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## Normalization of Thermal Mode of Extended Blind Workings Operating at High Temperatures Based on Mobile Mine Air Conditioners

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Thermal working conditions in the deep mines of Donbass are the main deterrent to the development of coal mining in the region. Mining is carried out at the lower technical boundaries at a depth of almost 1,400 m with a temperature of rocks of 47.5-50.0 °C. The air temperature in the working faces significantly exceeds the permissible safety standards. The most severe climatic conditions are formed in the faces of blind development workings, where the air temperature is 38-42 °C. It is due to the adopted coal seam mining systems, the large remoteness of the working faces from the main air supply openings, the difficulty in providing blind workings with a calculated amount of air due to the lack of local ventilation fans of the required range.

To ensure thermodynamic safety mine n.a. A.F.Zasyadko we accepted the development of a draft of a central cooling system with ground-based absorption refrigerating machines with a total capacity of 9 MW with the implementation of the three types of generation principle (generation of refrigeration, electrical and thermal energy). However, the long terms of design and construction and installation work necessitated the use of mobile air conditioners in blind development faces. The use of such air conditioners does not require significant capital expenditures, and the terms of their commissioning do not exceed several weeks.

The use of a mobile air conditioner of the KPSH type with a cooling capacity of 130 kW made it possible to completely normalize the thermal working conditions at the bottom of the blind workings 2200 m long, carried out at a depth of 1220-1377 m at a temperature of host rocks 43.4-47.5 °C. It became possible due to the closest placement of the air conditioner to the face in combination with the use of a high-pressure local ventilation fan and ducts, which ensured the air flow produced by the calculated amount of air. The use of the air conditioner did not allow to fully normalize the thermal conditions along the entire length of the blind face but reduced the urgency of the problem of normalizing the thermal regime and ensured the commissioning of the clearing face.

**Key words:** mine; thermal regime; artificial cooling; air temperature; rock temperature; mobile mine air conditioning; blind development; local ventilation fan; ventilation duct

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**Introduction.** The development of underground coal mining in the Donbass is associated with the need to mine at a depth of 1400-1500 m, to use high-performance mining equipment and largely depends on solving complex safety issues in the development of mineral and spatial resources of the subsoil [2]. An increase in the depth of development is inevitably accompanied by an increase in the temperature of the host rocks, which raises the problem of normalizing microclimatic working conditions in the workplace. For example, in the mine n.a. A.F.Zasyadko (one of the largest mines in the region) when mining the central part of the seam  $m_3$  at a depth of over 1200 m under natural conditions of the formation of a microclimate, the air temperature in the face areas was 32-34 °C, which significantly exceeds the permissible norms of safety regulations [6]. The further successful development of coal resources at great depths will depend on the resolution of aerological safety issues (an integral part of integrated safety), or rather, thermodynamic safety, which determines sanitary and hygienic standards at workplaces [2].

The high air temperature in the workings of the Donbas mines is determined by the following: the temperature of the rock mass at the reached depths is 43.4-47.5 °C; high power supply of mining and tunneling sites; considerable remoteness of working faces from the air supply openings (up to 4.5 km); the difficulty in providing blind development faces with the estimated amount of air in preparation for the excavation of long pillars along the strike (2000 m and more) due to the lack of local ventilation fans (LVF) of the required nomenclature and means for delivering air to the vents of domestic production; use of underground mobile compressor units to provide basic and auxiliary technological processes with compressed air.



Conducting stoping and headwork in unacceptable climatic conditions causes heat strokes and the growth of cardiovascular diseases among miners [4]. For working under conditions of high temperatures, miners are given additional paid vacations; wage supplements; compensation payments for temporary and partial disability due to thermal shocks.

