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V. Karabyn, B. Shtain, V. Popovych

L'viv State University of Life Safety, Lviv, Ukraine.
E-mail: vasyl.karabyn@gmail.com

THERMAL REGIMES OF SPONTANEOUS FIRING COAL WASHING WASTE SITES

Abstract. Spontaneous firing is a typical phenomenon at coal washing waste dumps containing argillites, siltstones, sandstones, and coal. The study of the spatial and temporal variability of the heat temperature field on the sites of spontaneous firing a topical issue for further modeling and forecasting.

At the area of the rocky dump spontaneous firingof the coal washing plant "Chervonogradska" of the JSC "Lviv Coal Company" (Ukraine), temperature measurements were performed at depths 0.5 m, 1.0 m, 1.5 m, 2.0 m, and 2.5 m along three profiles distanced 8 m, 15 m and 28 m from the edge of the dump. The measurements were taken twice at two-week intervals. The temperature measurements were carried out directly at the measuring points by a thermometer with a thermocouple and remotely in the infrared range using a FLUKE TiS40 thermal imager and a partial pyrometer "Smotrych - 4PM1".The temperature measurements were used to construct horizon maps and sections. The regularities of temperature variations in the vertical and horizontal directions were explained. The temperature gradients were calculated, and they reach 14.5 °C/m. The dependences of the temperature gradients variation on the depth and the absolute temperature values in the thickness of the heap were validated statistically. The harmfulness of water supply into the thickness of burning rock dumps leading to the intense spread of heating along the laterals was justified theoretically and confirmed experimentally.

Keywords: coal washing waste dumps, spontaneous firing, thermal field, thermal gradient.

1. Introduction. Coal mining is associated with the excavation of large volumes of rocks, water, and gas onto the surface. As a result, large areas of fertile soils are occupied by rock dumps. Each thousand tons of mining generates 110-150 m^3 of rock wastes, and 100-120 m^3 are produced at the enrichment of a thousand ton of coal [1].

The waste dumps often contain hazardous substances, and storage of the rock wastes causes a formation of the specific man-induced geochemical systems: "waste dump – soil – underground water (mining water) – surface water – soil" in the shallow horizon of the lithosphere.

Even greater amounts of pollutants are released into the environment in case of spontaneous firing of coal and coal washing stones. The issue of coal fires is typical of many countries of the world, including China, India, the USA, South Africa, Australia, France, Russia, Poland, and Ukraine [2-5].

The study of the process of coal mine dumps spontaneous firing is an actual issue of our time. The spontaneous firing of waste dumps causes environmental pollution due to the evaporation of toxic gases, formation of chemicals polluting aquifers, burnout of rock, and downwarping formation. As a result of this process, oxides of sulfur, chlorine, ammonium, hydrogen sulfide, phenols, and mercury are emitted [6, 7]. A significant proportion of these gases can cause a greenhouse effect. It is estimated that [8] coal combustion in China generates about 0.1% anthropogenic greenhouse gases.

Many scientists studied changes in the migration of chemical elements and compounds [4, 7, 9, 10], temperature conditions and kinetics of spontaneous firing of coal in laboratory conditions[11, 12], mineralogens [3, 13, 14], and relief formation [2, 4] in burning waste dumps, and their recultivation [15]. The studies of temperature features are rare; the majority were the remote measurements in the visible firing zones on the surface [8]. The authors did not find any scientific works dealing with the detailed analysis of the structure and dynamics of the fire thermal field of the waste dumps of coal washing factories. This article aims to contribute to the understanding of space and time temperatures distribution within the burning sections of the rock dumps of coal mining factories.

The researchaimis to establish the spatial and temporal variability of the temperature field of the rock dump #4 of JSC "Lviv Coal Company" as a scientific basis for the dump thermal state monitoring.

Control of the rock dumps thermal state is carried out for:

a) the timely detection of spontaneous heating zones on the existing dumps and taking measures to prevent spontaneous firing;

b) assessing the effectiveness of measures aimed at reducing the intensity of burning rock dumps;

c) obtaining initial data for the development of projects for rock dumps extinguishing or picking.

The study of the spontaneous firing processes was carried out within the dump of the coal washing factory of JSC "Lviv Coal Company."

2. Area description. In Ukraine, coal extraction is concentrated in three basins: Donetsk, Lviv-Volynsky Coal Basins, and Dnieper Brown Coal Basin. The Lviv-Volynsky Coal Basin (LVB) is located in the western part of Ukraine near the Poland-Ukraine border. Coal of the basin is mined by the underground method and enriched at the Chervonogradska enrichment plant of JSC "Lviv Coal Company".

2.1. Geological structure. The geological environment of the investigated territory is considered to be a part of the Volyn-Podolsk Plate of the Western European Platform, where the Paleo-Mesozoic-Cenozoic complex of terrigenous-carbonate and fluvio-glacial deposits of the Lviv-Volynskyi Coal Basin underlay. Coal layers are located in the rock mass of the coal formation lying in the secondary synclinal folds formed as a result of the Carpathians formation and the subduction of the East European platform for the Western European one. Coal formation of the Tournaisian, Visean, Serpukhovian stages of the Lower Carboniferous is carbonous one. The Serpukhov Stage is characterized by the primary productive carbonous stratum. *Quaternary deposits* are composed mainly of loessial (5-6 m),fluvio-glacial and alluvial rock complexes with a total thickness of 0.5 to 36 m.

