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DEVELOPMENT OF THE TECHNOLOGY FOR CONSERVATION OF SPOIL HEAPS IN ORDER TO REDUCE ITS NEGATIVE IMPACT ON THE ENVIRONMENT AND PRESERVE RESOURCE POTENTIAL

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РАЗРАБОТКА ТЕХНОЛОГИИ КОНСЕРВАЦИИ ТЕРРИКОНИКОВ В ЦЕЛЯХ СНИЖЕНИЯ ИХ НЕГАТИВНОГО ВОЗДЕЙСТВИЯ НА ОКРУЖАЮЩУЮ СРЕДУ И СОХРАНЕНИЯ РЕСУРСНОГО ПОТЕНЦИАЛА

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Coal mining is accompanied by bulk waste formation in form of spoil heaps from low quality ore. As a result of aggressive natural factors impact specific mineral and chemical composition of rocks, which forms spoil heaps, leads to the environmental man-caused load in form of dust and gas emission, water pollution and adjacent area littering. Thus, lands, where spoil heaps are disposed, are excluded from economic use, and their resource potential gets lost because of wind and water erosion, negative physical, chemical and biochemical processes, and transformation of rocks, which forms spoil heaps, that causes the reduction of its value as secondary resources. It defines the urgency of developing methods aimed at the lowering of ecological load, caused by spoil heaps, to acceptable level and at the preservation of its resource potential as artificial deposits. One of the possible solutions is to fill underground worked-out mine area with stowage materials using low quality ore. But this technology pushes up the cost of coal production and is not applicable to new coal mining objects, which has lack of free worked-out area as well as to waste dumps, accumulated during long years of coal production. One of the most common ways of reducing the negative impact on the environment of already formed spoil heaps is its recultivation. However, recultivation of coal mining waste, which is followed by application of antipyrogens, ameliorants and mineral fertilizers to waste dumps, considerably limits their further utilization as artificail deposits. Antipyrogens, ameliorants and mineral fertilizers, when entering into physical and chemical reactions with coal mining waste, make this waste unsuitable for application as a secondary resource, particularly during the production of many construction materials. It defines the prospectivity of spoil heaps conservation, which allows not only to reduce the negative impact of spoil heaps on the environment but also to preserve their resource potential. This study offers a method, a technology and technical solutions for spoil heaps conservation that ensure their geoecological safety as sources of environmental pollution and allow to use its resource potential for production of target products.

Ключевые слова:
терриконики, экологическая техногенная нагрузка, эрозия, выбросы в атмосферу, геоэкологическая безопасность, рекультивация, техногенные месторождения, ресурсный потенциал, консервация, технические решения, геосинтетические материалы, бентонитовые маты, отложенный спрос, строительные материалы, строительная керамика, энергоэффективные добавки.

Добыча угля сопровождается образованием крупнотоннажных отходов в виде террикоников из некондиционной руды. Специфический минералогический и химический состав пород, слагающих терриконики, в результате воздействия агрессивных природных факторов приводит к формированию экологической техногенной нагрузки на окружающую среду в виде пылевых и газовых выбросов, образования загрязненных вод, загрязнения и засорения прилегающих территорий. При этом исключаются из хозяйственного использования земли, занятые под размещение террикоников, а их ресурсный потенциал теряется в результате ветровой и водной эрозии, негативных физико-химических и биохимических процессов, преобразований слагающих терриконики горных пород, приводящих к снижению их ценности как вторичных ресурсов. Это определяет актуальность разработки мероприятий по снижению экологической техногенной нагрузки, формируемой террикониками, до приемлемого уровня, и сохранению их ресурсного потенциала как техногенных месторождений. Одним из возможных путей решения проблемы является заполнение подземного выработанного пространства шахт закладочными материалами с применением некондиционной руды, но использование данной технологии накладывает обременения на экономическую составляющую добычи угля, а к новым объектам угледобычи, у которых отсутствуют свободные выработанные пространства, а также к накопленным за предшествующие долгие годы работы угледобывающих предприятий отвалам она не применима. Широко распространённым способом снижения негативного влияния на окружающую среду уже сформированных террикоников является их рекультивация. Однако рекультивация отвалов из отходов угледобычи, сопровождаемая внесением антипирогенов, мелиорантов и минеральных удобрений в отвальные породы, в значительной степени накладывает ограничения на их дальнейшее использование как техногенных месторождений. Антипирогены, мелиоранты и минеральные удобрения, вступая в физико-химические реакции с отходами угледобычи, делают их не пригодными для дальнейшего применения в качестве вторичных ресурсов, в частности, при производстве большинства строительных материалов. Это определяет перспективность консервации террикоников, которая позволяет не только сократить их негативное влияние на окружающую среду, но и сохранить заложенный в них ресурсный потенциал. В работе предложены метод, технология и технические решения по консервации террикоников, обеспечивающие их геоэкологическую безопасность как источников загрязнения окружающей среды и возможность использования их ресурсного потенциала для производства целевых продуктов.

