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C.1.

RECENT STATE OF PROSPECTING AND EXPLORATION FOR GEOTHERMAL ENERGY IN SLOVAKIA

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INTRODUCTION

The use of geothermal energy, focused on substitution of fossil fuels and improvement of environment in Slovakia, started in 1958, when the Department of public health and Committee for building were in charge with the investigation of outlet geothermal heat from water of Slovak spas to use it for district heating and commercial areas. In some sites the direct heating by thermal water has gradually started, similarly as the heating with heat pumps and the warming of supply water with heat exchangers. Recently in Slovakia not only the geothermal energy of natural spring thermal water is used, but mainly of geothermal wells located away of thermal springs outflow areas.

On behalf of wider and systematic use of these energetic sources it is necessary to understand the peculiarities of particular occurrences of the geothermal energy sources as well as their attributes and possibilities of their use. This emphasizes the urgent seeking of energetic sources in the future providing sufficient amount of energy with lowering both consumption of fossil fuels and loading of environment. Regarding the long-term perspective in the frame of the concept of sustainability, the transition from the use of non-renewable sources towards the energetic systems based on renewable energy sources (RES) utilisation is suggested. Among RES the use of geothermal energy plays the foremost role. For comparison, the use of renewable sources of energy in Slovakia recently represents only 2.6 % from the total consumption of primary energetic sources.

The Government of the Slovak Republic in its Decree No. 282 of April 23, 2003 approved the Concept of renewable energy sources utilisation defining the general frame for the improvement of RES utilisation in Slovakia. The ratios of particular varieties of renewable and secondary energy sources in total amount of technically usable potential according to this concept are stated in Tab. 1.

The unambiguous advantages of the use of geothermal energy:

- It represents the inland (domestic) source of energy, being independent on international conflicts.
- It represents the less expensive source of energy than fossil fuels.
- It belongs among the renewable sources of energy.
- It lowers the load on transport communications by reducing the transport of fossil fuel.
- It lowers the risk of environment endangering by reducing the transport, processing

and use of fossil fuels (accidents on pipelines, building and operation of gas and oil products reservoirs, dumping sites management, emissions).

- It allows controlling the energy prices.
- The maintenance is safe with minimal impact on environment and taking the soil.

The use of geothermal energy becomes the mover of small and medium enterprising development in regions, i.e. farming of forced vegetables and flowers, fish and poultry farming, construction and use of facilities for recreational and rehabilitation purposes.

The evolvement of the use of geothermal energy is inevitably based on available data about distribution, quantity and quality of its sources, about terms for their optimum use for manifold purposes. The comprehensive information is given by investigation and survey.

Table 1 Ratio of particular types of renewable and secondary sources of energy in technically usable potential according to Concept of renewable energy sources utilization elaborated by Ministry of Economy of Slovak Republic and approved by the Decree of Government of the Slovak Republic No. 282/2003

Type	Technically usable potential	
	[TJ]	[%]
biomass	60 458	46.7
geothermal energy	22 680	17.5
solar energy	18 720	14.5
discharge heat	12 726	9.8
biofuels	9 000	6.9
small hydroelectric power plants	3 722	2.9
wind energy	2 178	1.7
Total	129 484	100.0

1. GENERAL GEOLOGICAL INVESTIGATION

The systematic investigation of geothermal energy sources using geothermal wells started in 1971 in Slovakia. The scientific and technical project “Geothermal energy” was dealt with at the Geological Institute of Dionyz Stur Bratislava.

Based on general investigation funded by the state budget (in 1971–1994), the superficial and deep geological setting of the Western Carpathians was characterized in relation to supposed spatial distribution of geothermal water, as well as the spatial distribution of the Earth heat. Overall, 61 geothermal wells were drilled. They gave the general opinion about amount of geothermal energy and water. Among the most significant results there belongs the delimitation of 26 perspective geothermal areas with favourable conditions for energetic use of geothermal water.

