THE EFFECTS OF REINJECTION OF GEOTHERMAL WATER IN POLAND

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ABSTRACT

The reinjection of geothermal water has been carried out in Experimental Geothermal Plant in Bahska–Bialy Dunajec since September, 1990. Geothermal water is found in Eocene limestones and Middle Triassic dolomites, which together compose one reservoir covered by impermeable flysch formation. The water mineralization – about 3 kg/m^3, dissolved gas – about 7 dm^3/m^3, temperature (in reservoir) – 88°C, static pressure – 25 kg/cm^2, dynamic pressure – 26 kg/cm^2 at the exploitation well and 24 kg/cm^2 at the reinejcion well.

Geothermal water is exploited from Bariska IG-1 well through 6 5/8″ perforated casing pipes, from the depth of 2565–2683 m, flows through 3 pipelines of 2 7/8″ and Alfa Laval heat exchangers to Bialy Dunajec PAN-1 well, where the water is self-injected to exposed reservoir at a depth from 2117 to 2394 m. About 850 thousand m^3 of geothermal water have flown through this system during 4 years. A detailed investigation of the pipes condition did not show any significant effects of scaling and corrosion:

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In Poland, the reinjection of geothermal water has been carried out in Experimental Geothermal Plant (EGP) in Podhale region, since September, 1990. The circulation is maintainded by density difference. Geothermal water is exploited from Bahska IG-1 well. It flows to Bialy Dunajec PAN-1 well, where the water is self injected (Fig. 1).

Bańska IG-1 ⇑ Bialy Dunajec PAN-1 ⇓

Average flow rate: 7–8 kg/s (25–29 m^3/h)

Temperature in the reservoir	86–92°C
Static pressure at the well head:	
– exploitation well	24 kg/cm^2
– reinjection well	23 kg/cm^2
Temperature of the water at the well head:	
– exploitation well	72–86°C
– reinjection well	40–55°C
Dynamic pressure at the well head:	
– exploitation well	26 kg/cm^2
– reinjection well	24 kg/cm^2
Static pressure at the well head (Sept., 1994):	
– exploitation well	24,399 bars
– reinjection well	23,664 bars

Bańska IG-1 exploratory well with 5261 m depth was carried out in 1979–1981. After testing some deeper horizons, where one obtained the weak water inflow of high mineralization or the lack of the inflow, cracked dolomites and dolomite limestones of Middle Triassic were testing. After perforation of the 6 5/8″ pipes into 2858–2960 m the formation tester was installed and geothermal water self-flow was obtained in amount of 10.2 m^3/h. The flow was observed by 24 hours. The well head pressure amounted to 24 atm.

Presently exploited Eocene horizon was facilitated when the cement plug had been carried out up to 2740 m depth in the well. The access of the level was as follows: a) perforation into 2565–2683 m was made obtaining the poor inflow of 0.43 m^3 of water/hour, b) hydroperforation into 2588–2590 m was made and 6.4 m^3 of the acid liquid was injected-obtaining a great inflow of geothermal water.

The well head pressure, measured basing on the tests carried out within 2858–2960 m and 2588–2683 m amounted to 24 atm., and results of investigations of the water mineralization show that these perforations were performed within one reservoir.

Bialy Dunajec PAN-1 geothermal well with 2394 m depth was carried out in 1989. It is cased with 9 5/8″ pipes up to 2121 m depth. Diamond bit, core apparatus, sinker bars of 4 1/2″, rodes of 5″ of a total length of 200 m were left in the uncased well. In 1989, one carried out the perforation of 9 5/8″ pipes in 2117–2132 m depth, drill pipes of 2 7/8″ were sinked and exploitation well head was installed. Performed tests of the water self-flow showed the efficiencyof 9 m^3/h, and injectivity tests – 10.5 m^3/h.

Instruments left in the well and small thickness of numulitic Eocene (2113–2125 m), which was considered as a main water-bearing level, predicted unfavourably the further geothermal works. However, when two acid treatments were carried out in October 1990 the water self-flow was obtained in amount of 192–217 m^3/h.

