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Opportunities of Improving the Microclimate in Underground Mines by Heat- and Hydro-Isolation

V.Bojilov
Emeraid-VLtd., Sofia, Bulgaria

K.Petrov
Geotherm Ltd., Asenovgrad, Bulgaria

T.Staikdvski
Minstroi, Madan, Bulgaria

ABSTRACT: This paper shows the results of large-scale testing of the heat-isolation of mine opening walls with high rock temperature. A technology for heat- and hydro-isolation is developed on the basis of Bulgarian and foreign experience in tunnel construction for mine openings with thermal water and passing highly water bearing zones. The properties of Bulgarian heat- and hydro-isolating materials as well as the technology of their placement and fastening onto the walls of mine openings are presented. The efficiency criterion of the use of heat isolation with respect to specific heat flow in a certain mine opening with and without heat isolation is shown. The values of the coefficient of non-stationary heat exchange are determined depending on the thickness of the heat-isolating layer and time for ventilation of the mine openings. The experience gained through these research activities can be applied successfully to other mines with similar conditions.

I INTRODUCTION

Recent investigation and experience from industry show that a reduction of thermal flow can be achieved in mines with ambient rock temperatures of more than 40-45° C by means of thermal isolation of the walls of mine openings. The efficiency of the applied thermal isolation is increased with the increase in temperature of the rock massif.

There are many examples of thermal isolation of mine openings in specialized literature (Voropaev, 1979, Shterban et. al., 1977, Baratov & Chemiaki, 1968, Voloshtuk et. al., 1975, Voloshruk & Andreev, 1972, Avksentiev & Skuba, 1984, Kara et al., 1975, Krasovitskii et al., 1977, Field, 1963, Psota, 1959). Investigations of suitable thermal-isolating materials have been directed towards froth polyurethane. A number of researchers consider that solid froth polyurethane has a broad potential to be used in mining. This is confirmed by different experimental works carried out in the United Sates and the Republic of South Africa on froth polyurethane covers (Baratov & Cherniak, 1968, Field, 1963, Niproruda, 1969).

In spite of the results achieved, however, the results presented in tie literature on the reduction of thermal flow do not provide a quantitative estimation of mass exchange, even though it is an important element of the thermal regime. Moisture isolation of the walls of mine openings and* the reduction of relative moisture content in mines with an overheating climate deserve special importance. Deciding topics in this direction contributes to the significant reduction of total refrigerating capacity as part of it used for the condensing of water vapors at a high relative moisture content (95-98%) varies within the range of 60 to 70 % or even more.

In Bulgaria, the topic of functions of froth polyurethane as thermal-isolation cover İs especially relevant in relation to the development of the Erma Reka ore region, known for its unique geothermal conditions and particularly complicated mining and thermal-hydrogeological conditions. The mining of ore bodies of temperatures between 0 and 95° takes place there. Considering that most of the ore bodies are hosted in porous-quartz zone with accumulated mermal water, topics of predicted complicated heat- and mass exchange are of major importance for implementation of the project for excavation of the ore reserves. In this respect, particular attention is given to opportunities for heat isolation of mining openings as a means of dealing with high temperatures in mines in parallel to efficient heat ventilation and cooling of the air with cold-producing machines.

2 DETERMINING THE EFFICIENCY OF HEAT-ISOLATING COVER

Continuing investigations in this direction for estimating the efficiency of heat-isolation, we considered the main heat-technical characteristics of the mine heat exchange.

For calculating the heat transfer coefficient, we used the following more important dependencies (Shterban et. al., 1977, Baratov & Cherniak, 1968, Donbas, 1979):

In the case of no isolation,

$$\alpha = 2.67\frac{\varepsilon(\rho v_a)^{0.8}}{R_0^{0.2}}, W/(m^2.K) \tag{1}$$

where:

e is the coefficient of relative roughness, depending on the support of the mine opening;

p - density of the air, Kg/m^3,

v_a - speed of the air, m/s,

Rd - equivalent radius of the mine opening, m.

