DEFINITION OF THE CLIMATIC CONDITIONS FOR OPERATION OF METAL MINES AS A FUNCTION OF MINING DEPTH – ON THE EXAMPLE OF COPPER MINE BOR

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Abstract

With the aim of definition of climatic conditions of miners' work, depending on the depth at which mining operation is carried out, it is necessary to define their entalpies, if the problem is solved on the basis of entalpies of input air and air taken out of the mine.

Because of this, the paper presents results of investigations of thermal characteristics of rock massif of underground pit Bor, as well as investigations of all relevant parameters required for forecasting of thermal regime and possible mining depth, without application of some of the procedures for decreasing the quantity of separated heat or air cooling.

First, after the abstract, data are presented on climatic conditions of town Bor environment and data on air temperatures recorded in areas of mine drifts. Later, data are presented on thermal characteristics of ore and surrounding rocks, which must be checked in the following period, i.e. to determine their more reliable values, so that at the end of that chapter, based on currently valid regulations, a graphical presentation is presented of entalpy changes of the air in accordance with prescribed temperature, humidity and air velocities.

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With the aim of definition of climatic conditions of operation, depending on mining depth, as already mentioned, we must know entalpy difference $\Delta i = i_2 - i_1$ at $t_2$ in $^\circ$C which is defined in mining regulations. By this relation entalpy $i_2$ is defined. However, the problem is to define corresponding values of entalpy $i_1$: $i_1 = 1.005t + (1.86t + 2500)x$, $\text{kJ/kg}$, since it depends on climatic conditions of mine location, annual season, mining depth, applied machinery, mining method adopted, thermal and physical characteristics of ore and surrounding rock, quantity of air introduced into the mine, spacing of mining areas, existence of oxidation processes and in our case the number of separately ventilated areas and others.

Starting from the basic equation of thermal balance of mining areas, and based on entalpy differences $\Delta i$, the value of maximal possible mining depth has been determined at which prescribed value $t_2$ of the air at mining site is not exceeded. For this purpose, methodology of B.I. Medvedev[1] has been used, defined for stratigraphic deposits with wide open face mining methods as well as other literature from this area [2-8] etc. adapted also for the purpose of forecasting of possible mining depth for metal mines.

For air temperature increase in separate ventilation of mining areas, methodology of E.I. Baranov and V.P. Cernjakov [3] has been used for calculation.

Keywords: operating conditions, entalpy, air temperature, mining, mining depth, climate, thermal characteristics

1. Introduction

Climatic conditions of working environment in underground mining are defined by the following number of factors: barometric pressure, humidity, temperature and chemical contamination of air. These factors are dependent on the structure of production system of the mine, depth at which mining operation is carried out, thermal and physical properties of ore and surrounding rock, locality of the mine and its climate, applied mining equipment, intensity of mining etc.

This has caused regulating bodies in many countries, as well as in our country, to regulate by law these problems in order to protect miners’ health and induce mining companies to pay due attention to this question. Accordingly, for a longer period, measuring has been carried out and collecting of required parameters as well as investigations, which are meritory for forecasting operating conditions in ore mining at larger depths.
In underground pit in Bor, the largest impact on air temperature has the applied diesel underground equipment [9] and number of separately ventilated mining areas. We can see from the following examples, that rock temperature in mining areas in coal and metal mines and depth at which these areas are located are significant [9]:

Let \( t_{st} = 50^\circ C, \ t_o = 0^\circ C; \ \alpha = 200W/(m^2.\circ C); \ D = 6.0m; \ c_p = 10^3 J/(kg.\circ C); \ G = 500kg/s; \ l = 120 \text{ m}, \) where are:

- \( T_{st} - \) temperature of mining area walls in °C;
- \( t_o - \) starting air temperature in °C;
- \( \alpha - \) coefficient of heat transfer in \( W/(m^2.\circ C)\);
- \( c_p - \) specific air heat in \( J/kg\);
- \( D - \) area diameter in m;
- \( G - \) air flow in kg/s;
- \( l - \) area length in m.

