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Heavy accumulation of fertile soil layer in the mined-out space of opencast using geothermal energy

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Abstract
The theoretical evaluation of accumulation of fertile soil layer is conducted on the basis of rate of increase of the organic matter of higher aquatic plants with the use of technique of intensive recovery of the biodiversity in the mined-out space of opencast using geothermal energy. It is established that the suggested technique allows increasing the accumulation rate of fertile soil layer, which is material

and energy basis for biodiversity recovery in the mined-out space of the opencasts.
Key words: MINED-OUT SPACE OF OPENCAST, GEOTHERMAL ENERGY, HYDROBIONTS, BIODIVERSITY, CLAY-GRAPHITE COMPOUND, FERTILE SOIL LAYER

Relevance

The open-cut mining leads to formation of dead areas without fertile soil layer in the mined-out spaces. The mined-out spaces after extraction of raw materials like refractory clay, fluxes, chalk-stone or chalky clay have the form of "lunar" dead landscapes; they are cavities without any fertile soil layer with edges subjected to erosion damage. Thus, the high level of environmental threat is developed [1]. The self-existing recovery of flora and fauna within such areas takes hundreds of years and in some cases leads to further environment deterioration.

The method of the biodiversity initial state recovery in the areas after mining of mineral products is necessary. This method must meet the requirements of cost characteristics and at least partial payback as far as possible.

Some researchers propose to restore the mined-out opencasts by applying the filling operation of the mined-out spaces with subsurface rocks. However, such recultivation is reasonable only for small-area and shallow opencasts with the availability of sufficient amount of worked-out rocks and fertile soil layer, as well as for the opencasts with high level of ground water depth.

The problem of recreation of mined-out spaces is often solved by filling of mined-out spaces of the opencasts with water making an artificial reservoir. However, it is often impossible to make an artificial reservoir because of relief complexity, structure fracturing of soil layer or other factors.

One of the advanced way of problem solving is the intensive creation of fertile soil layer on the pit floor.

State of problem

In order to speed up the recovery of biodiversity in the mined-out opencast spaces and polluted water purification, the authors have suggested using the method of the biological purification of quarry water by plants with increasing the path length and purification time by terms of making the labyrinth configuration to the water flow [2]. Hereafter, for the year-round control of water flows, it is suggested to improve the method of the bacterial purification of the quarry water by plants with the increasing the path length and purification time through temperature regulation, flowed through water streams regarding geothermal energy [2].

In this regard, it is required to drill boreholes 50…100 *m* in depth along the water track right and left from the auxiliary dams and arrange the geothermal heat transfer device in these boreholes; this device is transverse borehole collector "pipe-in-pipe" (Fig. 1). In this case, the plastic tube (32-50 *mm* in diameter) paths along the axis of steel one (100-120 *mm* in diameter) which is welded at the bottom.

The quarry water runs into the tube space through the convergent tube and moves downwards through the tube by impact pressure. As the quarry water runs, there is a heat exchange between the metal tube wall with the temperature of enclosing rocks and water flow, as a result of which the temperature of water is raised. At the bottom of tube, the water flow changes the direction by 180° and rises to the surface through the inner plastic tube by dynamic impact and density difference between heated and cold water. The interval between wells should not be less than 10…15 *m*. Such construction resists successfully soil movement and provides a good heat transmission.

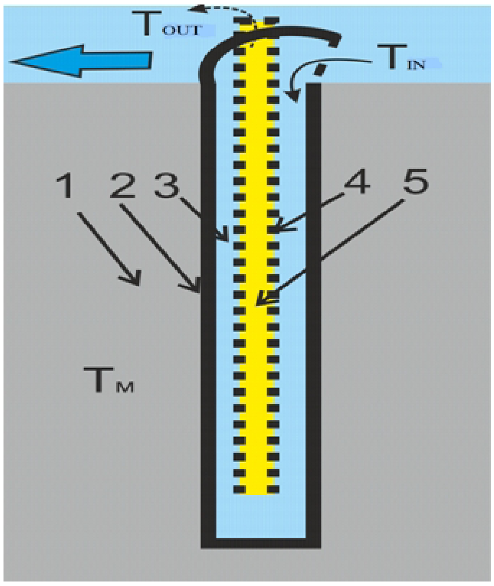

Figure 1. The operation scheme of transverse borehole collector "pipe-in-pipe":
a – vertical section; 1 – rock mass; 2 – metal pipe; 3 – stream of cold supply water; 4 - inner plastic tube; 5 – the stream of heated water; T_m, T_{in}, T_{out} – temperature of rock mass, running into and dropping out of the collector water respectively

As a result of year-round control of the quarry water streams by using of geothermal energy, the stable temperature conditions will be achieved.

On the basis of chemical analysis of water specimen, it has been concluded that it is necessary to remove suspended materials from water and take measures to reduce rigidity and salt content. It is reasonable to use such plants as bulrush, rush, reed mace, and water hyacinth because those particular plants purify water properly and they are of low-cost.

It is necessary to maintain the water temperature within 10…12 ^{0}C in the purification plant in order to prevent reduction of water purification efficiency in winter period. The water does not freeze over with such temperature; however, its temperature falls off significantly under the ice crust of the plant. At a temperature of waste water less than 7 ^{0}C, the living abilities of hydrobionts and their activity are reduced sharply. At temperature more than 28 ^{0}C, the nitrification rate decreases due to reduction of dissolved oxygen quantity in the water. Thus, the optimum temperature is 10…12 ^{0}C in winter period and no more than 25…28 ^{0}C in summer period.

The analysis of temperature conditions on the surface and in depth of earth cover under conditions of Donets Basin showed that the temperature on the surface could have both negative and positive values. The temperature at depths of 5…10 *m* has only positive values within 4…12 ^{0}C. The deepness of the neutral zone for Donets Basin is 10-15 *m* that determines the necessity of partial thermal protection of steel shell of the borehole collector.

The thermal calculation was conducted, and the water temperature in depth of borehole equation was obtained in order to determine the critical parameters of the technology [3].

$$T = T_{g0} + \frac{\text{grad}T_g}{A}(Az-1) + \left(T_1 - T_{g0}\frac{\text{grad}T_g}{A}(Az_1-1)\right)e^{-A(z_1-z)} \qquad (1)$$

where: $T=T(z)$ – current temperature of water, *K*;
T_{g0} – temperature of land surface, *K*;
$\text{grad}T_g$ – thermal gradient of ground, *K/m*;
z – ground clearance, *m*;
$z>z_1$ – ground deepness before which the temperature of the ground is constant (for Donets Basin conditions, z_1=15 *m*; $T_g=T_{g0}$).

$$A = \frac{\pi Dk}{Ms} \qquad (2)$$

where: k – coefficient of heat transfer, $W/(m^2{\cdot}K)$;
M – water expenditure, *kg/s*;
s – water specific heat, $J/(kg{\cdot}K)$;
D – borehole diameter, *m*.

Taking into account the heating temperature of water $T=T_2$, it is determined the necessary length of inner pipe z_2 by solving the equation:

$$T_2 = T_{g0} + \frac{\text{grad}Tg}{A}(Az_2-1) + \left(T_1 - T_{g0}\frac{\text{grad}T_g}{A}(Az_1-1)\right)e^{-A(z_1-z_2)}. \qquad (3)$$

At a section $0<z\leq z_1$ where $T_1>T_g$ for preventing of heat loss and a temperature drop of water, it is necessary to provide the thermal protection in the borehole.

The calculation data has demonstrated that 26 *m* deep borehole provides the change of 1 ^{0}C in temperature in the geothermal heating system. For increasing of water temperature from $T_1 = 7°C$ to $T_2 = 12°C$, 130 *m* deep borehole is required.

For providing the best heat transmission from the depth of solid to borehole collector, it is necessary to minimize the negative impact of rock fracturing nearby the surface of geothermal heat transfer pipes. To achieve this purpose, the authors propose to fill these holes with solidifying compound based on inexpensive material, for example, clay with addition of heat-conducting filler, in the function of which it is reasonably to use graphite powder [3].

The experimental investigation of heat-conducting properties of the clay-graphite mixture demonstrated that in case of increase of graphite powder in the mixture up to 50 % (mass), the increase of heat conducting coefficient of damped mixture is 157.12 % in comparison with heat conducting of dry bentonite; it is equal to 15.89 $W/(m{\cdot}{}^oC)$.

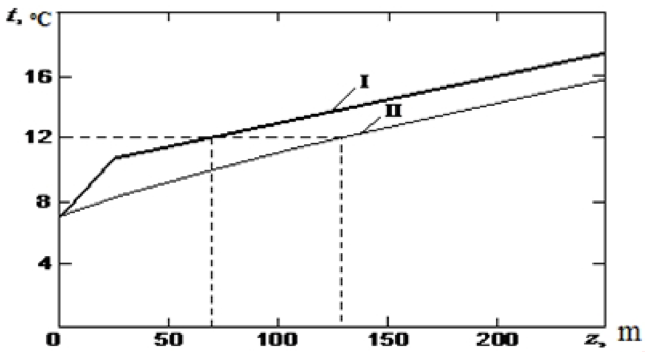

Figure 2. The temperature change of water in depth of borehole using clay-graphite mixture (I) and without it (II)

The thermal analysis with consideretion of clay-graphite mixture use allows determining that for heating of water to the same temperature, using a clay-graphite filler of space between tubes, it is required a borehole which is 1.7 times smaller than in the case of steel shell direct contact with enclosing rocks (Fig. 2).

The established regularity of heat transfer between the rock mass and aquatic medium in case of use of geothermal heat exchange units in the biological-purification installations will allow determining its key parameters (number of boreholes and their deepness) for temperature +10^{0}C maintenance in winter period.

The example of implementation of making fertile soil layer technology in the mined-out space of the opencast, which is 300x200 *m* in size (Fig. 3), with the use of geothermal energy, includes the following processes [3].

By means of earth movers and blade graders, the rebuilding of opencast bottom for 3.5° sloping is carried out. There is the main dam 5, which is 200 *m* in length, 3 *m* in width and 1 *m* high, in the center of mined-out space built from the materials unapt to slaking; they are pieces of sand rock and limestone.

The auxiliary dams are built to increase the time of water passing through the opencast, thereby increase the degree of water purification. The dams are arranged in chessboard order in 4 lines and each line includes 4 dams. The embankments of rocks unapt to slaking and covered with black soil bed will be basis for the dam. The distance between the auxiliary dams is 50 *m*. In order to minimize erosion and soil washing, surfaces of the dams are planted by bulrush, rush and reed mace.

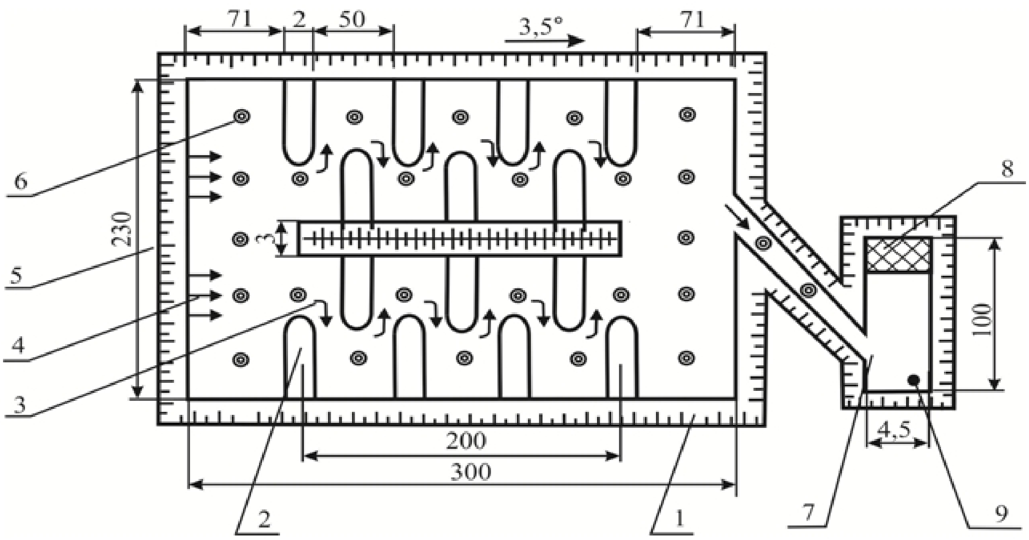

Figure 3. The installation for water purifying in opencast with the use of geothermal energy: 1 – opencast edge; 2 – auxiliary dams; 3 – bed; 4 – water inflow; 5 – main dam; 6 – transverse borehole collector “pipe-in-pipe”; 7 – water-collector; 8 – higher aquatic plants; 9 – pump

It is necessary to drill 24 geothermal boreholes (6) with diameter 200 *mm* and length 76 *m* along the stream bed to maintain required temperature water conditions (10…12 ^{0}C in period and up to 28 ^{0}C in summer period). The boreholes are arranged in 4 lines 6 items in each line; the distance between them is 50 *m*.

The heat exchangers are arranged in the drilled boreholes. The heat exchangers are cylindrical shell made of steel 4*X*13 with 20 *mm* thickness of wall, it is shut off from the bottom. The plastic pipe, which is 50 *mm* in diameter and 75 *m* in length, is located concentric in them. The space between shell and massif in the site from 10 to 75 *m* is filled with clay-graphite compound with 50 % graphite mass content. The heat exchangers are equiped with thermal isolation from cellular glass 20 *mm* thick at a depth of 15 *m* from the ground surface. The self-purification from suspended matter will be conducted by turbulent mode of water movement in the bottom-hole area of the heat exchanger.

In order to prevent erosion, the edges and benches of the opencast are planted with sloe as this plant has extremely bushy roots and it also grows quickly within a short period of time.

The water-collector 7, from which renovated water is fed by pump 9 for watering or other technical needs, is built at the bottom of opencast. The water-collector is designed for additional water purification, so the part of that will be planted with higher aquatic plants. The water hyacinth 8 is planted for biological water purification in the water-collector.

The maintenance of thermal water conditions in the biological purifier will allow creating comfortable conditions for living abilities of hydrobionts all year round; preventing freezing of shallow stream flows and death of water grass and shellfish in winter period. The living conditions of hydrobionts will also be improved due to water cooling in the shallow-water space of opencast in summer period. The water resource in the water purifier will perform year-around function of purification by way of carbon dioxide and other gasses dissolving with subsequent taking them by plants for cell composition and nourishing. Moreover, it will allow using nonfreezing water like a place for wintering of swimming birds.

As biodiversity recovery is directly connected with the formation of fertile soil layer, it is necessary to analyze the speed of its formation.

The paper objective is to evaluate theoretically the rate of fertile soil layer accumulation using geothermal energy for reduction of biodiversity of mined-out space of opencasts.

Researches results

The scale change of geographical situation, landscape influenced by natural disasters and human activity lead to gradual changes of local biocoenose state. The influences of forces, which change quality and quantity characteristics of circulation of elements and energy, usually affect biocenosis changes or destroy it. The new living organisms gradually appear in the place of previous biocenosis.

The elementary biocenosis arises and functions at the first stage. It includes restricted quantity of types of plants and animals. The elementary biocenosis changes into more complex ones gradually. It occurs when enough energy and material resources are accumulated, providing the emergence of new ecological niches, and proceeds until there appears the biocenosis, in which the biotic and abiotic relations meet requirements of the community of living organisms.

In the case of the mined-out spaces of opencasts, the biodiversity recovery is possible only with the sufficient amount of accumulated fertile soil layer, which contains material resources to create ecological niches.

The fertile soil layer is the upper humus layer of soil possessing chemical, physical and biological properties favorable to plant growth. Humus is complex dynamical composite of organic compounds formed at the mineralization of organic remains. The humus content of soils is determined by the terms and character of the soil-building process. It ranges from 1-2 to 12-15% in the surface soil layers and sharply or gradually falls with depth.

The organic part of the soil contains undergrad and semi-decomposed vegetable remains, soil organisms, and humus. The remains of plant and animal bodies rebuild and refresh humus stocks in the soils with gradual decompounding. The process is under way of active involvement of microorganisms and animals (earthworms, maggots). These complex biochemical decay and synthetic processes are simultaneous. Thus, the more biomass is produced in the ecosystem, the higher humus level is in the soil. Soil humusification can be implicitly inferred by the producing of plants biomass.

The process of fertile soil layer formation at the bottom of the opencast may be presented in the following way (Fig. 4). The labyrinthine drainage channel of the water purifier is a kind of plain catch basin. Precipitation of suspended materials gathering in mass at the bottom of the draining channel takes place. The plants, which grown along the shores, at the bottom and water surface, sorb suspended materials on the stems, leafs, and roots. Thus, the finely divided nonorganic phase of the layer is accumulated. The roots of the water and foreshore plants penetrate into the pores and fissures of roaches laying down the bottom of the opencast, and distract them by wedging. It is especially common for sedimentary rocks of the massive. Thereby, the second part of fertile soil layer inorganic component is formed.

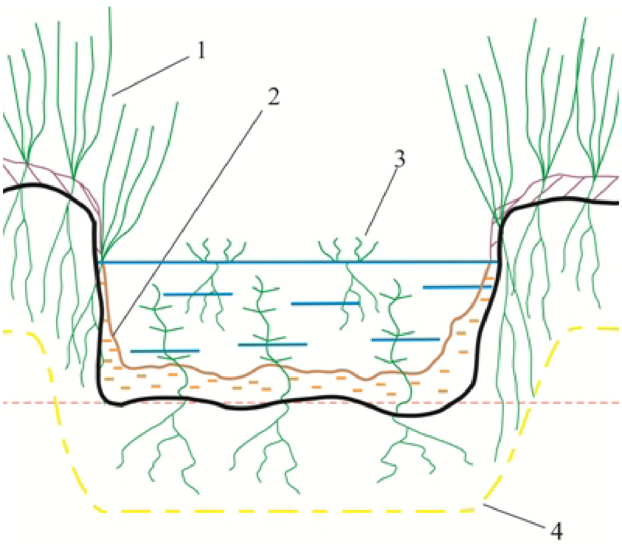

Figure 4. Diagram of formation of fertile soil layer in the drainage channel of water purifier: 1,3 – foreshore and water plants; 2,4 – upper and lower bounds of the fertile soil layer respectively

The plants absorb the salts from water as well as the carbon dioxide and other materials from the air by their roots, stems, and leaf. The root, underwater and surficial cell mass increases, and then it forms soil humus layer in the process of further cells die-away and decomposition.

It is possible to point out the upper fertile soil layer bound formed with alluvial deposits, and lower one formed with broken rocks. The productivity of the fertile soil layer is determined by its thickness and organic substance richness. The organic substance richness is proportional to formed and laid down cell mass of the plants.

The biomass of foreshore-water plants is estimated by three criteria, namely, weight of fresh just cropped mass, air-dry and oven-dry mass.

Depending on experimental tasks, the three ways of aquatic vegetation registering are used; however, the last one is the most advantageous as allowing the results of different authors to be compared.

The biomass of aquatic vegetation is expressed as a unit of weight per unit of area (g/m^2, kg/m^2, c/ha^2) with the including (or exception of) underground organs. Knowing the square of certain associations and their biomass, it is possible to calculate the storage of biomass vegetation for the whole water reservoir.

It is more complicated to select the quantitative samples of the underground organs of plants as many of them reach significant depth. For example, the reed reaches 1 *m*, equisetum – 80 *cm*, water arum and bean trefoil – 70 *cm*, sedge – 60 *cm*.

The analysis of root system is important for determination of biomass as the underground organs of many plants (reed mace, bulrush, cow lily, pond lily) can exceed above-ground ones by several times by biomass. According to the literature data, the ratio of the underground parts with the above-ground parts is 2.5:1 in narrowed-leaved catoptric, 1:1 in mace reed and reed, and 9:1 in bulrush. In the formed systems, underground organs (roots, rootstocks) are 50-100% of plant biomass. However, it is necessary to notice that they are being accumulated for a number of years, so they cannot be a great part of general annual production. According to another data, about a half of underground mass grows in a growing season.

For prior assessment of the rate of increase of organic mass, it is possible to use known facts of the foreshore-water plants rise rate. According to the paper [5] data, the annual productivity of water hyacinth is only 150-440 g/m^2 of dry weight, but its gain for the period from June to August is 14.6 g/m^2 of dry mass per day. During the short period of time, the higher rate of growth that is 30 g/m^2 of dry mass per day [6] is possible for the plant system; it in turn signifies the high nitrogen and phosphorous demand [6].

The data on biomass yield and growth rate of different water-plants are presented in Table 1.

Table 1. The maximum weight of growing crop and seasonal gain of some aquatic microphyte [5]

Type of microphyte	Maximum weight of the growing crop, g/m^2 of dry mass	Seasonal gain per day, g/m^2 of dry mass
Marsh grass (*Spartina Alterniflora*)	4200	10.0
Great bulrush (*Scirpus lacustrine*) and giant bulrush (*Arundo donax*)	10000	28.0
Radicle of roots (*Ceratophyllum Demersum*)	710	2.5
Water parsnip (*Berula Species*) and buttercup (*Ranunculus species*)	500	4.2
Delta Arrowhead (*Sagittaria Latifolia*)	810	7.5
Water hyacinth (*Eichhornia crassipes*)	1500	7.4-22.0

The yield of dry mass for such crops as mace reed (*Typha latifolia*) and swamp lily (*Saururus census*) is 1500 and 800 g/m^2 respectively [6]. The investigation results of an annual productivity (output) of the seven plants of salt lakes in Louisiana are presented in Table 2.

Table 2. The investigation results of an annual productivity (output) of the seven plants of salt lakes in Louisiana

Type of plant	Biomass gain, g/m^2 of dry mass
Alkali grass (*Distkhlis spicata*)	3237
Rush (*Juncus roemerianus*)	3416
Bur reed (*Phragmites communis*)	2318
Arrowhead (*Sagittaria falcata*)	1501

Marsh grass (*Spartina altemiflora*)	2658
Prairie Grass (*S. cynosuroides*)	1355
Marsh grass of salt pratum (*S. patens*)	6043

Consideration of underwater part of plants can affect significantly the values their productivity. For example, when studying the emergent microphytes of Wisconsin fresh-water marshes, it was established [6] that the primary annual output is in range from 1181 g/m^2 of dry mass for ling (*Cazex lacustris*) to 3200 g/m^2 of dry mass for mace reed (*Typha latifolia*); while an annual increasing of mace reed in Oklahoma was only 800 g/m^2 of dry mass [9].

For the opencast under consideration (Fig. 3), the following basic data are accepted. The parameters of auxiliary dam are the following: 2 *m* in width, 1 *m* in high, and 32 *m* in length. In total, 14 auxiliary dams were equipped; the area of each dam is 2*32 = 64 m^2. The total area of auxiliary dams is S_{tot}=14*64 = 896 m^2. The main dam is 200 m in length, 3 m in width, 1 m in high and 200*3=600 m^2 in area. Thus, the total area of dams planted with bulrush is 896+600=1496 m^2.

On average, the growth cycle of bulrush is 7.5 months (233 days) under the conditions of Ukraine. In this period, the growth of bulrush dry mass is 6.35 g/m^2 per day. The growth of dry mass is 2.21 t per year for the total area of dams planted with a bulrush.

The use of geothermal energy for temperature conditions controlling in the opencast will allow providing the bulrush growth during the year. Consequently, the annual gain of bulrush dry mass will be 233*6,35= 1479,55 g/m^2. For the total area of dams planted with bulrush, the dry mass gain reaches 3.47 *t* per year, it is 1.57 time higher than without using of underground heat.

The water-collector is arranged at the bottom of the open-cast, where water undergoes additional purification by water hyacinth (*Eichhornia crassipes*). The area of the water-collector is 450 m^2, 200 m^2 of which is planted with water hyacinth. On average, under the conditions of Ukraine, the growth cycle of water hyacinth is 5 months (153 days). In this period, the growth of water hyacinth dry mass is 7.4 g/m^2 per day. In such case, the annual gain of water hyacinth dry mass is 153*7.4= 1132.2 g/m^2. For the total area of water-collector planted with water hyacinth, the dry mass gain reaches 0.226 *t* per year.

The annual gain of water hyacinth dry mass will be 365*7.4 = 2701 g/m^2 of dry mass when using geothermal energy. For the total area of water-collector planted with water hyacinth, the dry mass gain reaches 0.54 *t* per year, it is 2.4 times higher than without using of underground heat.

Conclusion

The theoretical assessment of accumulation of fertile soil layer on the basis of evaluation of gain rates of the organic matter of higher aquatic plants using the technique of intensive recovery of the biodiversity in the mined-out space of the opencast with the use of geothermal energy was conducted. The annual gain of bulrush dry mass will be 3.47 t, which is 1.57 time higher than without using of underground heat. This figure for water hyacinth is 0.54 *t*, which is 2.4 times higher than without using of underground heat.

As can be seen from the above, the suggested technology, which provides the use of heating energy of subsurface resources, will allow increasing the rates of accumulation of the fertile soil layer by 1.5…2 times. This layer is material and energy basis for biodiversity recovery in the mined-out space of the opencasts.

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Logistics of raw materials supply for the ferroalloy industry

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Abstract
The problems of arranging traffic of material flows in the framework of micrologic system of the ferroalloy plant are studied in the paper. For the effective interaction of enterprises with the transport operators, the research task of the necessary car number for the delivery of raw materials and fuel should be fulfilled. The fulfillment of this task includes time scheduling of car stay on the house track of enterprise, which is the constituent part of the overall time of car cycle in the delivery route. On the basis of the statistical analysis and collinearity test of the initial parameters, the most

important of them were selected. The regression models were created and analyzed; the most adequate model with the minimum approximation error was selected. The suggested support system of decision making concerning determination of necessary cars number for delivery to the ferroalloy plant is based on the results of time scheduling of car stay on the house track with the help of the developed model.

Key words: LOGISTICS, FERROALLOY INDUSTRY, HOUSE TRACK, RAILWAY TRANSPORT, TRANSPORT OPERATOR, MATERIAL FLOW, INFORMATIONAL FLOW, THE INTENSITY OF UNLOADING, REGRESSION MODEL, MICROLOGIC SYSTEM

Introduction

The considerable quantity of agglomerate, ore, coal, limestone and other mineral resources pass to the ferroalloy plants every day. For delivery, the railway transport is used. The successful arrangement of material, informational and financial flows in the "suppliers - railway – ferroalloy plant – consumers" system is based on the logistic approach (Bauersoks & Kloss, 2001; Skovronek & Sariush-Vol'skiy, 2004); moreover, it is a part of social-economic stability of the particular area.

The effective interaction with transport operators is possible on the basis of determination of necessary car number for delivery of raw materials and fuel.

