Geothermal Possibilities in the 21st Century in Chile

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Abstract

The energy topic is certainly a basic factor for the development of Chile in the 21 century. Today, it has to import big quantities of oil and natural gas. Oil import has the disadvantage of important variations in price and gas of big supply instabilities. Hydroelectricity on the other side, depends strongly on yearly precipitations. In this complex situation where renewable energies are rethought, geothermal energy appears as the renewable with the biggest potential in Chile, situated on a strongly volcanic region, the so called "Pacific Ring of Fire". As well, it requires less surface area compared to other renewable energy sources. Nevertheless geothermal energy is scarcely utilised and nearly only for recreational or medical use (thermal water). Anyway, the promulgation of the "Sobre Concesiones de Energía Geotérmica" law (Law on Geothermal Energy Concessions) in 2000 and the concessions made since its promulgation let this renewable energy source appear in a brighter light.

In this article, places with geothermal energy potential are shown. The explorations done are mentioned and possible uses of water and steam are exposed. Further, two alternatives for areas without geothermal water or steam resources are shown. The first one is Underground Thermal Energy Storage, UTES, for which the results of a Thermal Response Test (the first in South America) and of a first experiment about solar energy storage in the underground, both carried out at our University, are included. The other one is called the Hot Dry Rock technology, where some measurements realized during a stay at the European HDR Project Soultz-sous-Forêts (France), are mentioned.

Finally, a short review about Chilean laws and the exploration concessions given by the state are included.

Keywords: Geothermal; Geothermal Applications; Underground Thermal Energy Storage; Thermal Response Test; Hot Dry Rock; Law on Geothermal Energy Concessions.

1. Introduction

Earth's temperature is increasing gradually with depth, in the centre reaching more than 4200°C. Most of the heat is generated by the decay of radioactive isotopes and a smaller part is heat conserved since the formation of Earth about 4.5 billions of years ago. It is estimated that 42 million thermal megawatts are continually radiated into space.

Geothermal energy has been used commercially for about one century and its large scale utilization (hundreds of MW) started about forty years ago, both for electricity generation and for direct application as space heating and combined with heat pumps.

Conventional geothermal technology uses steam or hot water sources. These hydrothermal resources are spread throughout the whole world but nevertheless are limited in quantity and quality of the resource.
As earth's temperature is increasing with depth, in most parts of the world there is the possibility to access geothermal energy contained in hot and essentially dry rocks (Hot Dry Rock Technology). On the other hand underground has been used with heat pumps since the end of the forties and since the beginning of the seventies it has been considered as a heat accumulator, showing its practical utility in the beginning of the eighties (UTES).
Underground heat exploitation is generally clean and, depending on the used technology, can be realized without carbon dioxide production due to the absence of fossil fuel use.

2. Chile's geothermal potential

Chile is situated in the so called "Pacific Ring of Fire", a zone of intense seismic and volcanic activity. This, in addition to the existence of intense shearing in the Earth´s crust makes Chile a country with huge geothermal potential. There are few in-depth studies about this resource and their use is limited mostly to tourism and medicinal purposes. In the last few years, promoted principally by constantly increasing oil prizes and by the reduction of natural gas exportation from Argentina to Chile, the interest in geothermal energy exploitation has grown, especially for the generation of electricity.
The "Servicio Nacional de Geología y Minería" (National Geology and Mining Service) published in the year 2000 the Decree No. 142 which identifies 120 zones as probable sources of geothermal energy.

3. Studies realized in Chile

In the twenties, the Italian engineers Ettore Tocchi and R. Corrandini realized the first studies about geothermal potential in Chile, but only after 1968 the first explorations were carried out.
The "Sociedad Geotérmica de El Tatio S. A." (economically supported by UNDP and CORFO – Chile) excavated 6 wells in El Tatio (north of Chile) with a depth of 600 meters, proving the existence of permeable zones with temperatures between 225°C and 254°C and a Hot Field area of about 30 km². Although pre-feasibility studies showed El Tatio to be one of the sites with the highest potential for the installation of an electric generator, until now no big project has been realized.
Since the promulgation of the "Sobre Concesiones de Energía Geotérmica" law (Law on Geothermal Energy Concessions) in 2000, 13 geothermal exploration zones have been conceded. (April 2004).
Since the year 2000 the authors started to study the utilization of the underground as a thermal energy accumulator, concreting this idea with a Borehole Heat Exchanger (BHE) of 16.9 m depth, which is connected to some solar collectors, allowing the seasonal storage of solar thermal energy.