Air temperature at the end of the area shall be:

\[
t = t_{st} - \left( t_{st} - t_o \right) e^{-\frac{\alpha \pi D}{c_p G}} = 50 \left( 1 - \exp(-7.5 \cdot 10^{-3} l) \right) = 30^\circ C
\]

so that heat quantity transferred to air shall be \( q = 500 \cdot 10^3 \cdot 30 = 15 \cdot 10^6 J/s. \) For the same values \( t_o, \ c_p \) and \( G \) at the shaft depth of 1000m, temperature obtained shall be \( \frac{dt}{dH} = 0.0098 \cdot 1000 = 10^0C, \) i.e. quantity of heat formed by compression, transferred to the air \( q = 5 \cdot 10^6 J/s. \)

Heat of modern, powerfull mining equipment for loading and transport of ore is frequently a dominant heat source and it may amount to tenths of mega Wats (depending on the number of diesel engines in operation) and these machines are arranged unevenly in particular mining sites, within the underground production system.

If mining is done with methods of backfilling of mined areas, then also significant quantities of heat are separated, since the temperature of backfilling material in hardening phase ranges from 20 - 50°C and this corresponds to separation of backfilling material heat even up to \( 42 \cdot 10^6 J/t, \) depending on its volume.

Based on these statements, legally regulated value of temperature \( t_2 \) in °C in mining sites can be endangered, not only depending on the depth but also on other very significant factors, which we have reduced to the name of the mining depth function.
2. Climatic characteristics

With the aim of monitoring climatic conditions of Bor area, in 1966 on the mountain Crni Vrh near Bor, Hydrometeorologic Association of Belgrade, has constructed a monitoring station at the elevation of k 820 m, and then in Bor at the elevation of k 382 m a local monitoring station.

Average monthly values (table 1) of air temperature $t$ (°C), barometric pressure $B$ (mbar) and relative air humidity $\varphi$ (%), are presented for the area of town Bor and presented absolute values are calculated values.

Periodic temperature oscillation can be presented by the expression:

$$t_i = 10 - 11.7 \cos \frac{2\pi i}{8760}, \text{°C}$$

where $t_i$ is the time since the beginning of the wave $h$ (as the starting temperature, the average temperature of month January is taken).

<table>
<thead>
<tr>
<th>Parameter/ month</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>XI</th>
<th>XII</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t$, °C</td>
<td>-1.7</td>
<td>0.3</td>
<td>4.3</td>
<td>10.4</td>
<td>15.5</td>
<td>18.5</td>
<td>20.5</td>
<td>20.2</td>
<td>16.3</td>
<td>10.4</td>
<td>4.6</td>
<td>0.7</td>
</tr>
<tr>
<td>$B$, mbar</td>
<td>978.1</td>
<td>977.0</td>
<td>977.7</td>
<td>974.0</td>
<td>973.1</td>
<td>972.8</td>
<td>975.1</td>
<td>975.1</td>
<td>978.3</td>
<td>980.2</td>
<td>978.6</td>
<td>978.6</td>
</tr>
<tr>
<td>$\varphi$, %</td>
<td>80.0</td>
<td>77.3</td>
<td>75.0</td>
<td>65.2</td>
<td>67.9</td>
<td>68.0</td>
<td>64.0</td>
<td>64.3</td>
<td>66.8</td>
<td>75.1</td>
<td>81.9</td>
<td>81.9</td>
</tr>
<tr>
<td>$x$, g/kg</td>
<td>2.67</td>
<td>3.09</td>
<td>3.99</td>
<td>5.29</td>
<td>7.74</td>
<td>9.40</td>
<td>10.0</td>
<td>9.86</td>
<td>7.97</td>
<td>6.15</td>
<td>4.46</td>
<td>3.36</td>
</tr>
</tbody>
</table>

Values of air and water temperatures according to the drifts is presented in the table 2.

