Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Geothermal Sciences – Research and Education

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Keywords: Geothermal sciences, education, training, university, numerical calculations, German geothermal projects

1. INTRODUCTION

Almost every geothermal powerplant worldwide is located in high-enthalpy hot reservoirs, so called hot spots, see Arslan (2008). These high-enthalpy hot spots correspond mainly with the Ring of Fire, a zone of frequent earthquakes and volcanic eruptions that encircles the basin of the Pacific Ocean. In Germany no such high-enthalpy reservoirs are found.

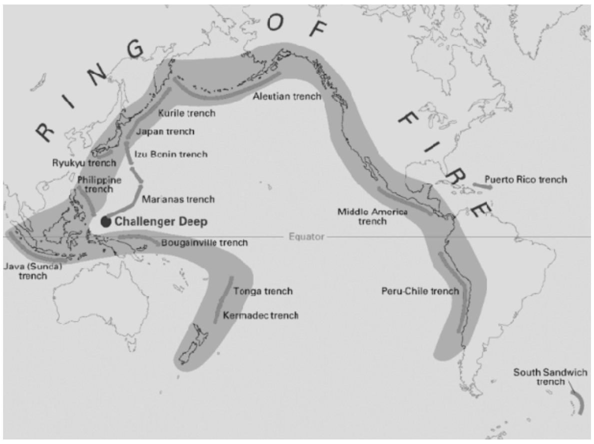

Figure 1: Ring of fire

Nevertheless 15 geothermal projects were raised in Germany up to the end of 2008, see Arslan (2009). To use the given low-enthalpy potential for a generation of geothermal power inventions and improvements needed to be performed by German scientists. An important part of these improvements is supported by universities and institutes of sciences. To understand the development of geothermal application and outstanding inventions, German application of research and education in geothermal sciences is pointed out in this paper.

National and international geothermal projects supported by German Universities and state-aided organizations are described. Examples of supervised shallow and deep geothermal systems are given.

2. EDUCATION IN GEOTHERMICS

Geotechnical and geological engineering is a traditional part of the education for civil engineers at German Universities. Due to the process of environmental and green thinking in all societies, the education and training of geothermal sciences is also becoming an important task at German Universities.

This paper gives an overview of study programs in geothermal engineering. German Universities teaching education in geothermics are listed; outstanding geothermal research programs of German Universities and state-aided organizations are pointed out.

3. INSTITUTES OF RESEARCH

3.1 Research and Education in Geothermal Basics

The education in geothermics at German Universities is primarily based on Technical Universities (TU), Universities and the Universities of applied sciences (FH). The education in geothermal sciences at all of these universities is based mainly on the common academics geology and/or geotechnical engineering. Besides these academics, thermodynamics are taught in mechanical engineering, mechanics or electrical engineering for example.

The main interest of education in geothermal basics is thermodynamic main theorems and thermal transport mechanisms such as transient change of heat content via conduction, convection, and radiation. Basic equations and formulas are summarized in the following:

Heat transfer always occurs from a higher-temperature object to a cooler temperature one as described by the second law of thermodynamics. The heat transfer formula can be written as

$$\rho c \frac{\delta T}{\delta t} = \mathrm{div}(\lambda \cdot \mathrm{gradT}) - (\rho \mathrm{c})_{\mathrm{Fl}} \cdot \mathrm{div}(\nu \mathrm{T}) + \mathrm{div}(\mathrm{D}_{\lambda} \cdot \mathrm{gradT}) + \mathrm{Q}_{\mathrm{i}}$$

with its terms of conduction, convection, radiation and thermal sources.

The heat transfer is based in principle on the Fourier´s law that can be written as:

$$\vec{q} = -\lambda \frac{dT}{dx}$$

The differential form of Fourier's Law of thermal conduction shows that the local heat flux, q, is proportional to the thermal conductivity λ, times the local temperature gradient. The heat flux is the amount of energy that flows through a particular surface per unit area per unit time. Heat always conducts from warmer objects to cooler objects, which is demonstrated by the negative λ.

The transport of groundwater is based on the analogous formula known as Darcy´s law:

$$\vec{q} = -k \frac{dh}{dx}$$

where q is the flux, which means the discharge per unit area, with units of length per time. The variable k stands for the permeability of the object (here ground).

