EVALUATION OF GEOTHERMAL RESOURCES IN THE POLISH LOWLANDS

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Key words: resources, low enthalpy, assessment

ABSTRACT

The paper presents an assessment of the geothermal energy resources accumulated in underground waters of Lower Cretaceous and Lower Jurassic aquifers in the Polish Lowlands. The evaluation was based on prepared hydrogeological models and modem techniques including digital mapping. The estimates were linked to economic assessments which allow a realistic view of the utilization opportunities of geothermal water in the prospective areas of the Polish Lowlands. Total disposable resources of both the Lower Cretaceous and Lower Jurassic formations in the Polish Lowlands amount to some $2.1*10^{18}$ J per year, which corresponds to 48 $*10^{6}$ TOE per year. Assuming that 3-4% of disposable resources will be utilized, the exploitable resources can be estimated as 1.32 - 1.76 millions TOE per year which corresponds to 120-160 installations of an annual heat capacity of 500 TJ each.

INTRODUCTION

In recent decades progressive degradation of the natural environment has been observed in Poland. This process affects areas of unique historical importance as well as regions of priceless landscape and tourist value. One of the principal sources of environmental hazards is coal-based energy production. Coal burning releases enormous amounts of gas and dust into the atmosphere, such as CO, CO_2, SO_2 and NO_x. The most effective counter measure is to eliminate sources of pollution. Therefore application of ecologically "clean" energy sources appears to be a vital solution to the problem. Among many possible solutions, unconventional energy sources cannot be neglected. In recent years, unconventional sources including geothermal energy are of rather marginal importance in Poland although they should be prominently ranged among renewable energy resources.

Geothermal resources in Poland are accumulated in underground aquifers in various stratigraphic units and at various depths in the Polish Lowlands, in the Sudety Mountains and in the Carpathians. These waters show temperatures between 20-40 and 80-100°C at wellheads. They can be utilized as heating medium and heated water for domestic usage; for balneological and recreational purposes; for the heating of greenhouses and fish farms after some treatment.

Geothermal aquifers of economic importance are accumulated in the Mesozoic cover. Most promising are the water quantities found in both Lower Jurassic and Lower Cretaceous sandstones in two Mesozoic sub-basins: Szczecin-Łódź and Grudziądz-Warszawa (Fig.1 and Fig.2).

Water quantities in Lower Cretaceous succession include sandstones and arenaceous mudstones. The Lower Jurassic comprises an arenaceous-clayey succession.

PREMISES FOR THE GEOTHERMAL RESOURCE CALCULATIONS

Taking into account the hydrogeothermal conditions of Polish aquifers, the authors propose the following classification and definitions of geothermal resources (Gorecki et al., 1995):

- sccessible geothermal resources - thermal energy accumulated in the Earth crust to a depth of 3000 meters and related to the mean annual temperature at the surface and converted into joules;
- static resources of water and geothermal energy - volume of gravitational geothermal water accumulated in pore spaces, joints or caverns of the specific water horizon, expressed in cubic meters or cubic kilometers and converted into joules;
- static recoverable resources of water and geothermal energy - portion of the static resources reduced by recovery factor R. expressed in cubic meters or cubic kilometers and converted into joules;
- disposable resources of water and geothermal energy - volume of gravitational geothermal water of a specific hydrogeothermal horizon or other reserve calculation unit that can be produced under given conditions without specifying the detailed localization and technical/economical parameters of production rate. These are expressed in cubic meters per day or per year and converted into joules per year;
- exploitable resources of water and geothermal energy - volume of gravitional waters which can be produced under given geological and environmental conditions with the rate under optimum technical/economical parameters. Expressed in cubic meters per hour or per day, at a given depression, and reconverted into joules per year.

Geothermal energy accumulated in both the Lower Jurassic and Lower Cretaceous aquifers has been estimated based on hydrogeological models and modem techniques including digital mapping. Estimates were linked to economic assessemnts which allow a realistic evaluation of the utilization opportunities of geothermal water in a prospective areas of the Polish Lowlands.

Accessible Geothermal Resources

The total volume of accessible geothermal resources accumulated to a depth of 3000 meters or to the top surface of the crystalline basement is the sum of the energy of all the calculation blocks. Accessible geothermal resources of the Polish Lowlands are $7.753*10^{22}$ J which is the equivalent of **$1.76*10^{12}$ TOE.**

As a comparison, Jonatansson (1993) reports available geothermal resources of Hungary calculated to a depth of 3000 meters to be $0.2*10^{12}$ TJ which corresponds to $6.8*10^{12}$ TOE.