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Level (m)</th>
<th>Air temperature (°C)</th>
<th>Water temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VII</td>
<td>160</td>
<td>14.2 15.3 18.0</td>
<td>14.5 14.9 15.2</td>
</tr>
<tr>
<td>IX</td>
<td>110</td>
<td>17.9 21.8 23.5</td>
<td>15.0 21.3 33.7</td>
</tr>
<tr>
<td>XI</td>
<td>42</td>
<td>17.5 19.8 24.8</td>
<td>17.0 19.5 24.0</td>
</tr>
<tr>
<td>XIII</td>
<td>18</td>
<td>19.5 22.0 25.1</td>
<td>18.0 20.5 22.6</td>
</tr>
<tr>
<td>XV</td>
<td>-78</td>
<td>21.0 21.8 24.2</td>
<td>20.0 21.7 25.6</td>
</tr>
</tbody>
</table>

Table 2. Air and water temperatures.
Temperatures of air and water increase with depth, and their variation at the same level are caused, apart from others, by the following; the age of the mining area, intensity of oxidation of sulphide minerals, type of mechanical equipment in operation etc. So far the largest impact has shown the spacing between mining areas from open pit slopes (in which the ore is mined and backfilling process of mined out volume has already started using waste from the other open pit) and insufficiently filled mining area towards it.

3. Thermal characteristics of deposits and legal regulations

In the period from 1981 up to 1985 in exploration drilling thermal coring investigations have been carried out with the aim of determination of intensity and distribution of temperature fields along the drill-hole profiles with special attention paid to maximal temperatures which may be expected in the vicinity of ore bodies. Based on measured data, coefficients of linear and non-linear regression have been calculated of temperature change with depth, i.e. the following equations are obtained:

Table 3. Coefficients of linear and non-linear regression for temperature change with depth

<table>
<thead>
<tr>
<th>Drill-hole</th>
<th>Linear regression</th>
<th>Non-linear regression</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-19</td>
<td>( t = 13.543 + 0.02697 \cdot H )</td>
<td>( t = 10.665 H^{0.1348} )</td>
</tr>
<tr>
<td>B-28</td>
<td>( t = 9.353 + 0.03483 \cdot H )</td>
<td>( t = 5.482 H^{0.2074} )</td>
</tr>
<tr>
<td>B-33</td>
<td>( t = 13.459 + 0.02548 \cdot H )</td>
<td>( t = 5.377 H^{0.2306} )</td>
</tr>
<tr>
<td>B-39</td>
<td>( t = 13.220 + 0.02072 \cdot H )</td>
<td>( t = 2.1753 H^{0.3897} )</td>
</tr>
</tbody>
</table>

where are \( H \) depth in m and \( t \) temperature in °C.
Applying these equations of forecasting of temperature with depth, on the actual planned mining level K-795m (depth about 1200 m), we would obtain, based on data according to drill-holes, the following temperatures:

Linear regression
B-19/ 45.9°C; B-28/ 51.15°C; B-33/ 44.03°C; B-39/38.08°C and B-45/ 39.54°C

Non-linear regression
B-19/ 27.73°C; B-28/ 23.85°C; B-33/31.78°C and B-45 / 34.47°C

Deviations of values of rock temperatures with the increase of depth are very significant between drill-holes in both regressions and clearly show that, before bringing any conclusions, it is necessary to obtain much more information than provided so far about changes of rock temperatures with depth.

Mining of ore from larger depths (1000m and more), apart from other problems (rock carrying capacity, possibility of rock bursts etc.) shall be carried out in unfavourable climatic conditions at the mining site which requires definition of mining depth (at the given construction of production system of the mine) to which it is possible to carry out mining operation without artificial cooling of air.

