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POSSIBILITIES FOR IMPROVEMENT OF CLIMATIC CONDITIONS IN SINGLE ENTRY DRIVAGES WITH HIGH ROCK TEMPERATURE

YÜKSEK KAYA SICAKLIĞINDA TEK GALERİLİ GİRİŞLERDE İKLİMLENDİRME KOŞULLARININ İYİLEŞTİRME OLASILIKLARI

Veliko KERTIKOV, *University of Mining and Geology, Sofia, Bulgaria*
Dejan MIRAKOVSKI, *Faculty of Mining and Geology, Stip, Macedonia*

ABSTRACT

Methodology for evaluation of distinct parameter influence over climatic conditions in dead-end headings is presented. Essence of this methodology is expressed through the optional calculations of design parameters of an auxiliary ventilation system (AVS), prediction of air temperature in dead end headings and overall analysis of results obtained. Also information about software developed for those kinds of calculations is given. Methodology is illustrated with numerical examples.

ÖZET

Bu çalışmada, tek girişli galeri annlarındaki iklim koşullarını etkileyen belirli parametrelerin değerlendirilmesi için bir metodoloji sunulmuştur. Bu metodolojinin gerekliliği, yardımcı havalandırma sisteminin (AVS) taraşım parametrelerinin opsiyonel hesaplanmasıyla, galeri arınındaki hava sıcaklığının tahmini ve elde edilen sonuçlann tüm analizleri ile açıklanmıştır. Aynca, bu çeşit hesaplamalar için geliştirilen bilgisayar yazılımı hakkında bilgi verilmiştir. Metodoloji sayısal örneklerle gösterilmiştir.

1. INTRODUCTION

Basic parameters which characterized climatic condition in dead-end headings are: air temperature (t) and relative humidity ((p), airflow velocity (v) and temperature of rock surface of heading (8_W).

Consequently to their impact on the human body, climatic conditions can be comfort, heating and cooling.

In terms of climatic comfort, heat equilibrium between human body and the environment is achieved without exerting any of heat regulation mechanism of the human body. Work in terms of climatic comfort is harmless, safe and efficient. Values of parameters mentioned above (t, cp, v and 9_W) which provide climatic comfort depends on the kind of work done. For example, as work becomes harder airflow velocity should be increased, and temperature and relative humidity of the air must be reduced.

In practice, values of this parameters can be obtained by mean of simple statistical questioning of workers and measuring of certain physiological parameters (skin temperature, body temperature, breathing air quantity, heart beating frequency, quantity of perspiration etc.), which will give us objective appraisal of human body condition.
Achieving of comfortable working conditions in mines with hard climatic conditions is difficult and expensive task. Generally, in those of mines work is done in harder conditions. A compromise is done through the introducing of **acceptable climatic conditions.**

Parameters of acceptable climatic conditions are defined on the base of complex theoretical and experimental researching. Methodological base of this research is solving of heat balance equation of human body in terms of heat equilibrium.

As mines get deeper, rock temperature increasing, which cause deterioration of climatic conditions in the workings. The problem is more expressed in case of single-entry developments because of constant exposure of virgin rocks and technical difficulties for ventilation of headings with greater air quantities.

The paper discusses possibilities for improvement of climatic conditions in dead-end headings without using refrigeration (air-conditioning) methods. There is no doubt that those techniques of artificial cooling of workings atmosphere are related with great financial expenses and they should be use only when all other means of climatization are depleted.

2. PARAMETERS WHICH INFLUENCE CLIMATIC CONDITIONS IN DEAD-END HEADINGS

Temperature and relative humidity in the airflow varied due to following ongoing processes:

- non-stationary heat-exchange between the rock mass and the airflow;
- evaporation or condensation followed with heat consumption or release;
- change of airflow potential in case of vertical movement of air, which result with increase or decrease in temperature;
- heat transfer by radiation between the rock walls and airflow in the heading;
- heat emission from local or linear sources;
- heat emission from oxidation processes.

Based on theoretical analysis of processes mentioned above, it can be said that temperature and relative humidity of the airflow in the heading are directly influenced by the following parameters:

- virgin rock temperature (9);
- physical characteristics of the rock massive (heat transfer coefficient [k], specific heat [C_{rock}], density [p
  rock -i />
- geometrical parameters of headings (length, L and cross section F);
- time for ventilation of heading (x);
- moisture content of rock walls in the heading;
- temperature and relative humidity of fresh (intake) air;
- angle of heading slope;
- power of local and linear heat sources (F_{ls});
- intensity of oxidation process relative to unit area of the heading.