To the acid treatment were prepared as follows: 50 m^3 of acid liquid included:

24 m^3 — 35% HCl,
8 m^3 — 10% acetic acid,
10 m^3 — 6% gigtar S,
8 m^3 — water,
50 kg — roksol AT2,
50 kg — roksol AT3.

At first, one carried out the cleaning acid treatment by injection through drill pipes 10 m^3 of fiuid that was received after 2 hours from the well. Geothermal water self-flow in amount of 80 m^3/h was obtained as a result of this treatment.

During the second acid treatment 40 m^3 of acid fluid was injected to the formation through drill pipes with 2-hours reaction time. When the reactive fluid had been received one carried out the investigations of the water self-flow during 1 hour by 6 days (22, 23, 25 Oct., 1990 and 7, 9, 10 Nov., 1994). The result of this acid treatment was satisfactory and comparable with the output from Baliska IG-1 well.

Having in disposal two wells facilitated in the same reservoir one started the construction of the connecting pipeline. In relation to the cost of construction and access of pipes of about 200 mm in diameter, one carried out a temporary connection with drill pipes of 2 7/8″ (3x1250 m) which are planning to be eliminated after construction of the permanent pipeline.

In 1990/1991 three threads of drill pipes were the only "radiator" emmitting geothermal heat to the atmosphere. In 1991/1992 and 1992/1993 heating seasons geothermal heat was supplied for heating the building of Experimental Geothermal Plant, greenhouse and wood drier. In 1993/1994 six detached

