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# Recent Studies of the Low Cretaceous Geothermal Reservoir in Mszczonów, Poland

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## ABSTRACT

The Warsaw synclinorium is a part of a large sedimentary structure named after the Middle Poland depression. Geothermal plant with well Mszczonów IG-1 is situated in the central part of this synclinorium. The waters that occur in the Low Cretaceous aquifer have been exploited for central heating and domestic hot water purposes since winter of 2000, as a single well system. First preliminary numerical model of exploitation was developed in 2000. Reservoir response during three years of production is analyzed in this paper. Numerical model was set up using the simulation code Tough2. New model respects well logging data and system parameters recorded during exploitation period. Future development is simulated on the basis of previous experiences. Because the production parameters have been stabilized since the first period of exploitation, the future production can be increased depending on the heat demand.

## 1. INTRODUCTION

In Poland in 70 - 80% of the area, geothermal water beds were identified at depths reaching 4000 m. The layers were formed mainly of sandstone and carbonates.

Main geothermal water containers originate from Jurassic (mainly Liassic and accidentally Dogger and Malmian), Cretaceous (mainly Lower Cretaceous) and older periods, with little superficial range in Cambrian, Devonian, Permian and Tertiary. Temperature of occurring water depends on bed level depth as well as geothermal grade, amounting to in the majority of Poland between 35 and 70 m. Total water volume accumulated in Poland amounts to about 6500 km$^3$ (Fig. 1).

The above approximation was performed on the base of data obtained from thousands of wells drilled all over Poland. By now, majority of them are closed or excluded from oil or natural gas exploitation. The closed wells have been under the interest of Mineral and Energy Economy Research Institute, Polish Academy of Science (MEERI PAS), as possible subject for water or geothermal heat exploitation (Balcer 1997, Bujakowski 1996, 1997).

In August 1996 MEERI PAS began a research project titled: "The pilot station of water and heat exploitation from the reconstruction well Mszczonów IG-1 ". Research section was titled: "Mszczonów IG-1 well adjustment to geothermal deposit exploitation needs for a heating network use". The base for the research was given by an agreement among State Committe for Scientific Research, Mszczonów Urban, District and Polish Academy of Sciences MEERI.


**Figure.1: Geothermal regions and subbasins of Poland and their characteristics (Ney, Sokołowski 1987)**

| District Name | District Area [km$^2$] | Geological Formations | Volume of Geoth. Water [km$^3$] |
|---|---|---|---|
| Grudziadz-Warsaw | 70,000 | Cretaceous/Jurassic<br>Triassic<br>Total | 2 766<br>334<br>3 100 |
| Szczecin-Lodz | 67,000 | Cretaceous/Jurassic<br>Triassic<br>Total | 2 580<br>274<br>2 854 |
| Fore-sudets Swietokrzyski | 39,000 | Permian/Triassic | 155 |
| Coastal | 12,000 | Permian/Carboniferous/<br>Devonian/Liassic/<br>Triassic | 21 |
| Lublin | 12,000 | Carboniferous/<br>Devonian | 30 |
| Baltic | 15,000 | Cambrian/Permian/<br>Mesozoic | 38 |
| Podlasie | 7,000 | Cambrian/Permian/<br>Mesozoic | 17 |
| Fore-Carpathian | 16,000 | Triassic/Jurassic/<br>Cretaceous/Tertiary | 362 |
| Carpathian | 13,000 | Triassic/Jurassic/<br>Cretaceous/Tertiary | 100 |

Mszczonów IG-1 well is located in central Poland, about 40 km SW from Warsaw. It is the first such reconstruction in

Poland that concentrated mainly on the following: elaboration of reconstruction methodology, test of Lower Cretaceous water-bearing level, existing at depth of 1602 - 1714 m beneath the surface of the area; execution of reconstruction of technical labor and deposit facilities, probing of water-bearing formation, geophysical test and recording results of scientific description. Forceful trends of ecologically clean heat source were strongly marked out in several regions of Poland (Fig.1.): in Podhale region in the South, where the first in Poland geothermal plant (Bujakowski, Barbacki 2004) has been operating since 1994; in Pyrzyce, North-West of Poland, where geothermal and natural gas powered heating plant has been working since 1996; in Mazovia region, central part of Poland, where one of the richest geothermal region, called Grudziądz-Warszawa is located. In Mazovia region, two geothermal plants are situated. The first is located in Mszczonów town (since 2000) and the second in Uniejów (2001). Recently activated facility has been operated since 2002 in Słomniki town (Bujakowski 1999).