For this purpose, based on already performed measuring (although not sufficient) for copper deposit in Bor, for orientational purposes, the following values are adopted for thermal parameters:

- geo-thermal gradient $\sigma = 0.031^\circ$C/m (geo-thermal degree $G_s = 32.2$ m$^\circ$/C);
- temperature of neutral layer $t_{ns} = 11.5^\circ$C;
- depth of neutral layer $h_{ns} = 26$ m;
- thermal conductivity $\lambda = 0.25$ W/(m°C) for shafts;
- thermal conductivity $\lambda = 02.5$ W/(m°C) for haulage shafts;
- ore volume weight $\rho = 2780$ kg/m$^3$;
- specific thermal capacity $c = 858$ J/(kg°C);
- temperature conductivity $a = \lambda/c\rho$, m²/s;
  - $a = 0.104 \cdot 10^{-6}$ m²/s - for shafts;
  - $a = 0.104 \cdot 10^{-5}$ m²/s - for drifts and cuts.
Process of backfilling of mined out area of former open pit, which is underway, shall affect oppositely the air temperature in underground pit, from the processes in the existence of short connections with the open pit area, i.e. rocks in pit slopes as well as the air in underground pit areas excavated in pit slopes shall heat up.

3.1. Legal regulations

Regulations on technical norms, or more precisely, its article 242 (Official gazette No. 24/1991 ) prescribes possible air temperatures in °C, depending on its velocity and relative humidity.

Fig. 2 presents air enthalpy values for prescribed $t$, and $v$. Based on data from table 1 for month July, we can calculate enthalpy of fresh air for underground pit - $i_j = 46.0 \text{ kJ/kg}$. Air in the mining area has a relative humidity of about 90% so that from the schematic diagram presented in Fig.2 we can read out $i_2 = 73.4 \text{ kJ/kg}$. Entalpy differences $i_2 - i_j = 27.4 \text{ kJ/kg}$ is the heat content which is available for ventilation.

![Diagram of air distribution](image)

Fig. 1. Linear schematics of air distribution.
Fig. 2. Air enthalpy values for prescribed $t$, and $v$.

4. Program description

In selection of parameters of mining areas which are being modelled, construction side of the model is not taken into the account, since the aim of modelling is simplification of thermal calculation.

One starts from the basic equation of thermal balance of mining area

$$\frac{k_i U_i}{G_i} \left( t_{str} - \frac{t_2 + t_1}{2} \right) + \frac{\Sigma Q}{G} = i_2 - i_1$$

(1)

Here the average ore(rock) temperatures about mining area is;

$$t_{str} = t_{ns} \pm \frac{\sigma l}{2} \sin \psi$$

(2)

Respecting the formulae;

$$l_{mi} = \frac{k_i U_i L_i}{G_i}$$

(3)
\[ l_{uk} = \sum_{i}^{n} l_{mi} \]  
\[ q_{mi} = \frac{\sum Q_{uk}}{G} \]  
\[ q_{uk} = \sum_{i}^{n} q_{mi} \]  
\[ t_{sstr} = \frac{\sum_{i}^{n} t_{sstr} l_{mi}}{l_{uk}} \]

one can write

\[ \sum_{i}^{n} l_{mi} t_{sstr} \frac{t_{1} + t_{2}}{2} l_{uk} + \sum q = i_{2} - i_{1} \]

where: \( L_{i} \) - length of underground pit area, m; \( l_{mi} \) - length of modelled area, W/(m\(^{2} \)°C) for \( k = 1 \) W/m\(^{2} \)°C); \( U_{m} \) - 1 m and \( G = 1 \) kg/s; \( U_{i} \) - circumference of the area, m; \( Q_{uk} \) - total heat quantity from absolute sources formed by air compression., J/kg.

For our conditions, basic equation for determination of mine depth to which air cooling is not required, is:

\[ \sum_{i}^{n} l_{mi} t_{sstr} - 2,25 l_{uk} + \sum q = 27400 J/kg \]

Since in thermal calculation of air temperature in shafts at the depth of 900 m, heat exchange between the air and shaft walls can be neglected, and adopt only heat generated from absolute heat sources (air compression) air entalpy change may be determined from:

\[ \Delta_{i} = 9.81 H \]

where \( H \) is shaft depth in m.
4.1. Simplified formula for air temperature calculation for modelled underground pit areas, for conditions of ore-body “Borska Reka”