The reduced coefficient of heat transmission o^ is used instead of a in cases of evaporation from the walls of the mine opening. The dependence is:

$$\alpha_{re} = \alpha + \beta\frac{(p_{wall} - p_a)}{\theta_{wall} - t_a} r \tag{2}$$

where, P is the coefficient of mass exchange, kg/(s.m".Pa);

Pwaiii Pa " 'he partial pressures of water vapour for temperatures of opening walls and the air in them, respectively, Pa;

0 *ai], t_a - temperatures in opening walls and the air in them, °C;

r - specific heat of vapour formation, J/kg; r = 2500 J/kg.

In the case of the existence of isolation,

$$\alpha_{is} = \frac{1}{\frac{1}{\alpha} + \frac{\delta}{\lambda_{is}}}, W/(m^2.K) \tag{3}$$

where:

XJS - coefficient of heat transmission of the heat-isolating material, W/(m.K);

8 - thickness of the heat isolation layer, m.

The characteristic K^ is the criterion for efficiency of the heat isolation cover - ratio of specific heat flow from the rock massif towards the air in a certain opening without isolation q_0 and flow in the presence of isolation qois, i.e.,

$$K_{ef} = \frac{q_0}{q_{0is}} \approx \frac{K_\tau}{K_{\tau is}} \tag{4}$$

where specific heat flow without isolation is

$$q_0 = K_\tau (t_0 - t_a) \tag{5}$$

and in the case of heat isolation,

$$q_{0is} = K_{\tau is}(t_0 - t_a) \tag{6}$$

t_0 - ambient rock temperature, °K;

ta - temperature of the air in the opening, °K.

Here, K_t and $K_{T|S}$ are the coefficients of non-stationary heat exchange W(m^2.k), calculated respectively for values of the coefficient of heat transmission without isolation ede and with isolation a,s between the air and walls of the mine openings (Shterban et. al,, 1977).

Calculations are carried out for a thickness of the heat isolation layer of 8 = 0.05m and initial ambient rock temperature of the Erma Reka mine t_{rm} = 348°K and cross-section of the openings S = 9.0 m^2.

Results for Kef are shown in Table 1.

Table 1. Results for K_{ef}.

Time for ventilation-	Specific heat flow at a speed of the ventilation stream V=0.5 m/s			Specific heat flow at a speed of the ventilation stream V=1.0 m/s		
τ, h	Non-isolated surface q_0, (W/m^2.K)	Isolated surface q_0,(W/m^2.K)	K_{ef}	Non-isolated surface q_0, (W/m^2 K)	Isolated surface q_0, (W/m^2.K)	K_{ef}
8	207 7	13.6	15 05	276.8	13.8	20.05
16	197.5	13.5	14.63	232.8	13.7	17.0
32	155.0	13.3	11,65	131.2	13.5	14,16
100	116.0	13.0	8.90	138.4	13.0	10.6
400	79.0	12.4	6.30	88.0	12 5	7.04
1000	64.0	12 2	5.24	68.2	12.3	5.54

Analysis of the results in Table 1 shows that q_0 of a non-isolated surface is significantly influenced by the time for ventilation of the opening, while an isolated surface q_{0ls} maintains almost constant values depending on T.

- the effect of heat-isolating cover can give the highest values for a minimum time of ventilation T;

- the specific heat flow for a heat-isolated surface is slightly affected by the speed of ventilation İn a certain opening.

Data for change of the coefficient of heat transmission a,$_{S)}$ depending on the reduced coefficient of heat transmission Ore and the characteristic for perfection of the isolation S/A« (m^2.K)W, are presented in Table 2. Their analysis shows:

- at one and the same value of ctre with the increase of 07Xi$_s$ values of Otis sharply decrease, from 3.4 to 4.5 times;
- the change of a,$_s$ in dependence on ctre at one and the same value of *b/hs* is not significant and reduces to insignificance with the increase of 8/AH$_s$; when S/Xis is equal to 3.3 then a,s has approximately equal values. Therefore, the interval from 2.7 to 3.3, where cc« is lower, is interesting for practical needs.

Table 2. Change of the coefficient of heat transmission a,$_s$ and the characteristics for perfection of the isolation 5/k,$_s$.