4. Possible applications

In northern Chile it seems quite attractive to use geothermal springs for electricity production, for seawater desalinisation (drinking water is scare in many regions of northern Chile) and

obviously for space heating. In the country's central and southern zones geothermal springs might be used for house and greenhouse heating, in agriculture, to dry fruits and vegetables, in roads to prevent them from freezing, etc.
In zones without geothermal springs (water and/or steam), geothermal deep heat may be used for electricity production via Hot Dry Rock technology. Another alternative is the use of heat pumps connected to the ground and the utilization of the underground as a heat and cold accumulator.

5. Underground Thermal Energy Storage (UTES)

With the construction of a Borehole Thermal Energy Storage [I] in 2002 the authors begin a practical study on UTES. The next step was the realization of the first Thermal Response Test in South America [II] and tests with solar energy accumulation.
Fig. 1 shows the experimental installation built in the area of the Technical University Federico Santa María (Quilpue).
A U-loop of HDPE (3/4" SDR 11) was inserted in the central borehole to a depth of 16.9 m. The borehole was subsequently grouted with a 12% bentonite mixture. Each of the Boreholes contains 4 thermocouples. An electric heater allowed the water heating in the response test. As thermal charge of the accumulator, three flat solar collectors in parallel connection were used each with an absorption area of 1.76m².
With the realization of the Thermal Response Test (TRT) the underground's thermal conductivity was determined, which is the fundamental parameter for the design of accumulators of this type. The TRT was first presented by Mogensen [III] (stationary system); later mobile conductivity measurement systems appeared in Sweden [IV] and USA [V].
The theoretical approach commonly used for TRT is based on the Line Source Model (LSM) presented by Carslaw and Jaeger [VI]. About 10 countries in the world are dealing nowadays with this type of investigation - like Germany, Sweden, Canada, USA, Norway, Netherlands, England and Turkey.

$$T_f(t) = \frac{Q}{4\pi\lambda H}\left[\ln\left(\frac{4at}{r_b^{\,2}}\right) - \gamma\right] + \frac{Q}{H}R_b + T_0 \qquad (1)$$

a - Thermal diffusivity, m^2/s;
Q - Heat injection rate, W;
r_b - Borehole radius, m;
C - Volumetric heat capacity, J/m^3K.
T_0 - Undisturbed ground temperature, ºC;
R_b - Borehole thermal resistance, m-K/W.
t - Time, s;
T_f - Mean fluid temperature, ºC;
H - Borehole depth, m;
γ = 0.5772 (Euler´s constant);
? ? Thermal conductivity of soil, W/m-K;

Eq. 1 is the result of the application of LSM for this type of application. If the heat injection rate remains constant (via electric heater) Eq. (1) can be re-written in a linear form as:

$$T_f(t) = k\ln(t) + m \qquad \text{with} \qquad k = \frac{Q}{4\pi\lambda H} \qquad (2)$$

Hence, λ can be determined from the slope of the line resulting when plotting T_f against *ln(t)*.
Fig. 1 presents the results of the Thermal Response Test which was realized in Quilpue (Chile) from 24th of June to 3rd of July 2003
Due to the excellent solar radiation in Chile, this source was considered most appropriate to realize a seasonal heat accumulation. During 29 days (from 18th of August to 16th of

September 2003) the accumulator was charged with solar thermal energy (Fig. 2). During this period the collectors' efficiency was measured to be 48% and the accumulation circuit's 92%. Although this first solar thermal energy accumulation was realized in winter, the results were considered satisfying. The TRT and the accumulation tests show that the technical and geological conditions to develop this type of application exist in Chile. Right now a deeper accumulation is realized which includes spring 2004 and summer 2005.

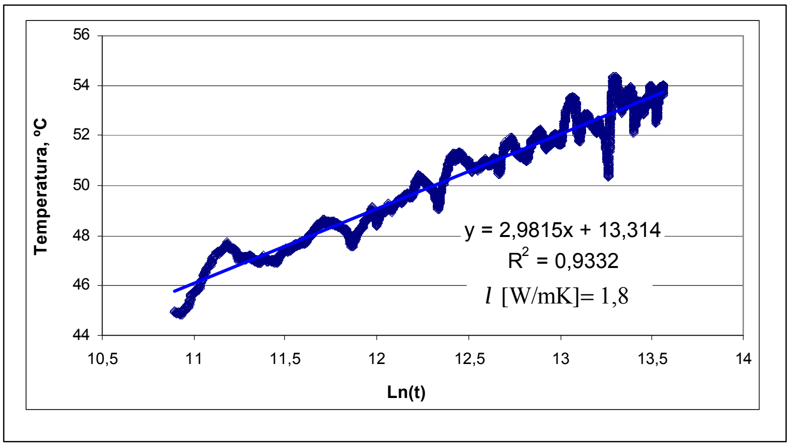

Fig. 1.- Thermal Response Test (Results)

