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Geological conditions and problems of thermal waters exploitation in Podhale region

Geological conditions of the occurrence of thermal waters in Podhale region are characterized. Chemical composition of thermal waters in borehole Bańska IG 1 is given. Water resources and their thermal energy are evaluated; physical model of reservoir and mathematical model of expected water circulation due to exploitation of reservoir by the borehole Bańska IG 1, as well as inferences of the rational exploitation conditions on the water reservoir are discussed.

GEOLOGICAL CONDITIONS OF THERMAL WATERS OCCURRENCE IN PODHALE REGION

Between the Tatra Mountains in the south and the Pieniny Klippen Belt in the north there is an asymmetric tectonic basin (Fig. 1) filled in with Podhale flysch formations (Fig. 2). Like the Pieniny Klippen Belt this basin, convex to the north extends from Dolny Kubin in the west through Witów – Biały Dunajec – Białka – Spiska – Stara Wieś to Kamienka in the east (territory of Poland and Czechoslovakia). The basin width in its western part is about 7 km, in the middle part – Biały Dunajec river cross-section – about 15 km, and in the eastern part about 18 km.

Podhale flysch formations which fill the basin (Fig. 2) are formed mainly by shales and clays interbedded with siltstones and sandstones. 8 sandstone layers characterized by good porosity are filled, with waters of various temperatures (from about 40°C at the depth of 800 m. to 70°C at the depth of about 2000 m), most often of very small mineralization increasing with depth.

The Podhale flysch formations of maximum observed thickness of 2560 m (primary thickness was much bigger) due to prevailing amount of clay layers, constitute an impermeable cover for aquifers occurring in the Middle Eocene lime-

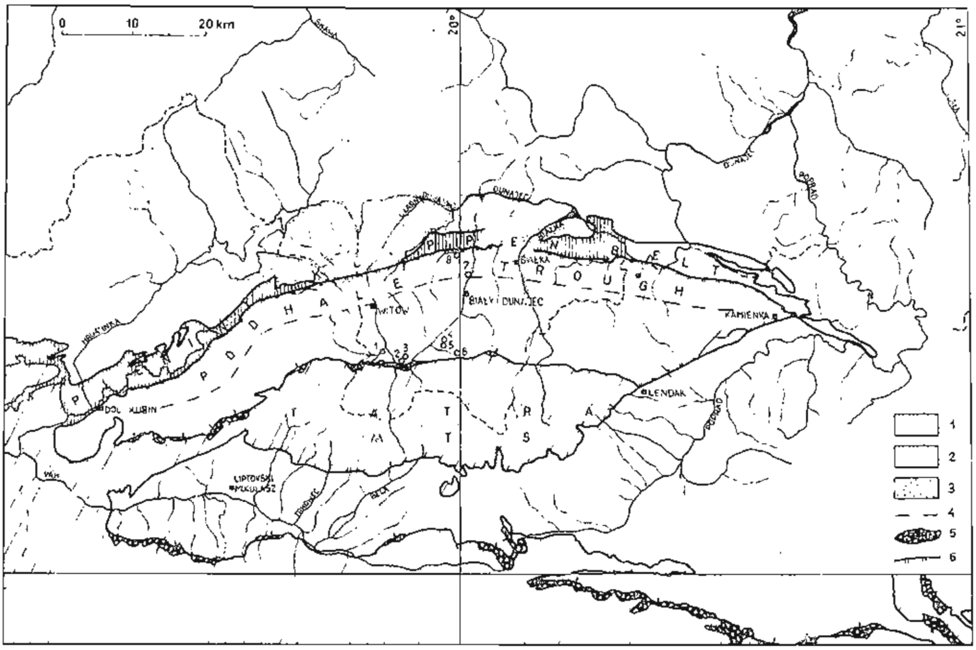

Fig. 1. Geological sketch-map of the Podhale region
Mapa geologiczna niecki podhalańskiej

1 – Cretaceous + Jurassic PKB; 2 – Tatric Mesozoic; 3 – Holocene and Pleistocene; 4 – axis of basin; 5 – outcrop of nummulitic limestone; 6 – peri- Pieniny fault; 1–8 – boreholes: 1 – Siwa Woda IG 1, 2 – Staników Żleb, 3 – Hruby Regiel, 4 – Zakopane IG 1, 5 – Zakopane 2, 6 – Jaszczurówka, 7 – Bańska IG 1, 8 – Maruszyna IG 1

1 – kreda i jura pienińskiego pasa skałkowego; 2 – mezozoik tatrzański; 3 – holocen i plejstocen; 4 – oś niecki; 5 – wychodnie wapieni numulitowych; 6 – uskok przypieniński; 1–8 – otwory wiertnicze

stone formations and for underlying dolomite and limestone formations of the High Tatric and Sub-Tatric Mesozoic units.

The Middle Eocene nummultic limestone thickness confirmed by drillings is as follows: Bańska IG 1 – 95 m; Zakopane 2 – 135 m; Zakopane IG 1 – 118 m; Siwa Woda – 135 m. The thickness of the Sub-Tatric Middle Triassic dolomites and limestones underlying the Middle Eocene nummulitic limestones is as follows: Bańska IG 1 – 635 m, Zakopane IG 1 – about 180 m.

Below the Triassic formations of the Sub-Tatric unit following beds have been found: 1 – in the borehole Bańska IG 1 green-grey marly conglomerates; anhydrites (ca 5 m); marls and limestones with Turonian and Cenomanian microfauna in the upper part and with the Lower Cretaceous and Jurassic fossils in the lower part the latter was accounted to the so-called Bańska unit of transitional features between the Pieniny and the Sub-Tatric units; 2 – in the borehole Zakopane IG 1 – Lower Jurassic formations of the Sub-Tatric unit (Fig. 2).