The terrain in the region is mild, with the difference in elevation of 15-20 m per km in all directions.

2.2. Hydrogeology. In hydrogeological terms, the Chervonogradskyi geological and industrial area is the part of the Volyn-Podilskyi artesian basin. Here, the following parts are distinguished: a non-pressure aquifer in Quaternary deposits, and pressure, namely the Senonian aquifer complex, which serves as the main source of drinking water supply, the aquifer of the Jurassic and Carboniferous sediments, and the aquiferous complex of the Devonian deposits.

2.3. Hydrology. The research area is located within the Western Bug river basin, which flows into the river Vistula. The river flow rate is 0.2-0.6 m/s. As a result of prolonged coal mining, a significant part of the research area has suffered subsidence, resulting in frequent flooding and swamping terrain. The rivers of the study area are contaminated with organic substances, nitrogen compounds, and heavy metals [16].

2.4. Administrative affiliation of the territory. The Chervonogradska enrichment plant is located in the Lviv region in Western Ukraine, 60 km north of Lviv and 65 km east of Tomaszow Lubelski in the Lublin Voivodeship of eastern Poland.

2.5. Characteristics of the rock dump of the coal washing plant. The area of the industrial estate of the coal washing plant is 36.0 hectares. The waste dump in the area of 73.7 hectares was put into operation in 1979. The height of the central part of the dump is 60 m, the area of the base is 650 thousand m^2; perimeter on the bottom layer is 3300 m. The volume of deposited rocks is 30 million m^3; hoisting slopes are about 31°.

Solid waste of coal washing is transported by cars and poured into the rock dump, distanced by 0.2 km from the company's industrial site.

Waste coal is a mixture of mudstones, siltstones, sandstones, marl, and coal. In the waste composition, pyrite is present. The specific weight of waste is 2.6 g/cm^3.

The object of the research is the temperature field of fire banks of coal washing plants.

3. Materials and methods. Temperature measurements were carried out by remotely in the infrared range with a thermal imager, with a pyrometer, and directly in the place of contact with the rock with a special thermometer.

3.1. Remote sensing methods. The reconnaissance temperature survey of the dump surface was carried out remotely at a distance of 1.5-20 m from the surface in the infrared range of 7.5 - 14 μm using the FLUKE TiS40 thermal imager. The thermal imager has a spatial expansion of 3.9 mrad, a detector expansion of 160x120, a thermal sensitivity (NETD) ≤ 0.09 ° C at a target temperature of 30° C, a temperature range -20°C – 350°C with a maximum error of ± 2.0°C.

The temperature within the open fires was measured using a partial-measurement laser pyrometer Smotrych - 4PM1, which is characterized by a range of measured temperatures -30 – 1200°C with a maximum error of ± 1.5°C and thermal sensitivity (NETD) of ≤ 0.1°C.

At the reconnaissance stage, a survey of the surface of the working places with probes was also carried out to identify cracks, cavities, etc. Remote temperature measurements were carried out on an area of 46,600 m^2.

3.2. Contact method. On the territory of Ukraine, to control the thermal state of the rock dump, the regulatory organization [NPAOP 10.0-5.21-04] determining the general methodology and the limit values of a rock dump thermal state. According to this instruction, the temperature limit in rock dumps at a depth of 0.5 m should not exceed 45°C, but it can reach 80°C at 1.0m depth.

Temperature measurements were carried out on the leveled surface of the first tier of the dump by a stepwise temperature survey in rocks along three profiles (AA^l, CC^l, DD^l) located parallel to the edge of the dump. Temperature measurements were carried out in 2 stages: in mid-September and early October 2016 with a two-week interval. AA^l profile laid at a distance of 7-8 m from the edge of the blade. CC^l profile laid at a distance of 15 m and DD^l the profile laid at a distance of 28 m from the edge of the dump. The distance between the temperature measurement points along the profiles AA^l and CC^l was 20 m, the distance between the temperature measurement points along the profile DD^l was 60 m. Additionally, between the main points, the temperatures in the firing source were measured. Along the profiles AA^l and CC^l, temperature measurements were carried out in at least 57 points.

Along the $AA^l$and CC^lprofiles, the temperature measurements were carried out at depths of 0.5, 1.0, 1.5, 2.0, 2.5 m, and along the profile DD^l the measurements were made at depths of 0.5 and 2.5 m. The temperature was measured at 173 points. At each point at both stages of the survey, the measurements were made three times and the average value was entered into the database.

Temperature measurements were carried out by equipment with a thermocouple (from now on thermocouple). The range of measured temperatures is from 30 to 1200°C with a maximum error of ± 2.0°C. The device is equipped with steel rods 0.5, 1.0, 1.5, 2.0, 2.5 m long. During the measurements of the temperature of the dump rocks, the air temperature varied between 19.1 and 21.5°C. In places with no obvious signs of burning, the temperature of the rocks on the surface of the dump, ranged from 22.7 to 29.0°C. The direct temperature measurements by thermocouple were made on a flat surface area of 33,300 m^2.