While these basics of thermodynamics are taught in different academics, the application for geothermal purposes are only taught in a few universities in geothermal lectures. An overview of German Universities and Universities of applied sciences teaching thermodynamical basics for geothermal purpose is presented in the following table.

Table 1: German Universities teaching geothermics

University	Institute	Education program and main aim
Technical University (TU/TH)		
TU Darmstadt	Institute of geology	Lecture and exercise; geothermal basics, heat transfer formula etc.
	TU energy center	summer school geothermics, application of numerical programs (FeFlow)
TU Hamburg-Harburg	Institute of geo-technics and con-struction operation	Pilot plant for shallow geother-mics "HafenCity Hamburg"
	Institute of electricity techniques	Optimisation of the electricity generation from geothermal district heating plants in Germany
TU Braunschweig	Civil engineering	Lecture geothermics; geothermal field and lab exercises
TU Karlsruhe	Institute of applied geosciences	Geothermics as main research
TU Munich	M.Sc. geology and hydrogeology	Lecture introduction to geothermics
RWTH Aachen	Super C Geotherm	Research group for geothermics
Universities		
University Stuttgart	Institute of geotechnics	Geothermics as main research, congress for geothermics in Stuttgart, partnership with VDI
University Duisburg-Essen	Institute of geotechnics	Geothermics as main research
University Siegen	Institute of geotechnics	Geothermics as main research
	Center for renew-able energies and optimization	Continuing education drillings for geothermal purpose and install-ation of closed loop systems
	Research center geothermics	Geothermics as an example for renewable energies
Leibniz Univer-sity Hannover	Institute of electric power systems	Lecture geothermics, since 2005
Johannes-Gutenberg University Mainz	(planned)	Topics not known yet
University of applied sciences (FH)		
FH Deggendorf	Mechanical engineering	Main research geothermal energy systems
FH Bochum	The geothermal center	Geothermal energy systems (planned)
FH Aachen	Summer school renewable energy	Renewable energies in general

Following the necessity of an environmental green thinking, more and more Universities and Universities of applied sciences are teaching basics of thermodynamics for geothermal purposes.

Besides this development at German Universities geothermal research programs are also supported by state-aided organizations and institutes of research. These organizations are described in the following.

3.2 State-Aided Organizations

The main state institute of geothermal research is the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). This institution coordinates all state-aided research institutes and supports geothermal research institute financially. The BMU decides on the financing of renewable energy projects. Therefore it channels the different aspects of research and coordinates the institutes to avoid an overlapping of their research programs.

The aim of the BMU is to develop the use of geothermics broadly to increase the energy yield and to arrange the development to be environmental and nature compatible. Above all joint research projects are promoted, which compile common solutions for industry and research, since the research results will transfer as briskly as possible into practice.

A brief summary of actual research and development projects on renewable energies supported by the German government by the BMU is given in the following table.

Table 2: German state-aided research projects

Institute	Year	Research field
State-aided institutes		
GeoForschungsZentrum, Germany (GFZ) (*Geological Research Center, Germany*)	2008 - 2010	Production and injection of thermal water Groß Schönebeck
	2008 - 2011	Monitoring of long term corrosion
	2007 - 2010	Predicition While Drilling
Bundesanstalt für Geowissen-schaften und Rohstoffe (BGR)	2008 - 2009	Workshop GeoHyBe
	2005 . 2009	GeneSys Horstberg II
Leibniz-Institut für Angewandte Geophysik (LIAG)	2008 - 2011	GeneSys GT1
	2005 - 2009	GeoTis
	2005 - 2009	GeneSys
	2006 - 2009	3D seismic investigation
	2008 - 2011	Characterization of aquifers in Munich
Universities		
RWTH Aachen	2006 - 2009	Rock properties of Germany
University Karlsruhe	2006 . 2010	Reduction of drilling risks
University Dresden	2007 - 2009	Electrical impulse drilling
University Berlin	2008 - 2011	Hydrogeological model of Munich
University Munich	2008 - 2009	MonKü - cooling water
Companies		
Geothermie Unterhaching	2008 - 2010	Monitoring Unterhaching
Herrenknecht AG	2008 - 2010	Pipe Express
Geothermie Neubrandenburg GmbH	2009	Modulare monitoring

A detailed overview on research projects including brief description of projects is available on the website of Projektträger Jülich (PTJ). The German government's site provides information about all support programs The online data base of the German government enables users to get information about concluded as well as current specific projects.

