Overview of geothermal activities in Morocco

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Abstract

In order to reduce the deficit of its energy balance, several research programs have been undertaken in Morocco for prospecting the possibility of new and renewable energy sources in the country. The temperature is studied by considering either the deep oil well data (1204 values) or data from shallow wells (300 wells and springs). Temperature measurements are treated in a synthetic way for each identified basin. This work allowed also to compare the importance and meanings of the temperature methods and to propose a conceptual model of hydrodynamic operation of the hot water aquifers in Morocco as well as a synthetic diagram explaining the different behaviours of thermal profiles in the investigated wells. In Morocco there are several geothermal anomalies and thermal clues, with occurrence of numerous hot springs and important deep aquifers; thus it could be considered as a real geothermal promising country. However, the present interest is focused on the double use of hot water for both current human needs and enthalpy. Further attention is needed toward a better knowledge and utilisation of this kind of energy, especially in the Northern and probably Southern part of Morocco where high enthalpy is expected to be found.

Keywords: geothermal, energy sources, well data, conceptual model, enthalpy, Morocco.

1 Introduction

The evaluation of hydrogeothermal resources of Morocco is mainly done on basis of the knowledge of the temperature, the chemical characteristics of water, the hydrodynamics of the reservoirs and their petrophysical features.

Petroleum wells are always drilled in areas, which are selected on basis of their specific geological and structural framework, wherever located. This exploration technique suffers from the lack of representativity.

Furthermore, research in Morocco showed a noticeable influence of the underground water movement on the temperature. The temperature is studied by considering either the deep oil information or shallow one. Temperature measurements are treated in a synthetic way for each identified basin.

2 Geological and hydrostratigraphical studies

Morocco is located in a strategic area at the interaction of several plates (Africa, European, Mediterranean and Atlantic). The structural framework is characterized by transition from the African domain in the southern part of Morocco to Alpine folded structures (Atlas domain and Rif troughs).

Four main structural units are defined from South to North (Figure 1): Anti-Atlas and Saharian domain corresponds to the Precambrian basement, Atlas corresponds to an Alpine intracontinental range, Mesetas corresponds to stable Paleozoic-Mesozoic basement, Rif represents the Alpine belt around the Western Mediterranean.

The hydrostratigraphical study (Figure 1) of each basin revealed several potential reservoir layers in which the carbonate aquifer of Turonian (Tadla basin and Agadir basin) and Liasic (North-western basin of Morocco and North-Eastern basin)
are the most important hot water reservoirs in Morocco (Zarhloule, 1999). These areas are different geologically and hydrogeologically.

Figure 1: Simplified geological map of Morocco with the study zones and the hydrostratigraphical logs.

3 Shallow geothermal prospection in Morocco

A shallow temperature measurements program has been launched to estimate the natural geothermal gradient in these areas, to determine the principal thermal anomalies, to identify the main thermal indices, and to characterize the recharge, discharge and potential mixing limits of the aquifers (Zarhloule et al., 1998, 2001).

The temperature data from depths between 15 and 500 m of 250 wells have been analysed. The temperature measurements were made at 5m depth intervals using portable thermistor probe equipment with 0.01°C resolution. The shallow temperature data allowed to establish a thermal profile for each investigated well, assumed to be in thermal equilibrium. Thermal behaviour is changing from well to another (Figure 2) as well as within the same well (Figure 3). Lateral and vertical temperature assessment seems to be affected principally by the depth of water table, water temperature and the well location within the hydrodynamic frame. The temperature values of water range from 18 to 55.5°C.
The bottom shallow wells temperature values are plotted against depth (Figure 4) showing a rather important disturbed points either for highs or lows. Giving the fact that normal temperature can be considered, at a given depth, as the one in agreement with the regional geothermal gradient, noticeably higher and lower values at the same depth should be considered as anomalous. Negative anomalies correspond to the recharge zone of each aquifer with topographic highs and infiltration meteoric cold water, whereas positive anomalies correspond to the shallow upcoming hot water and to the more or less well defined discharge zones.

Figure 3: Effect of hydrodynamism on thermal behaviour.

Figure 4: Bottom shallow hydrogeological wells temperature V.S depth.
The main thermals clues (80) (Figure 5) and the principal thermal anomalies that coincide with the zone of artesianism of Turonian and Liassic aquifers have been identified, as well as the potential mixing limit of the aquifers systems (Zarhloule, 1999).

Figure 5: Map of shallow thermal anomalies areas in Morocco.

4 Geothermal gradient map of Morocco: Temperature data from oil wells

In order to improve the knowledge of these structural domains, the geothermal data will be compared with the geological and geophysical features. The aim of this work is to establish the first geothermal gradient map for the whole of Morocco (Figure 6), by using data obtained from the numerous petroleum exploration wells that exist in the country (Zarhloule, 1999, Zarhloule et al., 1999). These offer several temperature values, measured either by logging or testing surveys. Both the corrected bottom-hole temperature (BHT) and the drill-stem test temperature (DST) are used to construct the geothermal gradient map. A total of 410 wells provided 1204 temperature values from a depth range of 120-4500 m and subdivided as follows: 1126 BHT and 78 DST.

The geothermal gradient ranges from 16 to 41°C/km. The geothermal anomalies are related to deeper hydrodynamic, recent tectonic, volcanism or to the elevation of the Moho.
Figure 6: Deep geothermal gradient map of Morocco.

5 Geochemistry of thermal springs

The study covers the entire Northern part of Morocco and includes the most important hot springs (47). Through lack of the deep data in the Northern Morocco basin, a geochemical study has been undertaken in order to evaluate underground temperature, to determine the origin-reservoir, to approach the origin-reservoir lithology and to characterize the Liasic aquifer from which the hot springs emerge. Chemical analysis of springs is used to determined the reservoir temperature and mixing of shallow cold water with deep hot water.

Measured temperature of hot springs ranges from 21 to 54°C and discharge rates from 2.5 to 40 l/s. Geothermometers applied are: silica (Fournier et Rowe, 1966; Arnorson et al., 1983); Na/K (Fournier, 1979; Truesdell, 1976; Michard, 1979; Arnorson et al., 1983; Arnorson, 1983), Na-K-Ca (Fournier and Truesdell, 1973), Na-K-Ca-Mg (Fournier and Potter, 1979), Mg/Li (Kharaka and Mariner, 1986) and Na/Li (Fouillac and Michard, 1981). Temperatures estimated by those geothermometers are plotted against the measured values to evaluate the applicability of the geothermometers use. Only the silica geothermometers seem to give plausible values. Alkaline geothermometers used for the thermal springs are not reliable for prospecting, inasmuch as the chemical composition is greatly affected by the
enormous dilution with the shallow cold water and probably affected by interaction with the evaporitic rocks that are ubiquitous in the basin.

The application of Giggenbach method (Giggenbach, 1986) to springs revealed that the waters result from mixing of deep water with shallow cold water. In this case the reservoir deep temperature is given by the mixing model.

6 Synthetic geothermal approach and conclusion

Geothermal studies of sedimentary basin have revealed lateral as well as vertical variations in the temperature fields. These variations are commonly interpreted as resulting from thermal conductivity heterogeneities or local variations in basement heat flow. Variations may also result from groundwater flow systems. The movement of water in deep aquifers can significantly perturb the local underground temperature distribution in sedimentary basins (Zarhloule, 1994).

In sedimentary basins of Morocco, the treatment and the compilation of geological, geophysical and hydro-geothermal data allowed the construction of a conceptual model showing the relationships between topography, hydrodynamism, chemistry and temperature of all hot aquifers in Morocco (Figure 7).

Figure 7: Conceptual model of circulation of hot water of the different aquifers in Morocco: relationship between hydrodynamism, temperature, chemistry and topography (schematic section).

The recharge zones are characterized by shallow cold water, low apparent geothermal gradient, negative anomalies and high topography. The waters are mainly HCO₃-Ca-Mg type, resulting from the great influence of carbonate rocks.

The discharge zones are characterized by shallow hot water, high apparent geothermal gradient, positive anomalies and low topography. The hot springs are generally Ca (Mg)-SO₄ (Cl) or Ca (Mg)-HCO₃ type, resulting from the main influence of evaporitic rocks.
The middle of the basin shows a low apparent geothermal gradient. However, the communication between the deep and the shallow aquifers found expression in a potential mixing zone, with hot water and high apparent geothermal gradient. In general the shallow geothermal gradient is high near hot springs. Hot springs represent discharge from a deep reservoir and upward moving groundwater flow. The upward moving water may come from the centre of the basin and the discharge zone may be related to the hydrologic limit of the aquifer or to the existence of faults or fractures.

7 References


Year-end geothermal development status of Turkey, 2002

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Abstract

The status of geothermal development in Turkey as of the end of 2002 will be presented in the paper. The potential of geothermal development in Turkey is large in terms of moderate and low temperature resources (<150°C). Therefore, the resources are mostly suitable for direct use applications. Although 6 high temperature fields suitable for generation of electricity have been discovered, only the Kizildere Geothermal Field has been developed already. Today, in Turkey the direct use capacity for heating is about 540.8 MWt and a number of spas, physical treatment centres with a capacity of about 327 MWt give a total direct use capacity of 867.8 MWt. Electricity generation takes place only in Denizli-Kizildere geothermal field with an installed capacity of 20.4 MWe.

Keywords: electricity generation, direct use, greenhouses, district heating, heat pump, Turkey.

1 Introduction

Turkey is among countries with significant geothermal potential. According to the resource assessment, which has been done by the Mineral Research and Exploration Directorate (MTA) (Erisen et al., 1996), the geothermal resources in Turkey are mostly of moderate and low-temperature. The main uses of geothermal energy in Turkey are: direct use applications such as space heating, domestic hot water supply, greenhouse heating, swimming and balneology, industrial processes, heat pumps and electricity generation. The data accumulated since 1962 show that the estimated geothermal power and direct use potential are about 4500 MWe and 31,500 MWt, respectively. The direct use capacity in thermal applications is a total of 867.8 MWt representing only 2.75% of its total potential. Since 1990, space heating and greenhouse development have exhibited a significant progress. A geothermal power plant with a capacity of 20.4 MWe and a CO2 plant with a capacity 120,000 tonnes/year have been operated in the Denizli-Kizildere Geothermal Field since 1984 and 1986, respectively. Ground source heat pumps have been used in residential buildings for heating and cooling for approximately 5 years. Present applications have shown that geothermal energy in Turkey is much cheaper compared to the other energy sources like fossil fuels and therefore is a promising alternative. As the projects are recognised by public, the progress will continue.