Evaluation of influence from distinct impacts on the environment can be done through the folio wings:

- modeling in laboratory conditions;
- modeling in real terms (in real mine conditions);
- analytically (by mean of calculations and predictions).

The easiest way to do this evaluation certainly is by means of calculations and predictions, and detailed discussion about this methodology follow. Methodology, generally is contained from two basic steps:

- performing of calculations for prediction of temperature and humidity of the airflow for different values of parameter evaluated;
- evaluating of predicted values for different values of the parameter.

As example, if we evaluate influence of airflow rate, really possible values for flow rate are given, and for this values air flow temperature is predicted.
These calculations are possible by using the appropriate computer programs.

3. METHODOLOGY AND SOFTWARE DEVELOPMENT FOR PREDICTION OF AIR TEMPERATURE IN DEAD-END HEADINGS

Methods and computer software are developed for prediction of air temperature in headings (Kertikov, 1997). Method is based on two differential equations for heat balance of airflow through the drivage and for reverse airflow through the duct. By solving of these two equations, formulas for prediction of airflow temperature and humidity are obtained.

Methodological and program solutions are separately conducted for forcing and exhausting ventilation schemes, and two computer programs are developed **TempFoVS** and **TempExVS.**

The effect of leaking ducts can be considered in the calculations by dividing the heading into short sections, and predicting the air temperatures consecutively, section by section, from the face to the entrance of the heading.
In the case of a forcing ventilation (Figure 1) the following input data is presented: the temperature at point 1 (t,), the air flow rate at point 3 (Q_3), the time for ventilation of the heading in section 3-5 (T_{35}), the heating of the air At_{35}, the relative humidity at point 5 (φ_5 , %) and the relative humidity rise in the direction 5-6 ($A(p_{J6}$, %/m).

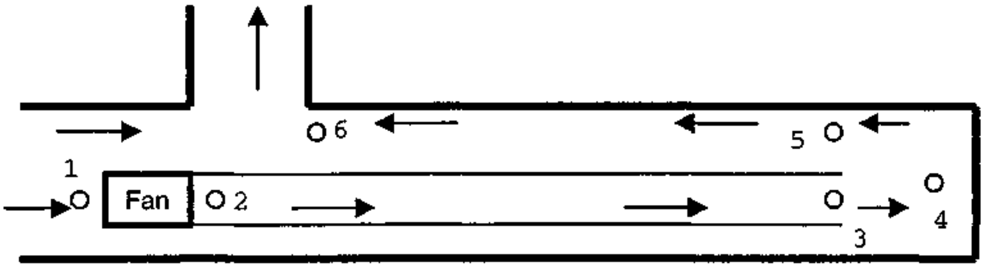


Figure 1. Forcing ventilation

The following conditions are included in the algorithms of the programs:

1. The heading is divided into short sections of length AL, which is usually equal to the length of a duct unit.
2. Air leaks from the duct into the heading (in the case of forcing ventilation) or air is sucked in from the heading into the duct (in the case of exhausting ventilation). Leakage quantity AQ is calculated separately for each section.
3. The temperature, moisture content and relative humidity are calculated after mixing of the leakage flow (AQ) with the main flow in the heading (in the case of forcing ventilation) or in the duct (in the case of exhausting ventilation).
4. The average time for ventilation of any particular section is calculated depending on the rate of face advance (V_f).
5. The values Q, K_t, K_t and the pressure loss in the duct P [Pa] are calculated for each section, starting at the face and moving towards the entrance of the heading, where K. is a coefficient of non-stationary heat transfer, (Scherban, Kremnev,

1977), W/(m^{2o}c) and K, is heat transfer coefficient through the wall of the duct, W/(m^2.°C). The last values of Q and P determine the fan operating point (Q_f , P_{fan})-

6. The temperature, moisture content and relative humidity are calculated for the beginning and the end of each section.

4. NUMERICAL EXAMPLES AND DISCUSSION

For a given long drivage, auxiliary ventilation system is designed. Forcing ventilation scheme and metal ducts are used. Basic informations about the drivage are given in Table. 1.