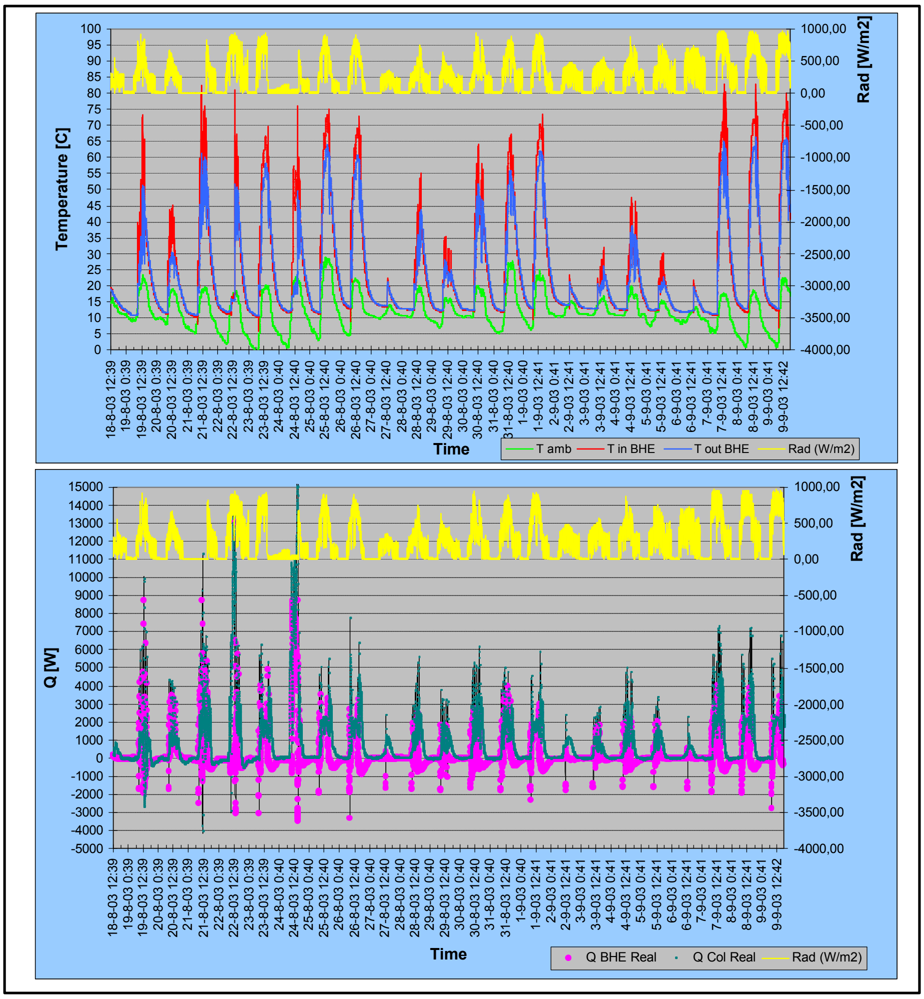

Fig. 2. - Solar energy charge in BTES

6. Hot Dry Rock (HDR)

The geothermal energy which is contained in hot and essentially dry rocks is known as HDR. In nearly the whole world one can access this heat by deep perforations (generally several kilometres). Countries like USA, United Kingdom, Germany, Japan, Switzerland and Austria have realized and/or are realizing projects with this technology. Although in Chile there is no HDR project realized until now, this technology is presented here due to its huge potential to be applied in Chile, mainly because of the important geothermal gradient in some zones of the country.

Basically, this technology consists of the perforation of deep wells until reaching the hot dry rock. Then the well is stimulated to increase the size and the number of natural fractures. This is realized by introducing large water flows at high pressures. Such a system is basically formed by one injection and two extraction wells. These wells are cemented (or protected) until the heat exchanger, consisting of hot rocks. The heat is extracted on the surface to produce electricity or for direct use (Fig. 3)

The geothermal energy in hot dry fractured rocks has the following benefits:

- It is one of the largest renewable energy sources; for example in Europe, 10% of the accessible hot rocks is equivalent to installed nuclear capacity in 2001.
- It is accessible all the time, night and day.
- It requires less surface area compared to other renewable energy sources.
- The electricity production by HDR technology reduces the emission of greenhouse gases, as there are no fossil fuels burnt during the production.