2 The potential and role of geothermal energy

Turkey’s energy use has increased steadily with economic and population growth. The status and projections of the installed capacity of electricity in Turkey are given in Table 1 (at the end of the paper). The Table also shows the situation of geothermal power production as compared to the other sources of electricity as of 2001 and projections for 2010 and 2020.

Turkey is poor in fossil fuel resources but rich in renewables such as geothermal, solar, wind, biomass and hydropower. The studies on renewable energy sources in Turkey were
initiated in 1960’s, but could not exhibit a significant progress by the time except hydropower, as happened in several well-developed countries. Geothermal resources of the country are wide spread but the favourable reserve for heating and generating electricity is limited and even this limited reserve has not yet been used.

Today in Turkey, mostly biomass and hydropower are in use but geothermal is in the third place. Renewable energy sources account for 30% of the total energy consumption of the country and 23% of which accounts for geothermal (WEC-TNC, 2000).

Geothermal electricity generation has a minor role in Turkey’s electricity capacity as 0.07%, but the projection foresight an improvement to 0.32% by the year 2020. Contrary to the capacity of installed geothermal the heat capacity is growing at a faster rate.

3 Geothermal energy in Turkey

In Turkey, around 600 geothermal prospects and 170 geothermal fields with a temperature range of 40-242°C have been discovered. The total proven geothermal electricity generation capacity is 200 MWₑ while direct use capacity is 2046 MWᵣ. These proven potential increases by 5% annually with new exploration and drilling activities. The estimated geothermal power and direct use potential are reported as 4500 MWₑ and 31,500 MWᵣ, respectively. The potential of geothermal development in Turkey is generally considered large in terms of moderate and low temperature resources (<150°C). Therefore, the resources are mostly suitable for direct use applications (TGA, 2002).

3.1 Electricity generation

High temperature geothermal fields suitable for conventional electricity generation are Denizli-Kizildere (242°C), Aydin-Germencik (232°C), Aydin-Salavatli (171°C), Canakkale-Tuzla (174°C), Kutahya-Simav (162°C) and Izmir-Seaferihsar (153°C). The other high temperature fields with electricity generation potential are Manisa-Salihli-Cafèrseyli (150°C), Aydin-Yılmazkoy (142°C), Izmir-Dikili (130°C) and Izmir-Balcova (125°C). A list of current and possible utilisation opportunities of high temperature geothermal fields is given in Table 2 (at the end of the paper). The assessment of the other fields is still in progress. The only operating geothermal power plant of Turkey is Kizildere geothermal power plant, located near Denizli City in Western Anatolia. Kizildere geothermal power plant was installed in 1984 with a capacity of 20.4 MWₑ. The total capacity of the field is estimates as 200 MWₑ.

3.2 Direct use

Direct use of geothermal resources has expanded rapidly in the last 36 years from space heating of single buildings to district heating, greenhouse heating, industrial usage, modern balneology and physical treatment facilities.

Before the 1960’s, geothermal resources were only used spontaneously in bathing and medical treatment in Turkey. The first space heating application by geothermal energy was in a hotel in Gonen-Balikesir in 1964. Then, the first district heating system was built again in Gonen in 1987 with a capacity of 16.2 MWᵣ (Mertoglu and Basarir, 1995; Mertoglu, 1998). After 1990, development of direct use applications increased steeply as 185% from 1990 to 1995, 173.4% from 1995 to 1998, 131.2% from 1998 to 2002. Development of installed direct use capacities from 1990 to 2002 is listed in Table 3.

Geothermal district heating applications have started in 1987 in Turkey with heating of 600 residences in Gonen and reached to about 32,000 residences recently (540 MWᵣ)(TGA, 2002; Mertoglu and Bakir, 2002). Data about major district heating systems are given in Table 4.
Table 3: Development of direct use (excluding spas) installed capacity in Turkey.

<table>
<thead>
<tr>
<th>Year</th>
<th>Installed Capacity (MWt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>40.0</td>
</tr>
<tr>
<td>1990</td>
<td>45.5</td>
</tr>
<tr>
<td>1995</td>
<td>129.7</td>
</tr>
<tr>
<td>1998</td>
<td>354.6</td>
</tr>
<tr>
<td>2000</td>
<td>493.0</td>
</tr>
<tr>
<td>2002</td>
<td>540.0</td>
</tr>
</tbody>
</table>

Table 4. The major district heating applications in Turkey (Mertoglu and Bakir, 2002).

<table>
<thead>
<tr>
<th>System</th>
<th>Temperature (°C)</th>
<th>No. of residences</th>
<th>Operational since</th>
<th>Potential (MWt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonen-Balikesir</td>
<td>80</td>
<td>3400</td>
<td>1987</td>
<td>32</td>
</tr>
<tr>
<td>Simav-Kutahya</td>
<td>120</td>
<td>3200</td>
<td>1991</td>
<td>25</td>
</tr>
<tr>
<td>Kirsehir</td>
<td>57</td>
<td>1800</td>
<td>1994</td>
<td>18</td>
</tr>
<tr>
<td>Kizilcahamam</td>
<td>80</td>
<td>2500</td>
<td>1995</td>
<td>25</td>
</tr>
<tr>
<td>Balcova-Narlidere-Izmir</td>
<td>137</td>
<td>11500</td>
<td>1996</td>
<td>115</td>
</tr>
<tr>
<td>Sandikli-Afyon</td>
<td>70</td>
<td>1700</td>
<td>1998</td>
<td>45</td>
</tr>
<tr>
<td>Afyon</td>
<td>95</td>
<td>4000</td>
<td>1996</td>
<td>40</td>
</tr>
<tr>
<td>Kozakli-Nevsehir</td>
<td>90</td>
<td>1000</td>
<td>1996</td>
<td>11.2</td>
</tr>
<tr>
<td>Diyadin-Agri</td>
<td>78</td>
<td>1037</td>
<td>1998</td>
<td>42</td>
</tr>
<tr>
<td>Salihli-Manisa</td>
<td>94</td>
<td>1500</td>
<td>2002</td>
<td>142</td>
</tr>
</tbody>
</table>

In Turkey, the first greenhouse heating system of 0.45 ha by geothermal energy was applied in Denizli-Kizildere geothermal field in 1985 and has growth to 1.395 ha today. Recently, the total area of greenhouses heated by geothermal energy has shown a rapid growth totalling an area of about 36 ha and a heating capacity of 81 MWt for an average heat load of 2.25 MWt/ha. However, if the potential of the country is taken into account, the utilisation of this form of energy is seen to be highly insufficient (Ozgener and Koçar, in press).

Ground Source Heat Pump (GSHP) systems have been in service in residential buildings for heating and cooling in Turkey for 5 years, while they have been in use in commercial buildings in the U.S. for approximately 50 years. There are a few Turkish companies importing GSHPs from abroad and making efforts to put them onto the Turkish market at an increasing rate. But in reality, interest in GSHPs is growing very slowly. At first GSHP is applied two buildings with a total capacity of 26 kW, representing a total floor area of 596 m². It is estimated that around 65 units are presently installed in Turkey, representing a total capacity of 800 kW. Considering the ongoing installations, it appears that the growth rate will increase in next years. (Hepbasli and Yilmaz, 2001; Hepbasli et al., 2001a, b, c; Hepbasli et al., 2002).

Industrial usage of geothermal energy is not common in Turkey. The most well known application is liquid CO₂ and dry-ice production process operating adjacent to the Denizli-Kizildere geothermal power plant since 1986. The process installed with a capacity of 40,000 tons/yr then the capacity was increased to 120,000 tons/yr in 1999. Another industrial usage in the region is in textile industry using chemical properties of geothermal fluid as a whitening material. In Balikesir-Gonen, the wastewater of the district heating system has been used for process hot water supply in 54 tanneries (Mertoglu and Basarir, 1995).
4 Conclusions

The main conclusions that can be drawn regarding the utilisation of geothermal energy in Turkey are listed below.

- Since Turkey is an energy importing country, renewable energy including geothermal energy use is very important.
- Geothermal energy offers technically and economically feasible possibilities for development of different agricultural production sectors in Turkey.
- GSHPs are economically preferable to the conventional space heating/cooling systems used in Turkey. The primary barrier to marketing GSHP systems in Turkey is, however, the incremental cost of installing ground heat exchangers, which makes the total investment higher. There is customer resistance to GSHPs technology in the country because Turkish heating systems differ in many respects from the US ones and the first installation cost of GSHPs is relatively higher compared to the other conventional systems.
- Up-to-date information on geothermal energy utilisation in Turkey could not be easily and completely found. Especially as regards city-based geothermal district heating systems and greenhouses, there were some differences between the data given by various researchers and companies. This means that, in general, good documented systems for geothermal energy should be established in the country.
- New financing mechanisms are needed to promote investment in energy efficiency and renewable energy.
- The first barrier preventing widespread use of renewables is the lack of a coherent national energy plan in which the role of renewables is well explained, as well as defining properties among alternatives.
- In Turkey, governmental investment on energy sector is far behind the demand. To meet the fast growing demand, the privatisation and restructuring studies have started on energy sector and required legislations for private sector and foreign investment are arranged. Electricity Market Law was enacted in March 2001 and the transition period was completed in September 2002. Electricity Market Regulatory Agency (EMRA) is fully authorised to regulate the market and licence the activities.
- Although Turkey has no specific laws for development of geothermal resources yet and the lack of governmental support, direct use applications have been growing rapidly and proved by public sector.
- Geothermal development offers a viable energy alternative to fossil fuel. However, environmental and social dimensions of geothermal development must be carefully and properly managed.
- In the long term, geothermal energy will remain a viable option to furnish clean, reliable power in Turkey.
- It should be underlined that is already confirmed and proven that geothermal energy can be commercially competitive with other energy sources (Gunerhan et al., 2001).
5 References


Table 1: Present and planned installed electricity capacity of Turkey (WEC-TNC, 2000; Arman, 2002).

<table>
<thead>
<tr>
<th>Year</th>
<th>Geothermal</th>
<th>Hydro</th>
<th>Fossil Fuel</th>
<th>Nuclear</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(MW)</td>
<td>(GWh/a)</td>
<td>(MW)</td>
<td>(GWh/a)</td>
<td>(MW)</td>
</tr>
<tr>
<td>2001</td>
<td>20.4</td>
<td>90</td>
<td>12,476</td>
<td>42,216</td>
<td>20,907</td>
</tr>
<tr>
<td>2010</td>
<td>258.0</td>
<td>4372</td>
<td>19,413</td>
<td>65,387</td>
<td>41,077</td>
</tr>
<tr>
<td>2020</td>
<td>350.0</td>
<td>5651</td>
<td>28,466</td>
<td>97,456</td>
<td>76,427</td>
</tr>
</tbody>
</table>

Table 2: High temperature geothermal fields and possible utilisation opportunities (Gokcen et al., in press).