In the limestone-dolomite formations of the Middle Triassic in the borehole Bańska IG 1 two aquifers were tested and from both a thermal water inflow was derived. From the lower layer of the temperature of about 90°C the inflow was 1.5 m^3/h, from the upper layer of the temperature 85°C – 10.2 m^3/h. These inflows were obtained after the $6^5/_8''$ pipe perforation and reservoir tester setting.

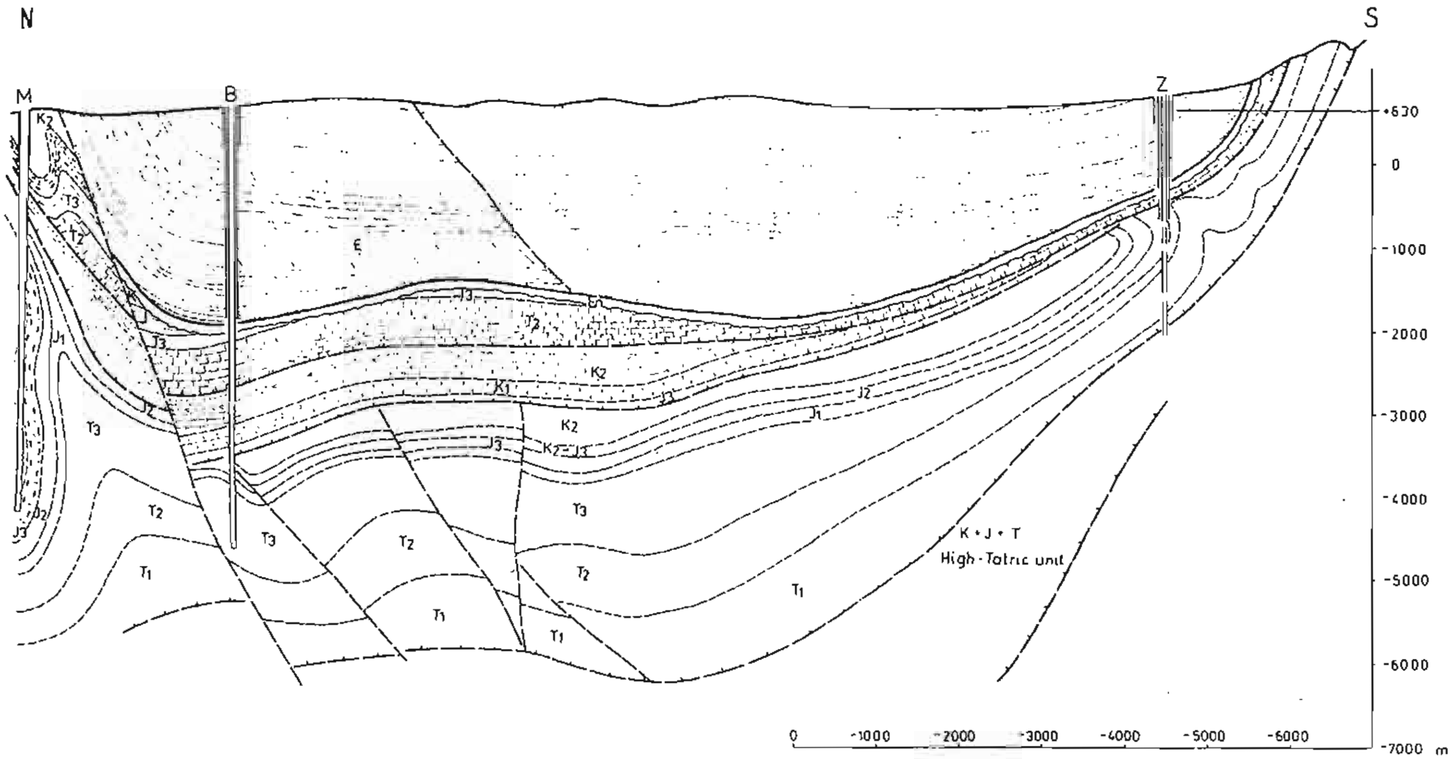

Fig. 2. Geological cross-section Maruszyna – Bańska – Zakopane (after J. Sokołowski)

Przekrój geologiczny Maruszyna – Bańska – Zakopane (według J. Sokołowskiego)

E – Eocene; En – nummulitic Eocene; K_2, K_1 – Upper and Lower Cretaceous; J_3, J_2, J_1 – Upper, Middle, Lower Jurassic; T_3, T_2, T_1 – Upper, Middle, Lower Triassic

E – eocen; En – eocen numulitowy; K_2, K_1 – górna i dolna kreda; J_3, J_2, J_1 – górna, środkowa i dolna jura; T_3, T_2, T_1 – górny, środkowy i dolny trias

It may be expected that after applying: flow intensification (hydroperforation and delamination of formation) it could be possible to obtain much higher yields from these layers.

In the borehole Zakopane IG 1 two aquifers in the Lower Jurassic of the Lower Sub-Tatric unit and in the Middle Eocene nummulitic limestones horizon have been tested. In the Lower Jurassic lower layer spontaneous flow of thermal water of the temperature ca 35°C on offtake and of capacity 50 m^3/h has been obtained; in higher layer – spontaneous flow of capacity 15.8 m^3/h; in the Middle Eocene limestones – spontaneous flow of capacity 1 m^3/h. Dolomitic Middle Triassic formations of the Upper Sub-Tatric unit, situated below the Middle Eocene limestones have not been tested.

