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UDC 550.42

# AGE OF HYDROTHERMAL PROCESSES IN THE CENTRAL IBERIAN ZONE (SPAIN) ACCORDING TO U-Pb DATING OF CASSITERITE AND APATITE

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Results of isotope-geochemical studies by PbLS step-leaching method of cassiterite from greisens located in Logrosán granite massif (Central Iberian Zone, Spain) and apatite from hydrothermal quartz-apatite vein on its exocontact indicate that in both cases a hydrothermal event is recorded in the interval of 114-126 Ma, which has been accompanied by lead supply. Within the limits of estimation error, the same age around 120 Ma corresponds to crystallization of hydrothermal apatite, formation of sticks and micro-inclusions in cassiterite from greisens and is suggested for Au-As-Sb-Pb ore mineralization, which calls for further confirmation. Xenogenous zircon from quartz-apatite vein does not react to this relatively low-temperature hydrothermal event either with building up new generations (sticks, areas of recrystallization) or with rebalancing of U-Pb isotope system. The age of greisen formation has been confirmed to be around 305 Ma by PbLS method on final phases of cassiterite leaching. Earlier it was estimated with $^{40}Ar/^{39}Ar$ method on muscovite.

***Key words***: isotope geochemistry, step-leaching method, U-Pb method, Pb-Pb method, Central Iberian Zone, cassiterite, apatite

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**Introduction and problem statement.** Isotope techniques play a crucial role in the research of hydrothermal processes nature, determination of ore formation age and mineral substance sources. Age determination of hydrothermal processes is based on direct dating of minerals with hydrothermal origin. As a rule, the difficulty of its realization lies in the complicated formation history of the objects under consideration, repeated activation of hydrothermal processes, frequent isolation breach in the instant isotope systems of geochronometric minerals, as well as a limited number of minerals suitable for dating. Age estimation of hydrothermal-matasomatic processes can be carried out by local U-Pb dating of zircon rims, formed in the result of these processes. For low-temperature metasomatites it is feasible to date mica and potassium feldspar with Rb-Sr method ([2] and others).

New prospects in solving the problem of dating polychronic processes appeared with the development of PbLS method – determination of isotopic age using Pb-Pb method on mineral step-leaching phases [7, 18]. The efficiency of step-leaching method has been proven for metamorphogenic minerals dating [1].

From the methodology position, the ore objects (Sn-W greisens and phosphate veins) mined since the Bronze Age and the territorially associated with Logrosán granite massif (Central Iberian Zone, South-Western Spain) are of special interest for hydrothermal process dating. Earlier, using U-Pb method on zircon, the crystallization age of granites has been determined as 308 ± 1 Ma [21]. Greisenization age, estimated with Ar-Ar method on muscovite from modified granites and veins with cassiterite, falls into the interval 308-313 Ma and corresponds to the age of granite intrusion [16]. Other age estimations of hydrothermal processes in this region are not available. Our attempts to determine the age of metasomatites (four samples with different mineral parageneses) with isochronal Rb-Sr and Sm-Nd methods have unfortunately failed, errorchrones obtained were characterized with very high MSWD values and inaccuracy of age estimation.

The current paper describes dating results, obtained with U-Pb and Pb-Pb step-leaching method for cassiterite from Sn-W ore veins, developing along Logrosán granites, and apatite from phos-

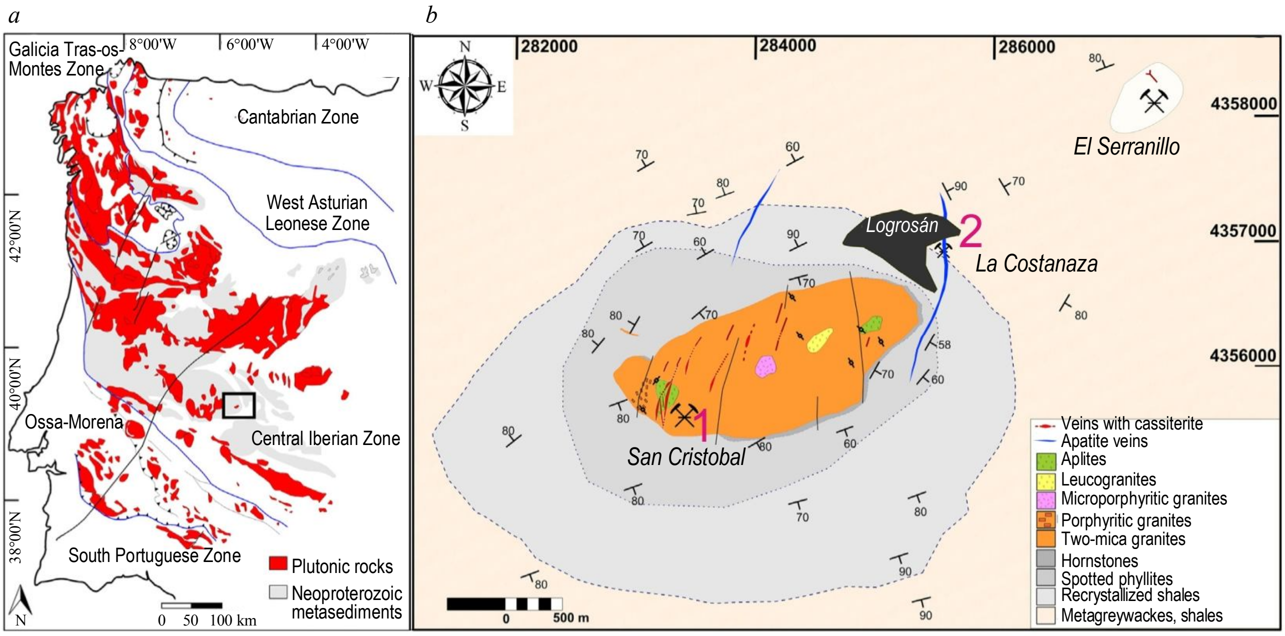


Fig.1. Scheme of geological structure of the Central Iberian Zone (*a*) and Logrosán granite massif (*b*) according to [8]. Hammers mark sampling places from quartz-cassiterite vein in greisens (1) and quartz-apatite vein in surrounding metasediments (2)

phate veins hosted by Precambrian metasediments in the contact area of Logrosán massif. Moreover, results of local U-Pb dating are presented for zircon, derived from the phosphate vein.

**Geological summary**. The Logrosán granite is situated in the southern part of Sn-W metallogenic province of European Variscides (Fig.1, *a*). The most important characteristic of Central Iberian Zone is a wide extension of peraluminous granitoid intrustions in the latest stage of Variscan orogeny. Host rocks are presented by Neoproterozoic metasediments: metagreywackes, shales, quartzites and, to a lesser degree, metasandstones. The Logrosán intrusive (Fig.1, *b*), also named San Cristobal after the height it forms, is a typical small granitic cupola (around 4 $km^2$ at the surface), composed of S-type two-mica granites rich in phosphorous and fluorine. Granite intrusion resulted in metasediments contact-metamorphic changes, presented by an inner zone of hornstones and external zone of spotted phyllites and chlorite shales [10].

Intragranitic hydrothermal complex is located in the eastern part of the massif and includes Sn-(W) mineralization associated with quartz-tourmaline veins and greisenization zones of 20-50 cm in thickness and crosscutting stockworks. Hydrothermal alteration of wallrock granites is shown by muscovitization of 2-10 cm interval from the vein contact. Thickness of altered rocks increases in the stockwork zones accompanied by intensive greisenization. In general, ore mineralization comprises cassiterite (the first, oxide-silicate stage of the mineralization process) and minerals of the second sulfide stage (arsenopyrite, stannite, sphalerite, chalcopyrite etc.) with a small number of minerals from tantalite-columbite family and less common wolframite [8].

In the altered host granites cassiterite occurs as scattered hypidiomorphic crystals without inclusions of any other minerals (first generation). In quartz veins cassiterite forms zonal well-bounded bipyramidal and columnar crystals (over 5 mm) with inclusions of Nb-Ta rutile and columbite intergrowths (second generation, Fig.2, *a*).

Phosphate deposit La Costanaza (currently abandoned, a museum is organized on the mining site) is located in the northeastern part of Logrosán granites contact area (see Fig.1, *b*). The deposit consists of separate subvertical quartz-apatite veins and veinlets ranging from several centimeters to 3 m in width and served as a base for distinguishing a special «Iberian» type [10]. Most veins have a curved shape with distinctive brecciated structure (Fig.2, *b*). The alteration of the Schist Greywacke Complex host rocks is characterized by silification and dolomitization. Quartz often forms well-bounded druses. Apatite is mainly presented by white radial-fiber or colloform aggregate –

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dahllite, or sporadically occurs as well-bounded white prismatic crystals (Fig.2, *c*). Accessory minerals include koalinite, calcite, Fe-Mg carbonate and Fe-Mg oxides and sulfides (arsenopyrite, chalcopyrite, pyrite, marcasite) mostly found on the periphery of quartz-apatite veins.

Hydrothermal apatite from La Costanaza deposit is defined by reduced content of Mn, Y, REE, Th, U, Pb and high content of F (3-6 wt.%) and Sr (up to 10 wt.% SrO), which makes it different from Logrosán magmatic apatite, which average SrO content does not exceed 0.01-0.12 wt.% ([10], authors' data). Elongated grains of the apatite are almost always zonal – the central part has low Sr content, whereas the outer part is rich in it, which is possibly the evidence of secondary recrystallization. The apatite from phosphorous-rich beds of host Schist Greywacke Complex (SGC) has SrO content of 0.16-0.22 wt.%, which is insignificant compared to hydrothermal apatite, whereas REE content in both magmatic and metasedimentary apatites is next higher than in the hydrothermal one [10]. Quartz-apatite veins of the deposit La Costanaza are suggested to form as a result of hydrothermal modification of sedimentary apatite from the schist and carbonate layers (source of Sr for hydrothermal apatite). In the process of long-term circulation of hydrothermal fluids Sr must have been supplied and REE subtracted.


Fig.2. External appearance of the rocks under investigation: *a* – quartz-cassiterite druse from greisens, museum exhibit from Logrosán village; *b* –quartz-apatite vein, under exposure and through electronic microscope; *c* – image from back-scattered electrons

The fluid cooling temperature after phosphate veins formation has been estimated in the interval of 125-350 °C based on fluid inclusions research in quartz; arsenopyritic geothermometer allowed to estimate the peak temperature of vein formation as 440 °C [10]. Direct dating of hydrothermal apatite by U-Pb method has never been carried out before due to extremely low U and Th content. However, with reference to a number of facts, it has been assumed that there is no genetic or temporal link between formation of phosphate veins and granite intrusion of Logrosán massif. Hydrothermal apatite has been proposed to date the Mesozoic activation period aged in the interval 201-120 Ma. In this period the Central Iberian Zone sustained a widespread formation of F-Ba polymetallic ores under similar thermal conditions [10].

Au-Sb ore occurrences are also known within Central Iberian Zone. Geochemical soil sampling carried out by the company Mineral Exploration Network Ltd. revealed contrast Sb and As anomalies, which allowed to estimate the scale of mineralization. Ore samples and placer gold grains analysis resulted in detection of galena and lead antimony sulfides (boulangerite, jamesonite), as well as inclusions of aurostibite and intergrowth of subgraphic (spongy) gold with berthierite and oxides of Sb and Pb sulphosalts. Such identifications suggest a complex paragenesis including two mineralization stages: early quartz-gold-antimonite-berthierite and late quartz-sulphosalt-aurostibite [4, 17].

**Results and discussions.**

***Cassiterite dating.*** Cassiterite and rutile belong to the same mineral group – rutile group ($M^{4+}O_2$). However, unlike rutile, which has long and successfully been used as a geochronometric

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mineral, there are only several publications dedicated to cassiterite dating, either with conventional TIMS method or with local LA-ICP-MS method (see review in [6]).

Cassiterite studies involve certain problems associated with the difficulty of its chemical decomposition during sample preparation; this is especially true in case of «young» age samples [5, 9]. Authors of the abovementioned publications preliminary washed cassiterite samples in 7M HCl solution or in 7M HCl/7M $HNO_3$ mixture to remove significant amounts of common lead. This procedure resulted in a substantial $^{206}Pb/^{204}Pb$ ratio increase.

It is known that most minerals appear as multiphase systems in relation to the distribution of $Pb_{COM}$ (common) and $Pb_{rad}$ (radiogenic) in the growth zones, altered segments of a mineral caused by overlapping processes as well as a result of trapping microinclusions of minerals during crystallization. In case of cassiterite, which is highly stable towards acid effects, the question more likely refers to a presence of trace contaminations, inclusions and outgrowths of other lead-containing minerals and not to heterogeneous zones of cassiterite. As a result a different ratios of $Pb_{com}$ and $Pb_{rad}$ could appear for Pb component at different stages of dissolution. Therefore, to obtain additional information on $Pb_{com}$ and $Pb_{rad}$ distribution we have analyzed acid leaching products used for cassiterite washing.

*Analytical method*. Preliminary washed in the ultrasound bath cassiterite crystals from the sample S-1 (greisen vein) were thoroughly grinded. Two series of experiments were carried out involving subsequent leaching of cassiterite with different acid solutions under varying length of exposure (Table 1).

*Table 1*

**Results of the U-Pb isotopic investigation of S-1 cassiterite**

| № | Treatment conditions | Isotope ratios | | | |
|---|---|---|---|---|---|
| | | 206Pb/204Pb | 207Pb/204Pb | 208Pb/204Pb | 238U/204Pb |
| | | I series; 110 mg | | | |
| 1 | L-1, 6N HCl, 60 °C, 2 h | 19.005 (0.06) | 15.679 (0.09) | 38.290 (0.12) | 22.230 (0.37) |
| 2 | L-2, 4N HBr, 60 °C, 4 h | 19.716 (0.29) | 15.806 (0.17) | 38.626 (0.19) | 69.033 (2.64) |
| 3 | L-3, 15N HNO3, 60 °C, 48 h | 32.793 (1.20) | 16.264 (0.92) | 38.412 (0.92) | 722.96 (1.98) |
| 4 | L-4, HF + HNO3, 220ºC, 384 h | 517.37 (0.86) | 41.510 (0.80) | 38.422 (0.75) | n.d. |
| | | II series; 300 mg | | | |
| 5 | L-1, 3N HCl, 60 °C, 1 h | 18.966 (0.06) | 15.663 (0.09) | 38.253 (0.12) | 21.730 (0.60) |
| 6 | L-2, 8N HBr, 60 °C, 2 h | 19.436 (0.07) | 15.685 (0.09) | 38.312 (0.12) | 37.810 (0.35) |
| 7 | L-3, 15N HNO3, 220 °C, 16 h | 25.941 (0.20) | 16.016 (0.12) | 38.373 (0.14) | 275.90 (0.63) |
| 8 | L-4, 10N HCl, 220 °C, 256 h | 286.33 (0.78) | 16.264 (0.92) | 39.948 (0.34) | 4997.5 (0.85) |
| 9 | L-5, HF + HNO3, 220 °C, 528 h | 855.40 (0.55) | 59.466 (0.49) | 39.844 (0.42) | 16709 (0.56) |

*Note*. Isotope ratios corrected for blank and fractionation. Numbers in brackets correspond to the measurement error (±2σ) in percent.

After each acidic treatment solutions were collected into boxies, evaporated and converted in to bromide form. The residues were twice rinsed with water, dried out and used for the next acidic treatment.

The subsequent treatments series of cassiterite portions did not lead to a full decomposition of the sample. All the leaching products were used to determine isotope composition of lead and after introducing a mixed indicator $^{208}Pb$-$^{235}U$ – to estimate lead and uranium content. Pb and U separation from cassiterite was carried out on ion-exchange resin in HBr form using method [14] with subsequent U detachment on UTEVA resin. The experimental blank did not exceed 0.05 ng of Pb.

Isotope ratios of lead and uranium were measured with a multicollector mass spectrometer TRITON TI in the Laboratory of Geochronology and Geochemistry of Isotopes, Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences. Calculations of isotope ra-

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tios and U-Pb age of cassiterite were performed with a standard procedure of Pb/U ratios (2σ) measurement error using K. Ludwig's computer programs [12, 13]. It should be noted that the use of leaching products for U-Pb system examination could be legitimate only if the dissolution is congruent and there is no fractionation of lead and uranium.

*Results*. The first three leaching phases in the first and second experiment series have low $^{206}Pb/^{204}Pb$ ratio (in the interval 19.0-32.8, Table 1). Calculations and formulations were carried out in $^{235}U/^{204}Pb$ – $^{206}Pb/^{204}Pb$ coordinates. When using calculation data for leaching products 1, 2, 3, 5 and 6 the imaging points shape an errorchrone with the following parameters: age 126 ± 5 Ma, MSWD = 179 (Fig.3, *a*). Adding data on leaching product 7 increases error of age determination (129 ± 24 Ma) and MSWD = 752, although the age interval stays the same.

Subsequent acidic treatment of cassiterite allowed to obtain leaching products with higher content of radiogenic lead ($^{206}Pb/^{204}Pb$ ratio falls into the interval 286-855). Using data from three leaching products 7, 8 and 9 (Table 1), an isochrone with the age 303 ± 3 Ma has been plotted in $^{206}Pb/^{204}Pb$ – $^{207}Pb/^{204}Pb$ coordinates (MSWD = 1.8, Fig.3, *b*). Inclusion of leaching product 4 increases the age determination error (298 ± 47 Ma, MSWD = 3.8). High mean MSWD confirms that cassiterite contains at least two radiogenic Pb components of different ages.

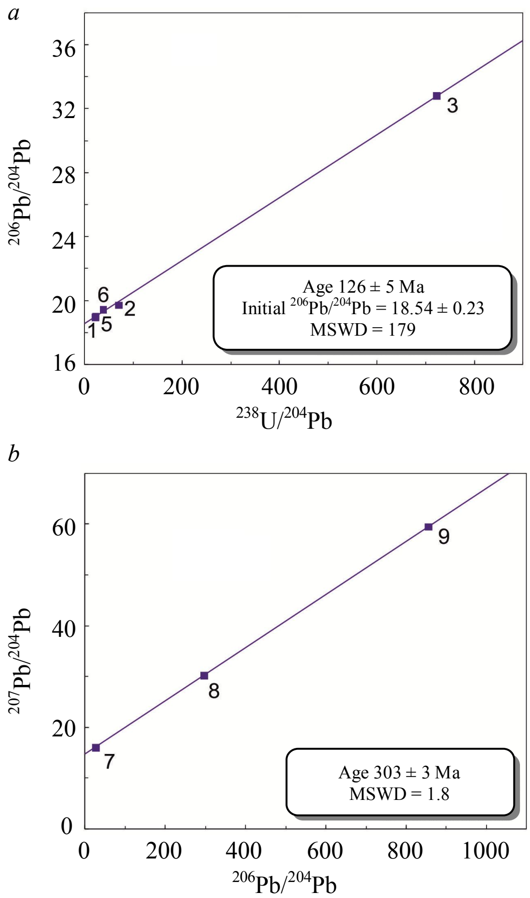


Fig.3. Results of isotope-geochemical study of cassiterite (S-1): *a* – plot in $^{238}U/^{204}Pb$ – $^{206}Pb/^{204}Pb$ coordinates, first leaching products; *b* – plot in $^{206}Pb/^{204}Pb$ – $^{207}Pb/^{204}Pb$ coordinates, subsequent leaching products. The size of dots bears no correspondence to measurement errors

Thus, as a result of subsequent series of acidic cassiterite leaching, two age values have been obtained. The age 303 ± 3 Ma can be attributed to cassiterite formation. It agrees with the age of magmatic zircon from Logrosán granite massif – 308 ± 1 Ma [10] – and with $^{40}Ar/^{39}Ar$ age from 308 to 303 Ma estimated for muscovite from Sn-W ore-bearing veins crosscutting the granites, which contain the analyzed cassiterite [16].

Apparently, as a result of cassiterite leaching at the first three stages of acidic treatment (Table 1), external sticks and microinclusions of other mineral phases containing significant amounts of common lead were being removed. This brought lead can be attributed to the second (later) stage of hydrothermal activity with the age of 201-120 Ma associated with an early Jurassic rifting and tholeitic magmatism, which caused widespread formation of F-Ba-Pb-Zn ore veins within Central Iberian Zone [10]. The age of 126 ± 5 Ma determined for cassiterite using the first leaching products falls into the mentioned time interval.

***Apatite dating***. The sample of apatite monofraction (P-1) was collected from a new-made shearing cut in the main quartz-apatite vein of La Costanaza deposit croscutting Neoproterozoic metasediments. According to classification of hydrothermal apatite proposed in [10] the apatite under consideration belongs to the fibrous type.

*Analytical method*. The apatite derived from the sample P-1 was additionally cleaned under binocular microscope for isotope research. To collect grains absolutely free from inclusions appeared to be impossible. Pb and U isotope analysis of the bulk portion of apatite 1 (Table 2) demonstrated the high content of common lead ($^{206}Pb/^{204}Pb$ = 20.7). A decision was made to apply step-leaching in order to extract Pb with different ratios of $Pb_{com}$ and $Pb_{rad}$ components. For this purpose a new portion of apatite (I series; 90 mg) was treated with 3N HCl twice, 1 h each time at the temperature 20 °C. The first leaching product was not measured. Isotope analysis was performed for the second one. The third portion of apatite (II series; 143 mg) was thoroughly leached at 20 °C in 1.5N HCl during 2 h (leaching product 3) and 1 h (leaching product 4). It should be noted that in all series of experiments multistep leaching failed to fully dissolve the apatite portion, which points to its modified structure and presence of trace microinclusions. Microprobe analysis of the non-dissolved residue showed that it consists of quartz and individual grains of goyazite (aluminophosphate of strontium).

*Table 2*

**Results of the U-Pb isotopic investigation of P-1 apatite**

| № | Treatment conditions | Isotope ratios | | | | | 206Pb/238U age, Ma |
|---|---|---|---|---|---|---|---|
| | | 206Pb/204Pb[a] | 207Pb/204Pb[a] | 208Pb/204Pb[a] | 238U/204Pb[b] | 206Pb/238U[b] | |
| 1 | Bulk apatite | 20.696 (0.46) | 15.775 (0.17) | 39.523 (0.24) | 59.480 (3.50) | 0.01719 (6.70) | 109.2 ± 6.8 |
| | | | | I series; 90 mg | | | |
| 2 | 3N HCl, 20 °C, 1 h | 19.832 (0.22) | 15.740 (0.13) | 39.141 (0.17) | 8.916 (4.12) | 0.01779 (26.6) | 108.7 ± 28 |
| | | | | II series; 143 mg | | | |
| 3 | 1.5N HCl, 20 °C, 2 h | 20.656 (0.36) | 15.764 (0.32) | 39.373 (0.33) | 52.466 (1.44) | 0.01874 (6.80) | 118.8 ± 6.8 |
| 4 | 1.5N HCl, 20 °C,1 h | 20.324 (0.36) | 15.790 (0.20) | 39.229 (0.24) | 35.034 (2.70) | 0.01857 (9.25) | 117.3 ± 9.4 |
| 5 | Plagioclase | 19.697 (0.54) | 15.217 (0.02) | – | – | – | – |

*Note*: *a* – isotope ratios corrected for laboratory blank and fractionation; *b* – isotope ratios corrected for blank, fractionation and common Pb.

*Results*. The obtained results for apatite selected in I and II experimental series are presented in Table 2. There has not been registered any significant difference in $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ ratios in leaching products, thus a plot has been constructed in $^{238}U/^{204}Pb$ – $^{206}Pb/^{204}Pb$ coordinates (Fig.4). For four points (bulk apatite and three leaching products, Table 2) the age was estimated to be 114 ± 8 Ma (MSWD = 1.9). High mean MSWD indicates that bulk apatite is quite heterogeneous and may contain inherited components. The initial ratio of $^{206}Pb/^{204}Pb$ obtained from age determination equals 19.680 ± 0.049. Analysis has also been undertaken for plagioclase derived from the apatite vein sample – its isotope ratio is 19.697. Adjustment for initial lead content allowed to calculate apatite age using $^{206}Pb/^{238}U$ ratio, the mean value of which across four points amounted to 114 Ma (Table 2). The age calculated in Tera-Wasserburg coordinates equals 111 ± 12 Ma (MSWD = 0.023).

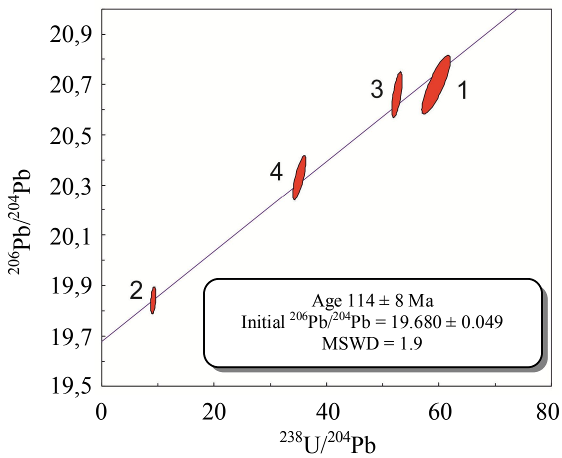


Fig.4. Results of isotope-geochemical study of apatite (P-1) in $^{238}U/^{204}Pb$ – $^{206}Pb/^{204}Pb$ coordinates. Ellipses of measurement errors correspond to 2σ, including inaccuracy of decay constant

Obtained results can be considered preliminary. A more ideal extraction of apatite monofraction and implementation of suggested dating approach by using subsequent series of leaching could significantly clarify development history of quartz-apatite veins. Nevertheless, a hypothesis on Mesozoic (201-120 Ma) age of hydrothermal phosphate vein genesis isolated in time from the age of Logrosán granites formation, which was proposed in publication [10] according to several indirect indicators, has been independently supported by PbLS dating method.

***Zircon dating.*** Around 25 grains and grain fragments were derived from a quartz-apatite vein (sample P-1). 15 of them were large enough for dating purposes.

*Analytical method*. Zircon dating with U-Pb method was carried out in the Center of Isotope Research, Russian Geological Research Institute, on the ion microprobe SHRIMP-II with standard technique [20]. Points for analysis were chosen using images of zircon grains in transmitted light, in cathodeluminescence (CL) and backscattered electrons mode. Content of REE and rare elements in zircon was estimated for the points earlier dated with U-Pb method (16 points) on the ion microprobe Cameca IMS-4f in Yaroslavl Branch of the Institute of Physics and Technology with methods described in [3, 11]. The size of analyzed mineral area did not exceed 15-20 µm in diameter; relative measurement error for most tests was 10-15 %; element detection threshold on the average amounted to 10 ppb. To plot spectra of REE distribution, zircon composition was normalized to the chondrite CI [15]. Estimation of crystallization temperature was carried out with Ti thermometer in zircon [19].

*Results*. Zircon grains are mostly short-columnar, with long axis size of maximum 100 µm. In CL they are characterized by a distinct oscillatory growth zoning in dark grey shades, less frequently – by sectorial zoning. No clearly defined rims or zones of zircon recrystallization have been identified.

In Tera-Wasserburg concordia diagram imaging points for zircon derived from quartz-apatite vein sample P-1 correspond to individual values of $^{238}U/^{206}Pb$ age that fall into the interval between 550 to 915 Ma (Fig.5, *a*). One point has an age over 2016 Ma. The diagram of relative $^{238}U/^{206}Pb$ age distribution in zircon has a distinct peak around 610 Ma (Fig.5, *b*). Using five points attributed to this peak, concordant age of 606 ± 7 Ma has been calculated.

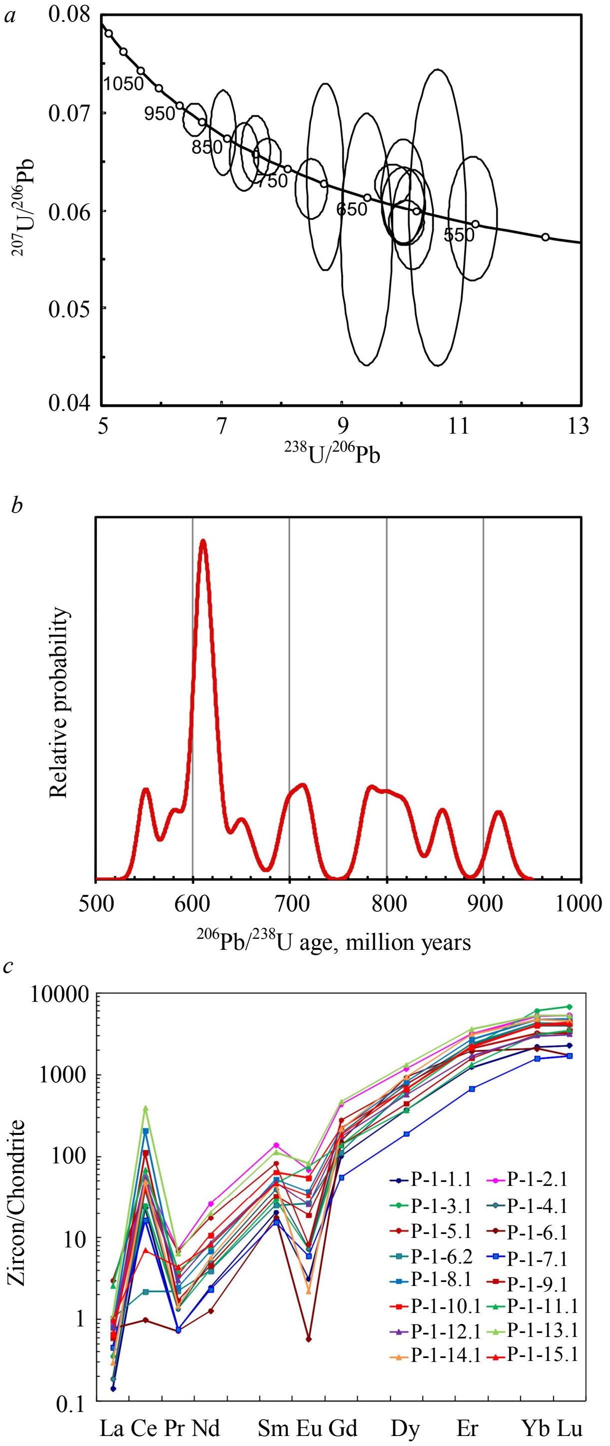


Fig.5. Results of isotope-geochemical study of zircon (P-1):
*a* – Tera-Wasserburg concordia diagram;
*b* – probability diagram for $^{206}Pb/^{238}U$ age;
c –spectra of REE distribution in zircon

Earlier in [21] local dating of zircon from Logrosán granite massif has been carried out using LA-ICP-MS method and resulted in following – for 40 % of grains U-Pb age estimations were older than it could be expected for Variscan granites. For the major part of xenogenous zircon apparently captured from metasedimentary complex, which has been cut through by the granites, estimated age falls into the interval 550-847 Ma. Paleoproterozoic age has been identified for individual grains [21].

Comparison of age distribution spectra for zircon captured by Logrosán granites and zircon from Neoproterozoic metasedimentary Schist Greywacke Complex (according to multiple literature sources) showed high degree of their conformity. Notably, in metasediments clearly prevails zircon aged around 600 Ma (Fig.10 in [21]). Apparently, dated zircon from the phosphate vein has all been captured from surrounding rocks of SGC. Thermal event aged around 308 Ma (granite intrusion) and subsequent hydrothermal processes registered with PbLS method had no influence upon U-Pb isotope system of xenogenous Neoproterozoic zircon derived from quartz-apatite vein.

The character of REE distribution in zircon corresponds to its detritus nature. REE distribution spectra are highly differentiated with an increase from light to heavy REE with an overall REE content around 1300 ppm, there are clearly defined positive Ce-anomaly and negative Eu-anomaly (Fig.5, *c*). Hf content in zircon averages approximately 9000 ppm, Y – 2000 ppm, P – 400 ppm, Li – 17 ppm. Temperature of zircon crystallization calculated with Ti thermometer [19] on the average equals 740 °C. Such peculiarities of zircon composition from the viewpoint of rare elements clearly point to its crustal origin from acid magmatic melts. Geochemical characteristics do not contain any traces of hydrothermal processes associated with phosphate vein formation.

**Conclusions.** Therefore, the results of isotope-geochemical studies of cassiterite from greisens located in Logrosán granite massif (Central Iberian Zone, Spain) and apatite from hydrothermal quartz-apatite vein on its exocontact using PbLS step-leaching method indicate that in both cases in the interval of 114-126 Ma a hydrothermal event is recorded, which has been accompanied by lead supply. Within the limits of estimation error, the same age around 120 Ma corresponds to crystallization of hydrothermal apatite, formation of sticks and micro-inclusions in cassiterite from greisens and is suggested for Au-As-Sb-Pb ore mineralization, which calls for further confirmation. Xenogenous zircon from quartz-apatite vein does not react to this relatively low-temperature hydrothermal event either with building up new generations (sticks, areas of recrystallization) or with rebalancing of U-Pb isotope system. The age of greisen formation has been confirmed to be around 305 Ma by PbLS method on final phases of cassiterite leaching. Earlier it was estimated with $^{40}Ar/^{39}Ar$ method on muscovite. [16].

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# MODELING OF GEOCHEMICAL PROCESSES IN THE SUBMARINE DISCHARGE ZONE OF HYDROTHERMAL SOLUTIONS

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The paper reviews the main methods and analyzes modeling results for geochemical processes in the submarine discharge zone of hydrothermal solutions of mid-ocean ridges. Initial data for modeling have been obtained during several marine expeditions, including Russian-French expedition *SERPENTINE* on the research vessel «Pourquoi Pas?» (2007). Results of field observations, laboratory experiments and theoretical developments are supported by the analysis of regression model of mixing between hydrothermal solutions and sea water. Verification of the model has been carried out and the quality of chemical analysis has been assessed; degree and character of participation of solution components in the hydrothermal process have been defined; the content of end members has been calculated basing on reverse forecasting of element concentration, depending on regression character; data for thermodynamic modeling have been prepared. Regression model of acid-base properties and chloridity of mineralizing thermal springs confirms adequacy of the model of double-diffusive convection for forming the composition of hydrothermal solutions. Differentiation of solutions according to concentrations of chloride-ion, depending on temperature and pH indicator within this model, is associated with phase conversions and mixing of fluids from two convection cells, one of which is a zone of brine circulation. In order to carry out computer thermodynamic modeling, hydro-geochemical and physicochemical models of hydrothermal discharge zone have been created. Verification of the model has been carried out basing on changes of Mn concentration in the hydrothermal plume. Prevailing forms of Mn migration in the plume are $Mn^{2+}$, $MnCl^{+}$, $MnCl_2$. Two zones have been identified in the geochemical structure of the plume: 1) high-temperature zone (350-100 °C) with prevalence of chloride complexes – ascending plume; 2) low-temperature zone (100-2 °C), where predominant form of transfer is a free divalent ion – lateral plume. Sulfate complex in insignificant quantities (1.5 %) is detected in the lateral plume, whereas hydroxide complex is stable at temperatures 325-125 °C and can only be found in the ascending plume. Results of modeling almost fully correspond to field observations. Verification of thermodynamic model proves its adequacy and allows to make a transition to the next stage of research – examination of geochemical dissipation for key ore components of hydrothermal solutions – Fe, Cu, Zn etc.

***Key words*:** mid-ocean ridge, regression model, thermodynamic modeling, hydrothermal solution, migration forms

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**Introduction.** From the very discovery of hydrothermal activity in mid-ocean ridges (1977, manned deep-submergence vehicle Alvin, Galapagos rift), examination of metal-bearing hydrothermal solutions, forming deep-sea polymetallic sulphides (DPS) rich in Cu, Zn, Pb, Ag, Au and a whole array of other rare chemical elements by the bottom of the World Ocean (hereinafter the Ocean), has become an important part of international research in the field of marine geology. From the viewpoint of applied oceanography, in the course of prospecting for active hydrothermal fields it proved to be a promising idea to examine the structure of near-bottom waters, geochemical and hydrophysical specifics of dispersion halos – hydrothermal plumes near black smokers [1, 2, 4, 6, 7, 9].

In these days deep-sea hydrothermal springs at the ocean bottom arouse great practical interest. It is confirmed by an agreement, signed in October 2012 between Russian Federation and International Sea-Bed Authority (ISA). Russia gained exclusive rights to explore and subsequently develop DPS deposits within the limits of Russian Exploration Region (RER-DPS) in the Mid-Atlantic Ridge (MAR) (12°48′36″—20°54′36″N) [5, 7].

Starting exploitation of seabed mineral resources implies the need to upgrade research methods of hydrothermal springs, including for the purposes of enhancing exploration efficiency. One of important areas of research in this direction is modeling of geochemical processes in the system geothermal fluid – ocean water. Hydrothermal plumes – principal research objects during prospecting for areas of modern ocean mineralization – form in the seabed layers on the mixing line of these two natural solutions. Hydrothermal plumes are complex dispersion halos, characterized by anomalous temperature and amount of suspended particles (turbidity), fluctuations of density, Eh, pH and other parameters [7, 17, 18].

In the process of upgrading methods of hydrothermal spring prospecting, special attention should be paid to examination of water migration of ore components and elements – geochemical reference points in hydrothermal plumes, because they serve as key indicators of modern hydrothermal activity at the ocean bottom [5, 8].

**Key features of the geological and geochemical model of suboceanic hydrothermal system.** Possible existence of hydrothermal convective system follows from the presence of a heat source – magma chamber, which ensures convection of sea water, as well as from fractured magmatic rocks, acting as permeable medium. Results of field observations, experimental tests and model calculations serve as a base for our understanding of oceanic spring formation [1, 2, 4, 6].

High-temperature metamorphization of sea water, absorbed on the flanks of hydrothermal systems, leads to formation of unsulfated waters devoid of magnesium in the subsoil oceanic structures. It is commonly believed that these waters serve as a source for seabed hot springs and bear the name of terminal solutions (TS) or end members [2, 3, 6, 10, 13, 20].

As the hot fluid progresses through the mass of magmatic rocks, the latter are desalinized and dissolved elements are transferred to the surface (Li, K, Rb, Ca, Cu, Fe, Mn, Zn, Pb, Co, Ni, As etc.). Thus, mineralizing fluid in the discharge zone of a hydrothermal convective system is a product of interaction between oceanic water and rocks composing the oceanic crust.

**Physical (experimental) modeling of hydrothermal mineralization in the Ocean and field data.** The concept that thermal springs of mid-ocean ridges (MOR) form as a result of high-temperature interaction between sea water and the rocks inside hydrothermal systems is primarily based on abundant data from laboratory modeling, reviewed in 1983 by M.Mottl [17]. Experiments on warming sea water and its exposure to basalts under conditions similar to natural ones showed that the decrease in pH of the solution, associated with Mg absorption by the rocks, leads to desalination of certain elements (including metal ones) and formation of the fluid with the composition really close to natural thermal springs.

As a result of laboratory tests, it was discovered that, when sea water and basalt are warmed to the temperature 300 °C, the solution becomes acidic (pH = 2÷4) and reduced. This causes a dramatic increase in the concentration of such metals, as Fe and Mn. In its turn, ocean water deposition of Mg, incorporated in secondary silicates or mineral associations, including $MgSO_4$ and $Mg(OH)_2$, facilitates the formation of $H^+$. Ocean water loses magnesium and sulfate ion, and becomes rich in metals and Si. pH value of the solution defines intensity of metal dissolving and formation of mineralizing fluid.

On the whole, field observations confirm results of physical modeling. At the same time, some variations of thermal spring composition have been detected, not only for different regions but also within the same hydrothermal field [2, 6, 7, 20].

Synthesis of physical modeling results and field observations leads to the conclusion that the most acceptable way to explain differences in mineralization of the solutions is offered by the model of double-diffusive convection [2, 12]. It is assumed that near the magma chamber beneath the main convective cell there is a circulation zone of the brine, formed due to differentiation of sea water on the magma contact in the moments of sudden crack opening. Currently, phase conversion and mixing of fluids from two convective cells offer the best explanation of the diversity of observed processes.

**Regression model of mixing between mineralizing thermal springs and sea water.** Results of field observations, laboratory experiments and theoretical developments are supported by the analysis of regression model of mixing between hydrothermal solutions and sea water in the discharge zone. Concentrations of components in the end members correspond to zero Mg concentration and are defined using graphs and regression equations for individual elements, based on Mg concentration ([element]/[Mg]). For instance, initial point of the trend line $[SO_4]/[Mg]$ indicates zero concentration of both sulfate ion and magnesium in the terminal hydrothermal solutions

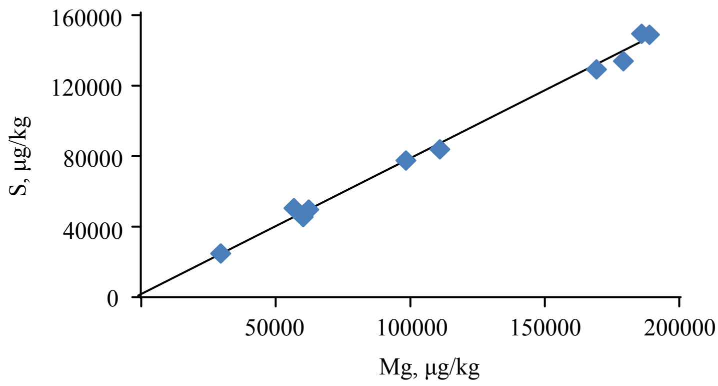


Fig.1. Dependence of [S] concentration on [Mg]
for hydrothermal solutions in several areas of MAR according
to *SERPENTINE* expedition data, 2007 [14]

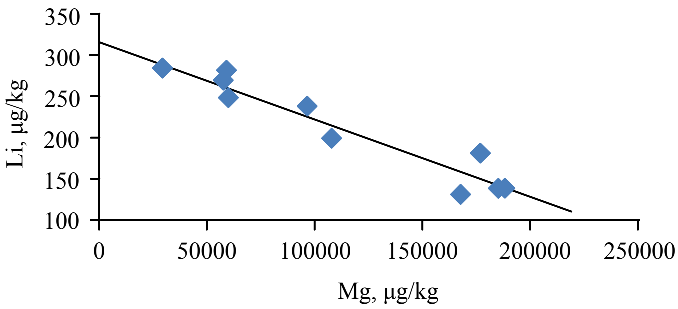


Fig. 2. Dependence of [Li] concentration on [Mg]
for hydrothermal solutions in MAR (14°45' N) according
to *DiversExpedition* data, 2001 [19]

(Fig.1). The start of the trend line in the point with zero S concentration hints at the prevalence of sulfate ion in the system. The shape of the graph corresponds to theoretical notions and confirms the quality of laboratory analysis. It corresponds to the results of physical modeling and allows to contemplate verification of the regression model using independent experimental data. Each observation point on the graph corresponds to a certain magnesium concentration, which reflects the degree of mixing between hydrothermal solution and sea water.

Analysis of regression model allows to address the following tasks:

1. The graph [S]/[Mg] is used to verify the model against results of physical modeling and assess the quality of chemical analysis (Fig.1). Deviation of sulfur concentration from zero allows to make assertions regarding possible presence of other forms of sulfur migration in the system, e.g. $H_2S$.

2. Determination of the source from which element gets into solution. Absence of magnesium in the end member allows to use results of regressions [element]/[Mg] in order to identify groups of elements according to their participation in hydrothermal processes. A positive trend relative to [Mg] indicates that the element comes from sea water, as its concentration decreases with the growth of hydrothermal component and decline in the share of sea water, the same way it does for magnesium. The first group includes Mg, $SO_4$, U, Mo etc. A negative trend indicates that the element accumulates in the solution as a result of hydrothermal transformations. The second group includes $H_2S$, Ca, $SiO_2$, Li, Rb, Mn, Fe, Zn and other elements [2, 6] (Fig.2). Incline of the trend line points to the negative correlation between Li and Mg and reflects the degree of mixing between hydrothermal solution and sea water. Li concentration in the end member amounted to 317 $\mu m/dm^3$.

3. Calculation of end member concentrations – reverse forecasting of element concentration using trend line (regression equation). Regression models of mixing serve as a calculation base for element concentrations in the terminal hydrothermal solutions that passed through the entire transformation cycle under maximal temperature and pressure inside the hydrothermal system. Adjusted concentrations allow to compare compositions of all end members of submarine hot springs, eliminating the effect of fluid dilution with sea water along the migration routes and in discharge zones. Results of analysis allow to specify fluid composition for observed hydrothermal fields (Fig.2). Calculated end member concentrations can be also used for thermodynamic modeling.