It is well known that the Pannonian Basin located in the Inner Carpathians displays a very high heat flow 80-100 mW/m^2 (Cermak, Kucerova, 1993). In the Polish Lowlands the heat flow (Plewa, 1994) is much lower in comparison with Hungary (30-40 mW/m^2 in northeastern part and 50-80 mW/m^2 in central and north eastern parts). Thus, the much higher temperatures in the Hungarian aquifers are understandable, as are the fourfold higher accessible resources.

Static Resources of Geothermal Energy

The static resources of the Lower Cretaceous aquifer in the Polish Lowlands amount to some $3.73*10^{20}$ J (Tab.1). Geothermal waters having temperatures over 60°C constitute only 15% of total static resources and occupy 5270 km^2, i.e. 4.6% of the total area of the Lower Cretaceous aquifer.

The static resources of the Lower Jurassic aquifer in the Polish Lowlands are $24.64*10^{20}$ J, i.e. are over 6.5 times higher than those of the Lower Cretaceous ones. Geothermal waters having temperatures over 60°C contribute 37.6% of the total static resources of the aquifer and occupy 24,656 km^2 of the basin.

Static Recoverable Resources of Geothermal Energy

This class of resources amounts to $4.55*10^{19}$ J in the Lower Cretaceous aquifer (Tab.1). About 31.4% of the total resources fall into the temperature range over 60°C and occupy 4.6% of total area of the aquifer. Static recoverable resources are 12.2% of static resources of the Lower Cretaceous aquifer.

In the Lower Jurassic aquifer the static recoverable resources of geothermal energy are $4.36*10^{20}$ J. Geothermal waters having temperatures over 60°C make up 50.2% of static recoverable resources and occupy 15.6% of the total aquifer area. The static recoverable resources are 17.7% of the static resources of the Lower Jurassic aquifer.

Disposable Resources of Geothermal Energy

Utilization of geothermal heat can be evaluated economically by means of various methods of different precisions. This is related to the stages of the preinvestment phase in which various analyses are prepared from general to detailed. Such a procedure makes it possible to eliminate sufficiently early the projects which have little development potential.

Apart from advanced, detailed economic analyses (e.g. those applied in feasibility studies) it appears reasonable in some circumstances to undertake simplified evaluations (i.e. for opportunity studies). Such evaluations can be applied to hydrogeothermal aquifers in order to select and classify the areas with a potential for utilization.

The authors have applied the so-called "power factor" (Gosk, 1982) which expresses how many times the thermal power of a geothermal recovery exceeds the thermal power equivalent to the investments and production costs of this energy. A power factor less than 1 indicates that the "energy value" of invested funds is higher than the energy produced. The power factor has a quasieconomic character and combines both economic and energetic aspects of geothermal heat production. However, no conclusions can be made on this basis about the competitiveness of geothermal heat versus conventional energy sources.

The power factor makes it possible to select and classify those parts of geothermal aquifers that have a potential for future utilization. The power factor has also been applied to estimate the disposable geothermal resources of the studied aquifers. These resources have been determined for the areas where the power factor exceeds 1 and the load factor of plant equals 1. Thus, only those areas have been taken into consideration which have potential for the utilization of geothermal heat resources.

Disposable resources of geothermal energy in the Lower Cretaceous aquifer are $3.82*10^{17}$ J per year, which corresponds to $8.68*10^6$ TOE. This means 0.84% of the recoverable static resources and 0.10% of the static resources of the aquifer.

In the specific temperature intervals of the Lower Cretaceous aquifers the following disposable resources are accumulated:

- up to 60°C - $2.40*10^{17}$ J/a, i. e. 62.8 % of the resources,
- 60 - 80°C - $1.23*10^{17}$ J/a, i. e. 32.2 % of the resources,
- over 80°C - $0.19*10^{17}$ J/a, i. e. 5.0% of the resources.

Waters of temperatures in excess of 60°C constitute 37.2% of total disposable resources and occupy 4349 km^2, i.e. 3.8% of total area of the aquifer.

The Lower Jurassic aquifer of the Polish Lowlands accumulates $17.31*10^{17}$ J per year of disposable geothermal resources which is the equivalent of $39.34*10^6$ TOE and equals 0.40% of the recoverable static resources and 0.07% of the static resources of the aquifer.