The part of overall time of car cycle in the delivery route is accounted for the raw materials supply, the part is accounted for movement and processing of the rail transport in the trunk railway stations, and part is accounted for the ferroalloy plants. The calculation of the last part is a very complex task.

The paper (Turpak and Grytsay, 2011) is devoted to the task of planning of the cars use. The investigations of dependence of time of the car stay on the house track of the metallurgical enterprise on the most important factors are conducted by the example of the metallurgical enterprise specializing in production of cast iron, steel and rolled ferrous products. The obtained regression model allows planning of the transport process and accordingly establishing of car cycle time in the delivery route and the necessary car number of the working track.

The absence of excessive number of cars cuts the costs for their servicing and increase the efficiency of their transporting.

For economic effect, the investigation must be integrated into the process model of functioning of the metallurgical enterprise logistic system (Hubenko, Derhausov & Nefodova, 2004; Parunakyan & Gusev, 2005).

Researches results

Statistical processing of output data

The length of cars stay in the metallurgical enterprise is determined by the temporal values of the cars delivery to the connecting station of railway trunks. It depends on the transport-technological process of cars treatment, technology of the materials handling and meteorological conditions. These processes depend on the goods properties and equipment of load points.

Depending on the goods type, the cars, which pass to the metallurgical plants, are divided into the following groups: container yard (CY), underground bunkers, limestone warehouse, inside storage of charging materials No 1 (CS ins.), outside storage of charging material No 1 (CS out.), charge workshop section No 2 (CWS 2), charge workshop section No 3 (CWS 3), charge workshop section No 4 (CWS 4).

The statistical data of the observations with different goods types to 8 load points in the period from November, 2011 to June, 2014 are presented in Table 1.

Table 1. The statistical data of the observations in the period from November, 2011 to June, 2014

No	Variable	Indexes	Range of values
1	Lay-over	y	11.41 – 24.56
2	CY	x_1	14 – 63
3	Undergr. bunkers	x_2	0 – 23
4	Limestone warehouse	x_3	0 – 53
5	CS 1 ins.	x_4	72 – 229
6	CS 1 out.	x_5	13 – 130
7	CWS 2	x_6	18 – 57

8	CWS 3	x_7	32 – 95
9	CWS 4	x_8	142 – 308
10	Agglomerate	x_9	104 – 241
11	Limestone	x_{10}	0 – 53
12	Coal	x_{11}	0 – 12
13	Electrode paste	x_{12}	1 – 9
14	Quartzite	x_{13}	37 – 128
15	Coke	x_{14}	33 – 220
16	Container	x_{15}	14 – 63
17	Ore	x_{16}	72 – 239
18	Shaving	x_{17}	1 – 16
19	Precipitation days	x_{18}	1 – 9
20	Number of days with t<0	x_{19}	0 – 10

Let us determine the main statistical characteristics: sample average, standard deviation of empirical distribution and coefficient of variations. The results of the main statistical characteristics of sample calculations are presented in Table 2.

Table 2. The main statistical characteristics

Variables and their characteristics		Property value	Variables and their characteristics		Property value	Variables and their characteristics		Property value
y	$\bar{y}$	15.216	x_7	$\bar{y}$	63.125	x_{14}	$\bar{y}$	126.917
	σ	3.193		σ	17.099		σ	44.602
	$v,\%$	20.986		$v,\%$	27.087		$v,\%$	35.142
x_1	$\bar{y}$	39.292	x_8	$\bar{y}$	216.375	x_{15}	$\bar{y}$	39.083
	σ	15.988		σ	39.906		σ	15.839
	$v,\%$	40.690		$v,\%$	18.443		$v,\%$	40.525
x_2	$\bar{y}$	5.125	x_9	$\bar{y}$	165.333	x_{16}	$\bar{y}$	147.542
	σ	6.110		σ	34.039		σ	42.358
	$v,\%$	119.3		$v,\%$	20.588		$v,\%$	28.709
x_3	$\bar{y}$	23.375	x_{10}	$\bar{y}$	23.292	x_{17}	$\bar{y}$	8.375
	σ	11.661		σ	11.782		σ	4.168
	$v,\%$	49.888		$v,\%$	50.586		$v,\%$	49.771
x_4	$\bar{y}$	136.792	x_{11}	$\bar{y}$	2.500	x_{18}	$\bar{y}$	4.667
	σ	34.554		σ	2.719		σ	2.036
	$v,\%$	25.261		$v,\%$	108.748		$v,\%$	43.627
x_5	$\bar{y}$	69.417	x_{12}	$\bar{y}$	4.958	x_{19}	$\bar{y}$	2.583
	σ	27.311		σ	1.922		σ	3.322
	$v,\%$	39.344		$v,\%$	38.762		$v,\%$	128.597
x_6	$\bar{y}$	37.458	x_{13}	$\bar{y}$	70.333			
	σ	10.726		σ	23.401			
	$v,\%$	28.634		$v,\%$	33.272			

The testing for normality of the investigated factors classification is carried out by criterion of U deviation range. According to (Lashchenykh, Kuzkin & Grytsay, 2011), the rejection lines of the criteria $U_1(\alpha) = 3.34$ i $U_2(\alpha) = 4.71$ are determined for $n = 24$ i $\alpha = 0.05$.

As $U_1(\alpha) = 3.34 < U = 4.118 < U_2(\alpha) = 4.71$, we can conclude that the final value satisfies the standard distributive law.

In order to determine the presence of anomalous values, let us put the statistical data in the order of increasing.

For the purpose of significance test of the suspect experimental data, let us use the Chauvenet criterion. According to this criterion, the element x_i with the volume n is an outlier if the probability of its deviation from the average values is no more than $1 / (12 \cdot n)$. We obtain the calculations for all sample units. The results of calculations are presented in Table 3.

The outliers are changed into the average values of corresponding characteristics for the further analysis.

Table 3. The results of outlier detection in the sample

No	Variable	Indexes	Range of values	Outliers
1	Lay-over	y	11.41 – 16.84	21.17; 21.67; 24.56
2	CY	x_1	14 – 63	–
3	Undergr. bunkers	x_2	0 – 8	14; 15; 16; 23
4	Limestone warehouse	x_3	0 – 42	53
5	CS 1 ins.	x_4	72 – 190	229
6	CS 1 out.	x_5	13 – 130	–
7	CWS 2	x_6	18 – 57	–
8	CWS 3	x_7	32 – 95	–
9	CWS 4	x_8	142 – 308	–
10	Agglomerate	x_9	104 – 241	–
11	Limestone	x_{10}	0 – 42	53
12	Coal	x_{11}	0 – 6	12
13	Electrode paste	x_{12}	1 – 9	–
14	Quartzite	x_{13}	37 – 92	118; 128
15	Coke	x_{14}	33 – 220	–
16	Container	x_{15}	14 – 63	–
17	Ore	x_{16}	72 – 239	–
18	Shaving	x_{17}	1 – 16	–
19	Precipitation days	x_{18}	1 – 9	–
20	Number of days with t<0	x_{19}	0 – 10	–

Let us change the variation range of values of numerical characteristic into another range, which is more convenient to use for the data of analytic algorithms, by normalization. Moreover, the variation ranges of different values are coordinated.

If the data outliers, which exceed to the typical dispersion, are not frequent, they determine the scale of normalization according to the previous formula. It will lead to the concentration of the main body of normalized variable x'_i near zero $|x'_i| \ll 1$. In this case, it is more reliable to use the static characteristics of data, namely, average value and dispersion, for normalization. The transformations are calculated for each value of x'_i:

$$x_i' = \frac{x_i - x_{aw}}{\sigma_x} \tag{1}$$

The sample with normalized values is presented in Table 4.

Table 4. The sample unit with normalized values

No	Variable	Indexes	Range of values
1	Lay-over	y	-1.19 –2.93
2	CY	x_1	-1.58 – 1.48
3	Undergr. bunkers	x_2	-0.84 – 2.93

4	Limestone warehouse	x_3	-2.0 – 2.54
5	CS 1 ins.	x_4	-1.88 – 2.67
6	CS 1 out.	x_5	-2.07 – 2.22
7	CWS 2	x_6	-1.81 – 1.82
8	CWS 3	x_7	-1.82 – 1.86
9	CWS 4	x_8	-1.86 – 2.3
10	Agglomerate	x_9	-1.8 – 2.22
11	Limestone	x_{10}	-1.98 – 2.52
12	Coal	x_{11}	-0.92 – 3.49
13	Electrode paste	x_{12}	-2.06 – 2.1
14	Quartzite	x_{13}	-1.42 – 2.46
15	Coke	x_{14}	-2.11 – 2.09
16	Container	x_{15}	-1.58 – 1.51
17	Ore	x_{16}	-1.78 – 2.16
18	Shaving	x_{17}	-1.77 – 1.83
19	Precipitation days	x_{18}	-1.8 – 2.13
20	Number of days with t<0	x_{19}	-0.78 – 2.23

Concept model formation

Let us calculate the correlation matrix that will bring an opportunity to determine the negligible and multicollinear factors. It is known that the factors with coefficient of correlation $r(yx_i) \leq 0.1$ are considered negligible and should be excluded from the further observation. The collinear factors x_i are the factors with the constraint $r(x_i x_m) \geq 0.8$. In this case, one of the factors should be excluded from the observation, but the factor with closer connection to final value is kept. The computations of matrix correlative coefficients are carried out in STATISTICA program by the Multiple Regression Results method. The results of calculations are presented in Table 5.

In the similar way, the matrix computations of correlative coefficients for the sample with changed anomalous values to the average ones and for the normalized sample are conducted.

Table 5. The matrix of correlative coefficients for primary sampling

Values	y	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}
y	1.00	0.17	0.74	0.40	0.59	0.57	0.30	0.25	0.42	0.66	0.40	0.18	-0.18	0.36	0.53	0.18	0.25	0.18	0.09	0.72
x_1		1.00	0.37	0.07	0.39	0.38	0.20	0.32	0.04	0.37	0.07	-0.06	0.08	0.34	0.15	1.00	0.16	0.28	-0.44	0.10
x_2			1.00	0.22	0.67	0.64	0.28	0.28	0.61	0.65	0.22	0.01	-0.15	0.66	0.59	0.38	0.34	0.32	-0.18	0.33
x_3				1.00	0.23	0.22	-0.29	-0.35	0.12	0.16	1.00	0.13	-0.12	0.23	0.24	0.07	-0.28	0.29	0.11	0.05
x_4					1.00	0.58	0.11	0.34	0.47	0.78	0.23	0.12	0.17	0.46	0.46	0.39	0.45	0.50	-0.22	0.28
x_5						1.00	0.04	0.03	0.56	0.55	0.21	0.18	-0.24	0.61	0.89	0.38	0.02	0.31	-0.08	0.30
x_6							1.00	0.65	0.29	0.25	-0.29	0.25	0.01	0.09	0.05	0.22	0.62	0.24	-0.29	0.14
x_7								1.00	0.15	0.24	-0.34	0.02	0.33	0.08	-0.07	0.33	0.85	0.12	-0.09	0.26
x_8									1.00	0.62	0.12	0.35	-0.05	0.66	0.74	0.04	0.21	0.26	-0.17	0.04
x_9										1.00	0.16	0.26	-0.02	0.42	0.54	0.38	0.21	0.12	-0.30	0.50
x_{10}											1.00	0.12	-0.12	0.23	0.23	0.07	-0.27	0.29	0.12	0.05
x_{11}												1.00	0.18	0.03	0.38	-0.06	-0.10	0.15	-0.20	0.06
x_{12}													1.00	-0.14	-0.22	0.06	0.27	0.03	0.02	-0.23
x_{13}														1.00	0.53	0.33	0.05	0.30	-0.13	0.10
x_{14}															1.00	0.15	-0.09	0.26	-0.08	0.21
x_{15}																1.00	0.17	0.28	-0.44	0.11
x_{16}																	1.00	0.35	-0.06	0.05
x_{17}																		1.00	-0.30	-0.32
x_{18}																			1.00	0.14
x_{19}																				1.00

The Table 5 shows that x_{18} (precipitation days) is negligible factor. The multicollinear factors are x_1 and x_{15}, x_3 and x_{10}, x_5 and x_{14}, x_7 and x_{16}. We exclude x_1 (CY), x_{10} (limestone), x_{14} (coke) and x_{16} (ore).

The conceptual model for the primary sampling will be of the form:

$$y = f(x_2, \ldots, x_9, x_{11}, \ldots, x_{13}, x_{15}, x_{17}, x_{19}) \quad (2)$$

For the sample, where the outliers were changed onto the average values of corresponding characteristics, the negligible factors are x_1, x_2, x_7, x_8, x_{13}, x_{16}, x_{17}.

The multicollinear factors are x_3 and x_{10}, x_5 and x_{14}. We exclude the factors x_{10} and x_{14} and obtain the conceptual model:

$$y = f(x_3, \ldots, x_6, x_9, x_{11}, x_{12}, x_{15}, x_{18}, x_{19}) \quad (3)$$

According to the matrix of coefficients correlation for the normalized sample, the negligible factor is x_{18}; multicollinear factors are x_1 and x_{15}, x_3 and x_{10}, x_5 and x_{14}, x_7 and x_{16}. x_1, x_{10}, x_{14} and x_{16} factors should be excluded.

We obtain the same conceptual model like for the primary sampling:

$$y = f(x_2, \ldots, x_9, x_{11}, x_{12}, x_{13}, x_{15}, x_{17}, x_{19}) \quad (4)$$

The next stage is development of the regression model of the car stay time on the house track.

Development of the regression model

The calculation of linear regressional dependence for each conceptual model obtained by the analysis is carried out in STATISTICA system. The regression coefficients for each model is calculated. The value of every coefficient is determined according to Student's t-test, coefficient of correlation and determination, standard and ratio errors of approximation and the expected value of Fisher's F-test are also determined. The results of the calculations are presented in Table 6.

Thus, the equation of linear multi-regression for the primary sampling is of the form

$$\begin{aligned} y &= 7.872 + 0.219x_2 + 0.087x_3 + 0.022x_4 + \\ &+0.019x_5 + 0.108x_6 - 0.036x_7 + 0.009x_8 - \\ &-0.02x_9 - 0.062x_{11} + 0.176x_{12} - 0.027x_{13} - \\ &-0.022x_{15} - 0.001x_{17} + 0.582x_{19}) \end{aligned} \quad (5)$$

The equation for the sample with exchange of the anomalous observations into the average values is of the form

$$\begin{aligned} y &= 9.668 + 0.08x_3 - 0.016x_4 + 0.022x_5 + \\ &+0.071x_6 + 0.005x_9 - 0.225x_{11} - 0.023x_{12} - \\ &-0.018x_{15} + 0.173x_{18} + 0.148x_{19}) \end{aligned} \quad (6)$$

According to the calculations, the equation of multi regression of sample with the normalized values does not have any intercept terms:

$$\begin{aligned} y &= 0.419x_2 + 0.319x_3 + 0.24x_4 + 0.161x_5 + \\ &+0.363x_6 - 0.19x_7 + 0.109x_8 - 0.213x_9 - \\ &-0.053x_{11} + 0.106x_{12} - 0.199x_{13} - 0.107x_{15} - \\ &-0.001x_{17} + 0.606x_{19}) \end{aligned} \quad (7)$$

Table 6. The results of the linear regressional model

Criterion of estimation (under the level of significance $\alpha = 0.05$)	Value
Fisher's F-test (F)	12.76
Table value of *Fisher's F-test* ($F_{tab.}$)	2.65
Coefficient of multivariable correlation (R)	0.976
Coefficient of multiple determination (R^2)	0.952
Standard error of regression estimation (σ)	0.071
Limit probability of hypothesis (p)	0.00029

Quality test of the regression dependence, significance of the equation and regression factors

In order to test the significance of regression equation and its sufficiency, Fisher's F-test is used as an output data. The results of calculation are compared with the table values, which are determined according to the freeness of bigger or smaller dispersion. In our case, the second sample does not meet the requirements $F = 1.46 < F_{tab} = 2.65$ of the sufficiency condition $F > F_{tab}$. Thus, this regression model is not sufficient.

The regression model is sufficient to the output data in the case when the expected value of the limit probability of hypothesis does not exceed the selected level of significance. According to the examined models with 0.05 level of sufficiency, the first and third models ($p = 0.00029 < 0.05$) are sufficient. The most qualitative model is the model for the third sample with a minimum error of approximation ($\sigma = 0.071$).

In order to test the significance of the regressional factors, let us use Student's t-test. If the expected value of the limit probability does not exceed the accepted level of significance 0.05, the factor is sufficient. The x_2, x_3, x_6, x_{19} (p-level values are 0.0158, 0.0087, 0.0492, 0.0029 respectively) factors are sufficient for the first sample. x_3 and x_6 (with *p-level* 0.0321, 0.0395 respectively) are sufficient for the second sample. The x_2, x_3, x_6, x_{19} factors (with *p-level* 0.0158, 0.0087, 0.0492, 0.0029 respectively) are sufficient for the third sample.

In order to test the normalcy of distribution of residuals, let us develop the normal probability diagram of residuals for the third sample (Fig.1).

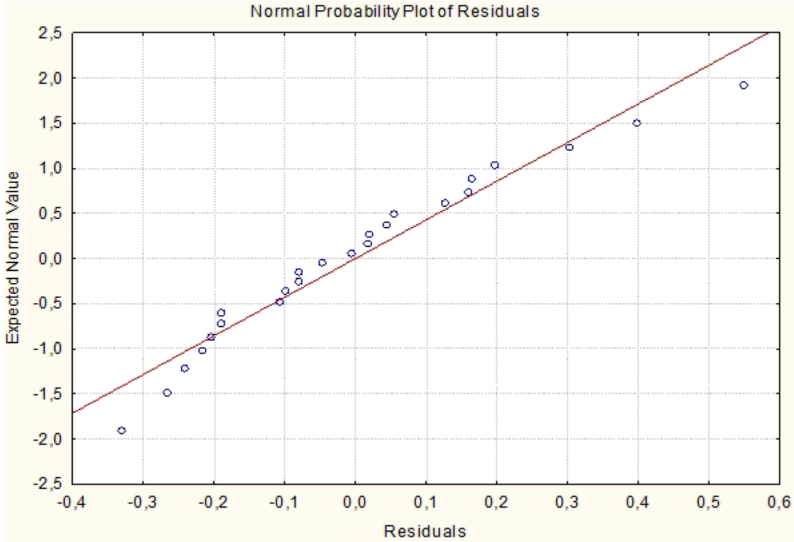

Figure 1. The diagram of residuals of sample regression with the normalized values

According to the analysis of residuals, it can be claimed that the regression model is well developed and the residuals of regression are of the normal distribution.

The support system of decision making on the subject of necessary car number determination for delivery process to the ferroalloy plant is based on the results of time scheduling of car stay on the house track by developed model.

Conclusion

1. The problems of arrangement of material flows in the “suppliers - railway – ferroalloy plant – consumers” system within the frameworks of micrologic system of ferroalloy plant were considered. It was established that the effective interaction with transport operators is possible under conditions of necessary car number for the supply of raw materials and fuel determination. Thus, an important research task is determination of time scheduling of the car stay on the house track of metallurgical plant that is the part of the overall time of car cycle in the delivery route.

2. As parameters of model of cars stay at the enterprise, the volums of cars passing to the points of the most intensive unloading (container yard, underground bunkers, limestone warehouse, inside and outside storage of the charging materials), the volumes of basic goods delivery (agglomerate, limestone, coal, electrode mass, quartzite, coke, ore, etc.), and the weather conditions (precipitations and environment temperature) were considered.

3. On the basis of statistical analysis and collinearity test, some parameters from the initial group were excluded. Three regression models were developed from sufficient parameters. Model parameters are the following: underground bunkers (x_2), limestone warehouse (x_3), inside storage of charging material No 1 (x_4), outside storage of the charging material No 1 (x_5), charge workshop section No 2 (x_6), charge workshop section No 3 (x_7), charge workshop section No 4 (x_8); the volumes of the basic goods delivery (agglomerate (x_9), coal (x_{11}), electrode mass (x_{12}), quartzite (x_{13}), container (x_{13}); and the weather conditions: precipitation days (x_{18}) and number of days with t<0 (x_{19}).

4. According to the examined models with 0.05 level of sufficiency, the first and third models ($p = 0.00029 < 0.05$) are sufficient. The most qualitative model is the model for the third sample with minimum error of approximation ($\sigma = 0.071$). In order to test the significance of regression factors, Student’s t-test for accepted level of significance 0.05 was used. In order to test the normalcy of distribution of residuals, the normal probability diagram of residuals for the third sample was developed which confirms the quality of regression model.

5. The decision support system on the subject of determination of necessary car quantity for delivery process to the ferroalloy plant was developed. It is based on the results of time scheduling of car stay on the house track by the developed model.

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Determination of rational placement for energy storages in the power supply system of the underground

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Abstract
The possible placements of energy storages in the power supply system of underground were considered. The advantages and disadvantages of each placement of the energy storages according to various indicators were defined. According to the results of the general analysis of existing researches, their comparative analysis and the proposed approach using a scoring scale was established, the placement of accumulators on underground rolling stock was the most appropriate.
Keywords: ENERGY STORAGE, UNDERGROUND POWER SUPPLY SYSTEM, UNDERGROUND ROLLING STOCK

Introduction

Nowadays one of the priorities of developed countries is to solve problems of energy saving and energy efficiency. Under conditions of constant increase in the energy resources cost for many modern enterprises reducing the energy intensity and energy component of the production cost is also one of the determining factors of effective development [1-6].

In papers [7, 8], the use of energy storages was proposed to solve these problems. The application of energy storages allows solving a number of complex problems. The main ones are the following: reduction of energy consumption from the mains by maintaining and reusing of excess energy; straightening of minute and hour load diagrams; providing static and dynamic stability of the power system; reduction of the installed capacity of power plants engaged in the supply and power conversion (transformers, converters, distribution substations, etc.); reduction of current loads and power units heating temperature, respectively, which allows increasing their service life; providing the uninterrupted stable power supply in emergency modes of the main supply sources [7-11].

The rail transport with abruptly variable load, and in particular, the underground is one of the promising areas of energy storages application [6, 10-16]. The main advantage of their use in the underground is a peculiarity of its rolling stock operation: distinct impulse uneven character of load; small distance between the railway hauls, as a result, frequent starting and braking; often changing profile of the track; stable movement schedule compared with other types of rail transport (shunting locomotives, main line electric locomotives, trams) [15, 16].

From analysis of researches [6, 10-15], it is known that most of the energy costs in the underground are the traction costs (about 70%) [15, 17, 18]. In order to reduce energy consumption for traction the undergrounds of Ukraine, new cars are bought and upgrades to existing ones that exhausted their service life are performed with the possibility of electricity generating to the contact system in regenerative braking mode. From the analysis of researches [6, 13, 15, 19], it has been established that the energy efficiency of regenerative braking depends on many factors (the presence of consumers in the power area of traction substations, the operating condition of other consumers, track profile etc.). As a consequence, the use of regenerative braking power has a probabilistic nature and can save about 10% consuming on the rolling stock traction [11, 15]. However, to provide the use of regenerative braking electricity at maximum efficiency without additional hardware including energy storage units is impossible [6, 10, 11, 15, 19]. Energy efficiency of regenerative braking and the payback period of additional technical means, in turn, are largely dependent on the choice of energy storages placement in the power supply system of underground.

Work objective is to analyze the problem of rational justification of the energy storages placement in the power supply system of underground.

Materials and research results

From the analysis of the electrical schematic diagrams and existing studies [6, 15, 20-24], it is know that the energy storages can be placed in front of the traction substation, directly on the traction substation, on the section pillars, on the output of traction substation along the contact system line (on the stations at the ends of console areas of electric traction network) and on the rolling stock of the underground. The structural scheme of the underground power supply system with possible placements of energy storages is shown in Figure 1. In the structural scheme (Figure 1) the following list of symbols was adopted: TPP - Thermal Power Plant; PL - power line; RS - regional substation; SP - section pillar; ES - energy storage; TS - traction substation; RS - rolling stock; CR - contact rail; OT – open track.

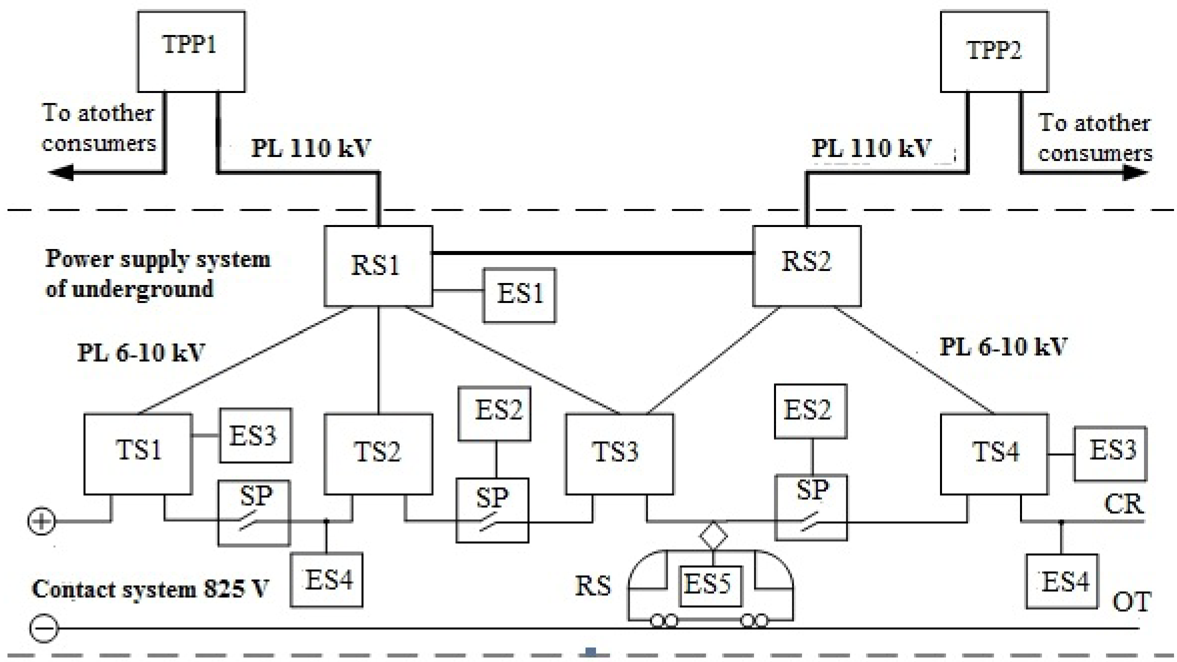

Figure 1. Structure scheme of the underground power supply system with possible placements of energy storages

When determining the rational placement a comparative analysis was proposed to carry out according to the following indicators: energy efficiency, capital investment, economic feasibility, impact on electric energy quality of the contact system, providing the increased crossing capacity of railway haul, the impact on the service life of power supply elements in the underground system, the ability to ensure the autonomous conduct of the rolling stock in case of emergency mode in the power supply underground system, the influence on acceleration and braking characteristics of the train, the implementation of energy processes control.