**Regression model of acid-base properties and chloridity of mineralizing thermal springs in the Ocean.** Assumed end member composition, obtained from the regression model, is widely used to compare compositions of hydrothermal solutions from different areas, when excluding the influence of fluid dilution with sea water. However, one should be very careful when using such calculation data for global geochemical developments. Content fluctuations of hydrothermal solu-

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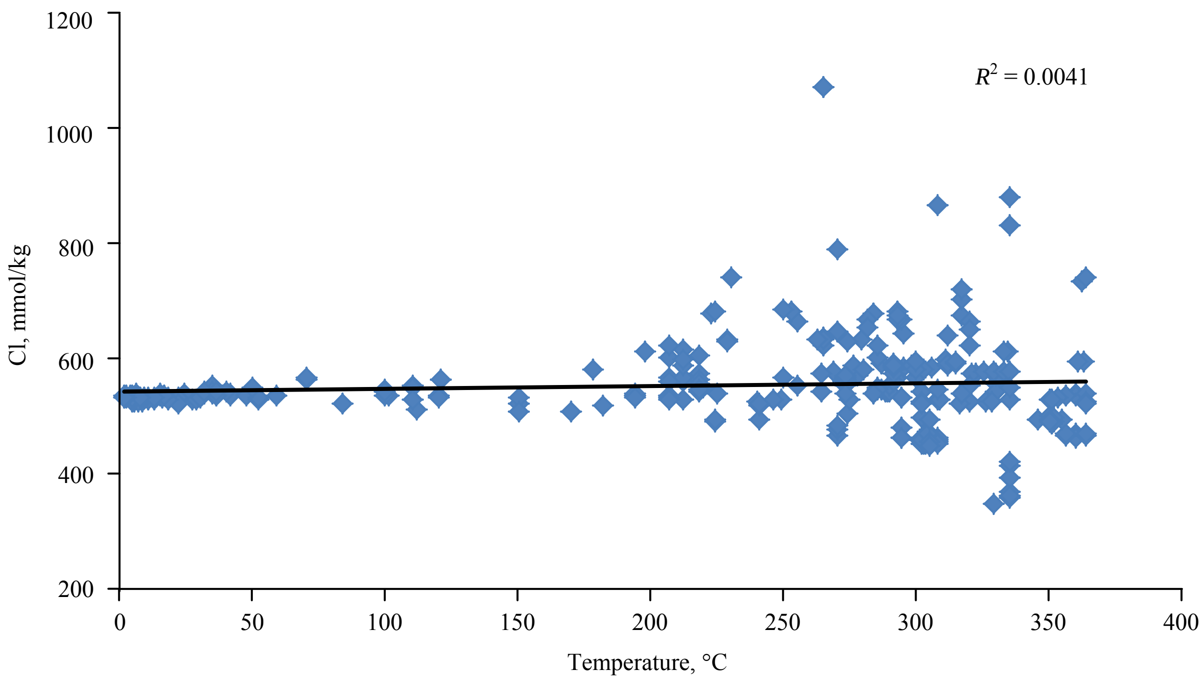


Fig.3. Dependence of [Cl⁻] on temperature according to data from hydrothermal solutions sampling

tions can be associated not only with sea water dilution, but also, even to a greater extent, with very unbalanced character of the hydrothermal system. Direct observations have proven the presence of phase conversions in the discharge zones and formation of craters caused by «hydrothermal explosions». Content fluctuations of thermal springs have been instrumentally confirmed for source outfalls [1, 7].

Regression models, constructed for sufficiently large amount of data, allow to offset content fluctuations, resulting from instability of physical and chemical conditions, as well as individual errors of sampling and chemical analysis, and to identify main trends of fluid content formation and interconnections between key indicators. Subsequent analysis was carried out using all currently available initial analytical information without adjustments for end members from author's and global databases [2, 6, 7, 20], including data collected by M.Mottl and available on the website http://earthchem.org/featured/mott (Mottl, M.J. (2012), VentDB: Mid-Ocean Ridge Hydrothermal Vent Chemistry Data Collection in the EarthChem Library).

Results of modeling demonstrate a strong tendency for increasing concentration of Cl-ion in oceanic hydrothermal solutions with rising temperature (Fig.3). In different intervals of temperature this connection manifests itself differently. Below 60 °C chloridity of the solution meets the standard for sea water. For higher temperatures (up to 180 °C) both elevated and lowered concentrations of $Cl^-$ can be observed, with the latter ones prevailing. The greatest deviations from [$Cl^-$] values are observed in the near-bottom oceanic waters for temperatures higher than 180 °C.

Analysis of regression model, linking concentrations of chloride-ion and acidity of hydrothermal oceanic solutions, shows that these parameters are characterized by a negative relationship (Fig.4). The highest values of [$Cl^-$], significantly exceeding standards for sea water, are observed in acidic solutions with pH = 2.3÷6.0. The same interval is characterized by visible, but not so significant deviations of the opposite sign. Regression modeling data confirms adequacy of the model of double-diffusive convection, discussed earlier. Differentiation of solutions according to concentrations of chloride-ion depending on temperature and pH indicator within this model is associated with phase conversions and mixing of fluids from two convection cells, one of which is a zone of brine circulation.

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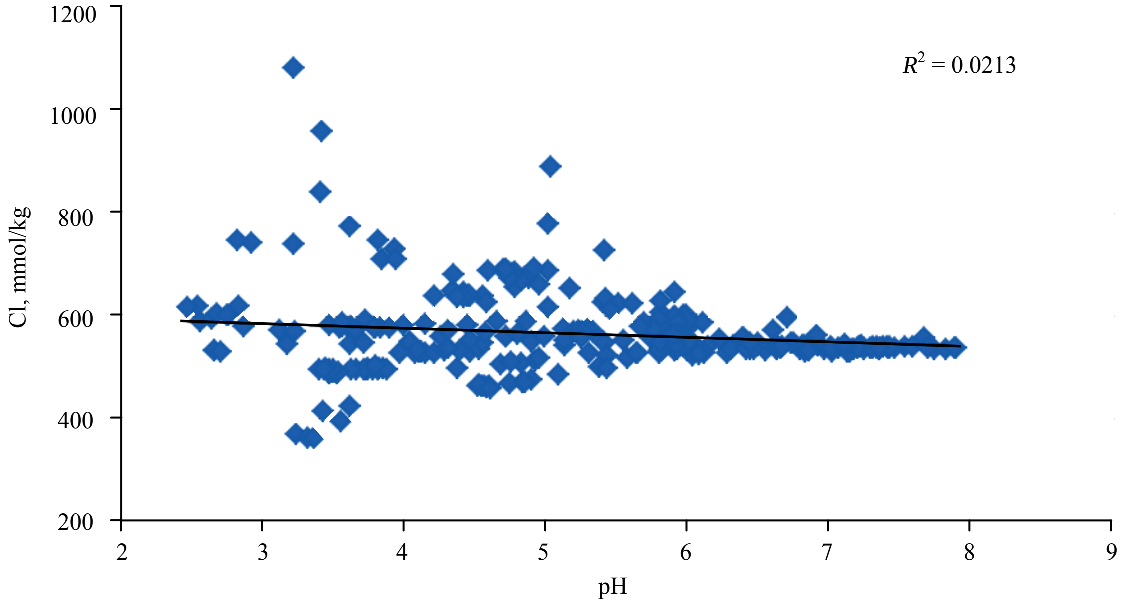


Fig.4. Dependence of [Cl⁻] on pH in hydrothermal oceanic solutions

On the other hand, discharge of desalinated waters has also been observed in real time and confirmed by analytical data [7].

It should be added that pH value of the solution defines intensity of metal desalination from surrounding rocks and formation of mineralizing fluid. The second parameter, after water acidity, that plays an important role in metal transfer is the content of chloride-ion, usually related to general mineralization [2, 6].

Results of correlation analysis also point to high negative coefficients of pair correlation between [Cl⁻] and pH [5, 7]. Results of carried out thermodynamic modeling confirm that metal transfer primarily occurs in the form of chloride complexes at high temperatures of the solution.

**Computer thermodynamic modeling of mixing processes in the discharge zone of hydrothermal solutions.** Theoretical justification and procedure of thermodynamic analysis of various geochemical processes, including oceanic geothermal ore genesis, have a longstanding history [3, 10-13, 16]. Hydro-geochemical model of hydrothermal discharge zone by S.M.Sudarikov and M.V.Zmievsky has been under development since 2010. Computer modeling has been carried out by M.V.Zmievsky in the Vernadsky Institute of Geochemistry and Analytical Chemistry of Russian Academy of Sciences, in the laboratory of Geochemical and Hydrothermal Modeling, using HCh software package [10, 11]. Initial data for modeling have been obtained by S.M.Sudarikov and J.-L.Charlou in the course of several expeditions, including collaborative work in the Russian-French expedition *SERPENTINE* on the research vessel «Pourquoi Pas?» [14, 15].

In the process of preparation for thermodynamic modeling, a hydro-geochemical model was constructed, nominally composed of two stages. The first stage corresponds to subsurface mixing of hydrothermal solutions and sea water, the second one – to post-discharge processes occurring in hydrothermal dispersion halos (plumes). Current paper focuses on the modeling results of the second stage conversions.

When constructing a physicochemical model using literature and analytical data, such parameters were assigned as temperature and pressure. Pressure has been assigned as a constant value – 300 atm (30 MPa), which corresponds to pressure at the depth of source location – approximately 3 km. Temperature has been assigned as a variable. Physicochemical model includes liquid, solid and gas phases. The number of dissolved forms of migration for different elements, existing in the system, is 152.

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Initial temperature in the observed area of hydrothermal system was 352 °C (temperature of the solution, measured at the source outfall), final temperature 2 °C (temperature of near-bottom waters). Overall the program contains 50 mixing stages with temperature differences of 7 °C. Basing on empirical data and literature, ratios of mixing solutions in the model vary according to a specially developed formula, which takes into account amount of hydrothermal solution, amount of sea water, numbers of mixing stages [5, 8].

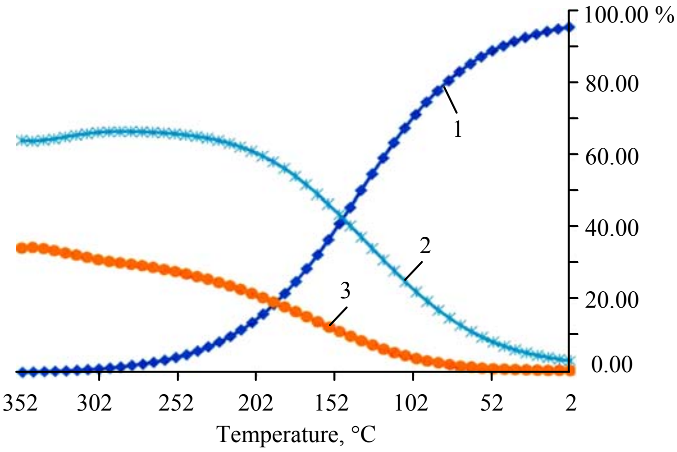


Fig.5. Ratios of the main forms of Mn water migration in the hydrothermal plume varying according to temperature and degree of fluid dilution with sea water
1 – $MnCl^{2+}$, 2 – $MnCl^{+}$, 3 – $MnCl_2^0$

It is most reasonable to verify the model against changes in manganese concentrations. Behavior of hydrothermal manganese in the plumes is fairly well understood [2, 7, 18, 19]. Mn dispersion halos are one of the main prospecting indicators of modern hydrothermal mineralization. Dissolved manganese forms the longest dispersion halos in the discharge zones due to its geochemical (migration) characteristics.

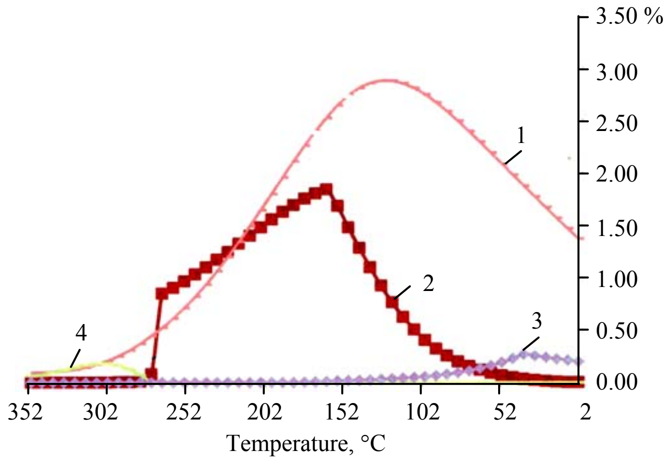


Fig.6. Ratios of secondary forms of Mn water migration in the hydrothermal plume varying according to temperature and degree of fluid dilution with sea water
1 – $MnSO_4^0$, 2 – $MnOH^+$, 3 – $MnCO_3^0$, 4 – $MnHSO_4^+$

Divalent manganese is quite resistant to the oxidizing environment of oceanic near-bottom waters. Besides, manganese does not form sulfide minerals in the zones of oceanic discharge of thermal springs. Hence, mineralization does not affect concentrations of different migration forms of this element in hydrothermal solutions and plumes, which makes modeling results for the dynamics of Mn dissolved forms more reliable.

Analysis of obtained results allows to state that prevailing forms of manganese migration in the plume are $Mn^{2+}$, $MnCl^+$, $MnCl_2$ (Fig.5). Moreover, geochemical structure of the plume is composed of two zones: 1) high-temperature zone (350-100 °C) with prevailing chloride complexes; 2) low-temperature zone (100-2 °C), where predominant form of transfer is a free divalent ion.

The first zone can be nominally associated with ascending plume with elevated turbulence, the second one – with lateral plume, within the bounds of which manganese in the form of a free divalent ion can be transferred at the distance of dozens of kilometers [18, 19]. Strong presence of sulfate and hydroxide complexes can also be noted (Fig.6). Sulfate complex in insignificant quantities (1.5 %) is detected in the lateral plume, whereas hydroxide complex is stable at temperatures 325-125 °C and can only be found in the ascending plume. These compounds are considered «secondary» forms of migration.

Impact of remaining forms of Mn transfer (e.g., carbonate) appears very small (< 0.5 %), and they are considered «insignificant» (Fig.7).

Presented results demonstrate practically full correspondence between modeling data and field observations. In particular, a great share of secondary and insignificant forms of Mn migration leave the solution with temperature decrease and take part in the formation of hydrothermal manganese crusts, widely occurring in the discharge zones of hydrothermal solutions [2, 4, 6, 17, 20].

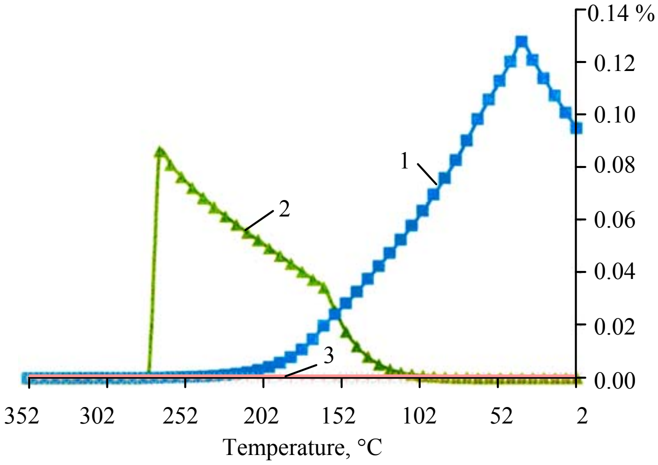


Fig.7. Ratios of insignificant forms of Mn water migration in the hydrothermal plume varying according to temperature and degree of fluid dilution with sea water
1 – $MnHCO_3^+$, 2 – $MnO^0$, 3 – total content of $MnHCO_3^+$, $MnO^0$, $MnO_2^{2-}$, $MnHS^+$, $Mn^{3+}$, $MnO_4^-$, $MnO_4^{2-}$

Verification of thermodynamic model proves its adequacy and allows to make a transition to the next stage of research – examination of geochemical dissipation for key ore components of hydrothermal solutions – Fe, Cu, Zn etc.

Identification of leading migration forms of ore-forming elements is needed to upgrade existing construction of ion selective electrodes, used to examine microcomponent content of near-bottom waters *in situ*. In the process of hydro-geochemical prospecting for hydrothermal sources at the oceanic bottom, ratio of different migration forms in the plume will allow to predetermine location of the discharge zone. In the long view, carried out research can improve efficiency of prospecting for mass concentrations of sulfide ores at the bottom of the Ocean.

**Conclusions.** The paper reviews the main methods and analyzes modeling results for geochemical processes in the submarine discharge zone of hydrothermal oceanic solutions. Initial data for modeling have been obtained by S.M.Sudarikov and J.-L.Charlou in the course of several expeditions, including collaborative work in the Russian-French expedition *SERPENTINE* on the research vessel «Pourquoi Pas?» (2007).

Results of physical (experimental) modeling of hydrothermal mineralization in the Ocean have been analyzed, along with field observations. Results of field observations, laboratory experiments and theoretical developments are supported by the analysis of regression model of mixing between hydrothermal solutions and sea water in the discharge zone.

Carried out analysis allowed: to verify the model and assess the quality of chemical analysis; to determine the source from which element gets into hydrothermal solution (degree and character of participation of solution components in the hydrothermal process); to calculate end member concentrations – reverse forecasting of element concentration using trend line (regression equation); basing on calculated concentrations of terminal hydrothermal solutions to prepare data for thermodynamic modeling.

Regression model of acid-base properties and chloridity of mineralizing thermal springs confirms adequacy of the model of double-diffusive convection for forming the composition of hydrothermal solutions. Differentiation of solutions according to concentrations of chloride-ion depending on temperature and pH indicator within this model is associated with phase conversions and mixing of fluids from two convection cells, one of which is a zone of brine circulation.

In order to carry out computer thermodynamic modeling of mixing processes between hydrothermal solutions and sea water, hydro-geochemical and physicochemical models of hydrothermal discharge zone have been created. The model has been verified against changes in manganese concentrations in the system: ascending plume – plume with neutral buoyancy. Analysis of obtained results allows to state that prevailing forms of manganese migration in the plume are $Mn^{2+}$, $MnCl^+$, $MnCl_2$. Two zones have been identified in the geochemical structure of the plume: 1) high-temperature zone (350-100 °C) with prevalence of chloride complexes; 2) low-temperature zone (100-2 °C), where predominant form of transfer is a free divalent ion.

The first zone can be nominally associated with ascending plume with elevated turbulence, the second one – with lateral plume, within the bounds of which manganese in the form of a free divalent ion can be transferred at the distance of dozens of kilometers. Sulfate complex in insignificant

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quantities (1.5 %) is detected in the lateral plume, whereas hydroxide complex is stable at temperatures 325-125 °C and can only be found in the ascending plume. These compounds are considered secondary forms of migration.

Presented results demonstrate practically full correspondence between modeling data and field observations. Verification of thermodynamic model proves its adequacy and allows to make a transition to the next stage of research – examination of geochemical dissipation for key ore components of hydrothermal solutions – Fe, Cu, Zn etc.

Identification of leading migration forms of ore-forming elements is needed to upgrade existing construction of ion selective electrodes, used to examine microcomponent content of near-bottom waters *in situ*. In the process of hydro-geochemical prospecting for sulfide mineralization at the oceanic bottom, ratio of different migration forms in the plume will allow to predetermine location of the discharge zone. In the long view, carried out research can improve efficiency of prospecting for mass concentrations of sulfide ores at the bottom of the Ocean.

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# STATUS AND DIRECTIONS OF IMPROVEMENT OF DEVELOPMENT SYSTEMS OF COAL SEAMS ON PERSPECTIVE KUZBASS COAL MINES

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The article presents the results of the analysis of the Russian coal mines experience in using the variant of the long-pillar development system with the abandonment of coal pillars in the mined out areas of longwall faces. In the Kuzbass mines, this option accounts for 90-95 % of the total volume of coal mined by the underground method. It is pointed out that it is necessary to take into account the negative influence of the pillars left in the worked out space on the geomechanical conditions of conducting mining operations in the overworked (underworked) seams.

A significant negative effect of the pillars is shown in combination with selective extraction of the adjacent layers on reduction of the balance reserves. The measures allowing to increase the efficiency of the use of long pillar mining systems for the development of adjacent series of seams are considered.

***Key words***: development system, long pillars, coal pillars, adjacent seams, negative influence of pillars, non-pillar mining method

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**Introduction.** During the last 15-20 years, in the Russian coal mines, when developing low-grade sloping coal seams with a thickness of 1.4-6.0 m, the most widely used system has been the development of long-pillar system with the preparation of extraction pillars with double workings, one of which is extracted after a longwall face, and the second one is reused when developing the adjacent pillar [6, 10]. During implementation of this system in a worked out area of longwall faces between adjacent sections, they leave the coal pillars that are not destroyed by rock pressure (Fig.1).

*Currently, the promising Russian mines using this type of development system mine almost all working areas with the most high-quality reserves. In the mines of the Kuznetsk basin this type of development accounts for more than 93 % of the total volume of coal mined by underground method* [8, 9].

Sharp, from 30 to 93 %, increase of production volumes at the Russian coal mines with the use of this development system after the transition of the coal industry to market relations due to the

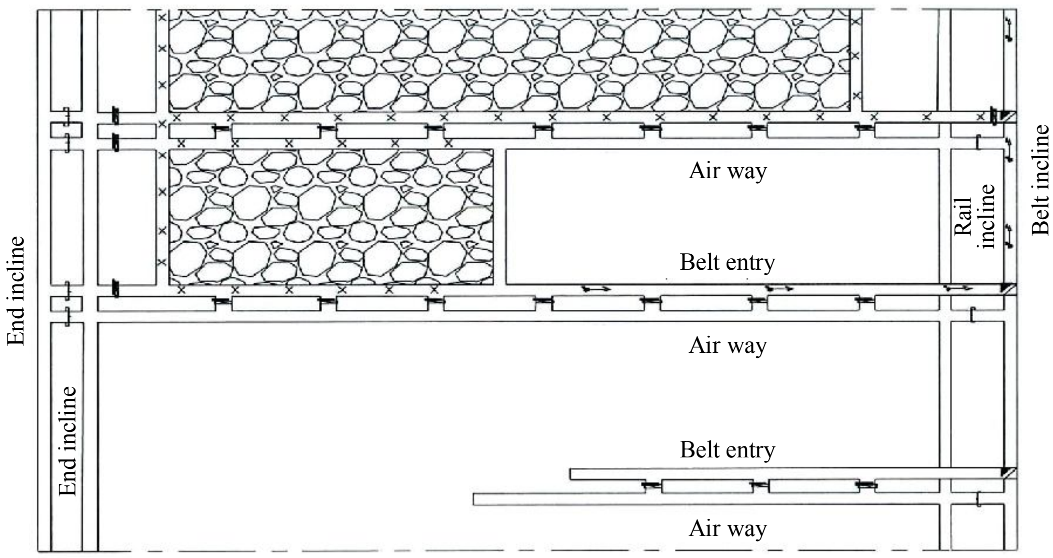


Fig.1. The principal layout of development system with long pillars with leaving pillars in worked out area used in promising mines in Kuzbass

fact that, despite its shortcomings (Fig.2), this system is most suited to the corporate interests of subsoil users during the seam excavation in favorable mining-geological and mining-technical conditions, using high-performance long wall mechanized set of equipment.

**Research results.** The economic attractiveness of this development system is mostly driven by the possibility of the use of roof bolting as the primary support of the development workings sections, as well as by creating conditions for the fullest use of the potential of modern high-efficiency longwall mining set of equipment and achieving high average daily load on longwall face.

The combination of these factors makes it possible to implement such progressive principle as «mine-longwall face» («mine-seam») in the favorable mining-geological and mining-technical conditions as the basis for forming the topology of mines. Mines, technological schemes of which are developed in accordance with this principle, are characterized by a high level of spatial concentration of mining operations and minimal production costs. Examples of such mines in the Kuznetsk basin are the following: «Taldinskaya – Zapadnaya 1», «Taldinskaya – Zapadnaya 2», «Kotinskaya», «Imeni V.D.Yalevsky», «Imeni A.D.Ruban», «Komsomolets», «Imeni 7 Noyabrya», and «Polysaevskaya».

When assessing the prospects for the use and the direction of improvement in the conditions of the Kuzbass mines, the development of long pillars with the abandonment of coal pillars in the mined out areas (see Fig.1), it is necessary to take into account the following trends in the change of

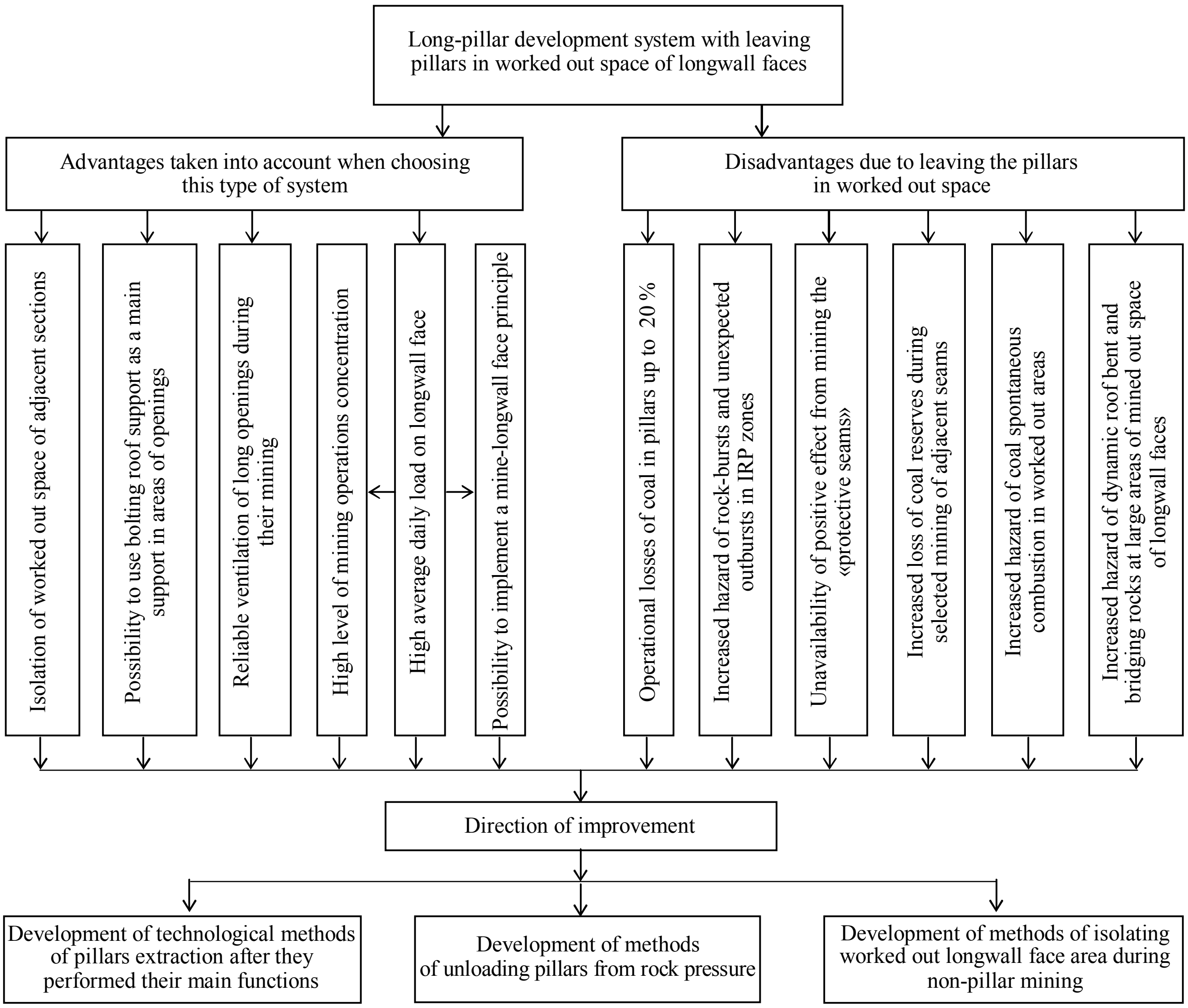


Fig.2. Assessment of long-pillar development system with preparation of pillars by double workings and leaving pillars in mined-out areas

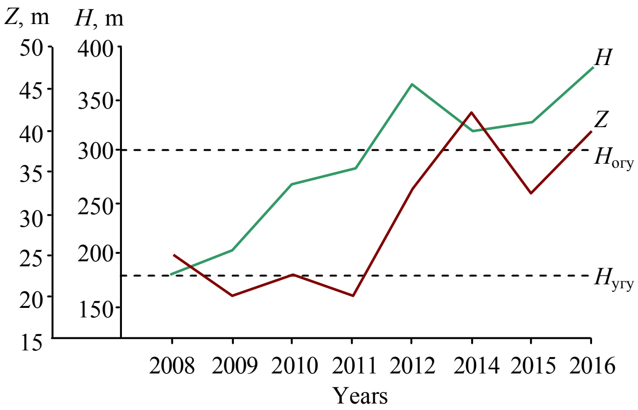


Fig.3. Changes of depth of mining $H$ and width of pillars $Z$, left in worked-out areas at mine «Kotinskaya»
$H_{yry}$ и $H_{ory}$ – limit depths of mining, after reaching them the seams are considered as hazardous or liable to rock bursts

mining, geological and mining factors: a rapid increase in the depth of mining, annual increments of which reach up to 25-30 m (Fig.3); an increase in the process of moving of mining operations to deeper horizons of outburst and rock-bump hazards of coal seams; an increase in the degree of negative influence of the pillars left in the worked-out space on the reliability of the functioning of the stopes and openings of adjacent coal seams in zones of increased rock pressure (IRP); an increase in operational losses of coal in the pillars left in the worked-out space; an increase of share of the overdeveloped (underworked) coal seams during performance of production tasks of coal companies in terms of production volumes.

*When evaluating the directions for improving the currently widely used development system* (*see Fig.1*), *it is fundamentally important to take into account that the prospects of coal companies depend on the efficiency of mining of previously overworked or underworked adjacent seams.*

So, in the next 5-10 years, the economic indicators of underground coal mining in 10 of the 12 mines of OJSC SUEK that develop formations of strata according to the «mine-longwall face» scheme will depend on the timeliness and efficiency of solving issues related to safe mining of previously overworked and underworked seams in the zones of influence of the pillars left in the worked out space of adjacent layers. It should be noted that the contribution of the mines of the coal company OAO SUEK to the total volume of coal mined by underground method in the Russian Federation is about 30 %.

Specificity of planning and conducting mining operations on the adjacent layers is associated with the need to take into account the IRP zones formed under (above) the pillars left in the worked-out space of the previously mined seam. The distance between the pillars, equal to the length of the longwall face, is 150-350 m. The length of the pillars is equal to the length of the extraction columns (up to 4000 m and more). The width of the pillars (see Fig.1), determined from the condition of ensuring a technologically satisfactory state of the developing areas of sections, fixed by the anchor support, reaches 35-40 m (Fig.3). With such a network of pillars left in the developed space above the seam, the total area of IRP zones in the overworked seam can reach 25-30 % and more of the area of the mine field. With the abandonment of the pillars in the developed space, it is practically impossible to use advanced development of «protective» seams as a regional method to prevent rock bursts and sudden outburst. Moreover, the probability of these dangerous events when developing the overworked (underworked) layers in the IRP zones is significantly increased.

It should be noted that in most of the Kuzbass mines, the depth of mining works has reached depths of 150-180 m, when exceeding, the seams are classified as liable to rock bursts. At present, more than 80 % of production faces are mined in conditions dangerous for rock bursts [9].

The negative effect of the coal pillars left in the worked-out space is manifested not only in increasing the outburst and rock burst hazard in overworked (underworked) seams in the IRP zones, but also in reducing the reliability of the functioning of the stopes and openings of these strata [2, 7]. When a certain maximum depth of mining operations is reached, the value of which depends on the specific combination of geological and mining factors, a change in the role of factors determining the state of the openings and the efficiency of controlling the rock pressure in the longwall faces are observed in the zones of IRP [2].

The technologically satisfactory condition of the openings is mainly determined by the values of the roof rocks subsidence and the swelling of the soil rocks. With the increase of stressed state of the rock mass near the openings, the role of these factors changes from the point of view of their influence on the stability of the workings.

In conditions characterized by values of coefficient $\eta_п < 0.4$ ($\eta_п = \sigma_{гм}/\sigma^{п}_{гм}$; $\sigma_c$ – stress in rock mass; $\sigma^{п}_{c}$ – ultimate compressive strength of immediate bottom during axial compression), the main type of deformation, determining the stability of the openings, is the subsidence of roof rocks. At the same time, the amount of the lowering of roof rocks exceeds 85 % of the value of convergence of the roof rocks and the floor. In these conditions, the violation of the normal mode of exploitation of openings occurs mainly as a result of faults and fractures of the roof rocks.

In conditions characterized by values of coefficient $\eta_п > 0.6$, the main type of deformations determining the stability of the openings, is rock swelling of the floor, the amount of which in convergence of rock of roof and floor can reach up to 70 % and more.

During descending mining of adjacent seams the negative influence of pillars on technical-economic indicators of mine operation process significantly increases when reaching depths, characterized by values of coefficients $\eta_п$ и $\eta_к$, equal to 0.25-0.35.

The different nature of the manifestations of rock pressure at different sections along the length of the openings and slopes also suggests different requirements for the methods of controlling the roof in longwall faces and ways of protecting the workings, which significantly complicates the fulfillment of the requirements for ensuring the reliability of their functioning.

The adaptation of production to the new conditions of mining operations during transition to the extraction of overworked (underworked) adjacent layers, as a rule, occurs with significant economic losses, increased risks of non-fulfillment of production tasks, a decrease in the safety of mining operations, and an increase in the operating loss of coal. This is evidenced by the experience of development process in 1972-1994 of adjacent coal seams $K_5^{1в}$ and $K_6$ in mines «Gukovskaya» and «Krasniy partisan» (Eastern Donbass) [2].

The issues under consideration are no less relevant for the coal industries of Australia, the USA, China, Ukraine and other foreign countries, developed in the field of mining [11, 12].

The presence of coal pillars in the worked-out space at high rates of longwall face advance increases the likelihood of congestion in significant areas and dynamic hanging of rocks of the main roof (bridging rocks) with falling of large masses of methane from the developed space into the longwall face and working sections, and thus appearance of serious accidents with explosions of methane and dust. The tragic consequences of the major accidents in the last 10-15 years on the most promising mines of Kuzbass show that this factor, which influences the level of industrial safety in the coal industry, should be the subject of detailed study. In the opinion of the author of this article, the significant complication of mining conditions in the overworked (underworked) seams with the use of technologies with the abandonment of the pillars in the worked-out space in combination with selective extraction of the seams is one of the main reasons why in the operating mines of Kuzbass up to 64 % [1, 5] of coal reserves previously attributed to balance reserves are now recognized as not promising for development.

*Despite significant shortcomings* (*see Fig.2*), *the development system of long pillars with the abandonment of the pillars in the worked-out space is planned to be used practically in all the mines of Kuzbass when developing low-grade sloping seams with one layer at full capacity.* At the mines of JSC «SUEK-Kuzbass» with the development of seams with thickness from 1.4 to 6.0 m, only this version of the development system is considered [6].

**Directions of technology improvement.** Depending on the specific combination of geological and mining and technical factors that determine the conditions for conducting mining operations, as well as the stage of development of adjacent layers, a reduction in the negative influence of the pillars can be achieved:

• when developing the first stratum of the suite with the complete development of the pillar on the same line as the longwall face; partial development of the pillar with a decrease in its width to the limit values at which the effect of the pillar on the working out of the adjacent layers is excluded; the creation of bands of rocks and other non-combustible materials between extraction sites; unloading the pillar from increased rock pressure after the fulfillment of its basic functions; increasing the length of the longwall face;

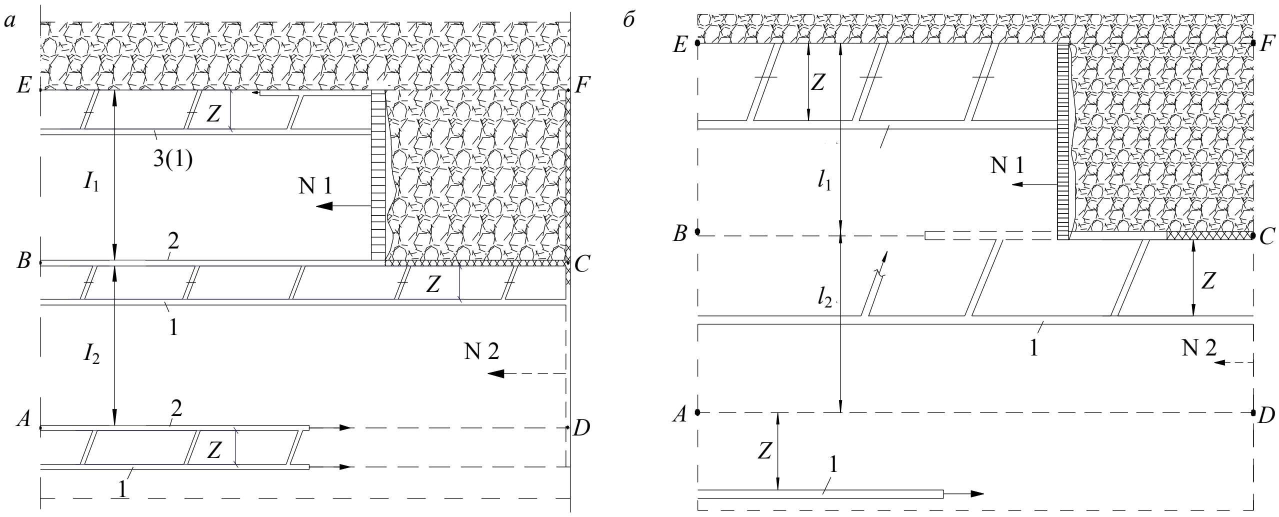


Fig.4. Variants of development system with long-pillar without leaving coal pillars in worked out space
*ABCD* – prepared columns; *BEFC* – developed columns; 1, 2 and 3 – sectional openings

• when working out the 2nd and subsequent adjacent layers of the formation by developing the pillars left in the worked-out space; the use of combined schemes that provide for a rational combination of the descending and ascending orders of development the adjacent seams and the locations of mutual arrangement of the pillars; unloading of the pillars left earlier in the worked-out space, from increased rock pressure; rational planning of mining operations in seams, taking into account the degree of negative influence of the pillars on the state of the openings and the management of the roof in the longwall faces.

When designing technological schemes for development of adjacent series of strata as an alternative to the development system presented in Fig.1, it is advisable to consider non-pillar technologies, in the implementation of which almost all drawbacks (see Fig.2) associated with the abandonment of coal pillars in the worked out space are eliminated [3, 4]. The creation of such resource-saving technologies is one of the priority directions of the research of the scientific school «Development of Solid Mineral Deposits» of the Stain-Petersburg Mining University. As an example in Fig.4 are shown schematic diagrams of the variants of the development system of long pillars with the extraction of the pillars on one line with the slope.

The area of application of the variant in Fig.4 *a* is gas mines with a long length of pillars and equipping longwall faces with high-performance mechanized complexes. It is advisable to consider the variant in Fig.4 *b* for sections of mine fields with limited dimensions and low rates of movement of the working face.

In order to ensure the possibility of using non-pillar technologies in development of coal seams liable to spontaneous combustion, within the framework of the scientific school «Development of Solid Mineral Deposits», options are being developed for creating the yielding strips of rock and other non-combustible materials between adjacent mined sections with characteristics that exclude formation of IRP zones in the underworked (overworked) coal seams.

## Main conclusions

1. When determining the directions for improving the technology for the development of flat coal seams with thickness of 1.5-6.0 m, it is of fundamental importance that in the short term the technical and economic indicators of underground coal mining in the mines of the Kuznetsk basin will depend significantly on the effectiveness of resolving issues related to development of adjacent layers, previously overworked or underworked using the development system long pillars with the abandonment of coal pillars in the worked-out space

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2. In assessing the economic feasibility and the permissibility of using a long-pillar development system with the abandonment of coal pillars in the worked-out space for the development of adjacent series of seams, it is necessary to take into account the additional operational losses of coal in the pillars (up to 20 %); costs associated with ensuring the safety of mining operations and the reliability of the functioning of the slopes and openings in the IRP zones, the total area of which is up to 25-30 % of the mine field area; reduction of balance coal reserves, associated with the worsening of mining and geological and mining-technical conditions of workings in overworked (underworked) adjacent seams; increased likelihood of hanging in large areas and dynamic sedimentation of rocks of the main roof (bridging rocks) with falling of large masses of methane from the developed space into the longwall face and working sections.

3. The priority areas of research in improving the long-pillar development system include the establishment of technology of erection between adjacent workings the air-isolating strips of non-combustible materials with parameters that provide technologically satisfactory condition of sectional openings having roof bolting support, insulation of developed areas of adjacent extraction sections, excluding formation of hazardous IRP zones in overworked (underworked) seams.

4. In current socio-economic conditions of the coal industry's operation, the problem of selecting coal mining technologies in promising Russian mines is beyond the scope of solving only technical issues. The present «conflict of interests» between the state and subsoil users demonstrates the relevance of issues related to the search for compromise solutions based on legislative acts and ensuring rational (from the state's perspective) development of nonrenewable natural resources and financial interest of companies in the use of resource-saving technologies

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# ANGLES OF TOTAL SHIFTS AND ANGLES OF MAXUMUM CROP DURING DEVELOPMENT OF FACES DIAGONAL TO SEAM STRIKE DIRECTIONS

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When predicting deformations and determining measures to protect underworked objects, angular parameters are used: the boundary angles, the angles of total shift, the angle of maximum crop. The values of these angular parameters are given in the normative documents, but only for sections across and along the strike of the formation. However, at present, longwall face mining is mainly being carried out along a diagonal direction to the strike of the formation. In connection with this, the determination of the values of the angular parameters for such conditions is a topical task.

The method of determination and the analytical dependences of the angles of total shifts and angles of maximum crop in sections of the longitudinal and transverse axes of coal-mining faces developed along diagonal directions to the strike of the formation are proposed. These angular parameters are used for prognosis of deformations of the earth's surface and for determining the characteristic zones of influence of mine workings on the local places.

***Key words***: angles of total shifts, angles of maximum crop, diagonal directions of contour of working, deformation of earth surface

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**Introduction.** Angular parameters are used to determine the boundaries of the zones of mine workings influence on the earth's surface and predict the deformations of the latter when working and protecting buildings, structures and natural objects [8, 12, 15]. Their normative values are determined by many years of research by many authors [2, 4, 6, 9-11, 13, 14] and are given in the «Rules for underworking ...» [1] only for the main cross-sections of the trough across and along the strike of the formation.

Currently, longwall faces are often mined along diagonal directions to the strike of the formation [5, 7]. The main sections of the trough should be considered cross sections along the longitudinal and transverse axis of a working. Therefore, the determination of the angular parameters in these sections is very important.

The analytic dependences of the boundary angles in cross sections, which are diagonal to the strike of the formation, were published by the authors of this article in [3]. Therefore, in this paper only the angles of total shifts and the angles of maximum draw are considered.

**Methods for determining angles of total shifts and angles of maximum draw.** Let us consider the coal seam working ($\alpha = 20°$) developed by «diagonal» longwall face in the contour I-II-III-IV (Fig.1). Let's assume we will replace the seam cutting area with short faces (with a slight discontinuity in time) along the strike (Fig.1, *a*) and across the strike of the formation (Fig.1, *b*) with the stopping of the bottom lines along the contour specified above. Then, according to the «Rules of underworking ...» [10], we get a flat bottom of the trough, bounded by lines 2, 3, with boundary points $E_{ai}$, $E_{bi}$ on the axes of the «diagonal» face (where *i* is the number of points). In this case, the distances $A_iE_{ai} \neq A_iE_{bi}$. Now the problem is reduced to finding the average weight points $E_i$. This principle is also the basis of the methodology proposed here.

Since the lines at the angles $\Psi$ and $\Theta$ have a constant angle of inclination in the bedrock and incrop deposits, in order to simplify the calculations, the process will be considered as occurring only in bedrock, assuming the depth seam incrop line equal to ± 0.0. Let us draw conditional advance of the «diagonal» face line to seam incrop point (Fig.2, *b*). Then $M_1$ point will be both the pit limit and flat bottom of the trough, since the depth $H = 0$.

From Fig.2, *b*, the seam inclination angle along the production line I-II and the distance $A_1M_1$ are:

$$\mathrm{tg}\alpha'_{\mathrm{I-II}} = \mathrm{tg}\alpha \cdot \sin\varepsilon, \quad A_1M_1 = \frac{H_{A_1}}{\mathrm{tg}\alpha \cdot \sin\varepsilon},$$

where $\alpha$, $\varepsilon$, $H_{A1}$ – seam inclination angle, acute angle between longitudinal axis of working and seam strike line, seam depth at point $A_1$.