Geothermal wells resulting from geological assessment were drilled out of the spring areas of thermal water used for healing purposes in spas. The total capacity of these wells (deep 210–2 800 m) was 904 l.s-1 of geothermal water with temperature at well head from 20 to 92 °C and TDS from 0.4 to90 $g.l^{-1}$. The heat output of verified geothermal water represented the total amount of geothermal energy 176 MW_t, of which the amount of 31 MW_t (131 $l.s^{-1}$) was obtained by the exploitation using reinjection system and the rest of 145 MW_t (773 $l.s^{-1}$) by exploitation using single wells. Knowledge gained during more than two decades lasting investigation of geothermal sources in Slovakia is presented in “Atlas of geothermal energy of Slovakia”, being compiled by the State Geological Institute of Dionyz Stur and published in 1995.

The text of the Atlas provides the summary of geological, geophysical, hydrogeothermic and geochemical data, obtained during geothermal energy investigations. Findings obtained mainly by basic research principally extended the knowledge about the Tertiary filling of basins, as well as about pre-Tertiary bedrocks of the whole Inner Western Carpathians, the heat and temperature fields and hydrogeothermal conditions.

Geothermal activity of the territory is visualized in maps, including thematic geothermal map, map of the heat flow on the surface, map of the heat flow on Moho-discontinuity, geothermal maps of Slovakia, maps of geothermal activity and hydrogeothermal maps of selected areas, maps of technological parameters of geothermal water and their removal after heat exploitation. Maps are supplemented by cross-sections, logging profiles of geothermal wells and tables with data obtained by geological investigations.

The knowledge on geothermal sources of Slovakia from the primary investigation became an integral part of next publication titled "Atlas of geothermal sources of Europe" (Publ. No.EUR 17 811 of the European Commission). This atlas contains the brief hydrogeothermal characteristics with evaluation of sources of perspective areas. The Liptov Basin and Central depression of the Danube Basin are evaluated in details.

The results of geological investigation of the sources of geothermal water in Slovakia were used also for establishing the map of "Sources of geothermal and mineral water", being a part of Landscape Atlas of the Slovak Republic, issued by the Ministry of Environment of the Slovak Republic and the Slovak Environmental Agency in 2002. Map schematically depicts the geological setting of the territory, main collectors of geothermal water, perspective areas or structures of the geothermal water, efficiency and temperature sources, as well as the heat power of geothermal water in evaluated areas.

Based on results of the primary investigation and survey of geothermal sources we can ascertain that Slovak Republic, owing to its natural conditions, possesses significant potential of geothermal energy, evaluated to total value 5 538 MW_t. The sources of geothermal energy are represented mainly by geothermal water bound to the Triassic dolomites and limestones of the Inner Carpathian tectonic units, less to Neogene sands, sandstones and conglomerates or to Neogene andesites and their pyroclastics. These rocks, as collectors of geothermal water located away of outflow areas, are in the depth 200 – 5 000 m and encompass the geothermal water with temperature 15 – 240°C. Taking into account the distribution of collectors and activity of geothermic field altogether 26 perspective areas or structures appropriate for obtaining geothermal energy were distinguished on the territory of the Slovak Republic.

2. REGIONAL GEOLOGICAL INVESTIGATION AND PROSPECTING SURVEY

Both, the Government of the Slovak Republic by the Decree No. 619 of September 7, 1993 and National Council of Slovak Republic by the Decree No. 339 of November 18, 1993, agreed the Strategy, principles and priorities of the state environmental policy with stated demand of next evaluation of perspective geothermal areas delimited by primary investigation.

The Proposal of the concept of geothermal energy utilisation in the Slovak Republic, approved by the Slovak Government by its Decree No. 861 of December 10, 1996 assigns the Ministry of Environment of the Slovak Republic to guarantee the regional investigation and prospecting survey of first perspective areas. The demand and support of these geological works was consequently stated in the National strategy of the sustainable development of October 2001 and in Concept of geological investigation and survey of the territory of the Slovak Republic by 2006 (with perspective by 2010) approved by the governmental Decree No. 334 of April 3, 2002. In agreement with above stated documents the Ministry of Environment of the Slovak Republic guaranteed full realization of regional investigation and prospecting survey in the area of Kosice Basin – the Durkov site, the Levoca Basin – part Poprad Basin, Liptov Basin, Skorusina Basin, Central depression of Danube Basin – Galanta area, Komarno block, Ziar Basin, Upper Nitra Basin, Topolcany embayment and Banovce Basin as well as the Humenne Ridge. In the territory of Rimava Basin recently the regional hydrogeothermal evaluation terminates and will finish in 2009, in Rudno Basin these works just start. Geological works have brought the results stated below.

