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Ecological Aspects of the Arctic Materials and Technologies

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Abstract

Generalizing analysis of the ecological aspects of the development and application of materials and chemical technologies, promising for management of the Arctic zone and cold regions is carried out. The requirements to the Arctic materials and technologies both in their functionality and in relation to minimization of environmental impact are discussed. The problems related to the arrangement of Arctic raw material processing at mining sites are discussed.

Keywords: the Arctic zone, mineral raw materials, chemical technologies, materials, ecology, anthropogenic pollution

INTRODUCTION

Arctic has always attracted the attention of mankind due to its queerness, inaccessibility, inscrutability and other features, but first of all due to its rich natural resources and strategic position. The historical experience demonstrates that development of the Arctic zone (AZ) is impossible without specific materials and technologies suitable for efficient application under severe climatic conditions to provide comfortable living conditions for humans and industrial activities on the industrial scale. As far as the ecology of Arctic and the effect of anthropogenic factors on it are concerned, this subject has been especially relevant during the recent decades, and it has expanded beyond the framework of scientific investigation embracing politics, economics, and public life. Generally available publications and mass media are mainly discussing the following issues: the current state of the environment in the region, the effect of global climatic variations and anthropogenic impact; the question "Where does the blame lie" is actively discussed. Another aspect is characteristic of scientific editions: specific technologies, processes and the possibility to reduce their negative impact on the environment; analytical monitoring of undesirable substances both in the environment and in industrial products, etc. Finally, a search for new specific actions aimed at solving the second question, "What is to be done?" In the majority of cases, definite problems related to specific materials and technologies are solved, while the generalizing analysis of the ecological effect of the used materials and technological processes is absent. An attempt at this kind of analysis is presented in the current communication.

NOTIONAL DESCRIPTION OF THE SUBJECTS OF ANALYSIS

It is reasonable to carry out the notional description of the definitions and terms used in the current communication. The definition of Arctic given in the Great Soviet Encyclopedia is: "a unique physic-geographical region of the Earth, which is adjacent to the North pole and includes the margins of Eurasia and North America, the Arctic ocean (AO) with the islands, as well as the adjacent parts of the Atlantic and Pacific oceans" [1]. The Arctic states include the countries that have an outlet to the seas of the AO, there are five countries: Russia, the USA, Canada, Denmark, and Norway. In Russia, the administrative legal definition of the Arctic zone of the Russian Federation (AZRF) has been introduced by the Decree of the President of the Russian Federation [2]. Cold is the basic climatic sign of Arctic, but its presence is not limited to the territories marked in the Decree, and many regions of the continent often have more severe climates. For instance, the pole of cold in the northern hemisphere is situated in Yakutia (−71.2 °C, Oymyakon settlement, 1924, https://basetop.ru/10-samyih-holodnyih-gorodov-mira/). When considering materials and technologies, it is more reasonable to understand AZRF as regions with cold climate, without tight relation to the administrative partitioning of the territories [3].

In addition to low temperatures, the climatic features of the AZ include the prevalence of low temperatures over the year; substantial amplitude of the difference between summer and winter temperatures (it reaches 100 °C in Yakutia); frequent passages through the water freezing and ice melting point; strong wind load; high humidity of the atmosphere; ice and snow cover; high solar radiation during the polar day, *etc*. A combination of these features makes the Arctic climate especially severe for humans, the materials, machines, and buildings in the region. Different territories of AZRF may be substantially different from each other in the listed parameters, and this is to be taken into account for the performance of the Arctic materials and technologies.

These are several definitions of the materials, but below we will adhere to the notion proposed by Academician I. V. Tananaev: a substance that possesses the properties providing its practical application. It is reasonable to consider the Arctic materials science (AMS) as an interdisciplinary branch of science that includes development of materials, investigation of their structure, search for methods to govern their characteristics, development of production technologies, revelation of the areas of application and performance conditions. The branches of science involved in the foundations of AMS may be divided into two groups. The first one forms the materials science component: chemistry in all its diverse directions (from analytical to nuclear), chemical technology, physics, mathematics, mechanics, biology, machinery engineering, transport, construction, *etc*. The second group is connected with the branches describing the conditions of their performance in the AZ: climatology, glaciology, oceanology, ecology, geography, *etc*.

In addition to the climatic features, the factor that is essential for AMS is logistics due to the fact that the AZ is remote from industrial centres and the residential areas. As a consequence, everything and everybody are brought to the AZ from elsewhere (people, machines, construction materials, fuel, food and all the things necessary for household and working facilities) with the help of different kinds of transport including very expensive ones, which causes an increase in the cost of the goods and materials.

