Can EGS (Enhanced Geothermal Systems) solve the energy problem?

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Abstract. Geothermal resources in the form of heat found in rock that is hot but is not in contact with sufficient mobile fluid to transport that heat to the surface are a large source of clean energy. Enhanced Geothermal Systems are those in which advanced technology is required to extract energy from the earth’s crust in areas where the natural permeability and/or fluid content are limited. The future commercialization of the Hot Dry Rock (HDR) or Enhanced Geothermal System (EGS) depends on solving technical and economic issues. A major barrier are the costs of drilling the wells, the supply of water and the pumping of the HDR produced hot water. This paper should show how such a Hot Dry Rock System works and it gives a short overview about the advantages and major barriers which are included in Hot Dry Rock Projects.

Introduction

Geothermal Energy is abundant in all parts of the world and can play a vital role in domestic and international energy supply and efforts to reduce greenhouse gas emissions and slow global climate change. In many projects all over the world this possibility is explored for EGS. Enhanced Geothermal Systems are those in which advanced technology is required to extract energy from the earth’s crust in areas where the natural permeability and/or fluid content are limited.

It is difficult to determine how much geothermal energy is accessible with current technology, or would be accessible with enhanced technology. Experts estimate that up to 72 GW worldwide could be produced with current technology at known hydrothermal sites (McLarty et al. 2000). With enhanced technology, these estimates increase to 138 GW (Gawell et al. 1999). (energy consumption of the world: 400 EJ/year (Fridleifsson 2003)). It is important to note that these estimates
are limited to known hydrothermal sites, which represent only a miniscule fraction of the accessible heat in the upper crust (McLarty et al. 2000).

In central Europe, temperature rises towards the interior of the earth with 3 °C each 100 m depth on average. However, there are regions that have to offer much more: In Iceland, temperatures of 1000 °C can be found in a few hundred meters depth. The median global heat flow through Earth’s surface is around 60 mWm⁻². (Berckhemer 2005)

![Fig.1. Worldwide seismicity and geothermal power plants (modified after Huenges and Jung 2004)](image)

**The HDR concept**

All recent HDR work is based on the concept outlined in a patent issued to the Los Alamos national Laboratory in 1974. That patent describes the formation of a fully-engineered geothermal reservoir in hot, crystalline rock by the application of hydraulic fracturing techniques and the subsequent circulation of water through that engineered reservoir to mine the thermal energy from the hot rock. For more than two decades, The US Department of Energy (DOE) has sponsored work at Los Alamos for more than two decades. There they developed heat mining technology to the point where extraction of the energy from HDR is practical and economic.

The HDR process is relatively simple: A well is drilled into hot, crystalline rock. Water is then injected at pressures high enough to open the natural joints in the rock. The water flows into the dilating joints and an engineered geothermal reservoir is thereby created. The reservoir consists of a relatively small amount of water dispersed in a large volume of hot rock. The relative dimensions and orientation of the reservoir are determined by the local geologic and in-situ stress con-
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Its ultimate volume is a function of the injection pressures applied and the duration of the hydraulic fracturing process. Seismic techniques are used to follow the growth of the reservoir and to assess its location and approximate dimensions. Using the microseismic data as a guide, one additional well is subsequently drilled into the engineered reservoir at some distance from the first well. In a HDR reservoir, that is properly engineered, there are a number of fluid-flow pathways between the injection and production wellbores.

For the operation of the heat mine, a high-pressure injection pump is used to circulate water through the engineered reservoir in a closed loop as shown in Fig.2.

Fig.2. A HDR heat mining system. Water is circulated around a closed loop to extract thermal energy from an engineered geothermal reservoir and deliver it to a power plant on the surface. A high-pressure injection pump provides the sole motive force. (modified after Duchane and Brown 1997)

The injection pump provides the fluid motive force for moving the water continuously around the loop to mine energy from the reservoir and deliver it to a power plant on the surface. The hydraulic pressure applied via the injection pump also serves to keep the joints within the reservoir propped open. By using a combination of injection and production control measures, an almost limitless variety of operating scenarios may be employed to mine the heat from an HDR reservoir. (Duchane and Brown 1997)
The first HDR project: Los Alamos Scientific Laboratory (LASL), USA

The first proposal to use geothermal energy from deep hot rocks of the crystalline basement came from physicists at the LASL in 1970. The active phase started in 1973. Germany and Japan contributed to the project financially and personnel.

Fenton Hill is located east of a Caldera about 40 kilometers west of Los Alamos on the west side of the Rio Grande Graben in New Mexico. Due to volcanism the thermal heat flow is about 250 milliwatts per square meter or about three times the average heat flow at the earth’s surface.