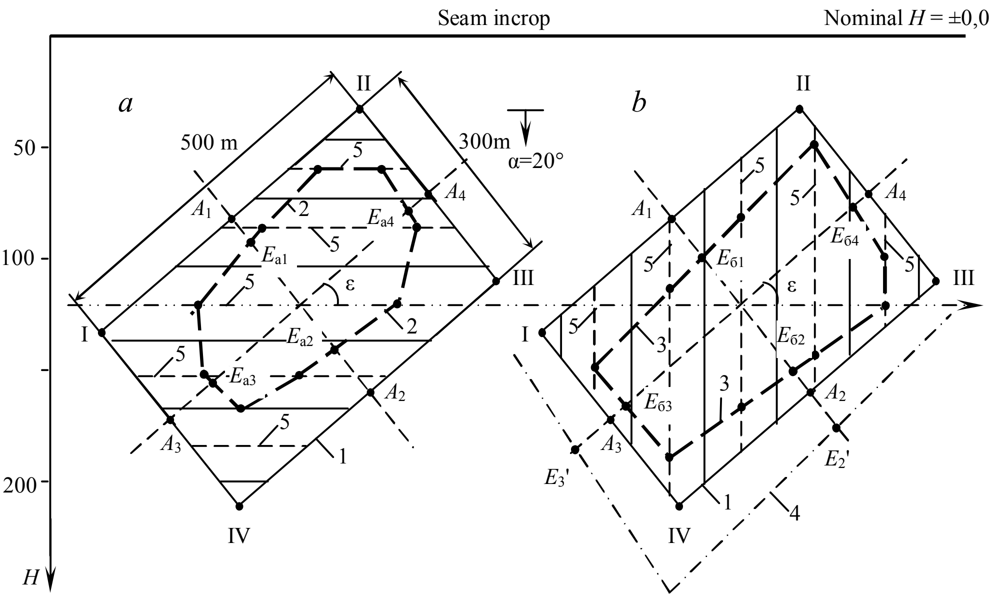


Fig.1. Layout of «diagonal» face with seam inclination angle of $\alpha = 20°$ with conditional replacement of area with short faces along the strike (*a*) and across the strike (*b*) of the formation

1, 2, 3 – pit limit points: coal seam mining with «diagonal» face; flat bottom of trough with conditional replacement of are with short faces along the strike and across the strike of the formation; 4 – when $\alpha > 90° - \Psi_1$ the trough flat bottom boundary of angle $\Psi_1$ (with replacement of faces across the strike) is set outside the contour of «diagonal» face; 5 – longitudinal axes of short faces; ε – acute angle between longitudinal axis of «diagonal» face and seam strike line; $A_1$-$A_2$, $A_3$-$A_4$ – lateral (short) and longitudinal (long) axes of the face

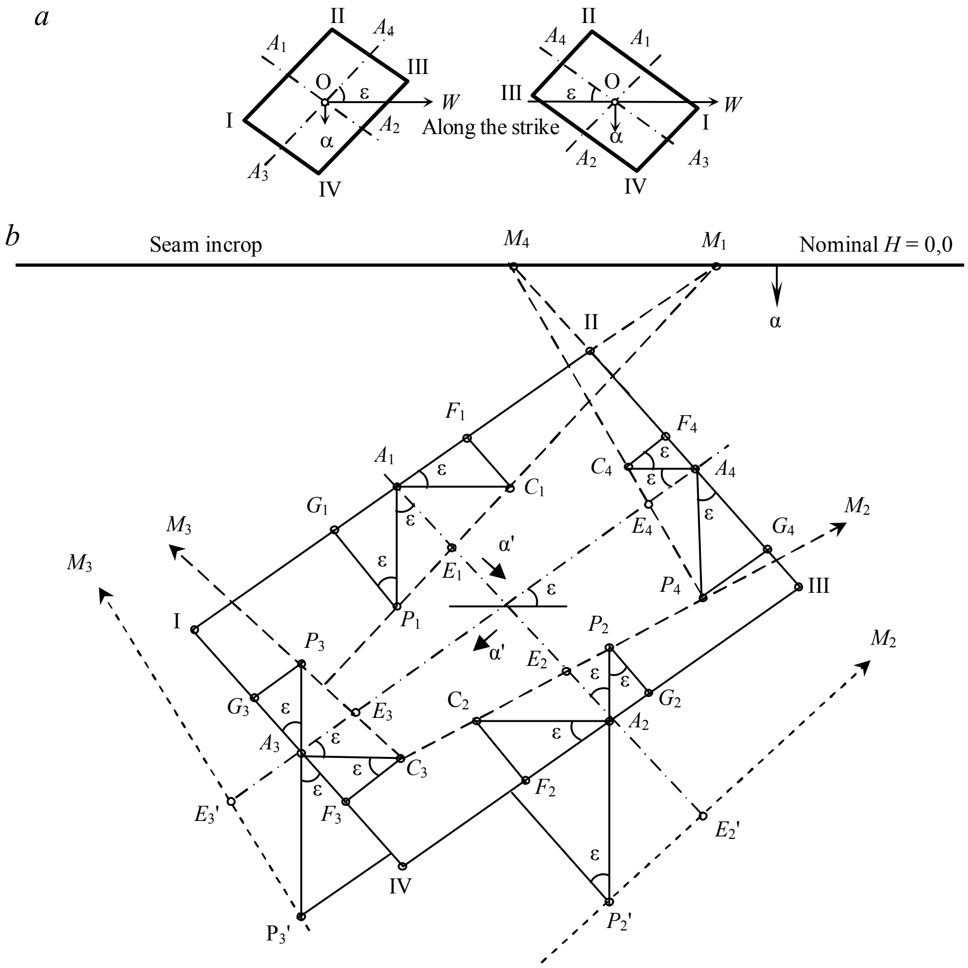


Fig. 2. Design layout for determining angles of total shifts in axial cross-sections of «diagonal» face:

*a* – orientation pattern of «diagonal» face along the seam strike line; *b* – a pattern of geometrical relations between angle and linear parameters of horizontal alignment. Also see p. 300

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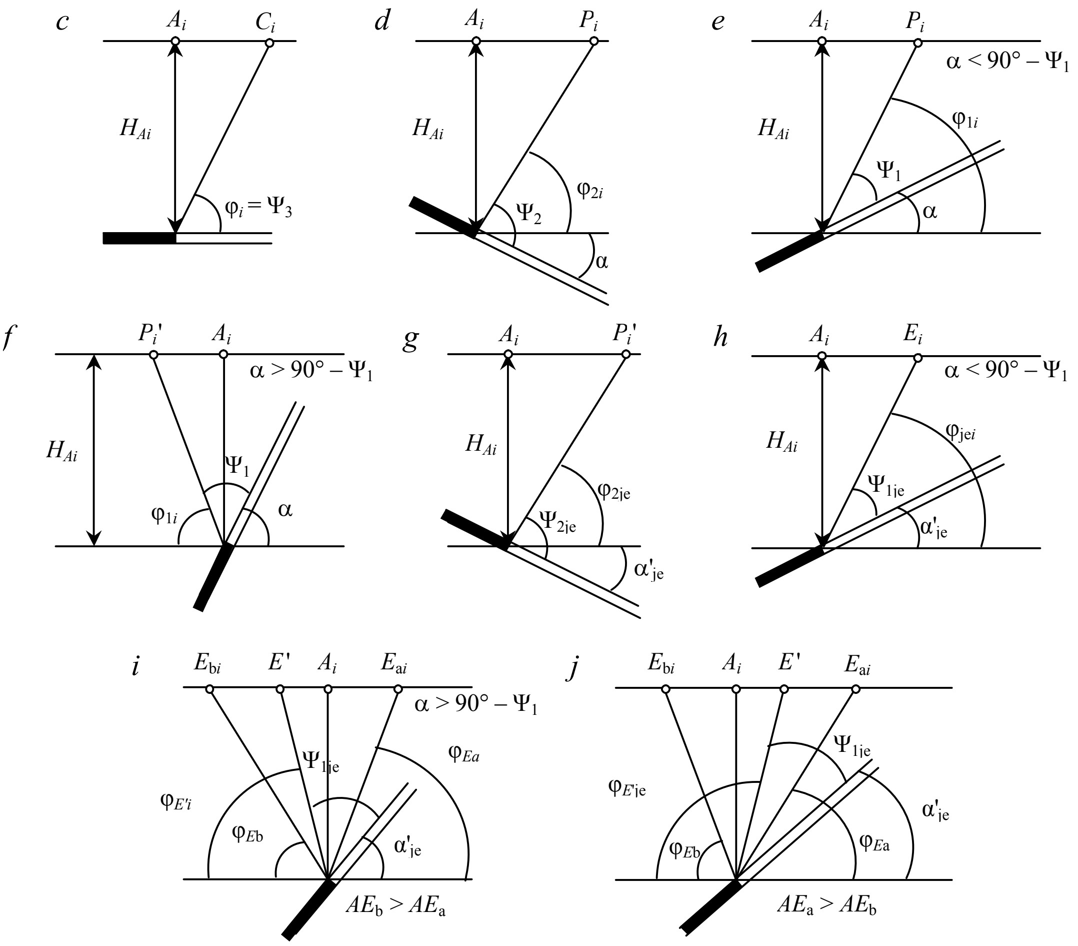


Fig. 2. Ending. Design layout for determining angles of total shifts in axial cross-sections of «diagonal» face:

*c-j* – the same in vertical cross-sections; $A_i$, $C_i$, $P_i$, $P_i'$ – boundary points (where $i$ – point number): contours of «diagonal» face at axial lines; flat bottom pf trough, determined by angle $\Psi_3$ (with conditional replacement with faces along the strike); the same with angles $\Psi_1$, $\Psi_2$ (with replacement of faces across the strike) with $\alpha < 90° - \Psi_1$; the same for angle $\Psi_1$ (when replacing faces across the strike) with $\alpha > 90° - \Psi_1$; $E_i$, $E_i'$, $E_{ai}$, $E_{бi}$ – boundary points of flat bottom of trough at axial lines of «diagonal» face: with $\alpha < 90° - \Psi_1$; with $\alpha > 90° - \Psi_1$ (*i*, *j*); with $\alpha > 90° - \Psi_1$ and replacement with faces along the strike; with $\alpha > 90° - \Psi_1$ and replacement with faces across the strike: $\alpha$, $\alpha'$, $\varepsilon$ – angles: seam inclination; seam inclination at axial cross-sections of «diagonal» face; acute angle between longitudinal axis of the face and seam strike line; $\Psi_1$, $\Psi_2$, $\Psi_3$, $\Psi_{1j}$, $\Psi_{2j}$, $\Psi_{1e}$, $\Psi_{2e}$ – angles of total shifts at cross-sections across and along the strike and in cross-sections of «short» and «long» axes of «diagonal» face; $\varphi_1$, $\varphi_2$, $\varphi_3$, $\varphi_{1j}$, $\varphi_{2j}$, $\varphi_{1e}$, $\varphi_{2e}$ – angles of inclination of lines corresponding to angles of total shift and linear parameters of horizontal alignment

Let us determine the distance $A_1E_1$ (between working boundary and flay bottom of trough boundary) separately with conditional replacement of face mining along the strike (a) and across the strike (b) accordingly in left and right columns:

*a*)

$$A_1C_1 = \frac{H_{A_1}}{\mathrm{tg}\varphi_3} \quad \text{(Fig.2, } c\text{)},$$

$$F_1C_1 = \frac{H_{A_1}\sin\varepsilon}{\mathrm{tg}\varphi_3} \quad \text{(Fig.2, } b\text{)},$$

$$A_1F_1 = \frac{H_{A_1}\cos\varepsilon}{\mathrm{tg}\varphi_3},$$

$$A_1E_{1(\mathrm{a})} = \frac{A_1M_1 \cdot F_1C_1}{F_1M_1},$$

$$A_1E_{1(\mathrm{a})} = \frac{H_{A_1}\sin\varepsilon}{tg\varphi_3 - tg\alpha\cdot\sin\varepsilon\cdot\cos\varepsilon};$$

*b*)

$$A_1P_1 = \frac{H_{A_1}}{\mathrm{tg}\varphi_2} \quad \text{(Fig.2, } e\text{)},$$

$$P_1G_1 = \frac{H_{A_1}\cos\varepsilon}{\mathrm{tg}\varphi_2} \quad \text{(Fig.2, } b\text{)},$$

$$A_1G_1 = \frac{H_{A_1}\sin\varepsilon}{\mathrm{tg}\varphi_2},$$

$$A_1E_{1(\mathrm{b})} = \frac{H_{A_1}\sin\varepsilon}{\mathrm{tg}\varphi_2 + \mathrm{tg}\alpha\cdot\sin^2\varepsilon},$$

$$A_1E_{1(\mathrm{b})} = \frac{A_1M_1 \cdot P_1G_1}{G_1M_1},$$

where $\varphi_2$, $\varphi_3$ – inclination angles of total shift lines at cross-sections across and along the strike at point $A_1$ (Fig.2 *b*, *e*).

We obtain two values $A_1E_1$ – the distance from the working face boundary to the boundary of the flat bottom of the trough in the section of the transverse axis $A_1$–$A_2$ of the «diagonal» face I-II-III-IV. At $\varepsilon = 0°$, the line (boundary) I-II is oriented along the strike of the formation and only the angle $\varphi_2$ affects the distance $A_1E_1$, i.e. the expression $A_1E_1$ (*b*). Similarly, at $\varepsilon = 90°$, only $A_1E_1$ (*a*) affects $A_1E_1$. For $\varepsilon = \varepsilon = 45°$ there must be an equivalent effect of the equalities with the indices (*a*) and (*b*). To fulfill these conditions, we take weighting coefficients $P_{(a)} = \sin\varepsilon$, $P_{(b)} = \cos\varepsilon$. Then the average weighting coefficient value of distance $A_1E_1$ is:

$$A_1E_1 = H_{A_1}\left[\begin{array}{l}\dfrac{\sin^2\varepsilon}{(\mathrm{tg}\varphi_3 - \mathrm{tg}\alpha\cdot\sin\varepsilon\cdot\cos\varepsilon)(\sin\varepsilon+\cos\varepsilon)}+\\ +\dfrac{\cos^2\varepsilon}{(\mathrm{tg}\varphi_2 + \mathrm{tg}\alpha\cdot\sin^2\varepsilon)(\sin\varepsilon+\cos\varepsilon)}\end{array}\right].$$

From Fig.2, *c*, *d*, *e*, *g*:

$$\varphi_3 = \Psi_3, \quad \varphi_2 = \Psi_2 - \alpha, \quad \varphi_2 = \mathrm{arctg}\frac{H_{A_1}}{A_1E_1}.$$

Then

$$A_1E_1 = H_{A_1}\left[\begin{array}{l}\dfrac{\sin^2\varepsilon}{(\mathrm{tg}\Psi_3 - \mathrm{tg}\alpha\cdot\sin\varepsilon\cdot\cos\varepsilon)(\sin\varepsilon+\cos\varepsilon)}+\\ +\dfrac{\cos^2\varepsilon}{(\mathrm{tg}(\Psi_2-\alpha) + \mathrm{tg}\alpha\cdot\sin^2\varepsilon)(\sin\varepsilon+\cos\varepsilon)}\end{array}\right]; \quad (1)$$

$$\varphi_{2j} = \mathrm{arctg}\left\{1:\left[\begin{array}{l}\dfrac{\sin^2\varepsilon}{(\mathrm{tg}\Psi_3 - \mathrm{tg}\alpha\cdot\sin\varepsilon\cdot\cos\varepsilon)(\sin\varepsilon+\cos\varepsilon)}+\\ +\dfrac{\cos^2\varepsilon}{(\mathrm{tg}(\Psi_2-\alpha) + \mathrm{tg}\alpha\cdot\sin^2\varepsilon)(\sin\varepsilon+\cos\varepsilon)}\end{array}\right]\right\}. \quad (2)$$

The formula is cumbersome, but simple in calculations. Nevertheless, to simplify it (and subsequent formulas) we introduce the notation: $A = \mathrm{tg}\alpha\cdot\sin\varepsilon\cdot\cos\varepsilon$, $B = \mathrm{tg}\alpha\cdot\sin^2\varepsilon$, $C = \mathrm{tg}\alpha\cdot\cos^2\varepsilon$, $\mathrm{D} = \sin\varepsilon + \cos\varepsilon$.

Then

$$\varphi_{2j} = \mathrm{arctg}\left\{1:\left[\frac{\sin^2\varepsilon}{(\mathrm{tg}\Psi_3 - A)D} + \frac{\cos^2\varepsilon}{(tg(\Psi_2-\alpha)+B)D}\right]\right\}. \quad (3)$$

From Fig.2, *g*

$$\Psi_{2j} = \varphi_{2j} + \alpha'_{A_1-A_2};$$

$$\Psi_{2j} = \varphi_{2j} + \mathrm{arctg}(\mathrm{tg}\alpha\cdot\cos\varepsilon), \quad (4)$$

where $\Psi_{2j}$, $\varphi_{2j}$ – angle of total shift and angle of inclination of total shift lines from the up dip in cross-section of longitudinal axis of working (in point $A_1$ at Fig.2, *b*).

Similarly, analytical dependencies are obtained for determining the angles of total shifts: $\Psi_{2e}$ (with $\alpha < 70°$), $\Psi_{1j}$ (with $\alpha < 90° - \Psi_1$), $\Psi_{1e}$ (with $\alpha < 90° - \Psi_1$) respectively from the up dip of the longitudinal axis, from the down dip in the section of the transverse axis and from the down dip in the section of the longitudinal axis of the «diagonal» face. The corresponding formulas are given in Table 1, where the accepted notations are also indicated.

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In addition, we will look at at the angles of total shifts from the down dip side of the formation in the axial sections of the «diagonal» face with $\alpha > 90° - \Psi_1$. In this case when replacing the coal mining area developed with faces across the strike the boundary of flat bottom of trough is located above the coal pillar, outside the mining contour (Fig.2, *f*). The details will be given on the examples of angle $\Psi_{1j}$ at point $A_2$ (Fig.2, *b*). Here the distance $A_2E_2$, when replacing the coal mining area developed by faces along the strike we calculate (applying the same method) using the formula:

$$A_2E_{2(a)} = \frac{H_{A_2} \sin\varepsilon}{\text{tg}\varphi_3 + \text{tg}\alpha \cdot \sin\varepsilon \cdot \cos\varepsilon}. \quad (5)$$

When replacing the coal mining area developed with faces across the strike the point $E_b$ is located outside the contour of «diagonal» face and distance $A_2E_{2(b)}$ is determined using the formula (Fig.2, *j*):

$$A_2E_{2(b)} = \frac{H_{A_2} \cos\varepsilon}{\text{tg}\varphi_1 + \text{tg}\alpha \cdot \sin^2\varepsilon}. \quad (6)$$

According to the justification stated above, we take weighting coefficients: $P_{A_2E_2(a)} = \sin\varepsilon$, $P_{A_2E_2(b)} = \cos\varepsilon$.

Then average weighting coefficient value is

$$A_2E_2 = H_{A_2}\left[\frac{\sin^2\varepsilon}{(\text{tg}\varphi_3 + \text{tg}\alpha \cdot \sin\varepsilon \cdot \cos\varepsilon)(\sin\varepsilon + \cos\varepsilon)} - \frac{\cos^2\varepsilon}{(\text{tg}\varphi_1 + \text{tg}\alpha \cdot \sin^2\varepsilon)(\sin\varepsilon + \cos\varepsilon)}\right].$$

Let us substitute the values $\varphi_3 = \Psi_3$ (Fig.2, *c*), $\varphi_1 = 180° - (\Psi_1 + \alpha)$ (рис.2, *f*) и $\varphi_{1j} = \dfrac{H_{A_2}}{A_2E_2}$.

Then

$$A_2E_2 = H_{A_2}\left[\frac{\sin^2\varepsilon}{(\text{tg}\Psi_3 + \text{tg}\alpha \cdot \sin\varepsilon \cdot \cos\varepsilon)(\sin\varepsilon + \cos\varepsilon)} - \frac{\cos^2\varepsilon}{(\text{tg}\alpha \cdot \sin^2\varepsilon - \text{tg}(\Psi_1 + \alpha))(\sin\varepsilon + \cos\varepsilon)}\right]; \quad (7)$$

$$\varphi_{1j} = \text{arctg}\left\{1 : \left[\frac{\sin^2\varepsilon}{(\text{tg}\Psi_3 + \text{tg}\alpha \cdot \sin\varepsilon \cdot \cos\varepsilon)(\sin\varepsilon + \cos\varepsilon)} - \frac{\cos^2\varepsilon}{(\text{tg}\alpha \cdot \sin^2\varepsilon - \text{tg}(\Psi_1 + \alpha))(\sin\varepsilon + \cos\varepsilon)}\right]\right\} \quad (8)$$

or with the above given notations

$$\varphi_{1j} = \text{arctg}\left\{1 : \left[\frac{\sin^2\varepsilon}{(\text{tg}\Psi_3 + A)\text{D}} - \frac{\cos^2\varepsilon}{(B - \text{tg}(\Psi_1 + \alpha))\text{D}}\right]\right\}. \quad (9)$$

If according to the calculations it will be $\varphi_{1j2} > 0°$ (i.e. $A_iE_{ai} > A_iE_{bi}$), then the boundary point $E'$ of flat bottom of trough of «diagonal» face is located inside the contour I-II-III-IV (Fig.2, *j*) and angle of total shifts equals:

$$\Psi_{1j} = \varphi_{1j} - \alpha'_{A_1-A_2};$$

$$\Psi_{1j} = \varphi_{1j} - \text{arctg}(\text{tg}\alpha \cdot \cos\varepsilon). \quad (10)$$

With $\varphi_{1j2} < 0°$ (Fig.2, *j*)

$$\Psi_{1j} = 180° - |\varphi_{1j_2}| - \alpha'_{A_1-A_2};$$

$$\Psi_{1j} = 180° - |\varphi_{1j_2}| - \mathrm{arctg}(tg\alpha \cdot \cos\varepsilon). \quad (11)$$

Similarly, the analytic dependence is determined for the angle $\Psi_1$ (at point $A_3$ in Fig. 2, b) of total shifts on the down dip in the section of the longitudinal axis of the «diagonal» working. The formulas are given in Table. 1.

The method of determining the angles of maximum seam crop will be considered using the example of a section along the transverse axis $A_1$–$A_2$ of a «diagonal» working (Fig.3).

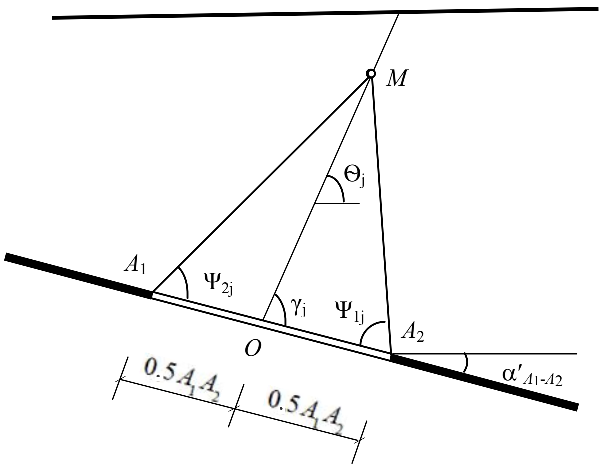


Fig.3. Cross-section of longitudinal axis $A_1$–$A_2$ of «diagonal» working

From triangle $A_1MA_2$ (Fig.3)

$$A_1M = \frac{A_1A_2 \sin\Psi_{1j}}{\sin(\Psi_{1j} + \Psi_{2j})}; \quad A_2M = \frac{A_1A_2 \sin\Psi_{2j}}{\sin(\Psi_{1j} + \Psi_{2j})}.$$

The *OM* line drawn from the middle of working at the angle of the maximum crop is the median of the triangle and its length is determined by the formula

$$OM = \frac{1}{2}\sqrt{2(A_1M^2 + A_2M^2) - A_1A_2^2};$$

$$OM = \frac{A_1A_2}{2\sin(\Psi_{1j} + \Psi_{2j})}\sqrt{2(\sin^2\Psi_{1j} + \sin^2\Psi_{2j}) - \sin^2(\Psi_{1j} + \Psi_{2j})}.$$

From triangle $OMA_2$

$$\sin\gamma = \frac{A_2M \sin\Psi_{1j}}{OM};$$

$$\gamma_j = \arcsin\left[\frac{2\sin\Psi_{1j}\sin\Psi_{2j}}{\sqrt{2(\sin^2\Psi_{1j} + \sin^2\Psi_{2j}) - \sin^2(\Psi_{1j} + \Psi_{2j})}}\right]. \quad (12)$$

The angle of maximum crop $\theta_j$ at the cross-section of traverse axis of «diagonal» working is:

$$\theta_j = \gamma_j - \mathrm{arctg}\alpha'_{A_1-A_2}$$

$$\theta_j = \arcsin\left[\frac{2\sin\Psi_{1j}\sin\Psi_{2j}}{\sqrt{2(\sin^2\Psi_{1j} + \sin^2\Psi_{2j}) - \sin^2(\Psi_{1j} + \Psi_{2j})}}\right] - \mathrm{arctg}(\mathrm{tg}\alpha \cdot \cos\varepsilon). \quad (13)$$

The same is for cross-section of longitudinal axis of «diagonal» working

$$\gamma_f = \arcsin\left[\frac{2\cdot\sin\Psi_{1f}\sin\Psi_{2f}}{\sqrt{2(\sin^2\Psi_{1f} + \sin^2\Psi_{2f}) - \sin^2(\Psi_{1f} + \Psi_{2f})}}\right]; \quad (14)$$

$$\theta_f = \arcsin\left[\frac{2\sin\Psi_{1f}\sin\Psi_{2f}}{\sqrt{2(\sin^2\Psi_{1f} + \sin^2\Psi_{2f}) - \sin^2(\Psi_{1f} + \Psi_{2f})}}\right] - \mathrm{arctg}(\mathrm{tg}\alpha \cdot \cos\varepsilon). \quad (15)$$

*Table 1*

**Formulas for determining angles of line inclinations (φ) and angles of total shifts (Ψ) at cross-section of traverse (index j) and longitudinal (index f) axes of «diagonal» working**

| Cross-sections | Working boundaries (Fig. 2 b) | Angles of line inclinations at angles of total shifts | Angles of total shifts |
|---|---|---|---|
| Along traverse (short) axis of working ($A_1$–$A_2$ at Fig.2) | At the upper boundary of the working (at point $A_1$) with α < 70° | $\varphi_{2j} = \mathrm{arctg}\left\{1 : \left[\frac{\sin^2\varepsilon}{(\mathrm{tg}\Psi_3 - A)D} + \frac{\cos^2\varepsilon}{(\mathrm{tg}(\Psi_2 - \alpha) + B)D}\right]\right\}$ | $\Psi_{2j} = \varphi_{2j} + \mathrm{arctg}(\mathrm{tg}\alpha \cdot \cos\varepsilon)$ |
| | At the lower boundary of the working (at point $A_2$) with α < 90° – $\Psi_1$ | $\varphi_{1j} = \mathrm{arctg}\left\{1 : \left[\frac{\sin^2\varepsilon}{(\mathrm{tg}\Psi_3 + A)D} + \frac{\cos^2\varepsilon}{(\mathrm{tg}(\Psi_1 + \alpha) - B)D}\right]\right\}$ | $\Psi_{1j} = \varphi_{1j} - \mathrm{arctg}(\mathrm{tg}\alpha \cdot \cos\varepsilon)$ |
| | At the lower boundary of the working (at point $A_2$) with α > 90° – $\Psi_1$ | $\varphi_{1j} = \mathrm{arctg}\left\{1 : \left[\frac{\sin^2\varepsilon}{(\mathrm{tg}\Psi_3 + A)D} - \frac{\cos^2\varepsilon}{(B - \mathrm{tg}(\Psi_1 + \alpha))D}\right]\right\}$ | With $\varphi_{1j} > 0°$<br>$\Psi_{1j} = \varphi_{1j} - \mathrm{arctg}(\mathrm{tg}\alpha \cdot \cos\varepsilon)$<br>With $\varphi_{1j} < 0°$<br>$\Psi_{1j} = 180° - \lvert\varphi_{1j}\rvert - \mathrm{arctg}(\mathrm{tg}\alpha \cdot \cos\varepsilon)$ |
| Along longitudinal (long) axis of working ($A_3$–$A_4$ at Fig.2) | At the upper boundary of the working (at point $A_4$) with α < 70° | $\varphi_{2f} = \mathrm{arctg}\left\{1 : \left[\frac{\cos^2\varepsilon}{(\mathrm{tg}\Psi_3 - A)D} + \frac{\sin^2\varepsilon}{(\mathrm{tg}(\Psi_2 - \alpha) + C)D}\right]\right\}$ | $\Psi_{2f} = \varphi_{2f} + \mathrm{arctg}(\mathrm{tg}\alpha \cdot \sin\varepsilon)$ |
| | At the lower boundary of the working (at point $A_3$) with α < 90° – $\Psi_1$ | $\varphi_{1f} = \mathrm{arctg}\left\{1 : \left[\frac{\cos^2\varepsilon}{(\mathrm{tg}\Psi_3 + A)D} + \frac{\sin^2\varepsilon}{(\mathrm{tg}(\Psi_1 + \alpha) - C)D}\right]\right\}$ | $\Psi_{1f} = \varphi_{1f} - \mathrm{arctg}(\mathrm{tg}\alpha \cdot \sin\varepsilon)$ |
| | At the lower boundary of the working (at point $A_3$) with α > 90° – $\Psi_1$ | $\varphi_{1f} = \mathrm{arctg}\left\{1 : \left[\frac{\cos^2\varepsilon}{(\mathrm{tg}\Psi_3 + A)D} - \frac{\sin^2\varepsilon}{(C - \mathrm{tg}(\Psi_1 + \alpha))D}\right]\right\}$ | With $\varphi_{1f} > 0°$<br>$\Psi_{1f} = \varphi_{1f} - \mathrm{arctg}(\mathrm{tg}\alpha \cdot \sin\varepsilon)$<br>With $\varphi_{1f} < 0°$<br>$\Psi_{1f} = 180° - \lvert\varphi_{1f}\rvert - \mathrm{arctg}(\mathrm{tg}\alpha \cdot \sin\varepsilon)$ |

*Note.* $A = \mathrm{tg}\alpha \cdot \sin\varepsilon \cdot \cos\varepsilon$, $B = \mathrm{tg}\alpha \cdot \sin^2\varepsilon$, $C = \mathrm{tg}\alpha \cdot \cos^2\varepsilon$, $D = \sin\varepsilon + \cos\varepsilon$; $\Psi_1$, $\Psi_2$, $\Psi_3$ – angles of total shifts at cross-sections across and along the seam strike [1]); α – angle of seam dip; ε – acute angle between longitudinal (long) axis of working and seam strike line.

**Conclusions.** Thus, the authors of the article proposed a method for determining and analyzing the dependences of the angles of total shifts and the angles of maximum crop in sections of the longitudinal and transverse axes of coal-mining faces developed along diagonal directions to the strike of the formation.

*Table 2*

**Angles of inclinations of total shifts lines φ (at cross-section) and angles of total shifts Ψ at cross-sections of axes of «diagonal» workings calculated according to formulas from Table 1 ($\Psi_1$ = 55°; $\Psi_2$ = 55° + 0,3α; $\Psi_3$ = 55°)**

| Seam inclination angle α, degree | Angle between longitudinal axis of working and seam strike ε, degree | Angles of total shifts lines inclination at cross-section of traverse axis of working, degree | | Angles of total shifts at cross-section of traverse axis of working, degree | |
|---|---|---|---|---|---|
| | | From up dip side $\varphi_{2j}$ | From down dip side $\varphi_{1j}$ | From up dip side $\Psi_{2j}$ | From down dip side $\Psi_{1j}$ |
| 20 | 0 | 41.0 | 75.0 | 61.0 | 55.0 |
| | 20 | 50.5 | 76.2 | 69.4 | 57.3 |
| | 40 | 57.2 | 73.4 | 72.8 | 57.8 |
| | 60 | 59.4 | 68.2 | 69.7 | 57.9 |
| | 80 | 57.6 | 60.3 | 61.2 | 56.7 |
| | 90 | 55.0 | 55.0 | 55.0 | 55.0 |
| 40 | 0 | 27.0 | –85.0 | 67.0 | 55.0 |
| | 20 | 39.5 | –89.7 | 77.8 | 52.1 |
| | 40 | 52.2 | 82.9 | 84.9 | 50.2 |
| | 60 | 55.9 | 73.8 | 78.7 | 51.0 |
| | 80 | 56.1 | 62.1 | 64.4 | 53.8 |
| | 90 | 55.0 | 55.0 | 55.0 | 55.0 |
| 60 | 0 | 13.0 | –65.0 | 73.0 | 55.0 |
| | 20 | 30.6 | –76.1 | 89.0 | 45.5 |
| | 40 | 46.5 | –89.0 | 99.5 | 38.0 |
| | 60 | 47.1 | 78.7 | 88.0 | 37.9 |
| | 80 | 53.0 | 64.4 | 69.8 | 47.7 |
| | 90 | 55.0 | 55.0 | 55.0 | 55.0 |

*Note.* When φ < 0° the boundary of flat bottom of the trough is located outside the working contour, i.e. above the coal pillar (point *E*' at Fig.2, *j*)

*Table 3*

**Angles of inclinations of total shifts lines φ (at cross-section) and angles of total shifts Ψ at cross-section of longitudinal axes of «diagonal» workings calculated according to formulas from Table 1 ($\Psi_1$ = 55°; $\Psi_2$ = 55°+ 0,3α; $\Psi_3$ = 55°)**

| Seam inclination angle α, degree | Angle between longitudinal axis of working and seam strike ε, degree | Angles of total shifts lines inclination at cross-section of longitudinal axis of working, degree | | Angles of total shifts at cross-section of longitudinal axis of working, degree | |
|---|---|---|---|---|---|
| | | From up dip side $\varphi_{2f}$ | From down dip side $\varphi_{1f}$ | From up dip side $\Psi_{2f}$ | From down dip side $\Psi_{1f}$ |
| 20 | 0 | 55.0 | 55.0 | 55.0 | 55.0 |
| | 20 | 58.9 | 64.7 | 66.0 | 57.6 |
| | 40 | 58.9 | 71.1 | 72.0 | 57.9 |
| | 60 | 54.4 | 75.1 | 71.9 | 57.6 |
| | 80 | 45.9 | 76.4 | 65.6 | 56.7 |
| | 90 | 41.0 | 75.0 | 61.0 | 55.0 |
| 40 | 0 | 55.0 | 55.0 | 55.0 | 55.0 |
| | 20 | 56.3 | 68.3 | 72.3 | 52.3 |
| | 40 | 54.9 | 78.6 | 83.2 | 50.3 |
| | 60 | 46.9 | 86.9 | 82.9 | 50.8 |
| | 80 | 32.2 | –86.8 | 71.8 | 53.7 |
| | 90 | 27.0 | –85.0 | 67.0 | 55.0 |

*Ending of Table 3*

| Seam inclination angle α, degree. | Angle between longitudinal axis of working and seam strike ε, degree. | Angles of total shifts lines inclination at cross-section of longitudinal axis of working, degree | | Angles of total shifts at cross-section of longitudinal axis of working, degree | |
|---|---|---|---|---|---|
| | | From up dip side $\varphi_{2f}$ | From down dip side $\varphi_{1f}$ | From up dip side $\Psi_{2f}$ | From down dip side $\Psi_{1f}$ |
| 60 | 0 | 55.0 | 55.0 | 55.0 | 55.0 |
| | 20 | 49.9 | 72.1 | 80.5 | 41.5 |
| | 40 | 46.2 | 84.9 | 94.3 | 36.8 |
| | 60 | 42.4 | –82.7 | 98.7 | 41.0 |
| | 80 | 18.5 | –69.9 | 78.2 | 50.5 |
| | 90 | 13.0 | –65.0 | 73.0 | 55.0 |

*Note*. When $\varphi < 0°$ boundary of flat bottom of the trough is located outside the working contour, i.e. above the coal pillar (point E' at Fig.2, *j*).

For visual perception in Table 2, 3 show values of the angles of inclination of total shifts (φ) and the angles of total (Ψ) shifts in the axial sections of the "diagonal" faces are calculated according to the formulas of Table 1. They make it possible to trace the nature of the variation of the named angles as a function of the angle of incidence of the formation α and the angle ε between the longitudinal axis of working and the strike of the formation. This, in turn, facilitates the forecast of deformations of the earth's surface from the influence of workings.

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# PREVENTION AND PROTECTION AGAINST PROPAGATION OF EXPLOSIONSIN UNDERGROUND COAL MINES*

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Over the past century, the coal mining industry experienced a large number of explosions leading to a considerable loss of life. The objective of this study is preventing the propagation of methane and/or coal dust explosions through the use of passive water barriers and its implementation to the Spanish coal mining industry. Physical and chemical properties, flammability and explosibility parameters of typical Spanish coals are presented. In this paper, a flexible approach to meet the requirements of the EN-14591-2:2007 standard is presented for the very specific local conditions, characterized by small cross-sections galleries, vertical seem, use of explosives, etc.

Authors have proven the viability of standard requirements to the typical roadway from Spanish underground mines, considering realistic roadway lengths as well as available cross-sections taking into account ubiquitous obstacles such as: locomotives, conveyor belt, ventilation ducts, etc.

***Key words*:** Passive water barriers, Spanish coal mines, methane explosion, coal dust explosion, dust inerting

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**Introduction.** An underground coal dust explosion involves several stages that can be summarized as follows [1]:

• formation of an explosive methane/air mixture;

• ignition of the mixture;

• development of the primary gas explosion;

• lifting of coal dust by pressure front of primary gas explosion and creation of the dust/air mixture;

• turbulent acceleration of the dust flame front, lifting more dust and creating an explosive zone in front of the flame;

• propagation of a dust explosion throughout the whole mine.

The first line of action to prevent explosions in mines is the implementation of preventive measures against both firedamp and coal dust [2].

Among preventive measures against firedamp, in simplified form, when emissions are low and gas is slowly released, the effect could be minimized with adequate ventilation. When gas is emitted as a continuous breath, airflow can be removed by sealing outlets through drainage techniques or just increasing the ventilation of the area to promote dilution. For higher emissions other preventive means should be considered, such as facilitating the partial release of gas with short drills for degassing and also by water injection.

Regarding coal dust, Spanish regulation provides that «measures must be taken to reduce flammable dust deposits, and proceed to safe disposal» [3, 4].

Preventive measures can be summarized in the following [5, 6, 7]:

• avoid accumulations of dust, especially if this is fine and dry. This requires to schedule a cleaning and maintenance program to prevent the formation of deposits. The points to be addressed with greater attention are those where dust tends to accumulate: near the start of the mine cut, at the bottom of inclined planes, beneath the conveyor belts at the transfer points, loading and unloading, dumping, storage, etc;

• water injection into the solid by short holes perpendicular to the front and by parallel long hole to the front to decrease dust production;

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• dust entrapment can be achieved through irrigation, which is cheap and simple, but may be ineffective, due to water evaporation. Another method to fix the dust is the use of hygroscopic salts. These, commonly $CaCl_2$ and $MgCl_2$, mixed with wetting agents, provide a binder solution that becomes a kind of crust of the deposited powder, thereby preventing its dispersion. There are three different ways of using the hygroscopic salts: as pastes, powders or flakes [8];

• the dusting of inert material on coal dust in certain proportions is suitable to prevent it from spreading an explosion along the galleries where it is deposited. The amount of inert powder required may vary between 55 % and 80 % by weight [9].

An explosion requires the simultaneous appearance of five factors, forming the so-called explosion pentagon: Combustible, oxidizer, mixing, ignition and confinement. [10].

The lack of one of the elements of the pentagon or braking connection between them excludes the appearance of the explosion. In the case of an underground coal mine this model says that:

• combustibles: coal dust and methane. Coal dust exists by its nature and participates in the explosion; methane plays also considerable role but rather as a primary explosion or as a constituent of hybrid mixtures;

• oxidizer is atmospheric air;

• ignition sources results from mining works;

• underground mine workings are confined spaces where overpressure can grow, without dissipating as it otherwise would in open space;

• mixing of combustible and oxidizer or the forming of the dust cloud in air occurs in coincidence with ignition. In a normal state the dust cloud is not in explosion concentration range for the mine air; the presence of people in such a cloud of dust is not possible.

Explosion protection can be established in successive stages. The purpose of primary explosion protection is to substitute the flammable substances or the atmospheric oxygen or reducing their quantities to the point where there is no danger of an explosive mixture forming. Increased air circulation, air flushing through ventilation can be achieved by structural measures. Replacing the atmospheric oxygen is not an option for areas where people work.

Much research has been carried out in Europe and elsewhere to understand how to control these dangers, but explosions still occur. [11, 12, 13]. In the coal mining industry, a methane explosion can initiate a coal dust explosion, which can then engulf an entire pit working. Stone dust is spread along mine roadways, or suspended from trays in the roof, so as to dilute the coal dust raised ahead of the combustion zone by the shock wave, to the point where it cannot burn. Mines may also be sprayed with water to inhibit ignition.

Good housekeeping practices, namely eliminating the build-up of coal dust deposits that may be disturbed and lead to a secondary explosion, also help mitigating the problem.

For this reason the measures available for such locations are limited to: the avoidance or restriction of substances which are capable of forming an explosive atmosphere and also to the avoidance or restriction of release of the flammable substances and therefore formation of explosive mixtures.

Action directed at secondary explosion protection aims to prevent sources of ignition. The hazard of combustion can originate from electrical and mechanical equipment, or even from persons. In practice, secondary explosion protection is implemented by technical action and organizational action. Organizational action may take the form of instructing the workforce and having plant and equipment cleaned properly.

Action directed at tertiary explosion protection aims to override the harmful effects of explosions and thus to minimize the risks to the health of workers. Such action could be:

• explosion pressure-resistant design;

• passive and active explosion barriers;

• automatic extinguisher systems;

• organizing escape routes.

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The aim of protection measurements is to prevent that the explosion will become increasingly important when propagating once it has started. It should be pointed out that secondary explosions of coal dust that happen after the primary ignition are really devastating, since they imply very big quantities of combustible matter, they generate devastating energies and are capable of propagating along kilometers of galleries. It is obvious that the sooner the explosion stops, fewer consequences will result.

If prevention measurements, such as limitation of coal dust generation during workings or elimination of ignition sources or neutralization of the settled dust by adding of incombustible matter, fail the passive barriers are the only way to protection, preventing the explosion flame front to propagate throughout the whole mine.

**Explosion prevention by means of inerting dust.** Inerting is a method of preventing the spread of a primary explosion. The method consists of the addition of inert powder (called sterile or diluent powder) to coal dust so as to form a mixture whose explosion parameters are reduced.

The application of inert powder has two purposes: it prevents dust dispersion, and also prevents participation of coal dust in an underground explosion. This is possible because inert dust acts as a heat sink (adsorption energy), provides a shielded radiation of the flame front and impedes the kinetics of combustion. The inert dust dilutes the concentration of coal dust and prevents oxygen or other gases to take part in an explosion.

Spanish regulations do not establish any minimum value for the concentration of inert dust in the mixture. However, foreign regulations fix the necessary percentage of inert dust, according to the characteristics of the mine or coal.

The minimum recommended requirements for inerting have been calculated using the method developed by some of the own authors [14, 15]. This method allows to calculate theoretically the percentage of inert (including moisture and ash) in the absence of firedamp that would be required to add to each carbon.

The calculation is based on the correlation existing among chemical composition and explosibility of coals. Two canonical variables are experimentally obtained: firstly, a set of variables, that are determined in the laboratory to chemically characterize a type of coal and secondly, a set of variables that characterize the explosibility of the coal:

$$VC_{12} = f\,(C, H, S, M, Cs, V);$$

$$VC_{11} = f\,(T_{\min}, LIE, EMI, P_{\max}, K_{\max}).$$

The first set is a linear combination of the variables related to chemical analysis, where $C$ is carbon content; $H$ is hydrogen content; $S$ is sulfur content; $H$ is moisture; $Cs$ is the ash content; $V$ is the content of volatile

The canonical variable $VC_{12}$ has all the characteristics of proximate and ultimate analysis of coal. Obviously, the volatile content carries more weight on $VC_{12}$ than other coal characteristics, but its advantage lies precisely in considering the influence of all the features.

$$VC_{12} = -3.05 + 0.052C - 0.039H + 0{,}041S - 0{,}012W + 0.064A - 0.057V.$$

The second set of variables $VC_{11}$ refers to linear combinations of the variables related to the parameters of explosion, where, $T_{\min}$ is the minimum ignition temperature; $LIE$ is the lower explosive limit; $EMI$ is the minimum ignition energy; $P_{\max}$ is the maximum pressure; $K_{\max}$ is the pressure rise constant.