FEATURES OF RAW MATERIAL MINING AND PROCESSING IN THE ARCTIC ZONE

Chemical technologies imply rational versions for processing natural, technogenic, and secondary raw materials taking into account the possibility of technical implementation, ecological safety, and economic efficiency. It is reasonable to understand Arctic technologies as chemical processes that are used in the AZ for industrial-scale mining and processing of raw materials, manufacturing the products that may be used also in the AZ. Unlike traditional technologies, the Arctic ones are implemented under specific climatic conditions, which require the application of construction and other materials that stay working and provide safety for the personnel and for the environment. Meeting these requirements to chemical technologies in the AZ is conjugated with higher expenses, which reduces the economic attraction of the Arctic technologies.

Inhomogeneity of climatic conditions in different sectors of the AZ affects also the implementation of chemical technologies. The most highly developed industrial regions of the AZ include the Kola Peninsula (the Murmansk Region). This is the warmest region in our AZ; it is very rich in mineral resources. Its level of urbanization is not lower than in the majority of the regions in the central part of Russia.

The Kola Peninsula accounts for about 1 % of the territory of Russia, while the percentage of the produced raw material and final products is many times higher. For example, according to the data for 2013, the region manufactured, %: apatite concentrate, 100; mica and the concentrates of niobium and tantalum, 80–100; nepheline concentrate and baddeleyite, 100; nickel, 45; ceramic raw material, 35; copper, 13; iron ore concentrate, 9.

ECOLOGICAL FEATURES OF THE ARCTIC ZONE

An essential feature of nature in the Arctic zone is its low ecological stability to external impact, in particular anthropogenic ones. The ecological fragility is connected to a definite extent with the features of the flora, which are formed by the climatic and geographic factors. First of all, this is permafrost, limiting the possibility of plants to develop a strong root system, which, along with strong wind load, provides plant stumpiness, thus ensuring protection with the snow cover from winter frost. Short summer weakens the time of vegetation during which the biomass of plants increases, in spite of the solar activity during the polar day. An additional factor that determines the ecological features of the AZ is the limited or almost completely absent biochemically active soil layer that normally provides biodegradation of pollutants, in particular industry-related ones. In other climatic zones, flora gets recovered from anthropogenic impact within a short time, while in the tundra the tracks of a road-free vehicle may stay over decades. The features of the flora naturally affect the fauna. The most urgent measures to be considered in order to decrease the load on the Arctic nature should be the possibility to file polluting wastes in the cavities of mine excavation sites or to recycle at least a part of the wastes to manufacture the necessary construction materials or so, and to provide transportation of the most toxic wastes outside the AZ.

The main source affecting the Arctic environment is the climate change, including global warming, which affects the Arctic ice cover and permafrost. They relate to emporal variations of solar radiation and the position of the Sun with respect to the earth. In addition, the opinion stating that human industrial activities cause imbalance of the planetary climatic processes, thus accelerating global warming, is actively expanding. Without discussing the reliability of the effect of anthropogenic factors on the global warming process, we are to recognize its obvious negative effect on the sites of intensive raw material mining and processing in the Arctic territories. A typical example is distortion of the ecological equilibrium accompanying an increase in the productive capacities aimed at mining and processing the copper-nickel sulphide raw material by Severonikel facilities (the Kola MMP, Nornikel company). The Monchegorsk District, formerly the greenest one in the region, has turned into the most polluted one on the Kola Peninsula. The situation is slowly improving due to expensive nature-protecting measures, but it will take at least several decades to recover nature to its initial level. The features of industry-related accidents in the AZ are to be specially mentioned, due to the difficulties in eliminating their consequences: high financial expenses, time intensity, and technological complications.

It has already been mentioned that two approaches may be distinguished in modern ecological activities. The first one is public and very noisy, involving the search for those to be blamed; this approach is participated by state structures, including specialized ministries, supervising bodies, various public organizations, and mass media. Another approach is aimed at the search for scientific and technological solutions of specific problems, it is less resonant, not so closely related to politics, and requires appropriate research and educational competences rather than emotional anxiety for the mankind and the planet. The number of persons implementing the second approach is smaller; these are first of all experts studying and developing Arctic. These are experts in chemistry, technology, and researchers in materials science.

WHY ARE WE TO STUDY AND DEVELOP THE ARCTIC ZONE?