## 2. RESEARCH AND RECONSTRUCTION WORK

There are two deep wells in the area of Mszczonów town: Mszczonów IG-1 and Mszczonów IG-2. Mszczonów IG-1 well, located in the town’s edge, was chosen to be reconstructed and to start water and heat industrial exploitation (Bujakowski 2000).

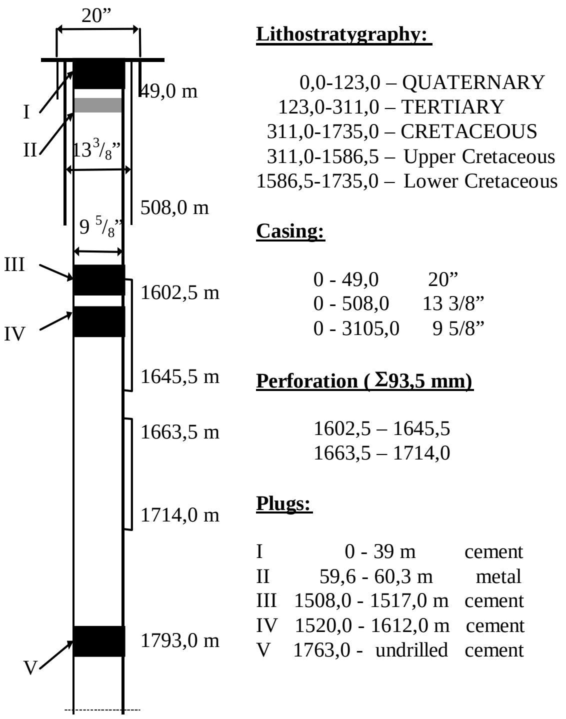


**Figure 2: Technical state of the well Mszczonów IG-1**

The geothermal project intended to use Lower Cretaceous water-bearing formation, existing at the depth of 1600 - 1700 m. The level was perforated in 1976/77 by Mszczonów IG-1 well, which was done for a certain parametric-structural targets as a part of Warszawa Syncline and Warszawsa Antycline research (Fig.2.). The well was closed out at 4119 m depth

One of important goals was to render accessible water-bearing collector, existing in sand formations of Lower Cretaceous, and probe it (with contemporaneous procedures).

Following parameters describe it:

- depth of water level 50.5 m beneath the surface of the area
- depth of the bed 1602,5 - 1714,0 m beneath the surface of the area
- flowrate - 10 $m^3$/h at depression of 0.5 - 1.0 m (capacity is designed by the compressor and boiler)
- flow rate calculated - 200 $m^3$/h t depression about 20 m
- temperature - about $45^0$C
- mineralization - about 1.0 g/$dm^3$.

**THE LITHOLOGY OF THE WATER-BEARING LEVEL:**

1602,0-1714,0 m Middle Albian – Barremian

1602,0-1645,0 m close-grained grey sandstone, changing partly into dark-grey sandy mudstone with little silexes consistent, to the floork dark-grey medium grained sandstone with loamy binder

1645-1651,8 m black and black-grey mudstones with a lot of muscovite, often with sand, weakly consistent/ changing into weakly consistent claystones

1651,8-1714,0 m sandstones (as above) with a little coal, with fragments of fauna, black mudstones with a lot of muscovite dust.

Lower Cretaceous formations in other, neighbouring wells, have the porosity of about 20-29% and permeability of approximately 1480 mD.

Performed job certified geothermal waters of the following parameters (Wojnarowski 1996, 1997):

| | |
|---|---|
| flow rate | 60 $m^3$/h |
| depression (S) | 24.6 m |
| temperature | $41.5^0$C |
| mineralization | 490 mg/$dm^3$ |
| water class | $HCO_3$-Cl-Na-Ca |

depth of water level at 49 m beneath the surface of the area.

The results confirmed the expected values and served as a base for the next elaborations dedicated to the water heat engineering and water development.