Waters of specific temperature intervals contribute the following values of disposable resources:

- up to 60°C - $7.89*10^{17}$ J/a, i. e. 45.6 % of the resources,
- 60 - 80°C - $5.48*10^{17}$ J/a, i. e. 31.7 % of the resources,
- 80 - 100°C - $2.52*10^{17}$ J/a, i. e. 14.6% of the resources,
- over 100°C - $1.42*10^{17}$ J/a, i. e. 8.2% of the resources.

Waters of temperatures above 60°C constitute 54.5% of the total disposable resources and occupy an area 24,369 km^2, i.e. 15.4% of the total area of the Lower Jurassic aquifers.

CONCLUSIONS

The calculated disposable geothermal resources of the Polish Lowlands can be correlated with the geothermal reserves calculated for Europe by Cataldi (1993) which are $6*10^{19}$ J/a, i.e. $1430*10^6$ TOE/a. According to this author, the utilization of geothermal energy in Europe is limited to a relatively small area of several thousands of square kilometers which contain about 5-10% of total reserves. Here, parameters of the reserves are especially favourable and, simultaneously, the energy market may be attractive for potential investors.

Total disposable resources of both the Lower Cretaceous and Lower Jurassic formations in the Polish Lowlands amount to some $2.1*10^{18}$ J/a, which corresponds to $48*10^6$ TOE/a. This value determines the hypothetical development programme of geothermal energy production in Poland. If, for instance, the number of 20 installations is considered with annual heat production *500* TJ each, then the utilized geothermal reserves will be 220.000 TOE/a which means anly 0.5% of the proved disposable resources of the Polish Lowlands. The question arises: what is the realistic figure of exploitable resources in this area?

Estimation of exploitable resources together with evaluation of the possible geothermal installations must take into account the following controls:

- geothermal energy must be utilized very close to the well site. Hence, exploitable resources will be limited to urban and industrial zones as well as to farmlands and recreational centres;
- due to significant capital *costs* of geothermal installations, the local energy market must be sufficiently attractive for investors;
- the development of geothermal installations is limited to the area of optimum parameters of waters.

Assuming that **3-4%** of disposable resources will be utilized, the exploitable resources can be estimated as 1.32 - 1.76 millions TOE which corresponds to 120 - 160 installations of an annual heat capacity of 500 TJ each. **This** value can be compared with data by Jonatansson (1993). According to these data, the geothermal potential of Slovakia which can be exploited and utilized economically **is** the equivalent of approximately 2000 MW. If a full load of installations is hypotesized, this value corresponds to an annual heat production of $6.3*10^{16}$ J or 1.4 millions TOE.

In conclusion, geothermal energy can be utilized in an economically resonable way in many areas of the Polish Lowlands. However, the scale of energy production will depend on various factors mentioned earlier. Of vital importance is a basic change or even breakthrough in energy management style and in the traditional way of **thinking** in the energy industry.

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TABLE 1. GEOTHERMAL RESOURCES IN THE POLISH LOWLANDS

Research area	Tempera-tures	Area	RESOURCES					
			Accesible geothermal resources	Static resources	Static recoverable resources	Disposable resources		
						Area	Energy	Energy
Formation	[°C]	[km^2]	[J]×10^{22}	[J]×10^{20}	[J]×10^{19}	[km^2]	[J/a]×10^{17}	[TOE/a]×10^6
Polish Lowlands	up to 3 km	261,706.5	7.75					
I. Early Cretaceous reservoir	up to 40	98,164.8		2.40	1.66	13,598.4	0.96	2.18
	40 - 60	12,086.4		0.77	1.46	8,808.0	1.44	3.27
	60 - 80	4,819.2		0.48	1.19	3,907.2	1.23	2.80
	80 - 100	451.6		0.08	0.24	441.6	0.19	0.43
	TOTAL	**115,521.6**		**3.73**	**4.55**	**26,755.2**	**3.82**	**8.68**
II. Early Jurassic reservoir	to 40	97,800.0		6.57	5.10	22,956.0	1.69	3.84
	40 - 60	36,144.0		8.80	16.60	35,472.0	6.20	14.09
	60 - 80	16,808.0		6.70	15.50	16,808.0	5.48	12.45
	80 - 100	5,416.0		1.78	4.40	5,336.0	2.52	5.73
	over 100	2,432.0		0.79	2.00	2,224.0	1.42	3.23
	TOTAL	**158,600.0**		**24.64**	**43.60**	**82,796.0**	**17.31**	**39.34**