Formula of A.N.Scebran and O.A. Kremenjev [1], after its transformation due to replacement of area chain by the model, obtains the pattern

\[
\begin{align*}
  t_2 &= -\frac{1}{2l} \left( n + \frac{c_p}{r \varphi_2} \right) + \\
  &+ \sqrt{\frac{1}{4l} \left( n + \frac{c_p}{r \varphi_2} \right)^2 - \frac{m}{l} + \frac{m + nt_1 + lt_1^2}{l} \varphi_1 + \frac{c_p}{l r \varphi_2} \left[ t_1 + \frac{t_{sts} - t_1}{l_{uk}} + \frac{q_{uk}}{c_p} \right]}
\end{align*}
\]  

(11)

where \( c_p = 1013 \approx 1000 \) - specific heat content of air at constant pressure, J/(kg°C); \( r \) - latent heat (\( r = 2490\text{J/}gr = 2490 \times 10^3\text{J/kg} \)); \( \varphi_1, \varphi_2 \) - relative air humidity at the beginning and end of area, parts of units; \( l_{uk} \) - total conditional length of modelled areas, J/(kg°C); \( t_{sts} \) average measured temperature of rock mass in the chain of modelled areas, °C; \( q_{uk} \) - summary heat separation from oxidation processes, local sources and air compression, J/kg; \( l, n, m \) - constants (for temperature range from 2 to 30°C \( l = 0.0186, n = 0.169, m = 3.872 \)).

In formula (11) un-known values are \( \varphi_1, \varphi_2 \) and \( t_{1,2} \). Relative humidity \( (\varphi_1) \) and air temperature \( (t_j) \) at entry point to the shaft is determined by measuring, and shaft depth \( H \) is the known value. Air temperature at the end of mining area is calculated with the known relative humidity, which is calculated by a particular mathematic law or determined by experience \( (\varphi_2 = L) \). In this manner a significantly simplified formula is obtained:

\[
\begin{align*}
  t_2 &= -1.83 + \sqrt{127 + A + B + \frac{H_{ok}}{3.35}} 
\end{align*}
\]  

(12)

Values for parameters \( A \) and \( B \) may be calculated from

\[
\begin{align*}
  A &= \frac{\varphi_1(m + nt + lt^2)}{rl} \quad \text{and} \quad B = \frac{tc_p}{\varphi_2 rl}
\end{align*}
\]  

(13)
for month July, when the value of average annual temperature $t=20.5^\circ\text{C}$, $A = 690.0$ and $B = 520.0$. According to the same principle values of parameters $A$ and $B$ may be calculated for other months and presented in tabular form.

Equation (12), by introduction of values of parameters $A$ and $B$ for the month with the highest temperature (VII), may be reduced to the form:

$$t = -18.3 + \sqrt{1347 + \frac{H_{ok}}{3.35}}$$

(14)

Obtained equation can be simplified for conditions of underground pit

$$t = -18.3 + \sqrt{1347} \left(1 + \frac{H_{ok}}{3.35 \cdot 1347}\right)$$

(15)

Since the parameter $H_{ok}/(3.35 \cdot 1347)$ is significantly smaller than unity, we have:

$$\sqrt{1347} \left(1 + \frac{H_{ok}}{3.35 \cdot 1347}\right) \approx \sqrt{1347} \left(1 + \frac{H_{ok}}{2 \cdot 3.35 \cdot 1347}\right) = 36.7 + 0.00407H_{ok}$$

so that with respect to (14), we have

$$t = 18.4 + 0.00407H_{ok}$$

(16)

In accordance with (16) the average air temperature at the end of mining areas chain, from the shaft to the area of return of ventilation flow behind the mining face shall be

$$t_{sr} = \frac{18.4 + 0.407H_{ok} + 26}{2} = 22.2 + 0.002H_{ok}$$

(17)

If we take into the account (10) and (17) equation (8) may be presented in the form

$$\sum l_{mi} t_{stsi} - (22.2 + 0.002H_{ok}) l_{uk} + \sum q = 27400 - 9.81H_{ok}$$

(18)
in which the average rock temperature along the mining area is determined according to the formula:

\[ t_{sr} = t_{ns} + \sigma\left(H_{ok} + \sum \Delta h_{sri} - h_{ns}\right) \]  

Equation (17) and (18) should be adjusted to the conditions of opening the mine by vertical, inclined and horizontal area.

