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METEOROLOGICAL CONDITIONS OF ICING OF UNDERGROUND EXCAVATION OF THE "RASVUMCHORR" MINE

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Abstact. The strong icing of underground excavation of the "Rasvumchorr" mine is caused mainly by meteorological factors. The ice forming in the air trunk begins, when the moisture content in the atmospheric air decreases below the critical value. In that case the walls of the air trunk cools as expends very much heat for the water evaporation in the injected dry atmospheric air despite the fact of positive temperature (about +3-5°C). Meteorological criteria of the ice appearance are established.
Preliminary theoretical study of a problem has shown unconditional prospects of temperature regulation of air depending on not only temperature but also absolute humidity of external air. At the same time the proposed method of the ice control is more economical than the present ones.

Introduction

Since 2004 the heating of air at the Rasvumchorr mine of JFS "Apatit" is being carried out by the electrical calorifers. The temperature regulation by the hot water calorifers was impossible. For this reason temperature had been kept at a level of +7÷12°C irrespective of temperature of the outside atmospheric air. The modern electrical calorifers provide the possibility of temperature regulation accurate within 0.2-0.3°C.
The technical modernization enabled the economy of electrical power as the air temperature in the underground excavation could be decreased up to +2°C according to order of safety. However in a number of cases the temperature decrease causes the intensive ice formation on walls of the air trunk and some underground excavations in sections with the water drip.
The icing is a dangerous industrial factor as limits the movement of underground transport. Besides the icing threatens the underground communications, which are fastened to walls of excavations and drops the economic characteristics of ventilators.
In the cold seasons between 2002 and 2006 the temperature of air in the air trunk was kept at a level about +4°C. This operating practice provided the optimal parity between the power consumption of electro-calorimeter and the probability and intensity of the icing in the air trunk. However the possibility of icing was not excluded. The ice control was being carried out by the temperature increase to +7÷9°C when the ice mass was amounting to critical values. At the same time, the absence of a rigorous criterion of icing creates a technological problem, as process of automatic control of temperature is impossible.

Analysis and discussion

The comparison of date with icing and data of the meteorological measurements show that all periods with the ice formation concurs with periods of the low moisture content of the atmospheric air. We have supposed that the icing is caused by strong cooling of excavation walls because of intensive evaporation and respective heat loss in conditions of injection of the very dry atmospheric air.
The observations snow that the icing in the mines appears in the broad temperature diapason, i.e. the air temperature is not determinative factor.
The equation of surface heat balance of mine wall includes the evaporation loss, the turbulent heat transfer, the heat transfer out of massive, and the heat exchange with the water, which leaks out of massive [*Galkin*, 2000].
Mass *M* of evaporated water from unit of surface in unit time:

$$M = f(u)\frac{(E^{/} - e)}{p} \quad /2/,$$

Where $E^{/}$ is maximal content of air water vapour under temperature of evaporation surface $t^{/}$;

e is partial pressure of water vapour in the air;

p is atmospheric pressure;

f(u) – function which is depended mainly on wind velocity.

The heat loss of evaporation surface:

$$Q_1 = f(u)\frac{(E^{/} - e)}{p}L$$

where *L* is latent heat of vaporization;
At the same time the heat transfer to surface by turbulent heat exchange with air:

$$Q_2 = \varphi(u)(t_{air} - t^{/}),$$

Where *φ(u)* is function depended on velocity of air flow; $t_{возд}$ is temperature of air in the air trunk.

The heat exchange with the water, which leaks out of massive:

$$Q_3 = cm(t_{water} - t^{/})$$

The heat transfer in the rock to surface:

$$Q_4 = -\lambda \frac{\partial t_{rock}}{\partial z}$$

where m, t_{water} and c — mass, temperature and specific heat of leaking water, λ is thermal conductivity of rock; $\frac{\partial t_{rock}}{\partial z}$ is the temperature gradient into rock.

The conditions of water freezing:

$$f(u)\frac{(E^{/} - e)}{p} L > \varphi(u)(t_{air} - 0) + cm(t_{water} - 0) - \lambda \frac{\partial t_{rock}}{\partial z} \quad (1)$$

Thus the ice forming on the walls of air trunk is depended on partial pressure of the atmospheric water vapor, atmosphere pressure, air flow velocity, mass and temperature leaking water and heat transfer out of massive (the its role is smaller according our estimation).

The icing control can be carried out by:

1) The increases of air temperature in the air trunk (t_{air});
2) The artificial moistening of air;
3) The decrease of air velocity u as $\varphi(u)>f(u)$ [*Sternzat*, 1978] (this is impossible according to normative-technical orders).

The equation (1) is not solved analytically as $f(u)$, $\varphi(u)$, m, λ, t_{nop} and z are unknown.

However we can simplify the problem. In fact, $f(u) \approx const$ and $\varphi(u) \approx const$ under $u \approx const$ as $f(u)$, $\varphi(u)$ are depended on airflow velocity.

$$\lambda \frac{\partial t_{rock}}{\partial z} \approx const$$

The role of atmospheric pressure is the least. The estimation of heat exchange with the water, which leaks out of massive, causes the severe difficulties, as m is a variable quantity. However the problem can be reduced to the problem of the air moisture content (partial pressure of water vapour) if $m \approx const.$

The distribution of air temperature and humidity along the air trunk were studied. The critical values of absolute humidity were defined using measurements at the boundary of sections with the icing and without ones. For example, we detected that the icing appears when the temperature of wet bulb is less than -0.8°C and not observed when it is more than -0.2°C. At that the icing occurs only at starting section of the air trunk as the intensive evaporation of water increases rapidly the air moisture content (fig.1).

