation with the increase of the time of P arrival (accumulation) in soils, because of water evaporation from the ground surface, as mentioned earlier, the P concentration increases directly depending on time. At equality of total recharge and discharge expenses the concentration will be equal to average content of harmful impurity.

Thus, the proposed mathematical model of transfer and accumulation of technogenic pollution in soils, based on the basic principles of hydraulics and engineering hydrology, complements and develops the database of environmental ecosystems monitoring in the zone of technogenic source impact (for example, tailing dump) in the part of calculation of polluting substances dispersion in biosphere in the GIS MapInfo – 6.0 format.

Experimental research of the development of technological solutions aimed at reducing and/or eliminating toxic waste damage of the past economic activity of the Khrustalnensky GOK former mining enterprise were successfully carried out in the year-round greenhouse of the Far East Forestry Research Institute in 2011 - 2017. Then the experiment was set up under production conditions at the mining enterprises (closed Solnechny GOK and Khrustalnensky GOK). The applications for inventions have been filed. As a result, the novelty of the proposed methods of the development of technological solutions for the management of toxic wastes, accumulated in the last century in the mining enterprises of the FEFD, was proved by the Patents of the Russian Federation (2013, 2014, 2015, 2017).

4. Conclusion

The researches carried out on the basis of the proposed principles of recycling, secondary use and processing have allowed to define the concept of the management system of toxic wastes accumulated by the past economic activity of the closed mining enterprises (tailings waste). This is a complex of measures for wastes processing, secondary use or recycling, based on the following principles: 1) Ensuring environmental safety and mining and environmental monitoring of these processes and changing the environment objects surrounding; and also 2) forecast of ecological situation on the basis of mathematical modeling. In order to ensure the ecological safety of toxic wastes stockpiled in the tailings, taking into account the zonal geographical peculiarities of the region, it is necessary to create and implement new technologies to eliminate the accumulated environmental damage of the past

economic activity of tin ore industry. The novelty of the methods and technologies proposed by the authors was proved by the Patents of the Russian Federation (2013, 2014, 2015, 2017).

We consider it necessary to develop the Program of Mining Territories Rehabilitation and the ways of its realization. According to the Russian legislation, it should be based on the complex schemes of territories rehabilitation and technical regulations, adopted at the regional level as normative acts (laws) aimed at ecological safety of ecological damage of the closed mining enterprises past activity, protection of environment and public health, and also rational use of natural resources and urban development of the territory.

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