The canonical variable VC11 takes into account the values of the parameters of ignition sensitivity and severity of explosion. According to the values that reach VC12 and VC11, usually very close quantitatively, coal dust is considered more or less dangerous. This method of canonical variables provided a graphical descriptive representation of the behavior of coals. A canonical diagram in which the values of the corresponding canonical variables representing each sample is readily obtained. As a result of a statistical study of values for coals of various ranks and origins established

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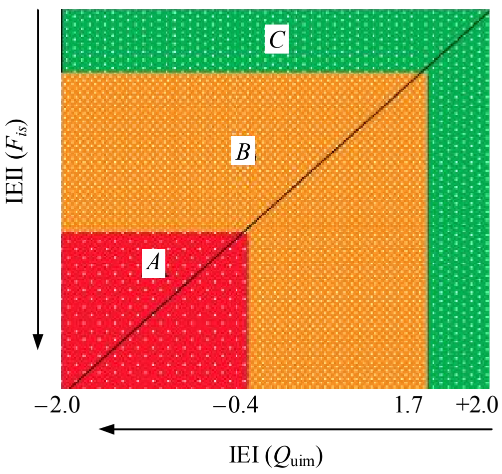


Canonical diagram for coals [14, 15]

that the values $VC_{12} = VC_{11} = –0.4$ and $VC_{12} = 1.7$ marked the boundary between three types of behaviors of coal dust (Figure).

Accordingly, three zones are distinguished in the diagram:

*A* = High Sensitivity and Severity,

*B* = Moderate Sensitivity and Severity,

*C* = Low Sensitivity and Severity.

It is also possible to calculate theoretically the percentage of incombustible material (water or stone dust) that would be required to add to each coal located in areas *A* or *B* to take it to the «safe area» *C*, that is, to inert it.

To find the percentage of inert to be added to a particular type of coal to inert it and place it in the «safe area» *C* the following equation is recommended: $Z = (VC_{12} \times 100-170)/(VC_{12}-3.35)$.

Where $Z = X + Y$, $Z$ = % inert to add $X$ = % sterile powder added $Y$ = % water added.

Experience has shown that very good agreement between the calculated values and those determined experimentally in the laboratory and full-scale test galleries is obtained. [16]

Canonical variables usually range between –2.0 and +2.0.

For a more intuitive understanding of its meaning two explosion indices, called Chemical Index (IEI) and Physical Index (IEII) are often used. They are immediately obtained from the canonical variables:

$$\text{IEI (Chemistry)} = 2 - VC_{12},$$
$$\text{IEII (Phys)} = 2 - VC_{11}.$$

As an example of calculation of the canonical variable, Table gives the canonical variable values and percentages of inert that are required for different coals.

**Chemical analysis for different coal samples leading to the required inert percentage**

| Coal | *C* | *H* | *S* | *W* | *A* | *V* | $VC_{12}$ | $Z = X+Y$ (%) |
|---|---|---|---|---|---|---|---|---|
| Teruel | 58.9 | 3.7 | 6.8 | 2.8 | 13.8 | 33 | –0.88 | 61.0 |
| Pittsburgh | 77.1 | 5 | 1 | 1.75 | 6.5 | 35.9 | +0.85 | 60.7 |
| Asturias | 70.1 | 4.7 | 1.7 | 0 | 9.7 | 37.6 | –1.04 | 62.4 |

Source: Adapted from [17].

**Explosion protection.** European Standardization Commission (CEN) issued the standard EN 14591-2:2007 «Explosion prevention and protection in underground mines – Protective systems – part 2: Passive water trough barriers» [18] requiring the use of water barrier, their construction, components, deployment, ways of use, marking, etc. The most important elements of the barrier are the own water containers (called also water troughs) deployed in the workings. According to EN-14591-2 «Water troughs barriers are designed and arranged in such a way that explosions are prevented from spreading through dangerous chain reactions and incipient explosions do not become detonations». Barriers are deployed in determined distance from expected ignition point what means do not protect the room between ignition and barrier itself. This standard works very well in the large workings cross section, as those present in Germany or in the majority of Polish coal mines. Standard is well known in Spanish coal industry but its implementation in the local conditions will require a flexible approach [19].

After an exhaustive study of the previously mentioned standard as well as other pertinent references, the Laboratorio Oficial J.M. Madariaga (LOM) and Laboratory of the Experimental Mine «Barbara» in Poland carried out a research study, considering the characteristics of the most usual Spanish collieries and work face conditions to be found in the underground installations of the main coal mining industry companies [20].

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Explosion barriers are divided into two groups depending on the extinguishing agent used: Stone dust barriers, where inert dust (mainly calcium carbonate) is used and Water barriers, where the extinguishing agent is water.

Depending on their mode of use, barriers are divided into:

• concentrated barriers (protecting determined working place where exists explosion ignition sources);

• distributed barriers (protecting all workings, playing the role of inertization. The amount of extinguishing agent on the distributed barrier is established to 1 kilogram per cubic meter of the space).

About 70 % of coal mines protected by barriers in Poland and in the UK still use stone dust barriers, while water barriers are mainly used in Germany, Czech Republic and other European countries.

The main advantage of water barriers is the reliable protection of workings behind the barrier; there are many examples of very effective barrier actions.

The disadvantages of water barriers are:

• big dimensions, up to 50 m long;

• diminishing of the working cross section;

• necessity of changing barrier position with movement of coal faces.

Deployment of barriers in the workings has to take into account the possible ignition sources of explosion and properties of coal dust.

In Spanish underground coal mines this factor differs considerably from other European countries, and that means that water barriers installation should be performed in a slightly different way than described in standard EN 14591-2:2007.

To analyze the influence of the particular characteristics of Spanish coals, data from various samples were considered. Based on the existing correlation between coal composition and explosibility of dust, some composition parameters were studied. So, humidity content of coal samples ranged from 2 to 20 %, ash content from 5 to 50 % and volatile matter from 6 to 35 %. Generally, these results say that explosibility of coal dust in Spanish mines is moderate with relatively low volatile content and high ash content. Taking this into account, one can say that the need of water barriers in the spirit of EN 14591-2:2007 Standard in Spanish coal mines is limited. This spirit supposes covering the whole mine with concentrated and distributed barriers, which seems to not have a big sense in some Spanish coal mines, depending on the explosion parameters of the particular coal.

In order to achieve final object of this research project, the use of barriers is proposed in selected places, such as:

• faces where blasting is performed;

• places with frequent methane accumulations;

• other places where coal extraction is performed.

The trough groups shall cover the greatest width of the roadway cross-section (floor width or roadway diameter) at the point of installation. The achieved coverage is as follows:

• at least 35 % for roadway cross-sections of up to 10 $m^2$;

• at least 50 % for roadway cross-sections of up to 15 $m^2$;

• at least 60 % for roadway cross-sections of over 15 $m^2$.

## Conclusions

Water barriers protect against flame propagation behind the barrier and do not protect the space between ignition source and barrier itself. Water barrier effectively suppress the flame propagation but not the pressure wave which runs along the working up to being suppressed by flow resistance. Water barriers or passive barriers generally are the last part of the protection system- or one of the last layers of protection. One important conclusion could draw – inerting of the settled dust is necessary.

The main conclusions obtained after the preliminary study are the following ones:

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It is necessary to perform a formally documented hazard analysis before undertaking any measures of prevention or protection. This analysis should include all important parameters of the coal dust explosibility.

Tests should be carried out using the configurations for the explosion tests for troughs described in Standard EN 14591-2:2007, especially in relation with the explosion overpressure range to be used during the tests. The tests can be carried out using both concentrated and distributed barriers. Nevertheless, the type of barriers to be tested is not completely defined at the present time.

Firstly prevention shall be applied and then protective measures. Before studying the viability of passive barriers installation, the possibility of coal dust inertization must be studied.

In those cases when it is unfeasible to install the passive water barriers according to Standard EN 14591-2:2007 a guideline for coal dust explosion prevention and suppression must be elaborated.

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UDC 631

# NEWEST TECHNOLOGY IN CADASTRAL ACTIVITIES

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The article provides comparative analysis of multiple innovative technology in the field of cadaster activities. This analysis covers almost all currently available intellectual developments in this area. Paying tribute to contemporary trends in cadastral areas, the authors note the urgent need to upgrade the cadastral activities in the Russian Federation in relation to the transformation of the national economy. The authors suggest classifying the cadastral activities depending on type and kind of activity carried out with an object of cadaster registry. The article covers the most urgent issues in the area of functionality of existing special software packages in order to improve the labour efficiency of a cadaster engineer. It is concluded that the main purpose of existing software systems for cadastral engineers is creation of documents in electronic format for facilitating the process of interaction with public authorities in the sphere of land property relations. It examines in detail several software packages («TechnoKad-Express», «ARGO», «PKZO», «Poligon», «ProGeo»). The article provides comparative analysis of special software systems according to a number of authors' criteria. Based on the characteristics of programs and their comparative analysis, it is concluded that all the described software systems to greater or lesser degree, meet the needs of the working cadastral engineer. The choice of a specific program depends on the financial possibilities, personal preferences and level of computer-literacy of cadastral engineer, including in the sphere of GIS-technologies.

***Key words*:** innovative technology, cadaster registration of real estate objects, cadaster engineer

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**Introduction.** The development of innovative technology in our country is a top priority. The field of cadastral activity is not an exception. The research in this area have theoretical and practical aspects as well. In his papers professor S.A.Galchenko describe the chronology of changes in special systems for performing cadastral registry keeping activities by government authorities [2]. The researchers also pay great attention to application of modern GIS-technology in cadastral sphere. These issues have been studied by such scientists as S.A.Subbotin, A.V.Skvortsov [11], I.N.Rotanova; K.V.Vorobiev; G.A.Steklova, V.S.Fedotova [10]; P.M.Mazurkin, A.N.Fadeev [5]; A.Dawidowicz (Poland), R.Zorbek (Poland) [13] and others. The new technological innovations in the field of cadastral activities are not left unattended too: N.V.Klyushnichenko – «one window» principle application [4]; G.F.Gorn, D.A.Krylov [3]; D.K.Rosu (Romania), V.Ciolac (Romania), O.N.Coltan (Romania) [12] – government authorities using electronic technology; V.L.Belyaev; V.M.Romanov; V.N.Nikitin [7]; N.A.Nikolaev [6]; N.V.Gavrushina [1]; V.A.Pavlova [8] – 3D-cadaster application.

**Problem description.** The efficiency of land resources management depends on relevance and accuracy of cadaster data and preparation of necessary information by cadaster engineers. In the market economy conditions the cadaster information produced because of cadaster activity creates in a given state and community a basis for establishment of innovative climate implemented through innovative technology. According to current legislation the main output documents of cadaster engineers' activity are delimitation plan; technical plan; map (plan) of land management objects; parcel plan; land parcel layout on cadastral territory plan (CTP) and inspection report.

These documents have to be produced in printed and electronic format (XML-file). In order to do this a cadaster engineer needs special software packages. Lately there have been technological advances in automation in the field of cadastral activities, particularly, there appeared new innovative technology of collecting, processing and provision of information. One of the key innovative trends in real estate cadaster is current cadaster engineer programming support, with the help of which they can not only significantly reduce working time for performing cadastral work, but substantially lighten the work of cadaster engineers [9].

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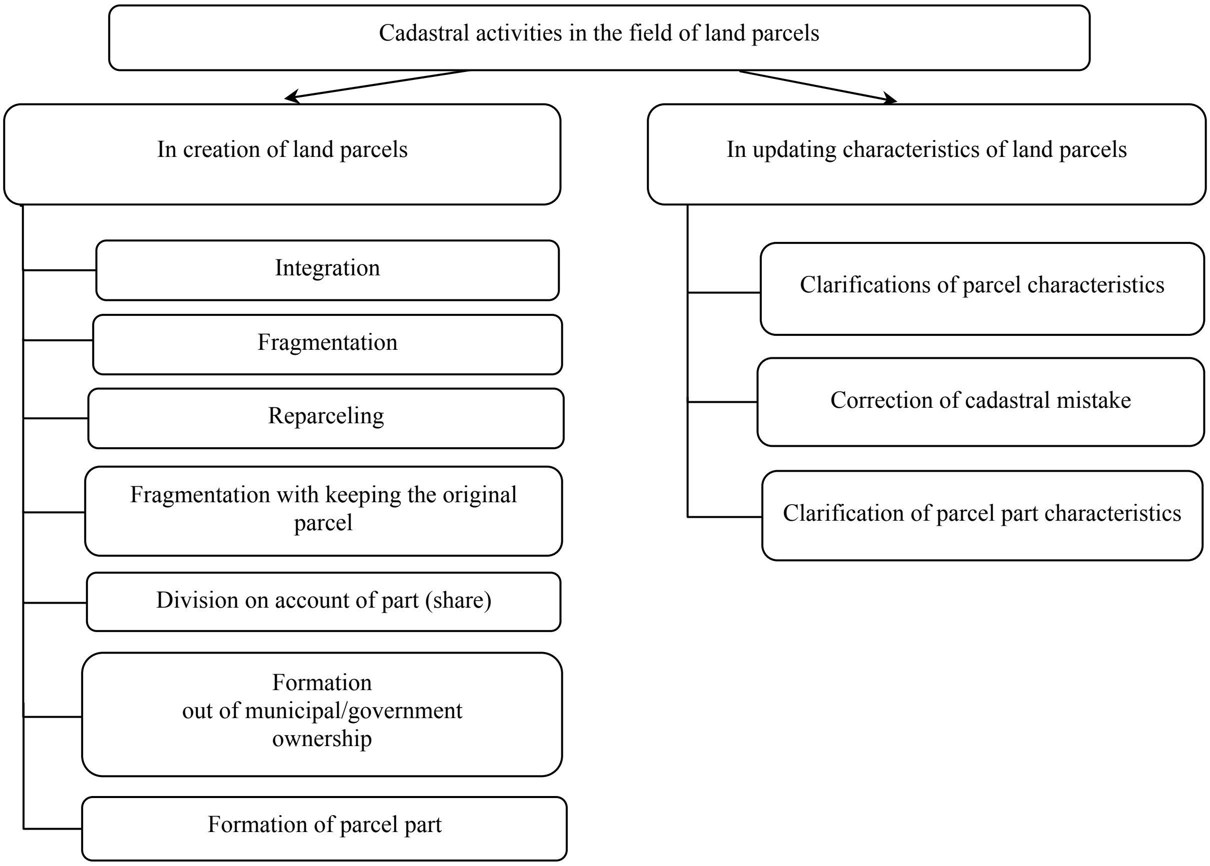


Fig.1. Types of cadastral activities resulting in delimitation plan

**Research methods.** Within the framework of this paper the authors have used such methods of scientific investigation as analysis of legislation and regulatorily framework, examining of software packages and analytical method.

**Discussion.** The innovative technology become of particular concern during times of transition and crisis (this is the period we are in now), when production technology is being changed almost completely and there arises an acute need in modernization of cadastral and other types of production and all public spheres management activities, their transformation to a new condition matching national purpose (shift to innovative economy).

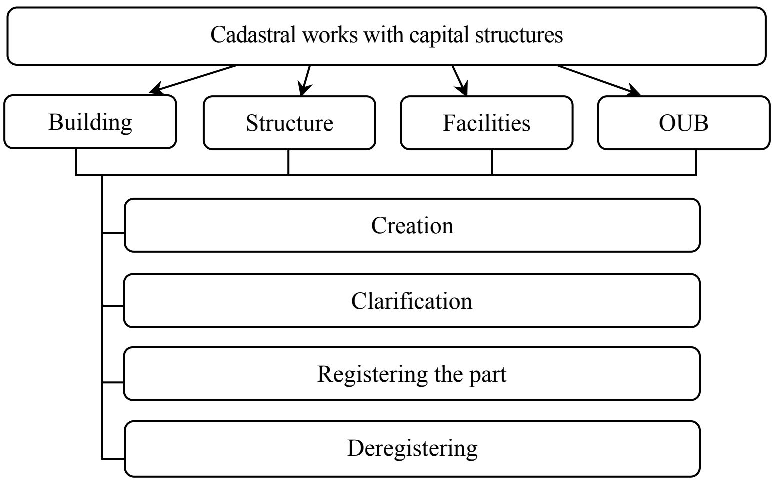


Fig.2. Types of cadastral work resulting in technical plan and inspection report

Different types of cadaster activities have specific output documents. For example, cadastral work with land parcels (LP), according to our opinion, can be divided into two large groups: activities connected with creation of land parcels and activities related to introduction of amendments to existing characteristics of land parcels, which depending on used tools and peculiarities of processes of cadastral works can be subdivided into specific types (Fig.1).

Cadastral works with capital construction objects differ depending on types and mode of interactions

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with this object (Fig.2). The output documents can be the following ones: technical plan and inspection report, the aim of the last one is to provide information for cadastral derigestering of a building, structure or object of unfinished building (OUB).

The document representing main information on land management objects and required for making entries in State Real Estate Cadaster is a map (plan) of land management objects. The peculiarities of creation of this document also depend on a type of an object for which this document is issued (Fig.3).

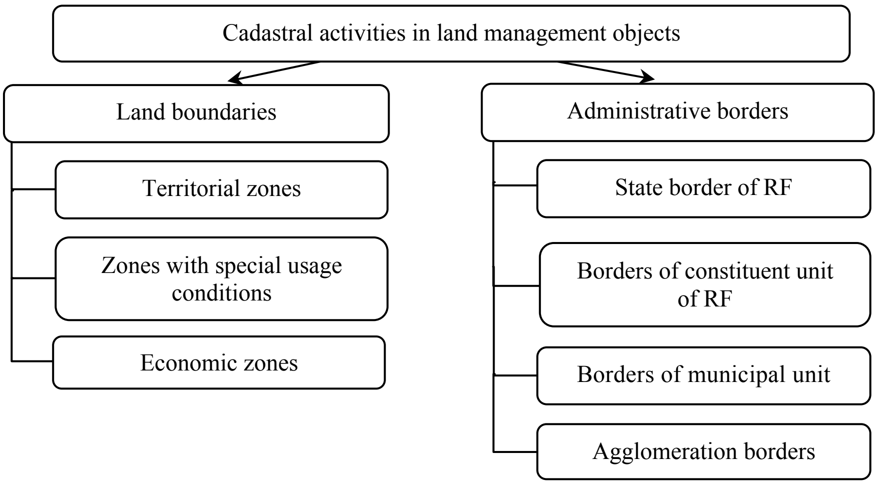

Fig.3. Types of cadastral activities resulting in a map (plan) of land management objects

It should also be noted that for preparation of delimitation plan for division of a land parcel on account of a part (share) it is necessary to create a delimitation project, which is also considered to be a cadaster documentation though it has only a printed approved version.

The last type of cadaster documentation, which can be prepared by cadaster engineer, is a layout of land parcel on cadaster territory plan. This type of document is required to form a land parcel out of municipal or government owned lands, it is approved by executive authority or local government institution.

From July 1, 2016, cadastral engineer must submit a printed copy of act of accommodation of land plot borders together with a covering letter to a government authority performing cadastral registration. The covering letter for an act of accommodation of land plot borders compiled during clarification of land parcel boundaries must be in XML-format.

The main goal of existing software packages for cadastral engineers is to create documents in electronic format, which significantly simplifies the interaction process with government authorities working in the field of cadastral registration. The amount of special purpose applications has now reached the number of more than 20 software packages, but according to our point of view among them there are undisputed leaders in this professional field. Let us have a close look at some of them: «TechnoKAD-Express», «ARGO», «PKZO», «Poligon» and «ProGeo».

One of the most popular software packages is «***TechnoKAD-Express***» (a package of software and services of TechnoKAD-Express // technokad.ru: official website of «Techno-Kad» company. URL: http://www.technokad.ru/productes/technokad-express/ (date of access: 17.02.2016)). This software package has three modules: «Delimitation plan», «Technical plan» and «Information inquiry». There is a possibility to purchase the whole set of modules or some of them (separately). This feature helps «TechnoKAD-Express» to enlarge its circle of customers. For example, the «Information inquiry» module is very popular among real estate agencies and design companies. The graphical part of cadastral documents is not created in «TechnoKad-Express» but for this purpose you could use a separate software «TechnoKad-Geo» or any other special purpose software. With «TechnoKad-Express» one can create such documents as delimitation plan, technical plan, map of land management objects, inspection report and different types of application forms.

Let us consider the distinguishing features of «TechnoKad-Express» software package in the area of creating text part of delimitation plans. When using «TechoKad-Express» the defining point is a type of performed activity, after that a user inputs information on unique characteristics of land parcels. The autocompletion function is not fully developed, so some data should be entered manually. The creation of template forms is also not a strong side of this software.

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The coordinates of land parcel can be produced only in two ways: by importing them from a file with mif extension, which is a feature of MapInfo files, or from a file with txt extension, which creates some requirements to additional software.

The developers of «TechnoKad-Express» closely work with representatives of cadaster registry office, which has positive effect on quality of this software package and provides quick update of information in accordance with current cadaster legislation changes and requirements to cadaster documentation. This software enables checking the prepared documents before sending them to cadaster registry office.

«TechnoKad-Express» is a unique software package providing a cadaster engineer with an opportunity to have a qualified electronic signature (hereafter QES), which is needed for approval of output electronic documents. Another not unimportant advantage of «TechnoKad-Express» program is a technology of submitting application forms on cadaster data changes with a unique service of issuing applicant QES.

Within the framework of software functionality, a user have a possibility not only to order the desired information from Unified State Register of Rights to Real Property but to pay for this service with upfront credit payment method.

The developers of «TechnoKad-Express» conduct workshops and webinars in different parts of Russian Federation.

According to our point of view, one of the disadvantages of this software is payment for submission of electronic documents for all types of cadastral activities to cadaster office through Internet. Besides this a user also should pay for annual license renewal to continue using the modules of «TechnoKad-Express» software.

A very special popularity among cadastral engineers has gained the «***ARGO***» package (Software package ARGO // new.argogeo.ru: official website of ARGO software. URL: http://new.argogeo.ru/ (date of access: 17.02.2016)). Its key advantage, according to its developers' point of view, is absence of need to use additional software since this package has all necessary features and functions for creating text and graphic parts of cadaster documents. The software has so many functions and possibilities, that it is a little bit difficult to use it without additional examination of guidelines.

This software package gives a cadaster engineer an opportunity to create such documents as delimitation plan, technical plan of a building, structure, object of unfinished building and a room, delimitation project, printed copy of a map (plan) of land management objects. There also a possibility to create electronic versions of these documents in XML format. The information on coordinates of land parcels boundaries for layouts of land parcels position on a cadaster territory plan can also be exported for electronic document flow.

Despite the high level of technical support, the software is not always able to perform well in non-standard situations. For example, the lack of ability to edit the text part, namely the act of accommodation of land plot borders, can hinder the work of the cadastral engineer, and thus a need to use advanced text editors arises.

The user interface of the program is similar to interface of the latest versions of AutoCad software, which makes it easily understandably for most experienced cadastral.

Compared to majority of similar programs, «ARGO» gives you the opportunity to work directly with the public cadastral map, namely: to search for real estate objects, to look through not only the boundaries of real estate objects, but their main characteristics. There is also a possibility to import rasters surfaces (layers) into a drawing directly from the public map, which greatly facilitates and simplifies the process of creating clear layouts of land parcels. The software package will recognize such formats as dxf, mif, and xml, the output data can be in the same formats, and in rtf, xls and pdf as well.

The ability to create different layers in the graphics part of the «ARGO» software allows you to simultaneously create all kinds of graphic documents for a specific object, but it also hinders

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their correct representation when you select different scales for various documents. The «ARGO» software works not only with imported objects. Using the program tools, you can create your own objects with the specified areas and configurations.

The software package supports parallel work on the same object from different computers, that are connected into one workgroup. The check of output documents is carried out only for accordance to the actual xml schema of Federal Service for State Registration, Cadastral Records and Cartography (FSSRCRC).

The program «***PKZO***» (Program of PKZO // pkzo.ru: official website of PKZO software. URL: http://www.pkzo.ru/product/ (date of access: 17.02.2016)) consists of three modules: «Delimitation plan», «Technical plan» and «Survey map». The program is based on GIS ObjectLand, despite that it supports both the import and export of other formats, such as dxf, mif, csv and shp.

The installation process and initial settings of the program requires both time and expertise. The ability to use one key for multiple workstations, on the one hand, reduces the cost of using this program, on the other hand, it leads to difficulties in work process, because you need additional software for setup procedures. For professionals working in GIS ObjectLand, the interface is simple, intuitive and familiar. «PKZO» provides broad opportunities for the formation of the graphic part of cadastral documents.

Unfortunately, the software does not have a possibility to directly interact with Federal Service for State Registration, Cadastral Records and Cartography, but it has a great advantage, which can be considered as a function of verification of documents on compliance to the relevant xml schema of Federal Service for State Registration, Cadastral Records and Cartography and checking of geometric correctness and the fact of crossing borders.

Another representative of software systems created for cadastral engineers, is a «***Poligon***» package (a series of Poligon programs // pbprog.ru: official website of the programmatic center of «Help to education». URL: http://pbprog.ru/products/programs.php?SECTION_ID=99 (date of access: 17.02.2016)). This name combines a number of different independent programs that are capable collectively solve practically any task facing cadastral engineer. By selecting the desired program, you can minimize material costs for the purchase of necessary programming support.

The software of «Poligon» package has a simple interface. Like the excel file, the application space is divided into sheets, each sheet corresponds to a separate section of created cadaster document. When entering the missing information in the sections of the cadastral document, the software gives you the opportunity to select them from collection of existing templates. In addition, the user is given the opportunity to create his own templates, which significantly speeds up and simplifies the process of creating a cadastral documentation.

The software of «Poligon» package is highly standardized, in order to import the coordinates, it support all currently available formats: dxf, mif, doc, xls, csv, txt.

The software package also allows you to create a number of additional documents that are included in the application, such as: notification on the meeting on approval of location of land boundaries with the receipt, the record of the land parcel formation process, the act of submission of landmarks for safety monitoring, the scheme of landmark location, the declaration, inspection report, etc.

The «Poligon» package is based on the Word program of Microsoft Office software or a free program Writer (OpenOffice.org), so the graphical presentation is not implemented. The key feature of the program lies in the fact that generation of graphical partitions of cadastral documents is done in Word (Writer) using AutoShapes with preset collection of symbols, line types and colors, which is suitable only for small and non-complex configuration objects.

Another advantage of the software is a possibility to create automatic layer of the public cadastral map and satellite image in all graphic sections and layout of cadaster territory plan, and attach a raster basis layer.

In contrast to the above mentioned software systems, the main author and developer of the «ProGeo» is known – N.G.Malyutin.

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The «***ProGeo***» software (Program, ProGeo // zwsoft.ru official website of «ZWSOFT». URL: http://www.zwsoft.ru/applications/programmnyi-produkt-progeo-progeo (date of access: 17.02.2016)) is an additional application to ZWCAD – a cheap analogue of AutoCad from China, so the visualization is provided by a CAD system. This innovative technology allows you to create both text and graphical parts of documents: delimitation plan, technical plan, map (plan) of land management object, the scheme of location of land plots on the cadastral plan of the territory, delimitation project, as well as related documents such as notification on the meeting on approval of location of land boundaries, the record of the land parcel formation process, and declaration.

The program allows you to develop projects both «from scratch», and on the basis of the imported data, the import is supported from both from the CAD programs and files created in specialized geodetic applications, as well as from files of arbitrary format. The software contains a set of additional tools that simplify the work of the cadastral engineer; all tools are based on the existing requirements of the cadastral documentation.

**Comparative analysis of software packages for cadaster engineers**

| Evaluation criteria | TechnoKad-Express | ARGO | PKZO | Poligon | ProGeo |
|---|---|---|---|---|---|
| Developer | LLC «TechnoKad» (Moscow) | LLC «Buznes POiNT» (Moscow region, Odintsovo) | CJSC «Radom-T» (Taganrog) | Program center «Help to education» (Kirov) | N.G.Malyutin (Rostov-on-Don) |
| Types of output documents: | | | | | |
| Delimitation plan | + | + | + | + | + |
| Technical plan | + | + | + | + | + |
| Inspection report | – | – | + | + | + |
| Declaration | – | – | – | + | + |
| Map (plan) of land management object | + | + | + | + | + |
| Delimitation project | – | + | + | + | + |
| Layout of land parcel location on CTP | – | + | + | + | + |
| Additional software (besides CryptoPro) | 1. TechnoKad-Geo<br>2. MapInfo<br>3. MC Office<br>4. Converter to pdf | – | 1. GIS ObjectLand<br>2. MC Office<br>3. Converter to pdf | 1. Microsoft .NET Framework<br>2. Microsoft Office or Open Office | 1. Microsoft Office /Open Office/ SoftMaker<br>2. ZWCAD/, AutoCAD/, BricsCAD/, GstarCAD/ nanoCAD<br>3. Converter to pdf |
| Visual interface | – | + | + | – | + |
| Direct interaction with FSSRCRC | + | – | – | + | + |
| Program cost, rub | 8000 | 13900 | 46000 | 25630 | 8000 |
| Update cost, 1 year subscription, rub | 1st year – 4800<br>2nd year – 3900<br>3rd year – 2700<br>4th year – 0 | 2560 | 13500 | 0 | 0 |
| Technical support | + | + | + | + | + |
| Check of documents before submission | + | – | + | – | + |
| Possibility to create covering letter for act of accommodation of boundaries in XML-format | – | – | – | – | – |
| Possibility to sign documents with QES | + | + | + | + | + |
| Work with one object on several workstations | – | + | – | – | – |

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The program creates the text part in Microsoft® Office (Excel), and SoftMaker Office or OpenOffice, and the graphical one in any CAD application. And when you first start «ProGeo» software, it automatically finds the previously installed versions of necessary programs. You can check the correctness of filling up the cadastral documents only after their creation. Check of the xml file is also done only after its compilation, and the program gives information about boundaries overlapping, even if such intersections are within acceptable limits.

The program is regularly updated, the technical support is carried out remotely, either through email or through the discussion forum on the website of the distributor.

We have done a comparative analysis of the considered software complexes (see table).

**Conclusion.** As it follows from the characteristics of programs and their comparative analysis (see table), all described software packages to a greater or lesser degree, satisfy the needs of the working cadastral engineer. The choice of a specific program depends on the financial possibilities, personal preferences, and level of computer literacy of cadastral engineer, including the sphere of GIS-technologies. Each of these software systems is being constantly improved to simplify, modernize and optimize the work of the cadastral engineer during creation and compilation of cadastral documentation. But we should not forget that no matter how «smart» the program is, most importantly, is what kind of professional uses it, because of his qualifications, experience and skills depends not only on the accuracy and correctness of the created cadastral documents, but all his activities as well.

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# COMPARATIVE ASSESSMENT OF STRUCTURAL-MECHANICAL PROPERTIES OF HEAVY OILS OF TIMANO-PECHORSKAYA PROVINCE

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The physicochemical properties of heavy oils of Yaregskoe and Usinskoe deposits and the residues of atmospheric distillation of petroleum (fuel oil) recovered from them are presented. The group composition of oil and the residues of its atmospheric distillation (fuel oil) is determined. When using X-ray fluorescence energy dispersive spectrometer, the content of metals in the products is determined. A conclusion is drawn about the distribution of metals in the initial oil and fuel oil. On the basis of rheological characteristics, the type of liquids is determined in accordance with Newton's law, as well as the presence of an anomaly in the viscosity of the studied media at different temperatures. The energy values of the thixotropy of heavy oils of Usinskoe and Yaregskoe deposits, as well as the activation energy of the viscous flow of all media studied, are obtained. The phase transition of atmospheric residues at 60 °C is discovered. Dependences of the enthalpy and entropy of the viscous flow of the studied hydrocarbon media are obtained with an increase in temperature from 10 to 140 °C. The dependences of the oil molecules and atmospheric residues jumping frequency on viscosity are obtained for the first time.

***Key words*:** rheology, heavy oil, atmospheric residue, Usinsk deposit, Yaregskoe deposit, structural-mechanic properties, entropy, enthalpy of activation of viscous flow, frequency of molecule jump, hysteresis looping, thixotropy energy

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**Introduction.** A serious problem of the modern oil industry is the increase in the production of heavy oil, which contains a significant amount of impurities (asphaltenes, sulfur, metals), as well as the depth of its processing, since direct distillation of oil produces a heavier residue than light distillates, which reduces the value of such hydrocarbon feed [2, 4].

The main problems in application of heavy oil arise due to its low mobility both in formation conditions and on the surface. Its extraction and transportation to oil refineries are associated with great technological difficulties and material costs.

For the correct selection of technological regimes of oil production, transportation and processing, it is necessary to know not only the physicochemical properties of the liquid being studied, but also its rheological properties. In connection with this, the necessary stage in the implementation of a particular technological process is the carrying out of special rheological tests of these liquids, which will allow to predict their rheological properties, and also to choose effective methods for regulating these properties [6, 9].

**Methodology and research methods.** In order to compare the structural and mechanical properties of heavy oils, as well as identification of phase changes in oil and fuel oil residue, the object of the study was the heavy oils of the Timano-Pechorskaya province (Usinsk and Yaregsky deposits), as well as atmospheric residues obtained by direct distillation of these oils (Table 1).

The concentration of metals contained in the test samples was determined using an X-ray fluorescence energy dispersive spectrometer Elipson 3 (Table 1). It has been found out that the metals contained in the oil from Usinsk deposit almost completely turn into fuel oil residue, while for the oil from Yaregskoe deposit only vanadium, iron and nickel are concentrated in the atmospheric residue, and the aluminum and silicon content remains the same as in the original oil. On the basis of this, it can be assumed, that the distribution of the latter to the light fractions of oil during its atmospheric separation. The rather high content of the abovementioned metals in heavy oils allows us to consider these systems as an additional hydrocarbon source of raw materials for the recovery of valuable metals.

*Table 1*

**Physical-chemical properties of heavy oils from Yaregskoe and Usinskoe deposits and their atmospheric residues (fuel oils)**

| Indicator | Yaregskaya oil | Atmospheric residue of Yaregskaya oil | Usinskaya oil | Atmospheric residue of Usinskaya oil |
|---|---|---|---|---|
| Density at 20 °C, kg/m$^3$ | 939.8 | 964.0 | 900.0 | 954.0 |
| °API | 19 | 15 | 26 | 17 |
| Kinematic viscosity, mm$^2$/s: | | | | |
| 40 °C | 562.18 | – | 48.65 | – |
| 80 °C | – | 150.53 | – | 548.94 |
| Pour point, °C | –18 | –10 | –28 | 14 |
| Sulfur content, % by weight | 1.232 | 1.251 | 0.971 | 1.490 |
| Aluminum content, % by weight | 0.0070 | 0.0070 | 0.0056 | 0.0075 |
| Silicon content, % by weight | 0.0070 | 0.0070 | 0.0063 | 0.0071 |
| Vanadium content, % by weight | 0.0160 | 0.0210 | 0.0092 | 0.0175 |
| Iron content, % by weight | 0.0047 | 0.0060 | – | 0.0024 |
| Nickel content, % by weight | 0.0047 | 0.0063 | 0.0046 | 0.0085 |
| Diesel fraction content 220-330 °C, % by weight | 29 | – | 21 | – |
| High boiling fraction (fuel oil) content, boiling away at temperature above 330 °C, % by weight | 71 | – | 70 | – |
| Saturated hydrocarbons content, % by weight | 16 | 15 | 22 | 20 |
| Linear paraffins content, % by weight | 3.78 | – | 3.14 | – |
| Aromatic hydrocarbons content, % by weight | 40 | 38 | 21 | 24 |
| Tar content, % by weight | 27 | 27 | 39 | 30 |
| Asphaltenes content, % by weight | 17 | 20 | 18 | 26 |

To study the influence of fractional and hydrocarbon composition of heavy oil before and after rectification under atmospheric pressure on rheological properties, we have conducted the group analysis of test samples using the following procedure (Table 1). A sample of oil (fuel oil) was dissolved by a 40-fold volume of hexane, after that it was set aside to stand for 16 hours in a dark place in order to precipitate the asphaltenes. After filtration, the obtained deasphalted product was separated into saturated compounds, aromatic compounds and tarss using hexane, benzene and ethyl alcohol. It has been discovered that for Yaregskaya oil the tar and asphaltene content in fuel oil increases as a result of the separation of light fractions, while the content of saturated and aromatic compounds in it decreases, whereas in the fuel oil of Usinsk deposit the content of aromatic hydrocarbons and asphaltenes increases as a result of toppping of the light fractions.

**Research results and their interpretation.** As it is known [10], the formation of supramolecular structures in oil dispersed systems with a significant content of resinous-asphaltene substances (RAS) occurs on the basis of an asphaltene core, which is a layered pack-like associates of polyaromatic structures and a solvate shell consisting of molecules of resinous-oil components. With a gradual increase in the concentration of RAS in highly viscous oils, sharp changes in their rheological properties can be observed, which corresponds to the critical state of the system when the critical concentration is reached. In practical terms, oil in this state loses fluidity, as a result of which the transportation processes of such hydrocarbons become more complicated.

Creation of effective methods for regulating the rheological properties of heavy highly viscous oils is impossible without studying the structural transformations and quantitative evaluation of in-

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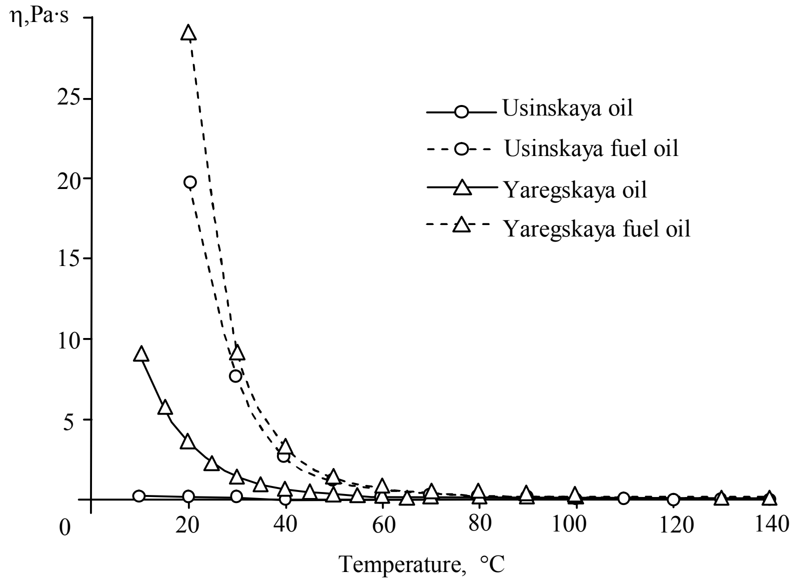


Fig.1. Dependency of dynamic vicsousity of oil from Yaregskoe and Usinskoe deposits and atmospheric residues from temperature

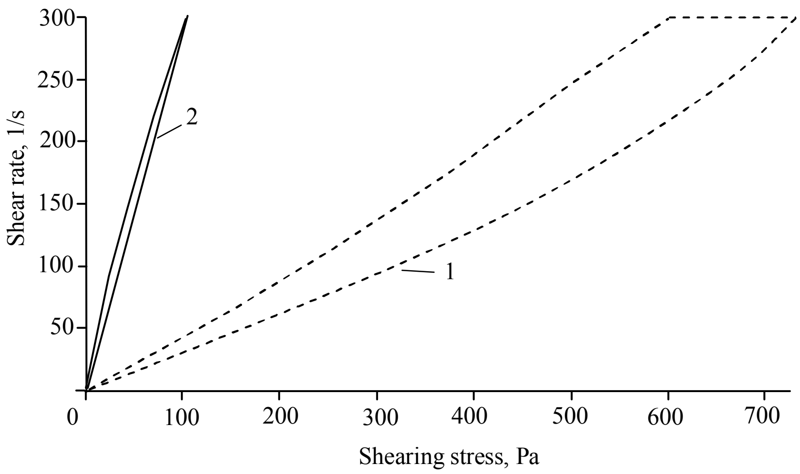


Fig.2. Hysteresis loops of oils from Yaregskoe and Usinskoe deposits
1 – Yaregskaya oil; 2 – Usinskaya oil

termolecular interactions in them [5, 13]. Such investigations can be carried out on the basis of the flow activation theory of Ya. I. Frenkel, H. Eyring [11, 15] and the results of experimental rheological studies of these oils.

A fluid, which properties obey Newton's law and can be described by an equation, are called Newtonian fluid:

$$\tau = \eta\gamma, \quad (1)$$

where τ – shearing stress; γ – shear rate.

If shearing stress is not proportional to shear rate, then such fluid is called non-Newtonian fluid and a relation τ/γ is an effective (apparent) viscosity.

The experiments of studying structural and mechanic properties of oils and resulting from them atmospheric residues have been conducted according to the following procedure. The shear rate during dynamic tests gradually increased up to the value of $\gamma_{max}$ (in seconds to the power of minus one degree) over e period of 300 s (forward move), then it was kept constant at the achieved value during 300 s (expectation of full destruction of internal structure of oil), and then the shear rate gradually decreased to a zero in 300 s (return move).

When studying the dependence of the viscosity of heavy oils and atmospheric residues from the temperature (Fig.1), a sharp decrease in viscosity was observed in a narrow temperature range (from 10 to 50 °C). It should be noted that there is a clear difference in the viscosity of the Yaregskoe and Usinskoe oil deposits at low temperatures, while the viscosity of fuel oil is similar in its indicators at temperatures above 30 °C, which is a consequence of the concentration of RAS in atmospheric residues of the Uinskaya and Yaregskaya oils, having a coagulation structure, resulting from direct distillation of oil under atmospheric pressure and separation of its light fractions.

When studying the rheological characteristics of a liquid, an important property is thixotropy, i.e. the ability of dispersed systems to reversibly liquefy under sufficiently intense mechanical action and solidify when staying at rest. Thixotropic media are the media whose structure deforms at a constant shear rate, which gradually leads to a decrease in the effective viscosity. Thixotropy is a reversible process, and after the removal of the loads, the structure of the liquid is gradually restored [3, 8]. The thixotropy energy is characterized by a hysteresis loop formed when the line of forward and return move does not coincide on the graph of the dependence of the shear rate on the shear stress. The area of the hysteresis loop, enclosed within a single measurement cycle, characterizes the amount of mechanical energy necessary to destroy thixotropic bonds per oil volume unit, so the larger the area of the «hysteresis loop», the more inclined the oil is to formation of structures under given temperature conditions.

As a result of laboratory studies, characteristic hysteresis loops for the Yaregskoe and Usinskoye oil deposits were obtained (Fig.2). The fact that the forward move does not repeat the line of the return move, indicates a thixotropic structure of the studied samples. In spite of the fact that both oils have a coagulation structure, 245 times more energy is needed to destroy the thixotropic ties of Yaregskaya oil than for Usinskaya one.

Thixotropic energy of heavy oils from Timano-Pechorkaya province:

| Indicator | Yaregskaya oil | Usinskaya oil |
|---|---|---|
| The hysteresis loop area, Pa/s | 320859.4 | 1307.76 |
| Thixotropy energy, J/m$^3$ | $711.01 \cdot 10^4$ | $2.91 \cdot 10^4$ |

According to studies made by G.I.Fuks the decrease of viscosity with increase of shear rate gradient contradicts the Newton’s law and is called viscosity anomality [3, 12].

When studying the dependecny of oils and atmoshperic residues vicosity from shea rate (Fig.3, 4) there was discovered an anomality of Yarhskaya and Usinskaya oils viscosity and their atmospheric residues at the whole range of investigated temperatures. Based on the behavior of the dependence of the samples under study, it can be concluded that they are viscoplastic liquids having a yield point, i.e. the limiting voltage below which the sample behaves as a solid. It should be noted that the dependency of shear yield point from temperature has a power-law form, which is confirmed by correlation coefficients from 0.9844 to 0.9987 (Fig.5). The structure of Yaregskaya fuel oil is more durable among all studied samples, that is indicated by high value of shear yield point at 20 °C.