The Arctic zone is an inherent part of the Earth, and it plays an essential part in the formation of global climate. The desire to understand the state of the evolution of our planet and its climate is quite necessary, so systemic and comprehensive investigation of Arctic is urgent [4]. The high sensitivity of the Arctic nature to climatic variations makes it a barometer for predicting the problems of the planetary scale. Another reason to study Arctic is the necessity of its development, especially for the RF due to some factors. The first of them is the presence of many fossil resources, both hydrocarbons (gas, oil) and minerals [5, 6], as well as biological resources. The second factor is logistic: the most convenient routes of many transcontinental aviation flights pass through the AZ. The outlook for transportation along the Northern Sea Route (NSR) should be specially stressed because it is the shortest way from Europe to South-Eastern Asia and, in spite of the difficulties related to the ice, it is free from the problems encountered recently by the Suez Canal, when an accident with a ship caused a week-long breakdown of the main sea route. The outlooks in favour of the NSR include global warming and substantial improvement of the modern ice fleet. The third factor is connected with the defense potential of the country. Russia's northern and eastern sea borders are extremely long and thus difficult to protect.

GENERAL ECOLOGCIAL SITUATION IN THE ARCTIC ZONE OF RUSSIA

In spite of the relatively weak industrial and transport infrastructure of the AZRF, the extent of its impact on the environment is substantial. The Ministry of Natural Resources and Ecology of the Russian Federation published annual State Reports concerning the state of the environment of the Russian Federation and its protection, and the parameters of emissions and pollution in 2017 over the AZRF are: the total amount of gas emissions is 6 908.388 thousand t, among which only 53 % passed through purification facilities, while the rest amount was emitted directly into the atmosphere. As far as solid wastes are concerned, their amount over the territory of the AZRF exceeded 32 million t, and only 58 % of this amount was utilized [7].

Industrial, transport-related and military objects are concentrated in separate regions of the AZRF, so these regions are under the greatest anthropogenic load, and often even overload. Within the UNEP/GEF Project "Russian Federation – Support for the National plan for the protection of the Arctic marine environment", 12 regions of the AZRF were distinguished, in which the negative anthropogenic action caused irreversible changes of the environment (Table 1) [8].

It follows from the data shown in Table 1 that the situation in the regions is evaluated as: strained, critical, crisis-related, which depicts the complicated ecological situation in industrial regions and the requirement of immediate and serious consideration of the problem. The most dangerous situation characterized as catastrophic is connected with accidents at the objects of nuclear power engineering and military infrastructure, which may lead also to radioactive pollution.

The regions marked in Table 1 are related to the sites of raw material mining and processing. The Murmansk Region should be considered as the region with the most substantial amounts of mined and processed raw materials. As long ago as during the early 1940s, Academician A. E. Fersman made an attempt to implement noospheric ideas formulated by Academician V. I. Vernadsky to the development of the natural resources of the Kola Peninsula [9]. He relied on the opinion that if nature prefers to concentrate a combination of raw materials of different chemical composition over definite territories, the industrial facilities are to be arranged in the corresponding manner to mine not separate components but the entire geochemical range of elements [10]. According to the idea of A. E. Fersman, the development of the Khibiny plant had to proceed on the basis of the use of the whole mined mass, a minimal amount of raw materials transported from other regions, to obtain high-quality products with no wastes at all. He believed that it was necessary to sharpen scientific and technological intentions to achieve the correct industrial activity ensuring no losses of the mined material, no wastes, no emissions into the air, and nothing to be washed off by water [9]. A. E. Fersman noted that the idea of integrated process was economic by its nature, to produce maximal values with minimal expenses and energy consumption: "This is the idea of protection of natural treasures from destructive consumption, the idea to use the raw material completely, the idea of possible conservation of our natural treasures for the future" [9].

It is reasonable to discuss integrated processing of multicomponent mineral raw materials by the example of apatite-nepheline ores (ANO) from the Khibiny deposits, which is a unique phenomenon in geology, both in the resources of phosphorus-containing raw materials and in the accompanying valuable components in the rock-forming minerals, first of all apatite, nepheline, sphene, and titanomagnetite. The scientific foundations of the integrated processing of ANO complex raw materials have been studied rather thoroughly. The developed technologies demonstrate the possibility to extract almost all valuable components from the mineral concentrates of ANO, but actually the efficiency of raw material consumption is still not very high, which is explained by the low demand of the market and low economical parameters of the manufacture of some products. The component most completely isolated from ANO is apatite concentrate,