The results of the comparative analysis of different energy storages placement for the above indicators are shown in Table. 1.

Table 1. Comparative analysis of storage units according to their placement

Indicator name	Energy storage placement				
	ES1	**ES2**	**ES3**	**ES4**	**ES5**
Energy efficiency	Minimum	Average	Average	Average	Maximum
Capital investment	Average	Minimum	Average	Average	Maximum
Economic feasibility *	Minimum	Maximum	Average	Average	Average
Impact on electric energy quality	Maximum	Average	Average	Average	Minimum (not influence)
Providing the increased crossing capacity of railway haul	Minimum	Average	Average	Average	Maximum
Impact on the service life of power supply elements in the underground system	Maximum	Average	Average	Average	Minimum
Ability to ensure the autonomous conduct of the rolling stock in case of emergency mode in the power supply underground system	Minimum	Average	Average	Average	Maximum
Influence on acceleration and braking characteristics of the train	Not influence	Not influence	Not influence	Not influence	Influence
Energy processes control	Complex	Complex	Complex	Complex	Simple

Note: the economic feasibility indicator is calculated only on the basis of savings from increased energy efficiency in energy supply system of underground

Performed comparative analysis on these indicators (Table 1) allowed us to establish the following:

- the main advantage of placement energy storage at the district substations (ES1) is the lack of impact on the acceleration and braking characteristics of the train and the need for fewer storage units (possibly only one). However, their energy capacity should be substantial and account for more than 10 GJ [6, 23]. With this placement, it is necessary to equip the traction substations with inverters, this follows with the need of additional investments. As a result, the capital investments for this placement are average. Other indicators emphasize only the shortcomings of this placement. In particular, the energy efficiency is small and amounts to 10% of the electricity are consumed in the traction [15]. The impact on electric energy quality and service life of the power supply elements of the underground system is the largest due to the non-linearity recovery source and low TS power factor in power inverting mode, as well as the transition of additional excess voltage through a significant number of the power equipment elements (wires, tires, valves, etc.). Providing of increase capacity is the smallest due to the influence of inertia conditions of the system and electrical equipment heating. The autonomous movement of the train is the least, since at occurrence of an emergency shutdown of the main power supply at the area from RS to the current collectors mounted on the train carriages; the further movement of the latter is not possible in the traction mode. When energy processes control a significant number of factors that complicate the overall control system should be considered. The increasing complexity of the control system consists in using a large number measuring and control devices at each stage of the electricity transit and development at these stages of complex multi-level algorithms;

- the main advantages of placing energy storage at the section pillar (ES2) are the lack of influence on the acceleration and braking characteristics of the train, little capital investments and the largest saving. The total amount of storages installation on SP is insignificant, and their energy consumption should be about 100-200 MJ [6, 23, 24]. Energy efficiency indicators of the impact on power quality, providing increased traffic capacity of railway haul, the impact on the service life of elements of underground power supply system, the possibility of providing the autonomous conduct of the rolling stock when emergency operation in the power supply system of underground are mediocre. Energy efficiency is up to 25% of the electricity consumed for traction [23, 24]. The impact on electric energy quality is carried out due to the non-linearity of the recovery source. The service life of power supply system elements of the underground is reduced by decreasing resource of wires, tires due to additional excess currents flowing. The movement of the train in the traction mode is impossible in case of emergency in the area from TS to the current collectors mounted on the carriages of the train. The disadvantage of placing ES2 is the need of taking into account other modes of conducting other electricity consumers and, as a consequence, this will complicate the construction of work algorithms and the development energy processes control system;

- the main advantages of energy storage placing at traction substations (ES3) are the lack of influence on the acceleration and braking characteristics of the train. Other indicators are mediocre, except for the indicator of the energy processes control. Synthesis of control system is complex due to the need of taking into account operating conditions of other consumers. The main advantages and disadvantages, as well as the mediocre characteristics under condition of energy storage placing on TS output along the contact system line (ES4) are similar to that when ES3 placing. The difference between ES3 and ES4 placements is determined by the basic functional purpose. For ES3 placing the primary functional purpose is to take regenerative braking electricity near the source of its release, thereby reducing the contact system losses; for ES4 placing it is stabilization of the contact system voltage at the ends of cantilevered areas of electric traction network, resulting in increased traffic capacity of railway haul. The total amount of installation ES3 and ES4 storages is medium, and their energy content should be up to 100 MJ [6].

- the main advantages of energy storages (ES5) placement in rolling stock are the following: the largest energy efficiency; no impact on the electric energy quality of contact system and the service life of its elements (wires, tiers, etc.); the ability to ensure the autonomous work of the rolling stock in the case of emergency mode in the power supply system of underground and increase the railway haul traffic capacity are the highest; energy processes control in comparison with other placements is the easiest. Energy efficiency is up to 35% of the electricity consumed on traction [6, 15]. Electric energy of regenerative braking circulates on a small circle without its release in the contact system, so there is no impact on the electric energy quality of the contact system and the life of its elements. There is a possibility of autonomous rolling stock conduct in case of emergencies at any part of the underground power supply system. The traffic capacity is increased to 50% [20]. The economic indicator is average compared to other placements. The disadvantage of ES5 placing is the need of the largest capital investments and impact on the acceleration and braking characteristics of the train. The total amount of installation of ES5 storages is the highest, because each rolling stock should be equipped with such system and it requires substantial investment [6, 20, 23, 24]. Their energy consumption should be up to 30 MJ [6, 15].

According to the results of the comparative analysis to answer unequivocally, which placement of energy storage is rational, is not possible, since there are both advantages and disadvantages for each placement. The only exception is placing on the regional traction substation (ES1), which can be excluded from the search of the rational due to the availability of a significant number of shortcomings. Thus, the author proposed to determine rational energy storage placement according to grade scale. The essence of this approach is to develop evaluation criteria for each indicator which is used for comparison, which will be determined by the total number of points for each placement and direct choice of the rational placements based on the maximum number of points.

In this case, the following criteria for indicators evaluation were adopted: energy efficiency, economic feasibility, providing increased traffic capacity of railway haul, possibility of providing the autonomous conduct of the rolling stock in case of emergency modes in power supply system of underground: when minimum values - 1 point, medium - 2 points, maximum - 3 points; investment, impact on electric energy quality and durability of elements of the underground power supply system when the maximum values - 1 point, medium - 2 points, minimum - 3 points. When influencing on the acceleration and braking characteristics of the train, and complexity of the energy processes control, it takes 1 point, in other cases - 2 points.

Taking into account adopted evaluation conditions the maximum points could reach 25 points. The calculation results for considered placing of energy storages are shown in the diagram in Figure 2.

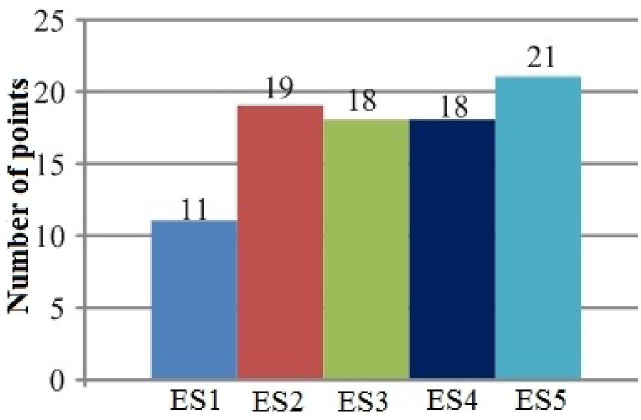

Figure 2. The results of points calculations for different energy storages placements

Thus, according to the analysis of numerous studies [6, 10, 15-17, 23] and the proposed approach, it is determined that the placement of storages on the rolling stock (ES5) is the most efficient for the underground conditions. The significant investment and impact on the acceleration and braking characteristics of the rolling stock are among the main drawbacks of placement ES5. However, significant investments can be compensated for the highest technical and economic effect by maximizing energy efficiency, minimizing the established capacity of power equipment, minimal influence on electric energy quality and durability of elements of underground power supply system and etc. The impact on acceleration and braking characteristics of the rolling stock can be solved by various methods depending on the project, in particular by allowing the program increase of the maximum traction (braking) value.

Conclusions

On the basis of the implementation of the generalized analysis of existing research, their comparative analysis and the proposed approach using a scoring scale, it is established that in the underground the most efficient placement of energy storage units is on the rolling stock.

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Determination of up-to-date directions of development of domestic system of testing and certification of railways rolling stock

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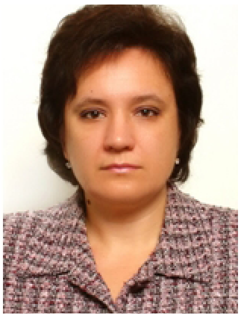

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Abstract
In the paper, researches results of development of system of tests devoted to up-to-date directions determination and certification of rolling stock and its components are provided. Necessity of synchronization of diagrams and domestic standards of test and certification activities in the field of rolling stock with European legislation is proved. Results and features of the experience analysis of appropriate types of activity of the European countries advanced enterprises are provided.
Key words: RAILWAY TRANSPORT, ROLLING STOCK, EUROPEAN INTEGRATION, DEVELOPMENT OF TESTS AND CERTIFICATION, CRASH-TEST

Problem statement

In recent years, increasing in need for transportations including the railways is observed due to integration of Ukraine into the international economic space. To satisfy the growing demand, and also to increase the attraction of the created transport corridors including transit, passing across the territory of the country ones, it is necessary to increase productivity of the transportation process by highly effective methods [1-5] performed in a railway system considering the necessary level of economy of area in general.

Operation of outmoded low dynamic rolling stock, which share is 90% in the railroads, is one of the reasons of insufficient level of traffic safety of the trains and high operating expenses caused by increase in expenses for repair work, and also the raised energy consumption for hauling operations. New requirements, which lead to increase in level of forces of dynamic interaction of rolling stock and rail track, are applied, which is inadmissible under the conditions of considerable wearing of carriage part of most advanced rolling stock [6-11].

The national-level program of adaptation of the legislation of Ukraine to the legislation of the Council of Europe approved by the Law of Ukraine No. 1629-IV of 18.03.2004 determines the regulatory framework regulating activities of a rail transport by the priority direction of adaptation. At the same time, one of the most important problems is the problem of safety in operation and renewal of rolling stock of Ukrainian railway. Therefore, “The technical regulation of safety of rolling stock of rail transport” No. 1194 of December 30, 2015 was approved by the resolution of Cabinet Council of Ukraine; it determines the main requirements to rolling stock, which is produced and upgraded, and also to its components and spare parts when designing, production, installation, adjustment, setting into operation, operation, repairing [12-18].

It is specified by the technical regulation that components of technical supply of safety of rolling stock of rail transport is designing, production, upgrading, installation, adjustment, setting into operation and repairing of rolling stock of rail transport.

Now, introduction of technical regulations of railway transport, interstate and international standards with safety requirements to the rolling stock and infrastructures and to estimation of compliance for the purpose of active participation in international transport and preservation of transit capacity of the state acquires relevance in Ukraine.

Analysis of the last researches and publications

The analysis of existing test centers (Fig. 1, Fig. 2) responsible for certification and setting railway rolling stock into operation shows that in our country there is no center which would have own testing ground and carry out testing for passive safety (crash-tests) according to DIN EN 15227-2011.

The objective of paper is scientific justification of necessity of synchronization of diagrams and testing procedure and certification of the domestic rolling stock with the European legislation on the basis of analysis results of appropriate experience of the European countries, and also determination of features of these measures implementation.

Figure 1. Testing ground Siemens

Figure 2. Testing ground Test Centre VUZ Velim

Statement of the basic material of research

At present time, the following directions in the field of scientific research, design developments and practical works on renewal of the rolling stock are considered as priority:

- to concentrate attention on creation of the new rolling stock;

- to calculate the expected reduction of operating expenses, to provide improvement of ecological and ergonomic qualities, increase in service live in case of creation of all types of rolling stock;

- to develop and introduce new technical solutions in a design of the rolling stock in general and bogies in particular for ensuring reduction of dynamic impact on path;

- to ensure safety of the movement at high speeds along the line.

The above-mentioned priority directions are:

1. To keep creation of new and modernized rolling stock for the railways of Ukraine in strict accordance with requirements of national regulating documents for procedures of development, testing, receipt and delivery of technical products to the production line.

2. PJSC "Ukrainian Railways" together with the industry scientific organizations should consider a problem of creation of the testing ground taking into account the modern requirements applied to rolling stock and railway infrastructure.

3. Gradual scheduled transition to service of the rolling stock taking into account the actual technical condition must become priority; to increase efforts on improvement and development of new technical solutions on identification and forecast of technical condition, creation of complex systems of local and remote control and technical diagnostics of details, knots and units of carriages and locomotives.

4. For the enterprises and organizations connected with designing, production, research, operation and repair of railway rolling stock:

- to use more progressive experience and advanced achievements of not only the enterprises of Ukraine, but also foreign countries (Fig. 3, Fig. 4);

- to develop native experimental base with the use of modern computing tools;

- to pay special attention to development and creation of advanced rolling stock including the way of modernization of existing one with the use of energy-saving technologies and alternative fuel types;

- to introduce progressive methods, technologies and diagnostic methods of rolling stock with a possibility of transmission of diagnosed data through cellular network; these methods allow reduction of expenses on its servicing and repair [6-13].

The behavior of vehicle is studied by the result of action of longitudinal dynamic loads by means of numerical modeling.

The result allows organizing the effective device of energy absorption in a design of rolling stock. Plastic and elastic devices absorb impact energy. In Fig. 5, the example of rolling stock clash at the railway crossing according to DIN EN 15227: 2008 is shown.

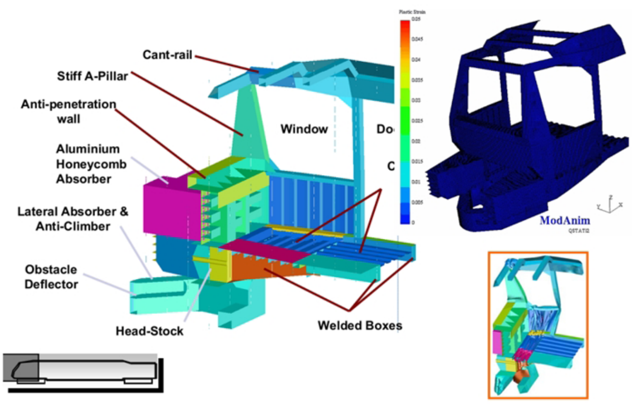

Figure 3. Computer modeling of the rolling stock

Figure 4. The locomotive model for carrying out a crash test

Figure 5. Clash of the rolling stock at railway crossing

Safety of the locomotive driver and passengers can be also optimized by means of numerical modeling and practical tests with human models. Interaction between interior objects of passenger carriages and passengers in case of clash is determined by means of computer modeling on human models (Fig. 6, Fig. 7). Special program developments allow designing systems of control.

Figure 6. Train Interior Passive Safety – before testing

Figure 7. Train Interior Passive Safety – after testing

Mentioned data show expediency of creation of special grounds for check of passive safety of the rolling stock of railway. At the same time, development of such direction requires development of corresponding methods and techniques, mathematical, computer and physical models.

Conclusions and suggestions

As a result of conducted research, it has been established that one of priority tasks in case of European integration of domestic railway transport complex is synchronization of schemes and order of its testing and certification of rolling stock with the European legislation. At the same time, an important component of successful implementation of such direction is development of adapted systems of crash tests of carriages, locomotives, multiple unit, etc.

The aforesaid proves expediency of carrying out of scientific-research and development works on creation of theoretical theses, methodological bases and practical means of tests and certification of rolling stock which will pass the standards of the European Union.

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Determination of parameters and efficiency of process lubricant screw supercharger application when drawing

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Abstract
The viscosity characteristics and pressure of the soap lubricant before wire-drawing process are determined with the use of dimensional analysis and within the framework of the developed method for calculating the parameters of the drive screw supercharger, which provides hydronic friction mode in case of “dry” wire-drawing process. The test calculations showed that in case of use of such tool, energy saving is several times higher than its consumption by the driving mechanism. Moreover, the substantial increase of drawing dies wear resistance and reduction of breakages can be expected which makes reasonable the use of supercharger in the practice of dry wire-drawing.
Key words: DRAWING, PROCESS LUBRICANT, SCREW SUPERCHARGER, PARAMETER CALCULATION, EFFICIENCY

The developed method of parameters analysis of the screw supercharger for providing hydronic friction mode under the dry wire-drawing process with the dry soap lubricant is presented by the authors of the paper. It was also found out that viscosity and pressure in the process lubricant before its going into the drawing die are the key values determining the tool characteristics. The problem of efficiency evaluation of the application of such tool was also set.

The purpose of the paper is determination of viscosity and pressure in the “dry” soap process lubricant before wire-drawing process which are important for creating the hydronic friction mode in the deformation zone, updating the method to the level of relevant calculation procedure as well as evaluation of efficiency of application of such tool for wire-drawing process.

The dependences, which describe the complex process of the dry soap lubricant moving during the steel wire-drawing process, are presented in the paper [1]. It has been noticed that one-dimensional flow of viscous plastic liquid is subjected to Shvedov-Bingham law:

$$\tau_l = A + B\frac{\partial V}{\partial y} \tag{1}$$

where $\partial V/\partial y$ − shearing stress and velocity gradient in the lubricant film respectively; A and B − boundary (minimal) stress of initial flow and plastic viscosity of process lubricant respectively, which depend on temperature and pressure. Moreover, at the wire-drawing speed V_0 for the process lubricant flow with the speed Vs at the output of screw supercharger (Fig. 1), it may be accepted:

$$\frac{\partial V}{\partial y} \approx \frac{2\cdot(V_0 - Vs)}{D_s - d_s}$$

but from the geometrical ratios, it follows that:

$$V_s = \pi\cdot\omega_s\cdot\frac{D_s - ds}{2}\cdot tg\varphi_{av}$$

where ω_s − angular rate of the screw supercharger shaft, s^{-1}; D_s, d_s − diameter of the screw according to the external element and diameter of its shaft respectively, *m* (Fig. 2); φ_{av} − average angle with the screw axis of the surface of its screw blade on the external element and on the shaft respectively, *grad* (6).

In this case,

$$\tau_l \approx A + B\frac{2\cdot V_0 - \pi\cdot(D_s - d_s)\cdot\omega_s\cdot tg\varphi_{av}}{D_s - d_s}. \tag{2}$$

According to the investigation data [2] for the dry soap process lubricant with temperature *T* (*K*) and pressure p_0 (N/m^2), the value *A* (N/m^2) is determined by the empirical formula:

$$A = 0.067\cdot10^6 + 4,44\cdot10^{-4}\cdot p_0 + \frac{65.54\cdot10^6}{T-273} \tag{3}$$

However, plastic viscosity of B (*Pa*s*) can be demonstrated by the computational scheme:

$$B = \frac{1+1,273\cdot10^{-9}\cdot p_0}{T-273}\cdot G \tag{4}$$

where

$$T = \frac{1240 + 2.25\cdot10^{-4}\cdot\frac{V_0}{R_a}}{1+86.7\cdot(\frac{d_0}{R_a})^{-0,503}} \tag{5}$$

$$G = 9.78\cdot10^{-5}\cdot G(\frac{V_0}{R_a})\cdot G(\frac{d_0}{R_a}) \tag{6}$$

$$G(\frac{d_0}{R_a}) = -1,5\cdot\frac{d_0}{R_a} + 12000 \tag{7}$$

$$\left.\begin{aligned}
&- G(\frac{V_0}{R_a}) = 35.6\cdot 10^3 - 9.88\cdot(\frac{V_0}{R_a})^{0,641} \quad \text{at } 0.02\cdot 10^6 \le \frac{V_0}{R_a} \le 0.2\cdot 10^6\\
&- G(\frac{V_0}{R_a}) = 11.66\cdot 10^3 - 3{,}32\cdot 10^{-3}(\frac{V_0}{R_a}) \text{ at } 0.2\cdot 10^6 \le \frac{V_0}{R_a} \le 3.0\cdot 10^6;\\
&- G(\frac{V_0}{R_a}) = 1700 \quad \text{at } \frac{V_0}{R_a} > 3{,}0\cdot 10^6,
\end{aligned}\right\} \tag{8}$$

where, d_0, R_a − diameter and height of the work piece (wire) microrelief.

During the "wet" wire drawing with the use of the liquid process lubricant, the viscosity of the last one can be determined according to the data of technical literature [2].

In order to simplify the practical evaluation of p_0, the proximal change of the "accurate model" of the lubricant film forming under the "dry" wire-drawing process [1] is allowable by the empirical formula, the general form of which can be obtained as a result of dimensional analysis [3].

For this purpose, the value p_0 with its dimensions ($Pa=N/m^2=kg*m^{-1}*s^{-2}$) was accepted as response function.

And as arguments the following values were accepted with their dimensions:

index of plastic ("effective") viscosity of lubricant B ($Pa*s=kg*m^{-1}*s^{-1}$);

V_0 ($m/s= m*s^{-1}$);

index of friction mode $k = \dfrac{\xi}{R_a}$ (non-dimensional);

index of annular space at the output of supercharger h (m);

diameter of the work piece passing through supercharger d_0 (m);

temperature of the lubricant T (K);

coefficient of heat capacity (for "compensation" of the absolute temperature grade) c_g ($J/kg/K= m^2*s^{-2}*K^{-1}$).

The corresponding parameters equation is of the form:

$$p_0 = W\cdot\left[B^a\cdot V_0^b\cdot k^e\cdot h^x\cdot d_0^g\cdot T^z\cdot c \right. \tag{9}$$

The formula with the dimensions:

$$(kg\cdot m^{-1}\cdot s^{-2}) = (kg\cdot m^{-1}\cdot s^{-1})^a\cdot(m\cdot s^{-1})^b\cdot(1)^e\cdot(m)^x\cdot(m)^g\cdot(K)^z\cdot(m^2\cdot s^{-2}\cdot K^{-1})^r \tag{10}$$

Formula of their "balance":

- at the dimension «kg»: 1 = a;

at the dimension «m»: $-1 = -a + b + x + g + 2r$;

at the dimension «s»: $-2 = -a - b - 2r$;

at the dimension «K» $0 = z - r$.

After simple transformations, the solving of this equations has determined that $a = 1$; $b = 1 - 2\cdot z$; $x = -1 - g$; therefore, that the equation (9) obtained the following form:

$$p_0 = N\cdot\left[B^1\cdot V_0^{1-2q}\cdot k^e\cdot h^{-1-g}\cdot d_0^g\cdot T^z\cdot c_g^r\right]$$

From this equation, after connection of the parameters with equivalent power coefficients into non-dimensional combinations (criteria), it was found that:

$$(\frac{p_0\cdot h}{B\cdot V_0}) = W\cdot(\frac{T\cdot c_p}{V_0^2})^z\cdot(k)^e\cdot(\frac{h}{d_0})^g \tag{11}$$

The formula (6) is linearized by logarithming

$$\ln(\frac{p_0\cdot h}{B\cdot V_0}) = \ln W + z\cdot\ln(\frac{T\cdot c_g}{V_0^2}) + e\cdot\ln(k) + g\cdot\ln(\frac{h}{d_0}) \tag{12}$$

Thus, with application of the method of linear regression analysis to the field of design data obtained for the dry soap lubricant with the index

$$c_g = 2300\frac{\text{J}}{\text{kg}\cdot\text{K}}$$

by computer model [1] within the limits of values changes

$5\cdot 10^6 \le p_0 \le 200\cdot 10^6 (Pa)$; $6 \le B \le 300 (Pa*s)$;

$0.2 \le V_0 \le 5 (m/s)$; $1\cdot 10^{-6} \le \xi \le 20\cdot 10^{-6}$ (m);

$1\cdot 10^{-6} \le R_a \le 20\cdot 10^{-6}(m)$; $1 \le k \le 10$;

$0.02\cdot 10^{-3} \le h \le 10\cdot 10^{-3}(m)$;

$3.0\cdot 10^{-3} \le d_0 \le 6.5\cdot 10^{-3}(\text{m})$;

$320 \le T \le 580$ (K), or $47 \le t \le 307$(°C),

it has been determined that In W = 4.59; z =0.074 ; e=2.80 ; g=1.09 (with the multiple correlation coefficients 0.93 and under probability 0.95).

As a result, the formula (9) has obtained the form:

$$(\frac{p_0\cdot h}{B\cdot V_0}) = 98{,}5\cdot(\frac{T\cdot c_p}{V_0^2})^{0,074}\cdot(k)^{2,80}\cdot(\frac{h}{d_0})^{1,09} \tag{13}$$

where:

$$p_{0} = 98.5 \cdot \frac{B \cdot V_0}{h} \cdot \left(\frac{T \cdot c_p}{V_0^2}\right)^{0,074} \cdot (k)^{2,80} \cdot \left(\frac{h}{d_0}\right)^{1,09} \qquad (14)$$

If the expression $k = \frac{\xi}{R_a} \to 3$ is accepted for the hydronic friction mode, the formula (14) could be slightly simplified:

$$p_{0} = 711 \cdot \frac{B \cdot V_0}{h} \cdot \left(\frac{T \cdot c_g}{V_0^2}\right)^{0,074} \cdot \left(\frac{h}{d_0}\right)^{1,09}. \qquad (15)$$

The comparison of formulas (14) and (15) allows calculating the interdepend parameters p_0, B and thereby the viscous shear τ_l according to the formula (3), the index of friction in lubricant film f_{lb} according to the formula (8), the moment on the screw shaft M_s (4) and, as the result, taking into account all necessary parameters, power N according to the formula (2).

Thus, on the basis of necessary power value N (kW) of the driving mechanism from the ordinary line of electromotor [5], it is possible to capture the certain type of the motor and determine its nominal speed n_n (r/min).

Taking this data into consideration, the total ratio i_Σ from the motor to the screw shaft is

$$i_\Sigma = \frac{n_n}{n_s} = \prod_{u=1}^{u} i_u , \qquad (16)$$

where i_u is the gear ratio of u-element of speed transmission from the motor to the screw shaft; n_s is the screw shaft speed which conforms to the angular rate of the screw supercharger ω_s according to (3).

Accordingly, it is necessary to check whether the rated-load torque M_{load} ($N*m$) of the motor is sufficient comparing it to torque rating M_{rat}, which is determined by formula (4) from:

$$M_{rat} = \frac{M_s}{i_\Sigma} \le M_{load} , \qquad (17)$$

where $M_{load} = \frac{9554 \cdot N_n}{n_n}$.