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Introduction

Despite the dynamic development of coal-mining cluster, development of new advanced technologies and methods of coal mining [1-3], the challenge of formation of spoil heaps from low quality ore is still on the front burner. During mining low quality ore is stocked into spoil heaps to a greater or lesser degree depending on production method. As a result, lands occupied by spoil heaps are excluded from economic circulation for a long time (until their liquidation).

Low quality ore of coal-mining industries stored into spoil heaps is usually presented by the following main groups of minerals: quartz, feldspar, illite, kaolinite and corundum, magnetite and hematite. The main chemical elements contained in the spoil heaps are oxides of silicon, aluminum and iron but there are also calcium and oxides of magnesium, manganese, sulfur, sodium, potassium, zinc, titanium, molybdenum, lead, vanadium, nickel and other elements [4].

Such a composition of spoil heaps of rocks and their physical and chemical properties when exposed to aggressive natural factors determine the inevitability of their negative impact on the environment [5].

Negative ecologic effects of spoil heaps

Spoil heaps are highly susceptible to wind and water erosion. They are sources of dust and gas emissions. Aeolian processes trigger blowing and deflation stockpiled in dumps small fraction rocks and sediment in the surface layers of soil of a surrounding area, which in turn provokes negative physical and mechanical reactions. Atmospheric precipitations lead to leaching from spoil heaps many tons of rock containing hazardous components on a surrounding area. Temporary water streams formed on the slopes of spoil heaps get into the area nearby which cause carryover of unbound particles of soil, its contamination and pollution, destruction of topsoil and disclosure of underlying layers. Spoil heaps are sources of air pollution in coal mining areas. Part of the spoil heaps is a subject to combustion processes, which leads to emission of atmosphere along with water vapor formed during evaporation and sublimation of entering into the combustion zone of precipitation such hazardous constituents such as sulfuric acid (sulfate ion), carbon dioxide, nitrogen dioxide (nitrate ion) [6-8].

Common methods to decrease negative impact of spoil heaps on the environment

Formation of ecological anthropogenic impact from spoil heaps determines relevance of search for ways to reduce their negative impact on the environment in order to prevent its degradation. One of possible ways to overcome the challenge is to fill out the space of underground mine by backfill materials with use of low quality ore [9, 10]. It should be noted that filling out the space in coal mines would greatly reduce the formation of spoil heaps but impose burdens on the economic component of coal mining. Even during the development of deposits of non-ferrous metals and rare earth elements, which ensure the best possible extraction of minerals by filling out is more relevant. Often such events are very expensive and have an impact on the cost of extracted minerals. Stowing complex consisting of the mining enterprise includes processes, violation of any of which may lead to the failure of the entire production process of the mineral [11].

Recultivation of spoil heaps is one of the ways to reduce its negative environmental effects. That method became popular recently [12]. The most efficient in terms of geoecology of common methods is sanitary and hygienic, which consists of two phases: technical and biological. In general, work on remediation are quite costly from an economic point of view. And if they are made of poor quality or not comply with the requirements of technical regulations, possible resumption of a negative impact on the environment as a result of secondary emission processes.