## 3. A CONCEPTUAL RESERVOIR MODEL

The Early Cretaceous reservoir in the Warsaw Synclinorium is a part of a wide permeable structure, which is found in a considerable area of Poland. It has the shape of a long syncline striking SE – NW. The deepest part of the aquifer is near the town of Mszczonow, in the southern part of the reservoir (Fig. 3).

In vertical profile, the Early Cretaceous permeable sandstones are separated by impermeable mudstone and clay layers. Previous research indicated that the upper sandstone layer has higher permeability than the lower one. New logging shows that lower layer is more permeable. The western side of the synclinorium is steep and the Early Cretaceous deposits reach the surface in this part of the study area. The eastern side, however, passes softly into a platform slope. Fluid recharge is believed to come mainly from S and S – SE where the Early Cretaceous formation contacts directly with Quaternary deposits.

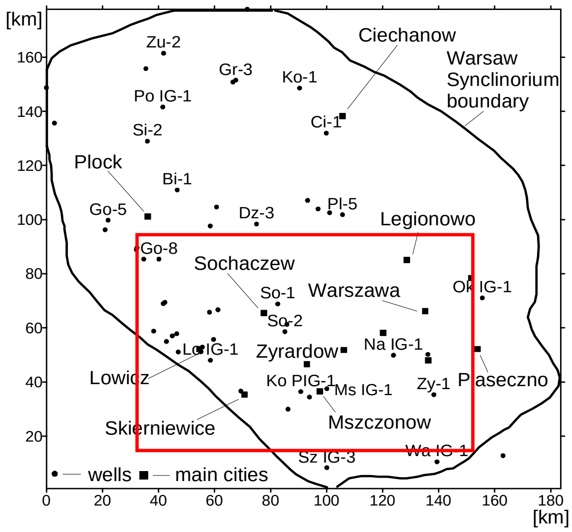


**Figure 3: Location of wells and towns in the Warsaw Synclinorium**

A topographically driven pressure gradient, from the Poland's highlands in the south to the lowlands in the north, results in a small regional flow. Water outflow from the Early Cretaceous reservoir, follows N and N-W direction, parallel to the strike of the Pomorze-Kujawy Antyclinorium.

Information on the hydraulic parameters of permeable and semi permeable rocks is rather limited as the Early Cretaceous reservoir has not been a subject of interest and large scale exploitation. Exceptions are, however, at the outcrops to the NE margins of the Lodz Synclinorium, at the SW margin of the Warsaw Synclinonium and, to some extent, in other sedimentary units where fresh groundwater is exploited.

Hydraulic parameters have therefore mostly been measured for the shallower parts of the aquifer, close to the outcrops. In these the reservoirs, temperatures are naturally too low for any substantial geothermal applications.

The geothermal aquifer hosted in the Early Cretaceous sedimentary unit is at confined conditions throughout almost all area. Unconfined conditions occur only in the outcrops and incrops under the Cainozoic (mostly Quaternary) deposits.

Information available on the Early Cretaceous geothermal aquifer comes mostly from oil and geological exploration drilling, made by both the local petroleum industry and the State Geological Institute.

The irregular borehole pattern and limited range of measurements and core sampling result in limited hydrogeological characterization of the reservoir. Well tests have been performed in a fraction of the boreholes, mainly in shallow wells at outcrops and incrops, but also in the most recent deep wells.

On the basis of data obtained from about 60 wells, spatial distribution of reservoir parameters using geostatistical methods was determined (Stopa and Wojnarowski, 1999).

Modeling the parameters of distribution was done via 3D conditional stochastic simulation methods.

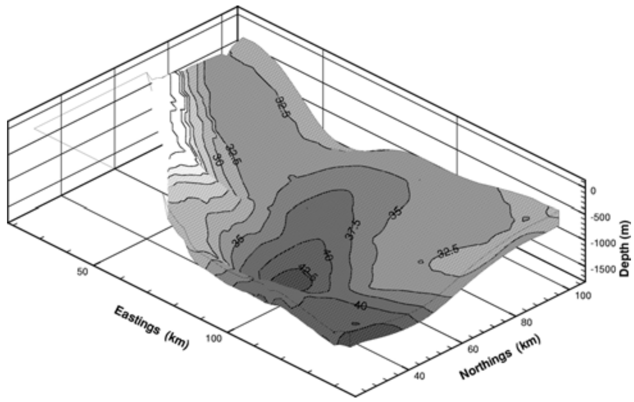


**Figure 4: A 3-D map of depth to the Lower Cretaceous reservoir and its temperature distribution. The study area is shown by a rectangle on figure 3**