When considering a viscous flow as a process whose velocity is determined by the energy necessary to overcome a potential barrier, the best results can be achieved by the joint application of the theory of absolute velocities and the statistical theory of a fluid based on the so-called free volume model [7, 8]. According to this theory, each molecule of a liquid is considered to be localized in a potential energy pit, i.e. in the region of the minimum of

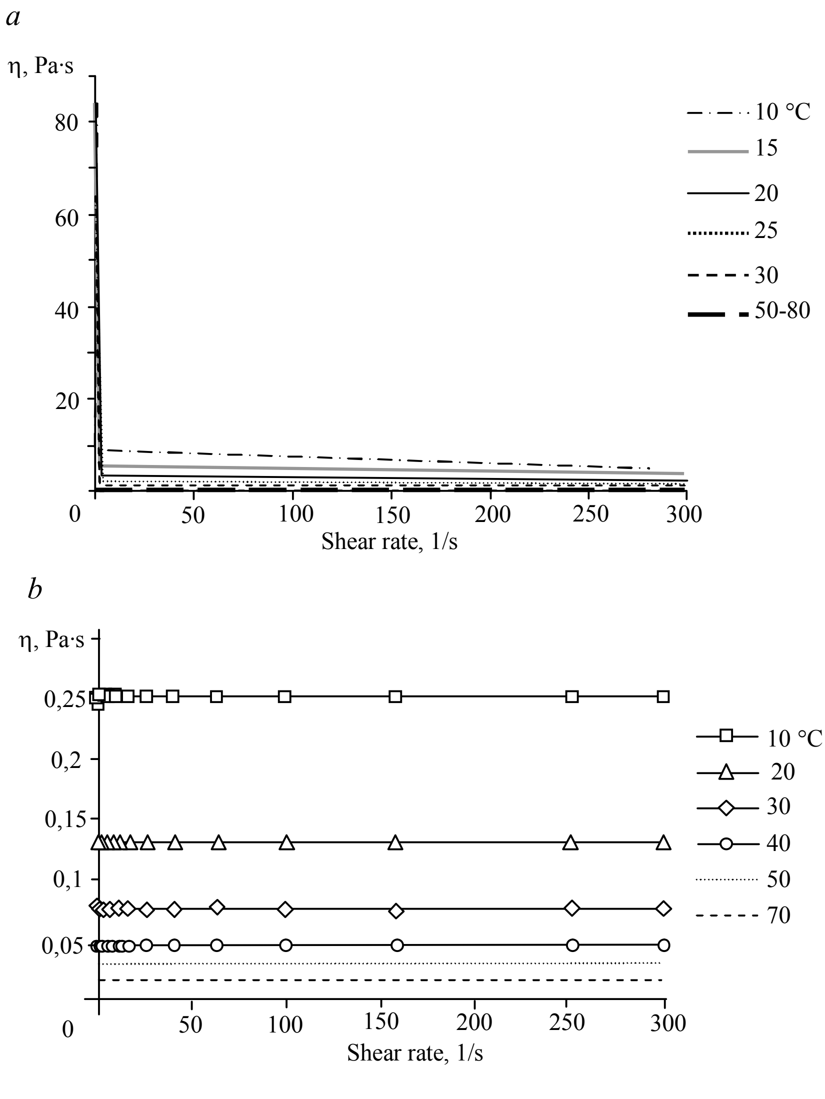


Fig.3. Dependency of viscosity from shear rate of Yaregskaya (*a*) and Usinskaya (*b*) oils

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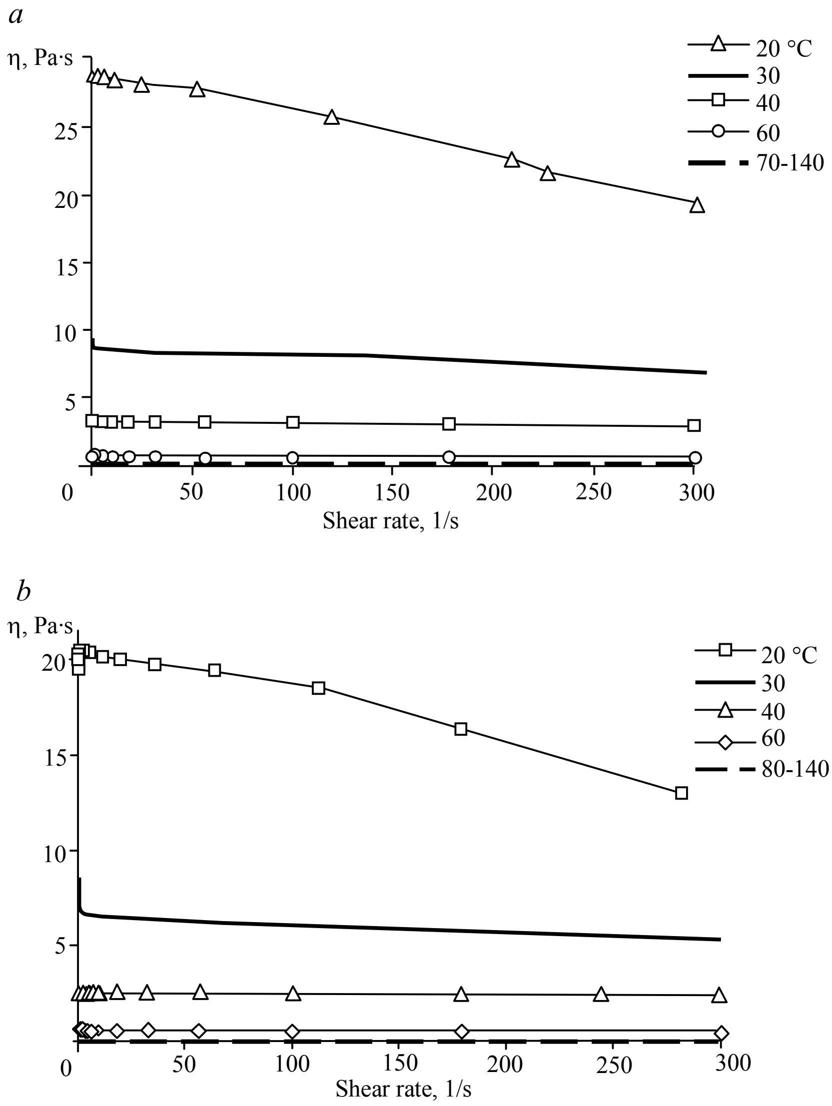


Fig.4. Dependency of viscosity from shear rate of atmospheric residue of Yaregskaya (*a*) and Usinskaya (*b*) oils

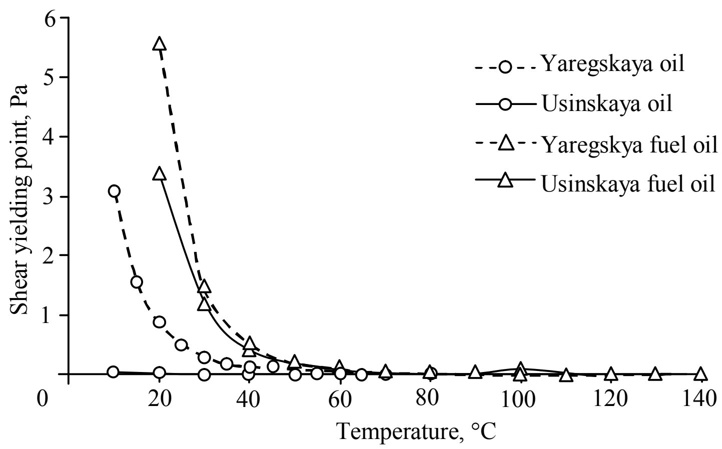


Fig.5. Dependency of yeild point from temperature

the potential energy, which is determined by the interaction of a given molecule with neighboring ones. This interaction leads to the establishment of short-range ordering, and long-range ordering almost does not exist [12]. According to H.Eyring theory the flow of liquids is accomplished by individual molecules jumping to a neighboring place, if it is free. These jumps always occur in a liquid and in the absence of flow only under the action of fluctuations in thermal energy. The presence of shear stress in the liquid during its flow makes it more likely that the molecules jump in the direction of the acting voltage. The probability of jumps is the higher, the greater is the thermal energy reserve in the system, i.e. higher temperature, and the weaker intermolecular interactions [11].

The frequency of molecular jumping is determined from a relation

$$J = \frac{1}{\tau}, \quad (2)$$

where

$$\tau = \tau_0 e^{-E_a/RT} \quad (3)$$

– residence time (Frenkel formula); $E_a$ – activation energy, which defines the energy which «kinetic» (structural) unit has to receive as a result of thermal energy fluctuation to detach from its neighbors; characterizes the strength of bonds in associative complexes in each structural state of oil system for a given temperature value; $R$ – gas constant; $\tau_0 = 10^{-13}$; $T$ – temperature.

The patterns that determine the probability of jumping determine the regularities of the viscosity. By analogy with formula (3), we can write

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$$\eta = \eta_0 e^{E_a/RT}, \qquad (4)$$

where η – dynamic viscosity; $\eta_0$ – pre-exponent of dynamic viscosity.

Taking logarithm of formula (2), we have

$$\ln\eta = \ln\eta_0 + \frac{E_a}{R}\frac{1}{T}. \qquad (5)$$

As the temperature is raised, the value of $E_a$ decreases, which leads to a gradual breakdown of supramolecular structures. Thus, the determination of the activation energy as a function of temperature gives an idea of the structural changes that are taking place in the substance.

It is known that the activation energy is equal to the work that must be spent to move the particles of the liquid, and is related to the energy of intermolecular interaction [8]. We have made the assumption that the free activation energy consists of two components:

$$\Delta G = \Delta G_0 + \Delta G_a, \qquad (6)$$

where $\Delta G_0$ – free energy associated with the process of momentum transfer in a gas; $\Delta G_a$ – the energy of hole formation in a liquid as a result of the displacement of structural elements.

According to the Frenkel-Eyring expression the change in viscosity is determined by the free energy for activation of viscous flow $\Delta G_a$ (5):

$$\eta = e^{\Delta G/RT} = e^{\Delta G_0/RT} e^{\Delta G_a/RT} = \sigma_0 e^{\Delta G_a/RT}, \qquad (7)$$

where $\sigma_0 = e^{\Delta G_0/RT}$ – viscosity of a substance in a state of gas, Pa·s; according to Frost's formula

$$\sigma_0 = T(6{,}6 - 2{,}25\lg M)\cdot 10^{-8}, \qquad (8)$$

M – the average molecular mass of the substance at temperature $T$.

The free activation energy of the viscous flow is determined by the Gibbs equation:

$$\Delta G_a = E_a - T\Delta S, \qquad (9)$$

where $\Delta S$ – activation entropy of viscos flow, J/(mol·K).

From relations (5) and (7) it follows:

$$\Delta S = (\ln\sigma_0 - \ln\eta_0)R. \qquad (10)$$

The enthalpy of activation of the viscous flow is determined from the relation (9):

$$\Delta H = E_a. \qquad (11)$$

The enthalpy and entropy energy values for activation of the viscous flow for multicomponent media are determined as the average over all components. Let us consider these averaged values.

When constructing the dependence of the logarithm of viscosity on the reciprocal temperature (Fig.6), it was found that the curve obtained for the Yaregsky and Usinskaya oils has a practically linear form. This is also confirmed by correlation coefficients, equal to 0.9949 and 0.9962, and perhaps, is determined by low content of solid par-

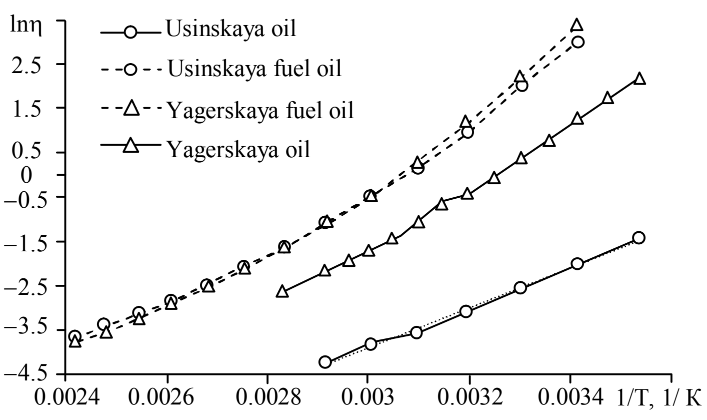


Fig.6. Dependency of Yaregskaya oil and atmospheric residues dynamic viscosity logarithm from reciprocal temperature

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affins in studied hydrocarbons, and values obtained for atmospheric residues of these oils are well approximated by two straight lines with an intersection point corresponding to 60 °C. On the basis of the obtained results, it is possible to assume a change in the structure of the atmospheric residues at a given temperature, as well as the precipitation of solid paraffins, i.e. at 60 °C, a phase transition of the media is observed. Thus, subsequent calculations for fuel oil should be carried out for two sections separately – before and after the temperature of the phase transition. As a result of the calculations, the activation energies of the viscous flow for oils and their fuel oils were obtained (Table 2).

*Table 2*

**The activation energy of viscous flow**

| Indicator | Yaregskoe deposit | | | Usinskoe deposit | | |
|---|---|---|---|---|---|---|
| | Oil | Fuel oil (20-60 °C) | Fuel oil (60-140 °C) | Oil | Fuel oil (20-60 °C) | Fuel oil (60-140 °C) |
| Activation energy, kJ/mol | 57.92 | 77.31 | 47.95 | 37.84 | 70.41 | 44.74 |

It should be noted that the temperature of 60 °C corresponds to the melting point of n-alkane $C_{27}H_{56}$. It can be assumed that solid paraffins are concentrated in the high-boiling fraction of oil (fuel oil) and when this temperature is reached, they plate out, forming a phase transition of the system.

The concept of «activation energy» was first introduced by Arrhenius, who tried to explain the temperature dependence of the rate of chemical reactions. He put forward the idea of the existence of active molecules that are in equilibrium with the original (inactive) molecules. The physical meaning of the activation energy of a viscous flow corresponds to the energy of the transition of liquid atoms from the initial (equilibrium) to the intermediate (activated) state, from which they then transfer to a new equilibrium position [11].

To estimate structural transformations and intermolecular interaction in disperse systems, free energy, enthalpy and entropy of viscous flow activation are more often used. The applied shear stress $\tau$ can cause the destruction of these structures and the reorientation of macromolecules, which is accompanied by a change in their conformations. These processes must have different effects on the enthalpy and entropy of viscous flow activation, while the enthalpy of activation should reflect the strength of the structure, and the activation entropy – the degree of its ordering.

The activation energy of the viscous flow of Yaregskaya oil is 1.5 times higher than the activation energy of Usinskaya oil (57.92 and 37.84, respectively) (Table 2), which suggests stronger links of the structure in the Yaregskaya oil, when for atmospheric residues, this indicator is practically the same. Table 2 shows a sharp decrease in the activation energy of the viscous flow of atmospheric residues after a phase transition (almost 1.5 times), which is a consequence of the destruction of the oil structure and the decrease in the strength of the bonds as a result of heating. The energy of activation of the viscous oil flow is much higher than the oil enthalpy, on the basis of which it can be concluded that the bonds in the fuel oil harden to the phase transition temperature in comparison with the strength of the bonds in the original oils, which indicates the formation of a stronger structure in fuel oil as a result of atmospheric distillation and topping of its light diesel fractions.

The dependence of enthalpy and entropy of viscous flow activation on temperature was determined from formulas (9), (10) (Fig.7). It should be noted that for oil, the obtained values have a linear form, while for fuel oils at the temperature of the phase transition significant changes occur. The strength of the bonds of the studied systems decreases with increasing temperature, and the rate of decrease in the strength of the Yaregskaya oil bonds is higher than that of the Usinskaya oil. For atmospheric residues, the rate of decrease in bond strength decreases after heating above the phase transition temperature.

The entropy, being a function of the thermodynamic probability of a system, is related to the mutual arrangement of its elements, and changes in entropy reflect changes in the arrangement of these ele-

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ments, i.e. structure of a body. The entropy of viscous flow activation is the difference between the entropy of the activated and the initial state, and positive values of this value mean that the particles, molecules or other elements of the structure in the intermediate (active) state are less ordered than in the original state. This can occur if the flow is associated with the destruction of the structure. If during a flow the orientation processes dominate and are accompanied by the straightening of macromolecules and the formation of new ordered structures, the entropy of the activated state must be less than the initial state, hence the entropy of the activation of the viscous flow must be negative [13].

Since the obtained values of the studied systems are positive, a structure is destroyed for all media, which increases insignificantly with increasing temperature.

However, it should be noted that the structure of the Usinskaya oil and its fuel oil is more ordered than the structure of the Yaregskaya oil and its atmospheric residue, respectively. The entropy of activation of viscous fuel oil flow after the phase transition temperature decreases, which is a consequence of the ordering of the structure after the precipitation of solid paraffins from the system.

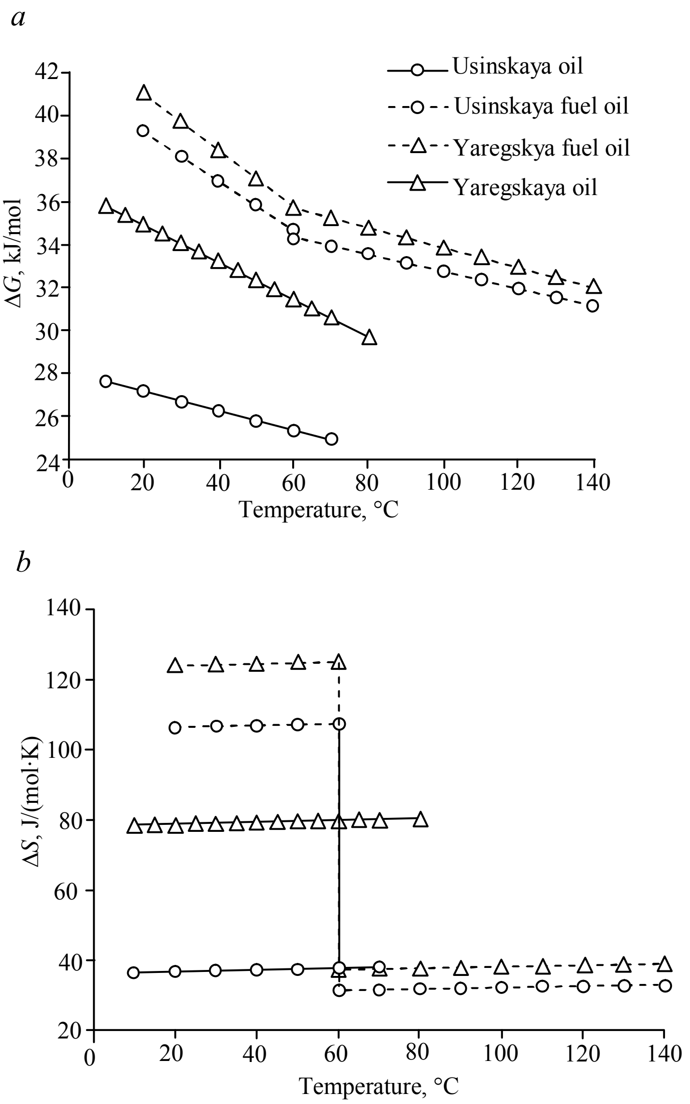


Fig.7. Dependencies of free energy activation (*a*) and entropy activation (*b*) of viscos flow of Yaregskaya and Usinskaya oils and atmospheric residues from temperature

High values of the energy of activation of oil and their rapid decrease with increasing temperature [1] were explained by the fact that in order to achieve the activated state of the liquid in the viscous flow, in addition to the work required for the formation of a "hole," it is necessary to expend energy for breaking strong intermolecular bonds.

The change in the free activation energy and the entropy of the viscous flow activation with temperature is associated with the flow mechanism itself, which is simultaneously occurring processes of destruction of the system structure and the orientation of macromolecules and elements of the destroyed structures.

Based on the research results and formula (2), the dependence of jumping frequency on viscosity for Yaregskoe and Usinskoye oil fields was determined:

$$J = 1589.2\,\mu^{-0.995}; \tag{12}$$

$$J = 165392\,\mu^{-1.018}, \tag{13}$$

and their atmospheric residues before and after the phase transition temperature, respectively:

$$J = 4.4014 + 7\mu^{-0.998}; \tag{14}$$

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$$J = 28.368\,\mu^{-1.005}; \tag{15}$$

$$J = 168056\,\mu^{-1.011}; \tag{16}$$

$$J = 348949\,\mu^{-1.012}. \tag{17}$$

It is determined that the dependence has a power-law character, which is confirmed by the correlation coefficients 0.9949; 0.9978; 0.9939 and 0.9964; 0.9901 and 0.9959, respectively.

## Conclusions

1. Based on the rheological studies of the heavy oils from Yaregskoe and Usinskoye deposits and the residues (fuel oils) recovered at atmospheric pressure, there have been determined the temperatures at which the studied systems show an anomaly of viscosity and behave like non-Newtonian fluids.
2. Based on the dependence of the shear stress rate, it has been determined that examined oils have a thixotropy. The energy needed to destroy the thixotropic properties of Yaregskaya oil is 245 times more than the energy required to destroy the thixotropic properties of Usinskaya oil.
3. We have determined the presence of a phase transition of atmospheric residues of oils (fuel oils) at 60 ° C, which may correspond to the precipitation of solid paraffins from the system.
4. On the basis of the obtained viscous flow activation energies of oils and their atmospheric residues, it has been found that the activation energy of the Yaregskaya oil is 1.5 times higher than that of the Usinskaya oil, while for the fuel oil these indicators practically coincide.
5. The linear dependence of the enthalpy and entropy of viscous flow activation on temperature for the studied heavy oils of the Timano-Pechorskaya province has been found, while for oil residues at the phase transition temperature, the values of these parameters change drastically.
6. The strength of the bonds of the studied systems decreases with increasing temperature, and the rate of decrease in the strength of the Yaregskaya oil bonds is higher than that of the Usinskaya oil. For atmospheric residues, the rate of decrease in bond strength decreases after heating above the temperature of the phase transition.
7. Based on the positive values of the entropy of studied systems, structural destruction has been observed, which increases insignificantly with increasing temperature. The structure of the Usinskaya oil and resulting fuel oil is more ordered than the structure of Yaregskaya oil and its atmospheric residue, respectively. The entropy of activation of viscous fuel oil flow after the phase transition temperature decreases, which is a consequence of the structure ordering after the precipitation of solid paraffin from the system.
8. Dependences of the molecules jumping frequency on the viscosity of oils and their atmospheric residues before and after the phase transition temperature, which have a power-law character, have been determined.
9. The oils of Yaregskoe and Usinskoe deposits have different physical-chemical and structural-mechanical properties, while the atmospheric residues, which concentrate in themselves resinous-asphaltene components, are practically similar in their properties and have similar energy values of enthalpy and entropy of viscous flow activation. Thus, it can be concluded that the light fractions separated from the oils by direct atmospheric distillation cause them to differ significantly due to the unequal content of solid paraffinic, aromatic hydrocarbons and resins in them, and the high-boiling fractions of oil (fuel oil) – resins and asphaltenes.

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# ENERGY EFFICIENCY OF HYDRAULIC TRANSPORTATION OF IRON ORE PROCESSING TAILINGS AT KACHKANARSKY MPP

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The article presents analytical calculations of specific pressure losses during hydraulic transportation of slurry tailings from iron ore beneficiation processes at the Kachkanarsky MPP during the storage of processing tailings in the tailings pond. The calculations were performed based on the results of experimental studies of dependence of specific pressure losses on roughness of inner surface of pipelines lined with polyurethane coating. In the process of experimental determination of pipeline polyurethane coatings roughness, it was established that the physical roughness of the coatings is more than four times less than the roughness of steel pipelines, which leads to a decrease in the coefficients of hydraulic resistances included in the design formula for the specific pressure losses - the Darcy-Weisbach formula. The coefficients of relative and equivalent roughnesses for pipelines with and without coating have been calculated. Comparative calculations have shown that the use of polyurethane coatings of hydrotransport pipelines contributes to a decrease in the specific energy during hydraulic transportation of processing tailings of iron ore from Kachkanarsky MPP in 1.5 times. To assess the nature and intensity of changes in the physical roughness of test pipes with polyurethane coating, experiments were performed on the roughness on a laboratory hydraulic bench. The prepared slurry of the iron ore tailings of Kachkanarsky MPP was pumped through a looped pipeline, in the linear part of which three test coated pipes were sequentially installed. Experiments showed that the roughness after running 484 hours on all the samples of the pipelines varies insignificantly. Roughness values are in the range from 0.814 to 0.862 μm. As a result of the processing of experimental data by mathematical statistics, an empirical formula is obtained for calculating the surface roughness of the polyurethane coating surface, depending on the time of operation of pipeline transporting the slurry of the iron ore processing tailings.

***Key words***: roughness, hydraulic resistance coefficient, equivalent roughness, particle-size composition, hydraulic mixture, specific pressure loss

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**Introduction.** One of the important directions of intensification of mining and ore production, increasing its efficiency and competitiveness in the current market relations is the creation of a powerful transport base capable of significantly increasing the productivity of transport systems while reducing the cost of transportation of mineral raw materials and products of its processing. The development of such a base is connected with the introduction of continuous types of transport, among which the most popular in mining industry has become the hydraulic pipeline transport.

Currently, in the mining and ore production industrial complex there are about 400 pressure hydrotransport systems, the total length of the pipeline which exceeds 1,300 km. These systems annually move more than 1.5 billion tons of various solid bulk materials, mainly tails of mineral raw materials and concentrates processing.

JSC “EVRAZ KGOK” is one of the five largest mining enterprises in Russia. The production capacity of the plant is more than 55 million tons of iron ore per year. The main consumer of EVRAZ KGOK's products is EVRAZ NTMK. EVRAZ KGOK extracts ore from three quarries with its further processing in crushing, mineral processing, agglomeration and lumping shops.

The analysis of hydrotransport systems operation process at mining enterprises shows that the efficiency of using this type of transport does not correspond to its technical capabilities, the work labor input during equipment operation, the abrasive wear of pipelines, the metal consumption and the energy intensity of hydrotransport systems are high.

The specific energy capacity of hydraulic transport depends on the specific pressure losses and the concentration of the solid phase of the slurry [3]:

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$$E = \frac{N}{q_s L} = \frac{\rho_m g I_m}{3.6 \rho_s c_v}, \quad (1)$$

where $E$ – process specific energy intensity, kW·h/(t·km); $N$ – pumps power, kW; $q_s$ – system productivity for solid materials, t/h; $L$ – pipeline length (transportation distance), km; $\rho_m$ – hydraulic mixture density, t/m$^3$; $\rho_s$ – solid tails density, t/m$^3$; g – acceleration of gravity, m/s$^2$; $I_m$ – specific losses of pressure, m wat.st/m; $c_v$ – volumetric concentration of solid particles in hydraulic mixture.

As it can be seen from formula (1), the energy intensity of the transportation process depends mainly on the specific losses of pressure $I_m$ during transportation of the slurry (slurry tailings) through the pipeline and on the value of the solid phase $c_v$ concentration in the transported flow of slurry. Reduction of pressure losses and increase in concentration lead to a decrease in work for pumping a given volume of solid material - milltailings.

It is known that the main energy losses during the pipeline transportation of fluids are spent on overcoming frictional forces of fluid flow on internal surfaces of the pipeline, and depend on the value of the hydraulic resistance coefficient λ, included into the Darcy-Weisbach formula [5],

$$I = \lambda \frac{v^2}{2gD}, \quad (2)$$

where $v$ – fluid flow velocity, m/s; $D$ – pipe diameter, m.

The hydraulic resistance coefficient is a function of relative roughness of pipe walls and Reynolds number [6, 7], defining the fluid flow mode, i.e.

$$\lambda = f(\varepsilon, \mathrm{Re}), \quad (3)$$

where $\varepsilon = \Delta/D$ – relative roughness of pipe walls; $\Delta$ – absolute (physical) roughness of pipe walls, μm; $\mathrm{Re} = vD\rho/\mu$ – Reynolds number; $\rho$ – fluid density, kg/m$^3$; $\mu$ – dynamic viscosity coefficient, Pa·s.

It follows from formulas (2) and (3) that by changing the physical roughness of the pipeline walls, it is possible to influence the value of the specific pressure losses during the hydraulic transportation of fluids, including slurries of ore processing tailings.

**Hydraulic resistance coefficient and flow patterns.** In the laminar fluid flow pattern ($\mathrm{Re} \le 2300$), the coefficient of hydraulic resistance does not depend on the pipe wall roughness, but is determined only by the Reynolds number value according to the Stokes formula [6, 7]

$$\lambda = \frac{64}{\mathrm{Re}}. \quad (4)$$

In the friction zone, characteristic for hydraulically smooth pipes (the height of unevenness is covered by a fluid film), the coefficient of hydraulic resistance also does not depend on the wall roughness. This flow pattern occurs at Reynolds numbers in the range $2300 < \mathrm{Re} \le 100000$. The coefficient λ is calculated by the Blasius formula

$$\lambda = \frac{0.3164}{\mathrm{Re}^{0.25}}. \quad (5)$$

Almost all hydrotransport pipelines operate in modes of transition to turbulent and in turbulent mode, when the value of roughness of the pipeline walls determines the value of hydraulic resistance values [8, 12].

Let us calculate the value of Reynolds number for the conditions of the Kachkanarsky MPP using the following formula

$$\mathrm{Re} = \frac{vD\rho_m}{\mu}. \quad (6)$$

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Let us set the following values of quantities: $D = 1000$ mm; $v = 4.8$ m/s; $\rho_m = c_v(\rho_s - 1) + 1 = 1092$ kg/m$^3$; $\mu = 1.017$ Pa·s.

It is assumed in the calculation that the mass concentration of the processing tailings slurry $c_p = 10$ %, which corresponds to $c_v \cong 3$ %, according to the formula $c_v = c_p \frac{\rho_m}{\rho_s} = 0.1 \cdot \frac{1092}{3300} = 0.033$.

For pipeline $D = 1000$ mm the Reynolds number is

$$\mathrm{Re} = \frac{4.8 \cdot 1.0 \cdot 1092}{1.017 \cdot 10^{-3}} = 5.154 \cdot 10^6.$$

For pipeline $D = 900$ mm, average velocity $v = 4.0$ m/s and the same slurry properties the Reynolds number will be

$$\mathrm{Re} = \frac{4.0 \cdot 0.9 \cdot 1092}{1.017 \cdot 10^{-3}} = 3.865 \cdot 10^6.$$

In fact, we get that the pattern of pulp flow in pipelines that is a developed turbulent one. Under the developed turbulent mode (quadratic friction zone), the coefficient λ does not depend on the Reynolds number, but is determined by the coefficient of relative roughness ε in accordance with the Shifrison formula

$$\lambda = 0.11\varepsilon^{0.25}. \qquad (7)$$

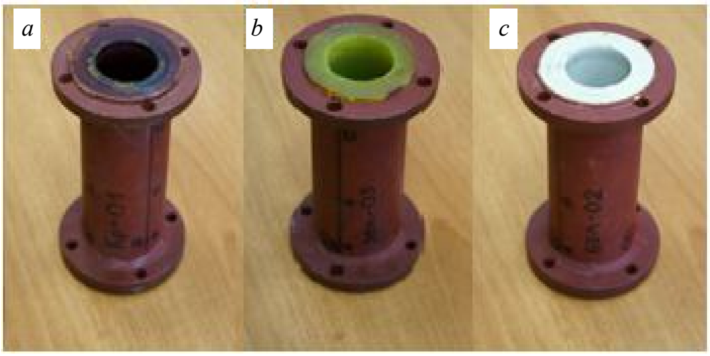


Fig.1. General view of test pipe samples with polyurethane lining: *a* – Shore hardness 83A; *b* – 85A; *c* – 90A


Fig.2. General view of measuring unit
1 – profilometer; 2 – PC; 3 – logement; 4 – test samples with polyurethane lining; 5 – a piece of steel pipe (new pipe); 6 – a piece of steel pipe with run in roughness (used pipe)

**Physical roughness of inner surface of pipelines.** At Department of Mining Transport Machines of Saint-Petersburg Mining University there have been conducted test research of roughness of pipelines fitted with polyurethane lining. The lining material is polyurethane with Shore hardness 83A, 85A and 90A (GOST 24621-91). The test pipe samples with lining are shown on Fig.1.

The surface roughness measurements were made using a special SJ-210 instrument. The contact profilometer (roughness meter) is an inductive sensor (detector in the form of a measuring probe) with a diamond needle and support on the measured area [11]. The needle (probe) moves perpendicular to the test surface. The sensor generates pulses passing through the electronic amplifier. The resulting mechanical vibrations of the probe are converted into a digital signal. Processing of several such signals makes it possible to calculate the average value of the parameter - the quantitative characteristic of section roughness from the calculation for a given length.

To do the measurement we have assembled a measuring unit which general view is shown at Fig.2.

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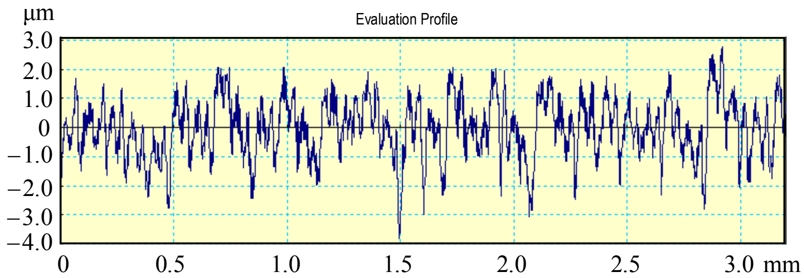
The measurement unit display sample N 1 is given at Fig.3. Measured and average roughness values of test pipe samples with lining are given in Table 1. Similar roughness measurements were performed for pieces of steel pipeline walls – new and used ones (Table 2).

To assess the nature and intensity of changes in the roughness of test pipes with polyurethane coating, experiments on development of roughness on a laboratory hydraulic bench were performed. The prepared slurry of processing tailings of iron ore of Kachkanarsky MPP with solid phase concentration $c_p = 10$ % was pumped through the looped pipeline (Fig. 4), in the linear part of which three samples of pipes with coating were installed sequentially. The total operation time was 484 h.

The hydraulic bench test results are shown in Table 3. From Table 3 it is seen that after working during 484 hours roughness of all test pipe samples changes slightly. The roughness values are within the range from 0.814 to 0.862 µm. As a result of experimental data processing using mathematical statistics, an empirical formula was obtained for calculating the roughness as a function of the pipeline operation time

$$R_a = 0.814 + 9.92 \cdot 10^{-5} T_{op}, \quad (8)$$

where $R_a$ – average roughness of pipe wall, µm; $T_{op}$ – pipeline operation time, h.




| Work Name | Sample | Operator | Mitutoyo |
|---|---|---|---|
| Measuring Tool | SurfTest | Comment | Ver2.00 |

| Standard | ISO 1997 | N | 4 |
|---|---|---|---|
| Profile | R | Cut-Off | 0.8mm |
| λs | 2.5µm | Filter | GAUSS |

| | | | |
|---|---|---|---|
| Ra | 0.799 µm | Rmr(c)2 | 2.609 % |
| Rq | 1.007 µm | Rdc | 0.581 µm |
| Rz | 5.335 µm | Rt | 6.557 µm |
| Rp | 2.236 µm | Rz1max | 5.868 µm |
| Rv | 3.099 µm | Rk | 2.536 µm |
| Rsk | -0.362 | Rpk | 0.771 µm |
| Rkµ | 3.108 | Rvk | 1.249 µm |
| Rc | 2.713 µm | Mr1 | 9.078 % |
| RSm | 65.9 µm | Mr2 | 88.797 % |
| RDq | 0.234 | A1 | 3.50 |
| Rmr | 0.109 % | A2 | 7.00 |
| Rmr(c)1 | 0.797 % | | |

Fig.3. Presentation of roughness measurement results: top – spectrogram of rough surface, bottom – a table with roughness values

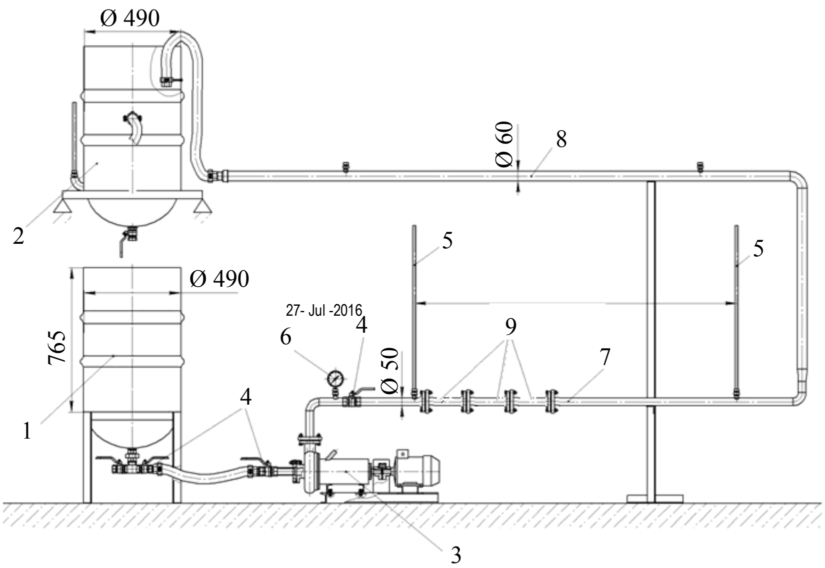



Fig.4. Layout of laboratory test bench

1 – feed tank 100 liters; 2 – measuring tank; 3 – pump CN30/18-U2 with induction motor; 4 – ball valve; 5 – piezometers; 6 – test pressure gauge; 7 – pipeline with internal diameter of 50 mm; 8 – pipeline with internal diameter of 60 mm; 9 – test pipe samples with internal polyurethane coating

Using equation (8) we can forecast developed roughness in time. For example, for time $T_{op}$ = 2000 h (3 months) of continuous operation of hydraulic transportation system the average roughness if internal surface will be $R_a$ = 1.012 µm; for $T_{op}$ = 2000 h (5 months) $R_a$ = 1,211 µm; for $T_{op}$ = 8000 h (about 1 year) $R_a$ = 1,608 µm.

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*Table 1*

**Results of roughness measurements of test pipe samples with polyurethane coating**

| Measurement point | Red sample, hardness 83A | | | Yellow sample, hardness 85A | | | Grey sample, hardness 90A | | |
|---|---|---|---|---|---|---|---|---|---|
| | Line I | Line II | Line III | Line I | Line II | Line III | Line I | Line II | Line III |
| A | 1.343 | 0.379 | 0.54 | 1.266 | 0.642 | 0.564 | 0.780 | 0.798 | 0.636 |
| B | 0.73 | 0.996 | 0.696 | 1.389 | 1.248 | 0.877 | 0.799 | 0.730 | 0.726 |
| C | 0.893 | 0.57 | 0.457 | 0.876 | 1.039 | 1.135 | 0.91 | 0.554 | 0.412 |
| $R_a$ | 0.988 | 0.648 | 0.564 | 1.177 | 0.976 | 0.859 | 0.830 | 0.694 | 0.591 |
| $R_{a(\text{av})} = \Delta$ | | **0.734** | | | **1.004** | | | **0.705** | |

*Table 2*

**Measured values of internal surface roughness of steel pipelines**

| Measurement point | New pipe | | | Used pipe | | |
|---|---|---|---|---|---|---|
| | Line I | Line II | Line III | Line I | Line II | Line III |
| A | 2.749 | 2.809 | 2.821 | 5.147 | 4.199 | 3.883 |
| B | 4.742 | 4.883 | 4.913 | 4.2 | 3.964 | 4.088 |
| C | 4.903 | 4.358 | 4.306 | 4.618 | 5.199 | 5.199 |
| $R_a$ | 4.131 | 4.016 | 4.306 | 4.618 | 4.454 | 4.39 |
| $R_{a(\text{av})} = \Delta$ | | **4.053** | | | **4.499** | |

*Table 3*

**Roughness values of used pipe samples**

| Test sample with Shore roughness | Average roughness ($R_a$·10$^3$) in operation time, h | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 4 | 28 | 52 | 148 | 242 | 484 |
| 83A | 0.734 | 0.815 | 0.908 | 0.876 | 0.764 | 0.95 | 0.828 |
| 85A | 1.004 | 1.031 | 0.975 | 1.063 | 0.782 | 0.788 | 0.822 |
| 90A | 0.705 | 0.783 | 0.872 | 0.962 | 0.983 | 0.854 | 0.935 |
| Average value | **0.814** | **0.815** | **0.918** | **0.967** | **0.843** | **0.864** | **0.862** |

**Determination of roughness, coefficients of hydraulic resistance and pressure loss.** The method for determining the roughness Δ, taken in hydraulics, takes into account that the natural (geometric $R_a = \Delta$) is always inhomogeneous, the ridges and gaps of roughness have different shapes, locations and sizes. The microrelief of pipe inner walls surface depends on many factors: material, method of pipe production, physicochemical properties of pumped fluid and service life.

Since natural roughness has variable irregular shapes (Fig.5, *a*), to establish in some geometric way the averaged value of the pimples height, which determines the effect of roughness on the loss of pressure, is impossible. That is why roughness parameter is viewed as imputed value, determined with special scale of artificial uniform roughness (Fig.5, *b*).

Such a scale is created with the help of calibrated grains of sand, glued to the smooth surface of the pipe. The set of such pipes for different diameters of grains Δ gives a number of relative roughness Δ/D, in which the λ values are obtained (I.Nikuradze formula) [4, 9, 10]

$$\lambda = \frac{1}{\left(2\lg\frac{\Delta}{D} + 1.14\right)^2}. \tag{9}$$

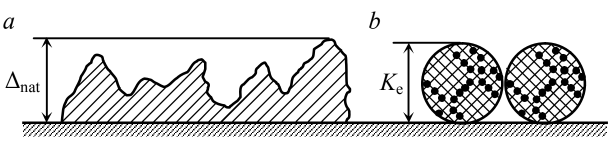


Fig.5. Natural (*a*) and equivalent (*b*) roughness

With the help of a special scale, the absolute roughness is assumed to be equivalent to a roughness, which is the size of sand grains of artificial roughness, which in the quadratic zone is equivalent to the hydraulic resistance of this inhomogeneous surface.

The results of studies [2]of relation between coefficient of equivalent and natural roughness on 13 samples of low and high pressure polyethylene pipes with diameters from 25 to 400 mm, as well as the results of studies performed by G.A.Trukhin (two reinforced concrete collectors with diameters of 1.6 and 1.94 m, allowed to find mathematical relationship in Research and Development Institution VODGEO (eight water lines made of different materials with various diameters from 0.7 to 1.2 m) to define this relation:

$$K_e = 2\Delta^{1.33} . \qquad (10)$$

On the basis of these assumptions, we calculated the value of equivalent roughness coefficient by formula (10), given by operating time of hydrotransport pipeline $T_{op}$ = 1000 h,

$$K_e = 2\cdot\left(0.814 + 9.92\cdot10^{-5}\cdot1000\right)^{1.33} = 1.772\ \mu\text{m}.$$

Thus, the expected value of equivalent roughness for a pipeline with a hardness of polyurethane coating of pipe internal surface in the range of 83A-95A after pipeline operating during $T_{op}$ = 1000 h during transportation of processing tailings slurry of Kachkanarsky MPP with mass concentration of solids about 10 %, will equal $K_e$ = 1.772 µm.

We take the obtained value of equivalent roughness for calculating the coefficient of hydraulic resistance λ and the specific pressure loss *I*. We determine the coefficient of equivalent roughness for a steel pipeline that was in operation. In accordance with GOST 8.586-1-2005 (ISO 5167-2003), the equivalent roughness for steel pipelines is calculated by the formula

$$K_e = \pi R_a . \qquad (11)$$

For calculation, we use the value of natural roughness of hydraulic transportation pipeline section $R_a = 4.49$ µm (Table 2),

$$K_e = \pi\cdot4.49 = 14.1\ \mu\text{m}.$$

It can be seen that the values of equivalent roughness for a used steel pipe line significantly exceed the values for a coated pipeline (by almost a factor of seven). Accordingly, the coefficients of hydraulic resistances and the specific pressure losses will be significantly different.

The coefficient of hydraulic resistance, which is a function of relative roughness in the quadratic area of friction (resistance), for a pipe of 1000 mm with an inner polyurethane coating in accordance with the Shifrison formula will be equal to

$$\lambda_l = 0.11\varepsilon^{0.25} = 0.11\left(\frac{K_e}{D}\right)^{0.25} = 0.11\left(\frac{1.772\cdot10^{-3}}{1000}\right)^{0.25} = 0.004 .$$

The coefficient of hydraulic resistance for used steel pipe is

$$\lambda_{st} = 0.11\left(\frac{14.1\cdot10^{-3}}{1000}\right)^{0.25} = 0.007 .$$

Specific losses of pressure are calculated for the conditions of Kachkanarsky MPP taking into account the new values of hydraulic resistance coefficients $\lambda_l$ and $\lambda_{st}$. For pressure losses in a pipe line coated with a layer of polyurethane with Shore hardness from 83A to 90A,

$$I = I_v + \Delta I_v = \lambda_l \frac{v^2}{2gD} + k_\rho \delta \sqrt[4]{j}\sqrt[3]{c_v^2} ;$$

$$I = 0.004\frac{4.8^2}{2\cdot9.81\cdot1.0} + 3.3\cdot0.056\cdot\sqrt[4]{0.2}\cdot\sqrt[3]{0.04^2} = 0.0155 .$$

In steel pipeline without lining

$$I = I_v + \Delta I_v = \lambda_{st} \frac{v^2}{2gD} + \Delta I ;$$

$$I = 0.007 \frac{4.8^2}{2 \cdot 9.81 \cdot 1.0} + 3.3 \cdot 0.056 \cdot \sqrt[4]{0.2} \cdot \sqrt[3]{0.04^2} = 0.0232 .$$

The calculation results for roughness coefficient, hydraulic resistance and specific pressure losses (pipeline $D$ = 1000 mm, operation time $T_{op}$ = 1000 h) are given in Table 4.

