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Drying of Potassium Mine Workings Using Automatic Air Control Systems

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Осушение горных выработок калийных рудников с использованием средств систем автоматического управления проветриванием

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In the conditions of potash mines, the problem of excess moisture loss from the air entering the mine during the warm period of the year is known. Physically, the process is related to the fact that warm air saturated with moisture enters the mine workings and cools down in the process of heat exchange with relatively cold rocks. When the air is cooled, its relative humidity rises until it reaches the dew point. Further cooling of the air leads to the loss of excess moisture while maintaining the maximum relative humidity. Moisture precipitation together with salt rocks creates a corrosive-aggressive environment, worsens the stability of workings and leads to soil erosion with the ensuing difficulties for the passage of mining vehicles. The introduction of heat engineering means of air drying is an extremely costly undertaking. At the same time, heat and mass transfer processes in mine workings depend on air distribution, which is controlled by modern automatic ventilation control systems. In this regard, the study considers the option of using the means of automatic ventilation control systems, along with their traditional use, for the purpose of draining mine workings. The paper shows that the amount of condensing moisture is determined primarily by the air flow. Therefore, the elimination of excess air supply to the mine and workings, implemented by automatic ventilation control systems, makes it possible to reduce moisture loss in mine workings. In addition, moving the recirculation ventilation systems, which are part of the automatic ventilation control systems, as close as possible to the shafts allows you to include a larger volume of air supply workings and service chambers in the recirculation circuit, which also makes it possible to drain them in conditions of hygroscopic rocks.

Ключевые слова:
горная выработка, рудничная вентиляция, тепловой режим, микроклимат горных выработок, воздухораспределение, осушение воздуха, расчет количества воздуха, системы автоматического управления проветриванием, вентиляция по требованию, рециркуляция, отрицательное регулирование.

В условиях калийных рудников известна проблема выпадения избыточной влаги из поступающего в шахту воздуха в теплый период времени года. Физически процесс связан с тем, что насыщенный влагой теплый воздух поступает в горные выработки и в процессе теплообмена с относительно холодными горными породами охлаждается. При охлаждении воздуха происходит повышение его относительной влажности вплоть до достижения точки росы. Дальнейшее охлаждение воздуха приводит к выпадению избыточной влаги при сохранении максимальной относительной влажности воздуха. Выпадение влаги совместно с соляными породами создает коррозионно-агрессивную среду, ухудшает устойчивость выработок и приводит к размыву почвы с вытекающими сложностями для проезда горных машин. Внедрение теплотехнических средств осушения воздуха является крайне затратным мероприятием. В то же время процессы тепломассообмена в горных выработках зависят от воздухораспределения, управление которым реализуется в современных системах автоматического управления проветриванием. В связи с этим в исследовании рассмотрен вариант применения средств систем автоматического управления проветриванием, наряду с их традиционным использованием, для целей осушения горных выработок. В работе показано, что количество конденсирующейся влаги определяется, прежде всего, расходом воздуха. Поэтому исключение избыточной подачи воздуха в рудник и по выработкам, реализуемое системами автоматического управления проветриванием, позволяет снизить выпадение влаги в горных выработках. Кроме того, перемещение систем рециркуляционного проветривания, входящих в состав систем автоматического управления проветриванием, максимально близко к стволам позволяет включить в рециркуляционный контур больший объем воздухоподающих выработок и камер служебного назначения, что также дает возможность производить их осушение в условиях гигроскопичных горных пород.

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Introduction

Conducting mining operations on a relatively shallow mineral deposits (with a mining depth of up to 500 meters), geographically located in areas with a characteristic warm climate, entails the problem of excessive moisture deposition in the main air supply workings. Since the temperature of the rocks with a specified depth range is low (15–18 °C), during the warm period of time the warm and humid air entering the mine workings is cooled and a significant amount of moisture condenses in the workings. The problem of moisture loss is especially acute in regions with a warm and humid climate.

Precipitation of moisture in mines at the main air supply (transport) workings entails a number of undesirable consequences, among which are the following:

1) corrosion and accident rate of equipment and transport;

2) disruption of automation and power supply systems;

3) precipitation and accumulation of condensation brines in transport workings creates difficulties for the passage of vehicles delivering miners to the faces.