Figure 4 shows the depth to the top surface of the Lower Cretaceous aquifer in the Warsaw Synclinorium and its temperature distribution. The temperature varies from about 10-15$^{o}$C on the S-W outcrops to about 40-45$^{o}$C in the deepest part of the reservoir. Thickness of the aquifer is variable. It changes from few metres to about 200 metres. Results of this analysis were used to build a preliminary numerical model of the Warsaw Synclinorium Early Cretaceous Reservoir (Wojnarowski, 2000). The preliminary modelling exercise suggests that the Early Cretaceous reservoir is of excellent production capacity, both in terms of pressure changes and cooling. Also it appears that as short distance as 1000-1500 m is sufficient for a production-injection well dipole and flowrates in the vicinity of 60 $m^3$/hr. The regional groundwater flow presumed in the reservoir does not have a noticeable influence on the predictions because of flow velocity is too slow.

### 3.1. The Numerical Model

Over three years of exploitation of the Warsaw Synclinorium Early Cretaceous Reservoir in Mszczonow allows for better understanding of reservoir changes. It also delivers data for numerical model calibration. New numerical model for one-well exploitation was developed. The simulator TOUGH2 was used for the modelling work (Pruess, 1991). Because of negligible influence of regional flow and also because the utilization of one-well system was done without any injection of cool fluids, radial model for simulate Mszczonow IG-1 well work was made.

### 3.2 Model Description

Modelled area of radial geometry was divided into the layers described by caprock, bedrock and permeable sandstone which were divided by impermeable clays. The model assumed porous media. Two high permeable zones divided by impermeable layers were specified. They permeabilities are listed on fig.5.

| Rock name | Horizontal perm. (mD) | Vertical perm. (mD) |
|---|---|---|
| Upper zone | 700 | 0.75 |
| Impermeable clays | 0 | 0 |
| Lower zone | 1250 | 1.25 |

**Figure 5: Permeabilities in Early Cretaceous reservoir model**

Since analysed reservoir in Warsaw Synclinorium is a part of the large aquifer, boundary conditions with constant pressure were assumed.

### 3.3 Historical Data Matching

The results from the initial-state model of the Early Cretaceous geothermal system reflected initial pressure and temperature profile were used for model calibration as a initial state of reservoir.

Geothermal plant has continuously been operating since July 2000. Figure 6 shows production history. Until September 2002, production was irregular because of carried out well tests and system development. Last period was more stabilized with visible production and stoppage stage in the winter. It can be observed that temperature has constant level during production. Small variation and decrease during no production period happened because of the method of measurement. Temperature sensor is mounted on the wellhead. Similarly, small variation of pressure is caused by the method of measurement. Pressure is measured indirectly by water level measurement. Hydrostatic pressure sensor is located above the pump unit.

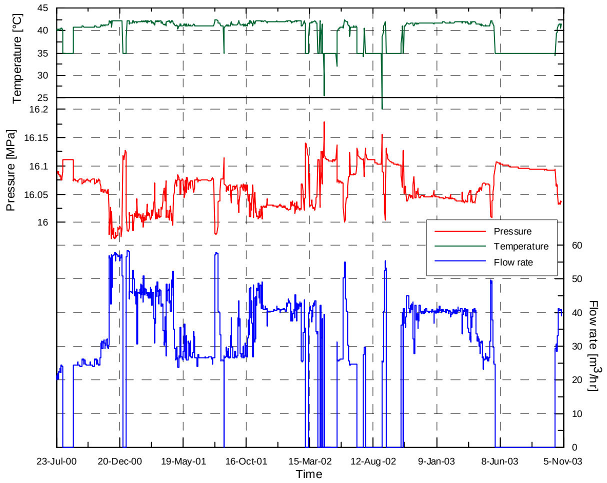


**Figure 6:Production history from well Mszczonow IG-1.**

Numerical model was calibrated for whole production data. After many runs with different rock properties, a final quantitative model has been derived that satisfactorily matches the production history.