*Table 4*

**Calculated results**

| Pipeline | Indicators | | | |
|---|---|---|---|---|
| | Physical roughness Δ, μm | Equivalent roughness $K_e$, μm | Coefficient of hydraulic resistance λ | Specific pressure loss $I$, m wat. st./m |
| Polyurethane coating | 0.913 | 1.772 | 0.004 | 0.0155 |
| Steel | 4.49 | 14.1 | 0.007 | 0.0232 |

## Conclusion

1. The established values of surface roughness of polyurethane coatings, relative roughness coefficients and calculated values of specific pressure losses confirm the efficiency of using pipelines with a polyurethane internal lining in transportation systems for processing tail slurry.

2. The Shore hardness of polyurethane coating surfaces in the range of values from 83 A to 90 A (experimental coatings) has no practical effect on the intensity of internal coating surface roughness changes.

3. Hydraulic resistances of slurry pipelines during transportation of tail slurry with mass concentration of solid phase of $c_p$ = 10 % is proportional to the ratio of equivalent roughness $K_e$ to pipe diameter according to the formula $\lambda = 0.11\left(\frac{K_e}{D}\right)^{0.25}$. For working diameter of pipeline of 1000 mm when operating in the zone of quadratic friction (developed turbulent mode of hydraulic mixture flow) the hydraulic resistance coefficient in average of 1000 h of continuous operation will not exceed $\lambda_{av}$ = 0.004.

4. The calculated values of specific pressure loss in pipeline with polyurethane coating with hydraulic transportation of hydraulic mixture of processing tailings with mass concentration of solid phase $c_p$ = 10 % equal to $I_{m\,l}$ = 15.5 m wat. st/km, that is almost 1.5 times lower than in steel pipeline without any coating ($I_{m\,l}$ = 23.2 m wat.st/km).

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# COARSE PARTICLES-WATER MIXTURES FLOW IN PIPES*

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The present paper is focused on evaluation of the effect of average mixture velocity and overall concentration on the pressure drop versus the slurry average velocity relationship, on slurry flow behaviour and local concentration distribution. The experimental investigation was carried out on the pipe loop of inner diameter D = 100 mm, which consists of smooth stainless steel pipes and horizontal, inclinable and vertical pipe sections. The frictional pressure drop in the horizontal pipe section were significantly higher than that in the vertical pipe due to the fact, that for stratified flow the contact load produced significant energy losses. The frictional pressure drop of coarse particles mixtures in vertical pipe increased with the increasing mixture concentration and velocity, what confirmed effect of inner friction, inter-particles collision, and the drag due to particle-liquid slip. It was found that for stratified coarse particles-water mixture the frictional pressure drop was not significantly influenced by the pipe inclination, especially for low concentration values. The effect of pipe inclination decreased with increasing mixture velocity in ascending pipe section; the maximum value was reached for inclination between 20 and 40 degrees. Inclination of pressure drop maximum increased with decreasing mixture velocity. In descending pipe section the frictional pressure drop gradually decreased with increasing pipe inclination. The effect of inclination on frictional pressure drops could be practically neglected, especially for low mixture concentration and higher flow velocities. The study revealed that the coarse particle-water mixtures in the horizontal and inclined pipe sections were significantly stratified. The particles moved principally in a layer close to the pipe invert. However, for higher and moderate flow velocities the particles moved also in the central part of the pipe cross-section, and particle saltation [1] was found to be dominant mode of particle conveying.
***Key words*:** hydrotransport, coarse particles pipeline installation, pressure drop, pipe inclination

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The hydraulic transport pipelines are commonly used for transport of bulk materials, like coal, ores, and waste materials. Mostly relatively fine particles are used, which in the turbulent flow are supported by turbulent diffusion in the core of the flow. Near the pipe wall a lift force contributed to particle conveying. Pipeline transport of coarse-grained material is not very frequently used due to the problems of severe wear, energy consumptions, high deposition velocity limit and consequently also operational velocities, and also material degradation. However, pipeline transport of coarse particles in form of heterogeneous mixtures is of potential importance in mining and building industry, dredging and poly-metallic nodules transport from the ocean bottom to the surface [5, 10].

The advanced knowledge of particle-water mixture flow behaviour is important for safe, reliable, and economical design and operation of the freight pipelines. The understanding of the slurry flow behaviour makes it possible to optimize transport parameters and energy requirements, to improve quality, safety, economy and reliability of the transport. Knowledge of the slurry flow behaviour, deposition limit and operational velocities, and the pressure drops associated with the slurry flow in horizontal, vertical and inclined pipe sections is essential to safe and effective design and operation of such pipeline installation [6].

A lot of theoretical or experimental studies have been carried out on transport of sand or fine particles in horizontal pipes [2-4, 10, 11]. However, a relatively little research has been done on hydraulic conveying of gravel or bigger particles, especially in vertical and inclined pipes. A progress in the theoretical description of heterogeneous slurry flow is limited due to the lack of experimental data of the flow behaviour and an inner structure of slurry flow.

The present paper is focused on evaluation of the effect of average mixture velocity and overall concentration on the pressure drop versus the slurry average velocity relationship, on slurry flow behaviour and local concentration distribution. The experimental investigation was carried out on the pipe loop of inner diameter $D = 100$ mm, which consists of smooth stainless steel pipes and horizontal (A), inclinable and vertical (B) pipe sections, see Fig.1.

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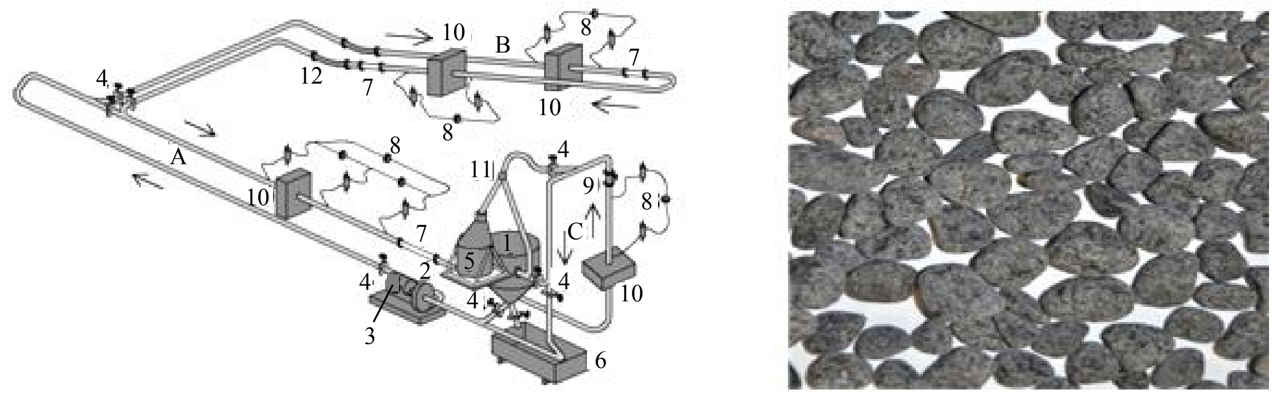


Fig. 1. Experimental test loop $D$ = 100 mm and the used graded basalt pebbles

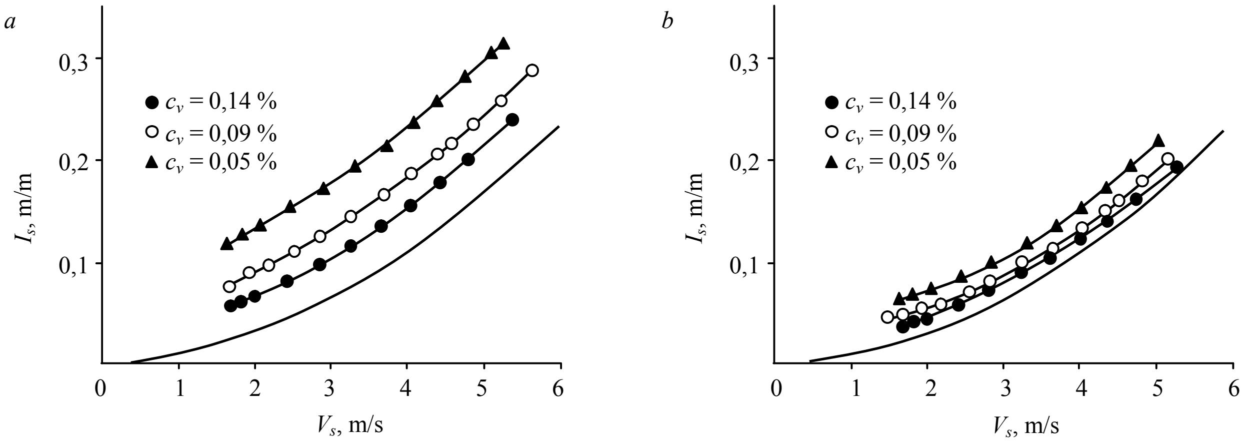


Fig.2. Pressure drop, $I_s$, in the horizontal (*a*) and vertical (*b*) pipe sections

Slurry was forced from a mixing tank (1) into the test loop by a centrifugal slurry pump GIW LCC-M 80-300 (2) with variable speed drive Siemens 1LG4283-2AB60-Z A11 (3). The pressure drop, $I_s$, were measured by the differential pressure transducers Rosemount 1151DP (8) over 2-meter long measuring sections, the mean slurry velocity, $V_s$, was measured in by a Krohne magnetic flow meter OPTIFLUX 5000 (9), mounted in the short vertical section (C) at the end of the loop. In the pipe viewing section (7) the mixture flow was recorded using a high speed digital camera NanoSence MK III+ with a frequency up to 2 000 frames per second, image resolution 1280 × 1024 pixels and frame rate 200 Hz [7]. The vertical $U$-tube (B) enables evaluating the delivered concentration of solid phase. To measure local concentration of solids, the loop is equipped with radiometric density meters (10). Water was used as a carrier liquid and the overall concentration, $c_v$, ranged from 3 to 15 %. The studied mixtures consist of graded basalt pebbles of narrow particle size distribution (particle diameter, $d$, ranged from 8 to 16 mm, mean diameter $d_{50}$ = 11.0 mm, density $\rho_p$ = 2 787 kg m$^{-3}$), see Fig.1.

Effect of mixture concentration and velocity on frictional pressure drop in horizontal and vertical pipe section is illustrated in Fig.2. The hydrostatic effect $\Delta p = (\rho_s - \rho_o)\, g.\, \Delta h$, where $\rho_s$ and $\rho_o$ is density of the mixture and carrier liquid, respectively, and $\Delta h$ is height of the mixture column, was extracted in Figs.2 and 3. Practically parallel course of pressure over velocity dependence $I_s / V_s$ with that of water confirmed that for stratified flow the main proportion of frictional pressure drop was due to the Coulomb friction between the particles and the pipe [8].

The frictional pressure drop in the horizontal pipe section were significantly higher than that in the vertical pipe due to the fact, that for stratified flow the contact load produced significant energy losses [9, 10]. The frictional pressure drop of coarse particles mixtures in vertical pipe increased with the increasing mixture concentration and velocity, what confirmed effect of inner friction, inter-particles collision, and the drag due to particle-liquid slip.

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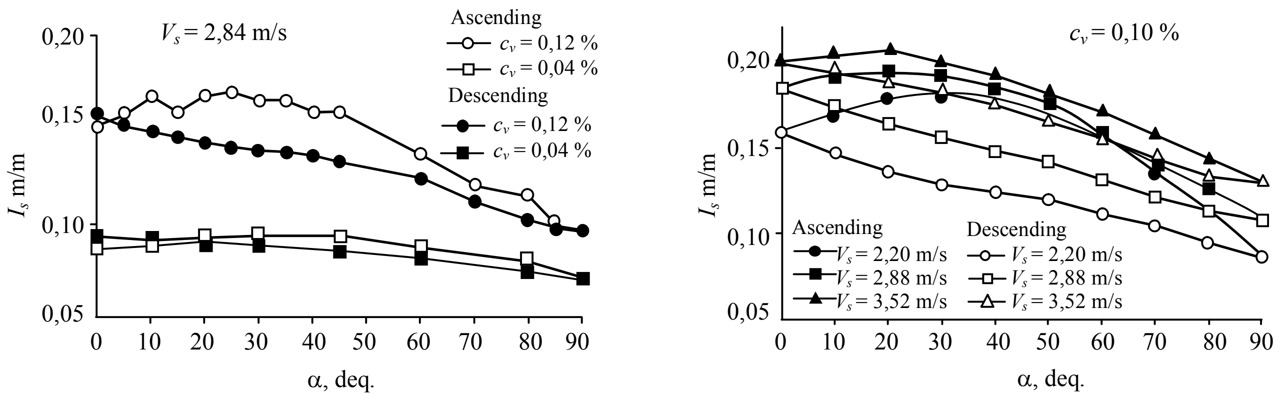
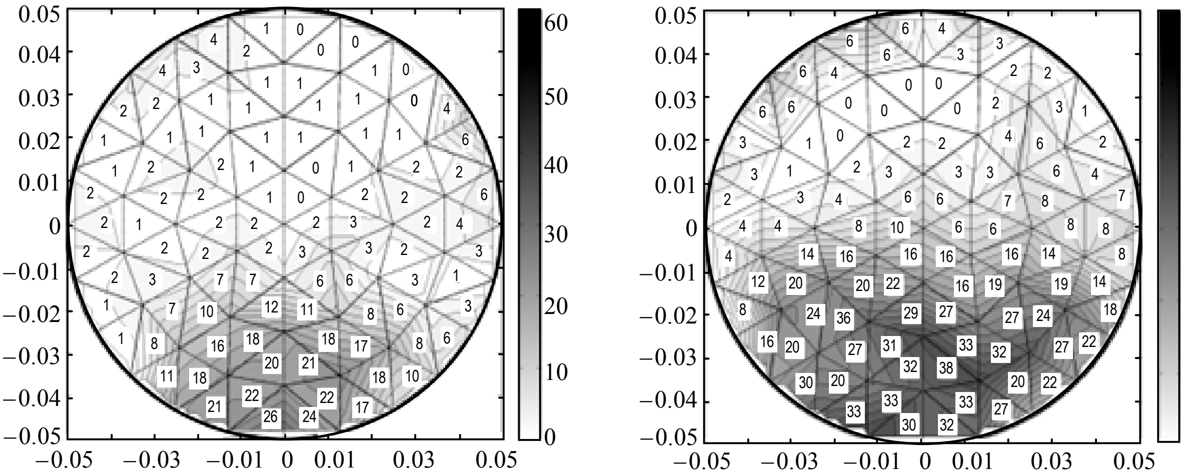
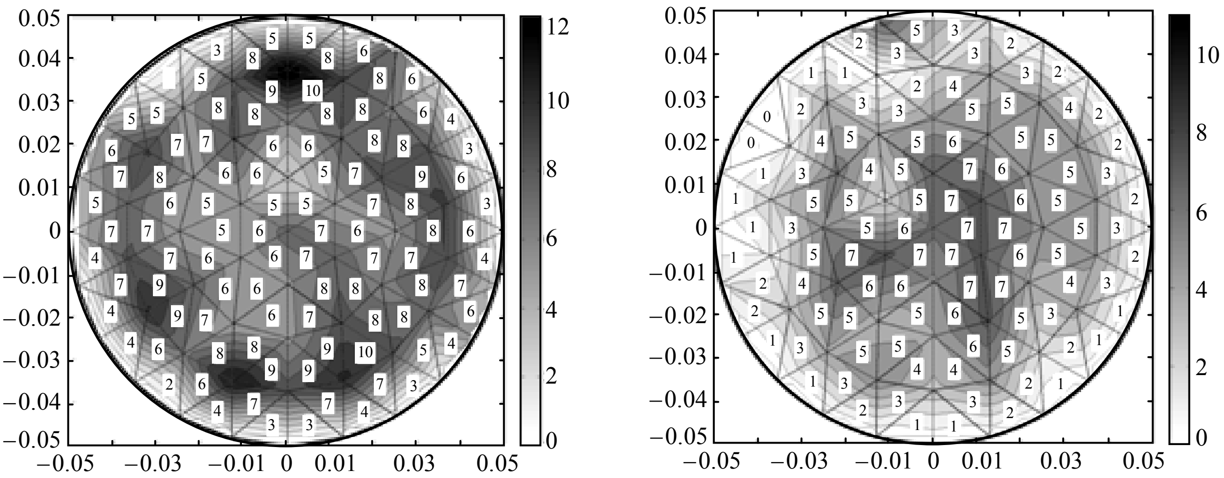



Fig.3. Pressure drop, $I_s$, in the inclined pipe sections




$c_v$ = 4.0 %, $c_{in}$ = 5.4 %, $V_s$ = 2.8 ms$^{-1}$ $c_v$ = 10.5 %, $c_{in}$ = 12.1 %, $V_s$ = 3.8 ms$^{-1}$

Fig.4. Maps of local volumetric concentration distribution in horizontal pipe section




Ascending pipe, $c_{in}$ = 5.4 %; $V_s$ = 2.05 ms$^{-1}$, $c_v$ = 4.5 %; Descending pipe, $c_{in}$ = 3.7 %

Fig.5. Maps of local volumetric concentration distribution in vertical pipe sec

The pressure drop in inclined pipe sections can be described by well-known Worster and Denny [11] formula, and can be divided into two parts – not recoverable frictional pressure drop, and the hydrostatic pressure difference, in principle change of potential energy. Fig.3 illustrates effect of the pipe inclination, alpha, on pressure drop, $I_s$, in inclined pipe sections for different values of mixture transport concentration and mean velocity, $V_s$.

It was found that for stratified coarse particles-water mixture the frictional pressure drop was not significantly influenced by the pipe inclination, especially for low concentration values. The effect of pipe inclination decreased with increasing mixture velocity in ascending pipe section; the maximum value was reached for inclination between 20 and 40 degrees. Inclination of pressure drop maximum increased with decreasing mixture velocity. In descending pipe section the frictional pressure drop gradually decreased with increasing pipe inclination. The effect of inclination on frictional pressure drops could be practically neglected, especially for low mixture concentration and higher flow velocities.

Local concentration distribution is important for understanding the physical mechanism of the heterogeneous mixture flow; it has a significant effect on both the mixture flow behaviour and pressure drop. The concentration distribution was measured using of a gamma-ray device and the effects of mixture velocity and concentration were analysed.

It is evident from observed local concentration maps that conveyed particles tended to occupy the bottom part of the pipe, see Fig.4. Concentration near the pipe lateral walls was observed slightly less than in central portion of the pipe cross-section. Concentration maps made possible to evaluate the in situ concentration, $c_{in}$, and compare it with transport concentration, $c_v$, which depends on particle slip velocity (e.g. velocity difference between particle velocity and carrier liquid velocity).

Local concentration measurement in the vertical pipe section illustrated effect of particle fall velocity on mixture concentration, see Fig. 5. The in situ concentration reached higher value in ascending section than in descending one. The flow pattern and concentration distribution were observed different in ascending and descending pipe section. For descending pipe section the concentration reached maxim in central portion of the pipe, in the direction to the pipe wall local concentration fluently decreased to the pipe wall. In ascending pipe section the maximum concentration was located in an annulus from about $r = 0.15\ D$ to $r = 0.40\ D$, with increasing flow velocity the width of annulus also increases.

The study revealed that the coarse particle-water mixtures in the horizontal and inclined pipe sections were significantly stratified. The particles moved principally in a – layer close to the pipe invert. However, for higher and moderate flow velocities the particles moved also in the central part of the pipe cross-section, and particle saltation [1] was found to be dominant mode of particle conveying.

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# THE INFLUENCE OF SALINITY OF FLY ASH MIXTURES ON ENERGY LOOSES DURING FLOW IN PIPELINES*

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In Polish mining for backfilling the fly ash mixtures are used. Last time for fly ash mixtures preparation the saline water from mine have been used, to thanks to that the saline water missing the surface waters. Usage of saline water for fly ash mixture preparation causes the changes in energy looses during the flow in pipelines. The paper presents the results of energy looses measurement in laboratory pipeline installation with diameter $D$ = 50 mm. The measurements have been performed for different fly ash – saline water proportions. Tested fly-ash from Siersza power plant has typical properties (grain size distribution curve, density) for ashes used for backfilling mixtures preparation. Increase of fluid (water) salinity modifies fluid viscosity. Brine in comparison with pure water retains as liquid with increased viscosity. Increased viscosity can influence on the mixture ash-brine properties for example causing flocculation effect. Also changeable salinity has an influence on proper determination of resistance (frictional) coefficient λ during mixtures flow in pipelines because it depends on Reynolds number which depends on liquid viscosity. Increase of fly-ash concentrations in fly-ash – brine mixtures cause increase of energy losses.

***Key words*:** hydrotransport, pipeline installation, saline water- fly ash mixtures

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**Introduction.** Exploitation of the natural raw material sources cause the creation of the after exploitation underground voids of large capacities. These empty voids left without filling can constitute the real risk for objects located on the earth surface and cause unfavourable changes in natural environment. For example the typical changes in natural environment in mining zone occurs as disruption in ground water conditions, surface deformation etc. From the other side, the exploitation of natural raw material sources, processing and end-usage cause creation of a significant waste amounts. Mining processes cause two types wastes creation: wastes from mining (gangue etc), wastes from process.

Second, significant group constitute wastes from power industry (from power and heat and power plants) where hard or brown coal is heated. The basic kinds of wastes in this group are: fly ashes, slag.

These wastes must be stored somewhere, the basic way to solve this problem is to store these wastes on the earth surface in dumps. Disadvantage of this storing way is intending bigger and bigger earth areas for that aim. Great dimension of these storage (dumps) causes changes in landscape and natural environment. The physical and chemical properties of the materials stored in dumps cause specific difficulty in their reclamation [1-5]. These storage areas without right protection systems which gives possibility of control the pollution migration are dangerous for natural environment resources (ground and surface waters, air, soil etc.) and indirectly or directly to the human. Wastes created in mining processes have not only the solid form, they can also have a liquid form. 1n natural resources exploitation the other natural resources are used as for example water. The physical or chemical properties of water after passing through the technological cycle are changed, for example it becomes strongly saline. For the sake of content of different chemical substances and toxins, these waters can not be directly released to the surface waters and can not be subjected to natural biodegradation process. To save clear natural environment there is a necessity to look for a new environmental friendly storage ways.

1n mining materials as fly ashes slag etc. as materials for empty void backfilling can be used. This way of waste development is not a pure storage because some of these materials properties for efficiency and mining safety improvement are used. Some characteristic properties of fly ashes for self-setting backfilling can be used.

**Backfilling mixture.** Most often a mixture for backfilling consist of specific proportions of fly ash, saline water, gypsum etc. Hydraulic filling is transported to the build in place in pipeline

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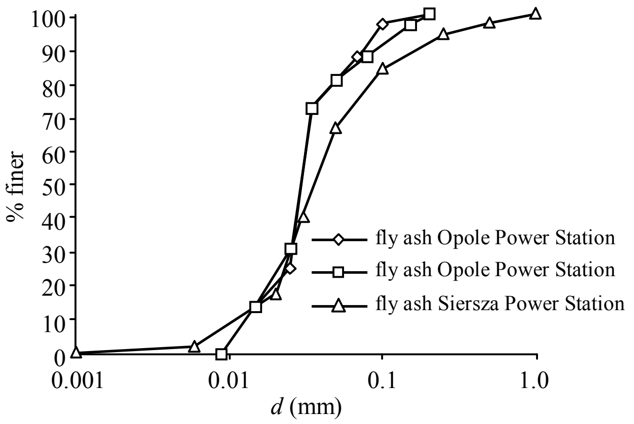


Fig.1. Grain size distribution curves for fly ashes from two Polish stations (Siersza and Opole)

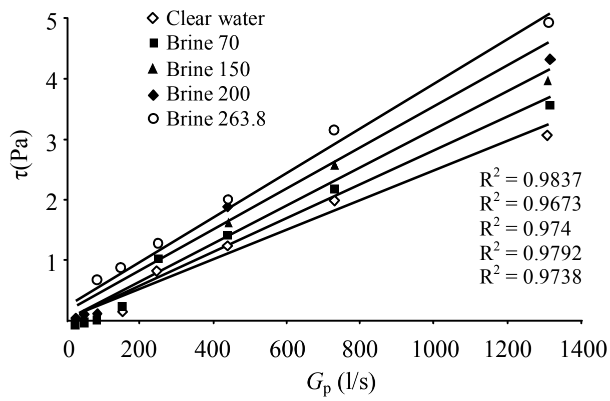


Fig.2. Pseudo-flow curves for pure water and different brines

installations. For proper hydrotransport pipeline installation design and work the knowledge of mixture parameters (viscosity, concentration, density), energy looses is very important. Mixture properties have big influence on pressure looses and flow conditions [6-9]. During mixture flow the pressure looses are higher in comparison with the clear water flow. Mixture properties depend on solid particles concentration, fluid viscosity etc. Properties of flowing mixture change with increasing of fine particles content. For low mixture concentration the Newtonian properties are characteristic, but if concentration increasing above the specific limit concentration the properties change and mixture becomes non- Newtonian. Mixtures for backfilling must have specific features: good transportation properties in pipeline installation, good migration parameters, adequate sedimentation and consolidation time, compressive strength, load capacity, high a wash out resistance in contact with tailwaters.

In Polish mining for self-binding filling the following materials are used: flu-ash, gypsum, Portland cement 35 and saline water with salt concentration between 0-70 g/dm$^3$. Content of free calcium oxide and gypsum cause that the ashes have hydraulic binding properties (pozzolana) and in contact with water they create ash-concrete with high compressive strength (1.9-6.8 MPa). Physical, chemical and mechanical ash properties depend on kind of coal that has been burned. The fly ashes density $\rho_s$ changing in a range 1.8-2.6 Mg/m$^3$. Specific for these materials is that they have characteristic grain size distribution curves, practically all fractions are smaller than 1 mm. Typical grain size distribution curves for fly ashes from two Polish power plants are shown in Fig.l. One can observed that these ashes have significant fractions content with diameter $d < 0.2$ mm and the percent fractions bigger than 0,2 mm is rather small (up to 15 % in extreme case).

**Brine Viscosity Meaurements.** Rheological characteristics (pseudo-flow curves $\tau = f(G_p)$ for pure water and brine have been measured with internal rotated cylinder viscometer Rheotest 2. All rheological characteristics for pure water and brine have been performed with measuring system N – especially designed for low viscosity fluids measurement. Pseudo-flow curves obtained for clear water can be treated as comparative characteristics to show the influence of salt content on increasing liquid viscosity [10-13]. The rheological measurements have been performed for clear water and different brines. The characteristics of tested brines is shown in Table 1.

Measured pseudo-flow curves for different evaporated salt concentration are show in Fig.2.

**Investigations for brine – fly ash mixture flow.** For the sake of increasing usage of saline water in hydraulic filling mixtures preparation, author performed laboratory tests on influence of saline water on mixture parameters and energy looses during flow in experimental pipeline installation with diameter $D$ = 50 mm. The experimental set up has been built in the Hydraulic Laboratory of Institute of Environmental Engineering of Agricultural University of Wroclaw and its scheme is shown in Figure 3. Measurements have been performed accordingly to the methodology described in.

*Table 1*

**The characteristics of tested brines**

| Name of brine | NaCl content |
|---|---|
| Brine 70 | 70 g NaCl/dcm$^3$ |
| Brine 150 | 150 g NaCl/dcm$^3$ |
| Brine 200 | 200 g NaCl/dcm$^3$ |
| Brine 264 | 264 g NaCl/dcm$^3$ |

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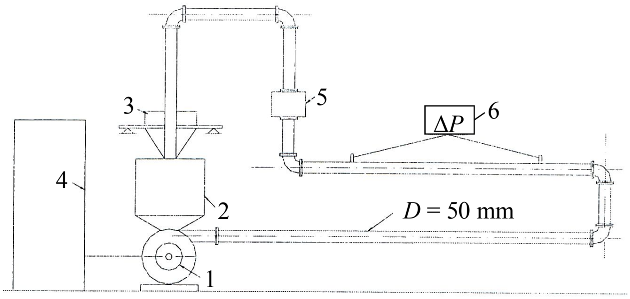


Fig.3. Scheme of the laboratory pipeline installstion
$D$ = 50 mm for hydrotransport parameters measurement
1 – pump, 2 – mixture tank, 3 – measuring tank, 4 – pump speed governor, 5 – inductive flow-meter, 6 – pressure difference transducer

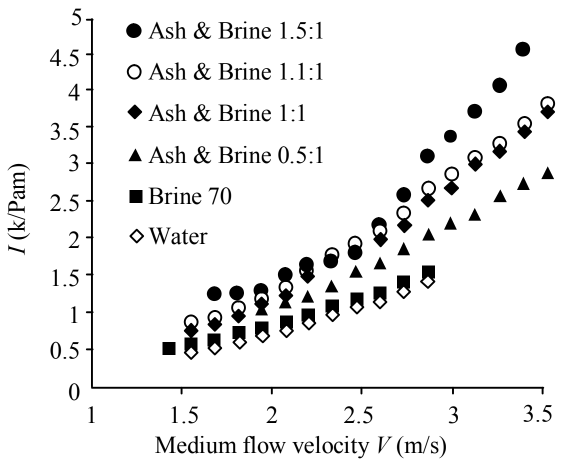


Fig.4. Measured losses I for different medium flow velocities

**Results.** For dry fly-ash the typical physical and geotechnical parameters as grain size distribution curve, density $\rho_s$ (kg/m3) have been determined. Grain size distribution curve obtained form sieve analysis is shown in Fig.1. Density has been determined with pycnometer method.

Grain size distribution curve shows that fly-ash from power station Siersza have characteristic diameter $d_{50} \approx 0.036$ mm. Sand fraction content ($0.05 \le d \le 2.0$ mm) constitute about 32 % of total sample mass, however dust content ($0.002 \le d \le$ $\le 0.05$ mm) reaches 68 %. Ash from Siersza power plant contains less than 2.5 % particles with diameter smaller than 0.006 mm. Maximal grain size diameter is $d$ = 1.0 mm. Accordingly to Polish standards (PN-74/B-02480) grain size distribution for investigated fly-ash correspond to grain size distribution characteristic for sand dust. Density of this ash is equal p5 = 2367.5 kg/m$^3$.

As it can be seen from Fig.2 brine viscosity increase with salt concentration. Brine retains as liquid with increased viscosity.

For energy losses measurements with described above installation ($D$ = 50 mm) the 70 gNaCl/dm$^3$ brine and fly-ash have been used. Energy losses have been measured in following sequence:

• characteristics $I = f(v)$ measurement during clear tap water flow in pipeline installation. This characteristics constitute comparable – control characteristics for checking

• correct work of measuring installation and calibration formulas,

• energy losses measurement for brine 70 flowing in installation,

• energy losses measurements for different mass ratios fly-ash and Brine 70 mixtures, for following different mass fly-ash – brine ratios: 0.5:1, 1:1, 1.1:1 and 1.5:1.

Measured characteristics of energy losses $I = f(v)$ are shown in Fig.4.

From obtained characteristics it can be seen energy loses have increasing tendency during increasing both flow velocity and fly-ash content in mixture. Simultaneously to energy losses measurement the following basic mixture parameters have been measured: mixture density $\rho_m$, mixture temperature $T$(°C).

*Table 2*

**Obtained and calculated investigation result**

| Parameters | Kind of mixture | | | | | |
|---|---|---|---|---|---|---|
| | Pure water | Brine | Ash-brine | Ash-brine | Ash-brine | Ash-brine |
| Weight ratio fly-ash-brine | – | 70 g NaCl/dcm$^3$ | 0.5:1 | 1:1 | 1.1:1 | 1,5:1 |
| T(°C) | 16 | 16*-17.5** | 21-21.5 | 25-26 | 27-27.5 | 28.5 |
| $\rho_m$(kg/m$^3$) | 1000 | 1021.2 | 1253.7 | 1420.0 | 1433.0 | 1501.5 |
| $\gamma_m$ (kN/m$^3$) | 9.81 | 10.02 | 12.30 | 13.96 | 14.06 | 14.73 |
| $c_v$ | – | 0.018 | 0.185 | 0.307 | 0.317 | 0.366 |

* the test beginning, ** end of test

On the basis of measured parameters the mixture density and volume concentration have been calculated (see Table 2). The data for mixture density and calculation from placed container method have been obtained. Density has been calculated from formula:

$$\rho_m = \frac{m_0 - m}{V_m}$$

where $\rho_m$ – mixture density, $m_0$ – container with mixture, $m$ – container weight, $V_m$ – mixture volume.

Mixture volume concentration has been from equation:

$$c_v = \frac{\rho_m - \rho_w}{\rho_s - \rho_w}$$

where $\rho_w$ – water density, $\rho_s$ – fly-ash density.

On the basis of known mixture density $\rho_m$ according to described in methodology the energy losses in meter of mixture column have been calculated from formula:

$$I_m = I_w \frac{\rho_w}{\rho_m},$$

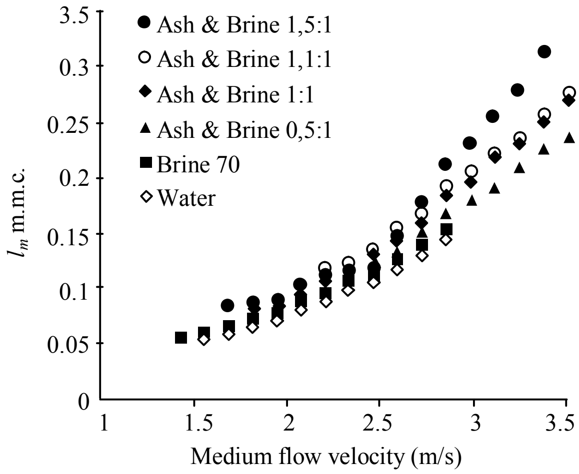


Fig.5. Measured energy losses in meter of mixture colump

where $I_m$ – energy losses in meter of mixture column, $I_w$ – energy losses in meter of water column.

Study results are presented in Fig.5. Results of energy losses measurements show that the energy losses magnitude increase with mixture flow velocity increasing and with increasing of ash content (mixture concentration).

**Concluding remarks.** Tested fly-ash from Siersza power plant has typical properties (grain size distribution curve, density) for ashes used for backfllling mixtures preparation. Increase of fluid (water) salinity modifies fluid viscosity. Brine in comparison with pure water retains as liquid with increased viscosity. Increased viscosity can influence on the mixture ash-brine properties for example causing flocculation effect. Also changeable salinity has an influence on proper determination of resistance (frictional) coefficient λ during mixtures flow in pipelines because it depends on Reynolds number which depends on liquid viscosity. Increase of fly-ash concentrations in fly-ash – brine mixtures cause increase of energy losses.

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## Geoecology and Occupational Health and Safety

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# SAFETY PROVISION DURING HEATING OF COAL DOWNCAST SHAFTS WITH GAS HEAT GENERATORS USING DEGASSED METHANE

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The article describes new technology of heating downcast shafts in coal mines in Ukraine using heat generators (air heaters) of mixed and indirect action type. It compares this method with traditional heating systems for downcast shafts and describes all their disadvantages. It is shown that application of new heating technology enables not building such elements as boilers and pipelines and not buying metal-consuming heaters. These peculiarities will help to significantly reduce capital and operation costs for construction and operation of heating system with significantly shortened commissioning periods for heating systems.

The article describes an example of heater unit design layout for heating downcast shaft in mine «Scheglovskaya-Glubokaya» at colliery group «Donbass» using mixed type heat generators. It presents a layout of sensors for controlling parameters of ventilation air flow taking into account incoming hazardous combustion products form methane-air mixture combustion in channels of heating unit. The article mentions features of automated control system providing protection of heat generators in emergency situations. It also notes disadvantages of mixed type heat generators limiting their application in Russian Federation.

Together with heat generators of mixed type the article also describes a working principle of heat generator of indirect action type, which to the fullest extent possible meets requirements of Russian Federation legislation and regulation for application of this heat generators in coal mines conditions. The article has a principal working scheme of heat unit layout using this type of generator. It is shown that after development of corresponding normative documents regulating processes of design, construction and operation of heating units using heaters of indirect action, their application in Russian coal mines will be possible without breaking Safety standards and rules.

***Key words*:** safety, mine, shaft, heating, technological process flow chart, temperature, heater, heat generator, methane-air mixture, concentration

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**Introduction.** The issue of provision of cage shaft safe operation has been and still stays to be one of the main pressing issues in coal mining. This issue becomes very acute in winter periods because due to huge water abundance in shafts in case of negative temperature of outside air it freezes and walls become covered with ice. This leads to icing of slopes, offtake rods, reduction of their cross-section area, which results in further jamming of hoisting vehicles, power cables breakage and ice falling in a shaft. The periodical freezing and melting of roof support materials causes temperature deformations, which leads to failure of upper part of shaft support. All of this significantly lowers safety of mining operations and creates real hazards for mine workers' health and safety, and justifies the need for improving existing methods and tools and finding new and more efficient air heating systems technology.

The technological process flow for heating downcast shafts that is being currently used in the majority of coal mines consists of the following key elements: coal or gas boiler for production of heating medium (hot water as a rule), calorific unit for heating the air coming into the mine, and heat network for delivering heating medium from boiler to calorific unit through pipelines. The presence of chain «boiler-heater transportation system-calorific unit» predefines the inadequate reliability of such systems since in case of appearance of emergency situations in at least one of any of these elements it creates a hazard of water freezing in heating network and parts of air heaters and consequently improper heating of air supplied in a shaft for its ventilation. This explains the necessity for presence of strict safety requirements applied for this technological flow process of heating mine shafts.

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For example, for provision of stable supply of heating medium to hot air units there must be an indispensable condition of creating in heating networks a backup supply network pipeline and calorific units must have additional tools for protecting heat exchange units providing measures for prevention of water freezing in emergency cases. Besides this, for provision of process reliability there should a possibility to have backup group hot air units with corresponding fittings for quick connection to hydraulic network and heat exchange surface area of hot air units should have extra 10-20 % [8].

Besides this, it should be noted that such shaft heating systems have low efficiency rate (60-65 %) due to multi-staged process of transferring heat from boiler to air. These technological processes have high heat lag and cannot provide timely reaction to wide fluctuations of atmospheric air temperature, as a result there were some cases of heavy icing of shafts causing drastic consequences [12].

The inadequate reliability, high energy and capital output ratio and long periods for building and installation works during implementation of traditional shaft heating process flow technology created a necessity to search for new methods and tools of providing temperature mode in downcast shafts in coal mines. The new trend in development of new shaft heating systems in coal mines is using hot air as heating medium, which significantly reduces the risk of emergency situations. The main tendencies and ways of improving the technology of coal mine downcast shaft heating systems are described in paper [3].

In the beginning of last decade in Ukraine they started to use a new technological system of shaft heating at some mines, its key element is industrial heat generators working on natural gas [6]. The usage of these heat generators as parts of heating system was justified from the point of view of significant reduction of capital and operational costs, because in this case there was no need to construct traditional boilers and heating pipelines. The process of putting this system into operation was also simplified and took less commissioning time but usage of this type of heat generators was limited by Ukraine State Health and Safety Supervision Authority due to presence of open flame. Therefore, they were classified as direct fired air heaters, which are prohibited to use in coal mines because of fire risk and possibility of toxic combustion products coming into air used for shaft ventilation. The obvious advantages of new downcast shaft heating technology raised the issue of adjusting gas industrial heat generators to coal mine conditions.

**Object and research methods.** Summarizing practices of applying principally new technology of heating downcast shafts based on industrial heat generators using mine degassing methane as fuel. The analysis of prospects and possibilities of using these systems for heating downcast shafts in coal mines of Russian Federation.

**Discussion results.** In December 2000 at mine «Glubokaya» of OJSC «Shakhtoupravlenie Donbass» as a result of an experiment they accepted into operation the first experimental-industrial calorific unit for heating downcast shaft air with industrial heating units of mixed type VGS-1, which had been working on natural gas till the end of heating season. Though at that moment several technical problems in the field of safety had not been resolved the first experience of its operation turned out to be very efficient. Due to absence of such structural elements as boiler and heating pipelines the annual economic effect form implementation of new air heating equipment was over 200 thousand dollars including capital costs expenses savings above 100 thousand dollars, which is two times less than expenses on construction of traditional downcast shaft heating system. in these conditions the commissioning period for new shaft heating system was 9 months instead of several years. The shaft heating process efficiency has also significantly improved [10].

The positive experience of using heating units VGS-1 for heating downcast shaft in mine «Glubokaya» allowed recommending this technological system of shaft heating for other mines as well. It was decided to construct another calorific unit at mine «Scheglovskaya-Glubokaya» of the same colliery group.

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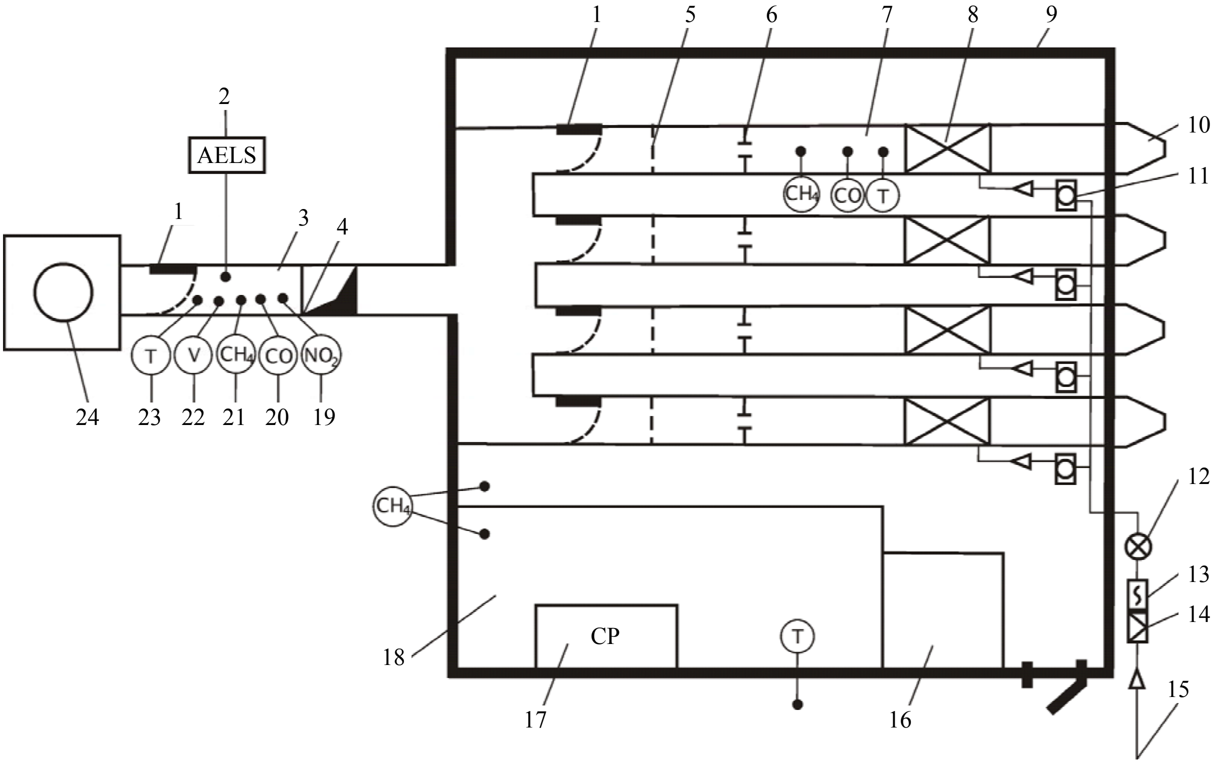


Fig.1. The scheme of calorific unit at mine «Scheglovskaya-Glubokaya»

1 – fire-proof door; 2 – AELS unit; 3 – common hot air supply channel; 4 – mixing chamber; 5 – protection screen; 6 – explosive valve; 7 – hot air channels of heating units; 8 – air heating units VGS-1; 9 – calorific unit building; 10 – air intake traps of heating units; 11 – gas equipment unit; 12 – gas offtake; 13 – flame arrester PGA; 14 – flame arrester OPS-2; 15 – gas pipeline supplying methane-air mixture; 16 – utility unit; 17 – control panel; 18 – operator's position; 19 – nitrogen oxides and dioxides control sensor; 20 – carbon oxide control sensor; 21 – methane sensor; 22 – air speed control sensor; 23 – temperature control sensor; 24 – downcast shaft

In 2006 OJSC «Dongiproshakht» implemented a project of using the mixed type of air heaters VGS-1 for heating cage shaft N 1 of mine «Scheglovskaya-Glubokaya» of OJSC «Shakhtoupravlenie «Donbass». In order to save fuel resources, instead of natural gas it was decided to use methane-air mixture (MAM) produced out of coalmine methane through degassing of a currently mined formation. Since application of such systems for heating downcast shafts is prohibited by safety rules the mine administration received a relevant approval of Ukraine State Health and Safety Supervision Authority for operating the heating unit under supervision of specialists from Makeevsky Research and Development Institution. This being said it should be noted that at that moment Ukraine didn't have current regulatory documents standardizing the processes of design, construction and operation calorific units using open flame heating units working on coalmine degassed methane. As a result, Makeevsky Research and Development Institution conducted relevant research and as a result developed safety regulations for systems for downcast shaft heating processes using flame heating units and degassed methane as fuel [1, 2, 9]. The principal diagram of design of calorific heating unit using air heaters of mixed type is shown at Fig.1.