At the same time, if neglecting the distribution of humidity indicators is permissible in coal mines, metal and polymetallic mines, then in the conditions of potash mines these phenomena are of particular importance, since in this case in the air and on the soil of mine workings it is formed aggressive components which cause significant damage in all areas of the mine. Moreover, moisture saturation of hygroscopic rocks, especially clay layers of the massif, reduces their physical and mechanical properties and leads to a decrease in the stability of mine workings and pillars, creates a danger of mining operations [1–3].

The damage can be most clearly seen while considering the disruption of the power supply to the mine, the downtime of transport and technological equipment. The damage associated with the failure of automation equipment and the disruption of the power supply to the mine consists primarily in the downtime of individual sections or panels in the event of a power outage. The calculation of damage from the failure of automation equipment, disruption of power supply to the mine, downtime of technological equipment and transport has been carried out on the basis of statistical processing of data from duty operators of potash mines for several years. The resulting numbers indicate a sharp increase in the number of power outages and equipment downtime between May and October each year. In particular, the results of long-term statistical studies at potash mines show [4] that moisture precipitation in the warm period of time leads to a twofold increase in the number of downtime of technological equipment and 1.89 times increase in the downtime of self-propelled vehicles at the mine. Due to the lack of a methodological basis it is difficult to quantify economic losses. However, even in the absence of calculations it is clear that additional downtime of mining production and the failure of expensive mining equipment result in significant material losses.

The problems of draining air-supplying mine workings were most intensively dealt with by aerologists and thermo physics of potash and stone-salt mines. It can be given special prominence to the studies of I.I. Medvedev, A.E. Krasnoshtein [5], B.P. Kazakova [6], N.D. Luzhetskaya [7], L.Yu. Levina [8] and others [9, 10].

Dehumidification of air entering mine workings as a means of normalizing microclimatic parameters in working areas is considered in the paper [11].

In the study [4] it is proposed comprehensive schemes for the formation and normalization of the microclimate of potash mines including the dehumidification of air-supplied mine workings. In particular, the following technical solutions have been developed:

– a multi-stage system for the air handling and regulation of its microclimatic parameters including technological units for air handling on the surface, in near-shaft yards and in separate areas of underground mine workings;

– the use of special heat and mass exchange workings by the application of energy and sorption properties of the rock mass, the energy capacity of underground brine collectors;

– use of recirculating ventilation.

At the same time, it should be noted that the implementation of mine air conditioning (dehumidification) systems in practice requires unreasonably large capital expenditures. The possibility of using recirculating ventilation has been proven with the help of experimental data, but no detailed research have been carried out to study the mechanisms of dehumidification of the atmosphere of mine workings using recirculation systems.

Research of the performance of various types of mine air dehumidification systems carried out by foreign scientists has been reflected in the works [12–14].

In the study [8] it is proposed to use water heaters of the mine in order to cool the air entering the shaft and to dehumidify it. However, in practice this measure requires the development of forced heating units and heat exchangers in the design different from the existing one. This is caused by the formation of a significant amount of condensation moisture on the elements of heat exchangers which, together with the presence of salt dust, creates an aggressive environment and leads to their rapid destruction and failure. Thus, to implement this measure it is necessary to create new, two-season forced air heating units in a special, moisture-resistant design, and this will also lead to a sharp increase in their cost.

At present, automatic ventilation control systems (AVCS) are widely used in potash mines, making possible to build the most efficient and reliable ventilation systems. The development of automatic ventilation control systems has the following conceptual orientations:

– improvement efficiency of monitoring and control of underground working areas ventilation and, accordingly, higher safety of mining operations;

– reduction of energy costs for providing mine ventilation.

The works of Ph.A. Abramov [15], L.A. Puchkov [16], S.V. Tsoy [17], B.P. Kazakov, Yu.V. Kruglov, L.Yu. Levin [18–21] and others [22–24] are devoted to the development of theoretical and technological basis of AVCS.

The concept of AVCS and the experience of its application at the mines of foreign mining enterprises are described in the works [25–29].

At present, the following technical means of the AVCS have been developed and tested in practice:

1) fan units with frequency regulation of the drive which allows regulating aerodynamic and power parameters of operation in a wide range;

2) recirculation units with the necessary system for monitoring the aerodynamic and gas-dynamic parameters of ventilation of individual sections of the mine field;

3) automatic ventilation doors providing the possibility of smooth regulation of aerodynamic resistance.