Recultivation of spoil heaps does not prevent their full contact with atmospheric water and antipyrogens, ameliorants and fertilizers injected into the body of the blade at its recultivation, come into physical and chemical reactions with coal waste, making them unsuitable for further use, in particular in the production of most construction materials. That is why over the time there is a significant loss of resource potential of spoil heaps, which reduces their value as a man-made deposits. Store of coal waste into spoil heaps in most cases is economically available for use in various industries as secondary materials, as they are partly disintegrated and placed on the surface [13]. Especially important is the fact that the waste heaps are located on industrial areas, with both its own transport network and other physical infrastructure, as well as potential users of secondary materials for a wide range of end products.

Due to its mineral and chemical composition waste coal can replace primary raw materials in large factories, for example, in the manufacture of building materials. With use of spoil heaps of coal deposits following can be obtained: gravel, sand from waste crushing, heavy and lightweight concrete, activated clinker-less mill ground hydraulic binders, granular insulation materials [14]. There are works on use of coal waste in petrurgical (stonecast) industry, in agloporite production, as a source of raw materials for the steel industry (in particular for the production of aluminum).

Today several advancement were achieved in the study the possibility of building ceramics production with use of coal waste [15]. It was established that unburned waste coal are highly burnable additives, and burnt spoil heaps are emaciations and intensifiers of sintering as part of the raw material charge for the production of building ceramics. With use of spoil heaps in the production of building ceramics single high-quality wall materials can be obtained with high added value, which makes the production of such attractive from an investment point of view.

It should also be noted that, in general, environmental activities in managing the treatment of coal waste is aimed to minimize sedimentation of no recycled waste residues into environment that reduces formed environmental artifical impact and compliance with applicable environmental standards and disposal limits of waste generated. Reducing the share of waste generated per unit of production and processing are promising ways of development of coal mining industry. Perhaps, tightening of the legal framework at the intersection of environmental and industrial activity, as well as its harmonization with European standards will allow in the near future to increase volume of recycled spoil heaps in several times.

However, because of its availability, today the primary raw materials are often cheaper than secondary objective. An economic component of the raw material extraction has traditionally been decisive in deciding on the development of natural or man-made deposits. At the same time, in recent years due to the depletion of available natural resources there is a tendency of increase of interest in anthropogenic deposits.

Spoil heaps conservation

All that determines the relevance of conservation of spoil heaps, which allows not only to reduce its negative impact on the environment, but also save resources embedded in it further processing. In the future with transformation into a real deferred demand development of spoil heaps would be allowed to finally overcome the challenge in order to obtain them from recycled materials. Number of spoil heaps, located now in the coal-mining areas is large. It’s contained potential resource is underestimated. Taking into account the growth of consumption of mineral raw materials in different sectors of national economy, especially in construction, at constant increase in the cost of primary resource extraction waste heaps have the prospect of being high demand product in the middle term as affordable competitive secondary materials.

The main difference from the spoil heaps recultivation is to preserve them as artificial deposits. In this case the resource potential of spoil heaps is saved by preventing their contact with aggressive natural factors that lead not only to the physical loss of the mass of spoil heaps of rocks as a result of wind and water erosion, but also to a decrease in important consumer properties of its components as a result of transformation under negative influence of physical, chemical and biochemical processes initiated by penetration of water, air, oxygen and microorganisms into the body of spoil heaps. Studies made by the authors allow to propose a method, technology and complex of technical solutions for spoil heaps conservation. Spoil heaps conservation technology, in general, presents a number of successively conducted technical operations aimed to prepare and design spoil heaps to retain the resource potential and an acceptable level of geoecological safety. The design scheme of spoil heap which was conservated is shown in Fig. 1.