[TOE] - Tons of oil equivalent 1 TOE = 4.4×10^{10} J

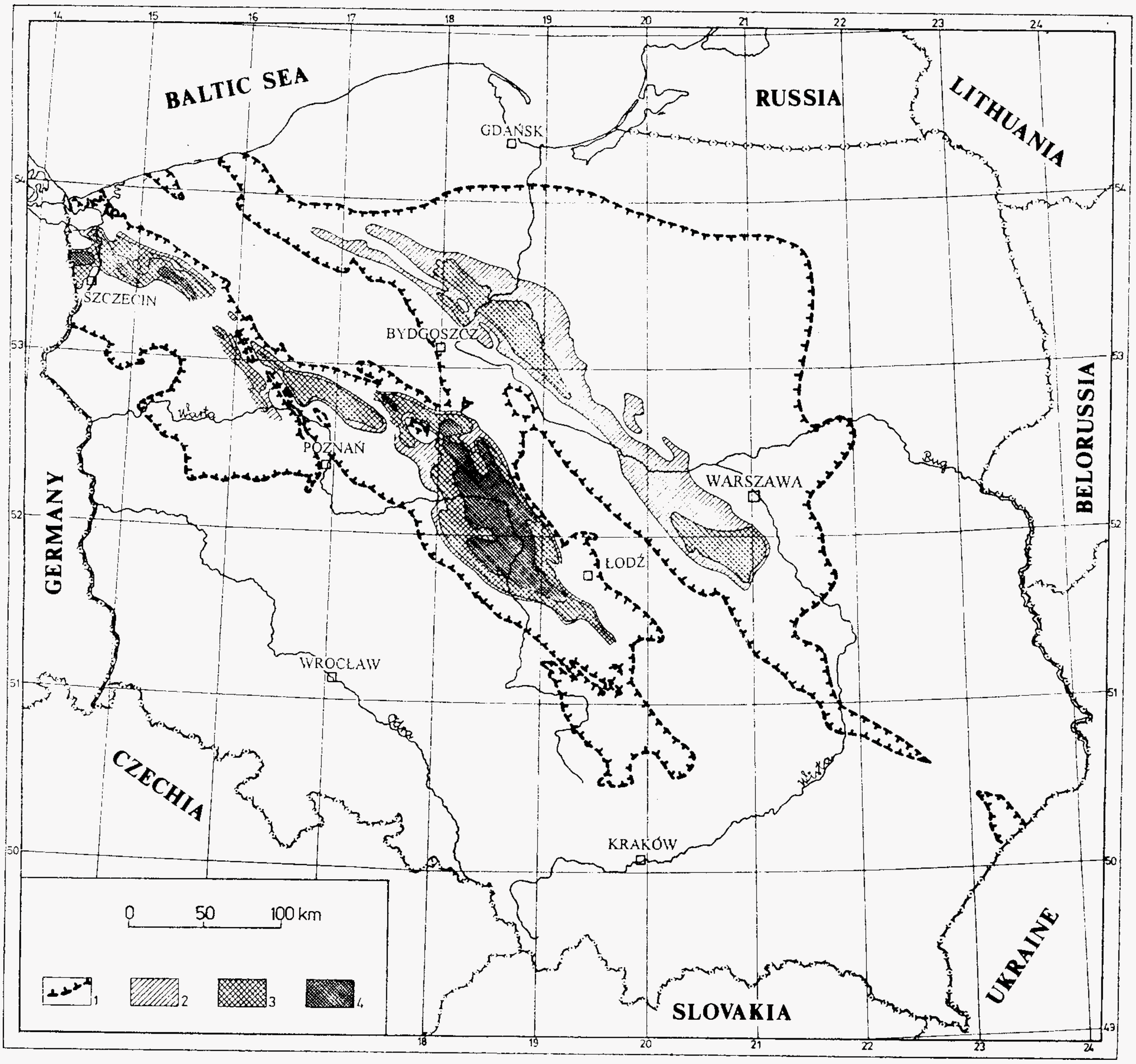

Figure 1. MAP OF UNIT DISPOSABLE RESOURCES OF GEOTHERMAL ENERGY OF LOWER CRETACEOUS AQUIFER IN THE POLISH LOWLANDS

1 - extent of Lower Cretaceous formations, 2 - values from 2 to 10 MJ/m^2, 3 - values from 10 to 25 MJ/m^2, 4 - values from 25 to 50 MJ/m^2,