For implementation of calculated gear system ratio i_Σ taking into account conic gearing “embedded” into the supercharger (Fig.1), it is reasonably to use gear system and driving mechanism. The letter will allow “soft” keeping the necessary rotation frequency n_s of the screw during the pressure fluctuation. According to it, at the gear system ratio $i_s = 0.5...3$ of the conic gear, the selection and calculation of the gear system with gear ratio i_{gear} and the driving mechanism with gear ratio $i_{bel} < 5...7$ were conducted:

$$i_\Sigma = \frac{i_{gear} \cdot i_{bel}}{i_s}. \qquad (18)$$

The calculations show that in such driving mechanism scheme, it is preferable to use the dual-stage worm gear system which can provide a great value of i_{gear} (up to several thousand).

With the purpose of test calculation of screw supercharger of dry soap process lubricant in actual practice of its use under the wire-drawing process, the dimensions of value are the following: $V_0 = 5\, m/s$; $d_0 = 7.0 \cdot 10^{-3}\, m$; $R_a = 4 \cdot 10^{-6}\, m$; the length of screw is $L = 120 \cdot 10^{-3} m$; efficiency of conic gear is $\eta_s = 1.0$; efficiency of the supercharger is $\eta_1 = 0.75$; efficiency of the motor is $\eta_{mot} = 0.55$; efficiency of the gear system is $\eta_{gear} = 0.30$; efficiency of the driving mechanism is $\eta_{dr} = 0.95$;

$$c_g = 2300 \frac{J}{kg \cdot K};$$

the density of the initial soap lubricant is

$$\rho_s = 1000 \frac{kg}{m^3};$$

the density of lubricant after temperature and power impact is

$$\rho_{TP} = 1300 \frac{kg}{m^3};$$

the density of wrought metal is

$$\rho_{met} = 1300 \frac{kg}{m^3};$$

coefficient of safety of material of the screw shaft is $k_s = 2$; the screw spade material (Steel 10) with flow limit

$$\sigma_{T.spad} = 210 \cdot 10^6 \frac{N}{m^2};$$

the load factor is $k_{spad} = 3$. The following results were obtained according to the calculations, which are presented by the arrows, with the dimensions in square brackets and the use of represented formulas in the round brackets.

$d_{s..in} = 10 \cdot 10^{-3} [m]$ (1); $\to$ $d_s = 26 \cdot 10^{-3} [m]$; $\to$ $D_s = 40 \cdot 10^{-3} [m]$ when $a = 2,3$; $\to$ $H_s = 30 \cdot 10^{-3} [m]$ (9); $t = 4$ $t = 4$ (10); $\to$ $V_0 / R_a = 1.25 \cdot 10^6 s^{-1}$; $\to$ $\frac{d_0}{R_a} = 1.75 \cdot 10^3$; $\to$ $T = 503 [K]$ (5); $\to$ $G(V_0 / R_a) = 7510$

(8); $\rightarrow$; $G\left({}^{d_0}\!/\!_{R_a}\right)=9375$ (7); $\rightarrow$ $G=6886$ (6); $\rightarrow$ $B=29.94+38.1\cdot10^{-9}\cdot p_0[Pa\cdot s]$ (4); $\rightarrow h=7\cdot10^{-3}[m]$; $p_0=1.122\cdot10^{6}\cdot B\,[N/m^2]$ (15); $\rightarrow p_0=33.72\cdot10^{6}\,[N/m^2]$

$\rightarrow$ and B = 31.2 [$Pa*s$] as a result of simultaneous consideration of (4) and (15); $\rightarrow A=0.367[N/m^2]$ (3); $\rightarrow P_s=49000$ [N] (13); $\rightarrow \varphi_D=13^0.4$ (6); $\rightarrow$ $\varphi_d=20^0.2$ (6) from; $\rightarrow \varphi_{aw}=16^0.8\succ10^0$ (6); $\rightarrow$ $M_s=248$ [$N*m$] (4); $\rightarrow w=3.45\cdot10^{-6}$[m³] – for (12); $\rightarrow \tau_{kr}=71.9\cdot10^6[N/m^2]$ for (12); $\rightarrow$ $\sigma_{sg}=100\cdot10^6[N/m^2]$ for (12); $\rightarrow \sigma_{eq}=175\cdot10^6[N/m^2]$ for (12); $\rightarrow \sigma_T=350\cdot10^6[N/m^2]$, on the basis of which the screw shaft material is Steel 40X with $\sigma_T\geq400\cdot10^6[N/m^2]$ $\rightarrow M_{man}=-30.4[N\cdot m]$ (14); $\rightarrow$ $\delta_s\geq1.61\cdot10^{-3}$[m] (15), on its base it is accepted that $\delta_s=2\cdot10^{-3}$[m]; $\rightarrow S_{corp}=3.52\cdot10^{-3}[m^2]$ for (16); $\rightarrow l_D=41.1\cdot10^{-3}[m]$ for (16); $\rightarrow l_d=27.7\cdot10^{-3}[m]$ for (16); $S_{vit}=0,5\cdot10^{-3}[mm^2]$ for (16); $\rightarrow S_{corp}>S_{vit}$ the condition (16) is performed; $\rightarrow$ it is accepted in advance f_{sm}=0.2 for (7) $\rightarrow k_{ots.1}=0.222$ - the first base to the stepwise approximation according to (7) $\rightarrow \omega_s=44\cdot10^{-3}[s^{-1}]$ - the first base to the stepwise approximation according to (20); $\rightarrow \tau_g=0.39\cdot10^6$ [N/m^2] – the first base to the stepwise approximation according to (2); $\rightarrow f_{sm}$=0.012 (8) $\rightarrow$ the check is $f_s\cdot H_s<<d_s$ - the condition of absence of self-braking of lubricant substance is satisfied; $\rightarrow k_{br.2}=0.17$ - the second base to the stepwise approximation according to (7); $\rightarrow \omega_s=41,5\cdot10^{-3}[s^{-1}]$ - the first base to the stepwise approximation according to (20); $\rightarrow$ n_s = 0.013 [sp/s]=0.4[$sp/\ min$] (3); $\rightarrow q_{TP}$ =2 [kg/tn] (19), that is conformed with the practice of wire-drawing process; $\rightarrow$ $N=0.105$ [kW] (2), on the basis of which the asynchronous three-phrase motor of AIR 56A4 type with the nominal rating power N_n = 0.22[kW] is selected, nominal speed is $n_n=1360$ [sp/min], efficiency of the η_{mot} = 66%, with weight 3.8 kg; $\rightarrow i_\Sigma=3375$; $\rightarrow M_{calc}=0.073[N*m]$; $\rightarrow$ $M_n=0{,}573[N*m]$; $\rightarrow M_n>>M_{calc}$; $\rightarrow$ for the driving mechanism of the screw supercharger; screw type double-stage regulator 5CH80/40 with $i_{eag}=1250$, $M=355\,[N*m]>>M_s$ and with weight 38 kg; $i_{bel}=2.7$ is selected for the transmitting rotation from the motor to the screw shaft (18).

Naturally, the necessary calculations should be conducted for all transmitting elements according to the known approaches.

Thus, let us compare the required power of the screw supercharger driving mechanism with the possible power saving during wire-drawing process and its application.

The power of the wire-drawing process is determined by the formula:

$$N_{draw}=\frac{\pi\cdot d_0^2}{4}\cdot V_0\cdot\sigma_{draw} \tag{19}$$

where according to the formula (6):

$$\sigma_{draw}\approx\sigma_T\cdot\left[\ln\mu+0{,}77\cdot\alpha+\frac{f_{draw}\cdot\ln\mu}{\alpha+\alpha^2+f_{draw}\cdot\ln\mu}+\frac{2{,}6\cdot f_{draw}\cdot\alpha}{\alpha+f_{draw}\cdot\ln\mu+2\cdot f_{draw}\cdot\alpha}\right] \tag{20}$$

σ_{draw}, $\sigma_Ò$ - wire-drawing stress and flow limit of the wrought material; μ - metal elongation ratio during wire-drawing process; α - half of the angle of conic working drawing die (Fig.1); f_{draw} - the friction ratio during wire drawing.

Usually, a = 0.1...0.12rad; μ = 1.25...1.40 at rough average steel wire drawing.

Taking into account the dependence of f_{draw} on the friction mode index

$$k=\frac{\xi}{R_a}$$

from the paper [7] , it may be accepted $f_{draw.0}$=0.2 for the usual terms (with «o» index), but $f_{draw.1}$=0.16 for the test score of the efficiency of screw supercharger application during the wire drawing with the hydronic friction mode (with «1» index).

Corresponding electric power reduction of the driving mechanism of wire-drawing machine under the comparable conditions:

$$\Delta N=N_0-N_1. \tag{21}$$

For the values $a=0.12$; μ=1.35; υ_T= 25·10⁻⁶ N/m², which are in the formulas (19) and (20), $\Delta N\approx0.7$ kW or about 14 %.

The presented data suggest that the energy saving during the advanced wire-drawing process is several times better than the calculated power necessary for the screw supercharger driving mechanism. It indicates the applicability of such tool in practice of wire drawing.

Conclusion

The calculation method of the screw supercharger parameters for providing the hydronic friction mode during wire drawing with dry soap process lubricant was developed. The calculations have proved that power saving during such wire-drawing process is several times higher than its consumption by the driving mechanism. Moreover, the substantial increase of drawing dies wear resistance and reduction of breakages are expected that makes profitable the use of the screw supercharger.

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Analysis of fractal characteristics of mining and geological parameters of minerals

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Abstract
The basic properties of fractals were studied and the main ways of their possible use in justification of mineral deposits characteristics were analyzed.
Key words: FRACTAL ANALYSIS, CRACKS, DEPOSITS, MINERALS, MINERAL FORMATION

Introduction

Fractal geometry and fractal analysis are relatively new branch of science, that declared itself after the publication of fundamental works of B. Mandelbrot, who has shown that the geometry of the most natural objects allows, in addition to the characteristics of traditional geometrical concepts, describing by fractal objects the parts of which are in some extent similar to the whole. In 1975, Benoit Mandelbrot coined the term “fractal” from the Latin word fractus, which meant “broken”. But only after the publication in 1983 of “The fractal geometry of nature” by B. Mandelbrot the concept of fractals had entered into other sciences, and became the basis for the consideration of a variety of natural forms. It turned out that fractals provide extremely compact way of describing objects and processes [4].

Analysis of recent researches and publications

The fractal characteristics of geological objects and processes were studied by such scholars as Bulat A. F., Dyrda V. I. [1], Vadkovsky V. N., Zakharov V. S. [2], Pozdnyakov O. V. [5], Koptikov V. P. [3], Goryainov P. M., Ivanyuk G. Yu. [7].

Fractal characteristics of large-scale geological structures and objects of seismic zones and unworked coals were studied in most of the papers from fractal analysis in mining. In turn, insufficient attention is paid to the problem of possibility of fractal analysis application to the study of characteristics of natural stone deposits and researches on the subject are not carried out.

The work objective is to analyze the experience of application of fractal analysis methods in geology and mining and to determine the prospects of using it for researches of natural stone deposits.

Presentation of the main material of the article

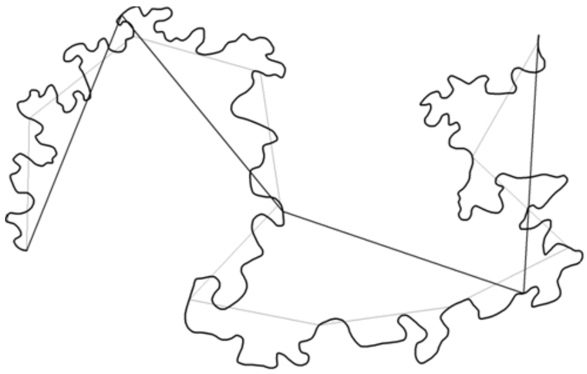
Traditional methods of mining geometry are based on a close approximation of mining and geological objects complex forms by geometrical figures: points, lines, segments, planes, polygons, etc., which metric and topological dimension are equal to each other. At the same time, when it comes to geometrization of geological structures (geometrization of mineral deposits), part of the information about the objects is lost, because the distribution of qualimetric characteristics of the deposits is averaged and shape of the geological structure is simplified artificially. Fractal geometry, which operates fractional metric dimensions of the studied objects, characterizes not only their geometric image, but also reflects the processes of formation and evolution. Many complex structures have a fundamental property of the geometric regularity – scale invariance, or "self-similarity". When considering such structures with different magnifications it turns out that the same structural elements are repeated at each scale level. These repetition laws define the fractional or fractal dimension of the structure. In this case, it is clear that fractal geometry describes natural objects more accurately and easier than Euclidean geometry.

The concept of fractals was first used to measure the shore lines of England, Australia and Norway. Measurements of their approximate length have shown that the length of the coast is a power function, which depends on the scale (length unit).

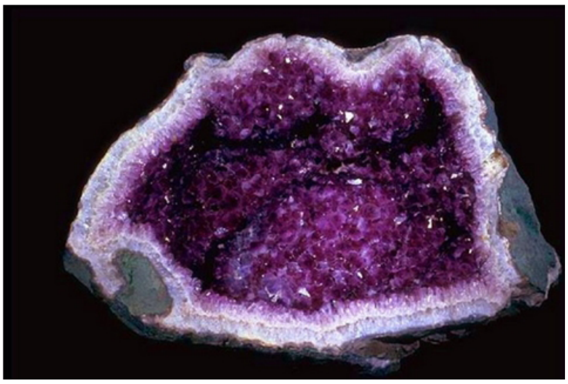
Any topographical profile is continuously formed by dynamic processes of destruction and creation, so we can assume that it is also fractal. This question has been studied according to the data of Vadkovsky V. N. and Zakharov V. S.: Himalaya-Tibet region has a dimension of 1,67, the southern regions of Lake Baikal - 1,674, Central Africa - 1,704, the North Atlantic - 1,484, etc.

High roughness means intensive endogenous feeding in the area. This is an important consequence of the fractals theory allowing geologists to compare quantitatively the tectonic regimes in the region.

Like the determination of sea shoreline structures it is possible to use fractal analysis for pegmatites contours or amethyst geodes shown in Fig. 1. In the latter case, the calculated value is equal to the fractal dimension $d = 1.14$.



a)



b)

Figure 1. Minerals contouring structure using fractal analysis

Recently, fractal analysis began to apply not only in mathematics, but also in many branches of physics, materials science, biology, geology and geophysics. It has been proved theoretically and experimentally that using fractal models as mathematical and natural objects as inanimate and living objects can be studied. Various researchers of natural objects fractality have revealed the presence of ordering in the structures that appeared to be disordered.

When studying the processes of rock destruction researchers have come to the conclusion that the process is non-linear. Hooke's law has the following form

Hooke's law was only at the initial stage of deformation. When a certain threshold value was reached, linear law ceased to operate, and there was a redistribution of stresses (disconnection), resulting in an extensive system of cracks. In cases of rock destruction in tension and shear, ypical configuration of cracks have a fractal structure with the dimension d = 1.12...1.65.

In theory of destruction, the theory of fractal structures is actively applied [8, 9]. The spread of cracks in the rock mass has a number of features – the fractal nature of the fracture process [9] and stochastic trajectory [10]. The trajectory of crack occurring at the same time can be curved; the crack propagation can be chaotic. The microstructure has a significant influence on the crack propagation stability, especially near bifurcation points. In some modes of crack propagation the process of self-sustaining destruction occurs when crack propagation becomes avalanche, self-supporting nature. The sufficient voltage level for such explosive crack propagation is much less than critical one.

The residual stresses have essential character [10]. Instability can be caused by non-uniform field of dislocations, inhomogeneous mechanical properties of the continuum, random fluctuations in the applied stress [10].

Usually it is assumed that the density W of microcracks has a fractal nature of hyperbolic distribution:

$$W(a_c) = \frac{N(a \geq a_c)}{V} = \lambda \cdot a_c^{-d},$$

where a_c - critical crack size; λ - constant, d - fractal dimension, $0 \leq d \leq 3$; $N(a \geq a_c)$ - a number of microcracks, which are greater than the critical length value [9].

According to the fractals theory for destruction, one crack is enough. Therefore, only one main crack determines the tensile strength of the material. Then the probability of failure is $P = 1 - e^{-nv}$, where P - the probability of finding at least one critical crack; V - volume of the sample; n - a number of critical cracks per volume unit. The transition from the dispersed destruction to the main crack [10] and emergence of bifurcation points corresponds to the phenomena of "catastrophe". Therefore, the classical destruction objects can be considered from the perspective of "catastrophe theory".

Fractal patterns have found their application in the study of logic and information descriptions of mineral deposits. The methods of fractal geometry can estimate the morphology of ore bodies on a quantitative basis, the complexity of the ore bodies is reflected in a regular increase in the fractal dimension *D*. With regard to the geology such an object, which structure when considered at different scale levels shows a fundamental similarity, at the same time the number of the structure fixing elements when transition from one level to another scale changes in the power ratio is called self-similar fractal.

The goethite mineral is a classic example of the fractal organization of mineral individuals (Fig. 2.). Moving up the hierarchy of the lithosphere the fractal property of structures and textures of rocks can be noted. Some self-similarity reveals itself in nodule of minerals and other geometric selection derivatives.

Figure 2. The goethite mineral

Such complex objects as breccia can be self-similar in the scale range of at least five orders of magnitude, and behind the apparent randomness of their structure, the strict laws can be viewed. The latter is well illustrated by the classic fractal "Apollonian gasket" analyzed in detail by B. Mandelbrot [4]. Its construction starts with three circle of arbitrary diameter in contact with each other, between which the round triangle with angles 0° will be located. The circle with the most possible diameter fits in this triangle and forms another three smaller rounded triangle. Endless repetition of this procedure creates "Apollonian gasket" (Fig. 3).

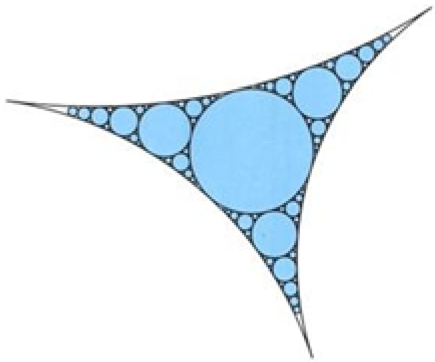


Figure 3. Apollonian gasket

It is interesting that large areas of ocean ice are fragmented like the Apollonian cascade. Even "effect of deliquescent floe" was formulated: each piece, despite its size can be with sufficient degree of confidence associated with its neighbors even with enough distant fragments. According to the theory of non-equilibrium fragmentation, the formation of fractal divisibility of rocks due to the fact that destruction probability of an inhomogeneous medium increases when same size fragments are interacting (i. e. the probability that a large fragment crushes the smaller and, especially, on the contrary is much lower than the probability of mutual destruction of similar in size rocks). As a result, similar in size neighboring fragments are destroyed and two identical pieces do not occur beside each other.

In order to self-similar fractal model will suit to the characteristics of the studied formation, there should be a proportional relationship between the number logarithm of *n*-dimensional cubes with a side δ $(N(\delta))$, covering *n*-dimensional fractal and with side size of δ. It is obvious that the natural object when increasing or decreasing the scale will not have an infinite self-similarity. Furthermore, similar may be only certain large-scale levels. Therefore, assessing the conformity of the self-similar fractal model explore some scale interval and determine the fractal dimension of the set, which would have been if the self-similarity of the object had been infinite.

Usually, to determine compliance of the fractal model with the real geological object the graph of dependence $lnN(\delta)$ from $ln(\delta)$: $\ln N(\delta) = a \cdot \ln(\delta) + b$ is built. Logarithms on any basis can be used, but the same for both axes. In the case of matching the graph points should be substantially approximated by a straight line.

The rate of growth of the elements number while increasing the scale is the fractal dimension *D*. It is defined as tangent of the angle of this straight line to the abscissa axis. The fractal dimension of investigated object is a quantitative characteristic of the filling degree of plane or space. The essence of fractal analysis is to study the dynamics of changes in the geometry of the studied object when scale changing.

In this regard, the scheme of fractal analysis is as follows:

1. By methods of fractal geometry the various geotechnical parameters of mineral deposits development are assessed.

2. The correlations between the fractal dimension of the geotechnical parameters and coefficients of variation statistics characterizing by variability are established.

3. The variable nature of fractal dimensions for various geotechnical parameters due to the complexity of geological conditions is determined.

Conclusions

The analysis of the information allows drawing a conclusion of the extensive use of fractal analysis methods in various branches of modern science. On the basis of applying fractal analysis in geology, we can make a guess about its use in the mineral deposits geometrization, in particular in the study of fracture parameters, and especially in dealing with assessment of the variability of geotechnical parameters for the purpose of further planning the mining operations conducting directions.

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Prospects for future mining of steep iron-ore deposits in the context of Kryvbas

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Abstract
A problem of mining of platform-like steep and synclinal iron-ore deposits with inside overburden rock dumps was considered. Expedient production concepts for typical deposits of Kryvy Rih iron-ore basin were demonstrated. Rational parameters to mine iron-ore deposits with inside overburden rock dumps were substantiated. Basic indices concerning deepening and continuous mining for iron-ore open pits were provided. Dependence of level depth with temporary dumps within advance zone on ore deposit thickness was determined. Poltava MPIW was taken as an example to prove both economic and environmental efficiency of the proposed decisions.
Key words: OPEN-CAST MINING, IRON-ORE DEPOSITS, INSIDE OVERBURDEN ROCK DUMPING, MINED OUT AREA, WORKING ZONE PARAMETERS

Introduction

Long-term practice of iron-ore open pits operation in Kryvbas shows that it is rather expedient to mine them one by one when mined-out area of previous open pit is used to stockpile overburden rocks of active one. In this context, relative closeness of open-pit fields as well as developed railroad network would make it possible to achieve high efficiency of open-pit mining as land would not be disturbed by outside dumps. Complete refilling of mined-out open pits and availability of soil layer at the level of undisturbed land would help to resoil considerable territories which today is surface disturbed by deep cuts, high dumps, and tailing pounds. At the same time, the lessons learned may be used effectively while prospective deposits mining. First, one should be geared to synclinal ones where deposit outbreak takes place under shallow overburden. The deposits are similar to Sklevatskoe magnetite, Inhuletskoe, Petrovskoe, Artemovskoe, Zelenorechenskoe and other deposits. Such deposits are characterized by the fact that value of plunge of axis of fold is within 15 – 20° [1].

Main part

Intensive formation of mined-out area to provide minimum continuous overburden rock mining is possible in terms of lateral primary mining of producing level as well as primary axis development with displacement of advance bench along synclinal flanks towards opposite edge of open pit (Fig. 1). The key criterion to determine mining parameters is to enable complete stockpiling of overburden rocks within mined-out area and its preparation for agricultural reclamation. Mined-out area within edge of open pit may be used for upper floor of constant dump at ground level of 60 – 100 m higher [2].

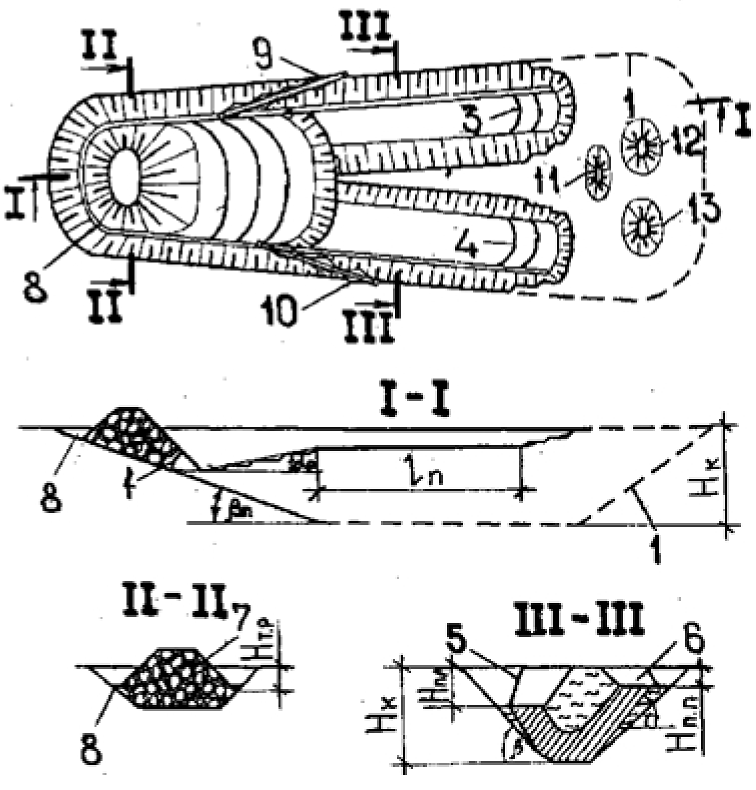

Figure 1. Analytical model for calculating parameters to mine synclinal iron-ore deposits with inside dumps

1 - lines of open-pit field; 2 - working benches within deepening zone; 3 and 4 - working benches within advance zone in terms of left and right wings; 5 and 6 - lines of temporary dump within advance zone in terms of left and right wings; 7 - permanent inside dump within deepening zone; 8 are residual trenches for open-pit transport; 9 and 10 - conveyors within left and right wings; 11 and 13 - temporary dumps of black soil, soft overburden rocks, and hard overburden rocks

It was determined that in terms of open pit deepening down to 100 m, mined-out area with steep floor at the edge cannot receive the whole amount of overburden rock even if height of surface dump is 60 m. When deepening angle of axis is 15° then further lowering of pit bottom at the depth of more than 150 m enables complete stockpiling of overburden rocks within mined-out area. That is impossible for δ = 20 – 30° (Table 1); thus, certain portion of overburden rocks (mainly soft ones) should be temporarily stockpiled within undisturbed area of open-pit field. Amount of such rocks is from 10 to 36 mln m^3; they will be subsequently reexcavated to mined-out area in the process of hydrotechnical reclamation of disturbed surface.

When deepening angle of axis is 20° (for the whole range of considered thicknesses of deposit series under mining) the mined-out area within edge lines of deepening zone can receive overburden rocks in full measure. When deepening angle of axis is 30° then it is expedient to stockpile from 52 to 58 m^3 of overburden rocks within intermediate level of advance zone. As subsequent mining (in terms of final depth) is characterized by horizontal advance only, then length of area for temporary stockpiling within advance zone ℓ_a (m) is determined on conditions of economic stockpiling of current rock amount within permanent dump. Reexcavation of previously stockpiled overburden rocks is also involved. Taking into consideration output data from Table 1 it is possible to say that if H_a increases, starting from 100 m depth amount of residual overburden rocks within advance zone decreases by 20 to 25 % in reliance on every subsequent 50 m. The length of intermediate level for temporary stockpiling of the amount is within 830 m on every wing of deposit under mining. If single-direction mining of open pit takes place, then length of temporary dump is no less than 1660 m.