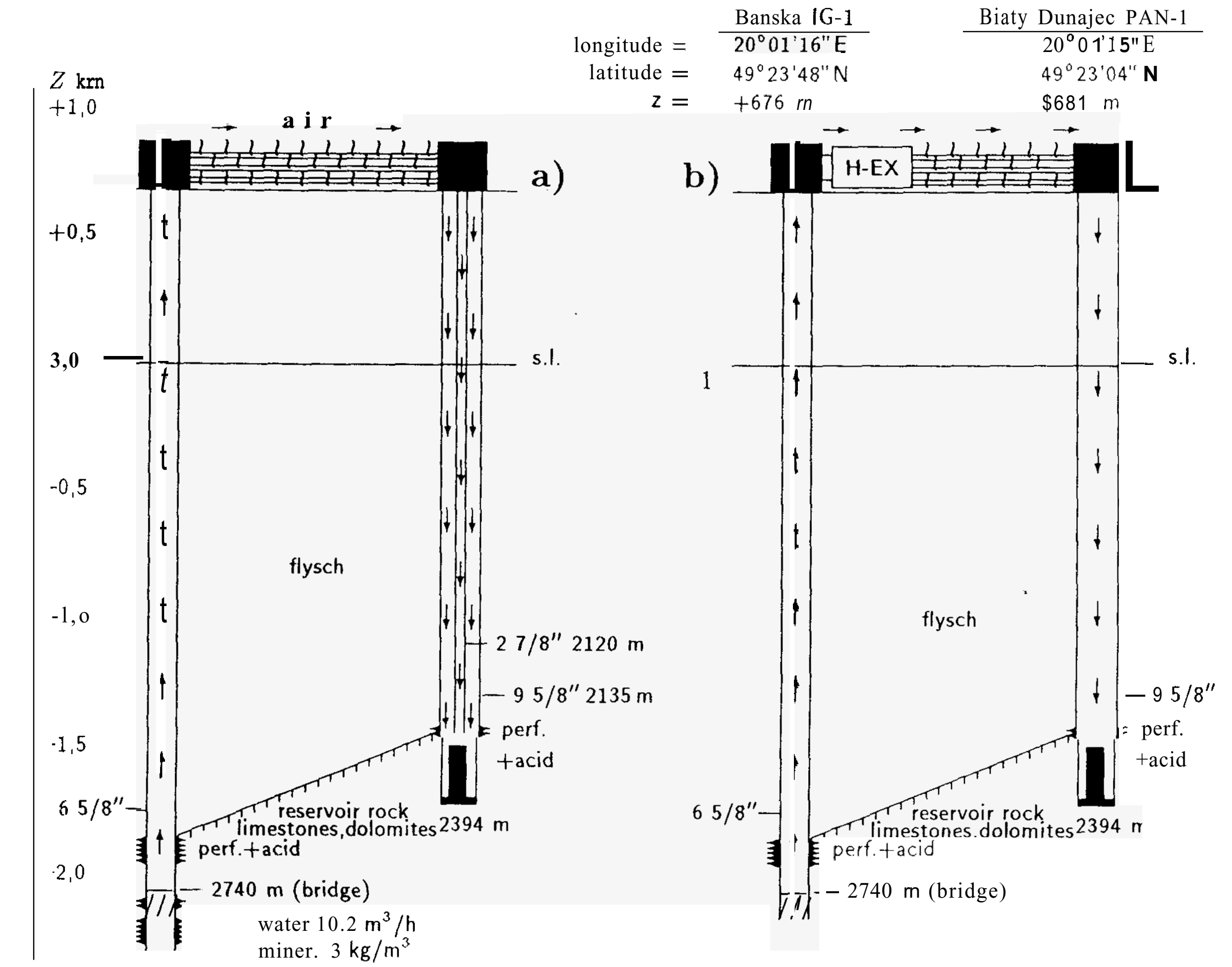

Fig. 1. The first and the present scheme of geothermal water circulation in Bańska–Biały Dunajec doublet
a) 1991–1992 heating season: circulation through oil exploitation well head, *3* pipelines of ⌀ 2 7/8", and pipes of 9 5/8" and 2 7/8" in Biaiy Dunajec **PAN-1** well
b) Sept., 1994. circulation through geothermal well head, heat exchanger and *3* pipelines of 2 7/8" after pulling the 2 7/8" pipes out of Biaiy Dunajec **PAN-1** well

houses were supplied with heat. Presently, pipelines to further houses are under construction.

Performed investigations of the water self-flowsfrom the wells as well as long-term geothermal water flow between wells (the tests were carried out in two directions) show that in Podhale exist fissured – porous reservoir of large thickness. It results from the tests in Baliska IG-1 well and from temperature increase of the water self-flow from Bialy Dunajec well with great output.

Cooling the rock mass around the sink well doesn't seem to be large as results from tests carried out after changing the oil exploitation well head into geothermal well head in September, 1994.

In Baliska IG-I exploitation well the static well head pressure amounted to 2.44 MPa, and in sink well – 2.37 MPa. The difference of pressure amounting to 0.07 MPa at the difference of the altitude amounting to about 5 m decreases to about 0.02 MPa and may results from differences of the water density in both wells of the same chemical constitution and of similar temperatures.

The precise measurements were carried out for the first time. They confirm the previous results of investigations and conclusions that large geothermal system, which will be profitable and safety for the natural environment, can be built in Podhale Region.

Geothermal water is exploited from Bariska IG-1 well (Fig. 1b) through 6 5/8" perforated casing pipes, from the depth of 2565–2683 m, flows through 3 pipelines of 2 7/8" and Alfa Laval heat exchangers to Bialy Dunajec PAN-1 well, where the water is self injected to exposed reservoir at a dept from 2117 to 2394 m. The water is self-injected to exposed reservoir.

SO_4^{2-}	910 – 973	Na^+	500 – 550
Cl^-	496 – 634	Ca^{2+}	215 – 240
HCO_3^-	287 – 383	Mg^{2+}	51 – 110