Coefficient of heat transmission a„ W/(m^2.K)	Coefficient of heat transmission for heat-isolated walls of the openings a $_s$ W7(m'· K)							
	Fora characteristic of perfection of heat isolation							
	0.67	1.0	1.3	1.7	2.0	2.3	2.7	3.3
2	0.85	0.67	0.56	0.45	0.4	0.36	0.31	0.26
3	1.0	0.75	0.62	0.49	0.43	0.38	0.33	0.27
4	1.08	0.8	0.65	0.51	0.44	0.39	0.34	0.28
5	1.15	0.86	0.67	0.53	0.45	0.40	0.34	0.28
6	1.20	0.88	0.68	0.54	0.46	0.41	0.35	0.29
8	1.27	0.89	0,70	0.55	0.47	0.41	0.35	0.29
10	1.29	0.90	0.7 İ	0.55	0.47	0.42	0.37	0.29
15	1.36	0.94	0.73	0.56	0.48	0.42	0.36	0.30
20	1.38	0.95	0.74	0.57	0.487	0.42	0.36	0.30
25	1.40	0.96	0 74	0.57	0.49	0.43	0.36	0.30
30	1.42	0.96	0.75	0.57	0.49	0.43	0.36	0.30
40	1.43	0.97	0.75	0.57	0.49	0.43	0.37	0.30

Table 3. Required thickness of heat-isolaiing layer for different values of the coefficient of heat transfer A„.

Coefficient of heat transmission for isolation A$_{is}$,W/(m.K).	Thickness of isolation S						
	Forecharacteristic of perfection of isolation S/Â„ ,(m^2.K)/W						
	1.0	1.3	1.7	2.0	2.3	2.7	3.3
0.03	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.05	0.05	0.06	0.08	0.10	0.11	0.13	0.16
0.08	0.08	0.10	0.13	0.16	0.18	0.22	0.26
0.10	0.10	0.13	0.17	0.20	0.23	0.27	0.33
0.15	0.15	0.19	0.25	0.30	0.34	0.40	0.49
0.20	0.20	0.26	0.34	0.40	0.46	0.54	0.66
0.25	0.25	0.32	0.42	0.50	0.57	0.67	0.82
0.30	0.30	0.39	0.5!	0.60	0.69	0.81	0.99
0.35	0.35	0.45	0.59	0.70	0.80	0.94	1.15
0.40	0.40	0.52	0.68	0.80	0.92	1.08	1.32

The data shown İn Table 3 allow the selection of the required thickness of the heat-isolating layer for different values of the coefficient of heat transfer *Xj*$_s$ and coefficient of perfection S/X«. They show that İn the case of the characteristic of perfection 5/A$_s$ = 3.3, achieved for material with XH$_s$ = 0.03 W(m.K), a layer of thickness of only 0.09 m is necessary, while for material of $X\backslash_s$ more than 0.30 W/(m.K), it has to be more than 1.0 m, which is obviously not rational from a technical and economic point of view.

In the case of high rock temperatures, within the boundaries of 70-80°C, like temperatures in the area of Erma Reka, the characteristic S/A« must be selected near to 3.0, which means that the heat transmission coefficient should not have a coefficient of heat transmission X_s of more than 0.1 W/(m.K).

In respect of the determination of the reduced coefficient of heat transmission ov, it should be mentioned that only experimental measurements can be used for obtaining precise values İn a radier wide interval of $6<a_{rc}<30$, given in Voropaev (1979) and Shterban et. al. (1977). This İs extremely important for the slope of mine openings.

3 RESULTS OF EXPERIMENTAL INVESTIGATIONS

Experimental investigations with polyurethane Elastopor H-206, corresponding to the requirements of class B-2 of DIN A 102/1984, were carried out in the Erma Reka area for small-scale drying of a horizontal opening at a level of 300m.