TABLE 1

Ecologically problematic regions of Russian Arctic

No.	Region	Pollution source	Priority pollutants	Evaluation of the urgency of ecological situation
1	West Kola	Nonferrous metallurgy, mining industry	Nitrogen dioxide, dust, heavy metals (Cu, Ni, Co), carbon fluoride	Crisis
2	Central Kola	Nonferrous metallurgy, mining industry, APS, transport	Sulphur and nitrogen dioxides, dust, heavy metals (Cu, Ni, Co, Pb, Cr), Sr, P, radionuclides	Crisis (catastrophic in the case of accident at APS)
3	Karelia	Pulp and paper industry, forest industrial complex	Carbon, sulphur and nitrogen dioxides, methylmercaptane, lignosulphates, methanol, mercury, furfurol, phenols	Strained
4	Arkhangelsk	Pulp and paper industry, forest industry complex, mechanical engineering, thermal power engineering, transport	Carbon, sulphur and nitrogen dioxides, heavy metals, methylmercaptane, lignosulphates, phenols, formaldehyde, methanol, polycyclic aromatic hydrocarbons (PAH)	Critical
5	Timan-Pechora	Mining and transportation of hydrocarbons	Petroleum products, carbon, sulphur and nitrogen dioxides, heavy metals, PAH	Critical
6	Vorkuta	Mining industry, thermal power engineering, construction	Dust, heavy metals, PAH, carbon black, hydrocarbons	Critical
7	Novaya Zemlya	Military objects, dumping of nuclear installations and radioactive wastes	Radionuclides, heavy metals	Critical (potential crisis)
8	Lower Ob	Mining and transportation of hydrocarbon raw materials	Petroleum products, carbon, sulphur and nitrogen dioxides, heavy metals, PAH	Critical
9	Norilsk	Nonferrous metallurgy, mining industry	Sulphur and nitrogen dioxides, dust, heavy metals, arsenic, formaldehyde, carbon black	Crisis
10	Yana-Indigirka	Mining industry	Dust, heavy metals, mechanical disturbance of geosystems	Strained
11	West Chukotka	Mining industry, APS	Heavy metals, dust, radionuclides	Strained (catastrophic in the case of accident at APS)
12	East Chukotka	Mining industry	Heavy metals, dust, PAH, hydrocarbons, carbon black	Strained

Note. APS – atomic power station; PAH – polycyclic aromatic hydrocarbons.

which is used to produce phosphorus-containing fertilizers, phosphoric acid and other phosphorus-containing compounds. Another extractable product of apatite processing is the concentrate of fluorinated compounds, but the compounds of strontium and rare earth elements (REE) are lost during processing, in spite of the availability of developed extraction flowcharts, though these elements are included into the list of components taken into account in the State Reserves. Experimental-industrial facilities created at the enterprises of Akron and FosAgro holding companies confirmed the possibility to obtain high-quality REE concentrate, but they are not in demand on the market. The development of the corresponding industrial works is possible only if the state assignment for REE concentrates is posed, along with compensation for the economic losses for plants manufacturing the import-substituting products. The production of individual REE should be organized at a separate plant taking into account the requirements of the market to the quality and amount of products, including the needs of the branches providing the defense-related safety of the country.

In the current situation, it is evident that business and the state apart from each other, cannot cope with the integrated industrial development of the new complicated technologies. First of all, initiative and readiness to spend a substantial time interval on implementation of the projects without a full insurance of the success. Second, essential financial investments with a long pay-back period are necessary. For this reason, it is necessary to unite efforts from all sides: the state, business, science and education. Only these measures will allow us to organize economically efficient enterprises with up-to-date world ecological standards. Business should act as an initiator of industrial development of the regions, while the goal of the state is to support initiatives, to issue long-term credits with low interest rates, to use special tax modes for stimulation, *etc*. [10].

SPECIFIC OBJECTS OF THE ANTHROPOGENIC ACTION ON THE NATURE OF THE ARCTIC ZONE

The list of pollution sources in the AZRF is rather broad: motor roads, railways, port structures, power transmission lines (PTL); gas and oil pipelines; energy generating facilities (hydroelectric and heat power stations, regional and atomic power stations); industrial enterprises (mining and metallurgic, mining-chemical, mining-concentrating plants, *etc*.); the missing sites of hydrocarbons, minerals, and biological raw materials (boreholes, open-pit mines, tree felling sites, *etc*.); residential and industrial buildings and other objects of the Arctic infrastructure. Existing objects and those under construction cause negative ecological effects both during building and while operating. The listed sources of pollution are described in detail in [11], so they will be considered in the general form in the current communication.