During the first phase of the project (1973-1979) LASL tested the basic HDR concept: connecting 2 boreholes by a single fracture at a depth of 3 kilometres in granodiorite rock at a bottom hole temperature of 195 °C. The fracture was generated in the first drill hole (GT-2) by hydraulic fracturing, and was identified by seismo – acoustic measurements. The subsurface flow path system consisted of several natural fractures in addition to the induced hydrofrac. The distance between inlet and outlet was about 90 meters. Circulation experiments were carried out over a total period of 100 days and demonstrated rather low water losses and low flow resistance of the system. This first result was beyond previous expectations. During the experiments a geothermal energy of 5 gigawatthours was extracted from the rock mass, an amount to cover the yearly energy consumption of several hundred households.

The second phase of the LASL- HDR project started in 1980. Objective of this project is to test the multifrac HDR concept. The system consists of two 4,500 meter deep boreholes, which are deviated on the last 1,000 meters to an angle of 30 degrees with respect to the vertical (Fig.4). The bottom hole temperature is 327°C. This high temperature in the vicinity of the Valles Caldera, however, induced various problems for drilling and borehole measurements and hydraulic tests.

![Fig.4. a) Original conceptual design of the Phase II HDR reservoir. b) View of the actual Phase II HDR reservoir (modified after Duchane 1993)](image)
A hydraulic connection between the two boreholes could not be achieved in the deeper part. Therefore, it was decided to fill this part of the boreholes with sand, and to carry out hydraulic fracturing experiments at a depth of 3.600 meters. This test was the largest hydrofrac operation ever conducted in the U.S., but failed with respect to connect both boreholes hydraulically. The spatial distribution of microseismic events monitored during the injection test shows that a large complex fracture system was stimulated over an extension of 800 meters and with a thickness of about 150 meters. Instead of being vertical the system is inclined by about 30 degrees. According to this information the second borehole was directionally deviated to penetrate this fracture zone. Thus, in 1986 - seven years after the start of the project phase – the second HDR circulation system could be completed. A one month circulation test indicates that the system may be characterized by rather favourable hydraulic properties. The thermal system capacity is in the range of 10 megawatts.

In 2001 the U.S. Department of Energy (DOE) has closed its Fenton Hill Hot-Dry-Rock project. (Tenzer 2002)

The European Hot-Dry-Rock Project

At first there has to be said that this HDR Project is not really Hot Dry Rock, because hydrothermal brines occur at depth in sediments and granite. But only the European EGS research has made significant process in the past decade and so it is important to know some aspects about this HDR Project.

Since 1987 several national HDR research programmes have been integrated into a single European programme on a site at Soultz-sous-Forêts, France, in the Upper Rhine Valley (Fig.3). The partners in this European Hot Dry Rock Programme are France, Germany, Italy, Switzerland and the UK. The costs have been shared between the appropriate research ministries and the European Commission.

The objective of the work is to develop techniques to circulate water in a closed loop between two or more boreholes through a stimulated natural fracture system in the rock. Such a fracture system can provide a heat transfer surface of several square km.

Fig.3. Location of Soultz in the Rhine graben. (modified after Bächler and Kohl 2005)
A circulation test carried out in 1997 showed for the first time that it was possible to circulate ca. 25 l/s between two wells at a depth of 3000-3500 m and with a separation of about 450 m. The test lasted for 4 months and produced excellent results (low resistance to flow, zero water losses). The heat produced could have been used for space heating. Both the funding agencies and the industrial consortium felt that energy production from HDR would be more attractive for electricity generation, for which around 200 °C would be necessary, so one of the wells was deepened to about 5000 m in order to access the required temperature.

Having achieved this successfully in 1998/9 (200°C at 5000 m), the aim of the European Hot Dry Rock Project is now to create the underground heat exchanger at a depth of 5 km. This involves the drilling of two more 5000 m wells, treatment of the intervening rock mass and demonstration of circulation between the wells at rates of up to 100 l/s.

If this step is successful, the following phase should see the construction of a pilot plant with 4 x 1.5 MW generating units. The last phase should eventually lead to an industrial plant (with further wells) with a capacity of 20-25 MW.