Difference in productivity of permeable zones was scaled on the basis of production log tests (Bujakowski et al., 2000). Figure 7, shows the match between observed and calculated pressure in Mszczonow IG-1 well.

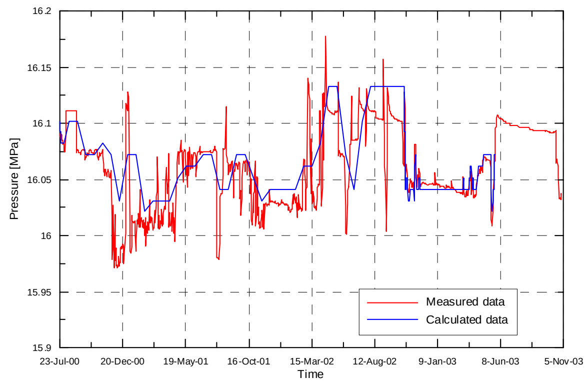


**Figure 7: Observed and calculated pressure in well Mszczonow IG-1**

### 3.4 Forecasting of Reservoir Behavior

The major question to be answered by the forecast runs was how the reservoir would behave as the generation capacity was increased. Two production scenarios were considered:

1. Production with maximum flow rate of 45 $m^3$/h.
2. Production with maximum flow rate of 60 $m^3$/h.

Production for the first case corresponds to the flow rate in previous winter, which was needed for heat production in geothermal plant. In second case, production reaches maximum allowed flow rate from Mszczonow IG-1well. Figures 8 and 9 shows simulated production scenario and forecast of pressure response for both cases. In forecast cases, assumed summer seasons are without production and maximum load of system during three months in winter is reached.

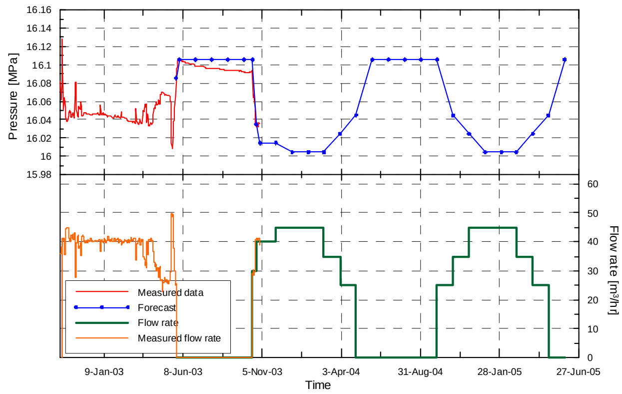


**Figure 8: Forecast results for the first case**

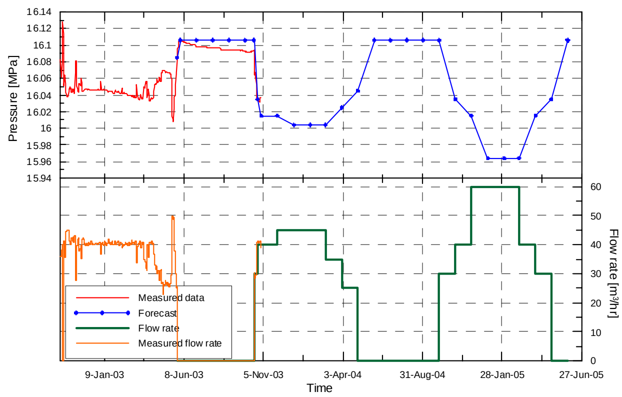


**Figure 9: Forecast results for the second case**

The field-wide production characteristics plotted on Figures 6 and 7 show that the pressure decline and buildup similar to the measured data is fast because of a very good permeability.

Produced water temperature during simulated period was constant just like during previous production. It shows very good properties of the reservoir which can be stable energy source for geothermal heating plant with maximum-allowed flow rate.

## 4. SUMMARY

The results from the simulation runs suggest that the Early Cretaceous Reservoir in the Warsaw Synclinorium can be the stable energy source for geothermal heating plant.

Current heat capacity of geothermal plant in Mszczonow can be increased. Maximum allowed production with flow rate of 60 $m^3$/hr doesn't lead to big disturbance in pressure field and probably could be increased if heat demand would be higher.

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