Characterization of Rock Temperature Changeability in the Halemba Coal Mine Deposit (the Upper Silesian Coal Basin)

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Abstract
The main geological element influencing the temperature changeability within the Halemba Mine area is Klodnica fault, which divides this area into two parts with different rock temperatures. The area lies to the north of the fault (the upthrow) and is characterized by a higher temperature than in the area located to the south (the downthrow). The same trend is shown in the case of geothermal gradient and geothermal heat flow. The reason for the higher rock temperatures in the upthrow of the Klodnica fault might be the occurrence of many smaller accompanying faults which could cause the better transport of radiogenic heat from the deeper parts of the rock mass towards the surface and in consequence make the rock temperature higher in the area of Halemba I. The rock temperature rises in the north-east direction. The distribution of temperature in the area of the Halemba Mine is an element of a regional trend, not only the local changeability.

1. Introduction

Rock temperature is one of the important parameters of rock mass physical properties resulting in both temperature mining hazards and possibilities of geothermal energy utilization.

The Halemba Coal Mine is located in the central part of the Upper Silesian Coal Basin (the USCB) within the Main Saddle in the zone of the Klodnica fault. This fault divides this mine area into two parts: the north part (Halemba I) in the upthrow of the fault and the south part (Halemba II) in the downthrow of the fault. The Klodnica dislocation of NW-SE direction is one of the largest dislocations in the USCB of the throw of about 280-480 m. There are many smaller faults accompanying the Klodnica fault of NNW-SSW direction.
Geological structures in the studied area contain the Saddle, Ruda and Załęże Beds which consist of sandstones, mudstones and claystones with coal seams belonging to the coal-bearing Carboniferous system. The Carboniferous is covered by Triassic limestones and Miocene clays of about 200 m thickness, especially in the south part of the area (the downthrow of the Klodnica fault).

The Halemba Mine is one of the deepest coal mines in the USCB. The coal is exploited at a depth of 1000 m.

The aim of this paper is to investigate rock temperature changeability in the area of the Halemba Mine and to present the natural factors influencing rock temperature distribution in the studied area.

The question of rock temperature changeability and the influence of geological factors on it within the USCB was presented by Karwasiecka (1996, 2002), Plewa and Plewa (1992) and Bulawa et al. (1995). In these publications, it is widely assumed that the large dislocations such as Klodnica, Bzie-Czechowice and others affect the geothermic field and the isotherms are parallel to the direction of these dislocations. That is why the influence of tectonics and other geological factors on rock temperature is a problem worth studying in the case of small areas. The Halemba Mine, which is characterized by the occurrence of Klodnica fault and temperature measurements at a considerable depth around 1000 m, seems to be a good example.

2. Method

In order to investigate rock temperature changeability in the area of the Halemba Mine, the data obtained from rock temperature measurements were used. The temperature was measured in surface bore-holes using a maximum thermometer 120 hours after the end of drilling and in underground mine excavations using a TC-150 digital thermometer. The temperature measurements in the bore-holes were carried out pointwise in three horizons: 525 m, 830 m and 1050 m, similar to the measurements done in mine excavations on three working floors given above. The measurements of temperature were carried out regularly in the mine in order to define the temperature mining hazards occurring on working floors. The measurements were done by mine workers who made it possible to realise this work (Janik and Kuś 1994, 1996).

On the grounds of rock temperature data taken from the bore-holes, the values of geothermal gradient as well as the values of geothermal heat flow were calculated. The heat flow density \([W/m^2]\) was calculated using the following formula:

\[ q = -\lambda \text{grad} T, \]

where \(\lambda\) is the thermal conductivity, and \(T\) is the geothermal gradient.

The geothermal heat flow density was calculated separately for both areas of the Halemba Mine (Halemba I and Halemba II) because of the different geological structure and different types of rocks, which are characterized themselves by various heat flow values. In the area of Halemba I, Triassic and Miocene formations do not occur and the formation of the Carboniferous lies just under the Quaternary, whereas in the area of Halemba II the overburden consists of Triassic, Miocene and Quaternary for-
mations. The geothermal gradient is different in the two areas; in Halemba I it amounts to 3.44 °C/100 m and in Halemba II – 2.83 °C/100 m. In order to calculate the geothermal heat flow density, the following values of heat flow were adopted (Plewa and Plewa 1992, Karwasiecka 2001):

- For the Quaternary: 2.2 W/m °C
- For the Miocene: 1.9 W/m °C
- For the Triassic: 2.2 W/m °C
- For the Carboniferous: 2.1 W/m °C

The heat flow density values given above with each rock stratum thickness and their percentage share are shown Table 1.