Construction of large transport and industrial objects (motor roads and railways, power transition lines, pipelines, the sites of mining and processing the mineral and hydrocarbon raw materials, *etc*.) involved vast territories over which substantial amount of land works, including felling of the vegetation. This will surely affect the state of flora, fauna, landscape, cryosphere, and water streams. In this situation, it is necessary to provide careful planning of the routes of power transmission lines, oil pipelines, roads, to make them optimal not only from the viewpoint of logistics and economics but also from the ecological position. To design pipelines and roads, it is necessary to take into account the routes of migration of the wild animals, in order to reduce the obstacles to their motion along the routes that had been formed during centuries. Construction personnel should use tender approaches with respect to the environment, for example, to apply polymeric protecting heels when using caterpillar vehicles to minimize the impact on the soil, use maximally ecological fuel and lubricating materials, and the corresponding mechanisms for construction. Road construction is accompanied by the use of a large amount of stone, crushed stone, sand, and all these materials are extracted from quarries, which causes damage to the landscape, affects flora and fauna, and changes local water streams. A large amount of water is used during construction, and its disposal without purification may worsen the quality of regional water resources. To arrange tree felling sites, it is necessary to build roads to carry the wood to the sites of its processing, similarly to the Gulag roads in Siberia, which poses an additional load on the environment. Construction of mining-metallurgical, mining-chemical, mining ore and concentrating plants is accompanied by the pollution of soil, open water bodies, groundwaters, and by landscape damage. The choice of plant location should take into account the wind rose to minimize the hazardous effect of gaseous and dust emissions. So-called fox-tails may be mentioned as an example: these are the traces of the action of gaseous emissions from the Norilsk industrial region over tundra, extending for several ten kilometres, which allows the USA and Canada to speak of Russia's barbarism leading to the global destruction of the Arctic ecology.

What is the negative effect of the operating industrial, transport and communal facilities on the environment? In the case of power transmission lines, this effect manifests itself as the application of electromagnetic fields in adjacent space, which may have a negative effect on fauna and on the population. The most substantial hazard is that caused by accidents that require substantial repair work to eliminate the consequences, because heavy vehicles are employed. Even more dangerous accidents are those happening at oil and gas pipelines, which are often accompanied by explosions, fire events and oil spillages, which are difficult to remove in all climatic zones, especially in the zones with cold climate. The necessary actions aimed at prevention of accidents are: the use of materials providing reliable long-term operation of pipelines under cold conditions, adherence to the technological culture of pipeline service operations in combination with the regular tests of pipeline state.

The negative effect of road operation is expressed in air and water pollution with the products of fuel combustion (the oxides of sulphur, carbon, nitrogen, ash, carbon black, mazut, *etc.*) [11]. In this case, the most critical accidents are those accompanied by fuel spillage, fires, migration of the transported hazardous and toxic products into the environment. As a rule, road and railway operations are accompanied by their contamination with metals, plastics, glass, cloth, household and repair wastes. Exploitation of the Arctic motorways implies systemic and attentive care, including repair works, which is important for the reduction of transport accident rates. For instance, the Norilsk – Dudinka railway needs an additional amount of crushed stone during the warm period, because the embankment gets immersed into the thawing ground. The actions aimed at a decrease of the negative effects of this kind involve first of all the use of ecologically friendly fuel and lubricating materials, reasonable vehicle operation and nature management, and rational utilization of wastes.

As far as the objects of power engineering are concerned, in the case of heat stations, their negative effect manifests itself in gas emissions requiring purification. Solid wastes are to be processed into useful products or properly utilized. The situation is better at stations working on oil products and natural gas because no solid wastes are formed, while gaseous emissions are much cleaner. The operation of hydropower plants is connected with forced water discharge in the cases of extremely high water episodes. As regards atomic power stations, they are most ecological in the case of nominal operation, but potentially dangerous in the case of accidents: it is difficult to eliminate their consequences from the technological and economic points of view under the conditions of the AZ.

The necessity to adhere to ecological requirements during managing the deposits, in particular with the use of soft technological reagents, to improve mining technologies and existing operation standards is evident for the purpose of reducing the environmental load. A fresh example is mazut spillage from the storage facility as a result of its pressurization failure: more than 21 thousand tons of mazut were spilled outside the industrial groups. More than 6 thousand tons got into the ground, 15 thousand tons got into the Daldykhan river. The owner of the reservoir, Nornikel company, paid a penalty for environmental hazard in the amount of 146 milliard roubles, which is a record for the Russian Federation. Raw materials extracted from quarries and mines are transported over long distances, which is the reason for the additional load on the environment.

The industrial activity of mining and concentrating plants is accompanied by the formation of substantial amounts of wastes filed in dumps; these wastes often contain valuable chemical products. For instance, the amount of wastes accumulated in the dumps and tailings of Apatite company has reached 1 milliard t and continues to increase, which makes the problems more severe for people and for nature. In this case, it is reasonable to use technologies providing integrated extraction of the maximal number of commercial products, with adherence to ecological factors, as stressed by Academician A. E. Fersman [9]. An important part in minimizing the ecological impact of gaseous, dust and liquid pollutants is played by the improvement of industrial technologies and purification systems.