<table>
<thead>
<tr>
<th>No.</th>
<th>Geothermal Field</th>
<th>Temperature (°C)</th>
<th>Current utilisation</th>
<th>Possible utilisation opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kizildere-Denizli</td>
<td>242</td>
<td>Electricity generation, greenhouse heating, space heating, simple balneology applications, CO₂ production, textile industry</td>
<td>Electricity generation, building heating and industrial applications, drying, thermal tourism, thermal facility heating, and cooling applications.</td>
</tr>
<tr>
<td>2</td>
<td>Germencik-Aydin</td>
<td>232</td>
<td>Greenhouse heating of 0.05 ha</td>
<td>Electricity generation, district heating and cooling, greenhouse, drying, textile industry, cold stores, thermal tourism and thermal facility heating</td>
</tr>
<tr>
<td>3</td>
<td>Tuzla-Canakkale</td>
<td>174</td>
<td>Greenhouse heating, space heating, simple balneology applications, salt production.</td>
<td>Electricity generation, thermal tourism and thermal facility heating and salt production.</td>
</tr>
<tr>
<td>4</td>
<td>Salavatli-Aydin</td>
<td>171</td>
<td>Thermal tourism</td>
<td>Electricity generation, district heating and cooling, greenhouse heating, drying, industrial process heat, thermal tourism and thermal facility heating.</td>
</tr>
<tr>
<td>5</td>
<td>Simav-Kutahya</td>
<td>162</td>
<td>Thermal tourism, thermal facility heating, greenhouse heating of 12 ha, district heating with the residences of 3200.</td>
<td>Electricity generation, thermal tourism, thermal facility heating, greenhouse heating, industrial applications, district heating application at Simav, industrial use.</td>
</tr>
<tr>
<td>6</td>
<td>Seferihisar-Izmir</td>
<td>153</td>
<td>Simple balneology applications, greenhouse heating of 0.6 ha at Seferihisa</td>
<td>Electricity generation, thermal tourism, thermal facility heating, district heating, greenhouse and industrial facility heating.</td>
</tr>
<tr>
<td>7</td>
<td>Salihli-Manisa</td>
<td>150</td>
<td>District heating application of 200 residences at Salihli</td>
<td>Electricity generation, thermal tourism, thermal facility heating, drying.</td>
</tr>
<tr>
<td>8</td>
<td>Yilmazkoy-Aydin</td>
<td>142</td>
<td>Not available</td>
<td>Electricity generation plus integrated use.</td>
</tr>
<tr>
<td>9</td>
<td>Dikili-Izmir</td>
<td>130</td>
<td>Simple balneology applications, greenhouse heating of 1 ha</td>
<td>Electricity generation plus integrated use.</td>
</tr>
</tbody>
</table>
Future geothermal survey – Study in Mongolia

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Abstract

The rural population of Mongolia is living sparsely, as in Iceland. Therefore Icelandic experiences could provide a suitable example for direct geothermal utilization to the rural consumers in Mongolia. The Shivert hot spring area is an appropriate site for direct geothermal utilization. Preliminary scientific studies have been carried out there. The Shivert area is located 20 miles northeast of the province centre of Arkhangai. The surface temperature of manifestations is 55°C and the flow rate is 4 l/s. Five geothermal prospecting boreholes were drilled there by Mongolian and Russian scientists in 1980. The preliminary study shows that the hot water temperature is higher than 70°C at a depth of 80 to 100 m. This represents a good potential for building a new and modern tourist centre in the Shivert area.

Keywords: Shivert hot spring, geothermal heating, hydrogeology, geology.

1 Introduction

The results of collective exploration work carried out in 1980 only permits general evaluation and do not suffice for a detailed, hydrogeological, balneological and thermal energy evaluation of the area. Figure 1 shows the Shivert hot spring location (number 24) in Mongolia.

Figure 1: Hot springs of Mongolia.
Collection of data to give us a real and detailed picture of the hydrogeological parameters of the Shivert area, needs to include a detailed study of geological structural and hydrogeological conditions. The following are recommended as a minimum for further complex geological exploration work:

1. Mapping of hydrogeological observations in the deposit area;
2. Ground surface geophysical explorations by vertical electric sounding, which makes it possible to determine the level of underground water and its minerals, fracture and fault zones, and drilling points;
3. Drilling of 80-100 m deep borehole in selected fracture zones, which will bring to the surface water with temperature higher than 70°C;
4. Optimal hydrogeological works;
5. Laboratory work to yield complete geochemical and balneological analyses.

2 Information on geological and hydrogeological conditions of the Shivert hot spring area

A geological profile of the Shivert geothermal aquifer zone is presented as Paleozoic and fourth age sedimentation. Moreover, in this area there was a marked presence of two lithologic-structural tectonic layers. The bottom layer is presented as Paleozoic, once intensively stationed pink granites. The upper layer is presented as fourth age unico-ordinately continentally, terrigenous and calmly lying deposit layer on the Paleozoic base, which has typical sharp facial inconstant character. Thickness of fourth aged lithologic-structural layers varies between 25 and 40 m in depth (REC Fund 1989).

2.1 Stratigraphy and lithography

The Paleozoic group (P2): In describing the area’s profile, the Paleozoic group formation is the older one. In the deposit area this layer lies everywhere at a depth of 24-50 m, and in the lithographic view they are introduced as pink granites. It is moreover observed as intensively fissured in the zone of core weathering. A minimum of three disjunctive submeridional stretch disturbances were also mentioned in the area, the last one forming a graben structure (see Figure 2). In the whole area the Palaeozoic layer is covered by sedimentary rocks of continental fascia.

The fourth system (Q): The fourth aged sedimentation is spread over the whole study area and mainly presented in three genetic types:

- **Lake type (QIII-IV)** - forming the central part of cross section and lying at a depth of 10-20 m. In the lithography it is presented in green grey clays, thin and fine green grey and middle fine gray sand with clay fraction admixture and small capacity (until 0.5 m) seam clay. Total thickness of sedimentation is no more than 10 m;
- **Alluvial type (a. QIII-IV)** - in a vertical cross section of the fourth aged sedimentation are observed two alluvial beds - bottom bed at a depth of 20-28 m, and an upper bed at a depth of 2-19 m. Both beds consisting of boulder-gallechnicovs and gravely-gallechnicovs sedimentation with sandy dark brown filler. The thickness of the beds is 7-9 m each.
- **Modern sedimentation (QIV)** – is presented by two genetic types:
  - **Alluvial (dQIV)** - locally spread in the bed of the Shivert River, consisting of non-sorted sand and gravely-gallechnicov sandy filler. Thickness of sedimentation is 2-3 m.
- Preluvialy-diluvial ($dQ^4_{IV}$) - is wide spread, and it is presented as a yellow grey sandy loam. Thickness of this sedimentation is varying between 2.5 and 5.0 m.

Figure 2: Geological and hydrogeological cross section of the prospecting area of Shivert.

2.2 Hydrogeological condition

In view of the hydrogeological conditions, the observed area represents difficult systems of artesian basins, with inter-mountain hollows. Underground water formed and accumulated in the crusts of a weathering zone, but also in the porous collectors of the sedimentation cover. Water is also collected in fracture zones and especially in the junction centres of differently oriented disjunctive distortions. It should be noted that the deposit area has extremely specific hydro-geological conditions, where the main defining role is played by the fissure-vein for water in fractures (REC Fund 1989) in the formation of hydrogeological, geothermal, and hydro chemical condition.

Palaeozoic group fissure-vein water (Pz): Within the deposit area 3 disjunctive distortions are selected with fissure vein thermal (30-57°C) nitric, mainly hydrocarbon-sulphuric sodium water with mineralization of 0.35-0.36 grams per litre. Water has an ascending character and discharges in fourth age cover, forming in the cover dome of scatter. Fracture zones play the role of “donors” of geothermal water, and upper lying permeable beds play “recipients” role.

A water bearing complex of fourth sedimentation ($Q^4_{IV}$): This is a water-bearing sedimentation complex represented in sand and gravel – galehnicovs sedimentation. In the study area under water of fourth age water bearing complex it contains only hydrocarbon-sulphuric sodium with mineralization 0.39-0.45 grams per
At a 25-30 m depth the temperature reaches 12-14°C, but at the same time the recorded water temperature is 49°C (see Figure 2) in the geothermal water dome area (borehole number 1) at a depth of 19 m. The well discharge varies from 0.8 to 4.7 liters per second.

Analysis of the above geological structure and hydrogeological conditions makes it possible to come to a conclusion about conditions of the thermal water formation in the Shivert area. Obviously, the main source rock is Palaeozoic granites, with water injected in the cover of fourth aged sedimentation, where there is a specific hydrogeological structure in the form of hydro injection dome of thermal mineral water.

At the centre of the dome in the region of boreholes number 1 and 2, the chemical contents of the water correspond to the underground fissure-vein water of Palaeozoic granites. But on the flanks of the region, boreholes number 3, 2, 4 and 5, the water contains the same chemical contents but with a low temperature and high mineralization. The reason for the high mineralization is the inflow underground water from the outside.

In conclusion we could say that there is some prospect and possibility to procure and utilize the thermal mineral water in the Shivert area. Analysis of the conditions of the geological structure makes it possible for us to make a confident forecast for obtaining thermal water with higher temperature.

3 Opportunity of geothermally heated tourist centre in the Shivert

The Shivert hot spring area is the best location and has a bright future as a tourist centre development. The Government decided to build a new road, which will interconnect central and western Mongolia. This road construction is named the “Millennium Road”. Shivert is located only 5 miles southeast from the new road.

The Shivert sanatorium was established in 1967. Most of the buildings were connected to the Central Energy System network, but none of them is in use any longer. There is also a winter building in the sanatorium with a capacity of 150 beds, and a 300-bed summer building. The operation of the sanatorium has ceased due to financial difficulties, but one building is however, still in use for veterans (Geodesy and Geographic Authority 1990).

Shivert is also one of the main tourist destinations in Western Mongolia. A tourist centre with geothermal water heating system could operate there all year around. A winter operated tourist centre is really necessary and suitable for Mongolian tourism.