Table 1. Parameters for iron-ore deposit mining with inside dump of overburden rocks

Description	Index					
Type of open-pit field	1	3	6	2	4	5
Positions of the deposits	synclinal			steep		
Annual ore output, million cubic meters	2.6	6.8	12.4	4.0	6.0	9.0
Horizontal thickness of ore zone, m	370	875	1300	200	300	800
Rate of deepening of mining operations, m/year	11.0	7.7	5.8	14.9	16.7	17.6
Length of deepening zone if $\alpha_w = 19°$, $b_{tr} = 40$ m: $\delta = 15°$	3040	3040	3040	–	–	–
$\delta = 20°$	2540	2540	2540	–	–	–
$\delta = 30°$	2040	2040	2040	–	–	–
if $\beta = 40°$, $b_{tr} = 40$ m: $\alpha_w = 19°$	–	–	–	2100	2100	2100
$\alpha_w = 30°$	–	–	–	1500	1500	1500
Amount of overburden rocks within deepening zone, million cubic meters: $\delta = 15°$	180.6	226.0	271.0	–	–	–
$\delta = 20°$	150.5	188.3	225.8	–	–	–
$\delta = 30°$	119.8	149.8	179.7	–	–	–
$\alpha_w = 19°$	–	–	–	323.3	300.7	219.7
$\alpha_w = 30°$	–	–	–	225.9	215.5	163.7
Capacity of inside dump within deepening zone, million cubic meters: $\delta = 15°$	202.2	287.1	369.7	–	–	–
$\delta = 20°$	129.8	181.7	283.6	–	–	–
$\delta = 30°$	67.4	94.4	121.6	–	–	–

$\beta = 40°$	–	–	–	421.8	448.4	613.5
Required capacity of inside dump in the process of advance zone progress, million cubic meters	–	–	–	618.1	562.8	417.2

Note: b_{tr} is width of residual trench bottom, m; α_w is angle of working area slope, degrees; β is angle of unworking area slope, degrees; δ is longitudinal angle of iron ore layer, degrees

In contrast to synclinal deposits, mining of steep ones is characterized by lower productive capacity and higher average opening coefficient. Such open pits as # 3 AMKR, # 1 CMPIW, Hannivka NorthMPIW, SMPIW and others have much worse economic performance. Skew angles of their edges are no less than 30 to 36°. Under such conditions, inside dump at intermediate level within advance zone requires complete overburden rock excavation on bottom layer of deposit as well as formation of spoil-pile wall with desired length (Fig. 2).

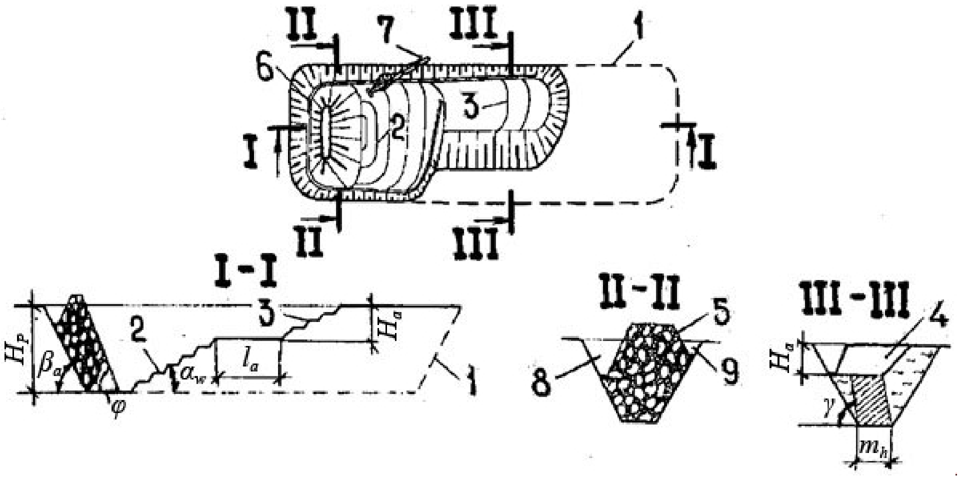

Figure 2. Scheme for calculating parameters of platform-like steep deposits with inside dump of overburden rocks

1 - lines of open-pit field; 2 and 3 -working benches within zones of deepening and advance; 4 - 5 are lines to locate inside dumps within zones of deepening and advance; 6 are railway tracks; 7 -conveyor hoist; 8 and 9 - residual trenches for transport

Receiving capacity of mined-out area within deepening zone $W_{mo.a}$ (cubic meters) is determined as follows

$$W_{mo.a} = \frac{0,3H_a b_{tr}}{K_{f.d}}\left[2m_h + 3H_P ctg\beta - 1,5(H_{b.l} + H_{h.l}) \cdot (ctg\beta + ctg\varphi) - 4b_{tr} - h_d ctg\varphi\right] \quad (1)$$

where $H_{b.l}$ and $H_{h.l}$ are depthes of residual trench from bottom layer and hanging layer of ore deposit, m; h_d is height of inside dump above ground level, m. H_P is depth of open pit, m; m_h is horizontal thickness of iron ore layer, m; φ is angle of inside dump inclination, degrees; $K_{f.d}$ is fragmentation index of inside dump.

Overburden rock amount within deepening zone $W_{or.a}$ (cubic meters) is

$$W_{or.a} = 0.34H_P(B_f L_s + m_h b_{tr} + \sqrt{m_h b_{tr} B L_s} - 0.5m_h(L_n + b_{tr})(H_P - H_o) \quad (2)$$

where B_f is width of open-pit field in terms of surface, m; L_s is length of deepening zone over the surface, m; $L_s = b_{tr} + H_P(ctg\beta + ctg\alpha_w)$; H_o is thickness of overburden, m.

Receiving capacity of mined-out area at the level of temporary dumping within advance zone $W_{d.a}$ (cubic meters) is calculated as follows

$$W_{d.a} = 0,3H_a \ell_a\left[m_h + (H_P - H_a)(ctg\beta - ctg\gamma) + 0.5H_a(ctg\beta + ctg\alpha_w)\right] \quad (3)$$

where γ is horizontal angle of iron ore layer

Length of temporary dumping level within advance zone is identified if current overburden rock amount from advance zone is stockpiled; in terms of mined-out edge of deepening zone it can be done taking into account reexcavation of previously stockpiled overburden rocks. Assumption of output data from Table 1 makes it possible to say that length of intermediate level for the amount stockpiling is from 3.5 (if m_h = =200 m) to 0.7 km (if m_h = 1200 m).

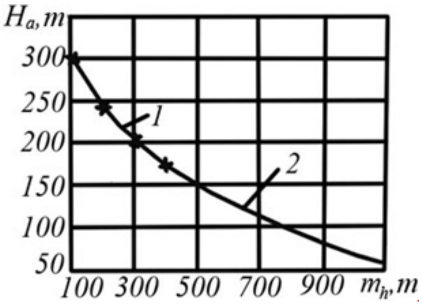

Figure 3. Graph of dependence of depth of level with temporary dump within advance zone H_a on thickness of ore deposits: 1 is area of inside dumps with relative height of ground level; 2 is area of overburden rock stockpiling at ground level

Figure 3 explains that while mining strata series which horizontal thickness is up to 300 – 450 m it is expedient to locate inside dumping level at 150-200 m; permanent inside dump should be formed with 60 to 100m relative height of ground level. It is rather efficient to apply railway transport at every mining stage if depth varies from 150 to 200 m. However, its operation involves certain limitations concerning intensity of working zone of open pit formation. In this context its productive capacity is of prime importance. Table 1 shows that if mining takes place in the period of deepening zone formation, then mining operations deepen considerably; in terms of open pits of 2nd, 4th, and 5th types it is from 14.9 to 17.6 meters per annum. Even upon availability of motor vehicles such intensification of mining operation is hardly achieved.

Table 2 demonstrates that while operating open pits of 2nd, 4th, and 5th types, planned advance of mining within deepening zone (when rate is 10 meters per annum) involves the necessity to displace upper benches for extra productivity increase by 12.5, 40, and 43.3 % respectively.

To normalize mining operations it is proposed to put into operation additional benches with their displacement in the line of course of ore towards oppo-site edge of open pit. Parameters of advance zone should provide increase in efficiency of ore mining in the context of allowable rate of mining deepening. In this case, deepening rate D_r (m/y) and advance intensity T_a (m/y) are determined as follows

$$D_r = \frac{H_d A_{od}}{P_d}, \text{ m/year; } T_a = \frac{A_o - A_{od}}{m_h H_c} \quad (4)$$

where H_d is depth of deepening zone, m; A_o and A_{od} are annual output of ore mining both in open pit and deepening zone, cubic meters; P_d are reserves of mineral within deepening zone, cubic meters; H_c is current depth of open pit, m.

Table 2. Basic indices of deepening and continuous mining system for iron-ore open pits

Description	Index					
Type of open pit	1	2	3	4	5	6
Volume of deepening zone, mln cubic meters:	98.5	244.0	636.8	437.2	758.3	2450.7
– ore	50.0	99.6	430.9	165.6	281.9	1571.0
– overburden rocks	48.5	144.4	227.9	271.6	476.4	879.7
– overburden of them	11.5	47.5	104.3	93.3	166.0	380.6
Share of overburden hard rock within upper part of deepening zone, mln cubic meters: – if current depth of open pit is, m:						
H_1=100	28.2	58.0	66.7	96.4	97.7	187.4
H_2 = 150	6.7	25.5	39.6	57.3	80.8	150.4
H_3 = 200	–	–	21.7	10.7	52.4	102.5
H_4 = 250	–	–	–	–	30.2	70.3
Deepening rate of open pit with specified productivity, m/y	11.0	14.9	7.7	16.7	17.6	5.8
Annual output of open pit if deepening rate is 10 m/y, mln cubic meters	–	3.5	–	3.6	5.1	–

Annual ore output within advance zone, mln cubic meters	–	0.5	–	2.4	3.9	–
Expenses connected with overburden hard rock displacement, UAH, mln $H_1 - \ell_{mv}$ = 1.5 km; $C_{tr.mv}$ = 0.6 UAH/m^{3}km	$\frac{25.38}{13.54}$	$\frac{52.2}{27.84}$	$\frac{60.3}{32.02}$	$\frac{86.76}{46.27}$	$\frac{87.93}{46.90}$	$\frac{132.66}{70.75}$
$H_2 - \ell_{rt}$ = 4 km; $C_{tr.rt}$ = 0.12 UAH/m^{3}km ℓ_{mv} = 2.25 km; ℓ_{rt} = 6 km;	$\frac{9.04}{4.82}$	$\frac{34.43}{18.36}$	$\frac{53.06}{28.51}$	$\frac{77.36}{41.26}$	$\frac{109.08}{58.18}$	$\frac{203.31}{108.43}$
$H_3 - \ell_{mv}$ = 3.8 km; ℓ_{rt} = 8 km	–	–	$\frac{39.06}{20.83}$	$\frac{19.26}{10.27}$	$\frac{92.52}{49.34}$	$\frac{184.5}{98.4}$
$H_4 - \ell_{mv}$ = 3.75 km; ℓ_{rt} = 10 km	–	–	–	–	$\frac{67.95}{36.24}$	$\frac{158.18}{84.36}$
Period of ore mining within deepening zone if D_r = 10 m/y, years	25.5	47	60	46	55	138

Note: numerator contains data for motor vehicles; denominator contains data for railway transport

Open pits of 3rd and 6th types are mined with 7.7 and 5.8 m/y deepening rates; that makes it possible to form their working zone without advance of upper benches. In each case, rock mass mining within deepening zones of the open pits is rather considerable being from 46 to 60 years. Open pits of 6th type are unique according to their reserves and occurrence mode. Long-term formation of mined-out area within their lines postpones the solution of inside dumping problem up to 138 years.

Open-pit mining practice shows that mining of long steep deposits is of the most intensive nature in the context of sites with the thickest deposits specified by minimum opening coefficient, considerable dimensions of working zone in a plan as well as projected depth of basic open pit. The sites of open pit with thinner deposits differ in higher opening coefficients. The tendency to decrease the total amount of overburden rock mining under the conditions lies in the fact of accelerating advance of horizontal mining operations in the line of the deposit occurrence in terms of poor intensity of deepening of bottom of open-pit. Projected mining depth within the sites is much less to compare basic open pit. Longer open-pit field makes it possible to use highly economical railway transport for rock mass. Railway tracks on both frontal edges of open pit help supply trains at rather considerable depth within deepening zone. Sequence of advance area mining is determined within central part of open-pit field and a part located far from deepening zone in accordance with value of opening coefficient being economic for mining operations. In this context, benches of 1st and 2nd orders are open form deepening zone. Temporary inside dump is formed at bottoms of average-order benches at the distance being no less than $\ell_{n.1}$ (m) from projected one determined as follows

$$\ell_{b.1} = h_2\left(\frac{b_b}{h_b} + ctg\alpha_b\right) + 2\sqrt{h_d b_b ctg\varphi_d} + b_s \qquad (5)$$

where h_2 is height of benches of 2nd order, m; b_b is width of bench, m; h_b is height of bench, m; α_b and φ_d are slope angles of bench and primary inside dump, degrees; h_d is height of primary inside dump, m; b_s is width of safety area between bottom edge of primary dump and bottom of central part of open-pit field, m.

After that working front of mining operations and dumping ones is advanced horizontally from deepening zone to opposite edge of open pit; transport communications are located at upper unfilled areas of edges within central and remote parts of open-pit field. While forming worked-out area within bottoms of benches of 2nd order inside dump together with overburden rocks excavated in the process of open-cut of walls of open pit is displaced from its primary location to stationary one within deepening zone. Reexcavation of temporary inside dump is performed with the help of transport communications of basic open pit.

Open pit of 5th type (PoltMPIW) is taken as an example to determine that height of average order is 170 to 180 m. It is not planned to deepen achieved depth within remote part down to finite value at the edge of open-pit field while mining. Then it is intended to mine central part at the depth of 320 m. 60 mln cubic meters of overburden rocks will be placed in temporary inside dump. Annual output of internal dumping is from 4 to 5 m^3. Width of bench (60 m), height of benches (15 m), slope angle of bench (75°), slope angle of dump (36°), height of temporary internal dump (45 m), and width of safety area between lower edge of dump and working bench (45 m) are those output data to calculate dumping parameters for temporary inside dump. Then length of bottom of level to locate temporary dump will be 1510 m.

In the context of PMPIW the technique of internal dumping has been industrially implemented since 1993. Within western edge poor ferruginous quartzites from –135 and –75 m levels were stockpiled in inside dump with – 150 m bottom grade (Fig. 3). Up to the year of 2000 almost 9 mln cubic meters of overburden rocks from central part of the open pit were stockpiled in temporary inside dump with –105 m bottom grade. Inside dumping made it possible to shorten the distance of overburden rock transportation using motor vehicles by 1.2 – 2.5 km; in terms of railway transport the distance was shortened by 5 km. 6 hectares of arable land was been disturbed by outside dumps. Annual economic effect exceeded UAH 6.5 mln.

Figure 4. Technique for PMPIW open pit mining with temporary inside overburden rock stockpiling within central part of open-pit field

Conclusions

In each case of control of overburden rock excavation can be achieved at the expense of increase in slope angles of highwalls. It is possible to increase slope angles of frontal spoil banks by means of their surcharging with the help of temporary inside dumps. Parameters of advance zone as well as volume of temporary dumping in it are determined by means of feasibility analysis depending upon transport type. Amount of reexcavation of temporary dumps depends heavily on lumpiness of overburden rocks and intensity of their use as by-product mineral raw materials. Environmental directivity of mining technique with minimum disturbance of land surface and its pollution is the key criterion of inside dumping within deep open pits.

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Methods and schemes of quarry fields opening-up under various conditions of deposits occurrence

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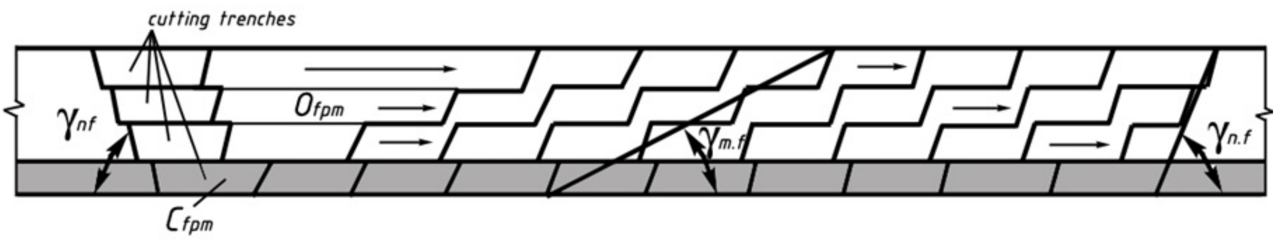
Abstract
The idea of opening, expressing the creation of conditions for cargo traffic mining companies transporting cargo from the bottom to the place of its reception within the boundaries of enterprise or outside it, is the same for cutting, quarry, or underground mine.
However, in open cast mining, the term "opening" is often understood as stripping or tunneling cutting trenches in contact with minerals, as there is no clear definition of the concepts of the method of opening, opening schemes and systems.
Based on a study of various options classifications methods of opening we offer a highlight of which is how to show what is done opening-up (by mine workings or without them), and all other descriptions should be attributed to the schemes, since they show the spatial position of the method (external, internal, individual, group and production, etc.)
Keywords: OPEN PIT MINING, CUTTING TRENCH, METHOD OF OPENING, SCHEME OF OPENING

In recent decades, periodical literature on open cast mining is mostly applied in nature, aimed at solving specific technical problems, including various case-studies [1-9]. Also, considerable attention is paid to geo-ecology of opencasts [10-14], to solution of economic problems in mining [15, 16]. However, there is a distinct lack of theoretical works, in primarily it concerns the papers aimed at the modernization and adaptation of existing classifications, concepts and definitions related to open pit mining, applied to current conditions. In addition, there are often discrepancies in some terms and definitions. Therefore, this article, in our opinion, highly relevant.

The concept of "opening" in the open cast mining should have a clear definition of its purpose, method of implementation and reporting schemes. Developing the theory of freight traffic overburden in the quarry, academician V.V. Rzhevsky found that freight traffic that determined the decision of opening the career field and that an opening is closely linked to the method of mining. At the same time it was emphasized features of the opening up the stripping and mining benches during the operation of career [17].

Open pit mining within the boundaries of the quarry field is carried out in accordance with the method of mining that determines the order of the mine-development, stripping and mining operations. This order should ensure the implementation of the specified production capacity quarry production of minerals and the appropriate volumes of overburden (Fig. 1).

Fig. 1 shows: O_{fpm} – overburden that removes in first phase mining; C_{fpm} – coal that removes in first phase mining; $\gamma_{m.f}$ and $\gamma_{n.f}$ – overall slope angle on mining and non-mining flanks of open pit, respectively; α_s – angle of coal bedding. The arrows indicate the direction of development of mining operations.



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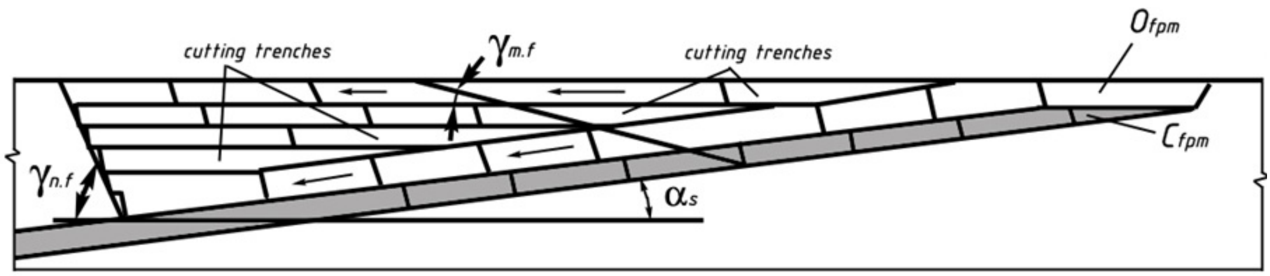

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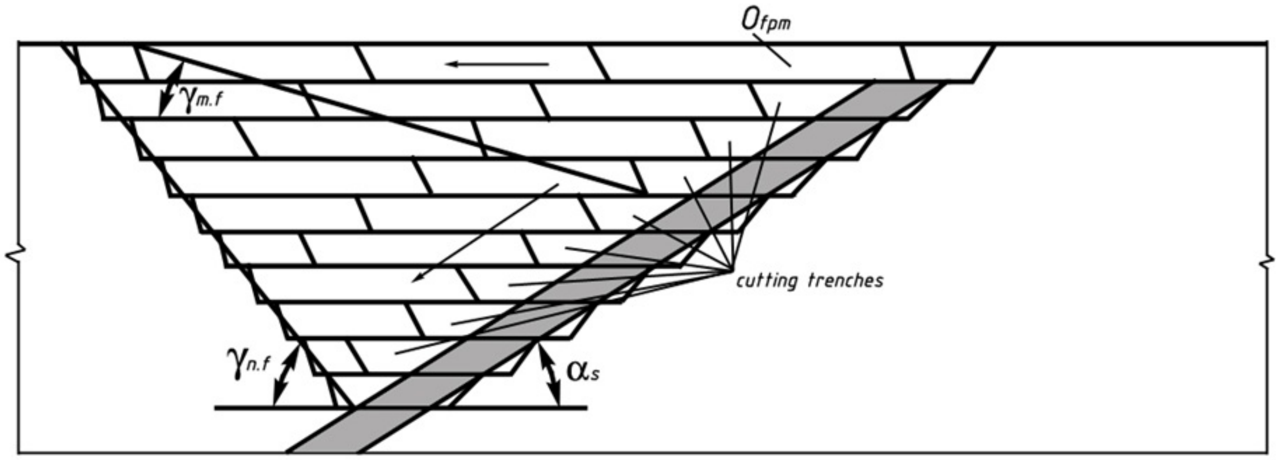

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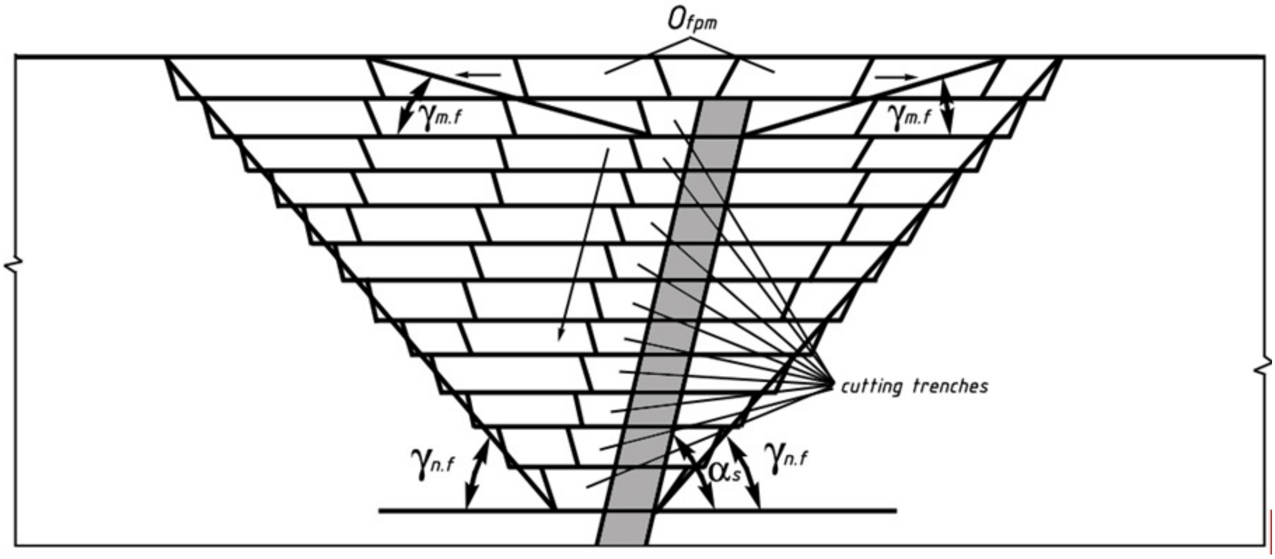

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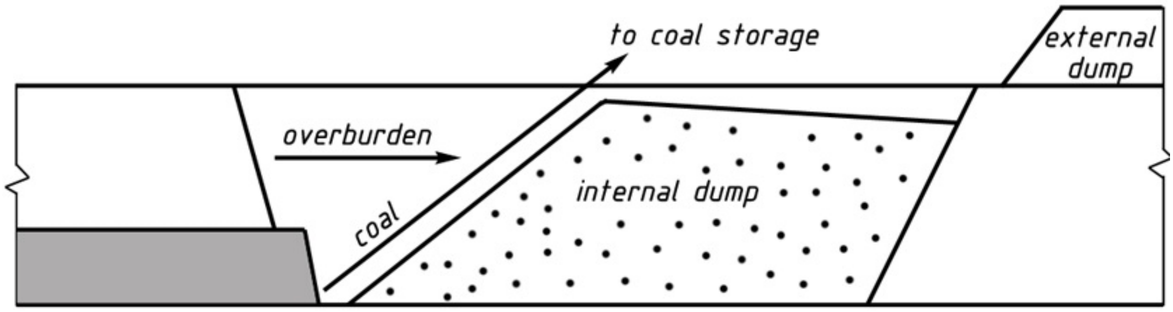
Figure 1. Directions of development open pit mining in various fields of bedding conditions: a – horizontal seam; b – flat seam; c – inclined seam; d – steep seam

Formed stripping and mining freight traffic determines a set of equipment that must comply with conditions of developing deposit, as well as the order of preparatory, stripping and mining operations; therefore, they define the method of mining, in accordance with the classification by V.V. Rzhevsky [17].

Features of the development of mining operations and formation of stripping freight traffic determined the dividing of mineral deposits, developed by open pit, of the dip angle to the horizontal, flat, inclined and steep (Fig. 2).