In the cycle of works it was built the theory and algorithmic base and developed appropriate software modules which make possible to regulate the operation of the AVCS elements and provide optimal ventilation modes. These modes are characterized by such parameters of the ventilation control equipment that all working areas of the mine receive the required amount of air with the joint minimization of the power consumed by the ventilation network fan units [20].

Despite the fact that the means of AVC systems open up wide possibilities for controlling the aerodynamic characteristics of the movement of air flows in mine workings, the possibility of using them to control the temperature and humidity parameters of mine air is usually not considered. At the same time, the influence of aerodynamic characteristics of ventilation on the formation of thermal and humidity parameters of the mine atmosphere can be considered proven [30–32].

In the works [33–35] it is described the experience of modeling heat transfer processes and controlling thermodynamic processes in the mine workings of deep mines of foreign mining enterprises.

In the present study the authors examine the possibilities of using AVCS tools to control thermodynamic processes in the atmosphere of mines and to reduce the amount of condensable moisture in potash mines in the warm season.

At the first stage, the dependence of the intensity of moisture precipitation in the workings on the air flow rate was investigated.

Dependence of moisture precipitation intensity on air consumption

The rate of moisture precipitation depends on the air flow rate in the mine workings and changes in its moisture content:

$$\frac{dm}{dt} = \Delta d\left(T,\ \varphi_{кр},\ P\right)\cdot\rho\cdot Q, \quad (1)$$

where m – moisture mass, kg; d – moisture conten in the air, kg/kg, is determined by I–d diagram; T – air temperature, °C; $\varphi_{кр}$ – critical relative humidity, %; P – absolute air pressure, Pa; ρ – air density, kg/m^3; Q – air flow rate in the workings, m^3/s.

Through a change in temperature, this expression can be represented as

$$\frac{dm}{dt} = \frac{\partial d\left(T,\ \varphi_{кр},\ P\right)}{\partial T}\Delta T\cdot\rho\cdot Q. \quad (2)$$

The partial derivative of moisture content from temperature included in the expression can be calculated as follows:

$$\frac{\partial d\left(T,\ \varphi_{кр},\ P\right)}{\partial T} = \frac{0{,}00020412\cdot P\cdot\left(11{,}52+1{,}62\cdot T\right)\varphi_{кр}}{\left(0{,}001\cdot P+\left(-611{,}71-37{,}33\cdot T-2{,}6244\cdot T^2\right)\varphi_{кр}\right)^2}. \quad (3)$$

The temperature difference between the beginning and end of a section of mine workings in a steady state can be determined by the expression:

$$\Delta T = T_m + \left(T_0 - T_m\right)e^{-\frac{\alpha PL}{cSv}}, \quad (4)$$

where T_0 – Air temperature at the inset, °C; T_m – the temperature of the walls of the mine working, °C; P – mining perimeter, м; α – heat transfer coefficient on the wall of the mine, W/m$^{2}\cdot$°C; L – working length, m; c – specific heat capacity of air, J/m$^{3}\cdot$°C; S – area of mine section, m^2; v – air velocity through the workings, m/s.

In this case, the heat exchange process is considered to be steady, i.e. quasi-stationary, and the temperature of the walls of the massif is locally unchanged over time. The dependence of the heat transfer coefficient α on the velocity of air movement is determined by the Shcherban formula [30]:

$$\alpha = 3{,}4\cdot\frac{v^{0{,}8}}{d^{0{,}2}}. \quad (5)$$

Substituting expressions (5) and (4) and finding from the original expression (3) the difference in moisture content Δd, we obtain the expression for it in the form:

$$\Delta d = \frac{0{,}00020412\cdot P\cdot\left(11{,}52+1{,}62\cdot T\right)\varphi_{кр}}{\left(0{,}001\cdot P+\left(-611{,}71-37{,}33\cdot T-2{,}6244\cdot T^2\right)\varphi_{кр}\right)^2}\times \left(T_m+\left(T_0-T_m\right)\exp\left(-\frac{3{,}4\cdot P\cdot L}{c\cdot S\cdot d^{0{,}2}\cdot v^{0{,}2}}\right)\right). \quad (6)$$

From the obtained expression it follows that the difference in moisture content between the beginning and the end of the site is weakly dependent on the speed of air movement through the mine workings, which is physically equivalent to the statement that the increase/decrease in the time of heat exchange is almost completely compensated by a decrease/increase in its intensity.