3.1 Floor heating

In the floor heating system steel pipes were mostly used before, but now only plastic pipes with high heat endurance are used. Much progress has been made in the production of plastic pipes with high heat tolerance and they will most likely cost less in the future in comparison with other pipe types. These pipes are laid 150-450 mm apart, depending on the size of surface to be heated and the diameter of the pipe used. A least distance from the floor surface to the pipe surface should be 40 mm. Designs have become better and there is much interest in utilizing 40-60°C hot water for heating (VEO, 2000).
The 40 m deep exploration borehole 1\textsuperscript{b} could give an output flow rate of 15 l/s by gravity flow at temperatures higher than the 57\textdegree{}C water in the surface manifestation. At this temperature it is possible to use floor heating system in the building.

4 Conclusion

Geothermal hot water is suitable for house heating in our extreme climate. Hot water of boreholes number 1\textsuperscript{b}, 2 and 4 could be used to heat the buildings of the Tourist Centre during winter. Drilling of 80-100 m deep boreholes in selected fracture zones could bring to the surface hot water with temperature higher than 70\textdegree{}C. After drilling of these wells more buildings can be connected to the geothermal hot water heating system.

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5 References


The possibilities of diverse use of geothermal energy in Lithuania

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Abstract

Lithuanian’s territory with regard to its geology and tectonics belongs to the western edge of the Precambrian East European platform. The sedimentary formations (from Vendian up to Quaternary) lie ontop of the Precambrian basement rocks. According to the depth of basement three large tectonic structures are determined in the territory of Lithuania: the Baltic Synclise (Craton) and its slope, the Mosurian-Belarusian Antecline, and the Latvian Saddle. Research of geothermal energy started in 1988. First of all (since year 1994) the shallow geothermal resources have been used in developing individual heating systems with heat pumps. The geothermal resources up to 100 meters depth are very attractive. It is very easy to use: they are spread everywhere and are renewable. The main deep-hydrothermal resources are related to aquifers of regional Cambrian and Devonian. Usage of geothermal resources from Devonian for the centralize heating started at 2000. The first geothermal demonstration plant in Lithuania was built in Klaipeda. The total capacity is 41 MW. Two production and two injection wells were drilled. The geothermal water (38°C and salinity ~98 g/litre) is pumped from 1100 m depth. Petrothermal resources are related to the Hot Dry Rocks (the temperature is 150-180°C at the depth 4-5 km). The legal and economical-technical problems hinder realization of usage of geothermal energy in Lithuania.

Keywords: Lithuania, geothermal energy, Cambrian and Devonian aquifers, Klaipeda geothermal demonstration plant, balneological health-resorts.

1 Introduction

In the context of the western part of the Eastern Europe Platform (with average density of heat flow of 40-50 W/m²) Western Lithuania has higher heat flow of 90-100 W/m² in the area over 42400 km² on land besides offshore to the West in the Baltic sea. Qualifying geologically, Western Lithuania must be considered a rare phenomenon (heat deriving from altered mantel) among those in old geological platforms. According to geothermal parameters it can be compared to areas of young orogeny (Kepezinskas et al, 1996).

In Lithuania geothermal data were being collected together with oil explorations. Since 1988 independent investigations of geothermal conditions have been carried out. Mostly by institutes of Geology (recently Geology and Geography) and Energy. Practical work is done by company “Geoterma”, which was consulted and financed by the Danish government to build Klaipeda Demonstrational Geothermal Plant with capacity of 49,3 MW. Since 1994 shallow geothermal resources have been used, mostly in household sector. These geothermal resources laying in depth up to 100 m are very attractive because they are easy to reach and technically simple to use. There are really favorable perspectives for development in this field (Suveizdis et al., 2000).

There are ideas to produce electric power using hot dry rock technology in Lithuania.
There is still no evaluation of possibilities to use thermal water for the spheres of health care, recreation and tourism developing them for business.

2 Methods

Geothermal investigations are a sort of geological exploration and are closely related with oil explorations. The first temperature measurements of geological section started with drilling deep wells. The first geothermal wells were drilled in Vydmantai (2 wells) and Klaipeda (4 wells). Geothermal plant is built in Klaipeda. Geological, geophysical, laboratorical and experimental data are being analyzed and generalized.

3 Regional hydrogeothermal aquifers

There are three regional hydrogeothermal complexes in geological section of Lithuania: Cambrian, Lower/Middle Devonian and Middle/Upper Devonian. In Eastern Lithuania Cambrian aquifer interconnects with Vendian aquifer, and Cambrian with Ordovician in Western Lithuania. All above mentioned aquifers have not only accumulated heat, but they are also rich in chemical elements. Up to now these qualities of underground waters are not utilized for human sake. The table shows generalized results of thermal water chemical analysis and collates them to those of famous spa resorts. Lithuanian thermal waters could be used for bathing, therapeutic purposes, recreation. The culture of balneology has been prestigious in Central Europe and Japan. According to historical sources it is aware that Grand Duke of the Great Duchy of Lithuania Stephen Bathor (XVI century) vested palace doctor M. Bucelli with the privilege to extract salts from mineral springs. It is still not available for everybody in our time, despite the fact that mineral waters were used for healing for centuries. Balnelogical culture in Lithuania is still not so well developed like in Central Europe. Natural and geological circumstances are favorable for this field. There are two places in Lithuania with people willing to utilize thermal waters not only for producing heat, but also for healing and recreation – Vilkaviskis and Baisogala.

The Mayor of Baisogala is taking an initiative to fund a geothermal heat plant and health, rehabilitation and recreation complex. Baisogala is a small town in Middle Lithuania with over 5000 inhabitants. It has old and noble past. Komarai manor house extant from XIX century is one of most beautiful places here. In Baisogala there is Lithuanian Institute of Animal science in which would be possible to carry out scientific research on underground mineral water use for cattle growing.

Vilkaviskis is situated in Southwest Lithuania and has population of over 15,000 inhabitants. The German engineering company Geothermie Neubrandenburg GTN and Lithuanian Institute of Geology in 1996 prepared the balneology-geothermal project for Vilkaviskis. Within the framework of a first study, the geothermal potential was evaluated and planning of heat recovery for energetic purposes was started. In the course of the investigations, the chemical composition of the deep waters was analyzed. It is known that Cambrian waters of similar composition are suitable also for balneological purposes. Water use for medicine is basically determined by the salt content (predominantly NaCl) and the contents of trace elements such as iodine, iron and others, as well as the temperature.
3.1 Cambrian hydrogeothermal aquifer and characterization of thermal water

The Cambrian deposits are one of the oldest sedimentary rocks in the Baltic basin. Mostly they lie on the top of Proterozoic basement, and only in the eastern part of the basin they cover Vendian. The Cambrian exists everywhere except for southern Lithuania and in some local geologic structures (Plunge, Veiverzenai, Baubliai). The thickness of Cambrian siliciclastic rocks varies from 0 to 177 m (Zemyte-1). The boring depth in western Lithuania is more than 2 km. Representative sections of Cambrian succession of Lithuania are in Figure 1 (at the end of the paper). The Cambrian rocks could be utilized as a source for energy and minerals, and as a reservoir. Existing data suggest the usage of Cambrian as follows:

Cambrian rocks are most important oil and gas bearing rocks in the region and economically profitable deposits have been found. Oil field exploration is one of the main aims of Cambrian studies in Lithuania.

In the frame of oil researches, higher temperatures (40-90°C) of Cambrian rocks and pore fluids have been found. Exploitation of terrestrial energy in western parts of Lithuania is important not only from energy point of view, but also from environmental aspects (low pollution in case of use renewable energy source).

After extraction of heat, the groundwater could be directed to extract chemical elements and compounds, which are dissolved in the water. Unfortunately, chemical composition of deep waters was formerly studied in connection with oil search and mainly only these components were analyzed which lead to hydrocarbon appearance. Presently the need for geothermal energy has grown and deep groundwater studies have been activated. The content of insoluble residue decreases from about 200 g/l in western Lithuania to about 100 g/l in the eastern part. Characterization of thermal water are presented in Table 1.

Table 1: Chemical composition of thermal water in Lithuania and in the famous resorts.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Cambrian</th>
<th>L-M Devonian</th>
<th>M-U Devonian</th>
<th>Blue Lagoon</th>
<th>Dead Sea</th>
<th>Tiberias</th>
<th>Baden-Baden</th>
<th>Sea water</th>
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<tr>
<td>pH</td>
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<td>3.1-5.9</td>
<td>3.5-7.4</td>
<td>4.7-7.4</td>
<td>6.9</td>
<td>7.37</td>
<td>8.2</td>
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</tr>
<tr>
<td>TDS</td>
<td>g/l</td>
<td>107.6-202.9</td>
<td>20.5-110</td>
<td>5.0-35.0</td>
<td>24.4</td>
<td>310</td>
<td>26</td>
<td>3.1</td>
<td>35.82</td>
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<tr>
<td>K</td>
<td>mg/l</td>
<td>340-936</td>
<td>80-554</td>
<td>167</td>
<td>1030</td>
<td>7560</td>
<td>291</td>
<td>32.9</td>
<td>392</td>
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<tr>
<td>Na</td>
<td>mg/l</td>
<td>22515-40260</td>
<td>1735-28218</td>
<td>5245</td>
<td>6910</td>
<td>34940</td>
<td>5600</td>
<td>851</td>
<td>10800</td>
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<tr>
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<td>mg/l</td>
<td>6426-30395</td>
<td>971-12353</td>
<td>1218-1856.7</td>
<td>1100</td>
<td>15800</td>
<td>2752</td>
<td>144</td>
<td>411</td>
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<td>Mg</td>
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<td>234-3023</td>
<td>60.8-358</td>
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<td>41960</td>
<td>595</td>
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<td>11.6-226.4</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>NH₄</td>
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<td>9.72</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Cl</td>
<td>mg/l</td>
<td>66690-126647</td>
<td>3617-60030</td>
<td>14317.92</td>
<td>13550</td>
<td>208070</td>
<td>15051</td>
<td>1442</td>
<td>19400</td>
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<td>HCO₃</td>
<td>mg/l</td>
<td>3-294</td>
<td>24-314</td>
<td>120.78</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Br</td>
<td>mg/l</td>
<td>261-1109</td>
<td>67-407</td>
<td>50-78.59</td>
<td>44.5</td>
<td>5.6</td>
<td>133</td>
<td>1.6</td>
<td>67.3</td>
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<tr>
<td>J</td>
<td>mg/l</td>
<td>0.41-3.81</td>
<td>0.16-1,65</td>
<td>0.21</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>SO₄</td>
<td>mg/l</td>
<td>33-2323</td>
<td>1409-3536</td>
<td>2390.9</td>
<td>31</td>
<td>0.5</td>
<td>695</td>
<td>209</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>mg/l</td>
<td>4.4-100</td>
<td>2.3-44</td>
<td>8.27,85</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
3.2 The Middle/Lower Devonian hydrogeothermal aquifer and characterization of thermal water

In its upper part the Parnu sandy layers (20-40 m thick) are singled out. In the middle part of aquifer there are Viesvile (Kemeri) layers (100-130 m thick), which upper part (about 35 m) is composed of clayey rocks mainly. These are Viesvile layers lying over the sandy Sesuvis layers (100 m thick). In the lower part of aquifer there is Gargzdai series reaching 200 m in thickness. All aquifers are with greatly varying lithology: sandy and sandstone light gray, fine-medium grained, some silt and clay, some gypsum, siltstone and claystone.

