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Complex evaluation of abandoned hydrocarbon wells for geothermal use in North Hungary

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ABSTRACT

It is a well-known fact that the geothermal conditions are very good in Hungary. There are thousands of abandoned wells as a result of the previous intense petroleum exploration activity. The purpose of the completed research is to introduce a new methodology to utilize abandoned or unproductive oil exploration drillings/wells for geothermal energy production in Hungary. An innovative and complex evaluation method was developed and improved to provide the possible future investors in the geothermal energy business with adequate information for the decision-making process. To achieve this goal, the different data of 1211 wells were investigated with the proposed evaluation system in North Hungary to give information about the geothermal energy potential on well as well as area scale. The most important parameters were determined, which are critical for the geothermal energy utilization or the balneological use. Creating a geothermal well can cost more than $ 5.7 million, depending on the depth, so the effectiveness of our research can greatly reduce the cost and designability of building such a system.

1. INTRODUCTION

The Faculty of Earth Science and Engineering along with Research Institute of Applied Earth Sciences launched the PULSE research project in 2016. The project is founded by the national GINOP program. The project meets the objectives defined by the National Energy Strategy (MND, 2012). Namely, it targets the pillars “Security of energy supply” and “Sustainability” along with “Renewable energy sources” (Ilyés et al., 2017). Out of the three modules of the project our team is involved in the third one, entitled “energetic utilization of unproductive and abandoned wells”. In this module a database of unproductive and abandoned hydrocarbon extraction wells is being built and an attempt is made to find new use of these, in the field of geothermal energetic applications. Another research direction in the module aims the undersurface storage of energy obtained from renewables or industrial waste heat. The idea of geothermal utilization of hydrocarbon wells seems obvious if we consider the general temperature range of 65 - 150 ºC of fluids extracted in oil fields (Liu et al., 2018). In spite of this, research of the topic has been started rather recently. First pilot tests for power generation have been initiated in the 2000’s in Wyoming, USA and Huabei, China.

Vast majority of geothermal power plants installed in developed oil fields use binary cycle systems. Direct utilization, with some exceptions, is also a rather newly discovered research field. Two recent reviews of Wang et al. (2018) and Liu et al. (2018) lists the already operating implementations.

In Hungary a research project regarding the geothermal usability of abandoned oil wells was initiated in 1995 by the Hungarian Oil Company (Árpási et al., 1997). The first geothermal power plant was to be established in Iklódbördőce (Zala County). The draft included modification of two abandoned hydrocarbon extraction wells (Bobok and Tóth, 2007). One for thermal water extraction and one for reinjection. Due to the low water yield, the investment was not completed (Tóth, 2017).

2. GEOTHERMAL ASPECTS OF NORTH HUNGARY

The two main geographic landscapes of the northeastern part of Hungary are the North Hungarian Mountains (NHM) and the Great Hungarian Plane (GHP). The pre-Neogene basement is buried in the GHP to depths reaching 7000 m. Pre-Neogene, pre-Cenozoic rocks however are outcropping and forming partially the NHM. Miocene volcanic rocks are also widespread in the mountainous range (Buday et al., 2015).

Both the mountainous range and the basement of the basin reflects a complex geologic structure. The basement includes a variety of Mesozoic (carbonates, shallow and deep-sea siliciclastic rock), Paleozoic (siliciclastic and low-grade metamorphic rocks) and older (metamorphic) rocks. Large areas have a still unidentified basement. The southeastern border of the area overlaps the Mid-Hungarian fault zone (WSW-ENE), which divides the Alcapa and the Tiszia plates. Another important tectonic feature, the Darnó zone (SW-NE) is crossing the area at the NW ending of the Bükk Mountains. The thickness of Cenozoic sediments of the basement also shows a large range. The deepest part of the basement is reaching 4000 – 5000 m in the area.

For the purpose of the current phase of the project, two regions of interest had been delineated (ROI 1 and ROI 2, fig.1). The thickness of Neogene sediments in ROI 1 increases dramatically from NW to SE, up to 4500-5000 m. The central part is characterized by a chain of depressions (3000 – 3500 m depths) elongated in SW-NE direction, followed to SW by a slightly elevated ridge (1000 – 1500 m depths) of the same direction. In case of ROI 2 the deepest parts are found in the center (~4000 m) and the northern edge (~5500 m) of the region. Towards the boundary the thickness of sediments generally is decreasing to about 1500 – 2000 m.