The primary data were merged into a database for further statistical processing. For each profile and interval of studies, the mean, median, mode, and standard quadratic deviation were calculated. All the samples that were used in the correlation analysis passed the test of the normal distribution. The significance of the Pearson's correlation coefficients was estimated using 2-tailed test of significance.

Since the number of measurement points in the profiles was different, the parameters of the temperature variation between the profiles and in time were calculated not by comparing the average temperature values, but by comparing the primary temperature values along those lines perpendicular to the edge of the dump, in which, at each stage of the study, measurements were made along three parallel edges of the profile bank.

4. Research results. *4.1. Remote temperature measurements.* According to the results of the research of the dumping masses by using the thermal imaging camera (in September), it was established that the temperature field of vaporization of the steam-air mixture does not exceed 82.8°C at a distance of 2-8 m from the edge of the slope. When examining the surface of the heap, the zones of an abnormal increase in surface temperature up to 54.5°C were detected (figure 1). The area of the heated surface of individual sections with a temperature of more than 50°C does not exceed 1.5 m^2.

The pyrometer recorded the temperatures of visible firing sites from 160.3°C to 997.4°C, with the average temperature 436.7 °C.

4.2. Immediate (contact) temperature measurements. Based on the results of the point measurement of the thermocouple temperatures, at the first stage of the research (in September 2016), we measured the rock temperatures from 35.0 °C to 98.6 °C along AA^l profile at the section 7-8 m from the edge of the slope (table 1).

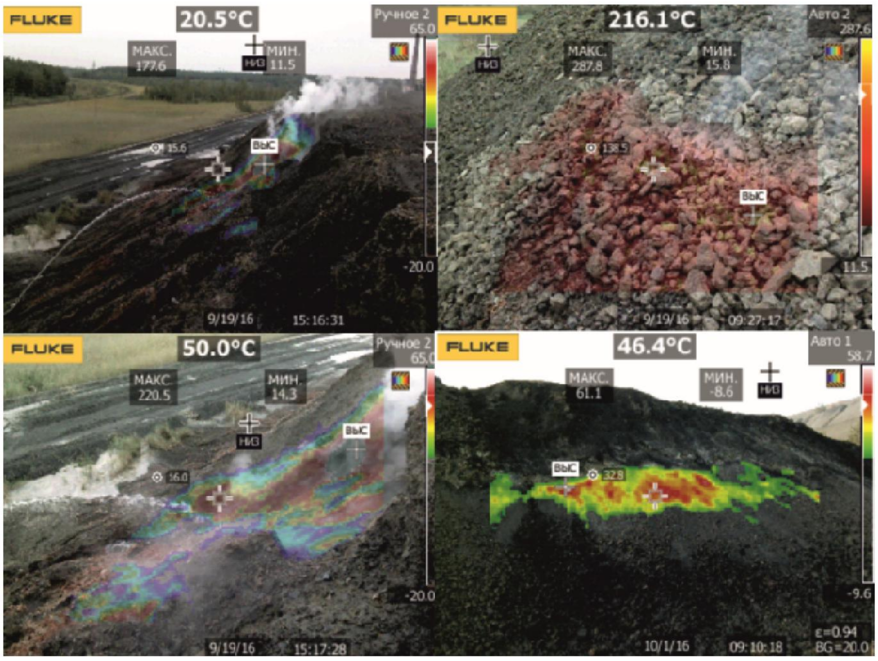

Figure 1 –The spontaneous firing sites of the coal washing waste sites (obtained by thermal imager)

Table 1 – Characteristics of the change in the average temperature of the dump rocks along the vertical and lateral (as of September 2016)

Depth, m	Min	Max	Mean	Median	Standard deviation
AA$^{|}$ profile					
0.5	35.0	80.9	55.9	55.4	11.32
1.0	42.1	85.1	65.7	67.7	10.96
1.5	46.9	86.6	70.4	72.7	10.38
2.0	50.5	92.4	72.8	75.6	10.21
2.5	50.7	98.6	77.2	77.2	10.30
CC$^{|}$ profile					
0.5	34.5	57.4	43.8	44.0	4.53
1.0	39.1	65.3	47.9	48.0	6.34
1.5	39.6	70.8	52.5	51.2	6.93
2.0	41.2	72.4	60.3	60.8	7.41
2.5	39.1	88.1	67.8	68.3	10.70
DD$^{|}$ profile					
0.5	34.8	44.4	40.9	41.5	2.92
2.5	36.2	77.2	50.8	49.0	12.3

The temperature of the rocks increases on the average with depth. The temperature at a depth of 2.5 m was higher compared to the temperature at a depth 0.5 m 1.4 times.

The rock temperature below 50°C is detected at 19 points (33%) at a depth of 0.5 m. Only 5 such points were found at a depth of 1.0 m. 2 points were detected at a depth of 1.5 m. We did not detect any points with temperatures below 50°C at depths of 2.0-2.5 m (figure 2).

One can see the vertical structure of the temperature distribution (figure 3) on the section along the slope of the rock refuse.