Kosice basin – Durkov site

Geothermal water reservoir is located in the depth of 2000 – 3500 m. During 1998 and in the first half of 1999 three geothermal wells GTD-1 to 3 were drilled with the vertical depth 2252 – 3210 m. The major inflow zones are located on the top of Triassic dolomites of Veporicum with fissure and karstic permeability. The free flow discharge during the short tests ranged from 50 to 65 $l.s^{-1}$ with the temperature from 125 to 134°C. The measured reservoir temperature in the depth of 3000 m reached 143°C. The average heat flow density is 94,4 $mW.m^{-2}$. The TDS of geothermal water is 29 - 32 $g.l^{-1}$. Chemical composition of geothermal water is the clear Na-Cl chemical type with the low $Na\text{-}HCO_3$ content.

In Durkov area the total amount of geothermal water is 170 $l.s^{-1}$ that corresponds to total recoverable amount of geothermal energy of 113,4 MW_t.

Levoca Basin – part Poprad basin

The geothermal water aquifers are in pre-Tertiary basement formed by Triassic carbonates represented by Choc and Krizna nappes. In the centre of Poprad Basin the thickness of Choc nappe reaches 200 – 1100 m. Extremely thick thickness of 1200 – 2000 m reaches the Choc nappe eastern and east-southern of Vrbov fault passing to Levoca mountains.

The temperature in Pre-Paleogene basement of Poprad Basin ranges from 50 to 85°C. The average heat flow density in the basin is 67 mW/m^2. The chemical composition of water is $Ca\text{-}Mg\text{-}HCO_3\text{-}SO_4$ type with TDS ranging from 2,9 to 4,1 $g.l^{-1}$.

The total amount of geothermal water of Poprad Basin is 215,6 $l.s^{-1}$ that corresponds to total recoverable amount of geothermal energy of 33,8 MW_t.

Liptov Basin

The basement of Paleogene of Liptov Basin is formed by Choc and Krizna nappes. From the morphological and structural viewpoints it can be divided into several depressions and elevations. The biggest thickness of Paleogene sediments is in Liptovska Mara depression and it reaches 2200 – 2300 m.

The geothermal field in Liptov Basin is very variable. In Kokava depression and in Besenova horst the geothermal field is disturbed by convective heat transfer, the temperature in the depth of 1000 m varies between 29 - 46°C, in the depth of 2000 m between 46 - 76°C. The heat flow density is ranging from 52,0 to 71,7 mW/m^2.

The total amount of natural geothermal water of Liptov Basin is 248 $l.s^{-1}$ that corresponds to total recoverable amount of geothermal energy of 34,5 MW_t.

Skorusina Basin

Skorusina Basin is composed by the rocks of Inner Carpathian Paleogene with thickness ranging from 200 to 2600 m, in their underlier the Choc and Krizna nappes, envelope unit and crystalline rocks occur. Geothermal waters are connected to Triassic dolomites, Krizna and Choc nappes. Their thickness ranges from 300 to 600 m, the maximum depth of deposition is in the NE part of depression i.e. -3600 m.

Depending on deposition depth of collectors the temperature of geothermal waters ranges in interval 25 – 125°C. In prevailing area the heat flow density ranges between 60 – 65 $mW.m^{-2}$. Geothermal water of chemical type $Ca\text{-}Mg\text{-}HCO_3$, respectively $Ca\text{-}Mg\text{-}HCO_3\text{-}SO_4$, has the TDS in the range 0,6 – 2,5 $g.l^{-1}$.

The total amount of natural geothermal water of Skorusina Basin is 118 $l.s^{-1}$ that corresponds to total recoverable amount of geothermal energy of 24 MW_t.