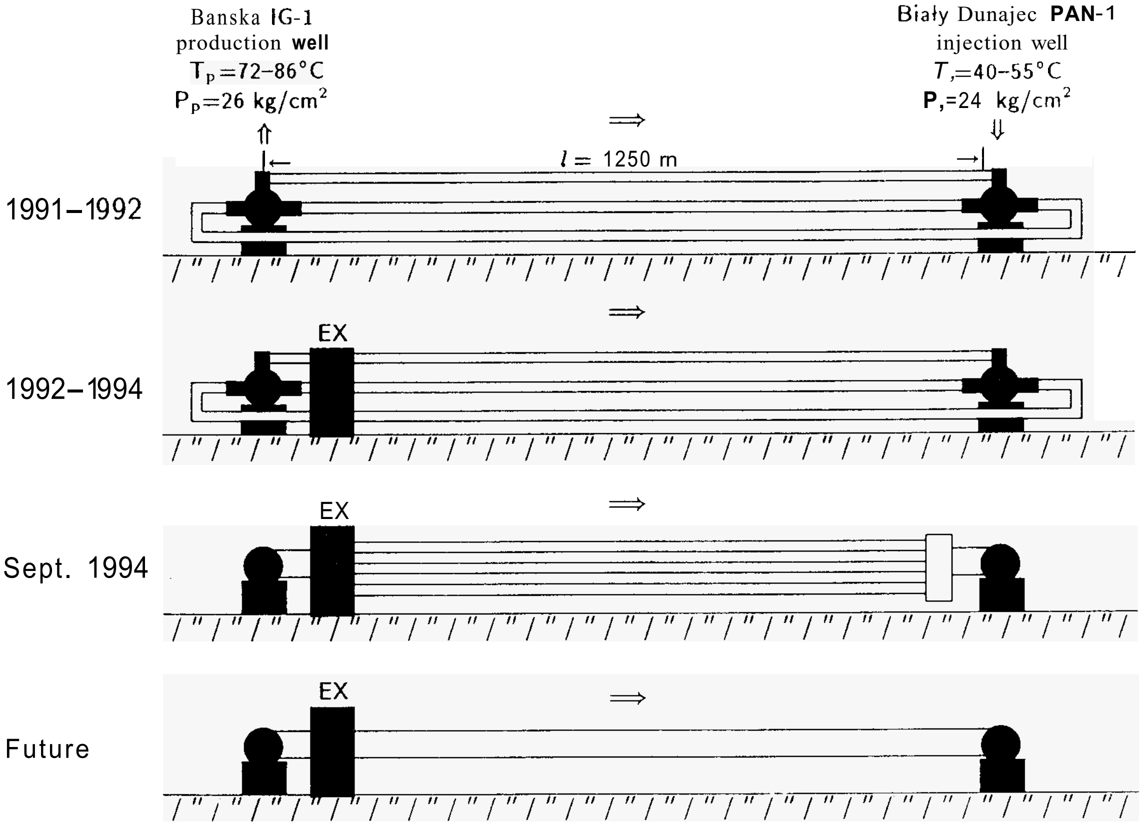

Fig. 2. The scheme of connection between wells and exploitation parameters

1990–1991 heating season: circulation through oil exploitation well head and 3 pipelines of ⌀ 2 7/8″ without heat exchangers
1991–1993 heating seasons. circulation with heat exchangers
September 1994. circulation through geothermal well head
Future. designed exchange of connections between wells

Carbon dioxide having passed to the gaseous phase, does not influence thermodynamical equlibrium between bicarbonates and carbon dioxide in the liquid phase. If geothermal water being in the state of thermodynamical equilibrium in the reservoir would be expended to the pressure of saturation, the point of the equilibrium would be shifted. A part of bicarbonates would decompose with liberation of carbon dioxide and precipitation of sparingly soluble calcium carbonate.

The following equation describes this process:

$$Ca(HCO_3)_2 \Longleftrightarrow CaCO_3 \downarrow + H_2O + CO_2 \uparrow$$

If the pressure in the plant would further decrease, more calcium bicarbonate would decompose and more calcium carbon would precipitate.

Precipitated calcium carbonate shows strong scaling tendency that might cause several problems during operation of the plant. In order to avoid it, pressure in our plant is maintained above the pressure of flashing, to prevent scaling in the equipment.

EVALUATION OF SCALING

After operating the plant for 18 months, three pieces of the pipes close to the injection head were investigated. Investigation of the inside surfaces of the pipes showed no traces of calcium carbonate scales. The results of the examination confirmed our assumption, that maintenance of sufficiently high pressure for the geothermal water prevents calcite scaling in the equipment.