In the area near to the Baltic Sea the roof temperature of the Parnu horizon exceeds +40°C, and at the foot of Lower Devonian it even exceeds +50°C. In the central part Lithuania the roof temperature is +20°C. Water mineralization is varying from 20 to 110 g/l (Table 1). The upper part of M/L Devonian aquifer – Kemeri (Viesviles) horizon is used as productive in Klaipeda geothermal demonstration plant. The geological actual section and construction of geothermal well Klaipeda-4I is presented in Figure 2 (at the end of the paper). Klaipeda geothermal demonstration plant has two production and two injection wells. The depth of wells is 1128 to 1228m. Low-temperature geothermal heat is extracted from geothermal water (38°C) using an absorption heat pump and transferred to district heating network of Klaipeda. Total thermal capacity of plant – 41MW: 17MW geothermal heat and 24 MW heat from boilers. Total amount of heat produced by KGDP in year 2002 was – 189000 MWh, but plant is still not handed over by State Commission because of problem gypsification in a pipeline system.

3.3 The Middle/Upper Devonian hydrogeothermal aquifer and characterization of thermal water

The Middle/Upper Devonian (Upninkai-Sventoji) hydrothermal aquifer consists of two stratigraphically isolated, but hydraulically related terrigenous variegated rock horizons. Their total thickness ranges from 170 to 200 m. Layers of Upninkai and Sventoji are composed of similar terrigenous deposits sand, weakly cemented sandstone, aleurite, clay, sometimes dolomitic marl.

Weakly cemented aleuritic sandstones with lenses and interlayers of fine and very fine sand represent the collecting layers. These deposits have accumulated rather high quantities of geothermal water. Aquifers (1-25 m thick) alternate with impermeable layers (3-25 m thick). Mean open porosity is rather high and ranges from 16 to 25%. Lithological composition of this aquifer (D2up-D3sv) is present in Figure 2.

Characterization of thermal water is present in Table 1.

3.4 Overview of the possibilities to produce electric power

In 1995 prof. Y.D. Diadkin (Sankt Peterburg) asked by Institute of Geology of Lithuania performed economical-mathematical simulation and presented tentative technological parameters of abyssal circulating system for producing electric power from geothermal heat in Klaipeda city. Using for calculations basic data (the thickness and the geothermal gradient of sedimentary cover - 2330m and 0.035 C/m; the geothermal gradient of crystalline basement rocks -0.03 C/m) it was assumed that the lowest temperature acceptable for electricity production must be 140°C and, in this
case, the depth of well was find 4103m. The price of produced power would be 12.3 ct US/kWh and price of produced heat 2.04 USD/GJ (0.734 ctUS/kWh).

In year 2001 average electricity tariff in Lithuania was 6.07ctUS/kWh (excl. VAT) and heat tariff - 2.73 ct US/kWh (excl. VAT).

4 Conclusions

Existing theoretical studies and practical results show that in Lithuania:
1. Shallow geothermal resources already are used in individual heating systems with heat pumps.
2. Hydrogeothermal resources of Cambrian, Middle/Lower Devonian and Middle/Upper Devonian aquifers could be used for heating, hot water supply, and balneological and therapeutic purposes,
3. Petrothermal resources could be used for heating and electric power production.

5 References

Figure 1: Representative sections of Cambrian succession of Lithuania.
Figure 2: Geological actual section of Klaipeda geothermal well KGDP-4I. (prepared by Petroleum Geology Investigators Aps, Denmark).
Geothermal energy use in Russia
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Abstract
Geothermal energy use is a way to achieve sustainable clean energy development in the world. Russia has rich high and low temperature geothermal resources and is taking good steps in this direction. The development of the present-day world is impossible without large cities. At present, urbanization has become a truly global process the rate and scale of which increases catastrophically. The gigantic concentration of people results in a multiple increase in the supplies of water, energy, and food to cities, which, along with an increased production and service, is responsible for the accumulation of a huge amount of polluted water and industrial and domestic waste in the city areas. This causes an aggravation of social, environmental, and economic problems in large cities. Under these conditions the problems of urbanization and municipal engineering take on an absolutely different social significance – they become part and parcel of the global problem of sustained development of the modern society. In this connection two important aspects could be considered: clean alternative renewable energy use and organization of environmental parks as a demonstration of preferences and advantages of such energetic supply, which is very close. The concept of environmental parks on the territories of big towns and for reserved territories is under elaboration. The choice of the optimal system for a nature-friendly energy support is based on the use of the deep-thermal energy and other ecologically pure sources, depending on the concrete conditions of the environmental park/aquapark, and takes into account all the environmental, economical and social factors. As a result the environmental passport of territories can be created. The concept of environmental parks could help to demonstrate the advantages of renewable alternative energy utilization.

Keywords: geothermal energy, Russia, sustainable development, environmental parks.

1 Introduction
In Russia geothermal research is carried out by 53 scientific centers and higher educational institutions located in different cities belonging to different offices: Academy of sciences, Ministries of education, natural resources, fuel and energy. They can be conditionally joined in some regional centres of science, such as Moscow, St. Petersburg, Northern (Archangelsk and Apatites), North-Caucasian (Makhachkala, Gelendgik, Groznij (before 1993)), Volga region (Yaroslavl, Kazan, Samara), Ural (Ufa, Ekaterinburg, Perm, Orenburg), Siberian (Novosibirsk, Tyumen, Tomsk, Irkutsk, Yakutsk), and the Far East (Khabarovsk, Vladivostok, South-Sakhalinsk, Petropavlovsk-on-Kamchatka). In such centers consisting usually of several institutes, future geothermal researches are in progress: theoretical, applied, regional, and creation of special instrumentation.

2 Geothermal energy use
In Russia, geothermal resources are used predominantly for space heating, both heating of several cities and settlements in Northern Caucasus and Kamchatka with a population of about 500.000. Moreover, in some regions of the country the deep heat is used for greenhouses of 465.000m² accumulative area. Most active use of the hydrothermal resources are in Krasnodar territory, Dagestan and on Kamchatka. (Fig. 1, Fig. 2) (Gadzhiev et al., 1980, Kononov et al., 2000). Approximately one half of
the extracted resources, is applied for heating of habitation and industrial buildings; a third to heat greenhouses, and about 13% for industrial processes. Besides this the thermal waters are used in approximately 150 health resorts and 40 factories that bottle mineral water. Quantity of electrical energy that is developed in geothermal power stations of Russia per 1999 has increased almost twofold. Nevertheless, it remains extremely minor, making up some 0.01 percent of the total development of the electric power in the country.

**Figure 1:** Geothermal resources of Kamchatka.
1 – geothermal deposits (1 – Pauzhetskoje, 2 – Nizhne-Koshelevskoje, 3 – Khodutkinskoje, 4 – North-Mutnovskoje, 5 – Big-Bannoje, 6 – Karimskoje, 7 – Semjachinskoje, 8 – Geysers Valley, 9 – Uzonskoje, 10 – Appelskoje, 11 – Kireunskoje);
2 – groups of thermal springs;

**Figure 2:** Map of hydrogeothermal deposits and perspective areas of Dagestan.
1-4 – measure (1 – Quaternary, 2 – Neogene, 3 – Cretaceous, 4 – Jurassic);
5 – perspective areas;
6 - hydrogeothermal deposits;
The most important new direction that the usage of low temperature geothermal resources has taken is the use of heat pumps. This way of heating is optimal for many regions of Russia – in its European part, in the Ural and elsewhere. But only the first steps have been taken in this direction.

Electricity is generated by a few geothermal power plants (GeoPP) located on the Kamchatka Peninsula and on the Kuril Islands. At present three stations are online in Kamchatka: Pauzhetka GeoPP (11MWe installed capacity) and the two Severo-Mutnovka GeoPPs (12 and 50 MWe). Moreover, another GeoPP of 100 MWe is now being projected in the same place. Two small GeoPP are in operation on Kuril’s Kunashir Isl., and Iturup Isl., with installed capacity of 2.6 MWe and 6 MWe, respectively.

3 Russia’s place among other countries in geothermal energy use

Russia has considerable geothermal resources and the available capacity is far larger than the current application. This resource is far from adequately developed in the country. In the former Soviet Union, geological exploration was well supported for minerals and oil and gas. Such expansive activities were not aimed at discovering geothermal reservoirs even as a side issue; geothermal waters were not considered amongst useful energy resources. Still, the results of drilling thousands of “dry wells” (in oil industry parlance) brought a secondary benefit to geothermal research. These are the abandoned wells themselves, and the data on the subsurface geology, water-bearing horizons, temperature profiles, etc. collected during the exploration. Not all currently operating companies are willing to disclose their well data; in spite of the fact that it is cheaper to turn them over to others for new purposes than to stand under the cost of maintaining shut-in wells.

Figures 3 and 4 show the rate development in the use of geothermal resources in the world and in Russia (Lund et al., 2000). They illustrate particularly the rapid progress that is taking place in Russia.

![Figure 3: Geothermal energy capacity changes from 1995 to 2000.](image-url)
4 **The concept of a nature-friendly energy support system for environmental park/aquapark**

The choice of the optimal system of nature-friendly energy support is based on the use of the deep-thermal energy and other ecologically pure sources, depending on the actual conditions of the environmental park/aquapark, and takes into account all the environmental, economical and social factors. As a result the environmental passport of territories can be created.