The following engineering measures are regularly carried out to improve and normalize the thermal conditions in the workings: optimization of the workings ventilation system to shorten the paths of fresh air movement; an increase in the flow rate of air supplied to the airing of stoping and development workings, up to values corresponding to the maximum allowable air velocity; the transfer of underground mobile compressor and power plants from workings with a fresh stream to auxiliary workings with a spray stream; increased air mobility at workplaces using air-ejectors, for example HD150 (Germany) [14]; drainage of the main air supply workings, etc. The implementation of these measures reduces the temperature in individual working faces by 2-3 °C, however, the full normalization of thermal working conditions at great depth is impossible using only mining engineering measures.

The experience of European coal-mining countries (Germany, Poland, Czech Republic) shows that the main way to normalize the climatic conditions in the working faces of coal mines is artificial air cooling [1]. In these countries they widely use underground stationary, mobile cooling systems [8, 12] and systems with surface refrigeration stations using the P.E.S. technology (pressure exchange system), providing a decrease (increase) in the hydrostatic pressure of water in the pipeline system without breaking the network and loss of cooling capacity [11]. At the same time, as part of the surface refrigeration stations, in addition to conventional freon vapor compression refrigeration machines, absorption refrigeration machines are also used. In this case, the principle of tri-generation is implemented at coal-mining enterprises: the generation of electricity, thermal energy and cold from accompanying methane gas, which leads to significant savings in fuel and energy resources.

When studying the possibility of using artificial air cooling at great depths, for example, on the seam m<sub>3</sub> of the mine n.a. A.F.Zasyadko, it is established that the cooling requirement of one stoping and development face in an unfavorable mining period (summer period at the borders of the mine field) will be 2000 and 500 kW, respectively, provided that the air temperature in the face does not exceed 26.0 °C [6]. The calculation of air temperature and cooling requirements of working faces was carried out according to the method [5]. If there will be two faces and up to six development workings operating simultaneously at the m<sub>3</sub> seam, we obtain the total cooling requirement of all working faces at a reached depth of about 7.0 MW.

When considering options for the production and supply of artificial cold to the places of consumption, it was taken into account that at the mine n.a. A.F.Zasyadko already operated a cogeneration station for electricity production from utilizing mine degassing methane, and there was an excess of hot water with a temperature of 96 °C and a flow rate of 100-150 m<sup>3</sup>/h. In this regard, it was decided to build a central cooling system with a capacity of 9.0 MW with ground-based absorption cooling machines and using P.E.S. technology to supply coolant (water with a temperature of +2.0 °C) to the local air-coolers [11]. The removal of the heat of refrigerant condensation was also planned to be carried out on the surface: in the summer period in cooling towers, in the winter – using the «free cooling» technology.

Given the scale and complexity of the task, the commissioning dates for the central cooling system will be 4-5 years with funding up to 20 million euros. This is due to the need to: develop a project for air conditioning; certification of foreign refrigeration equipment; construction of a surface complex for placement of absorption refrigerators; a significant amount of mining capital works in preparation for the placement of refrigeration and auxiliary equipment; installation of main and auxiliary equipment both on the surface and under the ground; laying a network of pipelines on the surface, in the air supply trunk, in mine workings (up to 5 km). To alleviate the problem of

normalization of climatic conditions in the areas of highest temperatures of the mine n.a. A.F.Zasyadko – a conveyor passage of the sloping eastern face no. 3 of the  $m_3$  working (hereinafter referred to as the conveyor passage), the air temperature of which already reached 36.0–38.0 °C, was decided to be implemented using local means of cooling – a shaft mobile air conditioner KPSH130 with a cooling capacity of 130 kW produced by JSC «Kholodmash» (Odessa, Ukraine) [3].

**Formulation of the problem.** The purpose of this work is to summarize the experience of using a mobile air conditioner for the normalization of temperature working conditions at the face of a blind preparatory development of great length, carried out at a depth at a temperature of host rocks up to 50.0 °C.

**Methodology.** Analysis of the actual state of the thermal regime for the current seam  $m_3$  of the mine n.a. A.F. Zasyadko and determination of prospects for its normalization based on the advanced world practices. Experimental study of thermal conditions of blind workings with a length of over 2000 m, carried out at a depth at rock temperatures of up to 50.0 °C, and its optimization using a shaft mobile air conditioner.