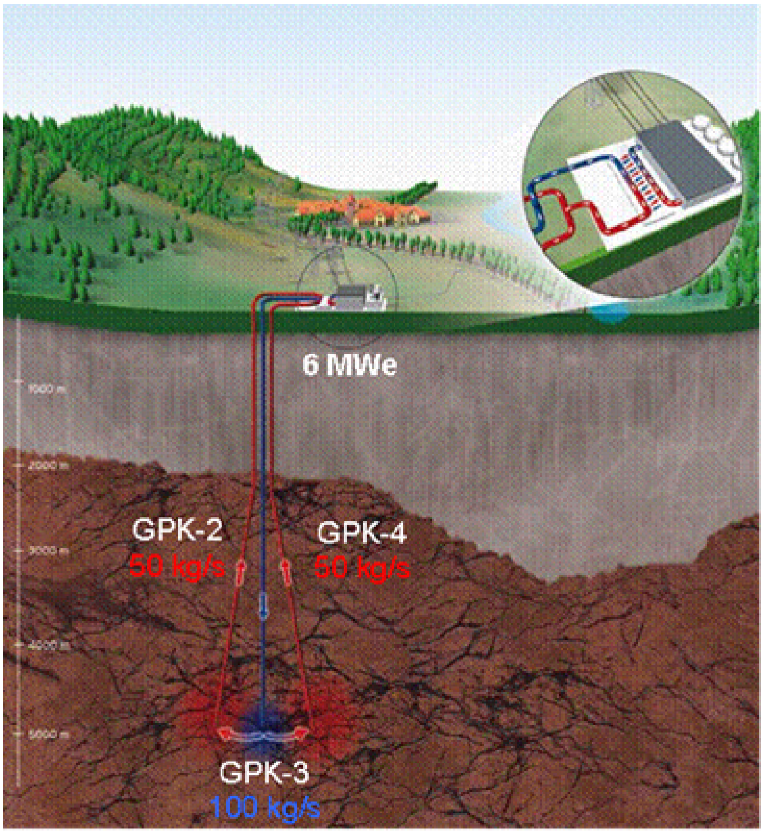

Fig. 3.- HDR Concept, Soultz – sous - Forêts

Although the theory seems simple, practical HDR-technology application is not. Scientists, professionals and technicians of different areas are making big efforts. Since the nineties, international teams of scientists are working in Soultz-sous-Forêts (from France, Germany and Italy as well as Switzerland, Britain, Sweden, Japan, USA and others countries) and have made great progress over the last decade. Fig. 4 presents as an example some of the results of this project. In the stimulation process, because of the constant injection of high pressured water, some perturbations are generated, which leads to microseisms. Seismological technologies allow to generate a general picture of the reservoir, including size, form and orientation (Fig.4b). Another on-site measurement of great interest is the geothermal gradient (Fig. 4c). Other thermophysical parameters have to be measured in the laboratory, for example the ones in Fig. 4d which are results of some measurements realized by the author [VII] during his time in the GGA-Institut (Hannover – Germany). By 2006 a 6 MW_{el} power plant in Soulz is supposed to work continuously.