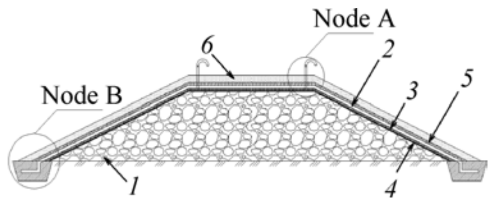

Fig. 1. The design of spoil heap conservation: *1* – spoil heap body; *2* – waterproof layer; *3* – gas drainage layer; *4* – separation geotextile; *5* – water-drainage layer; *6* – a protective layer of soil

Conservation work begins with flattening surface and slopes of spoil heaps body *1* with garbage collection and disposal of oversized. Then following systems are created: waterproof to avoid penetration of atmospheric precipitation into spoil heap body *2*, gas drainage for passive degassing of produced into the body spoil heap gases *3* with a separating layer of geotextile *4*, water drainage for removal of atmospheric precipitation, falling on the surface of the waterproof material *5*, a protective layer of soil over a waterproof layer *6*. In order to improve efficiency of drainage system a slope (~ 3%) is created on the surface of the spoil heap. A planned surface is covered by separating spoil heap geotextile material. A gas drainage system is installed above that for passive degassing of spoil heap body. Taken into account special importance to ensure steady work of degassing systems, gas drainage is made of the drainage gravel or shingle with thickness of 0.3 meters, with its coating of needle-punched nonwoven geotextile materials with high capacity and durability. Such geotextiles are able to protect sensitive to damage materials with low moister permeability (waterproof layer), which are stacked on top of the gas drainage layer from mechanical influence of drainage gravel. On top of the waterproof layer drainage layer is put for removal of atmospheric condensation. It is necessary to protect sealing by soil layer which thickness at least 1 meter, so plant roots do not reach waterproof material and it is not destroyed.

During the storage of coal waste, formation of gases in the body of spoil heaps is possible especially when activating biochemical processes and combustion. Rocks that fell into environment different to surface conditions get out of the balance and experience physical, chemical and biochemical transformations Loose carbon material of coal waste is rapidly oxidized until spontaneous combustion under the influence of atmospheric moisture and air oxygen. A common cause of spontaneous combustion of coal and other combustible rock of soil, roof and intercoal layers is the ability to absorb oxygen that react with potentially combustible matter. This process is accompanied by the release of heat and temperature rise, which further enhances an oxidation processes [16].

Rocks of carbonaceous clay composition that with increased porosity and content of sulfur and iron (in form of pyrite and marcasite) have a tendency to self-heating and self-ignition in water and air environment [17, 18]. Decomposition of pyrite and other sulfides happens as a result of both chemical interaction between minerals and agents of weathering and with participation of permanently presented in a surface zone free water exchange of thiobacteria *Thiobacillus ferrooxidaus* [17]. Due to acidification of a medium to a pH $\leq$ 3.5 and formation of sulfur in chemical oxidation of pyrite favorable conditions for bacterial activity are created. Those bacteria destroy sulphides and oxidize sulfide sulfur to sulfate ions. Under temperatures close to the boiling point of water, bacteria stop their activity. From that moment processes that caused by chemical reactions happen in the rocks.

To prevent accumulation of gases formed during mentioned processes, to fire and explosion of hazardous amounts it is necessary to install passive drainage systems to remove gas to the atmosphere. Active degassing systems for spoil heaps are irrelevant in terms of small volumes of gas formation. Taking into account that it is enough to remove them through exhaust pipes. The space between hoods is calculated for each single spoil heap. According to our preliminary estimates, this space in most cases is more than 50 meters. An important element of exhaust pipes is a non-return valve, which excludes outside air access into the body of spoil heap, but allows gas to flow free into the atmosphere. The device of exhaust pipes (node A) is shown in Fig. 2.

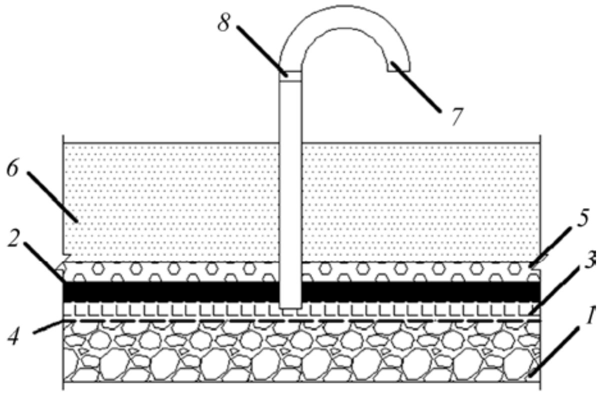

Fig. 2. Node A of exhaust pipe design; *1* – body of spoil heap; *2* – waterproof layer; *3* – gas drainage layer; *4* – separating geotextile material; *5* – water drainage layer; *6* – protection ground layer; *7* – exhaust pipe; *8* – non-return valve