The main directions of the required investigation are:

- Geological and geothermal assessments of the Park’s territory, taking into account the possibility to use the deep thermal sources for energy supply.
- Hydrogeothermal and hydrogeochemical assessment of the territory (hot springs, thermal and mineral waters).
- Geographical assessment of the territory from the point of view of the possibility to use non-traditional renewable energy sources (solar, wind, tidal energy and energy of small rivers).
- Assessment of the possibility to use other specific energy sources of concrete region (waste utilization, biomasses, etc.).
- Creation of criteria for choice of system of energy supply (depending on conditions of the region).
- Planning of energy supply for a concrete region using both thermal sources (heat pumps) and other nature-friendly energy sources.
- Optimisation of the system of energy supply on the basis of environmental, social and economical factors.
- Choice of specific type of heat pump (types of design and thermal energy extraction) depending on concrete geological, environmental, economical, historical and social conditions of the Park’s area.

5 **References**


Utilization of geothermal energy in Serbia

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Abstract
In Serbia, there are more than 60 hydrogeothermal low-temperature convective systems (T<150°C), as well as a large hydrogeothermal system in the Serbian part of the Pannonian basin. Estimated energy reserves of geothermal resources are about 800 MWt, but utilization of this is low, only about 80 MWt. Utilization of geothermal energy is mostly of the cascade type, with a few examples of integrated utilization. Integrated utilization combines the use of gas, oil, and electric power for heat pumps. According to the installations already built, utilization of geothermal energy is mostly for balneological purposes and tourism. From an energy point of view, utilization of geothermal energy is mostly for heating of greenhouses. Geothermal energy is now used for the heating of greenhouses only in three localities in Serbia. Eight ha. are heated by geothermal energy while the total area of other greenhouses heated by crude oil and gas totals around 64 ha. According to the potential of geothermal resources, near future development should focus on cascade and integrated utilization of geothermal energy.

Keywords: geothermal resources, Serbia, utilization, balneology, greenhouse, heat pump.

1 Introduction
Serbia is relatively small (about 80,000 km²), but her geological and tectonic structures are very complex. Because of that, geothermal characteristics are interesting. On two-thirds of Serbian territory, values of the heat flow density are greater than average values for the continental part of Europe; and on half of its territory they are around 100 mW/m² (Milivojevic, 1989). The development of geothermology in Serbia was established in the last century by S. Radovanovic, the first Serbian hydrogeologist, who can be considered as the “Father” of Serbian hydrogeology and geothermology (Radovanovic, 1897; Milivojevic, 1997). The examination of thermal springs (total of 196 in Serbia), was started more than 150 years ago, but the first modern hydrogeothermal research projects were conducted between the First and Second World War in the areas of the most well-known spas. The first, preliminary evaluation of geothermal potential was completed in 1975 (Milivojevic et al., 1975). Development of geothermal research in Serbia was at its peak between 1975 and 1988, when the evaluation of geothermal resources was completed (Milivojevic, 1989). In the period of time between 1991 and 1995, geothermal research stopped completely due to the economic crisis caused by the OUN embargo. The last geothermal well was drilled in 1991. In the last three years, a lot of effort has been put into continuing geothermal research, but the progress is very slow. The reasons for this are: economic difficulties; energetic focus on the import of oil and gas; as well as the fact that people are not conscious about the necessity of increasing energy efficiency and energy rationalisation.

2 The use of geothermal energy
In Serbia, use of geothermal energy is very low compared to the geothermal potential. The use of geothermal waters is mainly for balneological purposes. In Serbia, there
are 60 spas using geothermal waters for balneology, sports and recreational purposes. Other fields of direct uses are presented in Table 1 (Milivojevic et al., 2000). The total installed energy use is 74 MW, out of which 36 MW are in balneology, and 38 MW for other types of uses. According to Freeston (1995), Serbia takes 17th place in the world as far as the direct use of geothermal energy is concerned, using only about 10% of its real potential, which is estimated to be about 800 MW.

Table 1: State-of-the art on geothermal energy use in Serbia (Milivojevic, 2000).

<table>
<thead>
<tr>
<th>Type of Use</th>
<th>Installed Thermal Power(^{(1)}) MW(_t)</th>
<th>Energy Use(^{(2)}) TJ/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating</td>
<td>18.5</td>
<td>575</td>
</tr>
<tr>
<td>Bathing and swimming</td>
<td>36.0</td>
<td>1150</td>
</tr>
<tr>
<td>Agricultural drying</td>
<td>0.7</td>
<td>22</td>
</tr>
<tr>
<td>Greenhouses</td>
<td>8.4</td>
<td>256</td>
</tr>
<tr>
<td>Fish and other animal farming</td>
<td>6.4</td>
<td>211</td>
</tr>
<tr>
<td>Industrial process heat</td>
<td>3.9</td>
<td>121</td>
</tr>
<tr>
<td>Snow melting</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other uses</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Subtotal</td>
<td>74.0</td>
<td>2335</td>
</tr>
<tr>
<td>Heat pumps</td>
<td>6.0</td>
<td>40</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>80.0</strong></td>
<td><strong>2375</strong></td>
</tr>
</tbody>
</table>

\(^{(1)}\) Inst. thermal power (MW\(_t\)) = Max. water flow rate (kg/s) \times (Inlet temp. (°C) - Outlet temp. (°C)) \times 0.004184

\(^{(2)}\) Energy use (TJ/yr) = Annual average water flow rate (kg/s) \times (Inlet temp. (°C) - Outlet temp. (°C)) \times 0.1319

At most localities in Serbia utilization of geothermal energy is cascade and integral. Localities of this kind of utilization are shown in Table 2.

3 The use of geothermal energy for the heating of greenhouses

Fifteen years ago, the former Yugoslavia (SFRJ) was the second in Europe (not including former SSSR), just behind Hungary in the area of greenhouses heated by geothermal energy (Popovski, 1987). In the year 1990, it was fifth in the world in installed power of 111 MW\(_t\) (Andrejevski, 1995). In the former Yugoslavia, the heating of greenhouses by geothermal energy was mostly applied in the Yugoslav ex Republic Macedonia. The block of greenhouses in Bansko (Macedonia) was the first commercial block of greenhouses heated by geothermal energy in the world (Popovski et al., 1997). Geothermal energy is now used for the heating of greenhouses only in three localities in Serbia: Vranjska Banja, Srbobran and Knjazevac (Figure 1). The biggest greenhouse is in Vranjska Banja, and the smallest in Knjazevac. Eight ha. are heated by geothermal energy while the total area of other greenhouses heated by crude oil and gas totals around 64 ha.

3.1 Cascade utilization of geothermal energy in Vranjska Banja

Vranjska Banja is one of the most well-known geothermal localities in Serbia. Its natural geothermal resources have temperatures of 80-92°C and a yield around 80 l/s. The flow of geothermal water is from gneiss and granodiorite. The age of these
formations is Neogene. The geothermal water is collected from the springs and conducted to the users through a covered, concrete channel or conduit. The use of geothermal energy is of the cascaded type, so that the water can first be used for the heating of hotels, then the buildings for balneotherapy, schools, kindergartens, health centres and poultry farms. Then, finally, it can be used for the heating of two complexes of greenhouses.

Table 2: Utilization of geothermal energy for direct heat.

<table>
<thead>
<tr>
<th>Locality</th>
<th>Type (1)</th>
<th>Flow rate kg/s</th>
<th>Temperature °C</th>
<th>Energy use (2) TJ/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaniiza - 1</td>
<td>C(D/B)</td>
<td>20.0</td>
<td>72</td>
<td>121.35</td>
</tr>
<tr>
<td>Kaniiza - 2</td>
<td>C(D/B)</td>
<td>14.0</td>
<td>65</td>
<td>72.02</td>
</tr>
<tr>
<td>Prigrevica</td>
<td>I+C(D/B/HP)</td>
<td>21.0</td>
<td>54</td>
<td>80.33</td>
</tr>
<tr>
<td>Srbobran</td>
<td>I(G/Gs)</td>
<td>11.7</td>
<td>63</td>
<td>60.18</td>
</tr>
<tr>
<td>Becej</td>
<td>I(D/B/Gs)</td>
<td>19.4</td>
<td>65</td>
<td>104.91</td>
</tr>
<tr>
<td>Vranjska Banja</td>
<td>C(Ip/F/D/B/G)</td>
<td>77.0</td>
<td>96</td>
<td>467.20</td>
</tr>
<tr>
<td>Sijarinska Banja</td>
<td>C(D/B)</td>
<td>7.4</td>
<td>76</td>
<td>49.78</td>
</tr>
<tr>
<td>Josanicka Banja</td>
<td>C(D/B)</td>
<td>17.0</td>
<td>78</td>
<td>85.21</td>
</tr>
<tr>
<td>Lukovska Banja</td>
<td>C(D/B)</td>
<td>12.0</td>
<td>67</td>
<td>50.65</td>
</tr>
<tr>
<td>Kursumlija</td>
<td>C(D/B)</td>
<td>20.0</td>
<td>68</td>
<td>113.43</td>
</tr>
<tr>
<td>Palanka</td>
<td>C(B/W)</td>
<td>13.0</td>
<td>56</td>
<td>53.16</td>
</tr>
<tr>
<td>Ribarska Banja</td>
<td>C(D/B)</td>
<td>37.0</td>
<td>44</td>
<td>92.73</td>
</tr>
<tr>
<td>Palic</td>
<td>C+I(D/B/Gs)</td>
<td>17.0</td>
<td>48</td>
<td>51.57</td>
</tr>
<tr>
<td>Bujanovacka Banja</td>
<td>C(D/B/W)</td>
<td>7.0</td>
<td>43</td>
<td>17.54</td>
</tr>
<tr>
<td>Gamzigrad</td>
<td>C+I(D/B)</td>
<td>10.0</td>
<td>42</td>
<td>23.74</td>
</tr>
<tr>
<td>Ovcar Banja</td>
<td>C(D/B)</td>
<td>50.0</td>
<td>38</td>
<td>72.54</td>
</tr>
<tr>
<td>Vrnjacka Banja</td>
<td>C(B/W)</td>
<td>5.0</td>
<td>36</td>
<td>7.25</td>
</tr>
<tr>
<td>Niska Banja</td>
<td>I+C(D/B/HP)</td>
<td>60.0</td>
<td>37</td>
<td>94.97</td>
</tr>
<tr>
<td>Klokot</td>
<td>C(B/W)</td>
<td>15.0</td>
<td>34</td>
<td>17.80</td>
</tr>
<tr>
<td>Koviliaca</td>
<td>C+I(B/O)</td>
<td>130.0</td>
<td>30</td>
<td>102.88</td>
</tr>
<tr>
<td>Bukovicka Banja</td>
<td>C(B/W)</td>
<td>15.0</td>
<td>34</td>
<td>11.87</td>
</tr>
<tr>
<td>Prolom Banja</td>
<td>I(B/HP)</td>
<td>15.0</td>
<td>31</td>
<td>13.84</td>
</tr>
</tbody>
</table>

(1) Type of Use: C=Cascade, I=Integrated (Ip=Industrial process heat; A=Agricultural drying; F=Fishing and other animal farming; D=District heating; B=Bathing and swimming; G=Greenhouses; W=Bottled water; HP=Heat pump; Gs=Gas)
(2) Energy use (TJ/yr) = Annual average water flow rate (kg/s) x (Inlet temp. °C) - Outlet temp. (°C)) x 0.1319

“Cvece” greenhouse complex: The area of the greenhouses in this block is 7 ha. Its owner is a company called “Simpo” from Vranje. The complex consists of two parts: the “old” and “new” one. The “old” part of the complex occupies 2 ha and is built in the year 1970; and the “new” one in 1985. The amount of geothermal water used for heating is 45 l/s and the temperature 75°C.