Violation of the technology of forest felling leads to a large amount of non-commercial wood remaining at the felling sites, which hinders forest recovery. Wood processing is accompanied by the formation of is accompanied by the large amount of lignin-containing wastes, which are difficult to utilize and recycle. Due to climatic features, the Arctic plant raw materials contain the substances that are valuable for pharmacy and cosmetology, but isolation of these substances is complicated and requires development of efficient and ecological technologies (for example, the technology of extraction with supercritical fluids) [12].

The presence of military infrastructure (bases, airfields, roads, *etc.*), vehicles that do not always move along roads when on missions affects the nature of the AZ. The communal facilities also affect the landscape through the construction of living houses and social objects, and their operation is accompanied by the appearance of household wastes. The necessity to aim at materials that are environmentally friendly is evident both for operation and for waste utilization. It is also necessary to improve the ecological culture of the population.

REQUIREMENTS TO THE MATERIALS AND TECHNOLOGIES FOR USE IN ARCTIC

The major requirement to the Arctic materials is conservation of performance characteristics in the cold climate. In addition, they should be reliable and long-living (their transportation to the Arctic regions is expensive, and elimination of the consequences of accidents in cold regions involves great technological and economic problems); it should also be possible to repair them at the operation sites. Another requirement is to take into account the poor self-protective properties of the Arctic nature against anthropogenic action and the trend to minimize it.

What materials are more vulnerable in Arctic? The negative action of cold affects steel; the products made of this material exhibit cold brittleness at negative temperatures in the strained state, which may lead to destruction of the structures. The nature of cold brittleness involves many factors: external actions, the features of different crystal phases of iron, the size of crystal grains, the presence of impurities, etc. At present, the scientific and technological problems connected with the elimination of cold brittleness are principally solved by special doping and proper thermochemical treatment: the grades of cold-resistant steel have been developed for use in the construction of Arctic pipelines, Arctic ships and the Russian Prirazlomnaya sea oil-producing platform [13]. Currently, search for technological measures providing the optimal combination of functional and economic parameters for cold-resistant steel of different grades and purposes is carried out.

Another vulnerable material is polymers, which vitrify at negative temperatures and are crystallized, losing performance characteristics and becoming fragile, which may be accompanied by destruction. Polymers are used as construction and functional materials for making different parts used in technical devices. At present, polymer composite materials have been developed that exhibit substantial functional and performance merits for use in many areas, for example in plane and ship construction. High-molecular compounds are incorporated into lubricating materials, sealing compounds, glues, providing efficiency and reliability of the responsible units of devices for use in the North. Active search for compositions with increased cold resistance is carried out. In the Arctic, the structure and functional state of polymers are also affected by solar radiation and polar day, so it is necessary to develop resistant materials.

Unlike for materials intended for specific usage (for example, catalysts used in one chemical process), Arctic materials are developed for different devices and may operate in many climatic zones, but they should be applicable in Arctic. The Arctic materials should conserve performance characteristics to the highest extent, and so they should be stable against external action; however, after having worked out their resource, they will be stored for a long time under natural conditions. Here is a contradiction between the functional and ecological requirements to the Arctic materials. This contradiction is to be solved individually for each material. Materials containing valuable components in high demand should enter recycling after their performance is over, as this is done in many developed countries.

Two methods to prepare Arctic materials are implemented: the first one is in rendering additional properties to a known compound, for example cold resistance and hydrophobicity, which would provide its application under the conditions of Arctic; the second method is in developing the materials that are a priori aimed at application in Arctic, but this does not exclude their application in other climatic zones.

The problems related to the technology of raw material mining and processing in the AZ coincide in many aspects with the problems for any other region, but specific conditions of the AZ pose additional requirements to technologists. The main rules for technologists choosing the raw materials, implementing processing operations and ensuring long-term potential of the production in the AZRF are:

– There is nothing superfluous in nature, only some things are not properly arranged.

– Deposits are chosen according to resources, degree of investigation, availability, and product liquidity.

– The vitality of a technology is based on its economic parameters.

– Where is a processing plant to be built? Close to the deposit or close to the reagents and consumers.

– The requirements of consumers concerning the suitable quality and price of products, the manufactured amount and sales outlet are to be taken into account.

– Industrial flowcharts should be readily tunable depending on the requirements of the market.

– One should think of new products that would be able to compete with the known grades of products.

– The smaller is the amount of reagents used in the flowchart, the smaller is the amount of future wastes and the lower is the net cost.

– The wastes of today may tomorrow become commercial products.

– It is necessary to be aimed at green technologies and certified products.

– The personnel may provide solution to everything when they are educated and trained.