Waterproof screen for spoil heap can be made as usual for waterproofing facilities (landfills of solid municipal waste, industrial waste, storage, tailings minerals and other) of individual webs, interconnected by glue, welding or overlap. At its junction of waterproof materials to slopes of spoil heaps (Node B, Fig. 3) its increased overlapping has to be considered. In case of deformation forecast, movement or settlement a device that compensates fold and could help to avoid a fissure. Pairing the waterproofing layer with ground base have to be made with help of indent or a tooth filled with plastic material (clay, loam). Such an indent or tooth with waterproof material embedded in it eliminates the possibility of air leaks into the body of spoil heaps, which minimizes the possibility of spontaneous combustion.

Perforated pipes of ring drainage should be laid on the outer perimeter of spoil heaps at its base. That allows removing atmospheric water from the spoil heap body experienced preservation procedure. To ensure long-term functionality of a drainage system it is viable to provide filtering geotextile.

Selection of materials that provide long-term performance of spoil heap construction has to be done in a comprehensive way with considered affordability and durability in contact of aggressive environmental and anthropogenic factors, technological effectiveness in the conditions of conservation.

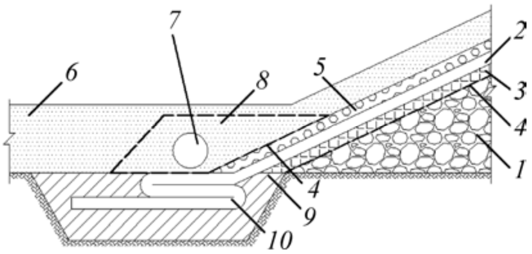

Fig. 3. Node At the junction of waterproof material to spoil heap slope: *1* – spoil heap body; *2* – waterproof layer; *3* – gas drainage layer; *4* – separating geotextile material; *5* – water drainage layer; *6* – protection ground layer; *7* – exhaust pipe; *8* – exhaust toe; *9* – plastic ground in a groove; *10* – compensating fold

Film screens of polyethylene with low density and 0.2-0.3 mm in thickness in accordance with state standard GOST 10354-82 are widely used as impermeable matter. They are also affordable.

Screens made of polyethylene film have certain deformability ability. That, on the one hand, makes them easy to use, but on the other hand, leads to the fact that screens are easy to damage by construction mechanisms during protective ground layer design. However, the films are subject to aging and a significant change of properties when the temperature drops, impact of freezing and thawing cycles and ultraviolet radiation. Frequently there are poor quality connection of individual panels during welding, violation of the structure, and in some cases, film integrity during indentation of relatively large ground fractions (greater than 5 mm).

Clays found nearby spoil heaps can be used for construction of impermeable screens if its properties meet requirements. Nevertheless, in order to achieve need coefficient of impermeability clay has to be of significant thickness and its construction is laborious and requires special equipment and personnel.

In this regard, the most promising method for conservation of spoil heaps is use of modern impermeable roll materials, such as bentonite mats with geotextile aggregate from calcium or sodium bentonite, which is more effective. World experience of application of these materials showed that they provided high reliability and almost complete sealed of impermeable construction. Bentomats usually represent a frame made of needled fabrics or polypropylene nonwoven web with sodium or calcium grains in between. Webs are interconnected by transverse needled method that provides strength and elasticity of the structure, as well as uniform distribution of the bentonite granules inside the frame and fixing them. Bentomat structure is shown in Fig. 4 [19].