Geothermal water is flowing from the conduit into a water tank. From the tank it goes into heating installations of the “old” part of the complex of greenhouses. Transfer of geothermal water to the greenhouses is through asbestos - cement pipes insulated by glass wool with the pipes placed in a concrete-covered conduit. Thermal
water first reaches a tank of 50 m$^3$. The total thermal power necessary for heating the whole greenhouse complex, which covers around 7 ha., is 15.2 MW.$_t$.

![Geographical position of greenhouses heated by geothermal energy.](image)

**Figure 1: Geographical position of greenhouses heated by geothermal energy.**

Thermal water is sent from the tanks into the heating installations in the “old” part of the greenhouses with the aid of circulation pumps. In that way, direct heating is achieved. In the “new” part of the greenhouses, heating is carried out with the help of a plate heat exchanger. Temperature of the water, which enters the exchanger, is 75°C, but 44°C at the exit. The return water is heated once again and, thus, it can be used for heating. The system of heating is combined: soil heating installations and aerial heating, i.e. aerial steel pipe heating system. Soil heating is put into effect through polyethylene pipes of ½” diameter dug to a depth of 30 cm (Milivojevic et al., 1998). The regulation of temperature is mechanical i.e. through windows, and automatic. Movement of the air in the greenhouses is both natural and artificial with the help of ventilators. The construction of the greenhouses is of Belgium origin. Plant growing is both on the ground and on benches. Trimmed flowers in flowerpots, 600,000 of them in total, are produced in the greenhouses. The value of the whole production is around 1.5 * 10$^6$ € per year.

**“Rasadnici” greenhouse complex:** The area of these greenhouses is 1.2 ha. This greenhouse complex has the oldest greenhouses heated by geothermal energy in former Yugoslavia. It was built in the year 1954. This is the location of the first vegetable production greenhouse (of tomatoes) in former Yugoslavia.

The greenhouses are heated by geothermal water that is taken from a concrete-covered conduit. This is “waste” geothermal water, which is coming from use in the “Cvece” complex of greenhouses. Temperature of the geothermal water that enters the greenhouses is from 37 to 40°C, and the amount of water is around 36 l/s.
Heating is performed through aerial pipes with 100 mm diameter. The heating system is open, i.e. thermal water circulates through the pipes directly from the conduit and without a heat exchanger (because of that, there are certain problems with corrosion). Finally, it reaches an exit conduit for further use. With this heating system, and with an outside temperature of minus 10°C, inside temperature in the greenhouses reaches 8-10°C. When outside temperature is lower than -10°C, the temperature in the greenhouses is maintained by the use of oil for heating. During cold winters, 40 to 60 tons of heating oil are consumed. The circulation of air in the greenhouses is free.

The complex of greenhouses consists of differently constructed greenhouses. The first construction was a Russian product, which occupies 0.2 ha. The span of this construction is 6 m and its length 30 m. The second type of construction was made in Holland and produced in 1964. The span of this construction is 12 m and its length 50 m. The regulation of temperature is mechanical. There are no problems with condensation. The hardening of glass surfaces is performed during the summer. Plant growing is both on the ground and on benches. The season starts on October 10 and lasts until April 15 of the following year.

Trimmed flowers and flowers in flowerpots are grown here. The production of flowers is about 90% of the total production, with 300,000 of trimmed flowers and 30,000 flowers in flowerpots produced per year. The production is complete, from seeds to flowers. Apart from flowers, there is also production of vegetables: 5-10 tons of cucumbers and 20-30,000 hot peppers (annually). The total value of this production is around 175,000 €.

### 3.2 Integrated utilization of geothermal energy use in Srbobran

The “Elan” complex of greenhouses is situated next to the town called Srbobran, 100 km north of Belgrade (Figure 1). It consists of 6 ha of the greenhouses heated by gas from the nearby gas field and a 0.5 ha plastic building heated by geothermal water from the nearby geothermal well.

The geothermal plastic building was built in the year 1982. Heating is by 11.7 l/s of geothermal water that has a temperature of 61°C. The total mineral content of the geothermal water is 3.67 g/l. According to its chemical composition, the geothermal water is of HCO$_3$-Na-Cl type, having NaCl of 1.46 g/l. The geothermal water has a lot of gas (CH$_4$ and CO$_2$), 1.37 m$^3$ of gas/1 m$^3$ of water. The aquifer of the geothermal water is sand from the Neogene period. Because of the high gas content, the geothermal water is degassed before use (Ceman, 1993). After being degassed, the geothermal water flows through a 200 m long pipeline toward the plastic building. Pumps are used to control the circulation of geothermal water. The use of geothermal water in the plastic building is direct, i.e. without heat exchangers. The plastic building is heated in two ways: 1) by aerial heating through finned aluminium pipes and through a convector with a 60/35°C regime; and 2) by soil heating through polyethylene pipes with a 35/25°C regime. Using this heating system, and with outside temperature measuring -20°C, a temperature of 0°C is reached above soil. Finally, the geothermal water is used for heating cold water from 12 to 20°C, which is used for irrigation. The regulation of temperature in the plastic building is automatic. The movement of air is carried out by ventilators, which are a part of a calorifer. Used geothermal water flows out of the plastic building through an open conduit into the sewage system.

The construction of the plastic greenhouse is lattice type with aluminium pipes. The plastic greenhouse is 90 m long, 48 m wide and 3 m high. Corrosion and
incrustation are not apparent. Nursery plants of cucumbers, tomatoes and lettuce are produced in this plastic building.

4 Conclusion

We have satisfactory experience with cascaded geothermal energy for the heating of greenhouses and plastic houses here in Serbia. Although the area of geothermal greenhouses and plastic buildings is quite small or just about 8 ha in three locations, their owners want to enlarge them since economic indicators show that the production of flowers and vegetables in geothermal greenhouses is better than in those heated by gas or liquid fuel. However, the lack of money for building new and modern complexes of greenhouses as well as for renovating existing ones prevents the enlargement and further development of these buildings. If the financial problems can be solved, the geothermal resources are available to increase the area of geothermal greenhouses and plastic buildings in Serbia by several hectares.

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Utilization of geothermal energy in Iceland

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Abstract

Geothermal energy provides over half of the primary energy supply of Iceland. The principal use of geothermal energy is for space heating and about 87% of all energy used for house heating comes from geothermal resources. The paper gives an overview of the main utilization sectors for geothermal energy in Iceland. Space heating is by far the most important one, but other sectors of direct use briefly described are: swimming pools, snow melting, industrial uses, greenhouses and fish farming. Geothermal energy plays an important role in fulfilling an increasing electricity demand in the country and several new installations for geothermal power production are at the planning stage.

Keywords: Iceland, geothermal energy, district heating, direct use, electricity generation.

1 Introduction

The primary energy use per capita in Iceland is among the highest in the world. Geothermal energy plays an important role in the energy balance of the country as it provides over half of the primary energy supply. Other energy sources are hydropower and imported fossil fuel. The share of renewables is about 70% of the primary energy supply of the country.

The geothermal resources in Iceland are closely associated with the country’s volcanism and its location on the Mid-Atlantic Ridge. The high-temperature resources are located within the active volcanic zone running through the country from southwest to northeast, while the low-temperature resources are mostly in the areas flanking the active zone. There are over 600 hot water springs in 250 low-temperature fields and 26 potential high-temperature areas have been identified.

An overview of the direct uses of geothermal energy in Iceland and how the uses are divided on the different utilization sectors is given in Table 1 and Figure 1.

Table 1: Direct use of geothermal energy in Iceland 2001.

<table>
<thead>
<tr>
<th>Utilization sector</th>
<th>Annual energy consumption</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TJ/year</td>
<td>GWh/year</td>
</tr>
<tr>
<td>Space heating</td>
<td>17,223</td>
<td>4,784</td>
</tr>
<tr>
<td>Swimming pools</td>
<td>1,200</td>
<td>333</td>
</tr>
<tr>
<td>Snow melting</td>
<td>1,150</td>
<td>320</td>
</tr>
<tr>
<td>Industrial uses</td>
<td>1,600</td>
<td>444</td>
</tr>
<tr>
<td>Greenhouses</td>
<td>940</td>
<td>261</td>
</tr>
<tr>
<td>Fish farming</td>
<td>1,680</td>
<td>467</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>23,793</strong></td>
<td><strong>6,609</strong></td>
</tr>
</tbody>
</table>

2 Space heating

The main use of geothermal energy in Iceland is for space heating. It had its beginning early in the 20th century and in 1970 about 43% of the population was served by geothermal district heating systems. After the oil crisis in the 1970s, high
priority was given to replacing imported oil with the indigenous energy sources hydro and geothermal. Today about 87% of the space heating is by geothermal energy, the rest is by electricity (11.5%) and oil (1.5%).

Figure 1: Direct uses of geothermal energy in Iceland 2001.

District heating in Reykjavik began in 1930 when water from a hot spring area in the city was piped 3 km to a primary school. Soon after the national hospital, a swimming pool and some 60 private houses were connected. In 1943 geothermal water from a large geothermal field located about 17 km from the city, the Reykir area, was piped to Reykjavik. Reykjavik Energy utilizes now four low-temperature areas within and in the vicinity of Reykjavik as well as the high-temperature field at Nesjavellir, about 27 km away. The water from the low-temperature fields is used directly for heating and as tap water, but due to high content of gases and minerals the water and steam from Nesjavellir is used to heat fresh water. Today Reykjavik Energy serves about 177,000 people or practically the whole population of Reykjavik and four neighbouring communities, as well as two towns in a separate system in West-Iceland.