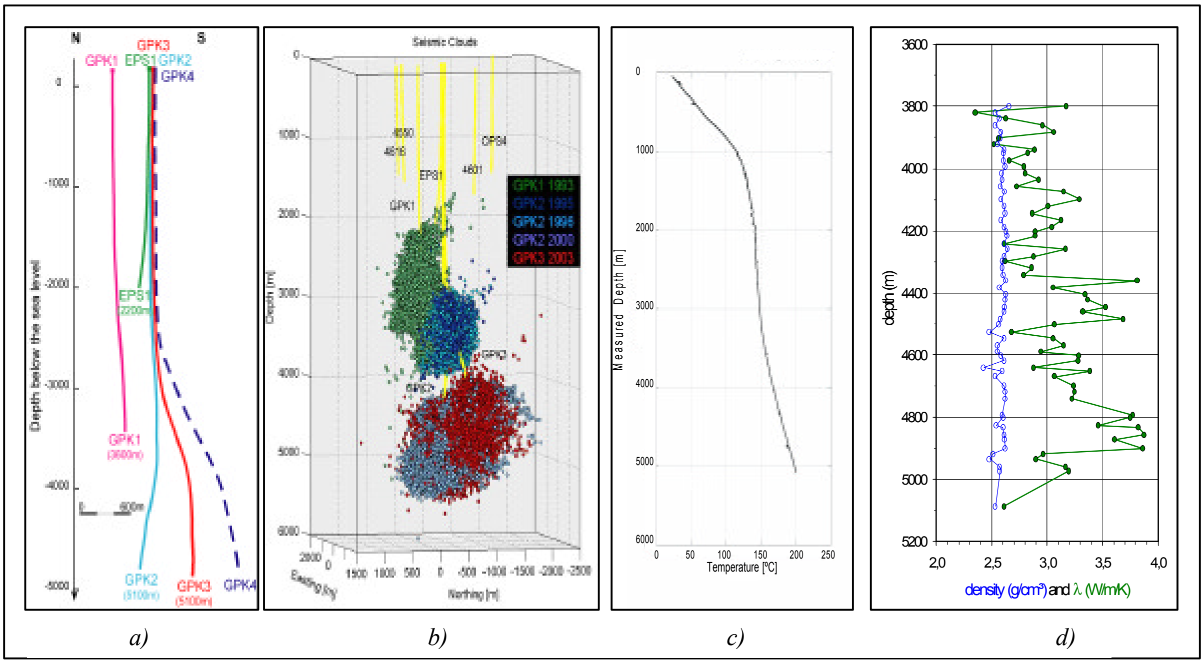

Fig. 4.- Example for the complex measurements realized in the European HDR-Project Soultz-sous-forêts (France) [Source: Leibniz Institute for Applied Geosciences - Hanover - Germany] a.- Boreholes b.- Micro-seismic activity detected during stimulation process c.- Temperature logs GPK3 (13th January 2003); d.- Thermal conductivity λ (blue) and density ρ (green) of the selected cutting samples from GPK3 (laboratory measurements).

7. Laws and concessions in Chile

In January 2000 the "Sobre Concesiones de Energía Geotérmica" law (Law on Geothermal Energy Concessions) was promulgated. In this law, the conditions and regulations for the participations of private enterprises in the exploration and exploitation of this energy source, are defined, excluding the thermal waters used for sanitary, tourism and recreational purposes. The concessions which the law establish may be for exploration of for exploitation. The main characteristics of these concessions are the following:

Exploration concessions: involve an area not bigger than 100.000 hectares, its for two years and with a single extension for two more, the applicant may be every natural Chilean person (with capital assets amounting to a minimum of five thousand UF, approximately 141.000 US dollars) or every corporate body organized under Chilean laws (with capital assets amounting to a minimum of ten thousand UF, approximately 282.000 US dollar).

Exploitation concessions: involve an area not bigger than 20.000 hectares, duration indefinite, the applicant may be every natural Chilean person (with capital assets amounting to a minimum of five thousand UF) or every corporate body organized under Chilean laws (with capital assets amounting to a minimum of ten thousand UF).

Additional to this law, there is a regulation which identifies the probable sources of geothermal energy (Decree Nº 142 – Ministry of Mining).

The Ministry of Mining is responsible for the application, control and fulfilment of the law and its regulations. This Ministry, in April 2004, gave 13 concessions for geothermal exploration (one to CORFO, two to Geotérmica del norte, one to Geotérmica del Tatio S.A., five to CFG Chile S.A. and four to the Universidad de Chile).

8. Conclusions

Economic growth is closely bonded to its capacity to respond to the growing energy demand. Actually, the energy offer is strongly dependent on external factors, such as international oil prices, gas imports from Argentina, amount of rainfall during the year, etc. To keep its economy growing, Chile needs to increase and diversify its energy matrix.

Chile's worldwide known geothermal potential and the possibility of exploiting this energy with very low environmental impact, make this alternative one of the most attractive for Chile in the present century.

The possibilities of this resource's exploitation reach from the use of steam and/or thermal waters for the production of electricity to the use of the underground as an accumulator or connected to heat pumps, and last but not least the HDR-technology.
In the year 2000, the Chilean state did a necessary but not sufficient step with the promulgation of the Law on Geothermal Energy Concessions. The exploration concessions given since the promulgation of the law and the words of the minister for economy and energy (Jorge Rodríguez) saying that in 2010 Chile could have a power plant using geothermal energy, give an optimist vision for the future of this energy source in Chile.

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