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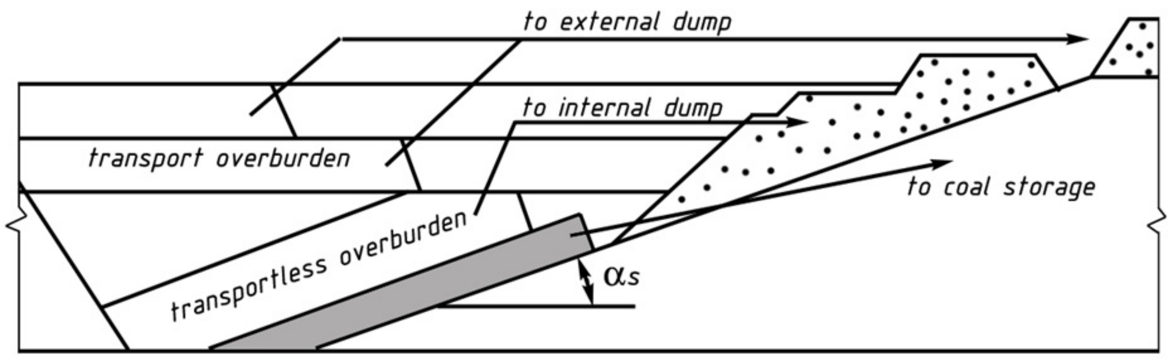

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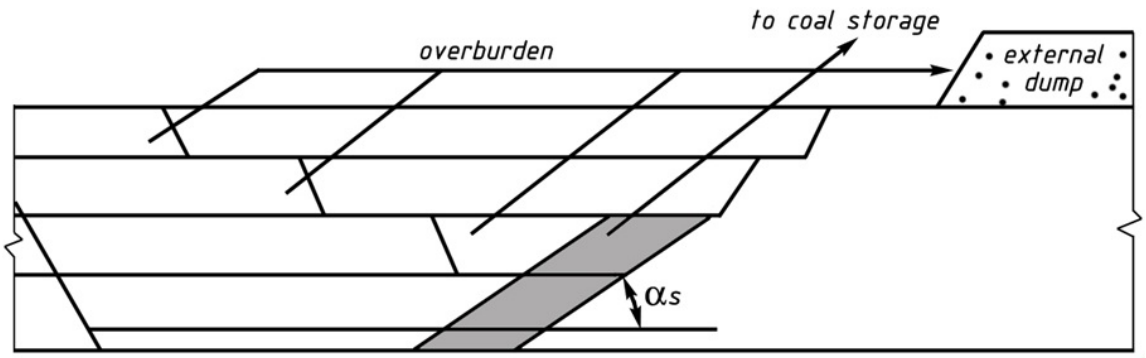

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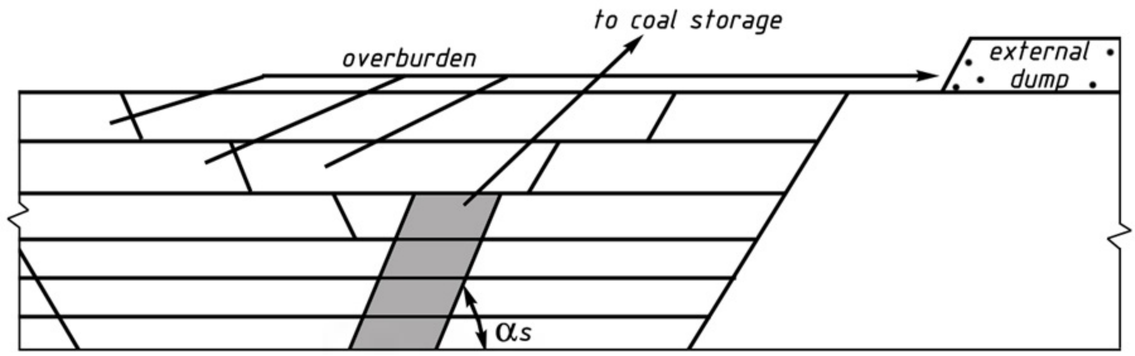

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Figure 2. Freight traffic quarry schemes at various angles of dip a – 0-5º, b – 6-14º, c – 15-45º, d – 46-90º

Horizontal deposits are seams with dip angle 0-5˚, which will be developed within the established quarry boundaries with the removal of overburden only from the hanging wall and complete placement of rocks during the operation of the quarry in the mined-out space as dredging the seam, where the overburden is moved by excavators or transport.

The limiting value of the dip angle 5º is determined by the possibility of direct vehicle entrance to the quarry face by seam floor, since it corresponds to the limiting gradient of 80 ‰.

Flat deposits are seams with dip angle 6-14º, which will be developed within the established quarry boundaries with the removal of overburden only from the hanging wall, placing it during the quarry operation partially in the goaf using draglines by transportless scheme, and the rest of the overburden will be transported to internal or external dumps.

The limit value of the dip angle 14º is determined by stable placement of the internal dumps on the seam floor without additional measures.

Inclined deposits are seams with dip angle 15-45º, which will be developed within the established quarry boundaries with the excavation of overburden only from the hanging wall and the rocks will be completely moved to external dumps.

The limit value of the dip angle of 45º is determined by stable position of non-mining flank of opencast with hard rocks.

Steep deposits are seams with dip angle 46-90º, which will be developed within the established quarry boundaries with the removal of overburden from both hanging and lying walls of the seam and the rocks will be completely moved to external dumps.

Quarry freight traffic overburden at various conditions of fields bedding have a different orientation. Mineral product in all cases is sent to the concentration plant or coal storage. The operation of all these freight traffic provided by one or another method of opening.

Method of opening is the creation of conditions for the transporting of working levels freight through open-cut workings (trench method) or underground mine workings (underground method), as well as using excavation equipment, special designs and constructions (special method).

Classification of opening methods by the presence and type of openings drilled (or their absence) presented in Table 1.

Table 1. Classification of opening methods

Opening method	Essence of the opening method
Trench	Opening by a system of open-cut workings
Underground	Opening by a system of underground workings
Special	Opening by a system of mining equipment, special designs and constructions
Combined	Opening by a combo of various methods, such as trench and special; trench and underground; underground and special; special, trench and underground

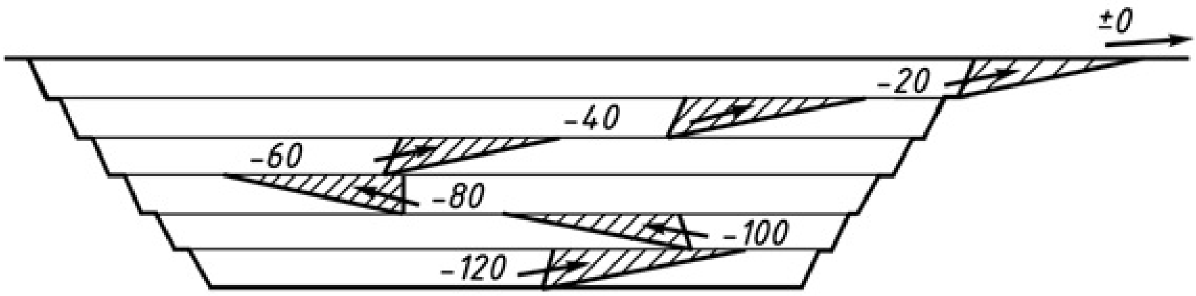
As can be seen from the table, each method is an opening system that provides quarry freight traffic working.

It is therefore proposed to consider that the purpose of opening is an establishing of communication of working levels freight traffic and places of freight acceptance inside the quarry and beyond its boundaries.

The opening method shows *what* opening of working levels is carried out, and the scheme – *how* does the transporting of freight at one or another method in a particular period of quarry operation.

Thus, the essence of the opening method is expressed through the opening system.

Opening systems on open cast mining are sets of incline trenches and semi-trenches, steep trenches, underground mines (crosscuts, tunnels, inclined shafts, adits), interconnected by transport communications and ensuring the conditions for the transport of minerals from the faces to their place of storage; set of excavation machinery, carrying out excavation and reexcavation of overburden for transportless scheme; excavators in combination with special designs for belt conveyors that providing rock mass transport; special structures (dams, viaducts, embankments, berms) to guide the freight traffic from the face to the storage places (Fig. 3).



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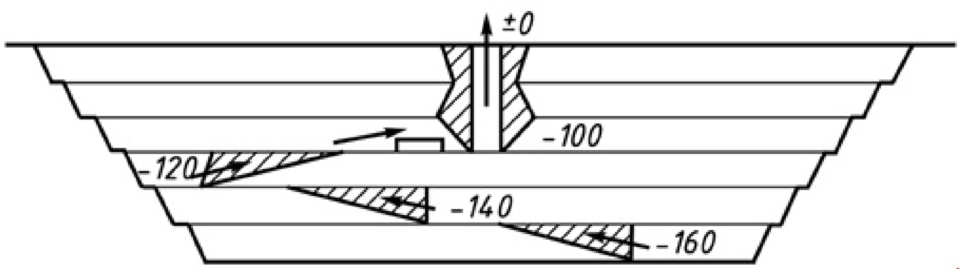

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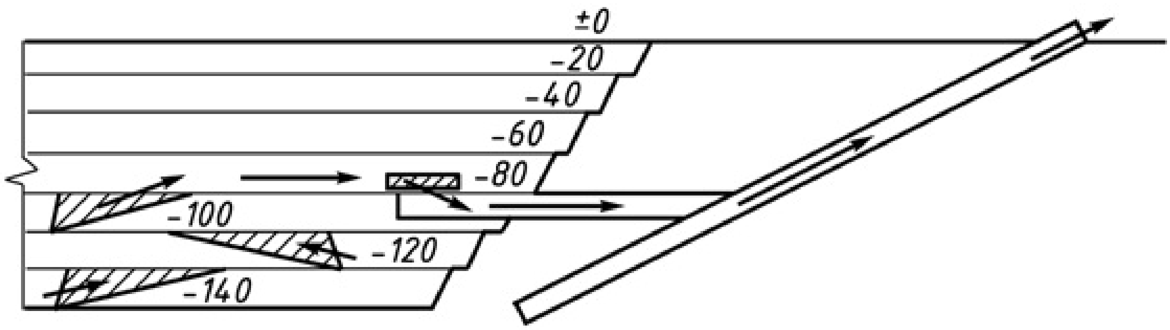

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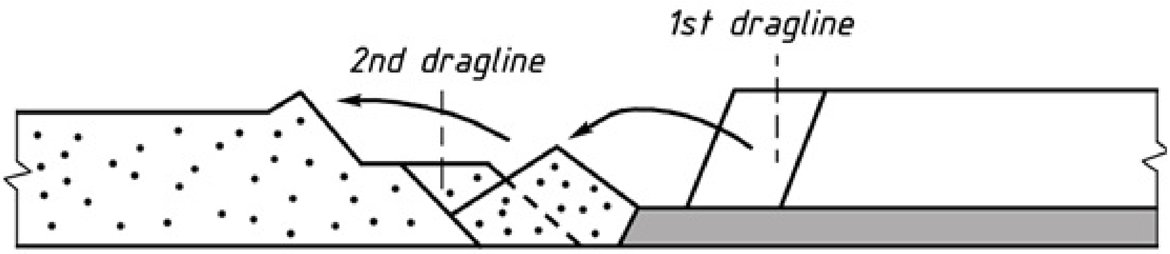

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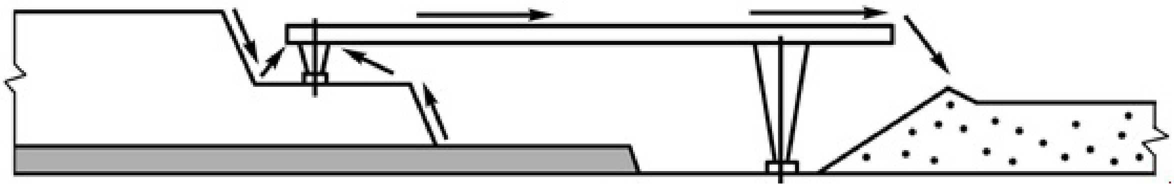

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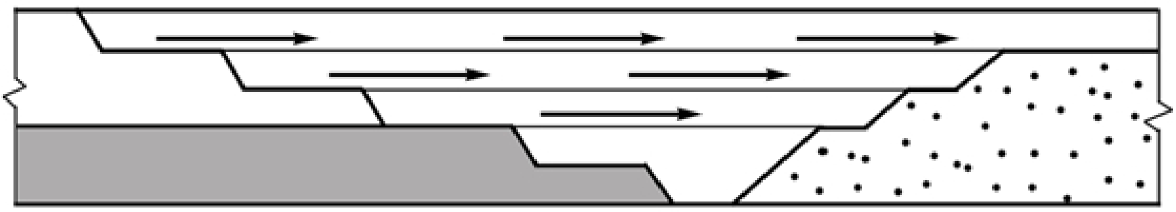

f)

Figure 3. Opening-up systems of : trench (a, b), trench-mine (c) and special opening methods (d, e, f)

Opening systems have various spatial development in different periods of the quarry operation depending on the method of opening, modes of transport, parameters of mining enterprises and other conditions.

Thus, embodiments of the spatial development of the working levels freight traffic are the essence of quarry opening schemes and are dependent on some factors, such as the methods of opening, conditions for doing opencast mining, system of mining, etc.

We propose the following definition: opening scheme is a description or graphic representation of opening systems spatial location of a one or another opening method in a certain period of the quarry exploitation.

The opening scheme is a qualitative characteristic of a quarry in a specific time period of its exploitation, and reflects the parameters of freight traffic that corresponding to a given production facility, the parameters of opening workings and equipment, ensuring the operation of this traffic. Therefore, exactly the scheme of one or another opening method should be subject to select the rational option.

Underlying of quarries opening schemes are the main attributes – ways of creating conditions for freight traffic, which are expressed by the presence or absence of mine workings, construction, equipment. The type of opening workings, designs and constructions is a basic of the opening scheme, depending on mining conditions (Table 2).

Table 2. Interconnection of methods and basic schemes of career working levels opening

<table>
<tr><td colspan="3" rowspan="2">Conditions of use</td><td colspan="4">Opening methods of quarry levels</td></tr>
<tr><td>Trench</td><td>underground</td><td>special</td><td>combined</td></tr>
<tr><td colspan="2">Upland quarry levels</td><td rowspan="5">Basic opening schemes</td><td>Direct entries, inclined semi-trenches and trenches, steep trenches (ore rolls)</td><td>Tunnels, galleries with the ore passes</td><td>Excavators, rope constructions</td><td rowspan="5">A combination of two or three basic methods</td></tr>
<tr><td rowspan="4">Depth quarry levels</td><td>Horizontal seam</td><td>Direct entries, inclined trenches</td><td rowspan="2">Tunnels under internal dumps</td><td rowspan="2">Excavators, conveyor systems, embankments, blasting</td></tr>
<tr><td>Flat seam</td><td>Inclined trenches</td></tr>
<tr><td>Inclined seam</td><td rowspan="2">Inclined trenches, steep trenches</td><td rowspan="2">Shafts with crosscuts</td><td rowspan="2">Draglines, embankments</td></tr>
<tr><td>Steep seam</td></tr>
</table>

Rational opening scheme determined, in the first place, by a rational way to move quarry benches' loads to places of their storage in accordance with the volume and orientation of freight traffic.

Dependence of the methods and schemes of quarries' opening on the parameters of the main freight flows is determined by technical parameters of options, which include number of mining and transportation equipment, options and volumes of the opening workings and others. These indicators are the starting values of economic calculations to select the effective variant.

Systematization of the main factors that determine the method and scheme of opening, and independent attributes that characterize the spatial development of load traffic in a specific period of exploitation, field observations and research of excavation, transportation and dumping machines, systematization of technological schemes and load traffic at the lateral and transverse development of the front of mining operations provided the basis to develop scientific and methodological principles for the calculation of technical parameters of opening schemes and economic indicators at the justification options for opening quarries.

The analysis of open pit mining and formation of load flows at the lateral and transverse mining systems applied to the conditions of various deposits shows a wide variety of schemes of any opening method, that are reflect the shape of the process, as well as all the possible methods of opening, that are reflect its kind (the content).

In the development of the depth type horizontal deposits, opening of rock benches carried out by direct entries on a relief and draglines that transship overburden in a goaf. Opening of coal benches carried out by sloping trenches with the creation of the transport lanes, usually on the ground of the worked-out seam in the zone of internal waste dumps.

In the development of the upland-depth type flat deposits, opening of transport benches in the upland part is carried out by direct entries on a relief or inclined semi-trenches. Transport benches of the depth part opened by inclined trenches.

Opening of rock benches that being handled by non-transport scheme, carried out by the dragline excavators. Coal seam at transportless stripping opened by inclined trenches on mining flank or by inclined semi-trenches that cuts on the seam ground in internal dumps zone.

In developing of the depth type inclined seams, opening of working benches is carried out by inclined trenches.

Working benches opening of upland-depth type inclined seams, carried out by direct entries and earth-fill coffer-dams on the horizon of the upland, and by inclined trenches on the depth part benches.

In developing of the depth type steep fields, opening is carried out by inclined and steep trenches.

Given the considered experience of the opening working benches of coal and ore pits, it should be noted the possibility of using underground mine workings at open-pit mining, in the development of the depth type horizontal, flat and inclined seams and for upland horizons of upland-depth type deposits.

It is also possible the formation of freight traffic using the skip hoists and aero-geotechnical complexes.

All this confirms the conclusions that the basis for the quarries opening schemes are the main attributes – methods of creation conditions for freight traffic, which are expressed by the presence or absence of mining workings, constructions, equipment. Type of opening workings, structures and constructions is a basic scheme of the opening depending on mining conditions.

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Reutilization of neutralization sludge formed during the processing of mining enterprises acidic industrial waters

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Abstract
It was established that neutralization sludges formed during the processing of acidic industrial waste waters of mining enterprises are aluminate and hydroxide. The structure, chemical composition and grain size distribution, fractal dimension, structural and rheological properties of the sludge were studied. Two methods of sludge reutilization were developed: low-temperature and high-temperature cementation with further use of the products obtained in the production of asphalt, construction and filling materials or in the manufacture of building ceramics and Portland cement clinker.

Key words: INDUSTRIAL WATER, NEUTRALIZATION SLUDGE, REUTILIZATION METHODS, CHEMICAL AND GRAIN SIZE DISTRIBUTION, FRACTAL DIMENSION

The number of papers devoted to reutilization and use of industrial neutralization sludge produced in the processing of acidic industrial waste waters is very limited [1, 3, 5-7, 10] It should be noted that the reutilization of these sludge is impossible without physical-chemical analysis of their composition and properties, which are determined by the matrix of industrial water, pH medium, temperature, the amount of reactants added and etc. It should be taken into account that during the neutralization not only metal hydroxides, but also basic salts can be formed. Iron hydroxide (III) is formed in the first stage of neutralization and it is capable of surface adsorption of other metal ions. In the course of time at the completion of the process of iron hydroxide precipitation, the formation of double hydroxides with subsequent precipitation or co-precipitation of basic salts of the respective metals is possible. Thus, co-precipitated neutralization sludge is mainly mechanical mixture of hydroxides and basic salts.

The research objective is to study neutralization of sludge generated during the acidic industrial waste waters processing of mining enterprises and to establish their operational properties and possible reutilization.

Materials and methods

The study was conducted with the use of neutralization sludge of JSC “Gaiskiy GOK» and CJSC «Buribaevsky GOK” and standardized test solutions, the composition of which is close to the actual neutralization sludges. The methods of atomic absorption analysis, potentiometry, photocolorimetry, x-ray phase (radiographic) analysis, thermogravimetric differential-scanning calorimetry were used in the study. The precipitation kinetics was evaluated by changes in the volume of precipitating solid phase during some period of time. The sludge density was determined by densitometeric method, water ratio - by gravimetric method.

Research results and their discussion

Results of study of kinetics of suspension precipitation obtained in the neutralization of acidic mine waters are shown in Fig. 1.

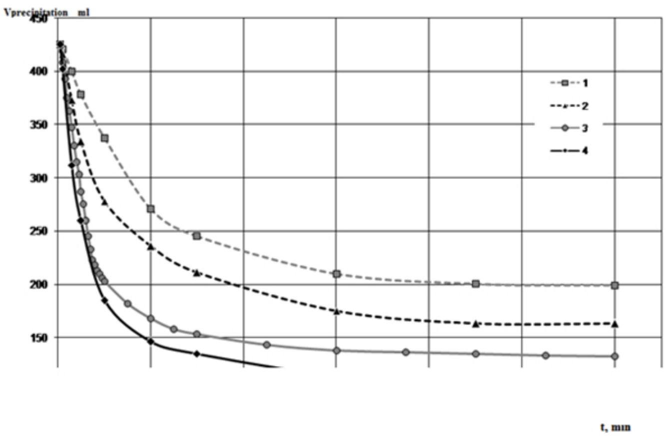
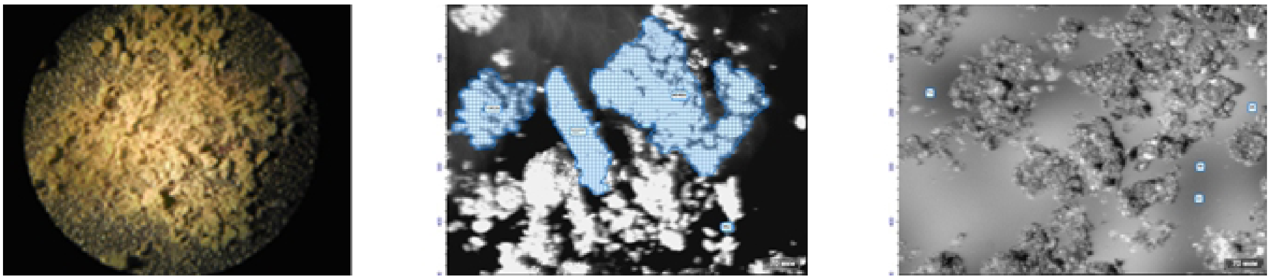


Figure 1. Kinetic curves of suspensions precipitation: 1 – $Fe(OH)_3$, 2 - $Zn(OH)_2$, 4 – $Cu(OH)_2$ of neutralized single-component model systems; 3 - of the acidic underspoil water of JSC “Gaiskiy GOK”

Analysis of the kinetic curves has shown that during the first 7 minutes the deposition rate is almost unchangeable, the initial section of the deposition curve is rectilinear. Accordingly, the formed particles of disperse phase have a sufficiently large sizes and approximately the same shape. After 10 minutes 76.3% of suspended mixture are precipitated. Rapid precipitation is due to the presence of such solutions coagulators-ions in the matrix as Fe^{3+}, SO_4^{2-}.

The liquid phase of industrial waste waters of concentration plant prior to the neutralization process is often a heterogeneous system containing suspended matters and colloids (degree of dispersion 10^6 mm^{-1}) in addition to true dissolved substances. Except ore and metal with minerals, the obtained precipitate contains clay particles formed as a result of concentrating repartition of host rocks; grains with fineness of 0.001-0.0002 mm are more than 95 %.

Microscopic analysis of the structural components of the precipitation formed by the natural deposition (Fig. 2 a, b) and in the neutralization process of the acidic underspoil water of JSC "Gaikiy GOK" (Fig. 2c) has confirmed that deposition of precipitates are uniform grains with fineness 1.0-0.2 microns (more than 95% of precipitate); neutralization sludges are homogenous mass with an average particle size of 70 microns which have a greater strength.



a) b) c)

Figure 2. Structure of solid phase acidic industrial waste waters:
a - the clay component formed during mechanical deposition; b - ore (dark) and non-metallic (light) mechanical sludge particles; c - the neutralization sludge

Neutralization sludges as chemical deposition products have high surface activity and dispersibility. The high degree of dispersion gives a stable coagulant structure to the sludges. Studing of this structure allows characterizing the degree of homogeneity, dispersion and properties of the resulting neutralization precipitation such as formability, strength, moisture content etc., as well as selecting the most comprehensive method for their processing.

The sludges are the closest analogues of highly plastic clay, so the physical and chemical processes of sludge formation are mainly identical to the formation of clay structure and are associated with water exposure. The signs of their commonality include the presence in sludges and clays of the smallest particles, the presence of the water adsorption and high plasticity [8].

As shown above, the iron hydroxide (III) is formed at the initially step of industrial waste waters neutralization. When precipitation the coagulated particles of iron hydroxide (III) form so-called chains, on which surface colloidal impurities are adsorbed. The pores filled with water are formed during the process of constructing chain structures jointed in rings. Consequently the precipitate contains a large amount of water retained by particles of iron hydroxide (III) [4]. The peculiarity of the investigated sludge as analogues of highly plastic clay is their flexibility, which determines the possibility of their use in the production of various building materials.

The basis of clay and sludge plasticity is their high absorption capacity and a high degree of self-organization. The research results [2] show an identity mechanism of clay and sludge plasticity and their topological similarity.

Despite the differences in chemical composition of clays and sludges the structural-rheological properties of the latter is much higher than that of clay. This is due to size factor of the sludge particles and big amount of adsorption-bound water.

Mineral sludges by definition of M. M. Sychev [9] are concentrated solutions of inorganic polymers formed in the hydrolytic polymerization process of low-concentrated non-equilibrium suspensions – industrial wastewater. The technology of their production allows attributing sludge to the nanodispersion materials of technogenic origin. The sludges have a spatial coordination of the dispersed phase due to coupling of colloidal particles and crystals through the water layer.

Chemical composition of the investigated sludge is shown in Table 1.

The true density of sludge 1 is equal to 4.592 kg/m^3, sludge 2 – 3.959 kg/m^3.

In accordance with the chemical composition, the sludges are classified as aluminate and hydroxide: these sludges contain predominantly oxides of di- and trivalent metals – Al_2O_3, Fe_2O_3, Cr_2O_3, NiO, ZnO, CuO.

Table 1. Chemical composition of the sludge neutralization of JSC "Gaiskiy GOK" (sludge 1) and CJSC "Buribaevsky GOK (sludge 2)

Oxides	Sludge 1			Oxides	Sludge 2		
	Sample No 1	Sample No 2	Sample No3		Sample No 1	Sample No 2	Sample No 3
CuO, %	1.45	1.40	1.37	CuO, %	1.33	1.44	1.29
ZnO, %	1.08	1.16	1.05	ZnO, %	0.12	0.08	0.11
Fe_2O_3, %	63.05	64.72	66.18	Fe_2O_3, %	58.03	58.17	52.22
MnO_2, %	0.027	0.020	0.020	MnO_2, %	1.15	1.12	1.23
CaO, %	0.68	0.79	0.72	CaO, %	0.41	0.43	0.42
MgO, %	0.48	0.45	0.36	MgO, %	0.95	0.86	0.92
K_2O, %	0.22	0.21	0.29	K_2O, %	0.66	0.59	0.56
Na_2O, %	0.14	0.11	0.18	Na_2O, %	0.05	0.11	0.13
Al_2O_3, %	29.10	33.71	31.03	Al_2O_3, %	41.06	35.30	41.24
SiO_2, %	0.02	0.01	0.01	SiO_2, %	0.01	0.01	0.01

Grain size distribution of neutralization sludge of the acidic underspoil water of JSC "Gaiskiy GOK" is presented in Table 2.