According to a project in order to maintain the air temperature in cage shaft not less than 5 °C with air flow rate of 900000 m$^3$/h there were installed four air heaters VGS-1 (item 8 at Fig.1) with heating power of 1 MW each. Every air heating unit warms the air up to 100 °C with air flow rate of 50000 m$^3$/h. The controlling and monitoring of air heaters operations was planned to be done through control switchboard panel (17), located at operator's unit (18). The protection of air heaters form working in emergency cases was provided with the help of automated system, which performed protective trip of heating unit by stopping gas supply to burner unit in the following situations:

a) when temperature of hot air rises above 100 °C;

b) when controlled flame of burner device is out;

c) when methane concentration reaches the maximum admissible concentration;

d) when electric voltage of automatic circuit is lost (loss of electric power supply);

e) when air flow speed or direction is changed.

The gas consumption and hot air flow in every heating unit, as well as air temperature and its flow rate at five meters from the connection point of heating unit channel and downcast shaft are under constant supervision. In case of emergency situation, the electric magnetic valves at the entrance of gas equipment unit are closed (11), before burners unit and at the ignition place, and the electric magnetic gas offtake valve (12) is opened (except for the cases when there is no electric power supply). When reaching the maximum possible values (controlled by automatic safety system) the sound and light alarm is switched on.

The building of heating unit and channels of air heaters are equipped with fire extinguishing systems. The air outlet channels of air heaters are provided with the possibility to install fire-proof doors with mechanic drive 1, which are designed for cutting off the channels off in case of fire due to air flow tripping in the shaft or if methane concentration in channels has been above 0.5 % for more than ten minutes. In place of connection of common air supply channel with a shaft there has been installed the fire-proof folding door. There are four fire-proof folding doors designed for regulation of the cold air supply process in mixing chamber, which simultaneously serve as fire-protection devices by cutting off the air heaters from a downcast shaft.

At levels 534, 784 and 915 meters of the mine they have installed the equipment for continuous automatic control of air flow consumption and direction DRPV-1, which provided protective trip off gas supply to burners in case of air flow tripping in a downcast shaft or abrupt reduction of air flow rate (for more than 15 %).

To discover and suppress the unauthorized burning there has been installed some equipment for localizing explosions through AELS (automated explosion localization system) unit. In order to do this, in common air supply channel for heated air they have installed two flame sensors and explosion suppressor VPU-30P (item 2). They also installed power source unit and coupling device USD in the operator's unit. The AELS unit works in a waiting mode. When there is a flash in calorific channel the flame sensor registers it and sends a control signal to ignitor of explosion suppressor VPU-30P, which switches on and injects to a place of flash a charge of inert dust and thus localizes further distribution of combustion and explosion.

When the air heaters are working there is a possibility to control the concentration of carbon dioxide concentration (CO) in the air within 5 meters from the point of connection of calorific unit and a shaft and in air intake channels of air heaters, as well as concentration of nitrogen dioxide ($NO_2$) and nitrogen oxides (calculated as $NO_2$) within 5 meters from the point of connection of calorific unit and a shaft. There is a set inspection period for these gases.

The gas supply for air heaters has been done through external degassing networks with a pressure of 15-20 kPa and concentrations of methane-air mixture from 30 to 50 %. The diameter of supplying pipeline is 325 mm (item 15). At the place of building entrance, they installed the fire arrester OPS-2 (item 14) and flame arrester PGA (item 13). The degassing gas consumption flow rate per one heater was 300 $m^3$/h. There has been introduced a gas offtake (item 12) for releasing the methane-air mixture excess, its diameter is 219 mm and the height is 2 meters above the highest point of the building roof. The gas offtake has manually operated valves.

The analysis of mine readiness for implementation of new technology solutions has shown that the project documentation was done in accordance with corresponding requirements of normative regulations [9], and operating personnel have been trained a course of «Peculiarities of operating gas heaters VGS-1 using methane-air mixture as fuel. Additional requirements to safety rules when operating VGS-1 working on methane-air mixture». The specialists have concluded that colliery group «Donbass» can provide the following of requirements of regulatory legal acts in the field of Occupational Health and Industrial Safety during implementation of a project on operation of gas air heaters VGS-1 working on coalmine degassed methane, and State Ministry of Industrial Safety, Occupational Safety and Mines Inspectorate of Ukraine has issued a relevant permission to perform highly hazardous operations.

The observation of operation of new downcast shift heating system using heaters VGS-1 has been performed within the framework of a program and method of conducting research tests with two air heaters VGS-1. The results of thermophysical measurements of working downcast shaft heating system are given in Table 1.

*Table 1*

**Results of thermophysical measurements**

| Sampling time | Outside air temperature, °C | MAM temperature in gas pipeline, °C | | MAM pressure, Pa | MAM concentration, % | Air temperature after heaters, °C | | Air temperature at the beginning of a shaft, °C |
|---|---|---|---|---|---|---|---|---|
| | | Beginning | End | | | № 2 | № 3 | |
| 19:00 | –8.3 | 32.6 | 1.7 | 12940 | 45.5 | 96.0 | 105.9 | 12.1 |
| 20:00 | –8.3 | 32.6 | 1.1 | 13040 | 45.6 | 104.1 | 110.5 | 12.1 |
| 21:00 | –7.0 | 32.7 | 1.4 | 13040 | 45.6 | 106.3 | 112.3 | 12.2 |
| 22:00 | –6.9 | 32.8 | 1.6 | 13140 | 45.6 | 106.5 | 112.7 | 12.0 |
| 23:00 | –7.0 | 32.9 | 1.7 | 13040 | 45.6 | 107.2 | 114.5 | 12.4 |
| 24:00 | –6.9 | 32.9 | 1.8 | 12940 | 45.6 | 108.0 | 117.1 | 12.6 |
| 01:00 | –5.9 | 32.9 | 1.7 | 12940 | 45.8 | 111.8 | 122.3 | 13.2 |
| 02:00 | –6.0 | 33.1 | 1.6 | 12850 | 45.9 | 118.2 | 119.6 | 13.1 |
| 03:00 | –5.5 | 33.2 | 1.4 | 11670 | 46.1 | 111.9 | 119.3 | 13.1 |
| 04:00 | –6.5 | 33.1 | 1.2 | 11180 | 46.1 | 113.3 | 120.1 | 14.0 |
| 05:00 | –7.0 | 33.1 | 1.1 | 11770 | 46.2 | 116.1 | 121.5 | 14.0 |
| 06:00 | –6.3 | 33.1 | 1.1 | 12450 | 46.1 | 114.0 | 118.0 | 13.7 |
| 07:00 | –6.5 | 33.2 | 1.5 | 12360 | 46.1 | 112.6 | 117.0 | 13.6 |

The analysis of the observation results has shown that the downcast shaft heating system had stable operation. The air flow consumption rate in air heaters VGS-1 at time of observation was 42000 $m^3$/h, and the fresh air consumption rate in a shaft was 780000 $m^3$/h. The air temperature after heaters was ranging from 96 to 121 °C, and in addition air temperature at the entrance to air supply shaft was from 12.1 to 14.0 °C. Methane-air mixture pressure and concentration in gas pipeline was supported within the set range of values. The unified telecomminucation system (UTAS) installed at the mine provided control of all key parameters of air heating system operation and was controlled by the mine dispatcher and calorific unit operator.

From data in table 1 it follows that in case of insignificant reduction of atmospheric air temperature (up to –8 °C) the methane-air mixture temperature at the end of suppling gas pipeline has almost reached the possible limit and was 1.0-1.7 °C. In case of further reduction of outside temperature, the temperature of methane-air mixture at the end of supplying gas pipeline will reach negative values. To avoid frosting of mine gas pipelines it was suggested to improve insulation of gas pipeline and dry the methane air mixture. In this case, the possible heat calculations of permissible length of overland pipeline (item 15 at Fig.1) from overland wells to heating unit building (9), which provides absence of icing at its internal surface, were suggested to perform using the method [4], based on analytic research [13].

During tests, they also analyzed samples of mine methane from degassing system of mine «Scheglovskaya-Glubokaya» of OJSC «Shakhtupravlenie «Donbass» for quantitative composition. The results are the following, %:

$O_2$ .......... 8.46
$N_2$ .......... 51.91
$CH_4$ .......... 38.84
$C_2H_6$ .......... 0.0615
$C_3H_8$ .......... 0.0106
$i$-$C_4H_{10}$ .......... 0.0023
$h$-$C_4H_{10}$ .......... 0.0019
$CO_2$ .......... 0.763
He .......... –
$H_2$ .......... –

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The tests were carried out on chromatograph LHM-8MD and «Gasokhrom 3101» using checking gas mixtures. As it is seen from the data there are no traces of sulfur-containing compounds in coalmine methane.

They also analyzed the composition of gas mixtures produced after MAM burning for presence of toxic combustion products. To reduce inaccuracy of measurements of combustion products samples they were taken directly after burners of air heaters in the channel of hot air (7) (Fig.1). The analysis results and MAC of toxic gases are shown in table 2. As it follows from Table 2, the concentration of toxic gases in channels of hot air do not exceed maximum allowable concentration and there were no sulfur oxides in flue gases.

According to results of testing the experimental-industrial unit for heating caged shaft N 1 of mine «Schglovskaya-Glubokaya» with air heaters of mixed type VGS-1 working on mine degassed methane as fuel was accepted to operation.

*Table 2*

**Results of coalmine methane combustion products analysis, mg/m$^3$**

| Component | Concentration | MAC |
|---|---|---|
| $NO_2$ | 0.0529 | 2.0 |
| NO (calculated as $NO_2$) | 0.0201 | 5.0 |
| CO | 0.0001 | 20.0 |

Among disadvantages of new downcast shaft heating technology using gas air heaters of mixed type there are coming of hazardous methane-air mixture combustion products ($CO_2$, $NO_2$ and nitrogen dioxides calculated as $NO_2$) into mine atmosphere, which is directly and strictly prohibited by currently valid Safety Regulations of Russian Federation [11]. We should not eliminate a hazard of reaching maximum allowable concentration value limit for these gases in the air coming for shaft ventilation, in case of violation of burning mode or troubles with operation of burning devices or failure of automatic control and protection devices. Besides this, there are also no legal and regulatory framework standardizing process of construction, design and operation of downcast shaft heating systems using gas air heaters.

The above mentioned disadvantages of this method of heating downcast shafts of coal mines with air heaters of mixed type predetermined the necessity to improve it keeping its key advantages: the production of thermal energy should be done (whenever it is possible) through combustion of natural gas or MAM; usage of air as heating medium instead of hot water. To do this, the mixed air heaters should be replaced with safer type of heat generators that do not emit toxic combustion products into mine atmosphere.

The solution of this task became possible after changing design of air heaters (Fig.2) [5]. The body of air heater has a sealed wall 4, dividing it in two parts: an outside air heating chamber 7 and heat exchange chamber 13. The sealed wall has thermal siphon pipes 6 with intermediate heating medium. Due to boiling and condensation of intermediate heating medium there is a process of transferring heat from combustion products to shaft ventilation air. The air heater is located outside the overmine building and heated outside air comes in a shaft 9 through hot air channel 8, which reduces the possibility of gases from chimney coming into the mine. The outside air supplying fan 3 produces overpressure in outside air heating chamber and the fan for removing combustion products 14 creates exhausting in heat exchange chamber. Due to this the combustion products do not come into shaft ventilation air, in case of sealed wall 4 or thermal siphon pipes 6 wear out.

The abovementioned engineering changes make the suggested unit design different from mixed type air heaters VGS-1 because hazardous methane-air mixture combustion products do not come into shaft air, which to the full extent meets the requirements [11]. The novelty of suggested downcast shaft heating method was confirmed by declarative patent of Ukraine of invention [7]. For the purpose of this suggested method of heating downcast shafts (Fig.2) there has been developed a principal scheme of heating unit layout, which was described in paper [5].

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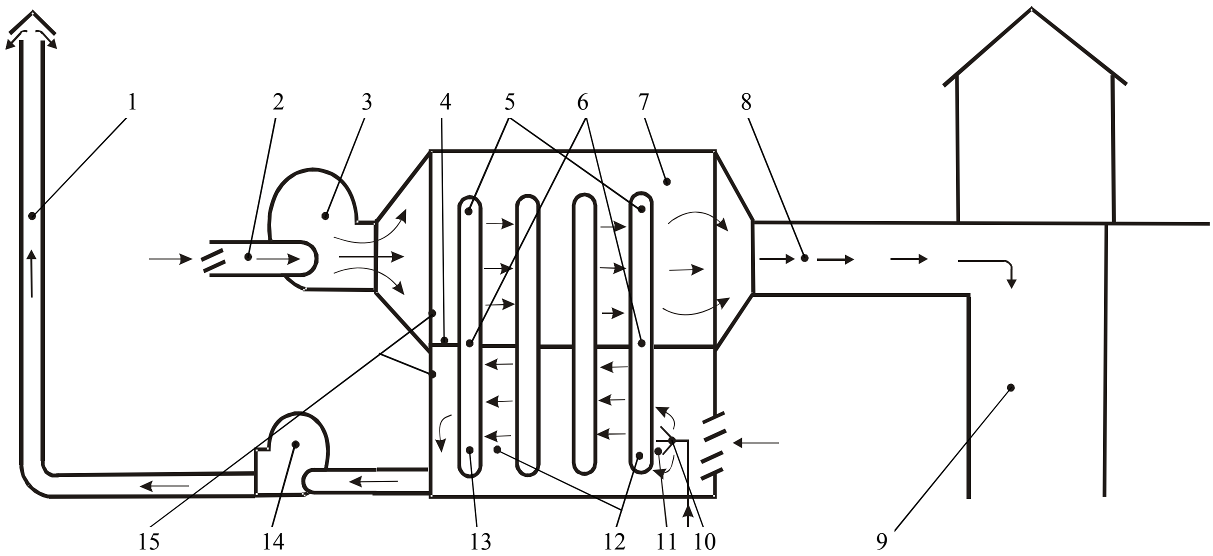


Fig.2. Heating of downcast shaft air

1 – chimney; 2 – outside air supply pipe; 3 – fan for supply of atmospheric air; 4 – sealed wall; 5 – condensing part of thermal siphon pipes; 6 – thermal siphon pipes; 7 – atmospheric air heating chamber; 8 – hot air channel; 9 – shaft; 10 – gas burner; 11 – gas fuel combustion chamber; 12 – evaporation part of thermal siphon pipes; 13 – heat exchange chamber; 14 – combustion products removal fan; 15 – air heater

The downcast shaft heating system using heat generator of indirect action with heating capacity of 750 kW has been successfully introduced at mine «Chaikino-2» of state company «Makeevugol» [2]. During acceptance inspection, the heating unit provided heating of 22000 $m^3$/h air up to 80 °C and had stable operation under methane-air mixture pressure from 8 to 12 kPa. Furthermore, the consumption of methane-air mixture was 220 $m^3$/h with methane concentration of 35 ± 2 %. The concentration of hazardous substances in outgoing combustion products didn't exceed the standard values. The safety automatic control of heat generator enabled its safe operation.

Despite positive experience of using mixed type heat generators at coal mines of Ukraine the application of such heating systems in Russian Federation coal producers is impossible taking in consideration the direct prohibition to use them in accordance with safety instructions [11] and absence of normative and technical documentation. That is why at the initial stages it is recommended to pay attention to heat generators of indirect action and develop corresponding normative documentation for their design, construction and operation of such heating systems from the perspective of coal mines of Russian Federation. In future, the variety of industrial gas heat generators can be expanded at the expense of mixed type heat generators since they are simple to use and operate when all necessary changes of current Safety regulations will be made [11].

**Conclusion.** Current level of telemetric, measuring and control equipment, automated systems enable provision of level required by Safety regulation of safe [11] temperature mode for air supplying shafts in coal mines by using industrial gas heat generators of mixed and indirect action. The implementation of these systems allows significant reduction of capital and operation costs for shaft heating systems with shorter commissioning periods for these systems. Usage of methane-air mixture instead of natural gas as fuel for heat generators promotes economy of fuel resources and improvement of ecological situation in coal mining regions due to reduction of hazardous emissions in outside air when recycling the coalmine degassed methane.

It is necessary to develop corresponding regulatory documents describing the processes of design, construction and operation of heating units using mixed and indirect action types of gas heat generators.

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# INSTRUCTIONAL MAPS OF SAFE WORKING METHODS AND PRACTICES FOR SEPARATE TYPES OF OPERATIONS CONDUCTED IN THE OIL MINE

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Instructing personnel in the issues of labor protection and industrial safety at hazardous facilities is one of the main tasks that face the employer; the quality with which this procedure is organized and carried out defines not only company's indicators, but the mere possibility of its normal functioning. The paper contains a detailed overview of the typical content of standard documentation, which is currently used when conducting operations in the oil mines of Yarega high-viscosity oil deposit. Distinct features and unique nature of this oil field require special measures to guarantee safety of personnel and all facilities in general.

The author proposes and reviews an additional type of operating guidelines – instructional map of safe working methods and practices. It is more illustrative than existing documentation (charts of inclined shaft development, labor protection regulations), which allows to upgrade the process of instructing personnel in the oil mines, to improve the quality of instructions and to reduce the risk of emergencies, accidents, industrial injuries.

The author reviews the structure of suggested instructional map, offers a detailed arrangement diagram for the main thematic sections of the map, as well as their content. Instructional maps are regarded as a type of operating guidelines that include: description and characteristics of equipment, instruments and appliances; general safety requirements; content and execution sequence of operational elements with their graphical images; distribution of responsibilities with an indication of their priority in case the operations are conducted by several workers; specific safety requirements for equipment, materials, instruments, safety clothes and footwear, personal protective gear etc. (prohibitions, warnings).

Advantages and disadvantages of proposed instructional maps of safe working methods and practices are highlighted.

***Key words***: instructional map, working methods and practices, safety of labor, oil mine, operational guidelines, training

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**Introduction**. Standard documentation used for conducting operations in the oil mines is basically a technological chart. A typical chart of construction and support of a development working includes the following sections:

1. Introductory sheet with technical documentation.
2. Report on the inspection of the working.
3. Table of contents.
4. Explanatory note.
5. Geological characteristic of the rocks.
6. Safety measures for blast-hole drilling.
7. Measures for safe conduction of switching operations.
8. Technical and organizational measures, eliminating the risk of injuries due to rock slides in the process of workings construction.
9. Plan of blasting operations in the oil mine.
10. Blast design.
11. Chart of hazardous zone safeguarding.
12. Measures for safe conduction of blasting operations.
13. Measures for safe degassing of the mine face.
14. Plan for boost fan installation.
15. Plan of antidust measures.
16. Lavatory location chart.
17. Chart of support.
18. Chart of temporary support.

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Each section is on the average no more than 2-3 pages long, and information on safety regulations in different sections may overlap and sometimes even contradict itself, as it is written by different people. Visual material is mostly presented in the form of charts, e.g. directions on where to place ventilation hose, type codes are introduced. But the major part of the documentation (around 95 %) is in the text form.

The purpose of this research was to develop new forms of operational guidelines – instructional maps of safe working methods and practices, examination of the possibility to create maps for separate types of operations conducted in the oil mine and their applicability in personnel instruction.

**Research methodology.** In Russian Federation, the legislation assigns to the employer the duty to organize personnel instruction and to test their knowledge. So, according to article 212 of the Labor Code of Russian Federation (LC RF) [10], the employer must provide for:

– training in safe working methods and practices, first aid treatment for industrial injuries, instruction in labor protection, traineeship at the workplace and test of knowledge of labor protection requirements;

– disqualification of persons who in the prescribed manner have not passed training and instruction in labor protection, traineeship at the workplace and test of knowledge of labor protection requirements.

Analogous to labor protection requirements set out in the article 212 LC RF [10], the law on industrial safety sets forth duties of companies, possessing hazardous industrial facilities, to train employees and to authorize them for work:

– to authorize for work at hazardous industrial objects only those persons, who satisfy relevant qualification requirements and have no medical contraindications to this work;

– to guarantee preparation and attestation of employees in the field of industrial safety.

Hence personnel training in the field of labor protection and industrial safety at hazardous industrial objects, and especially unique objects like oil mines, is one of the main objectives of the companies [8, 9, 13-17].

Organizational issues and requirements to personnel preparation and training in labor protection and industrial safety are specified in the Training Procedure [5], interstate standard GOST 12.0.004-90 [2] and RD 03-20-2007 [6]. Personnel training in safe working methods and practices is carried out using instructions on labor protection and operational guidelines [7].

Instructions on labor protection are developed relying on Methodological Recommendations [4], whereas operational guidelines, according to RD 03-20-2007 [6], must be based on the standards applied within the company. It should be noted that federal laws and regulations do not contain any methodological recommendations on the development of operational guidelines. Thus, the content of these guidelines and their correctness depend only on the knowledge, experience and competencies of specialists developing them.

Having thoroughly studied the process of personnel training in safe working methods and practices, the author offers to use instructional maps as an additional type of operational guidelines.

Instructional map is a detailed instruction-chart of conducting certain operations, which includes requirements towards technosphere safety (labor protection, industrial and environmental safety) [12].

The main purpose of development and implementation of instructional maps is to enhance the quality of training for primary occupation workers directly at their workplaces in order to prevent emergencies, accidents, industrial injuries at hazardous industrial objects.

The tasks of instructional maps are:

– visual representation and detailed description of every operation, conducted by the workers;

– emphasis on important aspects of operations that influence safety of the process and the facility;

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– development of worker's visual memory;

– elimination of inaccurate definitions and operations, which provide an opportunity for the worker to make the wrong choice of actions during operations;

– reduction of operation time with no compromise in safety levels of the facility and personnel.

When carrying out trainings in labor protection and safety, personnel, equipment and the facility itself have to be regarded as a single complex system. Basing on this, it is important to understand that distortions in the functioning of even one part of the system can lead to an emergency, accident or industrial injury. This principle is the cornerstone in the development of each instructional map. Hence the main supporting and basic elements of instructional maps are structured and visual means of presentation.

**Results and discussions.** Development of instructional maps for separate types of operations conducted in the oil mines included the following stages:

1) analysis of local documents;

2) selection of illustrations (photos, charts, figures);

3) formation of the instructional map (arrangement and adjustment to corporate style);

4) approval.

As a result of carried out research, general requirements to the map have been formulated. The following principal sections of instructional maps can be distinguished [2]:

1. Title: Instructional map of safe working methods and practices for … (type of operations should be specified).

2. Equipment characteristics. Description of equipment and technical appliances. This section must contain concise information on applied equipment with graphical materials.

If applicable, principal charts and equipment photographs can be included. Special attention should be given to the main elements and protection devices. With this in mind, any information should be ruled out that is not necessary for conducting operations and does not affect the safety of personnel and equipment in the working process.

3. Requirements to labor safety when conducting separate types of operations. It implies a detailed description of harmful and dangerous industrial factors, characteristic of conducted operations and applied equipment, which can cause an emergency, accident or industrial injury. It is important to identify safe methods of failure-free performance and practices in order to reduce or eliminate the influence of these factors on the personnel.

For illustrative purposes it is advisable to accompany the text with graphical materials. This section should also include information about necessary safety clothes and footwear, personal and collective protective gear.

4. Algorithm of operations. This is the main part of the instructional map, which contains an algorithm of worker's actions taking into account safe working methods and practices. This part of the instructional map can be logically divided into three sections: I – start of work; II – execution of operations; III – completion of work.

All the subsections of the instructional map are presented in the table with all the operations numbered in chronological order. Description of performed operations must be unequivocal and excluding any discretionary interpretation by the workers. It is also important to identify the location of the worker during operation.

In case of conditions, prohibitions, warnings that the worker has to pay attention to, they are described under the word «ATTENTION!» (written in red ink to highlight critical importance of the issue and to attract worker's attention to it). For illustrative purposes, as well as to promote better understanding and memorizing of the information, it is accompanied by photographs or graphical images. Conditions under the inscription «ATTENTION!» should be identified before or after description of the operation, depending on the time when the worker has to pay attention to them, i.e. in chronological order.

The resulting model form of the instructional map is presented in the figure [2].

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**Instructional map**
**of safe working methods and practices for …**

(type of operations specified)

Part 1. **Equipment characteristics**
Part 2. **Requirements to labor safety when conducting operations**

2.1. Harmful and dangerous industrial factors, and measures to reduce or eliminate the influence of these factors on the personnel

| Harmful and dangerous industrial factors | Measures to reduce and (or) eliminate their influence | |
|---|---|---|
| Item specified | Measures to reduce and (or) eliminate the influence of these factors on the personnel specified | Photograph |
| | | |

2.2. Instruments, equipment, personal protective gear necessary for conducting operations

| Item | Image |
|---|---|
| Item specified | Photograph |
| | |

Part 3. **Algorithm of operations and safety measures**

3.1. Organizational measures

| Number of operation | Content and sequence of performing operational elements (number of personnel – three workers) Special attention when conducting operations | | |
|---|---|---|---|
| | Worker 1 | Worker 2 | Worker 3 |
| 1 | Performs function 1. | Performs function 1.1. | |
| | Photograph | | |
| 2 | | | |

3.2. Execution of operations (description of the activities)

| Number of operation | Content and sequence of performing operational elements (number of personnel – two workers) Special attention when conducting operations | | | |
|---|---|---|---|---|
| | Worker 1 | | Worker 2 | |
| 1 | ATTENTION!<br>When conducting operation 1, it is necessary …<br>Photograph | | | |
| | Performs function 1.1. | Photograph | Performs function 1.2. | Photograph |
| 2 | Performs function 2.1. | Photograph | Performs function 2.2. | Photograph |
| | ATTENTION!<br>**It is prohibited to** … | | | |
| 3 | | | | |

3.3. Completion of work

| Number of operation | Content and sequence of performing operational elements (number of personnel – three people) Special attention when conducting operations | | |
|---|---|---|---|
| | Supervisor | Worker 1 | Worker 2 |
| 1 | | Performs function 1.1. | Performs function 1.2. |
| | | Photograph | Photograph |
| 2 | Performs function 2.1. | Performs function 2.1. | |
| | Photograph | Photograph | |
| 3 | | | |

Form of instructional map of safe working methods and practices

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So, the following instructional maps of safe working methods and practices have been developed for the oil mine section «Yareganeft» [1]:

• Performing operations on infrastructure development of the mine workings.
• Performing drilling and blasting operations.
• Maintenance of mine wells in the process of oil extraction.
• Performing operations on transportation of extracted oil and surrounding rocks.
• Maintenance of vessels functioning under pressure.
• Performing operations on carrying heavy objects, by human force or using means of small-scale mechanization.
• Performing high-rise operations.
• Performing ground works.
• Performing operations using small tools.
• Performing gas hazardous and fire works at the facilities of oil and gas extraction and processing.

Instructional maps as a type of operational guidelines on safety have the following advantages:

– visual representation and detailed description of every operation, conducted by the workers;
– emphasis on important aspects of operations that influence safety of the process and the facility;
– development of worker's visual memory;
– elimination of inaccurate definitions and operations, which provide an opportunity for the worker to make the wrong choice of actions during operations;
– reduction of operation time with no compromise in safety levels of the facility and personnel.

Alongside with apparent advantages, instructional maps have their drawbacks:

– impossibility to include all local laws and regulations of the company into instructional map;
– impossibility to specify and work out in detail certain types of operations;
– overlapping of local laws and regulations;
– high labor consumption;
– need to attract specialist from different areas;
– impossibility to photograph certain types of operations.

Nevertheless, research carried out in other companies, where instructional maps by the same developers have been introduced, showed a 20 % increase in the efficiency of personnel training.

## Conclusions

1. Existing documentation on conducting operations in the oil mines contains insufficient amount of visual material, even despite the fact that development of each inclined shaft is documented with a separate chart.

2. According to Russian legislation, the duty of personnel training in safe working methods and practices is assigned to the employer, hence the company has to be interested in improving the quality of the material which is used in the training process.

3. In the course of instruction and training it is feasible to use additional visual material, such as instructional maps of safe working methods and practices for separate types of operations.

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# SOURCES OF HEATING MICROCLIMATE IN THE PROCESS OF THERMAL MINING DEVELOPMENT OF HIGH-VISCOSITY OIL FIELDS

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The paper examines main sources of heating microclimate in order to develop technologies of microclimate parameter normalization in mine workings as a part of thermal mining technology of high-viscosity oil extraction.

Operations under conditions of heating microclimate, whose parameters exceed threshold criteria, can provoke dehydration, fainting and heat stroke among workers. In order to guarantee safe working conditions, provisions are made to introduce norms on threshold values of temperature and humidity parameters, going above which is probable when applying existing thermal mining technologies of high-viscosity oil extraction.

Basing on temperature-humidity survey, a comparative analysis of dependency between air temperature in the producing galleries and their configuration has been performed.

A hypothesis has been suggested that, from the position of temperature limits, the period of efficient service of circular producing galleries is shorter compared to extended panel ones.

***Key words***: thermal mining development, heating microclimate, temperature-humidity survey, heat emission, underground mining

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**Introduction.** Modern systems of labor protection have a great number of systems and methods improving labor conditions for a wide scope of professions in various sectors, but sometimes these methods have to be implemented in field-specific or experimental enterprises, where normalization of working conditions is complicated by specific character of the technology. One of such technologies is thermal mining development of Yarega area at Yarega oil-titanium deposit of high-viscosity oil (YOTD).

In the process of thermal mining oil extraction from Yarega area, currently carried out by method of single-plane and underground-surface development, one factor of industrial environment is microclimate of mine workings, which is characterized by constantly rising values of temperature and humidity of return air from producing galleries in the operational block. According to data from research on microclimate parameters, temperature values in mine workings, attended by oil mine workers, can reach 45 °C at relative humidity of 80 %.

Consequences of working under conditions of heating microclimate include feeling unwell, decline in performance and productivity, as well as heat stroke risk, in certain cases followed by death [12, 13, 15]. Besides, it should be noted that health conditions of workers, subject to such harmful and hazardous effects, deteriorate because of arising dysfunctions of cardiovascular and central nervous systems [7, 9, 14]. With this in mind, temperature limits for microclimate parameters in operational zones have been introduced [2, 4, 6].

The purpose of this research is to carry out comparative analysis of two methods of operational block development – using extended panel galleries and circular ones – from the viewpoint of temperature-humidity characteristics of microclimate.

**Research methodology.** Analysis of thermodynamic processes, occurring in saturated bedrocks, at this stage is decidedly generalized – in the context of specific academic disciplines. Speaking of conditions at unique deposits, only results of field-specific operations matter, but they can only be obtained in the course of particular object development and for this reason such information is often commercial (i.e. classified).

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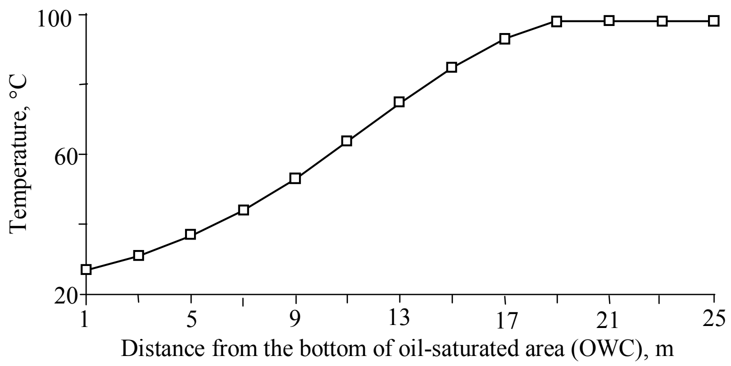
Modeling of thermophysical processes is carried out for the conditions of mine workings, based on results of research on microclimate parameters of mine air and can produce only a very superficial thermal model, based on statistical data; however, it offers no help in understanding thermodynamical processes.




Temperature changes along the thickness of operational block South-2

Currently there is no complex model of thermal mining development of Yarega field, and forecasts can only be based upon results of statistical processing of research data on microclimate parameters (air-depression and temperature-humidity surveys), compared to modeling data from thermal processes in the oil reservoir (e.g. software module CMG) and technological development processes.

**Results and discussions.** At present, operational blocks of Yarega area at YOTD are developed using technology of thermal steam treatment of the formation. Application of this method heats the formation throughout, which causes heat emissions into the air of mine workings, located directly in the productive beds [1, 8, 10, 11].

In the course of mathematical modeling of thermophysical processes for this technology three sources of heat emissions have been identified:

1) rock mass;
2) wellhead equipment;
3) outflowing liquid.

At initial stages of development, temperature of extracted liquid can vary across a wide interval (from 35 to 80 °C in the first 2-3 years of block exploitation), whereas heating of the air stream depends on the rates of extracted liquid withdrawal.

Temperature of wellhead equipment varies from the lowest temperature of extracted liquid to the temperature of steam injected into the formation. The influence of wellhead equipment on air temperature directly depends on the number of heated wells.

Due to specific features of the development process, the rock mass (according to field data and modeling) has an uneven temperature distribution across thickness (see the figure), which basically depends on the oil recovery factor [5].

According to the chart (recovery factor = 0.244), when oil recovery reaches 0.8, the formation temperature at the level of producing gallery (3-6 m) will correspond to the equilibrium temperature of heat transfer agent, changing due to diffusive mixing in the interval from 50 to 65 °C at constant injection volumes of the heat transfer agent.

Results of conducted temperature-humidity survey of mine workings in the operational blocks «Panel №1, block 345-North» and «1-T9» have shown that in case of five-fold difference in producing gallery lengths (500 and 110 m respectively) and identical temperature-humidity parameters of intake air, temperature and relative humidity of return air are approximately equal for both cases (deviation – 5 %):

| | Panel N 1 block 345-North | Block 1-T9 |
|---|---|---|
| Intake air temperature, °C | 21 | 20 |
| Intake air humidity, % | 14 | 15 |
| Return air temperature, °C | 38 | 39 |
| Return air humidity, % | 33 | 40 |
| Heat difference from the rock mass, kW/ % | 154/64 | 100/58 |
| Heat difference from extracted liquid, kW/ % | 82/34 | 69/39.3 |
| Heat difference from wellhead equipment, kW/ % | 5.1/2 | 4.7/2.7 |

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Average wall temperature in the workings across the block is approximately 40 °C (38-43 °C).

Thus, obtained data allow to suggest that the heating of the rock mass in case of circular galleries is to a greater extent predetermined by high density of producing and steam-distributing wells, which results in a higher percentage of heated rock area in the overall rock mass, and in case of extended panel galleries – only in rock mass heating across the formation. However, average wall temperatures for both workings are equal, which causes a logical contradiction provided that development period is the same for both cases. Compared blocks have different development periods: 345-North – 10 years (recovery factor = 0.5), 1-T9 – 4 years (recovery factor = 0.24).

Performed analysis allows to suggest that the system of underground-surface development with circular galleries has a «temperature limit» on the direct involvement of personnel in the processes of producing well drainage.

This limit is set at the level of 36 °C for short-term presence of personnel in the operational zone, not more often than 1-2 times per working shift [3].

Reduction of the ventilation stream temperature by increasing the airflow rate has its own limit too – maximum speed of the air stream (6 m/s).

Percentage share of heat emission sources into the air of producing galleries will allow to calculate threshold exploitation period of circular galleries from the position of permissible temperatures in case of constant oil withdrawal rates, which are responsible for the need to apply specific technologies to reduce the temperature in mine workings, applying the technology of thermal mining development.

## Conclusion

1. The method of thermal mining development has a significant disadvantage – high air temperature in the producing workings, which can limit applicability area of this efficient technology of extracting hard-to-recover high-viscosity oils.

2. Performed analysis showed advantages of using workings with smaller concentration of producing and steam-distributing wells as related to the length of producing gallery.

3. It is feasible to create a forecasting model of thermophysical processes in mine workings for the case of thermal mining technology of high-viscosity oil extraction, which will account for increased complexity of process modeling for Yarega deposit.

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# ASSESSMENT OF PROFESSIONAL RISK CAUSED BY HEATING MICROCLIMATE IN THE PROCESS OF UNDERGROUND MINING

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The paper reviews the possibility to apply probit-function to assess professional risks of underground mining under conditions of heating microclimate. Operations under conditions of heating microclimate, whose parameters exceed threshold criteria, can lead to dehydration, fainting and heat stroke for mine workers. Basing on the results of medico-biological research on the effects of microclimate on human body, the authors have assessed probabilistic nature of excessive heat accumulation depending on heat stress index.

Using Shapiro-Wilk statistics, an assessment has been carried out in order to test correspondence of experimental data on heat accumulation in the human body to the normal law of distribution for different values of heat stress index, measured in the process of underground mining operations under conditions of heating microclimate.

The paper justifies construction of a probit-model to assess professional risks caused by overheating for various types of underground mining operations, depending on their intensity.

Modeling results have been verified by way of comparison with a currently used deterministic model of body overheating. Taking into account satisfactory convergence of results, the authors suggest using probit-model to assess professional risks of overheating, as this model allows to obtain a continuous dependency between professional risk and heat stress index, which in its own turn facilitates a more justified approach to the selection of measures to upgrade working conditions of personnel.

***Key words***: professional risk assessment, heating microclimate, labor protection, probit-model, heat stress index, heat accumulation, underground mining, overheating

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**Introduction.** Methods of professional risk assessment and control, used in modern safety management systems, allow for early detection of hazards to health and life of personnel and their timely prevention in order to upgrade working conditions and safety at the enterprise. Risk assessment is an efficient tool to prevent accidents at hazardous industrial facilities, health and safety incidents and professional diseases.

In the process of underground mining, e.g. development of coal and oil deposits, an important factor of industrial environment is microclimate of underground mine workings, characterized by elevated temperature and air humidity in the operational zones. According to research data [12, 13] and performed special assessment of working conditions, air temperature can reach the values of 38 °C, relative humidity – 85 %.

Operations under conditions of heating microclimate provoke tension in various functional systems of the human body. Heating microclimate parameters can have the following effect on the workers: feeling unwell, decline in performance and productivity; an excessive overheating can even lead to death as a result of a heat stroke [5, 15, 18]. It has also been established that in the long term the influence of heating microclimate increases the risk of death from cardiovascular diseases [12].

The most widely used method of professional risk assessment for underground mining operations is the matrix method, attractive in its simplicity. The idea behind it lies in obtaining risk value from the matrix as a combination of two parameters: frequency, or probability, of the negative event and potential consequences of its occurrence. Usually, probability and severity of consequences are determined using the method of expert evaluations and data on previous accidents and diagnosed professional diseases. The drawbacks of this method come down to subjectivity of frequency and probability evaluations, as well as to impossibility of professional risks assessment with a sufficient degree of precision, as it results in cumbersome risk matrices [9, 19].

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Another method, used for professional risk assessment, is described in the Guidelines R 2.2.1766-03 [10]. However, the criterion for professional risk assessment within this method is its categorization depending on the class of working conditions, based on the index of professional diseases, which significantly reduces the applicability of this method at enterprises with no diagnosed cases of occupational illnesses.

The purpose of this research is to develop a method of professional risk assessment under conditions of heating microclimate; on the one hand, the method must offer higher precision of risk assessment as compared to the matrix method, on the other hand, it should be applicable under industrial conditions.

**Research methodology.** A method based on probit-function has found a wide application in the practice of risk assessment of accidents and fires at hazardous industrial facilities. This method is mentioned in a scope of regulatory documents on industrial and fire safety, e.g. in the Decree by the Ministry of Civil Defense, Emergencies and Disaster Response from 10 June 2009 N 404 «On Validation of the Procedure to Calculate Fire Risks at Industrial Facilities», in the Decree by Federal Service for Environmental, Technological and Nuclear Supervision from 11 April 2016 N 144 «On Validation of Safety Guidelines «Methodological Principles of Conducting Hazard Analysis and Assessing Risk of Accidents at Dangerous Industrial Objects».

For instance, when assessing consequences of accidents at hazardous industrial facilities and influence of hazardous factors, the probability of human exposure and damages to buildings and constructions is expressed as follows [16]:

$$P = f\left[Pr(D)\right], \tag{1}$$

where $Pr$ ($D$) – upper limit of the integral function under the assumption that the stochastic value, characterizing results of damages, has a normal distribution:

$$P = f\left[Pr(D)\right] = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Pr} e^{-\frac{t^2}{2}} dt. \tag{2}$$

In general case, probit-function takes the form

$$Pr(D) = a + b \ln D, \tag{3}$$

where $a$ and $b$ – constant values, depending on type and parameters of the negative exposure; $D$ – dose of negative exposure.

To justify the applicability of probit-model for professional risk assessment under conditions of heating microclimate the following steps have been taken.

1. As a metric of heat load on the human body in the process of underground mining operations (argument of probit-function), it was decided to choose WBGT index, widely used in international practice, or its Russian analogue – heat stress index. These indices take into account combined influence of microclimate parameters (temperature, humidity, air velocity and heat radiation) on the human body and are numerically equal in cases, where there is no solar radiation [2, 11, 17]:

$$\text{WBGT} = \text{HSI} = 0.7t_{\text{w}} + 0.3t_{\text{g}}, \tag{4}$$

where $t_{\text{w}}$ – temperature measured with a wet-bulb thermometer; $t_{\text{g}}$ – temperature inside the black globe (Vernon globe).

2. As a metric of exposure, it was decided to use body overheating, characterized by tension of thermoregulating reactions [1, 7], because when the threshold values of heat stress index are exceeded, operations under conditions of heating microclimate lead to body overheating, which is driven by accumulation of excessive heat.

Overheating (accumulation of heat in the body) $\Delta Q$ was calculated according to formula [6, 8]

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$$\Delta Q = C\Delta T_{\text{av}}\,, \tag{5}$$

where $C$ = 3.48 kJ/kg – thermal capacity of human tissue; $\Delta T_{\text{av}}$ – changes in average body temperature over the course of a working shift, °C.

3. Basing on the results of medico-biological research on the effects of microclimate on human body [1, 14], values of $\Delta Q$, calculated for different participants of the experiment, have been arranged in groups according to equal values of heat stress index. An apparent conclusion was that heat accumulation in the bodies of different workers has a probabilistic character, assuming that they operate under the same thermal conditions and perform the work of similar intensity (in publications [1, 14] only male workers have been considered; sample size – from 3 to 7 persons).

Verification of a normal distribution hypothesis for $\Delta Q$ (as a stochastic value) was performed using Shapiro-Wilk statistics [4]. Its results showed that with the probability of 0.8 the distribution of $\Delta Q$ is normal, which in its own turn allows to use the model based on probit-function for professional risk assessment.

**Results and discussion.** Using data from medico-biological research [1, 14] and software product IBM SPSS Statistics, parameters of probit-model have been calculated that allow to predict professional risk, associated with heating microclimate, which causes human bodies to accumulate heat equal to or greater than 7 kJ/kg, characterized by some researchers as «excessive» tension of thermoregulating reactions and, consequently, as a critical risk of body overheating (see Table) [1, 6, 7].

**Effect of workplace heat load on functional state of the human body**

| Class of working conditions according to R 2.2.2006-05 | Exceedance of the optimal level of heat stress index (upper limit) | Thermal state parameters | | Risk of body overheating according to MUK 4.3.2755-10 |
|---|---|---|---|---|
| | | Accumulation of heat in the body, kJ/kg (upper limit) | Tension of thermoregulating reactions | |
| 1 | – | ±0.87 | Very low (minimal) | Absent |
| 2 | 3.0 | 2.6 | Low | Low |
| 3.1 | 3.3 | 2.75 | Moderate | Moderate |
| 3.2 | 4.2 | 3.3 | Significant | High |
| 3.3 | 5.5 | 4.0 | Strong | Very high |
| 3.4 | 8.0 | 5.5 | Very strong | Extremely high |
| 4 | >8.0 | ≥7.0 | Excessive | Critical |

It should also be noted that calculations were carried out for workers, conducting operations of similar intensity, which can be classified as IIb. This category includes operations with energy expenditure in the interval 201-250 kcal/h (233-290 W), related to walking, moving and carrying objects up to 10 kg, i.e. associated with moderate physical exertion [11].

Probit-model equation takes the form

$$P = -109.339 + 31.993 \ln HSI\,, \tag{6}$$

where HSI – heat stress index, °C.

Calculated parameters of probit-model allowed to evaluate the risk of «excessive» tension of thermoregulating reactions for fixed values of heat stress index.