During the drilling of the well Zakopane 1 a spontaneous flow of thermal water of the capacity 133.8–273.0 m^3/h has occurred from an interval near the boundary between the Middle Eocene limestones and underlying Middle Triassic dolomites. Further drilling has been stopped because of such a considerable water in flow. The borehole Bańska IG 1 has been encased with $6^5/_8$″ pipes up to the surface and equipped with an exploitation well-head with three outflows of the 2″ diameter. Long lasting tests of outflow after the installation of the exploitation well-head displayed the capacity of 60 m^3/h through an outlet of the 2″ diameter. The temperature in the reservoir is 82°C, at outflow it is 72°C at the capacity of 60 m^3/h.

CHEMICAL COMPOSITION OF WATERS AND CONDITIONS OF THEIR CIRCULATION

From the analysis of geological development of the Podhale region it can be inferred that a substratum of the Middle Eocene limestone formation had been the subject of erosion and denudation processes for 40 million years i.e. from the middle part of Upper Cretaceous up to the beginning of the Eocene limestone sedimentation. In the Middle and Upper Eocene and in the Oligocene there was a strong subsidence which resulted in marine accumulation of about 100 m limestones and about 3–4 km flysch sediments. At the passage from Oligocene to Miocene there began the block uplift and emergence of the Tatra Mountains and of the Pieniny Klippen Belt as well as the formation of the tectonic basins: Liptów – to the south of the Tatra Mountains and Podhale – to the north of them. As the entire Oligocene–Eocene cover of the Tatra Mountains had been eroded, there appeared in their margin the Middle Eocene nummulitic limestone outcrops and in a further distance the outcrops of various links of the Podhale flysch. At that time a process started, of the surface waters infiltration to the Eocene and Oligocene reservoir horizons and of gradual mixing of these waters with waters existing in these rocks since the sedimentation period.

Waters presently occurring in the aquifer of the Middle Eocene nummulitic limestones are therefore the mixture of the precipitate waters from before ca 50 mln years waters of the Middle Eocene sea and waters infiltrating from the surface of the Tatra Mountains during the last several millions years. Due to this infiltration and water mixing a mineralization degree of the water in the borehole Zakopane IG 1 is about ten times lower than the same degree in the borehole Bańska IG 1 about 12 km distant from the previous one.

Chemical analyses of water from the well Bańska IG 1 taken up near the end of test exploitation 26–29.VI.1981 (have proved that total contents of solid components vary from 2995–3021.9 mg/dm^3 and basic components are ions (in mg/dm^3): SO_4^{2-} (909.4 – 925.9), Cl^- (634.6 – 570.8), Na^+ (550.0 – 525.0), Ca^{2+} (240.4 – 221.2), Mg^{2+} (57.3 – 51.06), then is small amounts: Li^+ (0.4), Ba^{2+} (0.11), Sr^{2+} (6.0), Al^{3+} (1.1), F^- (4.0), Br^- (1.73), H_2SiO_3 (0.75), HBO_3 (40.5), and in minute quantities: Fe^{2+}, Mn^{2+}, Ag^+, Zn^{2+}, Cu^{2+}, Ni^{2+}, Cr^{3+}, Mo^{4+}, V^{4+} and H_2S (up to 0.09), pH of water is in the range of 6.7 – 7.8. Natural gas has also been found in the amount of about 20 ml/l. It contains 17.9% of combustible components, 43% of nitrogen, 37.7% of CO_2 and 1.25% of inert gases (He, Ar).

The complex of aquifer Middle Eocene limestones has been found (below flysch) in boreholes: Staników Żleb on the ordinate +946 m, Jaszczurówka +846 m, Hruby Regiel +540 m, Siwa Woda +297 m, Zakopane IG 1 – 135 m, Bańska IG 1 – 1930 m.

Difference of levels between the highest point of top of the Middle Eocene limestone in the well Staników Żleb and the lowest point in the borehole Bańska IG 1 is 2876 m. So the complex of the Middle Eocene limestones lying earlier horizontally or nearly horizontally was displaced upwards together with the Tatra Mountains at least at the magnitude indicated above. Podhale Basin situated between the Tatra Mountains and the Pieniny Klippen Belt is distinctly asymmetrical. Its axis occurs at a distance of only 3 km of the Pieniny Klippen Belt (Fig. 1). Alimentation of the basin with surface waters takes place only in the southern part, along the Tatra Mountains margin through small surface outcrops of nummulitic limestone formations. These limestones are cut off to the north by a big regional fault and contact clay-marly Cretaceous formations of the Pieniny Klippen Belt.

Water reservoir of the Podhale region occurring in the Middle Eocene limestones is therefore a reservoir open from one side only and on small areas. So, the feeding of this reservoir depends on the area of outcrops surface, the morphology of their surface, permeability of rocks in the subsurface zone and on amount of precipitates in a near – Sub-Tatric zone.

Temperatures of waters in this asymmetrical reservoir are much differentiated. In the zone adjoining the Tatra Mountains the width of which is about 1 – 2 km, the temperatures in the reservoir do not exceed +20°C. In the next zone, about 3 km wide, their range is from 20 – 60°C, and in the main part of the basin they are 60 – 82°C and probably more. Temperatures of waters occurring in the lower beds of Mesozoic are relatively higher.