Central Depression of Danube Basin - Galanta area

From the structural – geological points of view the Central Depression of Danube Basin – Galanta area is represented by Galanta depression and its neighbourhood with occurrence and utilisation of geothermal wells. The average temperature in the depth of 1000 m is 50,3°C, in the depth of 1500 m 69,9°C, in 2000 m 88,5°C and in the depth of 2500 m up to 106,5°C. The heat flow density ranges between 71,4 – 81,6 mW/m^2, the average value is 76,8 mW/m^2.

In this area the petrogene geothermal water occur of $Na\text{-}HCO_3$ chemical type with TDS up to 1 $g.l^{-1}$, water of Na-Cl chemical type with the presence of A_1 component above 30 mval% and water of Na-HCO_3 chemical type with TDS ranging from 1 to 5 $g.l^{-1}$ and clear Na-Cl chemical type with TDS from 5 to 10 $g.l^{-1}$.

The total amount of natural geothermal water is 176,0 $l.s^{-1}$ that corresponds to total recoverable amount of geothermal energy of 39,7 MW_t.

Ziar Basin

Pre-tertiary bedrock of Ziar Basin is formed by Choc nappe - in SE and NW parts of the area by Triassic carbonates and in the central part by ipoltice group (shales, sandstones). In the deeper structure, under the Choc nappe, the Mesosoic rocks occur (Triassic – Cretaceous) of Velky Bok group or Krizna nappe. Heat flow density ranges in interval 80 – 100 $mW.m^{-2}$ the average value is 95 $mW.m^{-2}$.

The geothermal water collectors of upper hydrogeothermal structures are built by Triassic carbonates of Choc nappe in which the reservoir temperature of geothermal water ranges from 20 to 150°C. The Triassic carbonates of Velky Bok group or Krizna nappe form the lower hydrogeothermal structures in which the reservoir temperature of geothermal water ranges from 30 – 160°C. The chemical composition of geothermal waters of Ziar Basin represent probably Ca-Mg-SO_4 or Ca-Mg-SO_4-HCO_3 chemical type with TDS from 2 to 4 $g.l^{-1}$.

The total amount of natural geothermal water with the temperature of 60°C (Sklenne Teplice structure) and of 110°C (Ziar structure) is represented by 65,3 $l.s^{-1}$ that corresponds to total recoverable amount of geothermal energy of 22,29 MW_t.

Komarno block

Komarno block is delimitated by isobaths 700 – 800 m of Cretaceous carbonate basement, or tectonic lines passing by the neighbourhood of isobaths. Geothermal waters are stored in Triassic dolomites and limestones.

The geothermal filed of Komarno block is formed mainly by convective heat transfer and it is characterised by anomaly of low temperatures. Their average value in the depth of 1000 m is 24°C, in the depth of 2000 m 34°C and in the depth 3000 m 44°C. The heat flow density is around 60 $mW.m^{-2}$. The chemical composition of geothermal waters is represented by Ca-Mg-HCO_3 chemical type with TDS about 0,7 $g.l^{-1}$.

The total amount of natural geothermal water is 133 $l.s^{-1}$ that corresponds to total recoverable amount of geothermal energy of 9,7 MW_t.

Upper Nitra Basin

Geothermal waters of Upper Nitra Basin are connected with carbonates of Krizna and Choc nappes that reflect their chemical composition. Waters from carbonates of Choc nappe are of Ca(Mg)-HCO_3 chemical type with TDS up to 1 $g.l^{-1}$ and waters of Krizna nappe are of Ca(Mg)-HCO_3-SO_4 chemical type with TDS of 2,1 $g.l^{-1}$. Temperatures in the depth of 500 m under the surface are from 22,5 to 32,5°C, in the depth of 1000 m from 35 to 50°C, in the depth of 1500 m from the depth of 50 to 65°C, in the depth of 2000 m from the depth of 60 to 80°C, in the depth of 2500 m from 70 to 90°C and in the depth of 3000 m the temperatures will reach 80 – 100°C. The heat flow density is ranging from 70,2 to 84,4 $mW.m^{-2}$, the statistic average is 79,2 ± 4,6 $mW.m^{-2}$.

The total amount of natural geothermal water is 140 $l.s^{-1}$ that corresponds to total recoverable amount of natural geothermal energy of 29,1 MW_t.