**Discussion.** A conveyor passage with a cross-section of 22.0 m<sup>2</sup> was passed using the combine method at a depth of 1220–1377 m at a temperature of host rocks of 43.4–47.5 °C along with the seam  $m_3$ . The seam has several hazardous conditions due to dust, sudden emissions of coal and gas, and spontaneous combustion. The design length of the excavation was 2200 m (1900 m slope and 300 m installation passage of eastern slope of face no.3). At the time of introduction of the KPSH130 conditioner, the length of the excavation was 1600 m. At the maximum length of the excavation, the expected air temperature in the summer period of the year with the natural mode was expected to exceed 40.0 °C.

Before the installation of the KPSH130 conditioner, the generation was ventilated by a local ventilation fan (from now on referred to as LVF) ES9-500 manufactured by Corfmann [10]. The actual air consumption for airing the face was 400 m<sup>3</sup>/min (with an estimated value of 330 m<sup>3</sup>/min). The diameter of the ventilation duct was 1200 mm in the first 300 m of working, then a ventilation duct with a diameter of 1000 mm was stretched to the face. A fire and a drainage pipeline with a diameter of 150 mm each were laid in the mine.

The KPSH130 underground mobile air conditioner with explosion-proof electrical equipment is designed for cooling and dehumidifying air supplied mainly to blind development workings of deep mines. The air conditioner consists of two blocks: compressor-condenser and air-processing unit. Both units have devices for installation on unified wheelsets for a gauge of 900 mm, which makes it possible to transport the conditioner along rail tracks in horizontal and inclined workings to the place of operation (Fig.1)

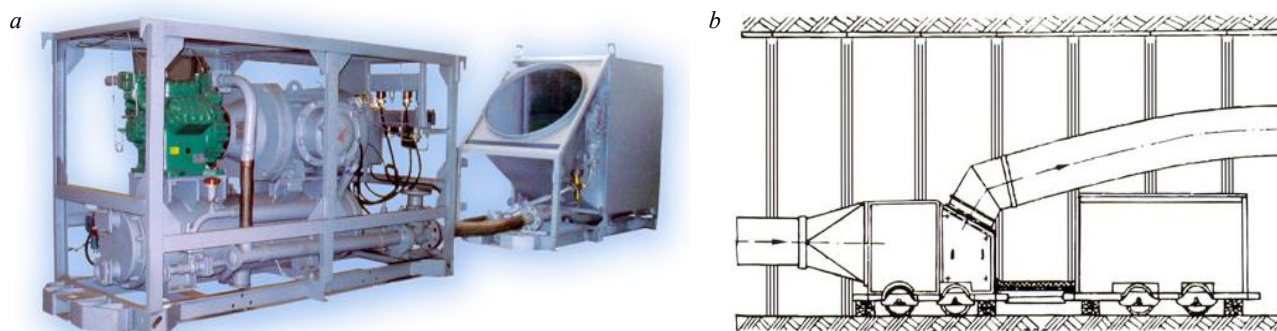


Fig.1. Mine mobile air conditioner KPSH130: *a* – condensing and air-cooling units;  
*b* – the working position of the air conditioner in the working



The KPSH130 conditioner is automated and has all types of necessary protection. A high degree of prefabrication makes it possible to install and put the air conditioner into operation by the specialists of the mine air-conditioning team. Considering that the air flow in the pipeline is characterized by low absolute and relative air humidity indicators, the expected decrease in air temperature in the face during the operation of the air conditioner KPSH130 will be 8-10 °C. The main technical characteristics of the air conditioner are as follows:

|                                                                                            |                                                                                       |
|--------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| 1. Machine type .....                                                                      | Compression, single-stage, direct evaporation, with water-cooled condenser, automated |
| 2. Cooling agent (refrigerant weight, kg).....                                             | R22 (60±2)                                                                            |
| 3. Lubricant.....                                                                          | Bitzer B5.2                                                                           |
| Refill oil weight, kg (including the compressor, kg).....                                  | 9.0±0.5 (5.0±0.5)                                                                     |
| 4. Cooling capacity, kW.....                                                               | 130                                                                                   |
| Parameters of air entering the air cooler:                                                 |                                                                                       |
| Temperature, °C.....                                                                       | 32±1                                                                                  |
| Relative humidity, %.....                                                                  | 70±5                                                                                  |
| Consumption, m <sup>3</sup> /s.....                                                        | 3.89±0.14                                                                             |
| Parameters of water entering the condenser:                                                |                                                                                       |
| Temperature, °C.....                                                                       | 35±1                                                                                  |
| Consumption, m <sup>3</sup> /h .....                                                       | 20±0.5                                                                                |
| 5. Cooling capacity deviation, %:                                                          |                                                                                       |
| downwards.....                                                                             | 7                                                                                     |
| upwards.....                                                                               | Not standardized                                                                      |
| 6. Power consumption with parameters according to item 4, kW.....                          | 36.5±2.55                                                                             |
| Maximum power consumption, kW.....                                                         | 40.5                                                                                  |
| 7. Loss of air pressure in the air cooler at flow 3.88 m <sup>3</sup> /s, Pa, not more.... | 980                                                                                   |
| 8. Condenser hydraulic resistance at a flow 20 m <sup>3</sup> /h, Pa, not more....         | 14000                                                                                 |
| 9. Dry weight, kg, not more than:                                                          |                                                                                       |
| air processing unit .....                                                                  | 1000                                                                                  |
| condensing unit .....                                                                      | 1650                                                                                  |
| assembly kit .....                                                                         | 225                                                                                   |
| 10. Overall dimensions of the block, mm:                                                   |                                                                                       |
| air processing unit .....                                                                  | 2255×900×1400                                                                         |
| condensing unit .....                                                                      | 2435×900×1250                                                                         |

The air conditioner KPSH130 was installed in the face of the conveyor passage at the end point of the track. Considering the slight cooling capacity of the air conditioner, to achieve the greatest cooling effect in the face and to reduce the total aerodynamic resistance of the ventilation duct, the air-cooling unit of the air conditioner was built into the pipeline at the minimum possible distance from its end. According to the penetration technology adopted at the mine, this distance was 50 m. As the face moved, the air conditioner moved to a new location, and the ventilation duct increased by the length of the pipeline section – 40 m (or two sections of 20 m each). Thus, the maximum removal of the air conditioner from the face was no more than 90 m, and the step of shifting was 40 m. The use of air conditioning in the development when contouring eastern sloping face number 3 with two parallel blind workings is shown in Fig.2.

According to the technical characteristics of the air conditioner KPSH130, the pressure loss in the air processing unit at a nominal flow rate is 980 Pa. In this case, the required air flow rate in the face will not be provided with an operating ES9-500 fan over the designed length. To solve this problem, the ES9-500 fan was replaced with a high-pressure dGAL9-500/500 fan manufactured by Corfmann with soft-start equipment that prevents the gap of the ventilation stack when the fan starts [10]. To improve the quality of the ventilation duct and reduce air leakage along its length, part of the ventilation ducts in the mine, starting from LVF, was replaced with Schauenburg (Germany) pipelines [13], they are denser, which reduces the leakage rate: mm with a diameter of 1200 mm – 100 m; flexible pipe with a diameter of 1200 mm – 300 m; flexible pipe with a diameter of 1000 mm – 700 m. Table 1 shows the parameters of the LVF dGAL9-500/500 operation on the

ventilation network calculated for Schauenburg pipes with a diameter of 1000 mm with an air-conditioner KPSH130 located 100 m from the end of the ventilation pipe.