All EGS research for the past 20 years - world-wide - has been directed at the achievement of the key target parameters (creation of a fracture network, sustainable high-rate circulation at depth, zero fluid-losses), but only the European work has made significant progress in the past decade. (Tenzer 2002, Rabemanana et al. 2003, Baumgärtner et al. 2003)

Advantages of EGS technology

Conventional geothermal applications, except for geothermal heat pumps, rely on the geological coincidence of water-bearing, hot permeable rocks occurring at economically accessible depths. This is a comparatively uncommon situation, and constrains the usable resource because it is site-specific and distributed unevenly among countries. The Hot Dry Rock (HDR) / Enhanced Geothermal Systems (EGS) concept aims to utilise the vast amount of heat stored in the Earth's crust which is not accessible by conventional geothermal technology. Hot Dry Rock comprises a huge amount of useful heat stored in rocks that are technically accessible but lack the natural permeability necessary for heat extraction.

Such heat stores are much more widely distributed and so offer a geothermal potential to many countries where conventional resources are absent (Fig.5). Even in those areas where good conventional geothermal resources exist, there is usually a much greater volume of heated rock than can be exploited with current techniques. The importance of this ‘potential’ resource can be judged by noting that cooling one cubic kilometre of rock (which is about the scale of a geothermal reservoir) by 1°C will provide the energy equivalent of 70 000 tonnes of coal. (Baumgärtner 2002)
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Positive aspects specifically for the EU

The EU want to ensure a sustainable energy supply based on Renewable Energy Sources (RES). EGS would offer a clean and secure energy supply.

Because of the resource estimates, it is realistic to foresee a situation by 2030-2050 where HDR/EGS technologies could permit significant levels of electricity generation in many countries that are not currently considered as geothermal. In Europe as a whole, for example, one could foresee power generation on a scale comparable to existing nuclear systems. This would represent some 10-20 % of total electricity demand. A study by Shell – which now participates in the European HDR research project – suggested that exploitation of the prime sites in Europe could support generation on a scale comparable to that of Europe’s current nuclear programme (40-80 GWe), while the total exploitable resource could be 100 times greater. (Baumgärtner 2002)

In addition, such systems would probably operate in a closed loop with re-injection of spent fluids and gases, so emissions to the atmosphere of greenhouse gases (other than water vapour) would be low. Therefore, by displacing fossil-fired units, development on the scale foreseen could result in avoided CO₂ emissions of around 100 million tonnes CO₂ per year in Europe, and several times this figure world-wide. A comparison of CO₂ emissions between conventional energy systems and geothermal plants is shown in Fig.6.
The major non-technical barriers that have to be overcome

In many cases, the major inhibitors to growth are non-technical issues such as lack of public awareness, an inappropriate regulatory environment, and the difficulty of competing with conventional energy sources. Public bodies at both the national and international level can contribute to the resolution of these issues.

The overall competitiveness of geothermal energy is to a large extent determined by comparison with both conventional and other renewable energy sources. Usually the cost of energy is based upon standard economic and financial analyses. The funding of geothermal projects by the main international financing agencies is currently based on strict application of a least-cost analysis as part of their procedure for granting loans for energy projects. It should be stressed that at present in Europe, the low cost of fossil fuels, especially natural gas, makes only the best geothermal resources competitive from a strict financial comparison. Nevertheless, geothermal energy could become more competitive compared with conventional sources of energy if the comparison is not limited exclusively to strict financial criteria, but also takes account of other factors such as shadow costs and their economic consequences (so-called “externalities”).

In the specific case of EGS, the same non-technical and institution barriers as exist for conventional systems will also need to be addressed. The difference will be that, as the new technology should be applicable in many countries currently regarded as effectively non-geothermal, legislative and regulatory issues will need to be addressed in those countries also. No developer can be expected to invest capital in a resource where the regulatory questions (and even, in some cases, the ownership) remain undefined. (Counsil 1995)
Conclusion

EGS systems aren’t in regular use yet, because the technology to develop fully engineered geothermal “reservoirs” (the Enhanced Geothermal Systems) is still under development. The major challenges are the cost-effective drilling and fracturing of deep crystalline rocks, and achieving a sustained circulation of fluids at a high enough rate. The necessary experiments for developing Enhanced Geothermal Systems are very large and expensive, requiring the drilling of boreholes 4-5000 m deep at a cost of several million euros each.

If EGS should solve the energy problem there had to be some research for these systems. Research on HDR/EGS systems is approaching the pilot plant stage. Success in these developments will greatly increase both the scale of the usable resource and the number of countries that can benefit from this large indigenous energy resource. Specifically, research and technology development is needed in the following areas: more cost-effective drilling, real-time reservoir characterisation and monitoring, improved numerical reservoir modelling and improved reservoir management techniques.
References


Berckhemer Hans (2005): Grundlagen der Geophysik, Frankfurt


Homepage: www.geothermie.de