The same has a coefficient of heat transmission of $X = 0.03$W(m°K) and density of $p = 60$ kg/m^3 (Niproruda, 1984). A polyurethane cover with thickness of about *0.05* m was injected by means of a small-dimension machine of the GRACO type with high pressure of the mixing chamber. In the case of an initial rock temperature of 46.4^{O}C, with the temperature of the non-isolated wall of 41°C and air in the opening of 30.4°C, a decrease in the temperature of the isolated wall of 7°C was achieved (to 34°C). Then, borehole chamber No. 2003 of area 500 m^2 in the same section was thermally isolated. Il was established that for an initial temperature of 60^{D}C and thickness of the polyurethane layer of 0.05 m, the specific heat flow from the massif was reduced 5 rimes. As a result, drilling works became possible.

In this case, the efficiency of isolation was assessed in the alternation of local heat flow from die walls of the rooms towards the air in diem. Meanwhile, İt is important to consider mat the main obstacle to good adhesion of polyurethane during its distribution is moisture covering the non-isolated surface as a condensing agent or water film. With the aim of overcoming such difficulties, investigations are continuing in the search for a solution for hydro- and heat- isolation on die walls of mine openings, as the coefficient of non-stationary heat-exchange for moisture-containing and wet rocks is about 15-20 W/m.^{c}K.

A technology for heat- and hydro-isolation was successfully developed and tested on the basis of Bulgarian and foreign experience in the use of rolls of materials for hydro-isolation of underground workings. Materials like polyvinyl chloride (PVC) folio and geotextile were used for trial drying of a part of the 300-m level in Erma Reka mine mentioned in the section above. It basically consists of fastening to the walls and roof of the opening a canvas of "sandwich"-type elements of PVC and geotextile, prepared in advance. The polyvinyl chloride folio "Plastifol A" is manufactured in Bulgaria especially for the needs of tunnel construction. It presents a mixture of suspended polyvinyl chloride with appropriate additions such as plastifiers, stabilizers, anti-aging agents, etc. Its main technical data are: thickness of 1.4 mm; width of 1300 and 2000 m; tensile strength of 18-20 Mpa; and a relative elongation of 260-300 %.

The geotextile, called geo-filts, type TX 0685-75, is produced in Bulgaria and is also designed for tunnel construction. In this case, it mainly performs the functions of a heat-isolating layer, and so it has to be more porous. Synmetic fibers (in mis case polyester Fibers) are used for its production. The basic data of the geotextile are: thickness, 608 mm: width, 2000 mm; tensile strength, 50-90 MPa; and relative elongation, 80 %.

Preparation of the canvas is carried out beforehand on the surface according to the following method. A layer of PVC folio is laid on a horizontal surface, and a layer of geotextile is put on top of it; on top of this is put another layer of PVC folio. The ends of the folio are adhered by an apparatus for hot air to open fields with a width of 50 mm. Afterwards, diese are used for attaching and fastening to the massif. The width of the separate canvases is 1300 or 2000 mm, and tiieir length is equal to the perimeter of the opening (without the floor) plus 500mm for putting down on the draining system. The coefficient of heat transmission of the "sandwich" element is $X = 0.058$ W/mK.

The results of the experimental application of the materials described show that a good heat-isolating effect is achieved. On the one hand, this is due to the thermophysical properties of the geotextile, and on me other hand, it is due to layers of air between the separate canvases and between the canvases as a whole and the walls of the mine openings.

Different supporting structures were developed for respective methods of support. A very important condition is me reliable support of openings that will be subjected to isolation inasmuch as monitoring the roof condition after isolation is impossible.

4 CONCLUSIONS

Heat isolation of the walls of mine openings is of double importance for the heat regime. Convection flow, on the one hand, is reduced through it, and on the other hand, thermal radiation; the wall temperature is reduced, which İs very important for the determination of normative values of temperature of the mine air. Underestimation of the radiation heat exchange, which is shown in me case of high rock temperature (high watl temperatures), leads to significant errors in the dimensioning of the ventilation-conditioning system. Furthermore, for cases of wall temperatures higher than 60°C, there are no regulated standard temperatures for air, and working operations in the presence of people are not allowed. This is why investigating the opportunities for application of special additional measures for normalizing the mine microclimate, for example, heat isolation and hydro-isolation, is of huge importance.

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