Topolcany Embayment and Banovce Basin

In the region of Topolcany embayment and Banovce Basin the geothermal waters are connected with Triassic carbonates which are underlying rocks of Tertiary rocks. Pre-Tertiary basement is formed by Paleozoic-Mesozoic rocks of Choc nappe, in the deeper structures, under Choc nappe, sporadically the Mesozoic rocks of Krizna nappe underlie the Tertiary rocks. Chemical composition of geothermal waters represents Ca-Mg-HCO_3 chemical type with TDS about 0,48-0,78 $g.l^{-1}$.

The temperatures in the depth of 1000 m under the surface in the area of Banovce Basin and northern part of Topolcany embayment are from 25 to 45°C, in the depth of 1500 m reach 35 – 55°C, in the depth of 2000 m 45 – 70°C, in

the depth 2500 m 60 – 85°C and in the depth of 3000 m 75 – 95°C. The heat flow density in the area represents the values 55,1 – 74,2 mW.m^{-2}, the average is 63,5 ± 7,6 mW.m^{-2}.
The total amount of geothermal water with the temperature 33 – 40°C (natural sources) in the area of Topolcany embayment and Banovce Basin is calculated to 141,7 l.s^{-1} that corresponds to total recoverable amount of geothermal energy of 12,469 MW$_t$.

Humenne Ridge

Humenne Ridge consists of Mesozoic rocks strip, mainly in the underground of Tertiary rocks, that stretches along the Klippen Belt. It is formed by Krizna nappe – sediments of Triassic up to Cretaceous. The aquifers of geothermal waters are the Triassic carbonates those thickness ranges from 880 to 1100 m. The chemical composition of waters represents the mixed chemical type Ca-(Mg)-Na-SO_4-HCO_3-Cl with TDS about 0,8 g.l^{-1} and Na-Cl chemical type with TDS of 4,7 and 10,6 g.l^{-1}.

The geothermal activity of the Humenne Ridge region is higher according to values of heat flow density, it gradually increases from Klippen Belt (75 mW.m^{-2}) towards Eastern Slovakian Basin (up to 95 mW.m^{-2}). The average temperature in the depth of 500 m is 29,3°C, in the depth of 1000 m 47,2°C and in the depth of 2000 m 83°C.

The total amount of geothermal water in Humenne Ridge region is calculated to 341 l.s^{-1}. The total recoverable amount of geothermal energy (heat output) of Humenne Ridge is 750,5 MW.

3. GEOTHERMAL ENERGY UTILISATION

In Slovakia there are registered 120 geothermal wells which proved about 1787 l.s^{-1} of geothermal waters with the temperature on the wellhead ranging from 18 to 129°C. Geothermal waters are exploited via deep wells with the depth from 92 to 3616 m. The free flow on the wellhead ranges from several decimals up to 100 l.s^{-1}. Prevail Na-HCO_3, Ca-Mg- HCO_3 a Na-Cl chemical types with TDS 0,4 – 90,0 g.l^{-1}. The heat output of the utilised geothermal waters to reference temperature of 15°C is 306,8 MW$_t$ that represent 5,5 % of the total geothermal energy potential of SR which was by geological research evaluated to 5538 MW$_t$.

From the present state of geothermal energy utilisation viewpoint the geothermal waters are used at 36 sites in total for agriculture, district heating and recreation. The total heat output of 131 MW$_t$ represent 2,3% of the total potential of geothermal energy of Slovak Republic and 42,7 % of the total heat output of so-far registered geothermal wells.

Geothermal waters in agriculture are used at 12 sites for greenhouses heating for forcing vegetable (cucumbers, tomatoes, peppers, aubergines, etc.) as well as flowers (Besenova, Podhajska, Cilizska Radvan, Topolniky, Tvrdosovce, Horna Poton, Dunajska Streda, Vlcany, Velky Meder, Topolovec, Dunajsky Klatov, Kralova pri Senci sites). The total area devoted to agriculture is about 25,86 ha. Geothermal waters for fish farming are utilised at 2 sites – Vrbov and Turcianske Teplice.