TENTATIVE ESTIMATION OF THE ENERGY CONTAINED IN THERMAL WATERS

On the basis of comparatively scarce data an attempt has been made to evaluate the energy of the Podhale thermal waters. It concerns, the entire area of the Podhale Basin, about 50% of which lies on the territory of Poland. The Middle Eocene limestone reservoir, being of complicated shape, can be approximated to the rectangular prism of dimensions 100 000 m × 100 m. Assuming the rock porosity average ratio = 10% according to measurements it varies from 3% to 17% the water resources in the reservoir can be evaluated on about 10 000 000 000 m^3.

The contents of thermal energy in water depends on temperature and this one – on depth of a given part of the reservoir.

On the basis of the commonly known principles of calorimetry has been estimated that in the peri-Tatric monoclinal zone of about 3 km width and temperature in the range of 20 – 60°C the water resources are 3×10^9 m^3, and thermal energy

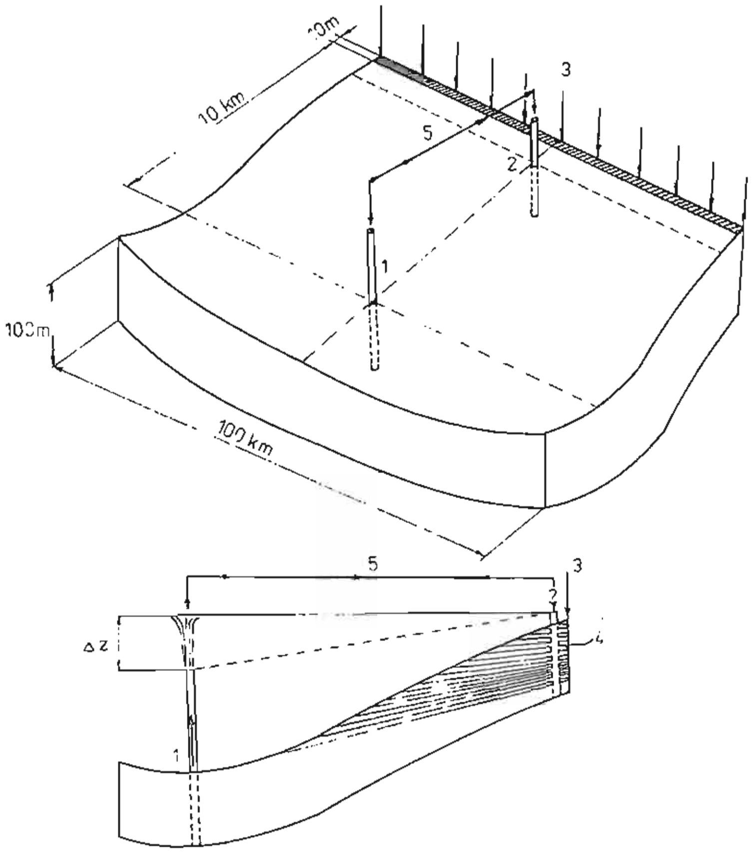

Fig. 3. Diagram of geological model of aquifer of nummulitic Eocene
Model geologiczny warstwy wodonośnej eocenu numulitowego

1 – production well; 2 – injection well; 3 – natural feeding; 4 – consecutive equipotential water surfaces when water table descends; 5 – pipeline for „return water" flooding; Δ_z – layer difference of well flow line

1 – otwór wydobywczy; 2 – otwór zasilający; 3 – zasilanie naturalne; 4 – kolejne powierzchnie ekwipotencjalne wody w miarę obniżania poziomu wody; 5 – rurociąg dla „wody powrotnej"; Δ_z – różnica poziomów wody w otworach

resources 6×10^{13} kcal, i.e. 25.11×10^{13} J. Within the main Podhale Basin of 6 km average width and temperatures within the range from 60° to 80°C, the water resources are 6×10^{9} m^3 and thermal energy resources contained in this water 3×10^{14} kcal, i.e. 12.555×10^{14} J. The total thermal energy resources accumulated in the water of this reservoir are $3,6 \times 10^{14}$ kcal, i.e. $15,066 \times 10^{14}$ J.

Dividing this value by mean caloric value of 1 kg of oil = 10 000 kcal we obtain equivalent of 36 mln t of oil or of 72 mln t of coal, the mean thermal value of which is 5 000 kcal/1 kg. In other words, the energy accumulated in 200 m^3 of thermal water of temperature 70°C can be recovered being as equivalent of thermal energy obtained due to combustion of one ton of oil or two tons of coal. Water output per day from the borehole Bańska IG 1 estimated at 1440 m^3 with regard to its caloric value would be the equivalent of 7.1 t of oil or of 14.2 t of coal of average quality.

PHYSICAL MODEL OF RESERVOIR AND MATHEMATICAL MODEL OF WATER FLOW

Taking into account that the Podhale Basin is asymmetric and its axis is located at the southern margin of the Pieniny Klippen Belt it has been assumed in model considerations that water reservoir has the same thickness at full length and inclines regularly in northern direction.

While modelling this layer for calculation purposes it has been transformed to the parallepiped shape of the dimensions 100 × 100 × 0,1 km; average porosity equal to 10% has been assumed. On the basis of such a model thermal water resources accumulated in the Middle Eocene reservoir of nummulitic limestones have been estimated as equal 10 km^3.

Areas of reservoir feeding by precipitation occurring in the peri-Tatric zone, after summing up their surfaces, have been approximated to the rectangle of the 0,01 × 100 km area.

Water downflow direction from the zone of feeding to the supply point in the belt 1 km wide was considered to be vertical to the said zone (from south to north). According to these assumptions a filtration stream is being modelled one-dimensionally in further considerations (Fig. 3).