Thus, the difference in air moisture content at the beginning and end of the section is weakly dependent on air flow (the increase in time of heat exchange is compensated by a decrease in its intensity). Based on this it can be assumed that the rate of moisture deposition in the mine workings depends linearly on the air flow through the site:

$$\frac{dm}{dt} = K\cdot Q, \quad (7)$$

where the coefficient K, which is equal to the amount of condensable moisture in the working, related to the air flow rate in it, can be considered as independent of the air flow rate in the first approximation (in fact, in accordance with all of the above, the dependence exists, but it is weak). This coefficient is determined only by the parameters of the thermal regime of the mine in the warm period of the year – the temperature and humidity of the air entering the mine, and the temperature of the rocks.

Methods of drainage of mine workings by means of the Automatic ventilation control systems

In the introduction it was shown that the existing concept of the use of AVCS is not focused on their application as a means of regulating thermal humidity parameters in the atmosphere of mine workings. At the same time, as it has already been shown and considered, such aerodynamic parameters as the distribution of velocities and pressures in the mine ventilation network most directly affect the formation of heat and moisture distribution in the mine workings. Thus, by controlling aerodynamic parameters through the capabilities of the AVCS it is possible to influence the formation of microclimatic parameters of minery atmosphere. Therefore, we will consider the possibilities of using the means of automatic control of thermodynamic processes occurring in the mine atmosphere, based on the established dependence of the amount of moisture falling per unit of time, in the form of the expression (7).

According to the accepted technical standards, air supply is carried out with a certain margin, determined at the stage of calculating the amount of air through the coefficients of leaking and irregularity. The irregularity coefficient characterizes the error in controlling the aerodynamic parameters of the ventilation system. Thus, with a known

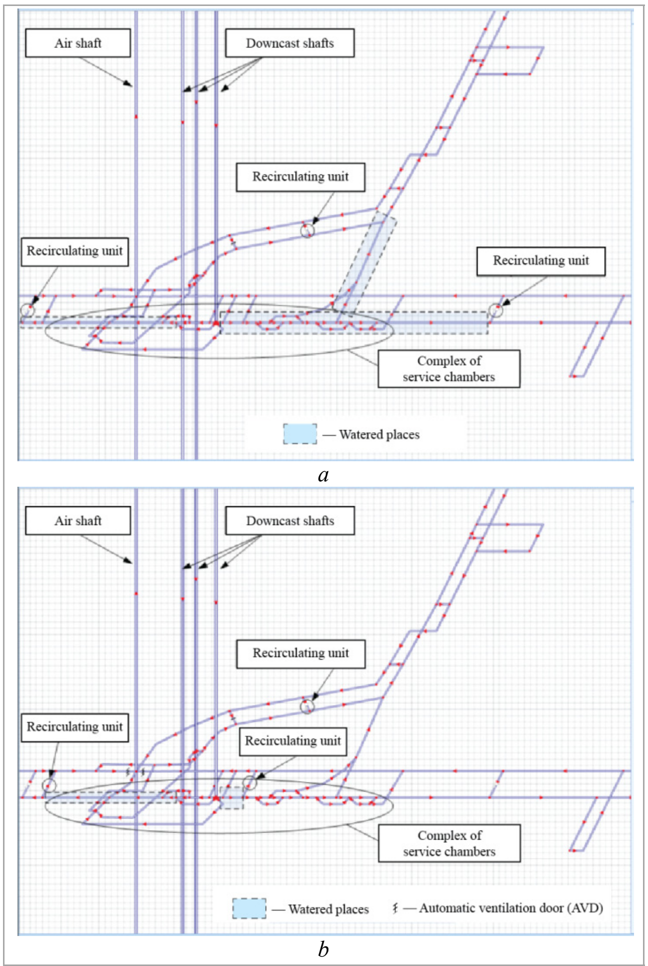

Fig. Traditional scheme (*a*) of recirculating ventilation facilities and moisture precipitation zones arrangement in the air supply workings and the proposed scheme (*b*) of the placement of recirculating ventilation facilities for dehumidification of the main air supply workings and service chambers

relative error of the means of negative control ε_R, the required safety factor will be determined as follows:

$$k_з = 1 + \frac{\varepsilon_R}{2}. \quad (8)$$

As a result, an excessive amount of air ΔQ, will be supplied to the underground workings of the mine and it is equal to:

$$\Delta Q = \frac{\varepsilon_R}{2} Q_{расч}, \quad (9)$$

where $Q_{расч}$ – actual calculated air quantity excluding the coefficient of irregularity.