To reduce the time of putting the KPSH130 air conditioner into operation, it was decided to carry out the removal of the heat of condensation of the refrigerant using a direct-flow scheme. For this purpose, water was taken from the existing fire pipeline with a flow rate of 15-20 m<sup>3</sup>/h to the air conditioner condenser directly at the place where the air conditioner was installed. Water purification from mechanical impurities to prevent clogging of the hydraulic cavity of the condenser was carried out using a filter W2788 with manual backwashing with a capacity of 800 l/min manufactured by Seetech (Germany) [15]. The filtration fineness was 100 microns. The heated water after the conditioner was drained into a water tank, where it was mixed with water pumped from the bottom of the mine. A closed trolley with a capacity of 4.5 m<sup>3</sup> served as a water tank. Then, water was pumped out of the trolley using the TsNS 60×150 pump through the existing pipeline with a diameter of 150 mm to the mine drainage system (Fig.3).

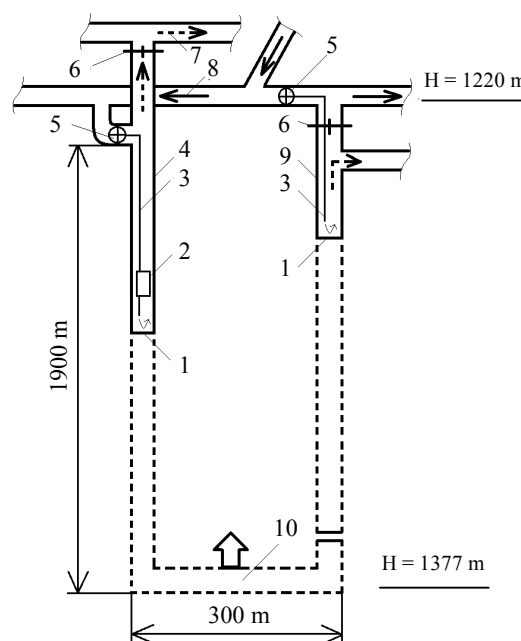


Fig.2. Layout of air conditioner KPSH130 in working

- 1 – face; 2 – air conditioner KPSH130;  
3 – ventilation pipeline; 4 – conveyor passage; 5 – LVF;  
6 – gauge door; 7 – inlet air stream; 8 – fresh air stream;  
9 – ventilation passage at the eastern slope face № 3;  
10 – installation passage of the eastern sloping face № 3

Characteristics of the ventilation network of conveyor passage

Table 1

| Pipeline length, m | Air consumption in the face, m <sup>3</sup> /s | Fan feed, m <sup>3</sup> /s | Air leakage rate | Fan depression, Pa | Shaft power, kW |
|--------------------|------------------------------------------------|-----------------------------|------------------|--------------------|-----------------|
| 2000               | 5.5                                            | 9.0                         | 1.64             | 3100               | 35              |
| 2500               | 5.5                                            | 10.25                       | 1.86             | 3950               | 50              |
| 2800               | 5.5                                            | 11                          | 2.0              | 4550               | 62              |