<table>
<thead>
<tr>
<th>Formations</th>
<th>λ</th>
<th>Halemba I</th>
<th>Halemba II</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>λaverage thickness [m]</td>
<td>%</td>
<td>average thickness [m]</td>
<td>%</td>
</tr>
<tr>
<td>Quaternary</td>
<td>2.2</td>
<td>88</td>
<td>8</td>
<td>74</td>
</tr>
<tr>
<td>Miocene</td>
<td>1.9</td>
<td>lack</td>
<td>--</td>
<td>208</td>
</tr>
<tr>
<td>Triassic</td>
<td>2.2</td>
<td>lack</td>
<td>--</td>
<td>53</td>
</tr>
<tr>
<td>Carboniferous</td>
<td>2.1</td>
<td>1033</td>
<td>92</td>
<td>1393</td>
</tr>
<tr>
<td>above 1000 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The percentage thickness was used in order to calculate a weighted average of thermal conductivity. The average value of thermal conductivity for the Halemba I area amounts to 2.1 W/m °C and for the Halemba II area to 2.1 W/m °C too. Using the obtained data, the heat flow density was calculated for both areas:

- Halemba I
  \[ q_I = 2.1 \times 0.03437 = 0.07218 \text{ W/m}^2 = 72.18 \text{ mW/m}^2 \]
- Halemba II
  \[ q_{II} = 2.1 \times 0.0283 = 0.05943 \text{ W/m}^2 = 59.43 \text{ mW/m}^2 \]

3. Results and Discussion

The surface bore-holes

On the grounds of the results obtained from the surface bore-holes, the graphs of vertical temperature changeability were drawn (Fig. 1). In all the analysed bore-holes the rock temperature rose with the increase in depth. Based on the temperature graphs, the geothermal gradient was calculated for the bore-holes. The highest value of geothermal gradient in the area under study, 4.50 °C/100 m, was noted in bore-hole
Halemba 88, in the south part of Halemba I area, whereas the lowest value, 2.5 °C/100 m, occurred in Panewniki 16. This bore-hole is located in the south part of the area of Halemba II.

Table 2 shows the temperatures measured in the bore-holes at three levels (525, 830 and 1050 m) and the geothermal gradient for each bore-hole. Some bore-holes, such as Panewniki 9, Mikołów 1, Mikołów 2 and Mikołów 3 are situated outside the area of the Halemba Mine.

Bore-holes Halemba 87 and 88 are characterized by the highest rock temperatures at all investigated levels (Table 2) and they are located in the area of Halemba I (central and south part). The lowest rock temperatures were noted in the Panewniki 19 bore-hole located in the south part of the Halemba II area.

In the area of Halemba I, to the north of Klodnica fault, the rock temperatures are generally higher than in Halemba II, to the south of Klodnica fault, the temperature difference being about 5-6°C.

The geothermal gradient

The differences in geothermal gradient between the areas of Halemba I and Halemba II divided by the Klodnica fault were clearly visible. The clear change of geothermal gradient is strongly marked along this fault.
Table 2
Rock temperatures in the bore-holes in the area of Halemba Mine
(Janik and Kuś 1994)

<table>
<thead>
<tr>
<th>Bore-hole</th>
<th>Rock temperature [°C]</th>
<th>Geothermal gradient [°C/100 m]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>level 525 m</td>
<td>level 830 m</td>
</tr>
<tr>
<td>Klodnica 1</td>
<td>24.2</td>
<td>33.6</td>
</tr>
<tr>
<td>Klodnica 4</td>
<td>23</td>
<td>30.5</td>
</tr>
<tr>
<td>Klodnica 5</td>
<td>23.7</td>
<td>31</td>
</tr>
<tr>
<td>Panewniki 9</td>
<td>23</td>
<td>29.9</td>
</tr>
<tr>
<td>Panewniki 15</td>
<td>24.5</td>
<td>32.9</td>
</tr>
<tr>
<td>Panewniki 16</td>
<td>25.1</td>
<td>32</td>
</tr>
<tr>
<td>Panewniki 18</td>
<td>22.9</td>
<td>32.1</td>
</tr>
<tr>
<td>Panewniki 19</td>
<td>20.7</td>
<td>28.9</td>
</tr>
<tr>
<td>Halemba 87</td>
<td>26.8</td>
<td>36</td>
</tr>
<tr>
<td>Halemba 88</td>
<td>26.6</td>
<td>39.2</td>
</tr>
<tr>
<td>Mikołów 1</td>
<td>23</td>
<td>31.8</td>
</tr>
<tr>
<td>Mikołów 2</td>
<td>20.8</td>
<td>28.4</td>
</tr>
<tr>
<td>Mikołów 3</td>
<td>22.1</td>
<td>31.9</td>
</tr>
</tbody>
</table>

To the north of the Klodnica fault (Halemba I) the geothermal gradient is higher than to the south of this dislocation (Halemba II). This means that the rock temperature rises faster with depth in the area of Halemba I (2.8-4.5 °C/100 m), than in Halemba II (2.5-3.2 °C/100 m).

In the area of Halemba II the decrease in geothermal gradient towards the north-west direction was observed, while the minimum value was noted in the central part of this area in the vicinity of the Panewniki 15 bore-hole as well as in the north-west part near the Panewniki 16 bore-hole.