5. Depth to which air cooling is not required

Equations (18) and (19) are adjusted to the conditions of opening the mine schematically shown in Fig.3 so that they read:

\[ \sum l_{mi} t_{sri} - 22.2 - 0.002(H_{ok} + L\sin \psi) + \sum q = \]
\[ = 27400 - 9.81(H_{ok} + L\sin \psi) \]

\[ t_{sri} = t_{ns} + \sigma\left(H_{ok} - L\sin \psi\right) + \sum \Delta h_{sri} - h_{ns} \]  

We denote \( H_{ok} + L\sin \psi = H \) and in (20) we replace the value of \( t_{st} t_{sri} \) so that we obtain:

\[ H = \frac{27400 - (t_{ns} - \sigma h_{ns} - 22.2) l_{uk} - \sigma \sum \Delta h_{sri} l_{mi} - \sum q}{(\sigma - 0.002) l_{uk} + 9.81} \]  

Since \( L\sin \) represent vertical addition to shaft length, depth to which air cooling is not required is following:

\[ H_{max} = \frac{27400 - (t_{ns} - \sigma h_{ns} - 22.2) l_{uk} - \sigma \sum \Delta h_{sri} l_{mi} - \sum q + L\sin \psi}{(\sigma - 0.002) l_{uk} + 9.81} \]  

Now, we have \( l_{uk} \) - actual conditional length of modelled area from shaft collecting station to the area of return ventilation flow, behind the mining faces, \( J/(kg\cdot{^\circ}C) \);
\[ \Sigma q = qu_k \] - specific separated heat from absolute heat sources in the chain, J/kg;

\[ L\sin \psi \] downslope cut depth, m;

\[ h_{sri} \] depth of middle mining area from the level of shaft collecting station.

Fig. 3. The conditions of the mine opening.

From point 8 according to Fig.4 to the area of return ventilation flow, we have four area chains \((8-9', 8-9-9', 8-9-10-10', 8-9-10-A)\) and accordingly four possible mining depths according to the formula (23), out of which neither is representative for complete underground pit (Table 3), with the total of conditional lengths \(\Sigma l_{mi} = 139.2 \, \text{j}(\text{kg}^\circ\text{C})\). In order to obtain one value for the possible mining depth to which artificial air cooling is not required we combine all areas (Fig. 1) at the same level into one, by summing all areas into one area \(F = 72.0\,\text{m}^2\) of total circumference \(73.5\,\text{m}\), through which total quantity of air is passed \(52.0\,\text{m}^3/\text{s} \ (62.92 \,\text{kg/s})\) and total heat separated in the amount of \(554750.0\,\text{W}, \text{i.e. } 554750/69.2 = 8816.9 \,\text{J/kg}\).
For such combined area, calculated conditional length is $\Sigma l_{mi} = 59.40 \text{ J(kg°C)}$.

Finally, we can determine the depth to which air cooling is not required (23)

$$H_{\text{max}} = \frac{27400 - (11.5 - 0.031 \cdot 21 - 22.2) \cdot 125.34}{(0.031 - 0.002) \cdot 125.34 + 9.81} - \frac{0.031 \cdot 40 \cdot 45.6 + 19405}{(0.031 - 0.002) \cdot 125.34 + 9.81} + 80 = 776$$

If we separate from canonic schematics (Fig. 4) separately ventilated area in branch 10-A we shall obtain

$$H_{\text{max}} = \frac{27400 - (115 - 0.031 \cdot 21 - 22.2) \cdot 112.33}{(0.031 - 0.002) \cdot 112.33 + 9.81} - \frac{0.031 \cdot 40 \cdot 45.6 + 117720}{(0.031 - 0.002) \cdot 112.33 + 9.81} + 80 = 914$$

Fig. 4. Canonic schematics.
Table 3. Mining area characteristics.