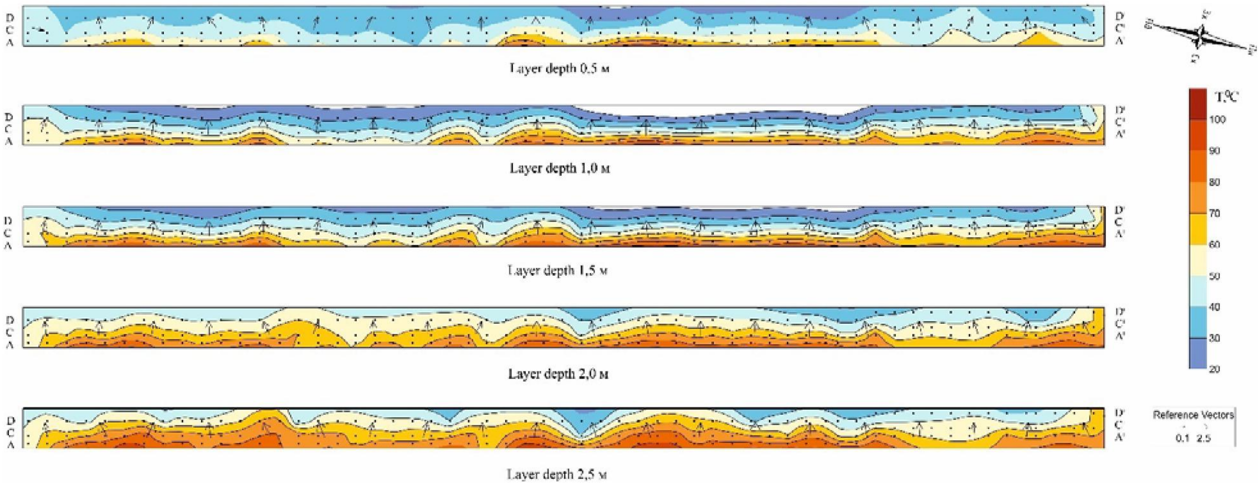

Figure 2 – The temperature field maps in the different depths (September, 2016);
the color identifies the temperature, the arrows correspond to the temperature gradients

After calculating the temperature difference between the deeper layer and the overlying layer and dividing it by the distance between these layers, we obtained a temperature change characteristic with a depth similar to the geothermal gradient:

$$Grad_t = (t_1\text{-}t_2)/\Delta l,$$

where $Grad_t$ – thermal gradient, t_1 – temperature in the deep-lying horizon, t_2 – temperature in the overlying horizon, Δl – distance between the layers.

The calculated thermal gradient is the averaged indicator of the temperature change on a specific section in a certain range of studies in a given direction (vertical or horizontal). It differs in a given direction from the traditional gradient (which is a vector directed to faster change of the temperature field). These vectors are presented on the maps and the section (see figures 2, 3). The averaged gradient has a different purpose, namely, characterizing the change in the temperature field deep down the rock dump along the vertical and deep down the terrarium along the lateral with distance from its edge. In some sections, the temperature with depth increasing or distance from the edge of the rock dump decreased, we obtained negative gradient values that are not typical of the traditional gradient.

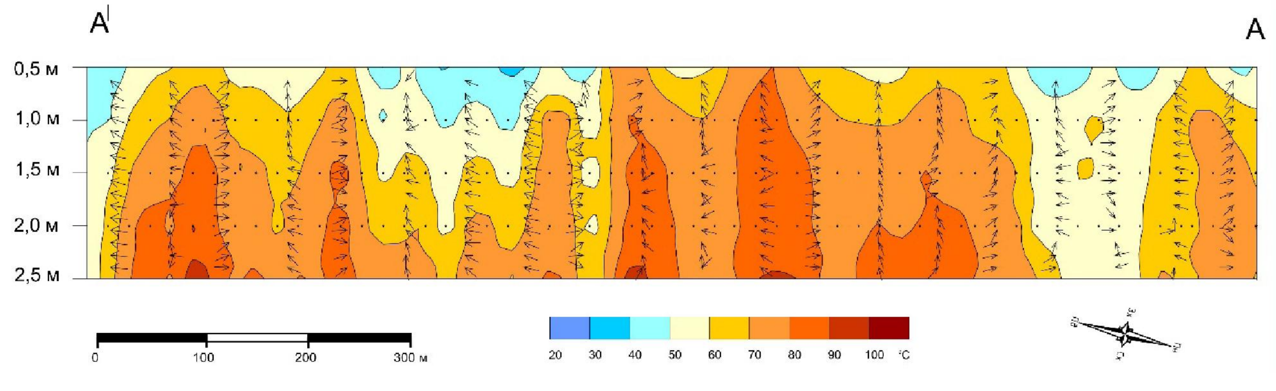

Figure 3 –The cross sectional view of the temperature field along $AA^{|}$profile (September, 2016)

The value of the calculated temperature gradient with depth along the profile $AA^{|}$varies from -3.0°C/m to 14.5°C/m with an average value of 2.7 °C/m. In 9% of the intervals, the coefficient is less than zero, which indicates a decrease in temperature with depth. In the depth interval 0.5-1.0 m, the average temperature change is 5.1 °C/ m, in the interval 1.0-1.5 m – 2.1 °C/m, in the interval 1.5-2.0 m – 1.4 °C/m, in the interval 2.0-2.5 m – 2.0 °C/m. That is, with depth increasing, the intensity of temperature changes decreases in general. In the intervals 0.5-1.0 m and 2.0-2.5 m, the temperature gradient tends to increase with increasing absolute values. However, these trends have not been statistically confirmed.