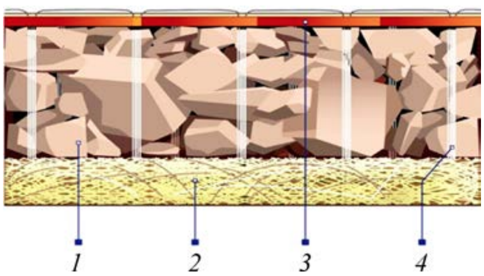

Fig. 4. Bentomat structure:
1 – bentonite grains; *2* – nonwoven geotextile web;
3 – woven geotextile web; *4* – needled fiber

Bentonite mats are produced by such companies as NAUE (Germany), HUESKER (Germany), GSE (Germany), Tehstroyteks (Belarus), CETCO (Poland), Carpi (Switzerland), ISOBENT (Belarus), BentIzol (Russia), Nilex (Canada) and others. Bentonite mats are manufactured in large volumes, competitive economically with natural clays and have been used widely in the last decade with design of impermeable constructions for a wide range of buildings such as landfills for waste disposal, storage, sludge and others. In terms of design of impermeable screens methodology challenges of its use are reviewed. The company NAUE made a significant contribution to development of methodology of buildings design with use of bentonite mats. This company is one of the world leaders in production of geosynthetic materials and has work experience for more than 30 years.

The bentonite mat structure contains strong and durable geotextile that securely holds the bentonite layer, thus provides long-term material operation. Waterproof of such roll material is caused by the swelling of bentonite in an enclosed space upon hydration. In addition, bentonite mats have the ability to self-recover after mechanical damage due to its increase in volume up to 12 times in contact with water. That is especially important because mechanical damage is possible during transportation and installation of the material. It was found that bentonite mats filled with sodium are most technology efficient from that group of waterproof materials, because they have the best penetration coefficient values [19].

Application of geotextiles to design both gas drainage systems and drainage systems to remove rain water is caused by their high strength, water permeability and durability of structure built with their use. At the same time geotextiles are easy to store, transport and install. The thickness of a drainage system designed with help of geotextiles is several times less than a drainage system of natural materials (drainage grains or pebbles) of the same permeability.

Conclusion

Comparative analysis of technical, economic and environmental efficiency of conventional strategy of spoil heaps treatment by reclamation with proposed strategy of its conservation allows making a conclusion that both these strategies provide an acceptable level of geoecological safety. Nevertheless, reclamation leads to a significant reduction in underestimated resource potential of spoil heaps, while during its conservation long-term safety in the period of deferred demand for secondary resources is ensured. Application of the proposed method, technology and complex of engineering solutions for conservation of spoil heaps reduce artificial environmental influence and provide long-term preservation of resource potential. Preservation of spoil heaps is technically feasible, affordable, environmentally safe and can be implemented in actual operating conditions of construction companies without use of special equipment and personnel.

Conservation of spoil heaps can prevent transformation processes of containing rocks, which occur under the influence of atmospheric condensation and trigger physical and mechanical reactions. Preservation of resources of spoil heaps together with minimization of contact with the environment allows achieving synergetic effect during reclamation of resource potential of accumulated large tonnage coal mining waste.

Analysis of current market and demand for primary and secondary mineral resources, as well as forecasts of its change in near future shows that the deferred demand for resource potential of spoil heaps at a constant rise in prices for primary mineral resources and complicating conditions of their technical and economic availability will eventually be transformed into a real one. Thus, spoil heaps as artificial objects in mid-term will be in demand. Depletion of easy to recover primary raw materials and stiffening of lows related to production waste lead to transformation of deferred demand in the real one.

Our research found that, along with well-known areas of use of spoil heaps such as production of sand and gravel, aggregates for concrete, stone casting, granular thermal insulation materials, technical grounds for land reclamation and other purposes. Besides, they can be used to produce construction ceramics by use of specific mineralogical and chemical compositions of spoil heaps. During the research technical solutions for use of spoil heaps matter as burnable and thinning agents were developed. That is possible during production of construction ceramic products which is competitive with analogs that were obtained from primary materials and are characterized by high value added. That represents important economic driver for development of spoil heaps as valuable artificial fields.

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