In Table 1 and Table 2, the following symbols are used:
(p, = relative humidity at point 1 ;
p_{at1} = atmospheric pressure at point 1 ;
p_{at5}= atmospheric pressure at point 5;
D = equivalent diameter of the heading;
hrwa = radiative heat transfer coefficient between the rock surface of the heading and the air flow;
h_{rd} = radiative heat transfer coefficient between the rock surface of the heading and the duct;

Table 1. Basic input data for the sample calculations

No	Parameter	Dimension	Value	No	Parameter	Dimension	Value
1	k	W/(m.°C)	3,1	13	h_{nva}	W/(m^{2o}C)	1,6
2	Proc	kg/m^3	2700	14	$h_{rw.}$	W/(m^{2o}C)	5,7
3	c	J/(kg.°C)	865	15	h_{rat}	W/(m^{2o}C)	1,1
4	L	m	300	16	h_m	W/(m^{2o}C)	2
5	$<P_5$	%	80	17	*35	sec	200000
6	$Aq>_{56}$	%/m	0,01	18	v,	m/month	120
7	9,	%	70	19	k,	W/(m.°C)	60
8	ti	°C	25	20	kdf	N s^2 / m^4	0,003
9	At_{35}	°C	1	21	$F_{,s}$	W/m	0,1
10	Pa,,	Pa	100000	22	CT	°C/m	0
11	P_{al5}	Pa	100000	23	e_5	°C	50
12	D	m	4	24	AL	m	5

h_{rat} = the radiative heat transfer coefficient between the heading air flow and the outer wall of the ventilation duct;
h_m = heat transfer coefficient depending on the intensity of moisture evaporation (Scherban, 1997);
b_t - thickness of the duct;
k_t = thermal conductivity coefficient of the duct;
k_{df} = duct friction factor;
o = geothermal gradient along the heading axis;
0_5 = virgin rock temperature at the point 5;
At_{35} = the rise in the air temperature at the face of the heading (route 3-4-5, see Figure 1);
d_t = duct diameter;
Q_3 = ventilation flow rate at point 3;
h_{lm} and k_{ms} are the thickness and the thermal conductivity of the duct insulation respectively, m;
Rn = resistance of leakage paths;
Tf = fan efficiency;
$T|_{em}$ = motor efficiency;
^ *fan* = heating of the air through the fan;
P_{fan} = static pressure of the fan;
X = actual moisture content of flow;
T| = coefficient of efficiency, which characterized the air leakage of the duct (7] = $Q_l IQ_2$) .

The values of h^,, h^t and h_{rat} have been tabulated in a previous work of the author [unpublished] and depend on: expected arithmetic mean temperatures of both radiating rock surface and air flow; relative humidity; diameters of both heading and ventilation duct.

Evaluation of distinct parameters influence can be done after performing of calculations with various values of the parameter evaluated. We will evaluate following parameters influence on the air flow temperature:

- air flow rate with respect to the duct diameter and fan type;
- thermal insulation of the duct;
- moisture evaporation;
- assembling quality of the duct.

4.1 Air flow rate influence

Airflow rate depends from duct diameter d_t and fan type used (VM-6m and VM-8m). From the aspect of the duct diameter, 5 different alternatives are analyzed. Parameters of auxiliary ventilation system (AVS) for all (5) alternatives (variant's) are given in the Table 2.

Values of Q3, Rn and Tjf are obtained by use of computer software for designing and performance evaluation of AVS (Mirakovski and Kertikov, 1999), with 20% air losses accepted (80 % efficiency).

Table 2. Input data for calculations

Para-meter	Dimen-sion	Fan type BM-6m / Alternatives				Fan BM-8m
		1	2	3	4	Alternative 5
		d_t=0.5	d_t=0.6	d_t=0.7	d,=0.8	d_t=0.8
Q_3	m^3/s	3,6	5,0	6,0	6,7	10,0
b,	m	0,0015	0,0015	0,002	0,002	0,002
b .»	m	-	-	-	0 and 0.01	-
^ins	W/(m.°C)	-	-	-	0,05	-
Tl	-	0,80	0,80	0,80	0,80	0,80
R_{fl}	$N.s^2/m^8$	5500000	2000000	1000000	500000	500000
'Hr	-	0,70	0,75	0,60	0,55	0,65
Tlem	-	0,90	0,90	0,90	0,90	0,90

Airflow temperature is predicted by use of **TempFoVS** software. Results obtained for all alternatives are given in the Table 3 and Figures 2 and 3.
From the results calculated (shown in Table 3 and Figures 2 and 3) it can be see that when duct diameter is increased, for alternatives 1,2,3, and 4, then:

- lower air flow heating from the fan (At_{fb},) as a result of lower fan pressure and
- lower air flow heating on the way 1-2-3-4-5-6 (see Figure 1) as a result of increase airflow quantity, are obtained.