**Rock temperature at levels of 525, 830, and 1050 m in the mining excavations**

Rock temperature values at the level of 525 m are varied and fluctuate between 21°C and 32°C (Table 3). The clear temperature boundary between the areas of Halemba I and Halemba II is not visible, but in the area of Halemba I the temperature of rock is slightly higher than in the area of Halemba II (Table 3). There are two positive and one negative geothermal anomalies in the area of Halemba I, while in the whole area of Halemba I and Halemba II the rock temperature generally rises from west to east.

At the level of 830 m the boundary of rock temperature between the areas of Halemba I and Halemba II is clearer than at the level of 525 m. This boundary is al-
most compatible with the Klodnica fault direction and it is interpreted as the result of the fault presence. In the upthrow (to the north of the fault) the rock temperature is higher than in the downthrow (to the south of the fault). Similarly, at the level of 525 m the rise in temperature from west to east is noted, the rocks of the lower temperature are located close to the west boundary of the area, whereas the warmer ones appear to the east of the studied area.

The level of 1050 m is characterized by the clearest boundary of temperature, which changes along the Klodnica fault – in the downthrow, the rock temperature is much lower than in the upthrow. The maximum range in the highest temperature (48°C) and lowest one (36°C) occurring there is 13°C (Table 3). Within the areas of Halemba I and II the temperature of rocks rises from west to east just as at the levels lying above. The location of the positive and negative geothermal anomalies at this level is the same as at other levels, while the areas of the negative ones are smaller than in levels lying above.

Table 3 shows the maximum, minimum and average temperatures obtained from the three analysed levels in the area of Halemba I and II.

<table>
<thead>
<tr>
<th>Level [m]</th>
<th>Halemba I (the upthrow of the Klodnica fault)</th>
<th>Halemba II (the downthrow of the Klodnica fault)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>temperature °C</td>
<td>temperature °C</td>
</tr>
<tr>
<td></td>
<td>maximum</td>
<td>minimum</td>
</tr>
<tr>
<td>525</td>
<td>32</td>
<td>21</td>
</tr>
<tr>
<td>830</td>
<td>42</td>
<td>32</td>
</tr>
<tr>
<td>1050</td>
<td>49</td>
<td>37</td>
</tr>
</tbody>
</table>

The natural factors influencing the distribution of rock temperature in the area under investigation

The main factor affecting the rock temperature changeability in the area of the Halemba is undoubtedly the Klodnica fault, which makes a boundary between the area of much colder rocks to the south and the warmer ones to the north. Within the area of Halemba I, to the north of Klodnica fault, accompanying faults in large numbers are located which are orthogonal to the Klodnica fault. These faults could cause a better transport of radiogenic heat from the deeper parts of the rock mass towards the surface and in consequence make the rock temperature higher in the area of Halemba I (Leśniak and Leśniak 1994). The area of Halemba II is characterized by a small number of faults, and that is why the pathway of the heat transport was probably more difficult that could cause the lower rock temperatures related to the Halemba I area.
Temperature distribution in the Halemba Mine in comparison with geothermal field of the USCB

The average geothermal gradient for the area of Halemba I amounts to 3.44 °C/100 m, therefore it is approximate to the typical temperature gradient for this part of the USCB (3.4 to 4.0 °C/100 m), whereas the gradient calculated for the area of Halemba II amounts to 2.83 °C/100 m and differs widely from the regional gradient. But the local gradient distribution within the area of Halemba is conformable to the regional geothermal gradient rise presented on maps from the south to the north (Karcwasecka 1996).

The geothermal gradient values in the Halemba region is approximate to the average ones appearing in this region of the USCB; therefore, the values of the area of Halemba I are more compatible to the regional geothermal gradient than the values noted in the area of Halemba II.

The analysis of the heat flow density shows the same trend which was obtained for both areas separately. For the area of Halemba I the heat flow density value (72 mW/m²) is closer to the regional values (65-75 mW/m²) than the value in Halemba II (59 mW/m²).

The horizontal distribution of rock temperature at the three analysed levels (525, 830 and 1050 m) is consistent with the main trend of temperature rise from the south-west to the north-east. The distribution of temperature in the area of the Halemba Mine is an element of regional trend, not only the local changeability. The main reason for the observed temperature distribution in this region of the USCB is probably the Kłodnica fault, which occurs not only in the Halemba area, but it is a regional dislocation in the USCB and its influence on the geothermal field is significant.

4. Conclusions

1. The Kłodnica fault divides the Halemba Mine area into two areas of different rock temperature values; in the upthrow of this fault (the area of Halemba I), rock temperatures are higher than in the dowthrow (the area of Halemba II).

2. The trend presented above is confirmed by the analyses of temperature distribution in the bore-holes and in the mining excavations (levels of 525, 830 and 1050 m) and also by calculation of such factors as geothermal gradient and heat flow density.

3. The Kłodnica fault strongly influences the temperature distribution. In the area of Halemba I, the large number of small faults accompanying the Kłodnica fault causes a better transport of radiogenic heat from the deeper parts of the rock mass towards the surface and in consequence they increase the rock temperature.

4. The distribution of temperature in the area of the Halemba Mine is compatible to the regional trend of the temperature rise in the north-east direction; therefore, this distribution becomes a significant element of the regional trend, not only the local changeability.
References


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