It has been assumed that thermal stream heating the water is directed vertically upwards, heat capacity of the source is arbitrarily high and thermal energy transfer occurs on the basis of thermal conductivity of the rocks and media accumulated in them.

While starting a mathematical description of the phenomenon of water circulation in reservoir, forced by extracting water from wells, a simplification of the phenomenon has been made according to the accepted physical model. In general formulation of the problem it has been stated that we deal with non-radial plane flow, evoked by the operation of N_1 producing well and N_2 flooding well with precipitation infiltration by feeding zone. It has been assumed that the analyzed aquifer has the same thickness everywhere and is limited by impermeable caprock and floor. Under these conditions water flow has been treated as plane, i.e. occurring in the identical way in every cross-section that is parallel to the caprock and floor.

In order to draw an explicit image of flow, a grid of equipotential lines and lines of current have been drawn. Both sets of lines are perpendicular to each other. While designating equipotential curves superposition principle has been applied, i.e. overlapping of streams coming from negative sources (exploitation wells) and positive ones (flooding wells and feeding area). According to superposition principle, flow potential – an equivalent of reservoir pressure in this case – is in every point the algebraic sum of potentials designated for single wells and corresponding to real production rate.

At full compensation of water obtained by water injected to reservoir in a natural or forced way we deal with stationary flow the image of which does not change with time. Practically this compensation is not full which is confirmed by our calculations, i.e. pressure is a decreasing time function. Due to slow speed of this decrease one can talk about quasi-stationary character of the phenomenon due to which flow simulation can be carried out by means of con-

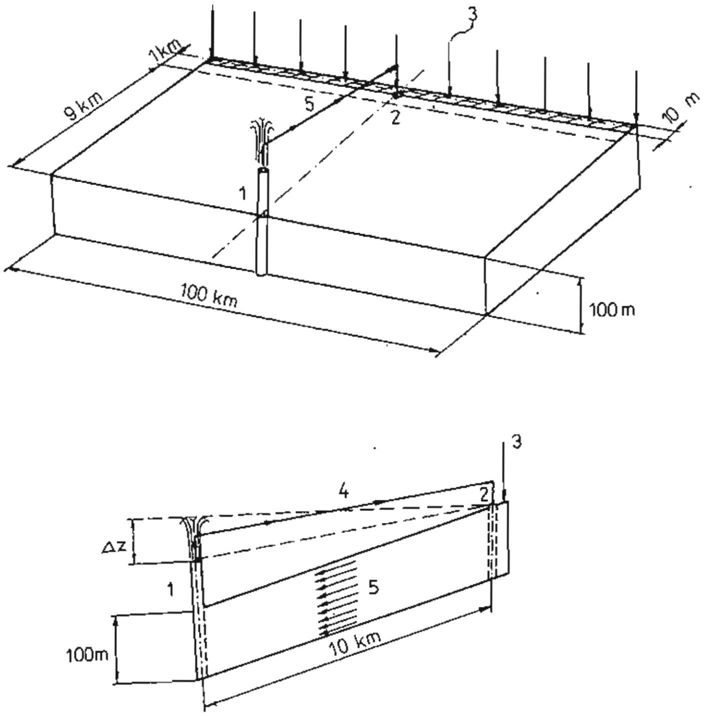

Fig. 4. Physical model of reservoir layer
Model fizyczny warstwy złożowej

1 – 3 – as given Fig. 3; 4 – pipeline for „return water" flooding; 5 – main direction of infiltration
1 – 3 – jak na fig. 3; 4 – rurociąg dla "wody powrotnej"; 5 – zasadniczy kierunek filtracji

secutive changes of stationary states in individual time steps. In our case the length of a single time interval is equal to one year, although it can be defined arbitrarily. Above all while, considering the seasonal fluctuations of precipitation a smaller time interval, e.g. quarter or month would be required.

If one production well with constant water flow capacity Q is active in the reservoir then at a satisfactorily small distance from the well the flow is plane radial and flow potential in a given point of reservoir is therefore expressed by the formula:

$$\varphi = \frac{\varphi}{2\pi h} \ln r + C \qquad [1]$$

where: Q – water flow capacity, m^3/h; h – aquifer thickness, m; r – distance of point from well axis, m; C – constant (depending on boundary conditions).

When it occurs a greater number of wells in this reservoir, the potential φ can be expressed (according to superposition principle) by means of the following formula:

$$\varphi = \sum_{i=1}^{N} \varphi_i = \sum_{i=1}^{n} \frac{Q_i}{2\pi h} \ln r_i + C \qquad [2]$$

where: φ_i – the value of φ in i – well; r_i – the distance of point from i – well; Q_i – i – well flow rate, treated as negative in case of production and positive in case of flooding.

Then the equation of every equipotential line (here the isobar) in flow plane assumes the form:

$$r_1^{Q1}\, r_2^{Q2} \dots r_N^{Q_N} = \prod_{i=1}^{N} r_i^{Qi} = C_1 \tag{3}$$

resulting from the rearranging the formula [2] when φ = const.

In order to determine the flow rates $Q_i (i = 1, 2, \dots N)$ at predetermined pressure distribution we assume the following boundary conditions: contours of all wells and the reservoir contour are isobars, radii of wells are identical and equal to r_0, if r_0 is considerably small when compared with mutual distances of wells and contour of feeding (which always occurs in practice).