Along the CC[|] profile set at a distance of 15 m from the edge of the slope, the rock temperature at a depth of 0.5 m is on the average 13.9 °C lower than the temperature along the profile AA[|]. Comparison of standard deviation values indicates a lower variability of the actual temperature values for the section CC[|] in comparison with the AA[|] section. The rocks along the DD[|] and CC[|]profiles at a depth of 0.5 m are characterized by the lowest temperature variability. The low value of the standard deviation indicates this as well as the proximity of the mean and median. In most layers in both sections, the arithmetical mean is less than the median, which indicates a significant amount of data exceeding the arithmetical mean and the individual anomalous values of low temperatures (see table 1).

Along the CC[|] profile, the temperature gradient varies from -3.5 °C/m to 11.0 °C/m with depth increasing with an average value of 3.0 °C/m. In 7% of the intervals, the temperature decreases with depth increasing. In the depth interval 0.5-1.0 m, the average temperature change is 2.0 ° C/m, in the interval 1.0-1.5 m – 2.3 °C/m, in the interval 1.5 -2.0 m – 3.9 ° C/m, in the interval 2.0-2.5 m – 3.7 °C/ m. There is a tendency to increase the intensity of temperature changes depending on depth increasing with increasing absolute temperatures in all intervals. This trend becomes statistically confirmed in the intervals 0.5-1.0 m and 2.0-2.5 m. Therefore, it is possible to talk about a new direct relationship between the change in the intensity of temperature growth with depth increasing in comparison with the absolute values of the temperature in the indicated intervals (figure 4).

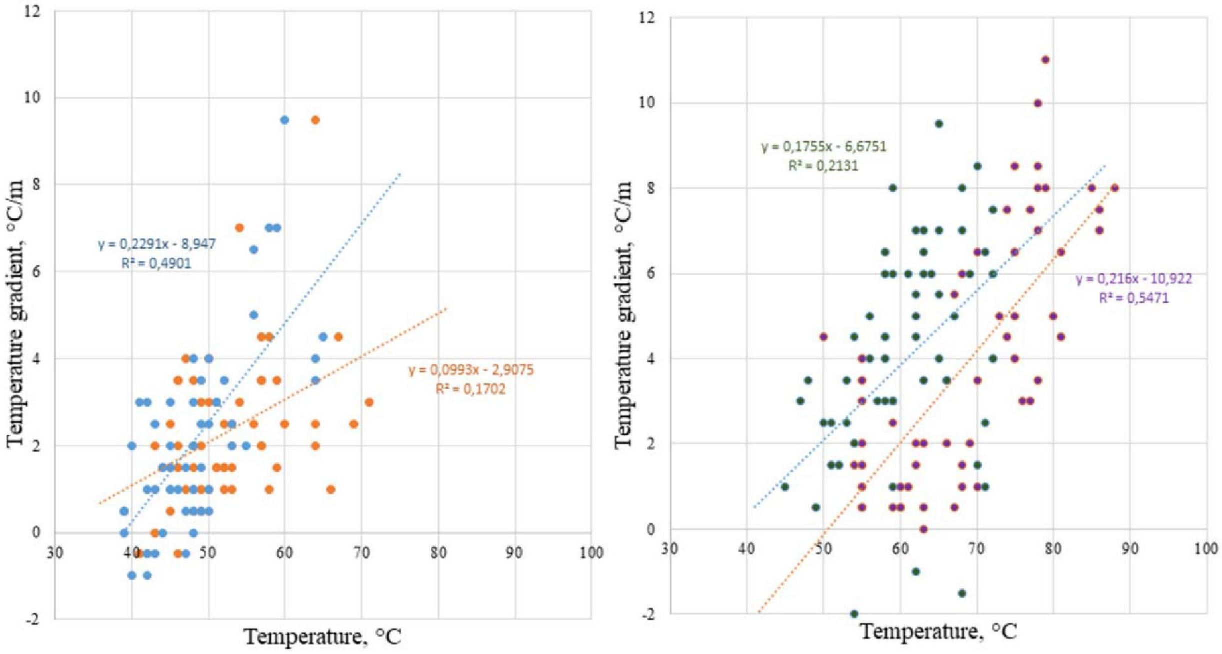

Figure 4 –The temperature gradient change with depth depending on the absolute temperature values along CC[|] profile (the color identifies the temperature gradients, the regression line and its equations blue - at depth 0.5-1.0 m, orange - at depth 1.0-1.5 m, green – at depth 1.5-2.0 m, purple – at depth 2.0-2.5 m)

The temperature naturally decreases from the profile AA[|] to profile DD[|] perpendicular to the edge of the rock dump (deep down the dump) (See table 1).

The temperature gradient horizontally at a depth of 0.5 m perpendicular to the edge of the dump was 1.7 °C/m between the profiles CC[|] and AA[|] and 0.2 °C/m between the profiles DD[|] and CC[|]. That is, at the edge of the slope (profiles AA[|] and CC[|]), the temperature decreased by 1.7 °C each meter deeper down the slope. The temperature decreased by 0.2 °C with further motion perpendicular to the slope of the heap. It should be noted that the temperature of rocks did not always decrease deep down the heap: on some sections (10%) with a rock temperature of up to 50 °C, an increase in temperature with the increasing of the heap depth was observed.