Geothermal energy is utilised for district heating of offices and industrial areas in Galanta, Topolniky, Komarno, Besenova, Velky Meder, Podhajska and Sturovo. In Galanta the flats, hospital and house for pensioners are heated by geothermal waters. In Novaky – Kos the geothermal energy is used for heating of dressing rooms for miners and heating of air ventilation in brown-coal mines.

At 32 sites the geothermal energy is used for recreation purposes, mainly in swimming pools (Poprad, Vrbov, Liptovsky Trnovec, Besenova, Oravice, Podhajska, Senec, Kralova pri Senci, Dunajska Streda, Galanta, Velky Meder, Lehnice, Diakovce, Topolniky, Tvrdosovce, Nove Zamky, Sala, Polny Kesov, Gabcikovo, Sturovo, Komarno, Patince, Banovce nad Bebravou, Male Bielice, Partizanske, Chalmova, Koplotovce, Kremnica, Sklenne Teplice, Rajec, Dolna Strehova, Tornala).

Mentioned above, the comparison of total documented and really used recoverable amounts of geothermal energy at Slovakia indicates the unsatisfactory utilisation of this energy source. In accordance with "Analyses of real utilisation of renewable energy sources in the Slovak Republic" elaborated by Ministry of Economy of the Slovak Republic in December

2005 there is stated that the causes of existed status are the high financial costs of geothermal wells drilling, of purchase of corresponding equipment and technologies and also the low information campaign about funding possibilities of projects from internal or external funds.

Despite the mentioned barriers there was increased the interest in geothermal energy utilisation in last years. As the example of contribution of this energy source utilization we can introduce that in our conditions for heat production of 25 MW_t from geothermal energy we can save 42.600 tons of brown-coal annually (200 days of heating) or 16 mil.m^3 of natural gas. By replacing of fossil fuels the emissions in case of brown-coal are lowered of 208 tons/year of solids, 790 tons/year of SO_2, 125 tons/year of NO_x and 42 tons/year of CO_2. In the case of natural gas the emissions are lowered of 1,5 tons/year of solids, 0,3 tons/year of SO_2, 59 tons/year of NO_x and 4,32 tons/year of CO_2 (Atlas of Geothermal Energy of Slovakia).

The actual example of the contribution of geothermal energy utilisation is the operation of energo-centre in Galanta. After coming into operation there was stopped the heating station for hospital based on low-energy brown coal where was the annual consumption of 6200 tons of coal which produced 330 tons/year of SO_2, 36 tons/year of NO_2, 159 tons/year of CO_2 and 600 tons/year of slag. The heating costs were also lowered in fee for air pollution (in 1996 it was 156 000 SKK). At the same time the consumption of the natural gas in heating station of the flat area "Sever" was lowered from 3 mil. Nm^3/year to 1,2 mil.Nm^3/year, so the emissions were lowered in 60% compared to previous status.

CONCLUSIONS

Summarising we can state that in Slovakia the basic research of the geothermal energy sources is completed and within the research there were 26 of prospective geothermal areas selected. Regional investigation or prospecting survey is completed in the area of Central Depression of Danube Basin (Galanta site), Komarno block, Liptov Basin, Košice Basin (Durkov site), Levoca Basin – part Poprad Basin, Ziar Basin, Skorusina Basin, Upper Nitra Basin, Topolcany embayment and Banovce Basin and Humenne Ridge. The works are still in progress in two areas, in Rimava basin and Rudno basin. The result of executed geological works is the cognition of hydrogeothermal conditions, amount of geothermal waters and their parameters, amount of geothermal energy. There are submitted new proposals of new prospective areas which should be verified by geothermal wells, there are evaluated the geological risks and the optimal using of geothermal waters is proposed. The method of hydrogeothermal evaluation is the same as the method of geothermal sources evaluation which is used in EU (Hurter – Haenel, 2002), it means that the results are comparable. The regional geological investigation and prospecting survey of selected perspective areas is provided by Ministry of Environment of the Slovak Republic in accordance with corresponding resolutions of Slovak government by Conceptual framework of geological investigation and survey of the area of Slovak Republic from the years 1996 – 2002, Proposal of conceptual framework of geothermal energy utilisation in Slovak Republic from 1996 and the Proposal of energic policy of the Slovak Republic from 2006.