– Continuous processes should be maximally involved in the technologies, and it is necessary to care for a decrease in energy consumption.

Development of deposits in the AZ is innovative because this requires the creation of unique technological approaches and measures, development and implementation of energy and resource saving, low-waste, ecologically balanced technologies for the raw material extraction and processing. The Arctic raw material and the technologies of its processing cause the necessity to verify and improve the geological and economic evaluation, substantiation of the conditions, determination of economically reasonable list of extracted components and the assortment of the final products, economic efficiency of the consumption of raw material, validation of the optimal version of investment project, *etc.*

The idea to create the Kola Chemical Technological Cluster (KCTC) is an interesting solution to the problems connected with the organization of chemical works in the AZRF (Fig. 1) [15].

The cluster is intended first of all for mastering and probation of technological schemes taking into account permanent improvements in the apparatus and technological arrangements, in obtaining the data for calculating the economic parameters and for preparing the technical and economic substantiation of new industrial facilities. The basic assortment of the manufactured products includes the materials that are required in the amounts of several ten or several hundred kg/year, for example special sealing compounds based on titanium dioxide for aerospace branch, the powders of rare metals (Ta, Nb, *etc.*), materials for opto- and acoustoelectronics ($LiNbO_3$, $LiTaO_3$, *etc.*), analogues of rare minerals similar to those occurring in the nature, as efficient catalysts for organic synthesis, sorbents for waste water purification from radionuclides and other toxic components. Pilot installations that are already available at the KCTC provide partial solutions for problems of this kind. In our opinion, the planned creation of larger installations indeed can provide for the need in a number of the products of this kind, not only for the region but for the whole country. Organization of the clusters of this direction in the AZRF is not just a set of the used technologies at one site on the basis of local raw material but the implementable model of the transition from the raw material economics, characteristic of Russia, to an innovative one. These clusters are able to meet the needs of the AZ in a number of import-substituting, strategic and construction materials without making noticeable hazard to the nature. The project of the organization and development of KCTC is based on the competitive advantages of the region.

The first steps towards launching KCTC have already been made – a pilot plant has been built for obtaining the analogues of rare titanium silicate minerals as functional materials for processing liquid radioactive solid and liquid wastes, as molecular sieves for gas separation. The efficient employment of the available experimental works at the Federal Research Centre “Kola Science Centre of the Russian Academy of Sciences”, as well as mining-concentrating and metallurgic plants of the region, namely JSC Apatit, Kovdor mining and concentrating plant, Kola mining and metallurgic plant – broadens the possibilities of KCTC and will promote acceleration of the creation and application of new materials in the AZ.

CONCLUSION

The major ecological problem for researchers in the areas of chemistry and materials science is to develop technologies and materials that would minimize the anthropogenic impact of the Arctic nature.

The three most relevant ecological directions may be distinguished: analytical chemistry, chemical technologies, and materials science.

The main purpose of analytical chemistry is connected with environmental monitoring, which means observation of the chemical composition of the atmosphere, hydrosphere, cryosphere, and lithosphere in order to detect environmental changes and their reasons. The next problem is control over industrial emissions, which provides the necessary information and suggests the actions to eliminate deviations from the ecological standards of the production process. Monitoring of the mined raw materials is to be stressed, because the composition of these materials may have a substantial effect on their ecologically optimal processing and on the amount of hazardous emissions. Another direction is control of industrial products for their correspondence to ecological standards.

As far as chemical technology is concerned, this means the following: 1) development of the processes for chemical and metallurgic production in Arctic with decreased environmental impact; 2) development of economically and ecologically efficient technologies for processing the Arctic mineral, hydrocarbon, plant and animal raw materials (ecological efficiency is especially important if the raw materials are processed