Besides Reykjavik there are district heating systems in about 30 towns and villages in Iceland, most of them municipally owned. Geothermal heating is now applied in all areas in Iceland where geothermal resources have been located. Resent developments in thede fields include district heating in Stykkisholmur, Drangsnes and Budardalur with a total number of about 1,700 inhabitants.

Figure 2: Space heating by sources 1970-2002.

The government subsidizes heating of dwelling houses by electricity and oil in order to keep heating costs comparable over the whole country. To encourage
installation of new geothermal heating schemes and expansion of older ones the government gives grants to this type of installation. The amount granted is the equivalent sum of expected subsidies over the next five years to the houses involved, as it would have been in case of continuing electrical heating.

3 Other direct uses

Following is a brief description of other geothermal utilization sectors than space heating.

3.1 Swimming pools

From the time of settlement of Iceland some 1,100 years ago until early in the 20th century the use of geothermal energy was limited to bathing, cooking and laundering. Some of these uses are today still significant and heating of swimming pools is one of the most important utilization sectors in the country. There are about 100 public swimming pools and about 30 pools in schools and other institutions heated by geothermal energy with a combined surface area of 28,000 m². This comprises about 90% of all swimming pools in Iceland. Most of the public swimming pools are open-air pools in constant use throughout the year.

Swimming is very popular in Iceland and the pools both serve for recreational use and for swimming instruction. In the greater Reykjavik area there are about ten public outdoor pools and five indoor ones. The largest of these is the Laugardalslaug, having a surface area of 1,500 m² and five hot tubs in which the water temperature ranges from 35 to 42°C. The Blue Lagoon at Svartsengi and the Health Facility in Hveragerdi, comprising geothermal clay baths and water treatments, are also very popular.

The number of visitors in swimming pools has increased in the last years reaching 4.7 million visits last year, which is equivalent to 16 visits per inhabitant. A new swimming pool of average size is using similar amount of geothermal water as 80-100 private houses.

3.2 Snow melting

The use of geothermal energy for snow melting has been widespread for a long time. It has become increasingly common to use return water from the houses, at about 35°C, for de-icing of sidewalks and parking spaces. Most systems have the possibility to mix the spent water with hot water (80°C) in periods when the load is high. Under
an extensive rehabilitation of streets in downtown Reykjavik a few years ago, a snow melting system was installed under pavements and streets covering about 40,000 m$^2$. Many streets in a new construction area in the eastern part of Reykjavik are having snow-melting system installed.

The total area covered by snow melting systems in Iceland is estimated to be about 740,000 m$^2$, of which about 460,000 m$^2$ are in Reykjavik. The total geothermal energy used for snow melting is estimated to be 320 GWh per year. Of that about 55% come from spent water from the houses and the rest from 80°C hot water.

### 3.3 Industrial uses

The use of geothermal energy for industrial uses began on a large scale in 1967 with the establishment of Kisilidjan, a diatomic plant at Myvatn near the Namafjall high temperature geothermal field. It is still the largest industrial user of geothermal energy in the country. The raw material is diatomaceous earth from the bottom of the lake Myvatn. The annual production is about 27,000 tonnes per year of diatomite filter aids for export. The annual steam consumption is about 270 thousand tonnes at 10 bar absolute for drying.

A seaweed processing plant at Reykholar uses geothermal water for drying. The annual production of seaweed and kelp is 2,000 to 4,000 tonnes and the processing plant is using 28 l/s of 107°C hot water.

On the Reykjanes peninsula a salt plant was in operation for more than 20 years, but it was closed down in 1994. From geothermal brine and seawater the plant produced salt for the domestic fishing industry as well as low-sodium health salt for export. Part of the plant was restarted in 1999 on a small scale.

At Hædarendi in Southern Iceland, a plant for the commercial production of liquid carbon dioxide has been in operation since 1986. The plant uses 6 l/s of geothermal water at 160°C with high gas content. The annual production is about 2,000 tonnes of CO$_2$, which is used in greenhouses, soft drink production and other food industries.

Geothermal energy has also been used for other industrial purposes such as drying of hardwood at Husavik which started in 1986, drying of fish at several locations, retreading of car tires in Hveragerdi and production of cements blocks at Myvatn.

### 3.4 Greenhouses

Geothermal heating of greenhouses started in Iceland in 1924, but prior to that naturally warm soil had been used to grow potatoes and other vegetables. The total area under glass is about 195,000 m$^2$. Of this area about 55% are used for growing vegetables (tomatoes, cucumbers, paprika etc.) and 45% for growing flowers for the domestic market (roses, potted plants etc.). In addition it is estimated that about 105,000 m$^2$ are used for soil heating. It has the main benefit of early thawing of the soil and the vegetables can be brought to market sooner.

The majority of the greenhouses are in the southern part of Iceland. Most of them are glass covered with heating installations made of unfinned steel pipes hung on the walls and over the plants. Undertable or floor heating is also common.

Artificial lighting has increased considerably in the last years, doubling the crop yield and allowing year-round production, but with increasing expenses in electricity. Enrichment of CO$_2$ gas in greenhouses during the winter has increased last years.
3.5 Fish farming
At present there are about 50 fish farms in operation in Iceland. The total production has been slowly increasing the last years and is now about 4,000 tonnes per year. Salmon is the main species with about 70% of the production but arctic char and trout are also raised. Geothermal water, commonly 20-50°C, is used to heat fresh water in heat exchangers from 5 to about 12°C. It is mainly used in the hatchery state of the fish production. A great expansion is expected in this sector with a considerable increase in utilization of geothermal energy.

4 Electricity generation
The electricity demand has increased considerably in Iceland in the last years due to a large expansion in the energy intensive industry. This has been met partly by increased geothermally produced electricity. Of the total electricity generation of 8,411 GWh in 2002 1,433 GWh or 17% came from geothermal energy, 82,9% from hydro and 0,1% from fuels. Figure 4 shows the geothermal generation of electricity in Iceland in the period 1970-2002. The total installed capacity of geothermal power plants is now 200 MW.

![Figure 4: Geothermal generation of electricity in Iceland 1970-2002.](image)

The first geothermal power plant with 3 MWe started operation in 1969 in Namafjall in North-Iceland. It has been in operation since, except for three years in 1985-1987 when the plant was closed mainly due to volcanic activity in the area. The reservoir temperature is about 280°C. Steam is separated from the water, at 9.5 bar absolute, to provide a steam flow rate of 12.5 kg/s to a single flash turbine.

The Krafla power plant in North-Iceland has been in operation since 1977. For the first 20 years it was generating 30 MWe in a double flash condensing turbine. Volcanic activity in the area caused inadequate steam supply in the beginning so expansion to the originally planned capacity was delayed. The capacity was increased to 60 MWe in 1997 by installing a second turbine. The reservoir temperature is ranging from 210 to 350°C. Steam is separated from the water in two stages, at 7.7 and 2.2 bar absolute, to provide 120 kg/s high pressure steam and 30 kg/s of low pressure steam. As a result of exploration drilling activity in the area the last years, further increase of 40 MWe are under preparation. Also it will be considered to build a new plant in the area in the future.

The Svartsengi co-generating power plant has been producing both hot water and electricity since it started operation in 1977. It is located on the Reykjanes peninsula, 40 km from Reykjavik, and serves about 16,000 people. The geothermal reservoir
fluid is a brine at 240°C with high salinity. The geothermal heat is transferred to freshwater in several heat exchangers. An expansion of the plant was completed in 1999 by installing a new 30 MWe turbine. The total installed capacity is now 200 MWt for hot water production and 46 MWe for electricity generation, of that 8.4 MWe come from binary units using low-pressure waste steam.

The effluent brine from Svartsengi is disposed of into a surface pond called the Blue Lagoon, where it has for a long time been used by people suffering from psoriasis and other forms of eczema, who seek therapeutic effects from the silica rich brine. Also it is very popular among tourists, especially after the opening of new facilities a few years ago.

At Nesjavellir high-temperature field, Reykjavik Energy is operating a co-generating plant. The plant started operation in 1990 with production of hot water for the Reykjavik area 27 km away. Freshwater is heated by geothermal steam and water in heat exchangers. At the end of 1988 the power plant started electricity generation of 60 MWe in two 30 MWe turbines. The working pressure of the turbines is 12 bar (190°C). The third 30 MWe turbine was installed in the year 2001 bringing the total installed capacity to 90 MWe. Further expansion of the plant to 120 MWe is under consideration.

At Husavik, located in the northern part of Iceland, the generation of electricity began in the year 2000 by installing a binary plant of Kalina type. Geothermal water of 120°C is used to generate 2 MWe of electricity and hereby cooling the geothermal fluid down to 80°C. The electricity generated is enough to provide more than half of the electrical demand of the town. The 80°C water from the power plant is then used for district heating of the town.

5 Geothermal exploration

During the past five years the Ministry of Industry has been running a programme to encourage geothermal exploration for domestic heating in areas where geothermal resources have not been identified, so-called “cold areas”. A total amount of 150 million ISK (1.9 million US$) have been granted for this purpose and used mainly for drilling 50-100 m deep thermal gradient exploration wells. This method has proven to be a successful exploration technique in Iceland.

Reykjavik Energy has the last years been drilling several exploration wells on Hellisheidi where they plan to build a new power plant for both electricity and hot water production. Also at Nesjavellir new wells have been drilled as a preparation for expansion of the existing power plant.

At Reykjanes Hitaveita Sudurnesja has been carrying out exploration drilling in connection with plans to utilise this high-temperature field for power production. There they plan to build a power plant of 40 MWe in the first stage. The company has also been involved in drilling activity at Trölladyngja, which is another high-temperature field on the Reykjanes peninsula.

A consortium of Icelandic energy companies is preparing the drilling of a 4-5 km deep drillhole into one of the high-temperature hydrothermal systems to reach 400-600°C hot supercritical hydrous fluid at a rifted plate margin on a mid-ocean ridge. The main purpose of the project is to find out if it is economically feasible to extract energy and chemicals out of hydrothermal systems at supercritical conditions. A feasibility report was completed in May 2003 and further proceeding of the project will depend on the financing available.

Figure 5 gives an overview of the geothermal drilling activity in Iceland since 1970.
Figure 5: Total depth of geothermal wells drilled annually in Iceland 1970-2002.

6 References