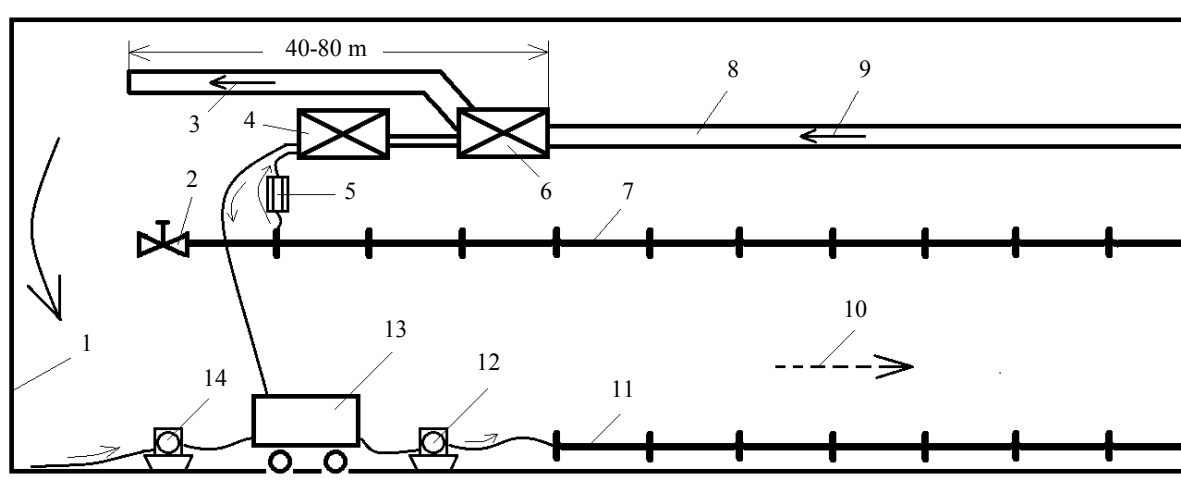


Fig.3. Connection diagram of the air conditioner KPSH130 in the face of the conveyor passage

- 1 – face; 2 – shut-off valve; 3 – fresh cooled air jet; 4 – condensing unit of the air conditioner;  
5 – manual backwash water filter; 6 – air conditioning unit; 7 – fire pipe;  
8 – ventilation duct; 9 – a stream of fresh uncooled air; 10 – outgoing air stream; 11 – drainage pipeline;  
12 – CNS pump 60 × 150 for pumping water from the water collector; 13 – water collector; 14 – face pump

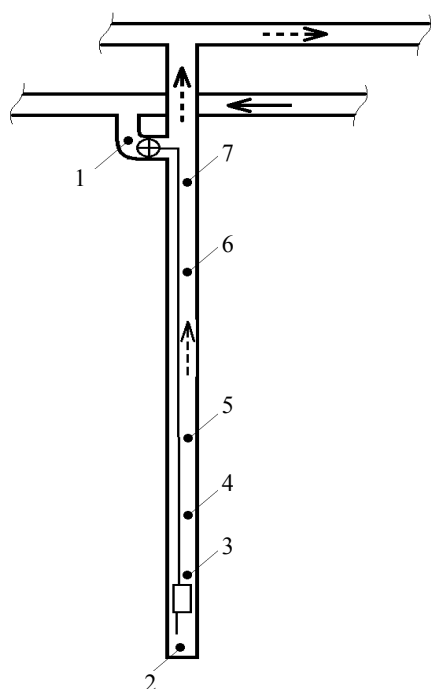


Fig.4. Location of measurement points  
air humidity parameters in a conveyor passage

1 – before LVP; 2 – conveyor passage face;  
3 – at the placement of KPSH 130; 4-7 – pickets 163, 120, 60  
and 21 respectively (distance between pickets is 10 m)

All work on the installation of the KPSH130 air conditioner and the dGAL9-500/500 fan was carried out by the mine maintenance team and took no more than ten days, including trial switching on of equipment at the mine site. The commissioning work was carried out by equipment manufacturers – representatives from the JSC «Kholodmash» and the company CFT (Germany) [7], representing Corfmann in the CIS countries. Maintenance and operation of this equipment were carried out by the mine.

**Results of experimental studies.** The introduction of the KPSH130 mobile air conditioner into operation allowed us to monitor the changes in the thermal and moisture parameters of the air both in the face and the bottom-hole zone of the conveyor passage and along the entire length of the roadway along the air jet (Fig.4).

In the course of experimental studies, temperature and relative air humidity were measured at all points. Air consumption was controlled only in the mine working. According to the results of measurements, the moisture content and enthalpy of air were calculated (Table 2).