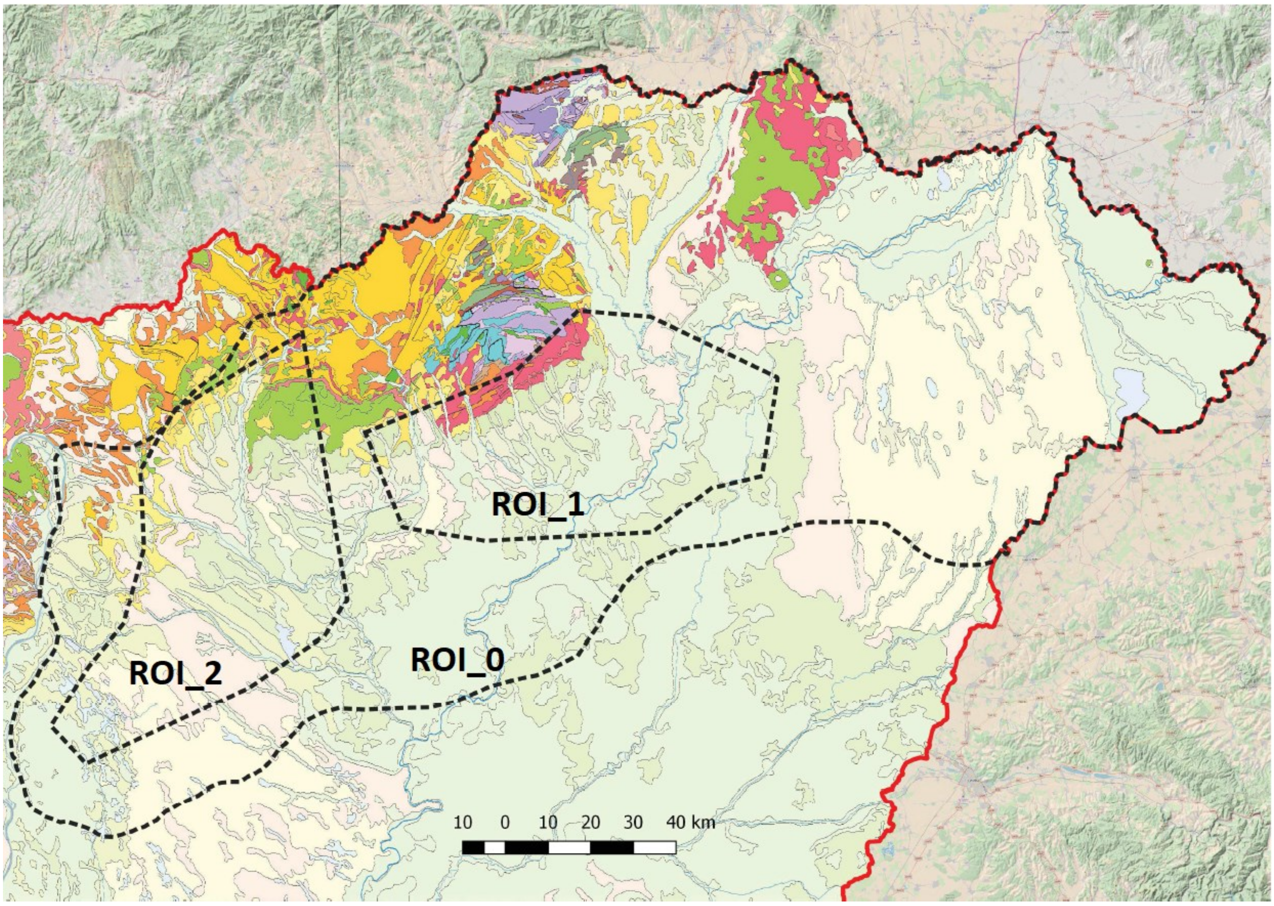

Figure 1: Geologic map of Northeast Hungary showing the regions of interest.

The Neogene sediments are mostly composed of river deposits (gravel, sand, clay, loess). In the northern part of two region of interest other types of rocks are also found. These zones are overlapping with the mountainous range and the feet of them. In case of ROI 1 Miocene acidic tuffs (of riolite, dacite and riodacite) are present on the surface of the northwestern part. In ROI 2 pyroxene and amphibole andesite and sandstone is found on the on the surface, both of Miocene age.