The hypothesis test is carried out by additional measurements in joint of air trunk and transport mine, where conditions for the ice formation are most favors as the air is most dry and at the same time the air velocity and evaporation velocity are the greatest.

Data of measurements in Fig. 2 verify our assumption on main physical causes of icing in the air trunk.

The conditions of the icing have been established using data of measurements and relations between the hygrometric characteristics of air (see, for example [*Psychrometric tables,* 1972]):

1) The intensive icing of air trunk and some sections of underground excavation begins, when the air temperature meets the following condition

$$T < -1.6e + 8.2 \quad (2)$$

where e is partial pressure of atmospheric water vapor.

The icing is impossible, when the air temperature meets the following condition

$$T > -1.6e + 9.3 \quad (3)$$

Simultaneously the defined relations define the upper limit of temperatures, which are the necessity for icing control. As already noted, earlier the air temperature increased up to +7÷9°C for the ice control. As indicated by Fig. 3, in a number of cases this temperature increase was not justified economically as it was possible to be limited by more low temperatures (for example, line 3).

This assumption was checked by definition thermal and hygrometric characteristics of air at the moment of the beginning of ice thawing of (occurrence of a liquid phase on dry ice surface).

Preliminary theoretical study of a problem has shown unconditional prospects of temperature regulation of air depending on not only temperature but also absolute humidity of external air.

The analysis of the climatic data shows enough ample opportunities for decrease of air temperature in underground excavation below established at present +4°C without the threat of icing of the air trunk (for example, line 1 and 2 in Fig. 2). As indicated by Fig. 2 the constant temperature at a level 4°C is not justified in respect to the ice control during the periods with high moisture content of the atmospheric air as overheating air takes place. For example, the decrease of temperature of heating air from 4° to +2°C is possible without the threat icing of the air trunk if the partial pressure of water vapor is more than 4.6 gPa.

During March and April, 2007 our estimates were examined experimentally. Using data of absolute humidity, the temperature of air heating was regulated in response to equations (3). In a number of cases the temperature had decreased up to permissible minimum (+2°C). The icing of air trunk was not observed during the experiment.

The experiment at the main heater and ventilator plant VOKD-1.8 has allowed to save till 45000 KWt only during the examined period without the threat icing of the air trunk. This fact shows in the best way the prospects of regulation of the power consumption of heat calorifers depending on the operative meteorological conditions.

Conclusions

Meteorological conditions of the strong icing of underground excavation of the “Rasvumchorr” mine were studied. Meteorological conditions of this process were defined experimentally. The ice forming in the air trunk and some section of underground excavation begins, when the moisture content in the atmospheric air decreases below the critical value. In that case the walls of the air trunk cools as expends very much heat for the water evaporation in the injected dry atmospheric air despite the fact of positive temperature (about 3-4.5°C).

Preliminary theoretical study of a problem has shown unconditional prospects of temperature regulation of air depending on not only temperature but also absolute humidity of external air. At the same time the proposed method of the ice control is more economical, than the present ones, as it allows to save the power consumption at the expense of temperature decrease during the periods with high moisture content of the atmospheric air.

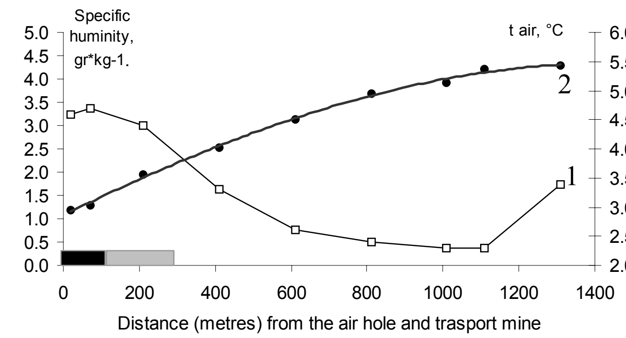

Fig 1. The distribution of air temperature and specific humidity along the air trunk and transport mine 15.01.2007 (sections with ice accumulation and ice melt marked by black and grey).

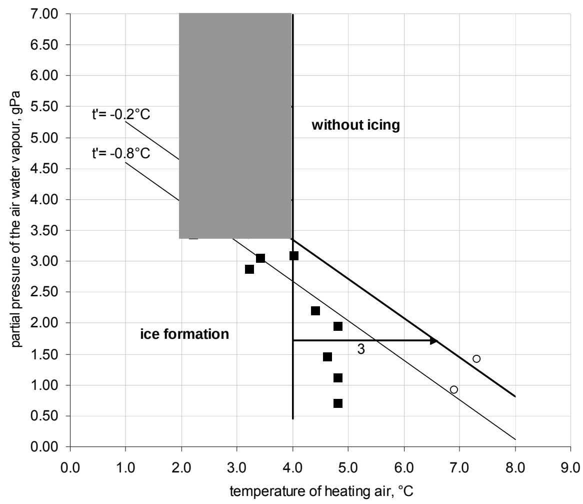

Fig 2 Areas with icing and without ones is depended on the partial pressure of water vapour in the atmospheric air and air temperature in the air trunk; the data of measurements are shown. Shaded area is area of temperature decrease below +4 °C without the threat icing

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