In the intervals of 1.0-1.5 m, 1.5 - 2.0 m, and 2.0-2.5 m between the profiles AA[|] and CC[|] the temperature decreased on the average by 2.6 °C/m, 2.5 °C/m, 1.8 °C/m, and 1.3 °C/m respectively. It means that the intensity of cooling of the dump deep down the heap in the interval 1.0-2.5 m naturally decreases.

Between the profiles CC^{I} and DD^{I} the temperature in the interval 2.0-2.5 m decreased by 1.1 °C on the average.

The slope of the dump was cooled with water after the first stage of the research. On average, 223 m^{3} of water per m^{2} of the surface of the dump was supplied per day.

After 14 days, the temperature of the rocks along the profile AA^{I}decreased by 1.5 °C on the average. The temperature decreased by 4.9 °C at a depth of 0.5 m. At depths of 1.0-2.5 m, the temperature change varies in the range from -1.7 to +0.5 °Cin comparison with the previous stage of research. It should be noted that the maximum temperature increased to 102 °C, which we did not fix during the first stage of the study (figure 5).

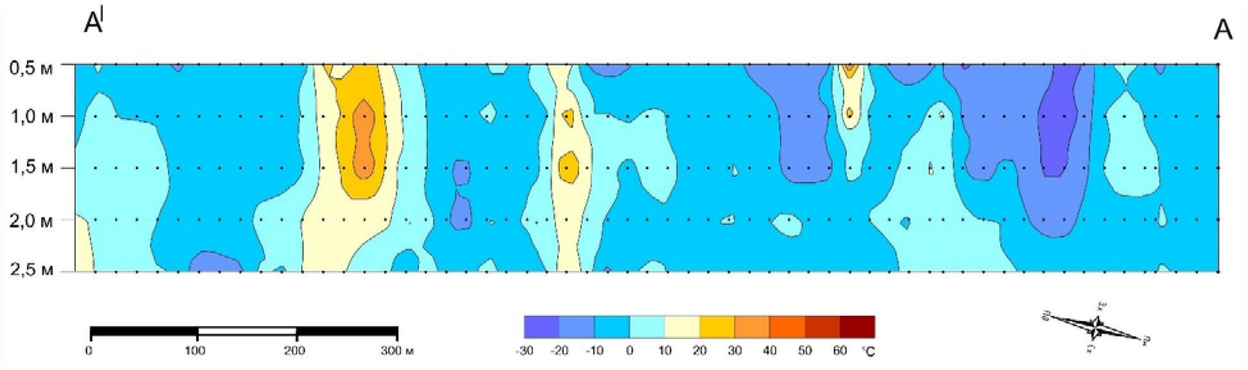

Figure 5 –The cross sectional view of the temperature field of the coal washing plant"Chervonogradska" along AA^{I} profile (September-October, 2016)

Along the CC^{I} profile, rock temperatures decreased by 1.5°C on the average. It increased by 2.2 °C along the DD^{I} profile. The increase of the average temperature by 3.2 °C at a depth of 0.5 m along the DD^{I} is especially noticeable (table 2). The latter fact may indicate an intensification of the lateral extension of the temperature field deep down the dump.

Table 2 – Characteristics of the change in the average temperatures of the dump rocks along the vertical and lateral (as of October 2016)

Depth, m	Min	Max	Mean	Median	Standard deviation
AA^{I} profile					
0.5	28.0	102.0	50.7	51.1	14.5
1.0	36.2	101.3	64.2	64.8	14.7
1.5	38.7	99.8	69.6	71.3	14.5
2.0	42.3	99.2	73.4	75.7	12.0
2.5	51.8	100.1	76.1	76.0	10.1
CC^{I} profile					
0.5	36.2	64.3	43.2	43.2	5.49
2.5	39.4	82.7	66.1	65.8	9.83
DD^{I} profile					
0.5	37.8	46.2	42.1	42.1	2.78
2.5	37.4	69.8	53.8	53.2	11.1

5. Discussion of results. *5.1. Regularities of the temperature change in the body of the dump.* Based on the full-scale results of our studies, namely, on the variability of the temperature field on the laterals, it can be argued that, despite the possibility of an aoxigenic rise in temperatures in rock dumps, the main factor of the rocks firing is their contact with oxygen. This is evidenced by a breakdown in temperatures perpendicular to the edge of the dump from 1.3 to 1.7 °C/m in different horizons at an interval of 8-15 m from the edge of the dump. At a distance of 28 m from the edge of the dump, the rock temperatures at a depth of 2.5 m were 50.8 °C, which is 26.4 °C less than the temperatures fixed along the profile laid in 8 m from the edge of the dump. The source of high temperatures in the surface layers of the dump is the sources of the anomalous temperatures in the depth of the heap. The results of pairwise correlation of temperatures between different layers confirm this fact also (table 3).