Generally speaking, Hungary may be characterized by a high geothermal gradient (of about 50 °C/km) due to the relatively thin crust. The actual spatial distribution of the geothermal gradient roughly reflects the geologic structure of the country. The region of interest of current project is characterized by values between 55 and 70 °C/km. The heat flow in the area varies between 80 and 110 mW/m2. Rock temperature under such conditions may range between 50 - 80 °C in 1000 m depth and 90 - 120 °C in 2000 m depth (Dövényi et al., 1983).

Although a few wells have been drilled in the 19th century, the large scale exploration in the area began in the 1950's. The majority of the wells are of hydrocarbon exploration and water wells. Exploration specifically for thermal water also dates back to the middle of the last century but it expanded in the last few decades.

3. DATABASE

One main pillar of the research work is the database of abandoned and unproductive hydrocarbon wells which has a theoretical potential of geothermal energetic use. The starting point of the database included three sources, namely:

- Geothermal survey of Hungary (Tóth, 2016),
- Database of unproductive hydrocarbon wells in the Bükk region,
- Cadaster of Hungarian thermal water wells (VITUKI, 1994, MFGI, 2015).

The Geothermal survey of Hungary (Tóth, 2016) includes basic data (name, identification code, coordinates, depth and year of construction, bottom hole and wellhead temperature) of 1704 wells from all around the country. 1540 wells were originally drilled for geothermal purpose and 167 were drilled for hydrocarbon exploration or extraction. All of them are considered to be potentially used with geothermal function.

In the northern region, based on all available data, the number of hydrocarbon (used, recultivated and abandoned) and thermal wells currently contains 1211 wells in the database with more detailed descriptions (eg. geological profile, cover and filtration, flow rate and water level).

The Cadaster of Hungarian thermal water wells is a large series, at the moment edited by the Mining and Geological Survey of Hungary. It also includes a details of every thermal water wells drilled in the country. The complete detailed description is however only available in the well log-books. Therefore, the database is not considered complete yet. It will be supplemented by the well log-books. In this process many geophysical logs will have to be reinterpreted.

The requirements on the database is to include every useful data about the structure of the well, the geologic profile, hydrogeological properties, testing results and temperature regimes. Availability of detailed description of the structure of existing wells are essential if geothermal application is considered. To handle this amount of complex information a relational database will be designed. The complexity is also reflected by the first drafts of the database scheme.

For the purpose of the project, the database includes highly detailed data for two selected area in Northeast Hungary. For wells outside the two regions of interest only the basic dataset will be available. The procedure of delineating the area of interest and the first results of analyzing the database are described in the next section.

3. RESULTS IN THE REGION OF INTEREST

As the work implies a vast labor of database building, two regions of interest had been delineated (ROI 1 and ROI 2). The initial area extended over Northern Hungary, and parts of Northern Great Plane and Central Hungary. Inside this area two smaller region of interest had been delineated (map on figure 1.). The delineation was based on geologic considerations and on former analysis of demands on geothermal energy. The two area of interest includes the following small regions:

- Bükkalja, Borsodi-Mezőség, Hevesi-sík
- Gödöllői-dombság, NW part of Jászság, Mátraalja, Cserhátalja, SW part of Pesti-síkság.

These includes a number of 1211 respectively 259 wells in the database at the moment.

During the project the database construction and the analysis is to be performed on the two area of interest. The methodology, which is also developed as part of the project will be applicable also outside them upon third party requests.

During and after the database building it was found that many wells will have to be neglected during the work. The reason of it is that the documentation of many wells lacks some important data. Hopefully the following data supplements will reduce the number of these data gaps. For this reason, some geophysical logs and other measurements will be reinterpreted in a later phase of the project. For some parameters or properties, estimation methods will be used, however the data obtained this way will handled aware of its uncertainty.

After the first stage of database building, the already available information is being used for a detailed geothermal characterization of the region of interest. The depth and thickness map of geologic (geochronological) units have been created. The most important results are the temperature distribution maps for different depths and different geologic units. An example for ROI 1 is presented in figure 2.

4. EXPERT METHOD FOR ESTIMATING GEOTHERMAL USE IN A SPECIFIC AREA

The cost of high-resolution geological exploration is very significant (Turai-Vurom, 2013), for a 10 km x 10 km x 5 km block profile around HUF 1 billion. In many cases, however, the cost and time requirements of the required geological exploration cannot be assured, and therefore only by using already known geological information. we have relative expert estimates that do not provide absolute geothermal energy estimates, only expert advice on the applicability of a given area for geothermal energy generation. In the next section, we present a much lower cost expert estimate using only existing infrastructure and geological information.