Obtained results have been verified by way of comparison between calculations of professional risk by method of probit-function and evaluation of deterministic criterion of critical overheating $P_D$, assuming the following values:

$$P_D = 0 \text{ if } \Delta Q \le 5.5 \text{ kJ/kg},$$

$$P_D = 1 \text{ if } \Delta Q > 5.5 \text{ kJ/kg}.$$

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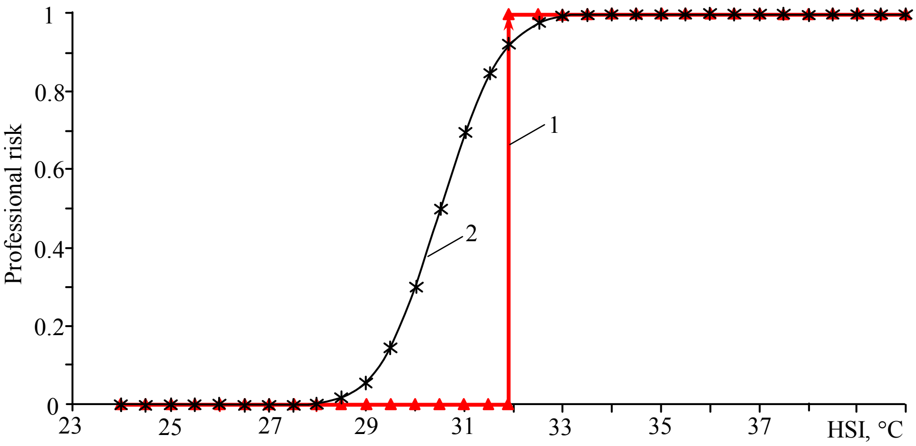
Results obtained for two calculation models are presented in the figure. As the optimal interval of heat stress index for IIb category of operations intensity has an upper limit of 23.9 °C [11], the minimal value of heat stress index, corresponding to «excessive» tension of thermoregulating reactions and critical overheating, equals 31.9 °C.




Professional risk assessment of excessive body overheating for IIb category of operations intensity
1 – deterministic model; 2 – probit-model

Comparison between results of overheating risk assessment using probabilistic and deterministic models demonstrates a theoretical possibility to use probit-function method to assess professional risks of body overheating. The advantages of this method include a relatively simple form of calculation model, applicable under industrial conditions, and the possibility to obtain a continuous dependency between risk and heat stress index. Apparently, one disadvantage of this method is the need to process large amounts of medico-biological data in order to make modeling results reliable. This is an objective difficulty, originating from the very idea of the method, which requires statistically significant sample sizes.

## Conclusions

1. Obtained results serve as an illustration that probit-function can be used as a tool to assess professional risks, caused by heating microclimate.

2. Currently the Labor Code of Russian Federation specifies employer's duty to organize and maintain the system of safety management. Professional risk management as a complex of interrelated measures, acting as elements in the safety management system, is aimed at reduction of risks to their threshold criteria. Bearing this in mind, greater precision of risk assessment provides an opportunity of a better justified selection of measures to reduce risks, not least from the position of economy.

3. It is feasible to continue research on the assessment of professional risks, caused by heating microclimate in the process of underground mining, in order to obtain more detailed probit-models for all categories of thermal states.

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# MINING EDUCATION IN THE 21st CENTURY: GLOBAL CHALLENGES AND PROSPECTS

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An analysis of development prospects for the world mining industry is presented, requirements to mining technologies are formulated, as well as key trends of technologic development in the mineral resources complex. The paper demonstrates the role of mining industry and professional education as essential components of sustainable territorial development. Global challenges have been formulated, which must be taken into account when forming general approaches to the development of mining education. Distinctions of mining education in Russia, Germany, USA and other leading mining countries have been analyzed. Professional standards for mining engineers have been reviewed for different countries, along with their relation to educational standards. It has been shown, what role professional communities play in the development of professional education and stimulation of continuous professional development of mining engineers. Authors point out the need for international integration in the issues of training and continuous professional development of mining specialists, as well as international accreditation of educational programs for mining engineers and their certification. Information is presented on international organizations, performing the function of international accreditation of engineering educational programs, history of their establishment and role within the context of economic globalization. The paper contains examples of successful international cooperation and modern integration processes among universities, aimed at unification of requirements and improvement of existing systems of training and continuous professional development of mining engineers.

***Key words***: mining, professional education, universities, educational programs, continuous professional development, international cooperation

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**Introduction.** Global rates of extraction and consumption of mineral resources are constantly increasing. Annual population growth of 1.0-1.3 % causes the amounts of extracted mineral resources to increase by 0.6-1.5 % [1]. Mining industry is an essential part of the world economy, giving employment to millions of people and annually producing goods worth hundreds of millions of dollars. Russia has the largest reserves in the world in a whole array of solid mineral resources, while mining is one of the leading industries of national economy, and this trend will continue in the next few decades. As for European countries, despite the development of recycling technologies (recovery and repeated use of metals) and their achievements in material science, allowing to substitute minerals with alternative materials, they are characterized by a growing dependency on the import of strategic metal ores [4]. This sets one thinking about extraction of mineral resources under conditions, which even a couple of years ago were considered too difficult for efficient mining production (great depth, high temperature, low content of the mineral component, deep sea mining etc.). In order to achieve economically and environmentally efficient extraction of mineral resources, there is a need for new technical and engineering solutions along the whole chain of technological processes (extraction – consumption – waste management) and for qualified personnel.

**Research methods.** Analysis and consolidation of information from literature sources, websites of universities, mining companies and organizations on development of mineral resources complex, mining technologies, professional mining education, international recognition of competences and qualifications of mining engineers, international collaboration of universities.

**Results of research.** ***Modern challenges in the field of mining technologies and personnel training.*** Across the world, mining industry aims at safe, economically and environmentally efficient extraction and processing of mineral resources that ensure sustainable territorial development. Mining industry offers a wide spectrum of career options, high salaries, opportunities for profes-

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sional growth. To a great extent this predetermines attractiveness of the mining engineering profession, similarity of key trends in the development of mining technologies as well as systems of personnel training in the leading mining countries all over the world.

Technology performance targets until year 2030 have been formulated in the UN Report on Global Sustainable Development 2016 [12]:

– improve progressively global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation;

– achieve higher levels of economic productivity through diversification, technological upgrading and innovation;

– upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes.

Development of mining technologies corresponds to the abovementioned targets and is based upon implementation of modern information technologies (IT and IoT) into design and production processes of mining operations, results of interdisciplinary research in the fields of extraction and consumption of mineral resources, industrial automation, environmental protection. Modern mining companies are capital and technology intensive, complex industrial systems, technological processes of which are equipped with facilities worth tens of millions of dollars. A significant share of mining enterprises is considered hazardous industrial facilities. Combined with the escalation of international competition and drastic rates of technology development, it leads to rising requirements towards the quality of labor resources (especially engineering professions), need for continuous improvement of knowledge, skills and competences.

At the same time, according to estimates by different researchers, in the next 10 years around 80 % of existing technologies will go out of date, and more than 80 % of employees will have an education received more than 10 years before that. Taking into account global character of mentioned problems, there is a substantial increase in the role of integration processes not only in the field of research on key aspects of mining technology development, but also in the fields of professional mining education, international accreditation of educational programs, as well as competence certification of mining industry specialists. International recognition of professional competences is crucially important for the operation of engineers in the context of global economy.

***Analysis of professional mining education systems***. Universities in Europe, USA, Canada and Australia apply a multi-level system of mining education: Bachelor – Master – Doctor of Philosophy. Alongside this, there is an extensively developed system of continuing professional education, offered both in conventional and online modes. Courses duration for bachelor's programs is normally 4 years; for master's – 2 years; for PhD – 4 years.

Analysis of curricula for bachelor's degree in «Mining Engineering» in the leading universities of Europe (AGH University of Science and Technology, Silesian University of Technology, Poland; Technical University of Kosice, Slovakia), North America (University of British Columbia, Canada), USA (South Dakota School of Mines and Technology, University of Arizona, University of Nevada, University of Kentucky), Australia (University of New South Wales) showed that they consist of humanities, natural sciences, general and special professional disciplines [3, 5, 7, 9, 10, 13-16]. Annually students master from 9 to 13 courses, their workload is estimated by the number of credit units per semester. Courses are divided into mandatory and elective (optional) ones. Elective disciplines constitute no more than 20 % of the curriculum; as a rule, they are introduced in the 3$^{rd}$ and 4$^{th}$ years for specialization in a narrow subject field, chosen by the student. Some optional courses require prior mastery of other disciplines. In order to obtain a bachelor's degree, students have to get a certain minimum of credit units, different for various universities. There is also minimum and maximum number of credits, specified for each semester.

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Universities in the USA require their students to pass an intermediate examination on Fundamentals of Engineering (FE), organized by the State Board of Engineering Registration. Passing an FE is a first step towards being registered as a professional engineer (PE). The second and final step in the process of registration and obtaining a PE license is successful passing of the final examination, which is usually held no sooner than four years after graduation and successful work in the chosen field. The examination is organized by SME`s (Society for Mining, Metallurgy & Exploration) Professional Engineers Exam Committee. The Committee develops tests, offers preparatory courses and a selection of educational materials to prepare for the examination. It should be noted that it is a voluntary procedure to pass the exam and obtain a professional engineer (PE) license. To be hired after graduation one only needs a bachelor's degree in Mining Engineering.

An intermediate degree in Fundamentals of Engineering is obtained by the students of Freiberg Mining Academy (Germany) on the completion of $4^{th}$ semester. After that the study continues within the framework of a mining specialization chosen by the student until $9^{th}$ semester inclusive. Then, the $10^{th}$ semester is dedicated to the internship in a mining company, and in order to be admitted to graduation paper defense the overall duration of industrial internship has to be no less than 6 months. After defense the graduate obtains the academic degree Dipl.-Ing. In Germany there are two types of higher education institutions: universities with an advanced scientific background, having both programs of engineer training and post-graduate (PhD) programs, and institutes with insignificant amount of research activity, realizing only programs of engineer training with no right to offer PhD programs. German universities are subject to federal land regulation, but in the field of development and realization of educational programs they operate with great autonomy.

In German universities students get their training in the field of Mining Engineering free of charge, whereas in the USA a semester can cost up to several tens of thousands of dollars. Students from the same state, where the university is located, pay less than students from other states and countries.

US universities encourage their Mining Engineering students to become part of the professional community – Society for Mining, Metallurgy and Exploration (SME) as student members. After graduation they are offered to continue their membership on a professional basis. Students can also become members of International Society of Explosives Engineers (ISEE). Both SME and ISEE organize meetings and events with student participation.

Industrial internship is an essential part of the learning process in European universities. In the universities of USA and Australia mandatory industrial internship is required only for individual specializations.

Almost all overseas universities offer various types of continuing professional education in the field of Mining Engineering: accredited short-term courses, interactive webcasts and online courses for lifelong education.

Universities of Arizona (USA) and British Columbia (Canada) offer combined distance learning programs, after mastering which students can get a Certificate in Mining Studies (CMS). The programs can be aimed at advanced study of certain issues, related professional fields or simply fundamentals of mining engineering. In order to obtain a certificate, the overall workload of selected online courses (each course terminates with a final project 5-10 pages long) has to exceed 160 h. In case of in-service training, it usually takes two years to get a CMS and it costs from 8500 to 11000 dollars depending on the set of selected courses.

There are some interesting joint initiatives between individual companies and European universities, when the education process of the students is paid for by the company and takes place subsequently (one or two semesters) in universities of different countries, participating in the agreement. The internship is organized within the company.

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In order to enhance the efficiency of research and quality of higher professional education in Russia, a network of federal and national research universities has been created; their key objectives are to satisfy labor and scientific requirements to modernize regional economy (federal universities), as well as to provide development of technology-intensive sectors of economy by integrating research and education (national research universities). There are three federal and five national research universities, associated with mineral resources complex, among those Saint-Petersburg Mining University.

In 2011 in Russia a federal state educational standard was introduced for the specialization «Mining Engineering», which provides for mono-engineering training of specialists (i.e. without separation into Bachelor and Master) in 12 specializations with the course duration of 5.5 years. The introduced standard prescribes competence approach to professional education. All the competences, needed by a mining engineer, are obtained in the course of lectures, practical and laboratory sessions, academic and industrial internships, research activity.

Comparative analysis of curricula and programs of Russian and overseas universities, as well as options to obtain qualification of the mining engineer showed that general understanding of professional competences needed by a mining engineer today are similar across the world. The difference lies in offered educational forms and patterns, as well as in the time needed to obtain required level of competences.

Thus, the following distinctive features of modern mining education can be highlighted:

• global focus of training, i.e. graduates are prepared to work worldwide, which requires similarity of educational programs and mutual recognition of diplomas. Mining education programs are developed in order to meet changing demands of national and global mining industry by the graduates, theoretically trained in mining engineering and capable of quick progress under adequate guidance. In some universities education process involves an overseas internship. All European universities offer a wide range of educational programs in English;

• opportunity to shape an individual educational pattern, based on selection of relevant elective courses;

• provision of academic mobility for students, mutual recognition of credit units earned in different universities;

• wide application of modern educational technologies, computer facilities for 3D-modelling of deposits and design, electronic information resources;

• realization of the «lifelong education» concept, i.e. acquisition of fundamental knowledge, skills and competences at a certain stage of education and regular improvement of qualification in the course of a career;

• availability of all types of courses and programs (anyplace, anytime);

• active involvement of the professional community in the process of training and continuous professional development of engineering personnel.

***Professional mining communities.*** Special mention should be made of international professional communities, such as e.g. Society for Mining, Metallurgy and Exploration (SME, USA) and Institute of Materials, Minerals and Mining (IOM3, UK) and their role in assuring the quality of mining specialist training and stimulating continuous professional development. Professional communities play a major role in the development of professional standards for various types of activities, which are later reflected in educational standards and programs offered by universities.

SME is an international organization, uniting professionals in mineral resources sector from over 100 countries [6]. SME claims that its mission is in active provision of its members with valuable information and in enhancement of the mining industry image through informational support of all its professionals and students using specialized products and services; strengthening of connections between professionals in the industry across the world; facilitating

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exchange of information and development ideas; promotion of labor protection, safety, environmental and social responsibility in mining industry. SME publishes periodicals (Mining Engineering Magazine, Minerals & Metallurgical Processing Journal, Tunneling & Underground Construction), collected volumes, books, supports online publications, global digital scientific library for the mining professional community OneMine.org, organizes regular meetings and exhibitions. All the information resources are available to the Society members with a substantial discount or free of charge. As already mentioned, it is SME that through its exam committee develops the program and holds the examination aimed at getting professional engineer (PE) license. SME is a member of international Accreditation Board for Engineering and Technology (ABET), whose activity targets assurance of the quality of overall engineering education. Russia is represented in the Board by the Association for Engineering Education of Russia (AEER), which joined ABET in 2012.

Institute of Materials, Minerals and Mining (IOM3) is a major UK engineering institution [8]. Its activities encompass the whole lifecycle of materials: exploration and extraction of mineral resources, preparation and processing, finishing and application of materials, product recycling and reuse. It was created as a leader in the worldwide materials and mining community, in order to develop material sciences and engineering, associated technologies in the fields of geology, mining and metallurgy, extraction and processing of minerals and petroleum. Today members of professional engineer communities, belonging to IOM3, number approximately 17500 people all over the world, and this number is constantly growing.

Institute of Materials, Minerals and Mining (IOM3) is licensed by the Engineering Council of United Kingdom (EC UK) to accredit UK and foreign educational programs that are terminated with a conferral of academic and professional qualifications in the field of engineering and material sciences. The Institute is also authorized to assess various events from the position of their conformance with the principles of continuous professional development (CPD).

IOM3 activity is based upon four principles: professional recognition of competencies; development and support of competencies among members of IOM3 community by promoting and certifying continuous professional development; provision of reliable technical information about cutting-edge achievements in engineering and technology; creation of networking opportunities for the professionals.

Institute of Materials, Minerals and Mining (IOM3) actively stimulates its members to take part in CPD programs in online mode through the personal account. Annually IOM3 certifies over 50 educational programs against their conformance with CPD principles of continuous professional development (CPD).

In Russia, the National Association of Mining Engineers was founded in September 2015. Some of its members have undergone all the required procedures and have been certified by IOM3, assuring international recognition of their engineering competences. An agreement has been signed between National Association of Mining Engineers (Russia) and Institute of Materials, Minerals and Mining (IOM3, UK) regarding mutual recognition of conferred degrees and qualifications, which is an important step in the integration process of Russian mining specialists into the global community of engineers.

***University cooperation.*** Training of personnel for technology-intensive mining industry requires not only qualified teaching staff, but also advanced class, laboratory and information facilities of the university. Taking into account solidarity in purpose of replacement of human resources in the mining industry, as well as high costs of modern simulation sites and laboratories, which in certain universities are only partially loaded, more efficient application of modern high-cost equipment can be achieved through the establishment of common use centers, open to other universities and interested companies.

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In 2009, in Russia 10 universities formed the National Research-Academic Innovative Technology Consortium of Mineral Resources Universities. The Consortium is a voluntary association of technical universities, training personnel for mineral resources, fuel and power sectors. The key objective of its activity is establishment of an efficient corporate training system of qualified personnel to fulfill the tasks of mineral resources, fuel and power sectors, as well as development and implementation of innovative projects, based on integration of scientific, academic, innovative and technological potential of member organizations; implementation of its results into the business community; creation of efficient innovative systems; development of high technologies.

Saint-Petersburg Mining University [2] and Freiberg Mining Academy (Germany) [11] have initiated a scope of international projects, among them Russian-German Resource Forum, established under the auspices and with direct involvement of the Russian President and German Chancellor in 2006 and uniting politicians, businessmen and researchers of both countries. In 2012 World Forum of Universities of Resources on Sustainability (WFURS) was established, which currently includes more than 90 universities from all over the world. One of the objectives of the Forum is to implement ideas of sustainable development into study plans and educational programs of mining engineers.

Among the examples of successful international cooperation of mining universities are: annual mining summer schools (AGH University of Science and Technology (Poland), Freiberg Mining Academy (Germany), Mining University of Leoben (Austria), China University of Mining and Technology (Xuzhou, China) etc.), international conference-competition for students and young researchers «Issues of Subsoil Use» (Saint-Petersburg Mining University, Russia); School of Underground Mining (National Mining University, Ukraine) etc. There are several programs of in-service training and double-degree master programs.

At the same time there is insufficient collaboration in joint research between Russian and overseas mining universities; in the development and implementation of joint continuing education and post-graduate programs. Programs «Invited Professor» also possess a significant potential to broaden collaboration.

## Conclusions

1. Development of the mining industry is a required condition to meet UN goals of sustainable territorial development.

2. Mining technologies are getting more research-intensive, there is a constant rise in requirements towards their economic efficiency, technological and environmental safety, as well as towards quality of human resources.

3. Despite the differences in training systems for mining engineers in different countries, general requirements towards necessary professional competences are similar. A crucial role in the formation of professional standards and requirements to training programs belongs to professional mining communities.

4. In the context of economic globalization, international recognition of professional competences becomes essentially important for engineers.

5. Improvement of training and CPD systems for mining engineers, procedures of mutual recognition of conferred qualifications and competences are a matter of worldwide cooperation between mining universities.

6. Development of cooperation also implies further broadening of academic mobility for students and teaching staff, joint participation in research.

7. Continuous efforts of all interested parties are needed to reach the common goal – training and continuous professional development of qualified mining engineers for highly efficient, environmentally sound mining industry, facilitating sustainable territorial development.

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# «RHETORIC PRACTICE» BY I.S.RIZHSKY (1796) AT THE MINING UNIVERSITY: HISTORY AND CONTEMPORANEITY

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The paper focuses on the continuity of rhetorical studies at the technical university. An analysis of rhetorical principles, described in I.S.Rizhsky's «Rhetoric Practice» (1796), is carried out. The author summarized methodical principles of teaching rhetoric at the first technical university of Russia – Saint-Petersburg Mining College. A comparison has been made between I.S.Rizhsky's work, classical treatises and the first Russian scientific rhetoric – «Rhetoric» by M.V.Lomonosov. It has been found that, following Lomonosov's scientific theory, I.S.Rizhsky created an original educational-scientific genre (rhetoric practice), addressed to a specific audience – students of Saint-Petersburg Mining College. The role of I.S.Rizhsky's scientific and educational activities in teaching humanities at the technical university has been defined. The paper justifies the necessity to republish works of scientists from $18^{th}$-$19^{th}$ centuries, whose names have left their marks in the development history of rhetoric as a study of Russian oratory traditions.

The paper also describes material of contemporary educational programs on the culture of speech, which focus on the historical tradition of Russian rhetoric. In particular, it has been noted that lecture and practical courses imply not only orthology studies (correctness, clearness, orderliness, expressiveness of speech), but also acquaintance with works on the history of European and Russian rhetoric.

***Key words***: rhetoric, rhetorical principles, contexture of scientific treatise, clearness of speech, oratory genres, «Rhetoric Practice» by I.S.Rizhsky

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**Introduction.** 230 years ago a theorist and practitioner of Russian oratory, philosopher, logician, translator of educational and scientific literature Ivan Stepanovich Rizhsky (1759-1811), whose name is associated with the humanitarization program of higher education, began his educational work in the Mining College, the first technical university of Russia. He received his education at the Trinity and Pskov seminaries. From 1778 till 1786 he taught rhetoric, poesy, history, Roman antiquities and philosophy at the Trinity seminary. In the course of those years he wrote and published two books: «Reduction of Divine Service by Ancient Romans» (Moscow, 1784) and «Political Gatherings of the Ancient Rome» (Moscow, 1786 and Saint-Petersburg, 1788). In 1784 he also published two translations from Latin: «Brief Notion of Ancient Roman Senate» and «Dwindling of Mahometan Religion». In October 1786 I.S.Rizhsky was invited to Saint-Petersburg Mining College as a professor. The President of the Berg-kollegia wrote to Rizhsky: «As improvement of the capacity to express their thoughts clearly and to argue sensibly is an important requirement for the students, so that later they could be better prepared for the positions assigned to them, I wish you would undertake teaching rhetoric and logic to them» [13, p.65]. In the capacity of a full professor of Russian philology and oratory, I.S.Rizhsky spent more than 10 years teaching humanities: rhetoric, Latin, logic, history and geography. His educational activity resulted in «Rhetoric Practice» (1796) and the first manual on logic in Russia – «Good Sense, or Intellectual Philosophy» (1790), both written specially for Mining College students. Rare book section of the Main Library in Saint-Petersburg Mining University preserves a first edition copy of «Rhetoric Practice». I.S.Rizhsky's treatise is a treasury of original, eloquently formulated ideas on the subject of rhetoric, its purpose and components. The author defines oratory as a subject of rhetoric: «To capture imagination, persuade the intellect and touch the heart of another with a word – that is the fine art called oratory, which constitutes the main subject of rhetoric» [7, p.1]. I.S.Rizhsky also translated from French a book by P.S.Pallas «Brief physical and topographical description of the Taurica» (1795). Right after being elected a member of the Imperial Russian Academy (May 1802), Rizhsky took the pains to translate 12 selected speeches by Cicero. In 1811 Rizhsky completed his last treatise – «Science of Poetry», which was published at the expense of the Academy in 1811.

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**Methods.** For the study of Russian rhetorical treatise, written at the end of 18th century, it is feasible to use a complex of linguo-cognitive methods, related to text analysis: selection of the scope of discussed topics and questions from the text under consideration; comparative composition analysis of thematically close works; search for common principles, similarities and differences when conveying the key information. As the main method, the authors used rhetorical analysis of the text, which allows to examine its composition, reveal examples of linguistic persuasion of the readers, assess means of the language and verbal expressiveness.

**Results.** Teaching, educational and scientific activity of I.S.Rizhsky contained numerous novelties or, using modern language, innovations. Even the structure of the manual «Rhetoric Practice» is innovative. It is composed of four parts: 1) «On the perfection of the word, which comes from expression, or on the embellishment»; 2) «On the perfection of the word, which comes from thought, or on the invention»; 3) «On the arrangement, or on various kinds of prose compositions»; 4) «On the style, or on the improvement of the word, depending on embellishment, invention and arrangement».

Classical antique rhetoric books have a different structure. E.g., Aristotle's «Rhetoric» is an extensive treatise on the art of persuasion, composed of three volumes. The first one describes general concept and main principles of rhetoric, provides a classical definition of rhetoric speech, based on the triad orator – speech – audience. Aristotle offers a clear, logically relevant typology of oratory speeches and examines internal principles of three speech types: deliberative, judicial, epideictic. The second book contains the fundamentals of oratory art and teaching on passions, morals and general methods of persuasion. The third book is dedicated to the problems of style and composition of speech.

In Russia the first original rhetoric was developed by M.V.Lomonosov. «Brief Guide to Oratory» (1747) is a scientific rhetorical theory, rendered in Russian. M.V.Lomonosov deemed it necessary to abandon the antique tradition and arranged the chapters in the following manner: «On the invention», «On the embellishment», «On the arrangement».

Thus, classical structure of the text is based upon the antique rhetorical canon; Rizhsky's compositional modifications were made on purpose and driven by the genre of the text being created. Justifying alternative composition of rhetorical manual, which differs from the classical structure, he emphasizes the need to take into account the targeted audience. As a reminder, the full title of the treatise is «Rhetoric Practice, Composed and Taught at Saint-Petersburg Mining College». The practicing pedagogue explains why he has changed the structure: invention principles «are obscure and intricate for the ones embarking on the oratory science»; at first it is better to introduce such principles that are easier than others and are the closest to grammar rules [7, p.7].

It has to be noted that way back in 1796 I.S.Rizhsky formulated an idea, which is still relevant today – about the citizen being responsible to the society, about the need to «master your mother tongue properly»: «To speak and write correctly, i.e. in fluent Russian, is the duty of every well-bred Russian citizen, but the writer has yet more responsibilities: on top of this, he has to be attentive that each of his words and phrases is neither higher nor lower than the expressed thought and perfectly fits the type and content of his writing» [7, p.11]. We see that in these lines the author refers to, in modern phrasing, communicative competence of the person as an essential element of forming the student's identity.

Basing on traditions of Russian rhetorical school, whose foundation is rightfully attributed to M.V.Lomonosov, I.S.Rizhsky understood a very close connection to linguistic and writing practice of Russian poets, writers, scientists and educators of the 18th century. A professor of Russian philology, I.S.Rizhsky creates an original educational-scientific genre (rhetoric practice), where he

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successively applies pedagogic principles of teaching oratory rules to students of the Mining College using «the best Slavic and Russian books, especially recently published ones» [7, p.11]. In particular, tropes and figures of speech, invention rules for compositions, or rhetorical places, principles of arrangement, including different types of periods, are demonstrated on the examples of famous and stylistically perfect contemporary poems and prose works, e.g.: M.V.Lomonosov – poem «Petriada», «Letter on the Usefulness of Glass», «Panegyric to the Sovereign Emperor Peter I», «Panegyric to the Sovereign Empress Elizabeth Petrovna»; M.M.Kheraskov – poems «Rossiada», «Battle of Chesma»; G.R.Derzhavin – poems «God», «Mirza's Vision»; prose extracts from the almanac «Aglaya», authored, edited and published by N.M.Karamzin – «Something on Sciences, Art and Education», «What the Author Needs»; N.M.Karamzin – «Letters of a Russian Traveler»; A.P.Sumarokov – «The False Dmitry».

Guided by the need to intensify lexical work, I.S.Rizhsky dedicates the first chapter of his rhetoric to the issues of integrity of Russian language, attitude to bilingualism, rules of mixing Slavic and Russian speech. In revised and corrected edition of «Rhetoric Practice» (1809), created in Kharkov, the author uses the image of metal, probably inspired by the atmosphere of the Mining College, in the halls of which from the very foundation of the university its students could get acquainted with minerals and metals. In the opinion of the pedagogue, integrity of the language implies such speech, which is similar to the metal devoid of all contaminants, i.e. words and phrases, alien to this language [8]. I.S.Rizhsky links integrity of Russian language to the precision of word choice, clarity of compositions, which depends on words and phrases, to the flow of words and fluidity of sentences. A section dedicated to word embellishment holds a special position within the book. Rizhsky's definitions are clear and concise, e.g. general word embellishments are defined as «such expressions of thought that either by modification of the original meaning of the words or by specific arrangement and selection of the words and phrases make the composition either beautiful and pleasant, or magnificent and important. Usage of words outside their proper meaning, but always because of a certain connection between both meanings is a trope; whereas an unusual arrangement and choice of words or meanings is a figure of speech» [7, p.33-34]. Among the scope of tropes – allegory, catachresis, synecdoche, metonymy, metalepsis, emphasis, hypallage, hyperbole, irony, sarcasm, charientism – the scientists distinguishes metaphor as the most widely used trope, aimed at magnificence and importance of style.

The second chapter of «Rhetoric Practice» contains a review of word perfection, originating from thoughts. Antique rhetoric produced a special technique for spatial organization of reasoning and understanding, known as «topics», in which the term «common places» corresponds to stable content- and thematic-driven elements. Aristotle's description of semantic topos arises from persuading character of the speech. M.V.Lomonosov identified 16 common rhetorical places. I.S.Rizhsky, who in many aspects follows his predecessor and agrees with him upon the definition of invention rules as the most important component of oratory science, illustrates rhetorical places with vivid examples from compositions of Russian authors. E.g., to characterize the whole and its parts, I.S.Rizhsky cites Lomonosov's poem «Petriada», which depicts the house of Neptune (Lomonosov himself describes the house of the sun after Ovid). In this chapter of rhetoric I.S.Rizhsky refers to poetic lines of his distinguished teacher especially often. Thus, the efficient cause is illustrated by an example from «Letter on the Usefulness of Glass», where the poet «with very picaresque description» speaks about the origin of glass. With the help of comparison «Mr Lomonosov multiplies and embellishes his panegyric to the sovereign emperor Peter the First» [7, p.99].

Thoughts, according to I.S.Rizhsky, must be «abundant, just, commensurate with the matter and composition, clear, natural and proposed with some reasonable condensation. But even more embellishment to the word is brought by sharp, strong, brave, expressive, fine, honest and sincere thoughts, revealing author's deep understanding of human nature and passions» [7, p.64]. Description of general rules how to excite and repress passion concludes the second chapter of rhetoric.

The third chapter of Rizhsky's treatise «On the arrangement, or on various kinds of prose compositions» describes means of distribution, arrangement and connection of thoughts invented by the writer, analyzes traditional compositions of prosaic works (chreias, letters, declamations, dissertations, ceremonial speeches etc.), solicited in the Russian society of that time.

Theoretical material of this chapter is accompanied by examples of great pedagogic value. E.g., when illustrating grammatical changes (in modern phrasing, explaining the rules of syntactic synonym selection), the author uses the following expressions: *love is earned with honesty; idle people are prone to corruptness*. In other examples the author reveals his own shrewd observations regarding the power of words, coming from an orator who can peacefully solve debatable questions in interstate relations: «Mouth of the true orator is an organ proclaiming wisdom to the mortals, and each word coming from it is the sharpest arrow, piercing human heart; hence this natural wizardry has often directed and still directs thoughts and destinies of entire nations, nations enlightened, victorious, proud of their glory, conquests, laws; it is not seldom that they supersede multiple troops» [7, p.159].

I.S.Rizhsky considers period to be an important structural element of any speech. In his work he offers a detailed classification of periods (in modern phrasing – sentences), each one of them is explained and exemplified. Thus, the author divides periods into simple and complex, the complex ones in their turn are divided into several categories: causative, comparative, contrary, concessive, conditional, elucidative, relatival, consecutive and some others. Conditional period, for instance, is accompanied by the following statement: «If you start something which is not impossible, either inherently or by circumstance, then be certain that in case you show all your commitment, you will always reach the desired goal, despite all obstacles and inconveniences» [7, p.157-158]. I.S.Rizhsky highlights advantages of the complex period, which allows to prepare the listener for perceiving the main topic of the speech.

Commenting an aphorism is an obligatory task in any modern rhetorical competition. In the foundation of this popular intellectual exercise lies the model of antique chreia. I.S.Rizhsky believes that chreia is only known among orators, because it is nothing more but a specific way of composing short writings, or sometimes parts of big speeches. These writings include seven compositional parts: proposal, rationale, contraposition, comparison, example, verification, conclusion [7]. Authonian chreia has a more difficult composition. Instead of the first part (proposal) it is recommended to use two others: «In the first part after a praise to the author, just and relevant to the subject, one should use the author's own words, which serve as material of the chreia, the reason why this part goes under this name in rhetorics – words with author's praise. In the second part of the chreia the meaning of these words is amplified with one or several periods, which will be the content of the entire chreia» [7, p.177-178]. Thus, the topic of authonian chreia is the words of a certain writer. Chreias are used to compose letters and short speeches.

I.S.Rizhsky analyzes the composition of a so called big speech. This is the form that fully reveals the talent of the orator, because «a big speech is the most perfect oratory work, which should give the orator victory over ignorance, prejudice and bias» [7, p.152]. There are several types of big speeches: liturgical, civil, courtroom, academic.

Obviously, modern notions of the scientific style and its genres started developing in Russian philology back in 18$^{th}$ century. Among big speeches I.S.Rizhsky distinguishes academic ones and divides them into declamations, solemn speeches and dissertations [7, § 167, 168]. Dissertations are

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characterized as compositions by «deeply enlightened men» [7, p.286]. I.S.Rizhsky remarks that «the content of these compositions does not require such art that excites imagination, i.e. it does not need rhetorical embellishment; on the contrary, their main perfection is in enlightened and profound ideas and their strong connection between each other» [7, p.287]. According to the author, there are abundant examples of such speeches, especially among compositions published by the Academy of Sciences.

Rizhsky's pedagogic observations on such type of academic speeches as declamations are also of great interest. In particular, the author mentions importance of correct topic choice for these speeches, as they are written as an exercise in oratory, and identifies certain stylistical distinctions of such compositions: «Hence everything in them, from the matter to the phrases, has to correspond to orator's skills and condition; for the same reason they always contain more embellishments than pure thoughts. Moreover, for the most part they are concise» [7, p.285].

Many bold observations, which I.S.Rizhsky expresses in «Rhetoric Practice», make assertions about the author's civic position, his opinion on specific features of social life and state structure in Russia of those times. For example, I.S.Rizhsky defines civil speeches as «important compositions, offered orally or in writing by state officials to other citizens or foreigners regarding the affairs associated with positions of the former» [7, p.281]. And later he mentions that in ancient times Roman history, and in his days English Parliament provided numerous examples of such speeches [7]. Apparently, in Russia such speeches were either very rare or altogether absent. It should be noted that civil speeches were studied by the particular rhetoric, the subject of which today, according to modern authors, is in consideration of rules and recommendations on making speeches in individual areas, types and genres of philology [2, 3].

Big speeches, apart from liturgical and civil ones, also include courtroom speeches, «made in the gathering of government or people, in accusation or vindication of someone. Currently they are used only in some foreign countries, but in Ancient Greece and Rome they were an important and most ordinary exercise for orators» [7, p.283]. In the meantime I.S.Rizhsky recognizes the difficulty of courtroom speeches, the need for specific talents and knowledge to compose such kind of speeches: «Surviving speeches of famous ancient orators demonstrate that such exercises required not only vast experience in oratory art, not only extensive knowledge of laws and customs, but also excellent education in all fields of philology. Everyone knows that Demosthenes and Cicero are considered masters of this type of oratory» [7, p.284].

Rizhsky's erudition is astounding; among authors of examples in his book we find names of mathematician L.Euler, historian Titus Livius, poet Virgil, philosopher J.-J.Rousseau, Marquise de Pompadour, politician and writer Pliny the Younger, German knight and diplomat Florian Geyer, brilliant orator and successful statesman of the Ancient Rome Cicero and certainly a famous scientist and pedagogue M.V.Lomonosov. For more examples I.S.Rizhsky redirects his readers to the works publishes by the Academy of Sciences and Moscow University.

Description of historical speeches, which contains many sharp and fair observations by I.S.Rizhsky – an experienced writer, scientist and pedagogue, concludes the third chapter of the book.

The fourth chapter of rhetoric «On the style, or on the improvement of the word, depending on embellishment, invention and arrangement» summarizes previous parts and in the scope of examined issues is similar to practical stylistics (it should be noted that by the time of this manual stylistics had not yet separated from rhetoric and become an independent discipline). Rizhsky's definition of the style is very close to its modern concept: «style is a general term under which we understand everything the composition borrows both from words and from ideas» [7, p.318].

The author engages in a discussion of Lomonosov's theory of styles and distinguishes three types of them: low, or simple, style; oratorical style; elevated style. The scientist holds the opinion that the low style is basically the same as colloquial talk; it is characterized by clarity and absolute precision of words and expressions and used in the following genres: conversations, letters to friends, narrations. There are several subcategories of the low style: conversational and written; depending on the application area – historical; on function – instructive; on the use of expressive means – meager and coarse. Instructive style is appropriate for the transfer of scientific knowledge, but special attention should be paid to the location of the writing and the way of expressing ideas, its (in modern phrasing – scientific style's) distinctions: comprehensibility, brevity and importance.

I.S.Rizhsky believes that in order to persuade the audience one should use «oratorical style». The author closely examines its subcategories: refined and philosophical styles, the first one is exemplified by Lomonosov's «Panegyric to the Sovereign Empress Elizabeth Petrovna», the second one – by speculations of a preacher. Here one distinctive feature of «Rhetoric Practice» should be mentioned: examples and citations, presented in the book – especially the ones belonging to author's contemporaries – usually are not attributed, which can probably be explained by fame and popularity of these works in Russia.

Elevated style (e.g., Lomonosov's poem «Peter the Great») is classified as «the most powerful oratory», the one that stands alone and «cannot persist continuously, but as a jewel shines only in special places» [7, p.351]. In our opinion, the image of jewels, used in this comparison, redirects the reader to the mineral collection of the Mining College. To compare prosaic and poetic styles, the author uses another image, based on natural observations. «Prose is like a beautiful field, which nature has dotted with various flowers; the word of a poet is a magnificent garden, where the best of the plants are carefully collected and elegantly arranged» [7, p.376].

Orator and writer should both improve their style, and the scientist offers the following ways of learning: exercise in composition, reading of good authors, their imitation and finally «acquisition of the right taste» [7, p.381]. It is speculations about the taste in oratory that conclude Rizhsky's «Rhetoric Practice». Aesthetic notion of the taste will be developed in more detail in the next edition of the book (1809) [8]. Here the author offers his understanding of the taste: «having a true taste in oratory means nothing else but, using elaborate intellect and multiple mental comparisons, to acquire separate notions about true beauty and actual ugliness of the human word, and according to these never be at fault in your own speculations» [7, p.395-396].

For modern editors and readers the publication form of 18$^{th}$ century scientific treatise is of a particular interest. Rizhsky's «Rhetoric Practice» begins with a dedication of the book to Director of the Mining College, Vasily Ivanovich Popov, the text lacks the table of contents, customary for modern editions, but it has a subject index, obligatory for all modern study guides. The margin contains notes in a special type – names of sections, which is convenient for readers, first and foremost students, working with the text.

It can be said that at the end of 18$^{th}$ century the author of «Rhetoric Practice» focuses not only on the problems of orthology (issues of correctness of the Russian language and its adherence to literature norms), but also issues of logic (construction principles of phrases and descriptions, speculations, argumentation), stylistics (functioning of linguistic units depending on situation, conversational aspect of professional communication). Basing on the analysis of «Rhetoric Practice», we can objectively estimate the significance of scientific and educational activity of I.S.Rizhsky in teaching humanities at the technical university and the role of humanities in the academic process of the Mining College at large. It should be noted that educational objectives, formulated in «Rhetoric Practice», are still highly relevant today.

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It is impossible to imagine revival and development of contemporary rhetoric without remembering its history. At the same time, as V.I.Annushkin justly remarked, in the history of Russian philology rhetoric is the least examined field. The reason for terminological inaccuracy, inconsistency is inability to read classical texts on rhetoric and philology, which in its turn is caused by inaccessibility (the works are not published or republished) of the most important texts in the history of Russian rhetoric, especially handwritten or rare printed editions of $17^{th}$-$19^{th}$ centuries. It is evident, though, that objectively a contemporary scientist and pedagogue must have an idea of the rhetoric subject in $17^{th}$-$19^{th}$ century, both from full scientific editions and reviews and directly from the texts of rhetorical manuals [4]. In this context it is reasonable to raise the question of republishing I.S.Rizhsky's «Rhetoric Practice» (1796), as well as other treatises of $18^{th}$-$19^{th}$ centuries, whose authors have left their marks in the development history of rhetoric as a study of Russian oratory traditions.

**Discussion of results.** $18^{th}$ century has introduced many novelties into the cultural life of Russian state: construction of a new capital – Saint-Petersburg, foundation of the first technical university – Mining College. Talented scientists and pedagogues were invited there, among those – I.S.Rizhsky, who wrote and in 1796 published in Saint-Petersburg an original manual on rhetoric, which was addressed to a specific reader – students of the Mining College.

In $20^{th}$-$21^{st}$ centuries in Saint-Petersburg Mining University philological disciplines are taught at the Department of Russian Language and Literature, founded in 1956 to teach Russian as a foreign language to overseas students. Now the department instructs students in the following subjects: «Russian Language and Culture of Speech», «Culture of Russian Scientific and Business Speech», «Culture of Speech and Business Communications». These academic subjects include the following sections: modern standards of formal Russian language, functional styles, rhetoric (culture of Russian speech).

To address pedagogic issues, the team of the department developed and published (as an appendix to the first issue of the journal «World of the Russian Word» in 2001) an educational program «Russian Language and Culture of Speech for Students of Technical Universities» [12]. The lecture course of this program has a computer version of lecture notes, and each teacher has his individual author's version. Research and methodology activities of the department in the recent years are aimed at creating a package of study guides for student seminars in line with the developed educational program. The concept of this training package implies that practical tasks are always accompanied by minimal theoretical comments. Teaching staff of the department, with assistance from colleagues from other non-humanitarian universities of Saint-Petersburg, have created practical manuals on the modern standards of formal Russian language and scientific style: «Practical Manual on Culture of Speech: Modern Standards of Formal Russian Language», under the label UMO of the Ministry of Education of Russian Federation (2004), «Guide on Scientific Style of Speech for Technical Universities» (2004). In 2006 Department of Russian Language and Literature published a study guide on rhetoric «Russian Language and Culture of Speech: Practical Manual on Rhetoric», which has a label of the Ministry of Education of Russian Federation and reflects original scientific-methodological concept and teaching experience of the department staff, acquired in the course of several years [11]. In 2011 the final part «Fundamentals of Business Communications» concluded the training package. The idea behind this manual dates back to 1995 [6]. It consists of five parts: «Introduction to Business Communications», «Written Forms of Business Communications», «Oral Communications in Business», «Organizational Communications and Corporate Culture», «Russian Business Culture: History and Contemporary State». Due to introduction of new disciplines into educational programs, the department also published study guides «Russian Language and Business Communications» and «Culture of Russian Scientific and Business Speech» (2015).

Humanitarization of higher education implies introduction of philological subjects into educational standards of technical universities, which has a goal of shaping communicative competences of students, both in their professional field and in interpersonal relations. High demand for the specialist in the labor market, his competitiveness under new economic conditions to a great extent depend on the skills of efficient communication in different fields, based on rhetorical laws. Success of any professional activity is closely linked to understanding laws of communication, primarily professional, business and interpersonal ones, and the ability to use communicative strategy and tactics in real life. With this in mind, requirements to the quality of specialist training have changed, regardless whether it is a future mining engineer, engineer-metallurgist, oil and gas engineer, geologist, construction engineer, economist or manager in the fields of mining engineering and geological prospecting.

Staff of the department has summarized its experience of teaching fundamentals of rhetoric within the programs of philological disciplines at various scientific and methodology conferences and seminars: on the 9th International Scientific and Methodology Conference «Rhetoric in the System of Communicative Disciplines» (Mining Institute, 2005) [9, 10], on the 16th International Scientific Conference «Rhetoric in the New Educational Space» (Mining Institute, 2012), on the conferences held every two years by the Department of Russian Language and Literature at Saint-Petersburg Mining University [1]. 18th century «Rhetoric Practice» has been analyzed and reflected in scientific publications of the department staff [5, 14]. By adding issues of professionally oriented rhetoric to the educational process of the first technical university of Russia, the department actively develops scientific and pedagogic ideas of I.S.Rizhsky and adopts them to modern conditions.

## Conclusions

1. «Rhetoric Practice» by I.S.Rizhsky is an original manual, based on the ideas of classical rhetoric. The uniqueness of this work lies in the fact that it is addressed specifically to students, which is reflected in the title itself – «Rhetoric Practice, Composed and Taught at Saint-Petersburg Mining College».

2. I.S.Rizhsky's manual is useful both for students and teachers, as, on the one hand, it contains substantial theoretical statements, described in the exact and carefully thought-out system, it has sufficient number of diverse examples from compositions of different genres, written by Russian and foreign authors; on the other hand, the manual offers methodological recommendations and pedagogical commentaries, which can be useful for the teachers of rhetoric.

3. Scientific and methodology activity of the Department of Russian Language and Literature on studying the issues of professionally oriented rhetoric makes it a relevant issue to republish I.S.Rizhsky's «Rhetoric Practice» (1796) for its subsequent use in the educational process.

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*of I.S.Rizhsky's treatise «Rhetoric Practice, Composed and Taught at Saint-Petersburg Mining College», published in Saint-Petersburg in 1796.*

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