Table 3 – Temperature Correlation Coefficients in Layers of Different Depths

Depths	2.5 m	2.0 m	1.5 m	1.0 m	0.5 m
AA profile					
2.5 m	1	0.93	0.87	0.74	0.69
2.0 m		1	0.96	0.83	0.73
1.5 m			1	0.93	0.84
1.0 m				1	0.89
0.5 m					1
CC profile					
2.5 m	1	0.82	0.50	0.28	0.32
2.0 m		1	0.69	0.46	0.41
1.5 m			1	0.88	0.57
1.0 m				1	0.76
0.5 m					1

It is important to note the decrease in the correlation coefficients in the deep horizons of the profile AA and partly in the profile CC with the temperature in the layer at a depth of 0.5 m, which indicates the influence of atmospheric cooling factors and possibly better convection in the surface layers. At the same time, the temperature correlation coefficient between the layers of 2.5 and 0.5 m is significant in both profiles, indicating the dominant role of firing source in the depth in the formation of the temperature field of the whole body of the heap. The decrease in the correlation coefficients of temperatures from the layers along the CC profile indicates that the temperature of the overlying horizons is influenced not only by the temperature from the lower-lying horizons, but also by the temperature that is transmitted laterally from the horizon AA. This assumption justifies the results of pairwise correlation between the temperatures measured at one depth in parallel profiles (table 4).

Table 4 – Temperature Correlation coefficients between Profiles

	AA 2.5 m	AA 2.0 m	AA 1.5 m	AA 1.0 m	AA 0.5 m
CC 2.5 m	0.57	0.49	0.45	0.37	0.40
CC 2.0 m	0.60	0.53	0.43	0.29	0.23
CC 1.5 m	0.49	0.50	0.50	0.43	0.34
CC 1.0 m	0.33	0.37	0.41	0.42	0.32
CC 0.5 m	0.39	0.37	0.44	0.46	0.46

The correlation coefficients of temperatures fixed on one horizon along parallel profiles turned out to be the highest in the deeper layers and less in the surface layers. It should be noted that close correlation links in diagonal directions, primarily between a layer of 2.5 m along the AA profile and a layer of 2.0 m along the CC profile. The obtained statistical regularities shed light on the issue of estimating the share of vertical and lateral heat displacements in the body of the rock dump.

5.2. The water effect on the spread of heat in the body of the dump. The data obtained during two stages of research experimentally confirm the harmfulness of water supply into the thickness of the firing rock dump, leading to the intensification of firing and intensive fire propagation along the laterals. It is known that liquids transfer heat better than gases. The coefficient of thermal conductivity of water at a pressure of 10^5 Pa and a temperature of 333 K (60°C) (the average temperature for the conditions of a firing dump) is $653 \cdot 10^{-3}$ W/(m·deg). Under the same conditions, the thermal conductivity of atmospheric air is $29 \cdot 10^{-3}$ W/(m·deg), that is, 8 times less. Under conditions of a temperature of 373 K (100 °C), the thermal conductivity of water vapor and atmospheric air is $25 \cdot 10^{-3}$ W/(m·deg) and $32 \cdot 10^{-3}$ W/(m·deg), respectively [18, 19]. High thermal conductivity of water is achieved due to the high water pressure in comparison with the gas. When the water changes into the water vapor, the pressure decreases sharply, and then the thermal conductivity of the water vapor decreases sharply in comparison with the liquid water.

These processes are directly related to the processes of heat transfer in the body of the rock dump under investigation. In our opinion, when water with a temperature of 50-80 °C is more dynamic in comparison with a "dry" gas, transferring heat vertically and laterally, evaporating and contributing to the development of firing sources extension.

The results of the long Ernst Beier experiment [17], which showed that the adsorption of oxygen by coal increases with air humidity increase, confirm our hypothesis. Slow oxidation of coal is accompanied by heat emission, which, of course, contributes to its spontaneous firing. Dump fire monitoring can be done using complex multiphase foam gels [20], but not water supply.

The results of our studies indicate a high variability in the parameters of the thermal field, leading to the need to create a system of constantly monitoring the temperature field of fiery heaps.

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7. Conclusions. In the case of the coal washing plant rock dumps firing, the temperature of the rocks increases with depth and decreases perpendicular to the edge of the dump. On average, the temperature at 2.5 m is 1.4 times higher compared to the temperature at a depth of 0.5 m. The temperature gradient along the profile laid in 8 m from the edge of the slope varies from -3.0 °C/m to 14.5 °C/m with an average mean of 2.7 °C/m. Along the profile laid at a distance of 15 m from the edge of the dump, the temperature gradient varies from -3.5 °C/m to 11.0 °C/m deep down the heap with an average mean of 3.0 °C/m.

The intensity of temperature changes is more significant in the surface layers and lower in the deeper ones. There is a tendency to an increase in the temperature changes intensity with an increase in its absolute values.

Perpendicular to the edge of the dump, there is a breakdown in temperatures from 1.3 to 1.7 °C/m in different horizons at an interval of 8-15 m from the edge of the dump. This fact indicates that the main factor in the rocks firing is their contact with oxygen.

The harmfulness of the water supply into the thickness of the firing rock dump leading to an intensification of the fire propagation along the laterals has been experimentally confirmed.

The obtained trends and regularities of changes in the dynamics of temperature extension along the vertical and lateral lines provide a reliable experimental basis for heat exchange processes simulation in rock dumps of coal washing plants in the firing process.