To assess the use of all deep wells for geothermal energy production in the area, an expert estimate has been developed, where each parameter tested is weighted by 1-5 points (1 point: weak, 5 points: excellent). The names of the examined geological and infrastructure parameters and the qualification of the DEP-24 (Demjén Pentecostal) borehole are shown in Table 1. From the table it can be seen that according to the arithmetic mean (3.1) of the rating of the eight parameters examined, deep well drilling is conditionally recommended because the well, despite its advanced age and low value of well function, has high temperature but moderated geothermal energy has good infrastructure.

Table 1: The interpretation of the DEP-24 well

DETAILED GEOTHERMAL ENERGY QUALIFICATION			
	Test Parameter	***Value***	***Result (points)***
1.	**Year of drilling** *(scale -1970 – 1; 1971-1980 -2; 1981-1990 -3; 1991-2000 – 4; 2001- 5)*	1971	**2**
2.	**Well function** *(scale: technically eliminated, recultivated - 1; technically eliminated - 2; secured with cement plug - 3; designed for oil production - 4; water producing, water repellant, producing gas - 5)*	technically eliminated, recultivated.	**1**
3.	**Fluid volume (m^3/nap)** [**Tested** - Estimated] *(scale: 1-10 -1; 11-100 – 2; 101-1000- 3; 1001-5000 – 4; 5001- 5)*	233.2	**2**
4.	**Average Fluid Temperature (°C)** [**Tested** - Estimated] *(scale: 4-20 -1; 21-40 – 2; 41-70 – 3; 71-100 – 4; 100 – 5)*	50	**3**
5.	**Geothermal energy (kJ) from the fluid:** *scale: 0-500e – 1; 501e-1M; 1M-5M; 5M-10M -4; 10M- 5)*	48 M	**5**

6.	**Geothermal energy (kJ) from rock**	…	**4**
7.	**Total length of screen section (m)** *(scale: 1-20 -1; 21-40 – 2; 41-70 – 3; 71-100 – 4; 100 – 5)*	85	**4**
8.	**Total distance of infrastructure (km)** *(scale: 0-5 -5; 5-10 -4; 10-20 -3; 20-30 -2; 30- 1)*	7.1	**4**
		Average	**3.1**