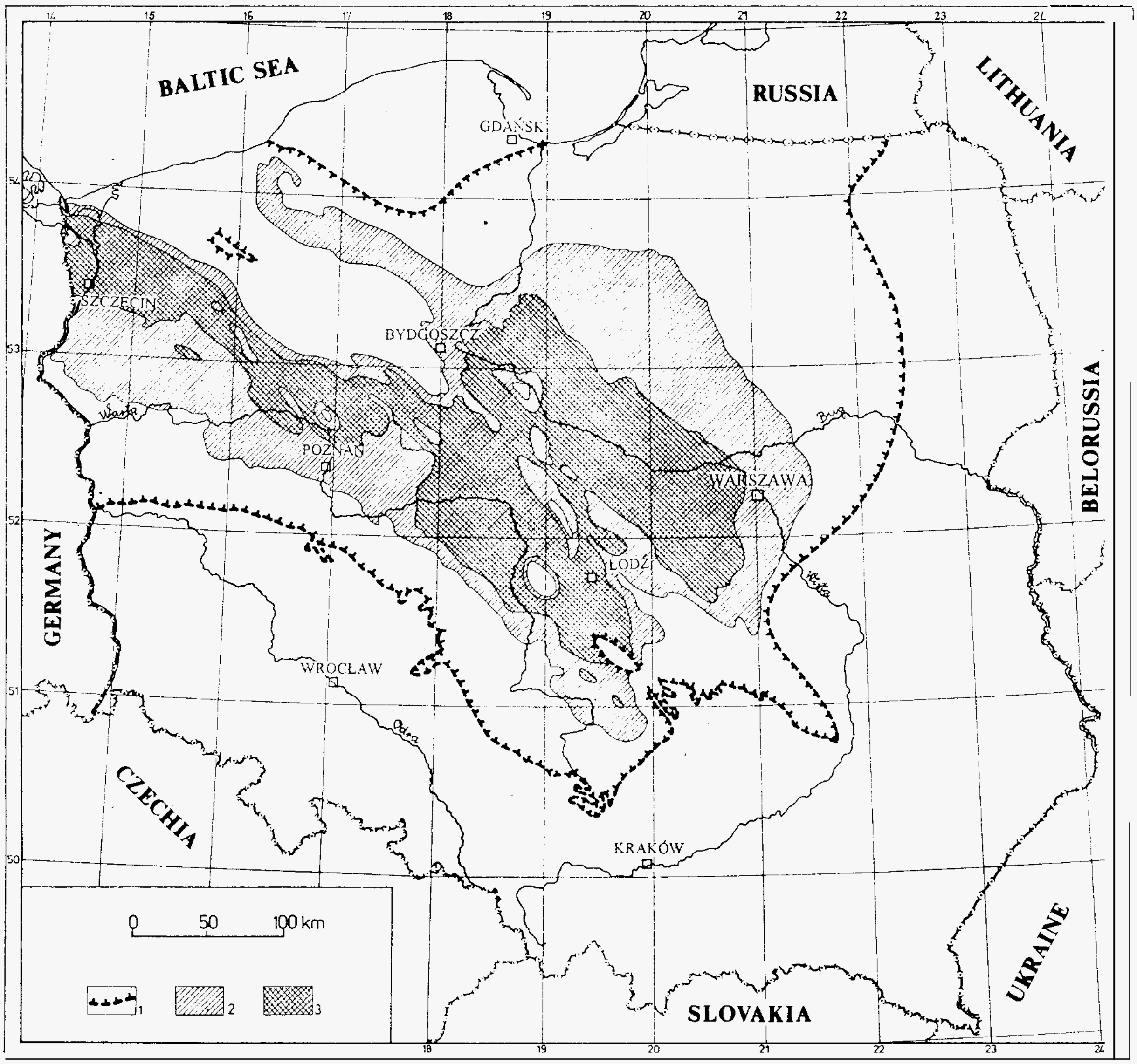

Figure 2. MAP OF UNIT DISPOSABLE RESOURCES OF GEOTHERMAL ENERGY OF LOWEK JURASSIC AQUIFER IN THE POLISH LOWLANDS

i - extent of Lower Jurassic formations, 2 - values from 5 to 20 MJ/m^2, 3 - values from 20 to 100 MJ/m^2