Evaluating the structure-rheological properties of the sludges the plastic consistency (velocity of the suspension flowing from the hopper), plastic strength (when immersing the cone to the solution), the rate of solid particles falling in the low-concentration suspension (settling time), the amount of sedimentation sludge were studied. The results obtained are shown in Table. 3.

It has been established that the positive effect on the rheological properties of the neutralization sludge have the following oxides Al_2O_3, Fe_2O_3, RO ($CuO+ZnO+MnO_2$), which are present in the sludge in the form of amorphous hydroxides. They greatly increase the adsorptive capacity of the particles, thereby enhancing the ductility. The higher rheological characteristics of neutralization sludge of the acidic underspoil water of JSC "Gaiskiy GOK" are due to a significant content of zinc oxide in its composition. Higher volume of this sludge precipitation also proves its higher ductility and therefore, the sludge self-organization degree.

Peculiarity and difference of the sludge materials obtained by grinding is their high dispersion. Material with such dispersion has a fractal structure, which determines the features of contact interactions of solid phase particles in the sludge. With the increase of fractal dimension the cohesiveness ability of sludge particles increases, i. e., the adsorption-bound water layer is enlarged, which positively affects the properties of sludge.

Table 2. Grain size distribution of neutralization sludge of the acidic underspoil water of JSC "Gaiskiy GOK" (sludge 1) and CJSC "Buribaevsky GOK" (sludge 2)

Grain size class, mm	Sample No1				Sample No2			
	Yield		Total yield		Yield		Total yield	
	g	%	top	bottom	g	%	top	bottom
	Grain size distribution of neutralization sludge of the acidic underspoil water of JSC "Gaiskiy GOK" (sludge 1)							
+ 25	-	-	-	-	0.16	0.067	0.067	98.35
-25+16	-	-	-	-	0.172	0.12	0.187	98.28
-16+1	0.1162	0.08	0.08	98.57	0.26	0.17	0.357	98.16

-1+0.63	0.3926	0.26	0.34	98.49	1.192	0.79	1.147	97.99
-0.63+0.4	1.7723	1.18	1.52	98.23	5.214	3.47	4.617	97.2
-0.4+0.315	5.182	3.45	4.97	97.05	10.295	6.86	11.48	93.73
-0.315+0.2	18.081	12.05	17.02	93.6	23.192	15.46	26.94	96.87
-0.2+0.16	3.228	2.15	19.17	81.55	3.275	2.18	29.12	71.41
-0.16+01	36.5824	24.39	43.56	79.4	44.118	29.41	58.53	69.23
-01+0063	37.147	24.76	68.32	55.01	27.654	18.44	76.97	39.82
-0063+005	42.107	28.07	96.39	30.25	12.09	8.06	85.03	21.38
-005+0	3.277	2.18	98.57	2.18	19.901	13.27	98.3	13.32
TOTAL	148	98.57			147.6	98.358		
Smple weight	M_{init} = 150 g				M_{init} = 150 g			
Grain size class, mm	Sample No1				Sample No2			
	Grain size distribution of neutralization sludge of the acidic underspoil water of CJSC "Buribaevsky GOK" (sludge 2)							
+ 25	0.1762	0.25	0.25	99.5	0.12	0.08	0.08	94.12
-25+16	0.6220	0.44	0.69	99.25	0.088	0.06	0.14	94.04
-16+1	2.16115	1.34	2.23	98.81	0.224	0.15	0.29	93.98
-1+063	11.6445	8.32	10.55	97.27	1.0783	0.72	1.01	93.83
-063+04	10.31855	7.37	17.92	88.95	2.2881	1.53	2.54	93.11
-04+0315	6.4115	4.58	22.5	81.58	4.28345	2.86	5.4	91.58
-0315+02	10.8924	7.78	30.28	77.0	13.4159	8.94	14.34	88.72
-02+016	1.974	1.41	31.69	69.22	3.15615	2.1	16.44	79.78
-016+01	19.2778	3.77	45.46	67.81	31.2853	20.86	37.3	77.68
-01+0063	34.7222	24.8	70.26	54.04	52.3323	34.89	72.19	56.82
-0063+005	34.8237	24.87	95.13	29.24	29.6382	19.76	91.95	21.93
-005+0	6.1152	4.37	99.5	4.37	3.2621	2.17	94.12	2.17
TOTAL	139.14	99.5			142	94.12		
Sample weight	m_{init} = 140 g				M_{init} = 150 g			
Grain size class, mm	Sample No3				Sample No3			
	Yield		Total yield		Yield		Total yield	
	g	%	top	bottom	g	%	top	bottom
	Grain size distribution of neutralization sludge of the acidic underspoil water							
	JSC "Gaiskiy GOK" (sludge 1)				CJSC "Buribaevsky GOK" (sludge 2)			
+ 25	-	-	-	-	0.2042	0.14	0.14	99.23
-25+16	0.175	0.12	0.12	99.3	0.1853	0.12	0.26	99.09
-16+1	0.414	0.28	0.4	99.18	1.016	0.68	0.94	98.97
-1+0.63	2.518	1.68	2.08	98.9	7.0155	4.68	5.62	98.29
-0.63+0.4	9.16	6.11	8.19	97.22	10.543	7.03	12.65	93.61
-0.4+0.315	11.603	7.74	15.93	91.11	7.112	4.74	17.39	86.58
-0.315+0.2	27.355	18.24	34.17	83.37	14.004	9.34	26.73	81.84
-0.2+0.16	4.864	3.24	37.41	65.13	2.218	1.48	28.21	72.5
-0.16+01	41.744	27.83	65.24	61.89	23.912	15.94	44.15	71.02

-01+0063	26.451	17.64	82.88	34.06	42.208	28.14	72.29	55.08
-0063+005	10.983	7.32	90.2	16.42	38.396	25.60	97.89	26.94
-005+0	13.647	9.1	99.3	91	2.003	1.34	99.23	1.34
TOTAL	149	99.3			148.82	99.23		
Sample weight	M_{init} = 150g				M_{init} = 150 g			

Table 3. The averaged rheological properties of the neutralization sludge of the acidic underspoil water

Rheological properties of the neutralization precipitation	CJSC "Buribaevsky GOK"	JSC "Gaiskiy GOK"
Plasticity indicator	1048.76	1165.28
Time of suspension flowing from the hopper, s	20.84	4.89
Ratio of precipitation volume to the volume of initial suspension	1.21	1.13
Suspension density, g/sm^3	0.77	0.88
Elasticity indicator	1.19	1.30
Threshold of structure formation, %	17.04	9.01
Plastic strength , 10^{-2} mPa	0.31	0.52

The fractal dimension of the investigated sludge was calculated using the program «Shlam» based on their grain size distribution (Table 2). The program «Shlam» on the basis of two-dimensional and three-dimensional diagrams of the chemical composition of sludge and sludge simulated aggregate models during the study allowed establishing a link between the chemical composition, structural and rheological properties of hydrolytic sludge and properties obtained based on these materials, as well as determining the most effective area of neutralization sludge application.

When calculating the fractal dimension the range of variation percentage of the particle amount of this diameter were selected as restriction, and as the optimality criterion the total squared deviation from the average percentage of particles of the given diameter was used. The results obtained are shown in Fig. 3 and Fig.4.

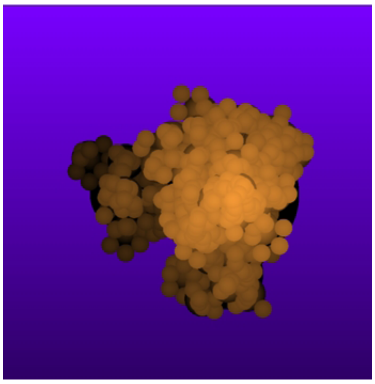


Figure 3. Aggregate model of neutralization sludge of JSC “Gaiskiy GOK”

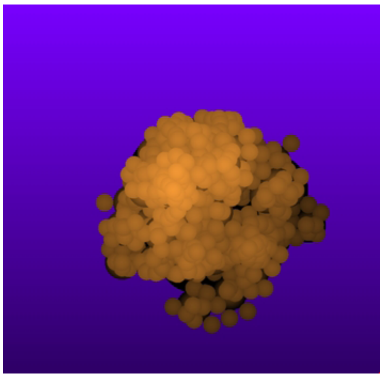


Figure 4. Aggregate model of neutralization sludge of CJSC “Buribaevsky GOK”

Analysis of the aggregate models data showed:

- “Gaiskiy GOK” sludges form precipitates with a higher aggregate dimension, their nonuniform structure have more points of contact and adhesion between itself and therefore characterized by a high threshold of structure formation and plastic strength, but a smaller value of plasticity index that ultimately determines the improved binding properties of building mixtures with additives of this material.

- “Buribaevsky GOK” sludges form a precipitation in the form of regular, uniform aggregates characterized by the large indicator of elasticity and plasticity, lower threshold of structure formation and plastic strength index that allow us to attribute these sludges to additives with high degree of plasticity and better transportability, pumpability with the possibility of their use in drilling fluids.

On the basis of conducted researches the following sludge reutilization methods were developed.

The first method involves the sludge drying and its use as a mineral powder in the composition of asphalt concrete mixtures in the construction of roads or other building and filling mixes (low-temperature carburizing).

The second method provides the involvement of the sludge into the clay mass composition in the production of building ceramics, or as a part of the raw material mixture for the production of Portland cement clinker (high cementation).

A study of low-temperature carburizing method has shown that after the removal of moisture by drying or by reacting with calcium oxide sludge analyzed according to its physical and chemical indicators meets the requirements for mineral powders that are recommended for all types of asphalt concrete mixtures.

The method of high-temperature cementing sludge is based on the application of the wet sludge in the composition of clay raw materials in the production of building ceramics. To justify the sludge use in this method, the behavior of air-dried hydroxides of heavy metals and co-precipitated with iron hydroxide at temperature influence has been investigated.

Thermogravimetric studies have shown that during high temperature impact the heavy metal hydroxides form oxides (except the basic copper salt) having substantially lower solubility in water and co-precipitated ones with ferric hydroxide and metal hydroxides are insoluble ferrites (in a temperature range from 400 ^{o}C to 650 ^{o}C). Therefore, high temperature cementation in a matrix of clay raw material is a very effective recycling process of sludges containing heavy metal hydroxides.

The calculation of raw mixture composition has shown that the tested sludges can be advantageously used as a raw iron component in the manufacture of Portland cement clinker (Table 4).

Table 4. Chemical composition of clinker raw ferrous component

The chemical composition of raw material mixture and clinker,%									
Components	Amount	LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Sum
Limestone	77.99	34.83	0.16	0.08	0.16	39.13	3.52	0.05	78.70
Clay	20.26	1.88	12.71	2.96	0.79	0.58	0.59	0.04	19.76
Sludge	1.74	0.11	0.00	0.51	1.10	0.01	0.01	0.00	1.75
Raw material mixture composition		36.82	12.87	3.55	2.04	39.72	4.12	0.09	99.21
Clinker composition		0.00	20.36	5.62	3.23	62.86	6.53	0.14	98.74
Minerals		C3S	C2S	C3A	C4AF	Sum			
		58.84	14.10	9.40	9.83	92.16			

Conclusion

Investigation of the structure, chemical and grain size distribution composition, fractal dimension, structural and rheological properties of sludge neutralization produced in the processing of acidic industrial waste waters of the mining enterprises helped to develop two methods of sludge reutilization.

The first method (low-temperature carburizing) involves drying sludge and its use as a mineral powder in the composition of asphalt concrete mixtures in the construction of roads or other building and filling mixtures.

The second method (high-cementation) envisages the involvement of sludge into the clay mass in the production of building ceramics or in the composition of raw mixture for the production of Portland cement clinker.

Use of the program «Shlam» on the basis of two-dimensional and three-dimensional diagrams of the chemical composition and simulated aggregation models of sludge allows establishing a link between the chemical composition, structural and rheological properties of the hydrolytic sludges and the properties obtained based on these materials, as well as determining the effectiveness of their reutilization by these methods.

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Study of strain resistance of steel applied for manufacture of large-sized shaped sections

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Abstract
The strain resistance is an important physical value, which characterizes metal flows. It is used for evaluation of energy-efficiency of metal forming processes, particularly for determination of energy-power parameter. At present time, many experimental researches for determination of given value were conducted; however, the problem of determination of reliable data of the metals and alloys strain resistance value under the conditions of the hot-forming method is relevant.
The experimental researches and theoretical analysis of strain resistance value of steel 5ps, 09G2D and 63 at a temperature comprised between 800…1200 °C and strain rate in the range of 0,1; 1 and 10 s^{-1} are conducted in the paper. Hensel-Spittel regression equation coefficients are determined; they are necessary for quantitative assessment of metal stress resulting from the process of the computer modeling. Moreover, regarding the energy-efficiency of the strain resistance, the correct temperature velocity parameters for considered values of strain degrees are determined with the use of methods of hardening and softening.
Key words: STEEL, RHEOLOGY, EXPERIMENT, DEFORMATION, DEPENDENCE, HARDENING, SOFTENING, STRAIN RESISTANCE, METHOD, ENERGY-EFFICIENCY

At present day, new steel and alloy stamps are commonly being introduced in the perspective of increase of the strength-weight ratio of final product. However, the use of these steels under the conditions of traditional rolling plants is problematic because of the complex technical process, which involves adherence to the temperature velocity parameters and high level of energy power parameters (EPP) of the strain resistance. According to it, the most relevant problems are development of advanced and improvement of current strain technological mode of traditionally used grades of steel such as Steel 5 (used for production of the angle sections and roll-formed channels) [1], 09G2D (used for production of the section of car post) [2] and Steel 63 (used for production of the crane rails) [3], with the chemical composition presented in Tables 1-3.

Table 1. The Chemical Composition of Steel 5ps

Melting No	C, %	Mn, %	Si, %	S, %	P, %	Cr, %	Ni, %	Cu, %
6968	0.37	0.71	0.06	0.023	0.021	0.08	0.02	0.03

Table 2. The Chemical Composition of Steel 09G2D

Melting No	C, %	Mn, %	Si, %	S, %	P, %	Cr, %	Ni, %	Cu, %	Al, %	Ti, %
13471	0.1	1.67	0.34	0.14	0.17	0.01	0.01	0.27	0.06	0.01

Table 3. The Chemical Composition of Steel 63

Melting No	C, %	Mn, %	Si, %	Max					
5592	0.62	0.81	0.23	S, %	P, %	Cr, %	Ni, %	Cu, %	As, %
				0.028	0.036	0.04	0.01	0.02	0.008

The rheological characteristics of the strain materials, which are changed in a high range according to the thermomechanical conditions of metal forming, are one of the potential factors in solving of this problem. Much attention is paid to the issue of obtaining of solid data on rheology of metals and alloys under the conditions of hot strain [4-6]. It is also proved, by the fact, that nowadays the mathematical simulation of the strain (rolling, forging, pressing, etc.) with the use of the finite element method (FEM) [7-8] is widely practiced. Moreover, the finite element method (FEM) requires solid data on the strain resistance of metals in the context of calculation of emerged stresses (qualitative data) and the following calculation of energy power parameters, which determine energy efficiency.

The purpose of this paper is experimental investigation of the steels strain resistance (St5ps, 09G2D, St. 63) in the uniaxial compression process as well as evaluation parameters of hardening and softening by hot-forming method.

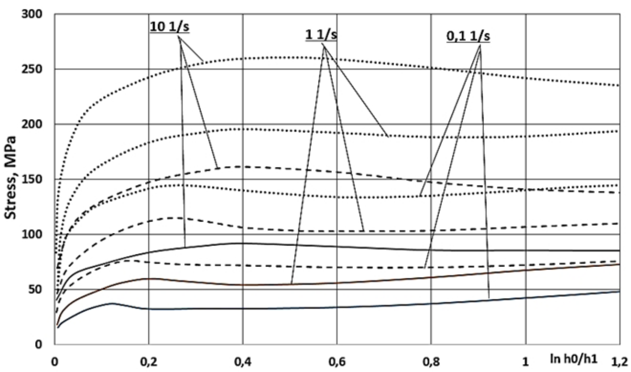
For achievement of the specified purpose, the investigations of rheological properties of the selected grades of steel by the physical simulation process Greeble 3800 [9] of the Czestochowa University of Technology (Poland) were conducted. According to the designed plan, the investigation has been conducted for three temperatures T= 800 °C, 1000 °C and 1200 °C, and for three strain rates $\dot{\varepsilon}$= 0,1; 1 and 10 s^{-1} which are typical almost for the full range of conditions of the traditional process of plastic strain, particularly for the rolling operation. As a result of investigation, the curves (stress-strain curves) of the true strain impact ($ln\ {}^{h_o}/_{h_1}$) on strain resistance (σ_s) for the selected alloy have been obtained (Figures 1-3).

One of the most widespread yield stress calculation models, which is used in the theoretical researches (computer modeling), is Hensel-Spittel equation [10]:

$$\sigma_{yi} = Ae^{a_1 T}T^{a_9}\varepsilon^{a_2}e^{a_4/\varepsilon}\left(1+\varepsilon\right)^{a_5 T}\ e^{a_7\varepsilon}\dot{\varepsilon}^{a_3}\dot{\varepsilon}^{a_8 T} \qquad (1)$$

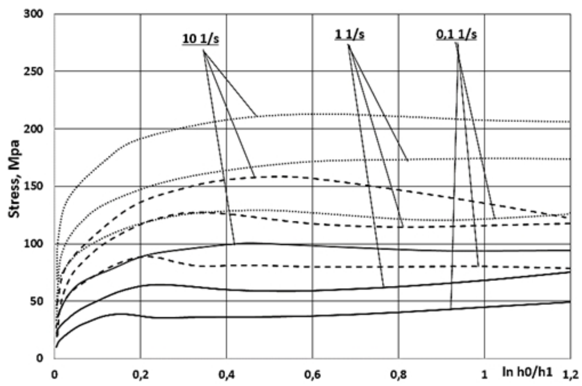
where: σ_{yi} – yield stress; ε – strain intensity; $\dot{\varepsilon}$ – strain rate intensity; T – temperature, A, a_1, a_2, a_3, a_4, a_5, a_7, a_8, a_9 – coefficients of regression.

The steel stress-strain curves obtained (Figure 1-3) with the use of statistical analyses, regression coefficients (Table 4) of equation (1) have been approximated and determined. They are necessary for the further computer modeling of the process of section rolling.



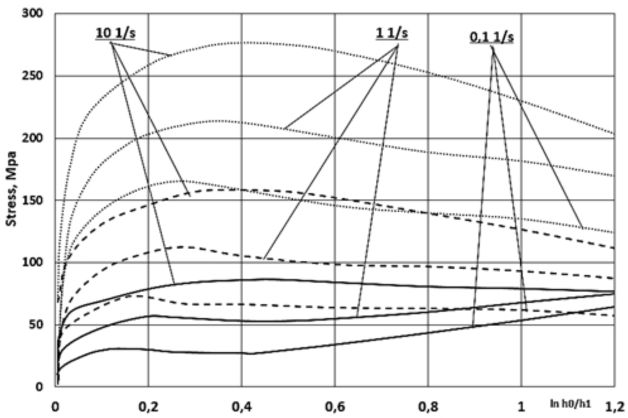
······· - T=800 ºC; - - - - T=1000 ºC;——— - T=1200 ºC

Figure 1. Stress-strain curves for steel 5ps



······· - T=800 ºC; - - - - T=1000 ºC;——— - T=1200 ºC

Figure 2. Stress-strain curves for steel 09G2D



······· - T=800 ºC; - - - - T=1000 ºC;——— - T=1200 ºC

Figure 3. Stress-strain curves for steel 63

Table 4. Coefficients of regression of the equation (1) for the alloys under study

Alloy	A_1	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
St. 5	0.017	-0.005	0.165	0.014	-0.002	5.53	0	-0.28	0.0001	2.03
09G2D	2.07	-0.01	0.22	-0.05	-0.002	0	0	-0.46	0	5.07
St. 63	21702.2	-0.003	0.103	0.065	-0.01	0	0	-0.52	7.96	-0.34

Due to the use of plastic layer materials by the authors of papers [11, 12], it is established that the rheological curves of the metals cannot be shown in the form of monotonic increasing functions which is confirmed by the Figures 1-3. The listed curves have peak of maximum hardening and so-called area of dynamic softening. However, until to present time, the property of the softening has not been used for designing or improving the strain process, which has significant impact on EPP.

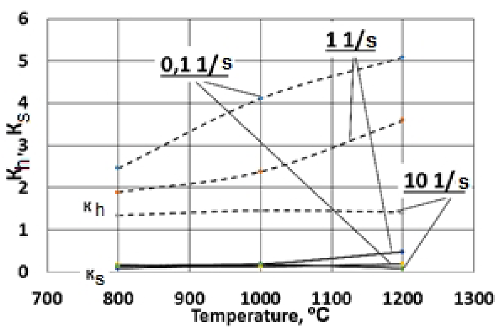
In order to determine the correct strain temperature range of the investigated grades of steel in the context of EPP process, let us use the method of hardening and softening [13]. According to this method, hardening and softening evaluation of different rheology metals is carried out by coefficients (2) and (3) respectively.

$$K_h = \frac{\sigma_{max} - \sigma_0}{\sigma_{max}} / (\varepsilon_{x1} - \varepsilon_0); \qquad (1)$$

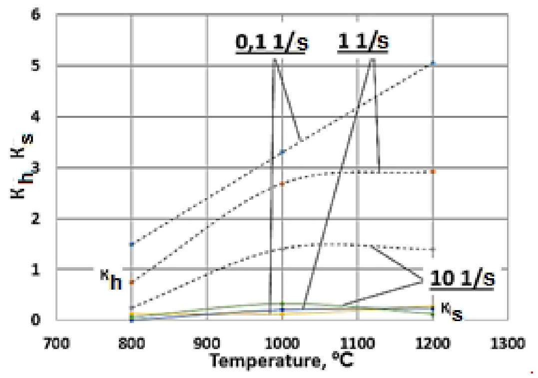
$$K_s = \frac{\sigma_{max} - \sigma_2}{\sigma_{max}} / (\varepsilon_{x2} - \varepsilon_{x1}); \qquad (2)$$

where: σ_0 – strain resistance at low strains; σ_{max} and σ_2 – strain resistance for $\varepsilon = \varepsilon_{x1}$ and $\varepsilon = \varepsilon_{x2}$ respectively.

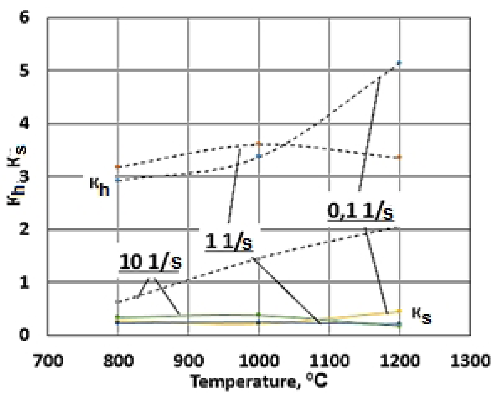
The graphical analysis of specified hardening and softening parameters is provided in Figure 4. From the analyzes of present data, it is evident that steel hardening effects dominate significantly over the steel softening effects during the strain process. According to this, the qualitative picture of change of curves of strain-hardening coefficient (K_h) for the conditions under consideration is different that is due to different chemical compositions. The determined circumstance is also confirmed with the data in paper [14].



a)



b)



c)

Figure 4. The dependence of hardening intensity (K_h) and softening intensity (K_s) for: (a) Steel 5ps; (b) – 09G2D; (c) – Steel 63

The qualitative data range of temperature 900…1100 ºC, which is traditional for the process of section rolling, demonstrates that K_h falls within the limits of 1.4…4.5 irrespective of steel grade.

When comparing the terms of the metal hardening relative coefficient ($\delta K_h = K_h / K_s$), it is established (Fig. 4, a) that the most adverse conditions, according to the energy performance of the rolling operation, are strain at a temperature of T<900 ºC ($\acute{\varepsilon} \leq 1s^{-1}$) and T>1100 ºC ($\acute{\varepsilon} \leq 10s^{-1}$) in the whole range of the considered degrees of strain. The temperature velocity parameters at the level of T=900…1100 ºC ($\acute{\varepsilon} \leq 1...10s^{-1}$) in the range of strain degrees $ln\, h_0/h_1 = 0{,}25...0{,}8$ are the most favorable conditions.

In the same way as for Steel 5, the data analysis (Fig. 4, b) shows that the temperature velocity parameters are T=900…1100 ºC and ($\acute{\varepsilon} = 1...10s^{-1}$) in the range of strain degrees $ln\ h_0/h_1$= 0.35...0.6.Upon that, when using higher singular degree of strain $ln\ h_0/h_1 \geq 0{,}45$, it is necessary to apply the average temperature in the metal from the required range (for example, T=1000 ºC) and $\acute{\varepsilon} \geq 5^{s-1}$.

The Steel 63 is exception from the considered materials (Fig. 4, c). The conducted analysis of its hardening and softening effects showed that the use of the strain rates $\acute{\varepsilon} \leq 5^{s-1}$ at T=800…1200 ºC leads to significant predominance of hardening effects and may have undesirable effect on the power performance of strain process. The most favorable conditions concerning considered situation are the use of higher rates $\acute{\varepsilon}$ = 5...10s^{-1} within the limits of temperature T=800…1100 ºC (at $ln\ h_0/h_1 \geq 0{,}4$). So, for example, the range of the strain relative coefficient of the metal is equal to ($\acute{\varepsilon}$ = 10s^{-1}): δK_h^{800}=1,84; δK_h^{1000}= =3.9; δK_h^{1200}= 13.2 .

Conclusions

1. The obtained results during the experimental investigations and theoretical analysis have allowed establishing the interconnection between stress and strain states of the carbon constructional steel and making an assessment of strain resistance value regarding the stress-strain curves.

2. The value coefficient analysis of hardening and softening showed that the most favorable conditions according to the energy performance of operation are strain conditions, which fall within the range of:

- Steel 5: T=900…1100 ºC; ($\acute{\varepsilon}$ = 1...10s^{-1}) ; $ln\ h_0/h_1$= = 0.25...0.8;
- Steel 09G2D: T=900…1100 ºC; ($\acute{\varepsilon}$ = 1...10s^{-1}); $ln\ h_0/h_1$= 0.35...0.6.;
- Steel 63: T=800…1100 ºC; $\acute{\varepsilon}$ = 5...10s^{-1}; $ln\ h_0/h_1 \geq 0{,}4$.