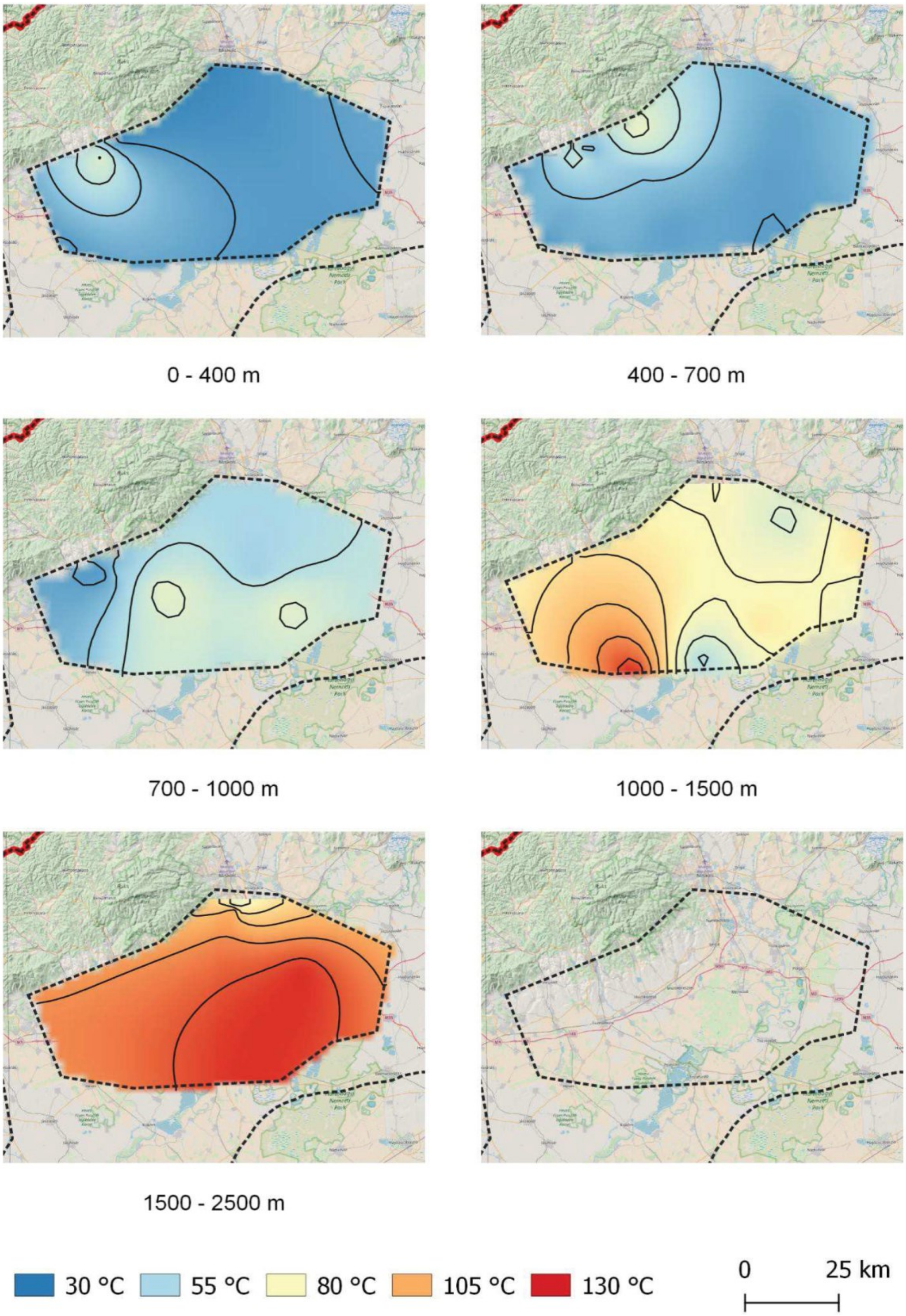

Figure 2: Temperature distribution in different depth intervals inside ROI 1

The distribution of the parameters examined for the evaluation is shown in Fig. 3. In the figure, besides the serial number and value of the parameters, the mean of the parameters is shown with a dashed line and also with a number in the middle.

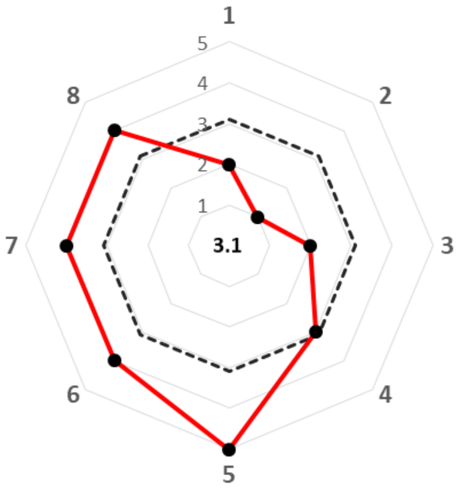

Figure 3: Distribution of the parameters examined for evaluation and the mean of the parameters (middle)

Pool modeling can be used to accurately determine the amount of geothermal energy that can be extracted from the rock matrix (parameter 6) and the pore fluid (parameter 5). Basin modeling is used for temporal and spatial modeling of sedimentation basins in hydrocarbon exploration, but this approach is also well suited for thermal history reconstruction during geothermal exploration.

Basin modeling is suitable for erecting a 3D geothermal model below the investigated area, provided that preliminary geological-geophysical surveys can determine the values of the input parameters needed to construct the model.

If the amount of geothermal energy that can be extracted from the fluid is known from test wells at a given well (parameter 5), then this is subtracted from the total energy determined by basin modeling to yield geothermal energy from the rock matrix (parameter 6).

The result of geothermal modeling using the PetroMod software in the case of DEP-24 drilling is shown in Fig. 4.