Decrease of the temperature of the water in the plant makes it undersaturated, mainly because of higher calcium carbonate solubility at lower temperature. After reinjection into the resorvoir undersaturated water solves carbonates from the rock formation. When spent geothermal water is heated again, it becomes oversaturated and calcium carbonate precipitates in the rock formation, what may alter the porosity and decrease the permeability of the formation.

Sparingly soluble calcium sulphate is not expected to precipitate in the plant from geothermal water because its solubility rises when the temperature of the water in the plant falls. After reinjection the temperature of the water rises but only to the point of reservoir temperature at which calcium sulphate is solved.

Because reinjection of geothermal water has been carried out for relatively short time of 3 years, further investigations regarding the influence of the geothermal water on the equipment and the reservoir rock formation are required.

EVALUATION OF CORROSION

In order to determine the corrosion effects in the pipeline supplying geothermal water from Bańska IG-1 well to Bialy Dunajec PAN-1 well, two segments of 2 7/8″ drill pipes were cut out. One of the examined segments included screwed joint. Geothermal water was flowing through examined pipes from November 1990 to the moment of segments drawn in August 1992.

Both segments were cut along the axis and then the half of each of them were exposed to the mechanical cleaning and etching in 10% hydrochloric acid for total removal of corrosion products. Such preparated pipes' segments and drew corrosion products constituted the material for examination.

After examining the surface of the straight segment of the pipe one noticed that in spite of long-term exposure to geothermal water it underwent corrosion to a low degree. The corrosion on its surface was in general uniform corrosion with small corrosion pits frequently occuring. The depth of the corrosion pits did not exceed 1 millimetre. The influence of the corrosion on the thickness of pipe walls during these months is unnoticable.

The traces of mechanical erosion caused by particulates suspend in the water were not noticed. The pipe surface was covered with uniform layer of corrosion products in brown-black colour and about 1 mm thick. This layer adhere rather weekly to the steel surface and doesn't, protect against further corrosion. Water trapped under this layer caused the corrosion pits.

The corrosion of the pipe segment with the screwed joit was a little different. It was a pitting corrosion with wide pits, with connection between each of them. The depth of these pits reached up to 1 mm, and their surface to 10 mm^2. The cause of such corrosion development on the joint could be a change of pipeline diameter. This could cause the water whireles and stagnations that intensify the electromechanical corrosion and favour the pitting corrosion. This part of the pipeline was also covered with a layer of corrosion products but traces of mechanical erosion were not noticed.

Results of chemical analysis of corrosion products give:

iron	58.1%
sulfides	3.5%
silica	2.3%
carbonates	not detected

The main component of corrosion products is iron linked in the form of oxides and hydrated oxides. Regarding the reduction medium, in which the corrosion occurs, the most part of iron is linked in the form of oxide FeO. Other oxides exist in smaller amounts. Beside oxides iron sulfide FeS constitutes as much as 9.6% of the corrosion products. It has risen to such large amount (1 mg/dm^3) as a result of great aggressiveness of this compound.

A detailed investigation of the pipes condition did not show any significant effects of scaling and corrosion. The changes of absorptiveness of Bialy Dunajec PAN-1 well were not observed, either.

In our opinion, the lack of harmful influence of geothermal water on the pipes and the reservoir is a result of air tightness of the system and maintenance of properly high pressure in it. This prevent raleasing of carbon dioxide from geothermal water, remaining in the state of thermodynamic equilibrium with calcium and magnesium bicarbonates dissolved in it.

SUMMARY

Experimental exploitation and reinjection of geothermal water in closed circulation was carried out in Podhale. It showed as follows:

1. the possibility of initiation of the flow between wells of high and level pressure after cooling the exploitation well by draining water to the surface reservoirs and then by directing exploiting water to the sink well;
2. the possibility of self-injection of great amounts of water without pumps;
3. constancy of the water flow within 4-years exploitation;
4. low corrosivity of water in relation to drill pipes of 2 7/8″ used for pumping.

Tested way of exploitation can be reccommended especially for the use in the mountainous reservoirs, where hot fresh waters occur and are utilized for consumption, balneological and heating purposes.

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