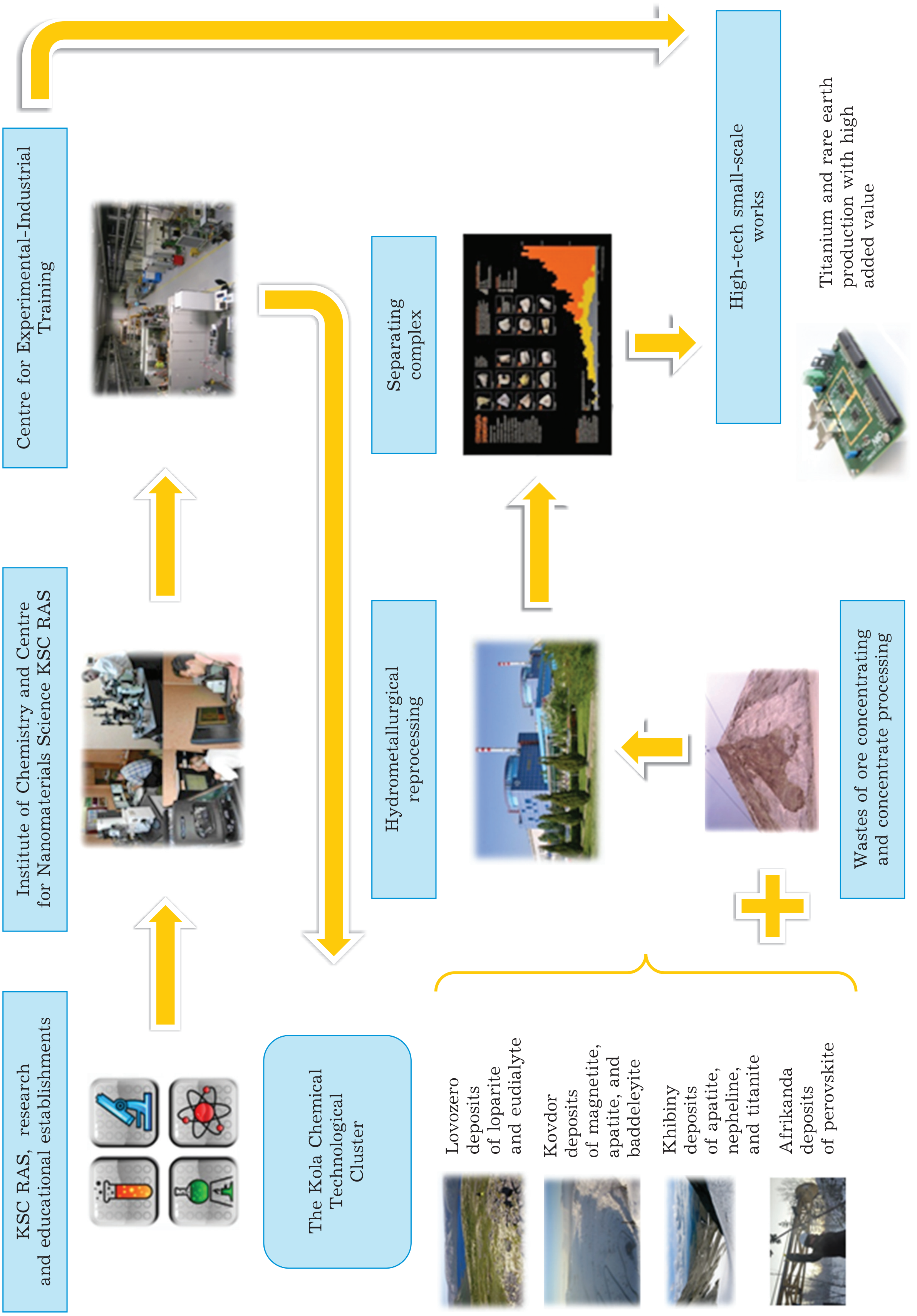

Fig. 1. Scheme of the Kola Chemical Technological Cluster based on the operating plants of the mining industrial complex.

within the AZRF); 3) development of the technologies for processing industrial wastes to reduce environmental load, as well as development of ecologically sound methods for utilization, elimination and storage of industrial and household wastes.

The materials science direction is aimed at minimizing the negative effect of the used materials. When developing materials, one should take into account whether they are friendly to the Arctic environment, for example, coatings for structures and technical devices should exclude the emergence of hazardous components. It is reasonable to develop methods to adapt available materials to Arctic conditions, which will decrease research and industrial expenses. To decrease the rate of accidents, we need reliable, long-lasting materials because accidents produce the most substantial damage to the environment. It is desirable that the materials could be repairable at the operation sites, which will reduce expenses and the time to eliminate the consequences of accidents. It is reasonable to develop and use resource-saving (in energy and mass) materials and technologies, including the development of artificial materials with high functional and economic parameters, to replace the natural raw materials. For example, high-quality wood was used previously for pylons of power transmission lines, but wood is a rather short-lasting material and is currently in high demand. A solution to this problem is to switch to pylons made of polymer composite materials, which are not worse than wood in functionality but better in lifetime. This approach is also promising for replacement of wooden railway sleepers for composite ones. It is also reasonable to develop efficient materials, in particular sorbing materials, to mitigate emergency oil spillages, to extract natural and applied radionuclides.

High requirements to the Arctic materials make necessary their thorough tests with respect to physical-mechanical, physicochemical and other properties. In addition, monitoring of the strength and performance characteristics of constructions and objects is important. For this purpose, it is necessary to develop the procedures for laboratory and field tests, as well as a network of testing centres for materials and constructions in the AZRF.

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