Accordingly, an additional amount of moisture in the volume

$$\Delta m = K \frac{\varepsilon_R}{2} Q_{расч}. \quad (10)$$

will be introduced into the mine at each moment of time.

According to recent studies traditional means of negative and positive control of air distribution create actual coefficients of irregularity in the range from 1.3 to 1.6. Even despite this fact, the standard coefficients of irregularity at potash mines range from 1.1 to 1.25. In practice, this leads to the precipitation of 10 to 25 % of additional moisture (from the total mass) into the mine during the warm period.

One of the fundamental ideas of using AVCS is that the means of monitoring and control of air flows allow the increase of the accuracy by several times (accordingly, to reduction of error) of regulation. The error in regulating air distribution using automatic ventilation doors (AVD) and recirculation units is from 8 to 10 % which makes it possible to ensure coverage factor of no more than 1.05. Thus, the use of the ACS makes it possible to reduce the supply of excess air and, accordingly, the precipitation of condensation moisture into the air supply workings of the mine.

An important component of modern AVCS is recirculating ventilation systems for partial air reuse.

In the works [36–39], recirculation is considered as a potential method of energy saving by reducing external air inflow.

In addition, recirculating ventilation systems can be considered as a means of draining mine workings. In the works [4, 40, 41] it is shown that the air flow moving along the workings in hygroscopic rocks is dried due to mass transfer processes between air and rocks. So, the air is naturally dehumidified and can be used to dehumidify the air supply workings.

Existing schemes of the partial air reuse involve the installation of recirculation fans outside the yards and service chambers as shown in the Fig. There are two reasons for such measures:

– unfavourable mode of operation of recirculation units in conditions of high general shaft depressions typical for the near-shaft yards of the upper horizons;

– the possibility of improving ventilation of remote areas of the mine field.

The main task of recirculation units is to ensure that the amount of air supplied to the mine can be reduced by operating the main fan unit. However, with such their placement, the sections of the main air supply workings and service chambers located in the yard near the shaft do not fall into the coil, and it is they that are associated with the main problems of moisture precipitation in the warm season. Thus, in the warm season, all these areas are watered as shown in the figure *a*.

Therefore, consideration of the possibility of draining these workings allows us to take into account the probability of the recirculation unit dislocation in order to involve the maximum possible volume of workings in the recirculation coil. At the same time, the installation of automatic means of negative regulation in the main ventilation workings in the area of their interface with the ventilation shaft makes it possible to control the value of the mine ventilation pressure drop of the near-shaft yard and individual directions. This makes it possible to neutralize the difficulties of ensuring the operation of recirculation units in an area with a significant value of the mine general shaft depression.

Figure *b* shows an improved scheme of recirculation ventilation using the means of automatic ventilation for dehumidification of air supply workings and service chambers.

To ensure the stable operation of the recirculation fan it is necessary to place the AVD near the recirculation unit, outside the coil, to regulate the air distribution between the directions of the mine, and reduce the load on the recirculation unit. In this case, the change in the resistance of the AVD is equivalent to a change in the reduced equivalent pressure characteristic of the main fan unit in the direction of the recirculation unit operation. Thus, the use of AVCS makes it possible to significantly expand the volume of mine workings involved in recirculation ventilation within the mine field, and the area of change in its parameters selecting the most effective ones for draining service chambers and transport workings of the mine.

Conclusion

Based on the results of studies of AVCS application for the control of thermodynamic processes in the mine atmosphere the following conclusions can be drawn:

– the amount of condensable moisture in the mine workings per unit of time in the warm period of the year is mainly determined by the air flow, the initial microclimatic parameters of the air and the temperature of the rock mass;

– the use of AVCS at potash mines will reduce the standard coefficients of irregularity, which leads to a decrease in the amount of moisture at the main air supply workings;

– installation of automatic ventilation doors at the main ventilation workings in the area of their interface with the ventilation shaft creates favourable conditions for the operation of recirculation units which drain the complex of service chambers;

On the base of the obtained results it has been developed and put into operation drainage systems for the workings of the near-shaft yard and the main air supply drifts with the use of automatic ventilation control systems for all mines of Belaruskali JSC.

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