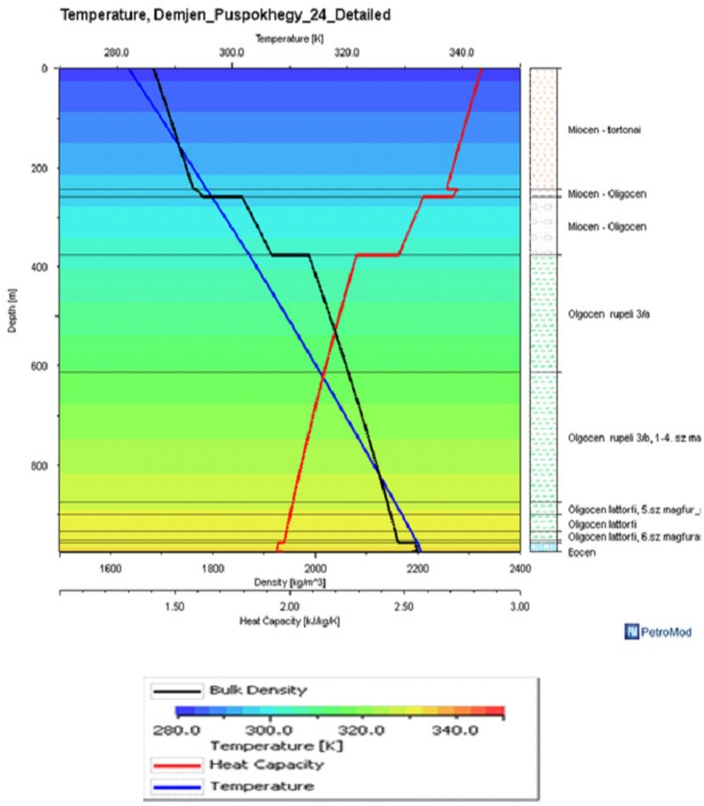

Figure 4: Depth distribution of rock density (in black), heat capacity (in red) and temperature (in blue) in DeP-24 well

Then, for each well in the area, calculate the mean rating result (E_i) and construct the area value (A_v) with the following relationship:

$$A_v = \frac{\sum_{i=1}^{N} E_i}{N} \quad (1)$$

Based on the area value, the use of the area for geothermal energy production can be divided into the following three groups:

- TÉ <3.0 - geothermal use of the area is not recommended,
- 3.0 <TÉ <4.0 - geothermal use of the area is recommended,
- 4.0 <TÉ ≤ 5.0 - geothermal use of the area is strongly recommended.

If a smaller part of the area can be given a higher TI value, then it is advisable to consider narrowing the area. By limiting the area, the amount of geothermal energy that can be extracted will generally be smaller, but due to the improvement in extraction efficiency, it is still worth considering the area narrowing in such cases.

5. HEAT STORAGE IN GEOLOGIC FORMATIONS

In addition to geothermal energy production, the research also focuses on the possibility of energy storage in geologic formation. For this, the source of energy may be a renewable or industrial waste heat. Progress have also been made in this research direction. Two staring points were the review of literature and construction of idealized conceptual models. The conceptual models are used to simulate the heat transfer and storage in a theoretical case. The aim of simulating theoretical test cases is to identify factors affecting the possibility of heat storage and to determine the ideal conditions for it.

Later adequate flow and transport model for a few actual test sites will be built. The selection of test sites will partly be based on the conclusions of the conceptual models.

The first theoretical test case represents a porous media flow model for a depth of around 500 m. This resembles the geological, hydrogeological conditions of a large industrial site in Tiszaújváros. The industrial plant serves as the source of waste heat.

6. CONCLUSIONS AND FURTHER WORK

A large database of wells of potential geothermal use have been built and will be supplemented in the near future. The database includes abandoned and unproductive hydrocarbon wells and many already used geothermal and water wells. Information on geologic strata, temperatures, flow rates, water chemistry as well as screening and casing is found in the database. The dataset serves as basis for geothermal assessment of some selected areas. Twofold analysis will be made: localized in a well scale and regional, which finally may lead to further geothermal developments.

Based on data availability, geologic and infrastructural considerations, two regions of interest have been delineated. This takes into account the previously formulated demands on geothermal energy.

The analysis and interpretation of the database gave insight into geothermal conditions of the regions of interest. As the database will be supplemented with further details, it will allow the proper geological, technical and economical assessment of possible geothermal developments.

In cases where the detailed geological model is not known and the cost and time needed to develop the model cannot be provided, the article presents an expert method. The suitability of the studied area for geothermal energy production can be estimated by expert method.

As an alternative solution, the heat storage in underground media is also being inspected. This may improve the reliability of renewables and may enhance the use of waste heat in industrial sites. The first simulations in this respect have also been started. The flow and heat transport simulation resemble the geologic and hydrogeologic conditions of a large industrial site nearby (in Tiszaújváros). The simulation domain extends 500 m deep and is composed of porous medium.

In the near future, in a following stage of database building, an extensive completion of the database will be proceeded. This certainly imply the modification of the current database scheme. The development of a step-by-step methodology of well scale and regional scale geothermal assessment is on the way. Currently the two selected ROIs are being investigated. After that an almost algorithmical description of the methods will be formulated.

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