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The application of fuel burning pulsating resonance during drying and heating processes of steel-teeming ladles

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Abstract
The results of the experimental-industrial tests of the fuel burning pulsating resonance system at the posts of drying and heating of steel-teeming ladles are given in the paper. The high performance and efficiency of the system were established. Reduction of the natural gas saving was 2.7 ÷ 26.1% when ladles drying, and 19.5 ÷ 37.8% when heating.
Keywords: PULSATION, BURNING, NATURAL GAS, STEEL-TEEMING LADLE, DRYING, HEATING

Introduction

In ferrous metallurgy in addition to the basic metallurgical industries a number of ancillary areas are also significant consumers of fuel. Among these consumers the ladle preparation is stood out, namely the processes of drying and heating of ladle linings. Often these processes use scarce and expensive natural gas in a large amount.

Problem state

The application of a number of methods and devices for drying and heating of the steel-teeming ladles is possible (see. Fig. 1).

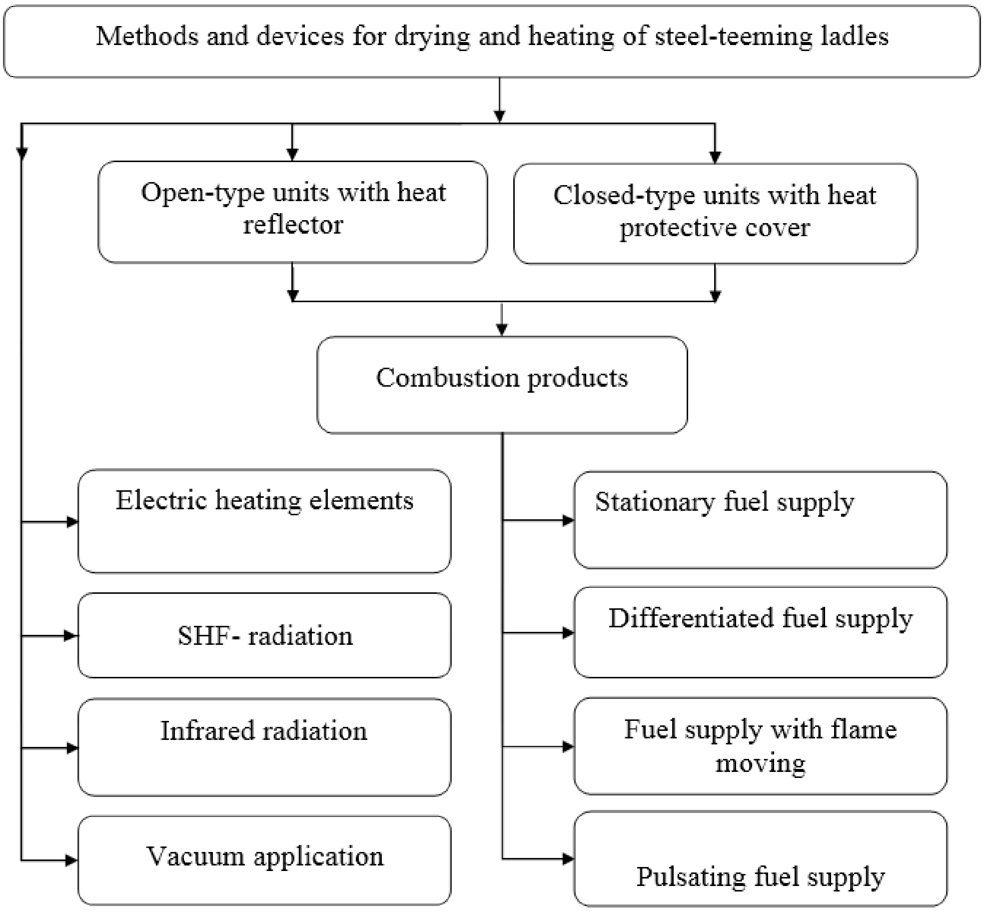

Figure 1. Methods and devices for drying and heating of steel-teeming ladles

More than 80% of the steel teeming ladles drying and heating processes are carried out with the combustion products. The differentiated supply, fuel supply with flame moving, pulsation and other methods are applied to eliminate thermal defects of ladle linings and more efficient use of fuel heat in addition to the stationary fuel supply.

However, drying and heating of combustion products has a number of drawbacks:

- low coefficient of fuel power usage (30%);

- contamination of workplaces and environment with harmful components (oxides of sulfur, nitrogen, carbon) of fuel combustion;

occurrence of thermal defects on the ladle linings.

In order to eliminate thermal defects of the lining the application of “soft” mode of drying and heating of ladles with adjustable fuel supply is proposed [1]. When drying the temperature of the lining external surface in this case as opposed to “hard” mode does not exceed the evaporation temperature of water, which helps to reduce thermal lining defects.

The introduction of additional structural elements (insert pieces) to the workspace of ladles leads to intensification of heat transfer between the flow of combustion products and lining, which increases the utilization coefficient of fuel combustion power [2, 3]. The disadvantage of this method is the complexity of the devices design for drying and heating of steel-teeming ladles.

A number of other design and technological solutions aimed at improving the processes of drying and heating of steel teeming ladles with using fuel are known [4-6].

In the paper [4], the use of the cyclic modes for drying and heating of steel teeming ladles is proposed. The application of cyclic modes improves coefficient of fuel power utilization and reduces the risk of local overheating of the lining. The disadvantage of the cyclic mode is the impossibility of reducing the duration of the drying and heating processes.

A method of combined heat supply mode into the workspace of the ladle is known, which is also the alternation supply of the combustion products and the heated air [5]. This method of supplying heat allows eliminating lining overburning, however, it requires significant fuel consumption.

When ladles drying and heating processes according to the method proposed in [6], recuperative and regenerative burners have been used. They allow reducing fuel consumption due to heating fuel and air by combustion products. It does not provide uniform heating of the lining and reducing the duration of drying and heating.

The electrical heating elements [7], SHF radiation [8], infrared radiation [9] and vacuum application [10] can be used as an alternative to the combustion products.

Widespread use of electric heating elements that improve thermal efficiency coefficient of drying and heating processes up to 50% holds back a little service life of heating elements and complicated technology of their production.

Drying and heating of the ladle lining by means of SHF-radiation ensures uniform heating of the lining entire volume, which eliminates the occurrence of thermal defects therein and improves coefficient of processes efficiency up to 60%. At the same time disadvantage of this method is a significant decrease in the efficiency coefficient of drying process as removing moisture from the lining, because a major component which absorbs microwave radiation is water. When using SHF-radiation an emergency organization to protect staff from the influence of microwave radiation is required.

In paper [10], the results of experimental studies of the vacuum use in the drying and heating processes of steel-teeming ladles are shown. The duration of processes, and accordingly, fuel expenditure are reduced by 30%. A significant drawback of this method includes reduction in hardness of the lining, which worsens its quality.

In general, alternative technologies listed significantly complicate the drying and heating processes as compared to conventional processes using fuels and in some cases require the application of expensive custom equipment. At the same time, alternative solutions are energy-intensive technologies.

Research problem statement

In order to reduce the consumption of natural gas it is advisable to use fuel burning pulsating resonance [11], from introduction of which we should expect:

- more thorough heat treatment of the inner surface of the ladle working volume by eliminating stagnant zones insufficiently washed with products of combustion;
- intensification of heat exchange between combustion products and the ladle lining;
- improved fuel efficiency due to the reduction of unburnt fuel.

There are three options of excitation of the fuel burning pulsating resonance mode: pulsations excitation on the gas pipeline, on the air pipeline and share excitation of pulsations on the gas and air pipeline.

The objective of this work was to evaluate the applicability of the burning fuel pulsating resonance for drying and heating processes of steel-teeming ladles through the introduction of the developed system and evaluation of its performance in industrial conditions.

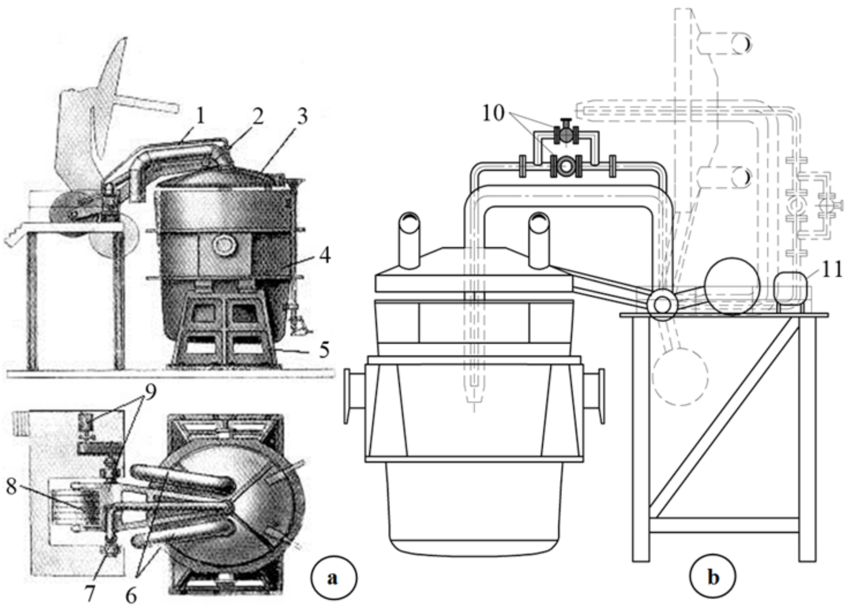

Figure 2. Stand for ladle drying

a – general view; b – arrangement scheme of the pulsating unit; 1 – gas pipeline; 2 – burner; 3 – cover; 4 – ladle; 5 – supports; 6 – exit flue for combustion products; 7 – air piping; 8 – counterweight; 9 – cover swing mechanism; 10 – pulsating unit; 11 – power supply and control

The researches were preceded by the development of hardware for fuel burning pulsating resonance on the drying and heating stands of steel-teeming ladles, the assembly of pulsating devices on the gas pipelines of drying and heating stands, the acoustic analysis of the ladles working volume and selection of standard ladles for comparison with experimental data.

Research on the drying post

The research was carried out in the Electric Steel Melting Shop No2 JSC "Oskol Electric Steel Works." General view of the stand for the drying of steel-teeming ladles and the arrangement scheme of pulsation unit is shown in Fig. 2.

The stand consists of supports on which the ladle is mounted and swing cover with the burner.

On the stand, the burner of "pipe in pipe" type is installed. The pulsations of the gas flow are created by pulsating unit mounted on the gas pipeline and executed in the form of mechanical pulsator with cylindrical interrupter of the gas flow. The pulsator is driven by DC electric motor that is connected to the network via resistor.

By rotating pulsator, the passage section of the pipeline supplying the natural gas is overlapped with predetermined frequency, which leads to periodic compression and rarefaction of natural gas flow and formation of elastic oscillations.

The scheme of hardware of fuel burning pulsating resonance when drying the steel-teeming ladles is shown in Fig. 3.

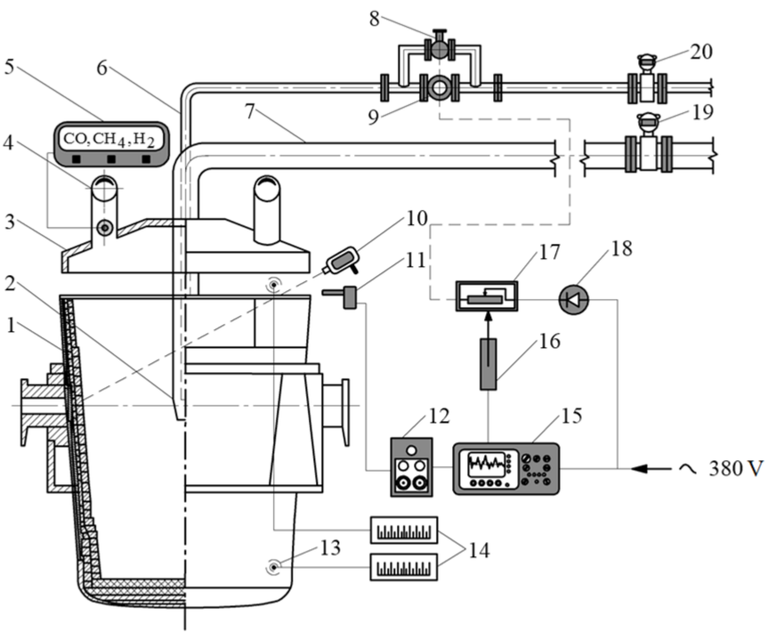

Figure 3. The scheme of hardware of fuel burning pulsating resonance when drying the steel-teeming ladles

1 – ladle; 2 – burner; 3 – cover; 4 – exit flue for combustion products; 5 – chromatograph; 6 – gas pipeline ; 7 – air piping; 8 – bypass; 9 – pulsating unit; 10 – thermal radiation pyrometer; 11 – acoustic probe; 12 – preamplifier; 13 – thermocouple; 14 – potentiometers; 15 – spectrum analyzer; 16 – actuating mechanism; 17 – resistor; 18 – rectifier; 19, 20 – flowmeters

An acoustic probe that sends a signal to the preamplifier, from which the amplified signal is routed to the spectrum analyzer, determines required frequency of interruption of gas flow for the resonance.

The frequency at which the maximum amplitude of the oscillations is determined by spectral analysis and thus the number of electric motor revolutions, which is necessary to obtain a resonant frequency, is determined:

$$n = 60 \cdot \omega / 2 \cdot \pi, \text{ r/min}, \quad (1)$$

where ω - circular frequency of the gas flow interruption, Hz

The pulsator by-pass in combination with a valve mounted thereon allows adjusting the amplitude of pulsations by changing the amount of gas passing through the pulsator. When the valve on the bypass is closed gas completely passes through the pulsator. Opening of valve bypasses some part of gas to bypass and reduces pulsator gas flow, which decreases the degree of gas condensation before the pulsator and accordingly reduces the pulsations amplitude.

Thus, the amplitude of the pulsations is adjusted by the position of the valve in the bypass, which allows changing the ratio of gas consumption passing through the pulsator and the bypass. The pulsations frequency is adjusted by changing the electric current voltage supplied to the pulsator's drive by altering resistance of the resistor with actuating mechanism.

The temperature of the ladle lining surface was determined with pyrometer at 500-700 mm below the upper edge of the ladle. The ladle shell temperature was measured by contact thermocouple. This allowed us to control drying processes of the ladle in accordance with the technological instructions.

Chemical unburning was evaluated according to the content of carbon monoxide (CO) in the combustion products, which was determined by chromatography.

Drying of the ladle lining was carried out after the complete replacement of the working layer. The test results are shown in Table 1.

Table 1. The results of tests during drying process of steel-teeming ladles

Test No	Ladle No	Pulsations frequency, Hz	Lining temperature, °C	Shell temperature, °C	Total natural gas consumption, m^3	Natural gas saving, %
-	H	-	~900	75	2570	-
1	36	45÷55 18÷25	~900	77	2370	7.8
2	31	18÷25	1050÷1060	78	2500	2.7
3	2	18÷25	~1100	75	2295	10.7
4	5	18÷25	1050÷1120	79	2230	13.2
5	12	18÷25	1050÷1120	80	2215	13.8
6	25	18÷25	~900	87	2020	21.4
7	36	18÷25	~900	74	1900	26.1
8	30	18÷25	~900	76	2200	14.4

Changes in the supply of the natural gas during the experiments are presented in Fig. 4.

Drying of the first test ladle (No 36) had been taking place according to the schedule for five hours corresponding the technological instruction, i.e. according to the schedule of the standard ladle (H). At the end of the fifth drying hour the pulsating unit for fuel burning was on and began searching for the resonance mode. The frequency of pulsations when searching of the resonance mode was changed in the range of 15 ÷ 60 Hz. At the same time bypass remained open. With open bypass resonant mode was not detected requiring bypass overlap.

When completely overlaped bypass the significant resonance effect in the frequency range of 45 ÷ 55 Hz was found, however, work in this frequency range was not possible due to the resonant excitation of the drying post structures.

A second less intense peak of the resonance frequency (subharmonic) was detected before completion of the drying process in the range of 18 ÷ 25 Hz . The definition of this range occurred at the beginning of the tenth hour of the ladle drying. At the same time decreased in the sixth hour fuel consumption was increased to the standard, since the delay of ladle lining heating was observed.

Drying of the second test ladle (No 31) was carried out on the standard schedule in the pulsating resonance mode with a frequency range of pulsations 18 ÷ 25 Hz.

Due to incorrect installation of the ladle relative to the cover (eccentricity was about 300 mm) the resonance effect was slightly weakened.

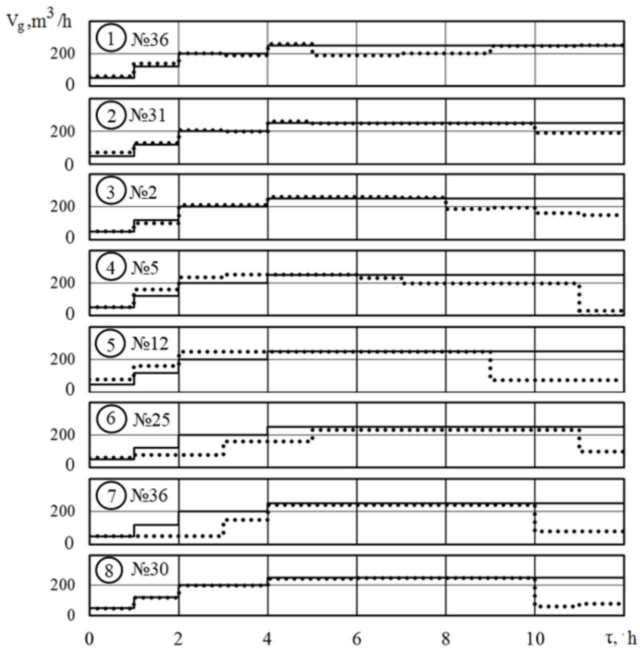

Figure 4. Changes in the supply of natural gas (V_g) during the ladles drying when fuel burning pulsating resonance

1…8 – numbers of the tests; ———— standard mode; .... test mode

Nevertheless, after seventh hour of ladle drying the temperature on the lining on distances of 500-700 mm from ladle edge was 1050-1060°C, that was significantly above the standard (900°C). The ladle shell temperature reached the standard value (75°C) after ten hours of drying. All this allowed us after the tenth hour and to the end of drying to reduce the gas consumption in relation to the standard consumption.

Drying of the third test ladle (No 2) during the first seven hours was carried out by the standard schedule of fuel supply in pulsating resonance mode with frequency range 18 ÷ 25 Hz . .

During this period the flame stability was studied. Artificial flameout was produced by supplying excess air followed by reduction of the combustion process.

The high stability of the flame was established, which was not inferior to the flame in the normative drying mode. Enough solid and stable flame was maintained at a greater deviation from the stoichiometric ratio “fuel-air”. On the eighth hour of drying the tests related to the flame stability were stopped.

After eight hours of drying temperature of the ladle lining was 1040°C. The lining temperature after ten hours was 1100°C. Exceeding of the standard temperature (900°C) allowed reducing the gas flow rate after the eighth and the tenth hour of the ladle drying, respectively, maintaining pulsating resonance mode of fuel combustion.

In subsequent tests (No4÷8) the search of the optimal drying mode was carried out.

When drying of the fourth and fifth tests ladles (No 5 and No 12) the fuel consumption was increased in the first drying hours. The lining temperature was 1050÷1120°C at the end of the drying process on both ladles, the lining temperature had reached the standard value (900°C) considerably earlier than twelve hours of drying and, therefore, the drying cycle could be shortened to 9-11 hours. However, the actual reduction of the drying time was not possible, since it would lead to violation of the technological process organization in the lining of the shop. In particular, reducing of the drying time violates the work cycling of refractory lining area that creates a shortage of time for refractories burning and has a negative impact on their durability.

To keep the standard drying time the fuel supply for the ladle No 5 (after seventh hour of drying) and for the ladle No 12 (after the ninth hour of drying) was reduced. At the same time, the fuel burning pulsating resonance mode was maintained.

In the next two test ladles (No25 and No36) for maintaining the drying time within the standard value the gas supply during the initial drying period was slightly reduced. However, the rate of the lining temperature increase was significantly faster than standard, which required reducing the fuel consumption at the end of drying: for the ladle No 25 at the twelfth, and for the ladle No 36 at the eleventh hour to avoid overheating (over 900°C).

Drying of the last test ladle (No 30) was carried out in the resonance mode (18÷25 Hz) at the standard gas consumption up to the tenth hour of the drying inclusively. The gas consumption was reduced after the tenth hour of drying to exclude overheating.

In general, the test of fuel burning pulsating resonance mode on the drying stand of steel-teeming ladle allows us to note the following:

-work of pulsation unit on the gas pipeline stand provides the gas consumption and gas consumption change in accordance with the technological instruction;

- practically confirmed possibility of pulsating resonance frequencies search in an industrial conditions when a negative impact of temperature, acoustic interference and equipment inertia;

- sufficiently high efficiency of pulsation unit and the ability to stable maintaining required resonant frequencies of gas pulsations during the drying process have been established;

- more intensive course of the drying process, thereby reducing process time and thus decreasing the fuel consumption have been noted;

- saving of natural gas at the fuel burning pulsating resonance mode in comparison with the standard indicators was 2.7÷26.1 %;

- Test results allow us to recommend an experimental implementation of fuel burning pulsating resonance mode.

Research on the heating post

Research of fuel burning pulsating resonance during the heating of steel-teeming ladles in MSP-2 were held on the post No 1 of intense ladles heating for melting.

The scheme of hardware for fuel burning pulsating resonance is shown in Fig. 5.

The ladles after long idle hours were selected for tests, i. e. ladles heating was carried out from cold state.

The ladle was laid on movable trolley in horizontal position and moved to the deflection (refractory) wall with raised burner of GOP-9 type. The burner axis is located at a distance of 1/3 of the ladle diameter from the bottom edge.

In accordance with the technological instruction when the ladle has more than 6 idle hours without heating, the duration of the heating should be not less than 6 hours.

The search of resonance frequencies was performed similar to the tests on the ladles drying stand. The resonance frequencies range on the heating stand is slightly different from the resonant frequencies on the drying stand due to changes in the acoustic characteristics of the stand. Setting the resonance frequencies led to the working frequency range 18÷30 Hz.

The changes in gas consumptions during the tests are shown in Fig. 6.

The test results are presented in Table. 2.

Table 2. The results of tests on the heating post of steel-teeming ladles

Test No	Ladle No	Pulsations frequency , Hz	Lining temperature, °C	Shell temperature , °C	Total natural gas consumption, m³	Natural gas saving, %
-	H	18÷30	700	93	2000	-
1	38	18÷30	879	89	1550	22.5
2	9	18÷30	910	97	1610	19.5
3	19	18÷30	750	82	1335	33.3
4	8	18÷30	737	77	1245	37.8
5	12	18÷30	777	84	1425	28.8

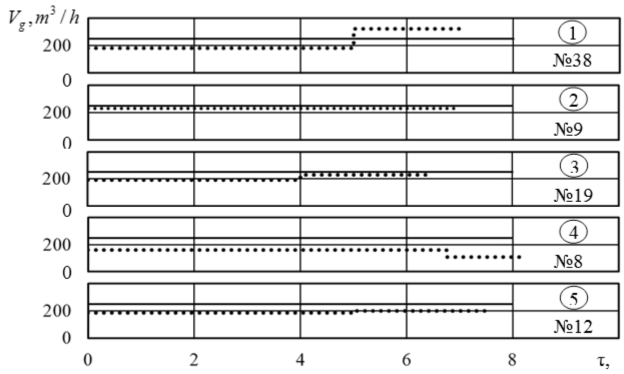

Figure 6. Changes in the supply of natural gas (V_g) during the ladles heating when fuel burning pulsating resonance

1…8 – numbers of the tests; ———— standard mode; .... test mode

Considering the more intensive heating when fuel burning pulsating resonant mode the gas consumption on heating the first test ladle (No 38) was reduced by 28% compared to the standard mode. After fifth hour of drying in the rate of heating the significant ladle underheating was established, which required increasing the gas flow rate over the standard by 30%. After seven hours of drying, the process was complete with the ladle overheating: 879°C instead of the standard value 700°C.

On the second test ladle (No 9) during the seven hours the consumption of natural gas was maintained by 8% lower than the standard rate. However, after seven hours of heating the significant overheating of ladle lining was obtained: 910°C instead of 700°C.

On the subsequent test ladles (No 19, No 8 and No 12), reduction in gas consumption was due to the need of excluding the significant ladles overheating over standard values. The final temperature of the ladles lining surface was 750°C, 737°C and 777°C respectively.

In general, the results of the tests of the fuel burning pulsating resonance system in the ladle heating post allowed, besides the above mentioned features of the system in the drying post, note the following:

- high excitability of the resonance frequencies in the ladle due to a small extent and volume of the gas pipeline area between the pulsating unit and the burner compared to the drying stand, where a large distance between the pulsator and the burner slows excitation of resonant frequencies due to the pulsations dissipation of the gas flow;
- significant increase of the heating intensity compared to the drying as a result of less high end lining temperature (777÷910°C instead of 900÷1120°C) and the absence of moisture vapor;
- the feasibility of use the fuel burning pulsating resonance mode at the posts of intensive ladles heating for melting was established, i.e. pulsating resonance mode allowed forcing the heating resonant pulsation of the flame along with an increase in gas consumption;
- natural gas saving is 19.5÷37.8%, that allows recommending fuel burning pulsating resonance mode on the heating stands to experimental implementation.

Conclusion

1. Experimental-industrial research had shown a high efficiency of developed fuel burning pulsating system when drying and heating of steel-teeming ladles. Reducing the consumption of natural gas; and therefore, its savings were 2.7÷26.1% when drying ladles, and 19.5÷37.8% when heating.

2. As a result of the test of fuel burning pulsating resonance mode on the ladles drying stand was found that work of the pulsation unit on the gas pipeline of the stand provided the gas consumption and the gas consumption changes in accordance with the technological instruction. In practice, the ability to search the pulsating resonance frequencies in industrial conditions despite the negative impact of temperatures, acoustic interferences and equipment inertia was confirmed. Sufficiently, high efficiency of the pulsating unit and the ability to stable maintaining the required resonance frequencies of the gas pulsations during the drying process was established. The intensive course of the drying process allowed reducing the process time and thus shortened fuel consumption.

3. Test results of fuel burning pulsating resonance system in the ladle heating post indicate the feasibility of using the fuel burning pulsating resonance mode at the posts of intensive heating of ladles for melting, since the pulsating resonance mode allows us to force the heating for melting by the flame resonance pulsation along with an increase in the gas consumption.

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