Flow rates Q_i are calculated on the basis of the system $N+1$ of algebraic linear equations because C_1 is the additional unknown value. These equations have the following form:

$$\sum_{i=1}^{j-1} \frac{Q_i}{2\pi h} \ln r_{ij} + \frac{Q_i}{2\pi h} \ln r_0 + \sum_{i=j+1}^{N} \frac{Q_i}{2\pi h} \ln r_{ij} + C = \varphi_j \tag{4}$$

$$j = 1, 2, \dots, N$$

$$\sum_{i=1}^{N} \frac{Q_i}{2\pi h} \ln r_{ik} + C = \varphi_k \tag{5}$$

where: r_{ij} – distance of wells of index, i, j; i_{ik} – distance of i – well from feeding contour.

The system of equations [4], [5] is solved for Q_1 and constant C, from the latter we determine C_1 using [2] and [3].

It is remarkable that the same system of equations serves for determination of the potential φ_j, φ_k when flow rates Q_1 are known and constat C is assumed arbitrarily.

In the discussed case the feeding contour is in fact a set of areas which are mutually isolated, plane and located regularly along the line of about 100 km. Assuming such a contour as a full line does not affect the correctness of these considerations according to the same rule as assuming wells as geometrical points in comparison with r_{ij}, r_k although $r_0 > 0$. The form of the formulae [4], [5] suggests a treating of the flow in the vicinity of every well as plane-radial which is true. The flow in the vicinity of feeding contour is of plane-parallel character of current lines which are perpendicular to contour lines. It is in accordance with the assumption of contour line as being equipotential. In reality this assumption is correct only at an initial moment. Later on, the feeding contour ceases to be the isobar due to differentiated water outflow which depends on the distance from the production well, especially when this is a single well. Nevertheless even in this extreme case the isobar value is locally preserved at every time interval corresponding to stationary state.

Interference of wells manifests itself by occurrence of decreased flow rates from production wells in comparison with flow rates obtained from these single wells and at the same dynamic bottom pressures. Decrease of these flow rates is closely connetted with well network in the reservoir. Their best location is at considerable mutual distances, but close to feeding contour. The latter requi-

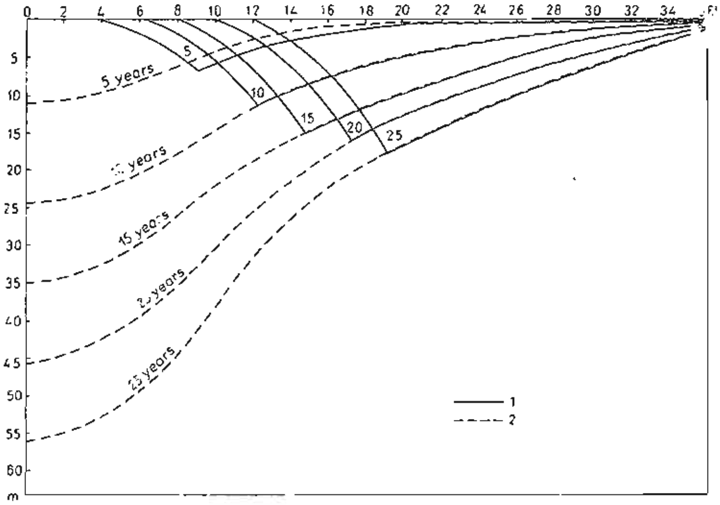

Fig. 5. Descent of water table in the feeding zone as a function of time and distance from transverse axis of the basin for one well variant

Obniżenie się zwierciadła wody w strefie zasilania jako funkcja czasu i odległości od osi poprzecznej niecki – wariant dla jednego otworu

1 – flow rate the production well $Q_p = 60$ m³/h, water influx injection well $Q_z = 42$ m³/h, natural feeding $HD = 0.36$ m per year; 2 – water output capacity from the production well; Q_p and HD – as given p. 1

1 – ilość wody z otworu wydobywczego $Q_p = 60$ m³/h, dopływ wody do otworu zasilającego $Q_z = 42$ m³/h, zasilanie naturalne $HD = 0{,}36$ m/rok; 2 – wydajność z otworu wydobywczego w warunkach zatłaczania; Q_p i HD – jak w p. 1

rement usually conflicts with technological conditions imposed on reservoir exploitation. In our case it cannot be satisfied because the most interesting due to technical reasons – zone of the deepest position of the reservoir, is situated at the distance of 12 km from the feeding contour. The first requirement can be fully satisfied.

Fig. 5, 6 present the curve of water table descent in five-years periods. Fig. 5 refers to exploitation by one well of initial flow rate $Q = 60$ m³/h in two variants, namely without and with flooding of 70% of obtained water on one well located near the contour centre. Fig. 6 refers to three production wells which are located along the line parallel to feeding contour by the mutual well spacing 1 km, and in two variants as above. On ordinate axis the distance from the contour centre in km and on abscissa axis the water table decrease in m in the subcontour zone have been marked. Both figures have been plotted on the basis of simulation calculations that were carried out for various variants.

PROBLEMS OF POSSIBLE EXPLOITATION

1. On the basis of reservoir feeding area and average yearly precipitation sum it can be inferred that the amount of infiltrating water is about 400 000 m³ per year. For expected possible water intake from the production well – 526 000 m³ per year, water shortage can amount to 126 000 m³ per year.

It is worth to emphasize that while calculating the amount of infiltrated water only the average area of nummultic Eocene formations has been assumed.