Table 3. Results from prediction of airflow temperature for all alternatives

Para-meter	Dimen-sion	Fan type BM-6m / Alternatives				Fan BM-8m
		1	2	3	4	Alternative 5
		d_t=0.5m	d,= 0.6m	d_t=0.7m	d_t=0.8m	d_t=0.8
t,	°C	25	25	25	25	25
At_{fan}	°C	3,89	2,85	2,37	1,67	3,12
t_2	°C	28,89	27,85	27,37	26,67	28,12
t_3	°C	31,39	29,80	29,15	28,43	29,12
ts	°C	32,39	30,80	30,15	29,43	30,12
t_6	°C	34,28	32,38	31,54	30,73	30,81
$<P_5$	%	80	80	80	80	80
$<P_6$	%	78,9	79,1	79,4	79,8	78,8
X_5	g/m^3	24,66	22,48	21,64	20,74	21,59
X_6	g/m^3	27,11	24,36	23,30	22,31	22,15
Q_3	m^3/s	3,6	5	6	6,7	10
Qfan	m^3/s	4,5	6,3	7,5	8,4	12,5
"fan	Pa	2927	2291	1514	971	2163

Comparison of results obtained for the alternatives 4 and 5 (see Figure 3) show as that use of bigger funs (VM-8m instead of VM-6m), beside bigger airflow rate didn't mean better climatic conditions at the heading. Main reason for this is larger airflow heating from the fan (Δt_{fan} =3.12 °C) as a result of large fan pressure (P_{fan}= 2136 Pa) and low fan efficiency $(r\backslash_f = 0.55)$.

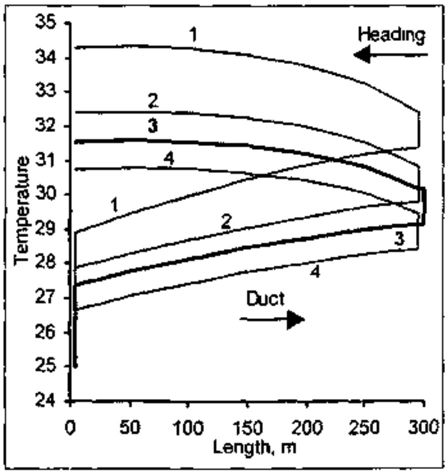


Figure 2. Temperature curves for alternatives 1, 2, 3 and 4

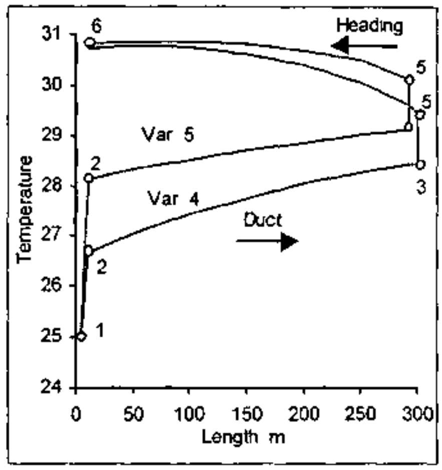


Figure 3. Temperature curves for alternatives 4 and 5

4.2. Thermal insulation of the duct

When thermal insulation of the duct is used, as in case of Alternative 4 (thickness of thermal insulation is $b,_{ns}$ = 0.01 m) good climatic conditions are achieved (see Figure 4). Financial effect from use of thermal insulation should be considered.