<table>
<thead>
<tr>
<th>Mining area</th>
<th>Air flow Q</th>
<th>Area of mining area F</th>
<th>Circumference of mining area L</th>
<th>Length of mining area V</th>
<th>Air veloc. V m/s</th>
<th>Coefficient of heat transfer α W/(m²°C)</th>
<th>Coefficient of non-stationary temperature exchange Kc W/(m²°C)</th>
<th>Conditi-onal length of modelled area Lₙₑ W/(kg°C)</th>
<th>Separated heat Σq₁ W</th>
<th>Air quantity G₁ kg/s</th>
<th>Separated heat q₃ W</th>
<th>Conditi-onal length of summ. mining area Lₙₑ W/(kg°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>8-9</td>
<td>(40)</td>
<td>12.0</td>
<td>12.25</td>
<td>24.0</td>
<td>3.33</td>
<td>9.913</td>
<td>0.615</td>
<td>3.74</td>
<td>2088.0</td>
<td>(48.40)</td>
<td>33.18</td>
<td>1.60</td>
</tr>
<tr>
<td>8-9'</td>
<td>12.0</td>
<td>12.0</td>
<td>12.25</td>
<td>8.0</td>
<td>1.00</td>
<td>3.508</td>
<td>0.641</td>
<td>43.26</td>
<td>180615.0</td>
<td>14.52</td>
<td>2870.55</td>
<td>18.46</td>
</tr>
<tr>
<td>9-9'</td>
<td>12.0</td>
<td>12.0</td>
<td>12.25</td>
<td>8.0</td>
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<td>12.25</td>
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<td>6.911</td>
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<td>62.92</td>
<td>8816.90</td>
<td>59.4</td>
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</table>

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If we separate from the same schematics separately ventilated area in branch 7-8 we shall obtain

\[ H_{\text{max}} = 1112.0 \text{ m.} \]

With the aim of pointing out influences of particular parameters in equation (23) on mining depth to which separate air cooling is not required, the numerator is given the pattern \( H_{\text{max}} = 27400 + 11.451 l_{uk} - 0.0155 \Delta h l_{mi} - \Sigma q \). If variable parameters (Fig.5) are assigned increasing values, we may conclude that the influence of separated heat from absolute sources on \( H_{\text{max}} \) is the largest, while influence of other parameters is almost negligible.

![Graph](image)

**Fig. 5.** *Plots of \( H_{\text{max}} \) vs. \( L_{uk} \Delta h \).*

6. Results and discussion

Metodology [1] of thermal calculation of modelled mining areas may be applied not only in mines with stratigraphic but also with non-strati-
graphic deposits, with certain modifications conditioned by characteristics of underground production processes, which is proved by this paper.

Absolute heat sources, shown by a steep straight line, which, by the increase of abscissa, increases the value on ordinate, mainly represent in thermal sense in mining process the applied machinery, while other sources, represented by a line which on ordinate has a very mild slope, and represents a contribution of relative heat sources.

Large contribution in the increase of straight line on 'y' axis have absolute heat sources produced mainly by diesel underground pit machinery and fans for separate ventilation as well as by the number of mining sites with separate ventilation in underground pit production system.

From the given data it may be seen that by excluding the area with separate ventilation in branch 10-A, Fig.4, maximal mining depth is increased for 148 m and by excluding one additional area, for additional 228 m, i.e. mining level depth is increased from 776 m to 1112 m and this level represents almost the final depth of ore body, so that the problem of decreasing the air temperature, i.e. mining depth in this case ceases to exist.

Endangering the prescribed value of air temperature may be expected primarily in separately ventilated mining sites. If as a solution on these sites artificial air cooling is applied, in this manner it shall be possible to influence the lowering of total level of mining.

7. Summary conclusions

The approach to definition of climatic operating conditions as a function of mining depth, in the exposed manner, makes easier and more simple thermal calculations for mines with non-stratigraphic layers. Reliability of obtained results is conditioned by the accuracy of parameters input into the calculation and application of computers with corresponding programs shortens the time required for this job.

It is desirable for this problem that formulated programs for computers are fitted with the imitation modelling [10] into one logical model.
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