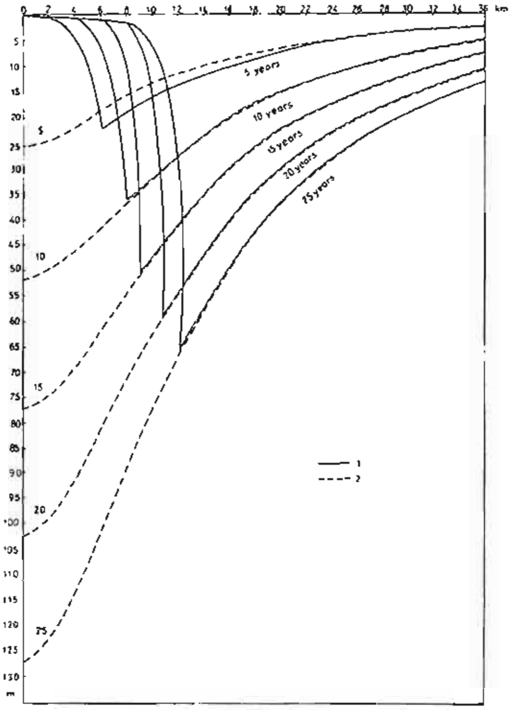

Fig. 6. Descent of water table in the feeding zone as a function of time and distance from the transverse axis of the basin for three well's variant

Obniżenie się poziomu wody w strefie zasilania jako funkcja czasu i odległości od osi poprzecznej niecki – wariant dla trzech otworów

1 – flow rate from the network of production wells Q_p = 44,5; 35,8; 44,5 m^3/h, water influx to the feeding well Q_z = 87 m^3/h, natural feeding HD = 0,36 m per year; 2 – water output capacity from the network of production wells, Q and HD – as given p. 1

1 – ilość wody z grupy otworów wydobywczych Q_p = 44,5; 35,8; 44,5 m^3/h, dopływ wody do otworu zasilającego Q_z = 87 m^3/h, zasilanie naturalne HD = 0,36 m/rok; 2 – wydajność z grupy otworów wydobywczych; Q_p i HD = jak w p. 1

One cannot exclude additional feeding by Mesozoic formations. If such a feeding exists, it is possible that ground waters descent would not occur.

2. The said shortage which can be unnoticed in the exploitation of single wells can cause the occurrence of water table descent in the peri-Tatric zone. In the exploitation of one or several wells located close one to another the greatest hazard would occur in the area between Kościelisko and Jaszczurówka.

3. From the above inferences one can conclude that thermal water exploitation should be carried out only when thermally exploited waters will be injected to the zone of the biggest hazard by water table descent.

4. Assurance that the possibility of water injection in the hazard zone would create a chance of utilizing the exploited waters for various purpose and at various stages.

5. It seems that the best exploitation system in view of present knowledge would be a grid of wells in the distance not smaller than 3 km from the margin of the Pieniny Klippen Belt between the villages Białka and Skrzypne.

6. The run of curves which designate water table descent (Fig. 6) along the contour line when the injection well is feeding (with 70% of obtained water) indicates purposefulness of locating such a well network of injection wells as to the obtained maximum values of water table descent were the smallest. It means that water should be injected at least to three feeding wells from which one ought to be located in the middle and the remaining ones in the distance of 10 km from it.

7. The most rational well network consists in arranging the production wells in one line every 10 km and arranging the same line of injection wells which is situated near the feeding contour at the smallest distances from their corresponding production wells.

8. The amount of injected water should be a little smaller from the amount of obtained water. One has to attempt to apply "a close circuit" of thermal water.

9. Values which have been presented in this paper should be treated only as approximate ones, estimated on the basis of presently available data. Nevertheless the results present the importance of the problem and the hazards associated with it.

Translated by Jan Sokołowski

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ГЕОЛОГИЧЕСКИЕ УСЛОВИЯ И ПРОБЛЕМЫ ЭКСПЛУАТАЦИИ В БУДУЩЕМ ТЕРМАЛЬНЫХ ВОД ПОДГАЛЯ

Резюне

Между Татрани и Пенинской утесовой зоной расположена асинетричная впадина, заполненная породами подгальского флиша, состоящимии в основном из глинистых сланцев, перемежающихся алевролитани и песчаниками. Флишевые породы служат изолирующей покрышкой для водонасыщенных горизонтов в нуммулитовых известняках среднего эоцена, в доломитах, известняках и мергелях среднетриасового возраста в реглевых элементах основания Подгальсхой котловины.

Скважиной Баньска ИГ 1 вскрыты и подготовлеиы к эксппуатации термальные воды среднеэоценового известкового горизонта. Эта скважина оборудована эксплуатационной головкой с треня отводами диаметром по 2″. При пробной эксплуатации скважины через один 2″ отвод, длившейся несколько дней, получен приток порядка 60 м/час. Температура воды в пдасте 82°C, на устье при нормальном дебите 72°C.

Судя по геологическому строению Подгаля и химизму полученных вод, эти воды являются смесью реликтовых атмосферных вод, возраст которых может быть более 52 мил лет, вод эоценового моря и младших инфильтрационных вод, проникающих в пласт посредством выходов нуммулитовых известняков в предтатринской зоне.

Суммарное содеожание минеральных компонентов в водах скважины Бальска ИГ 1 колеблется от 2995 до 3021,9 мг/дцм^3.

Изогипсы среднеэоценового водоносного горизонта местятся в границах от +946 м в предтатринской зоне до —1930 м в скважине Баньска ИГ 1. Температуры составляют: примерно 48°C на изогипсе —500 м, около 60°C на изогипсе —1000 м, 72°C на изогипсе —1500 м, 82°C на изогипсе —1930 м (на глубине 2560,5 м).