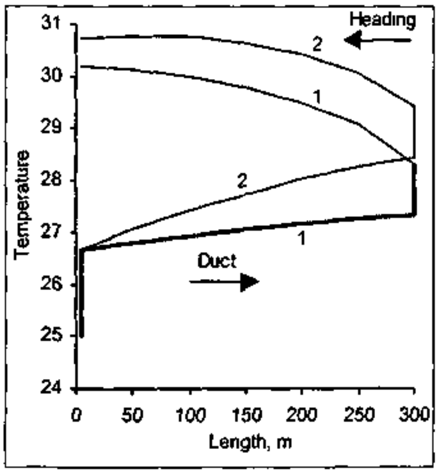


Figure 4. Temperature curves:
1 - with insulation
2 - without insulation

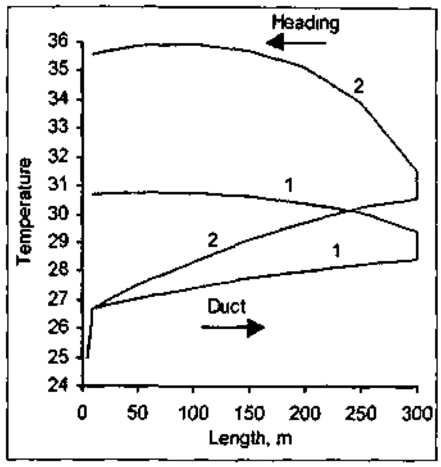


Figure 5. Temperature curves:
1 - by "wet" heat exchange
2 - by "dry" heat exchange

4.3. Moisture evaporation

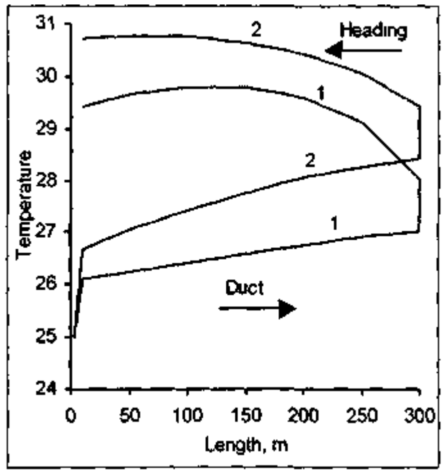
Temperature lines shown on Figure 5 for parameters of AVS as in case of Alternative 4, illustrated the difference between air flow heating in terms of hypothetical "dry" heat transfer (heat transfer without moisture on rock walls) compared to the real conditions in mine workings where complex process of heat transfer and moisture evaporation exist.

4.4. Assembling quality of the duct

Results obtained for Alternative 4 (see Table 2 and Table.3) are compared with results obtained for new alternative, which only differ with lower assembling quality of the duct. For new alternative T| = 0.45 is accepted. For parameters of AVS with lower assembling quality of the duct following results are obtained: R,,= 42000 $N.s^2/m^8$, Q_3 = 4,3 *m'/s*, 0^=8,7 *m'/s* and $P_{ya,,}$=643Pa.

Results from temperature prediction for both alternatives are illustrated on Figure 6. Opposite to the accepted opinion, in case of bigger air losses better climatic conditions are achieved. Explanation for this is following:

a) lower fan pressure (Pf_{an} = 643 Pa) which result with lower heating from the fan ($A/_{Jta}$= 1,11 °C);
b) high air flow rate leaking through the joints has a smaller temperature then airflow through the drivage and reduce it's heating



1 – by η = 0,45
2 – by η = 0,80

Figure 6. Temperature curves:

CONCLUSION

By evaluation of influencing factors on air temperature in some underground mine workings, as we shown before through the example calculations and cost effectiveness analyses, the most appropnate means for improvement of climatic conditions in those working can be chosen.

REFERENCES

Kertikov V. (1994). *Studying the Influence of Some Factors on the Ventilation Flow Temperature in Vertical Shafts.* 16* World Mining Congress, Sofia, 1994, Book 4, pp. 95-102.

Kertikov V. (1997). *Air Temperature and Humidity in Dead-End Headings with Auxiliary Ventilation.* Proceedings of 6th International Mine Ventilation Congress, Pittsburgh.,1997, Chapter 42, pp. 269-275.

Mirakovski D, and Kertikov V. (1999). *Design and Performance Evaluation of Auxiliary Ventilation Systems.* 16th Mining Congress of Turkey, Ankara, 1999, pp. 225-230.

Scherban A., Kremnev O. and Juravlenko V. (1977). *Rukavodstvo po regulirovaniju teplovogo rezima shaht.* Nedra, Moskva, p. 360