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В. В. Карабын, Б. В. Штайн, В. В. Поповыч

Львов мемлекеттік тіршілік қауіпсіздігі университеті, Львов, Украина

ӨЗДІГІНЕН ЖАНУДАН ТУЫНДАҒАН КӨМІРДІ БАЙЫТУ ҚАЛДЫҚТАРЫНЫҢ ТЕРМИЯЛЫҚ РЕЖИМДЕРІ

Аннотация. Құрамында агриллиттер, алевролиттер, құмдақтар мен көмір болатын көмірді байыту қалдықтарын жинау көп жағдайда олардың өздігінен тұтануына алып келеді. Өздігінен жану аймақтарындағы температуралық өрісінің кеңістіктік және уақыттық өзгергіштігін анықтау мұндай үрдістерді ары қарай модельдеу мен болжау үшін өзекті мәселе болып табылады.

АAҚ «Львовская угольная компания» (Украина),"Червоноградская" көмір байыту фабрикасының жыныстар үйіндісінің өздігінен жану аймағында үйінді шетінен 8 м, 15 м және 28 м қашықтықта орналасқан үш профильдер бойымен 0,5 м, 1,0 м, 1,5 м, 2,0 м, 2,5 м. тереңдіктерде температуралар өлшенді. Өлшеу жұмыстары 2 апта интервалымен 2 рет жүргізілді. Температураларды өлшеу тікелей өлшеу нүктелерінде жылу сезгіш элементі бар құралдың көмегімен және қашықтықтан инфрақызыл диапазондаFLUKE TiS40 тепловизоры мен ішінара өлшейтін «Смотрич - 4ПМ1» лазерлік пирометрінің көмегімен жасалды. Температураларды нүктелік өлшеу нәтижелері бойынша карталар мен қималар тұрғызылды. Тік және көлденең бағыттарда температураладың өзгеру заңдылықтары түсіндірілді. 14,5 с/м жететін температуралар градиенттері есептелді. Температура градиенттерініңүйінді қабаттарының тереңдігі мен температуралардың абсолютті мәндеріне тәуелділігі статистикалық негізделді. Жанып тұрған жыныстық үйінді қабаттарына судың берілуі жанудың интенсивтілігінің латераль бойынша артуына себеп болатыны теориялық негізделіп, тәжрибелік түрде дәлелденді.

Түйін сөздер: көмірді байыту үйінділері, өздігінен жану, жылу өрісі, температуралық градиент.

В. В. Карабьн, Б. В. Штайн, В. В. Поповыч

Львовский государственный университет безопасности жизнедеятельности, Львов, Украина

ТЕРМИЧЕСКИЕ РЕЖИМЫ ОТХОДОВ УГЛЕОБОГАЩЕНИЯ ВЫЗВАННЫХ САМОВОЗГОРАНИЕМ

Аннотация. Складирование отходов углеобогащения, которые содержат аргиллиты, алевролиты, песчаники и уголь в отвалы часто влечёт к их самовозгоранию. Установление пространственной и временной изменчивости температурного поля отвала на участках самовозгорания является актуальным вопросом для дальнейшего моделирования и прогнозирования таких процессов.

На участке самовозгорания породного отвала углеобогатительной фабрики "Червоноградская" ОАО «Львовская угольная компания» (Украина) выполнено замеры температур на глубинах 0,5 м, 1,0 м, 1,5 м, 2,0 м, 2,5 м вдоль трех профилей расположенных на расстоянии 8 м, 15 м и 28 м от края отвала. Измерения осуществлено дважды с интервалом 2 недели. Измерения температур осуществляли непосредственно в точках замера измерительным прибором с термопарой и дистанционно в инфракрасном диапазоне с помощью тепловизора FLUKE TiS40 и лазерного пирометра частичного измерения «Смотрич - 4ПМ1». По результатам точечных измерений температур построено карты и разрезы. Объяснены закономерности изменения температур в вертикальном и горизонтальном направлениях. Рассчитаны градиенты температур, которые достигают 14,5 С/м. Статистически обоснованно зависимости изменения градиентов температур от глубины и абсолютных значений температур в толще отвала. Теоретически обосновано и экспериментально подтверждено вредность подачи воды в толщу горящего породного отвала, которая способствует к повышению интенсивности распространения горения по латерали.

Ключевые слова: отвалы углеобогащения, самовозгорания, тепловое поле, температурный градиент.

Сведения об авторах:

Vasyl Karabyn – Doctor of Philosophy, Associate Professor Department of ecological safety, Lviv State University of Life Safety, Lviv, Ukraine. E-mail: vasyl.karabyn@gmail.com. Number ORCID: orcid.org/0000-0002-8337-5355

Bohdan Shtain – Doctor of Philosophy, Post Doc, Lviv State University of Life Safety, Lviv, Ukraine. E-mail: lviv.ptarr@gmail.com. Number ORCID: http://orcid.org/0000-0002-2580-406X

Popovych Vasyl – Doctor of Technical Sciences, Associate Professor, Department of of ecological safety, Lviv State University of Life Safety, Lviv, Ukraine. E-mail: popovich2007@ukr.net. Number ORCID: http:// orcid.org/0000-0003-2857-0147