Качество и температура подземных вод Подгаля позволяют использовать их в следующих областях: в рыбоводстве, в плавательных бассейнах, для обогрева почвы, в бальнеологии, в теплицах, коровниках, для обогрева жилых и промышленных объектов. Самым правильным и экономически обосиованным может быть комплексное использование этих вод для всех вышеозначенных цепей, что позволило бы в махсимальной степени использовать тепло этих вод в интервале температур от 72 до 20°C. При такой системе использования термальных вод можно было бы из 1 м^3 воды получать энергию, раную энергии, получаемой от сожжения 5 кг нефти или 10 кг среднего по качеству каменного угля.

Суточный дебит воды из скважины Баньска ИГ 1, составляющий 1440 м^3 по калорийности соответствует 7 т нефти или 14 т каменного угля. Годовой дебит, составляющий 525 600 м^3 равнозначен энергии, получаемой из 2628 т нефти или из 5256 т угля.

После того как будут пробурены 10 следующих скважин можно будет получать в год 5 256 000 м^3 термальных вод, что в калориях равнозначно 26 280 т нефти.

В связи с тем, что по оценочным данным количество водных отходов, которые могут попасть в водоносные эоценовые известняки через раскрытые зоны литания, составляет максимально 400 000 м^3 в год, необходимо разработать и внедрить в практику такую систему эксплуатации термальных вод Подгаля, которая гарантировала бы стабильность водных ресурсов. Такого состояния можно достичь путем возврата использованных вод в тот же водоносный горизонт, из которого они были извлечены, только в зону более мелкого его залегания, где температура вод в пласте порядка 20°C.

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WARUNKI GEOLOGICZNE I PROBLEMY PRZYSZŁEJ EKSPLOATACJI WÓD TERMALNYCH PODHALA

Streszczenie

Między Tatrami i pienińskim pasem skałkowym znajduje się asymetryczna niecka tektoniczna wypełniona utworami fliszu podhalańskiego zbudowanego głównie z iłołupków przewarstwianych mułowcami i piaskowcami. Utwory fliszowe stanowią pokrywę izolacyjną dla bardziej zasobnych poziomów wodonośnych występujących w środkowoeoceńskich wapieniach numulitowych oraz dolomitach, wapieniach i marglach środkowotriasowych jednostek reglowych w podłożu niecki podhalańskiej.

Otworem wiertniczym Bańska IG 1 udostępniono i przygotowano do eksploatacji wody termalne poziomu wapieni środkowoeoceńskich. Otwór ten wyposażony został w głowicę eksploatacyjną z trzema

odpływami o średnicy po 2" każdy. Kilkudniowa próbna eksploatacja otworu prowadzona przez jeden dwucalowy odpływ wykazała wydajność otworu rzędu 60 m³/h. Woda w złożu ma temperaturę 82°C, na wpływie przy pełnej wydajności – 72°C.

Z analizy rozwoju geologicznego Podhala i chemizmu udostępnionych wód wgłębnych wynika, że są one mieszaniną reliktowych wód opadowych sprzed około 52 mln lat, wód morza eoceńskiego i młodszych wód infiltracyjnych, przedostających się do złoża poprzez wychodnie wapieni numulitowych w strefie przytatrzańskiej. Łączna zawartość składników mineralnych stwierdzonych w wodzie z otworu Bańska IG 1 waha się od 2995 do 3021,9 mg/dcm³.

Izohipsy środkowoeoceńskiego poziomu wodonośnego mieszczą się w przedziale od +946 m w strefie przytatrzańskiej do –1930 m w otworze Bańska IG 1. Szacunkowo określone temperatury wynoszą: ok. 48°C na izohipsie –500 m' ok. 60°C na izohipsie –1000 m, 72°C na izohipsie –1930 m (na głęb. 2560,5 m).

Jakość i temperatury wód wgłębnych Podhala pozwalają na zastosowanie tych wód w następujących dziedzinach: hodowli ryb, w basenach kąpielowych, do ogrzewania gleby, w balneologii, w szklarniach, w oborach hodowlanych, w grzejnictwie mieszkalnym i przemysłowym. Najbardziej zasadne i opłacalne ekonomicznie byłoby kompleksowe wykorzystanie tych wód do wszystkich wymienionych celów. Umożliwiłoby to maksymalne wykorzystanie ciepła zawartego w wodzie w przedziale temperatur 72–20°C. W ten sposób z 1 m³ można by uzyskać energię równoważną energii uzyskanej ze spalenia 5 kg ropy naftowej lub 10 kg węgla kamiennego średniej jakości.

Dobowe wydobycie wody z otworu Bańska IG 1, wynoszące 1440 m³, odpowiada pod względem kaloryczności ok. 7 t ropy lub 14 t węgla kamiennego. Roczne wydobycie – 525 600 m³ – jest równoważne energii uzyskanej z 2628 t ropy lub 5256 t węgla.

Po odwierceniu dalszych 10 otworów można by wydobywać rocznie 5 256 000 m³ wody termalnej, co w kaloriach byłoby równoważne 26 280 t ropy naftowej.

W związku z tym, że według szacunkowych obliczeń ilość wody opadowej, która może przedostać się do wodonośnych wapieni eoceńskich przez otwarte strefy zasilania, wynosi maksimum 400 000 m³ rocznie, konieczne jest opracowanie i zastosowanie takiego systemu eksploatacji termalnych wód Podhala, który gwarantowałby zachowanie stabilności zasobów z tych wód. Stan taki można uzyskać poprzez doprowadzenie wykorzystanych wód do tego samego poziomu wodonośnego, z którego zostały pobrane, tylko do strefy płytszej o niższych temperaturach – rzędu 20°C.