Table 2

Heat and humidity parameters of air in conveyor passage

| The number of the measurement point in Fig.4 | Temperature, °C | Relative humidity, % | Moisture content, g/kg | Enthalpy, kJ/kg |
|----------------------------------------------|-----------------|----------------------|------------------------|-----------------|
| Before installation of KPSH130               |                 |                      |                        |                 |
| 1                                            | 30.0            | 64                   | 15.3                   | 69.2            |
| 2 (MP186)                                    | 40.5            | 39                   | 16.6                   | 83.4            |
| 4                                            | 38.4            | 48                   | 18.3                   | 85.8            |
| 5                                            | 40.8            | 45                   | 19.5                   | 91.2            |
| 6                                            | 38.9            | 52                   | 20.5                   | 91.9            |
| 7                                            | 37.5            | 55                   | 20.2                   | 89.6            |
| 2 days after the start of KPSH130 work       |                 |                      |                        |                 |
| 1                                            | 30.2            | 65                   | 15.7                   | 70.4            |
| 2 (MP188)                                    | 26.4            | 80                   | 15.2                   | 65.2            |
| 3 (MP183)                                    | 31.4            | 65                   | 16.6                   | 74.1            |
| 4                                            | 36.6            | 52                   | 17.6                   | 82.1            |
| 5                                            | 39.8            | 46                   | 18.8                   | 88.4            |
| 6                                            | 38.5            | 50                   | 19.3                   | 88.3            |
| 7                                            | 37.2            | 54                   | 19.4                   | 87.3            |
| 18 days after the start of KPSH130 work      |                 |                      |                        |                 |
| 1                                            | 30.4            | 52                   | 12.5                   | 62.6            |
| 2 (MP193)                                    | 25.2            | 72                   | 12.7                   | 57.6            |
| 3 (MP188)                                    | 28.0            | 65                   | 13.6                   | 62.9            |
| 4                                            | 36.2            | 42                   | 14.1                   | 72.6            |
| 5                                            | 39.4            | 41                   | 16.2                   | 81.2            |
| 6                                            | 38.0            | 44                   | 16.4                   | 80.4            |
| 7                                            | 36.7            | 49                   | 16.9                   | 80.2            |

The use of air conditioner KPSH130 gave the following result. The thermal conditions in the face were completely normalized. The air temperature here dropped from 40.5 to 25.2 °C. In separate maintenance shifts, the air temperature dropped to 24.0 °C. In the face zone (50 m from the



face), the thermal working conditions were significantly improved, and the air temperature here did not exceed 28.0 °C (measurement point number 3 in Fig. 4). As the distance from the face increases, the cooling effect from the air conditioner operation is expected to decrease and already at the end point of the outgoing air stream in the mine (measurement point 7 in Fig.4), the air temperature during KPSH130 operation was slightly different from the air temperature during the natural ventilation mode. However, due to a sharp decrease in the moisture content of the air stream after the refrigeration device, the heat content of the air was noticeably lower. According to the proposed scheme, the air conditioner has worked stably until the end of the blind workings – the point of the conveyor passage connection with the ventilating runway of sloping eastern face no. 3 (see Fig.2) and the organization of ventilation of the excavation site due to general depression.

## Conclusions

1. At the coal-mining enterprises of Donbass with the temperature of the host rocks up to 50.0 °C, the air temperature in the stoping and development faces significantly exceeds the permissible safety standards. The total cold demand of stoping and development faces of the largest mines can reach 7.0 MW, which makes the problem of solving thermodynamic safety one of the main constraints to the development of coal mining in the region. The solution of the problem requires the construction of large surface complexes, providing the production of artificial cold to cool the air in the working faces.

2. Before the commissioning of central cooling systems, air cooling in the faces of the blind workings with highest temperatures can be accomplished with the help of local low-power cooling means – mobile air-conditioners of the KPSH type. The introduction of such air conditioners with a capacity of only 130 kW will make it possible to fully normalize the thermal working conditions directly in the faces of the blind workings with their total length of up to 2200 m and the temperature of the host rocks up to 50.0 °C.

3. The experience of using a mobile air conditioner at great depths can be used to improve and normalize thermal working conditions at other underground facilities, for example, at the deep mines of OJSC MMC «Norilsk Nickel» or in oil drilling adits using the thermo-shaft method [9].

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