The principles as well as the main research aspects of the former mentioned state-aided organizations (GFZ, BGR, LIAG) are described in the following.

GFZ

The GeoForschungsZentrum Potzdamm (GFZ) describes their main aim as follows:

The GFZ German Research Centre for Geosciences is working on urgent social, scientific and economic questions.

Besides detailed researches in geothermics the GFZ works in the areas of "Earth and Environment" as well as "Energy" in general. The overarching research aim of the GeoResearchCentre is to develop strategies and to demonstrate practical options, e.g. to preserve natural resources and to exploit them in an environmentally friendly way.

The research programme of the GFZ concerning renewable energies concentrates continual and long-term research, interdisciplinary collaboration between a large number of scientists, and large-scale investment in experimental equipment.

The Renewable Energy Programme is engaged in fundamental questions belonging to materials and process research as well as in the problems involved in putting renewable energies into industrial practice.

The main aim can therefore be summarized to design systems for producing low-price and environmental friendly energy. Therefore the research is focused on exploring suitable geological structures in low-enthalpy regions for the use of geothermal techniques worldwide, by increasing the fluid productivity of geological formations, by developing process technologies for the installation of geothermal power plants and by monitoring all aspects of systems in operation.

BGR

The Federal Institute for Geosciences and Natural Resources (BGR) is the geoscientific center of excellence within the federal government and part of its scientific and technical infrastructure.

The BGR concentrates on geoscientific and natural resource issues, such as stimulating economic development, long-term protection and improvement of the quality of life and enhancing technical and scientific expertise.

LIAG

The Leibniz Institute for Applied Geophysics (LIAG) concentrates its research in the field of physical geosciences. Therefore the uppermost part of the earth`s crust is investigated to find areas of an accessible and economic use for geothermal belongings as well as essential resources.

An important issue for the institute is the development of research methods for geological measuring and interpretation techniques such as seismics, magnetics, gravimetry, geoelectrics, well logging, geologic age dating, and basics of geothermics.

Presently, the institute conducts research in the topical research field of:

- ground water systems - structure, quality, processes
- geothermal energy - research and development for economic use

Most of these issues are handled in cooperation with multiple partners such as federal state geological surveys, universities, institutes of sciences, private companies, and industry.

As shown before, basic research programs in geothermal education and application are performed by universities and stated aided organizations. All of these programs are leading to outstanding geothermal pilot projects. Some of these shallow and deep geothermal pilot projects are demonstrated in the following:

4. DEEP GEOTHERMAL PILOT PROJECTS

No high-enthalpy hot spots are found in Germany (see figure 1). To produce geothermal green energy the efficiency of deep geothermal projects needs to be raised. Therefore costs of drilling and the risk of failure need to be minimized. The degrees of efficiency need to be raised before an economical use of a deep geothermal source can be guaranteed. By raising the total degree of efficiency, even low temperatures of around 100°C can be used economically for a production of geothermal power.

To achieve the aim of an efficient use of low-enthalpy geothermal power production different research projects are actually supported. These projects of deep geothermal systems supported by German institutes of sciences are pointed out in the following.

4.1 Numerical Analyses

Especially in deep geothermics numerical analyses are essential for a correct dimensioning of the geothermal system, see Huber (2006).

Therefore German Universities and state-aided organizations are developing numerical programs for a detailed use of application on geothermal systems. In this progress the subsoil is analyzed as a three-phase model in actual sciences projects with a separated consideration of conduction, convection and advection and their subsequent interface.

Most common numerical programs for geothermal purpose base on the finite-element-method and the finite-differences method. For further information see Huber (2007).

4.2 Geothermal Powerplants

Neustadt-Glewe

Since 2003 the first German geothermal powerplant produces geothermal electricity in Neustadt-Glewe. The research project was supported by the BMU.

Neustadt-Glewe is neither located in a high-enthalpy region, nor in a geological hot spot. At the site, water of a temperature of only 98°C is raised by the production well of a depth of 2,200 m. Therefore it is a geothermal pilot project for the production of geothermal electricity by low temperatures.

The geological conditions at site of Neustadt-Glewe are shown in the following figure.

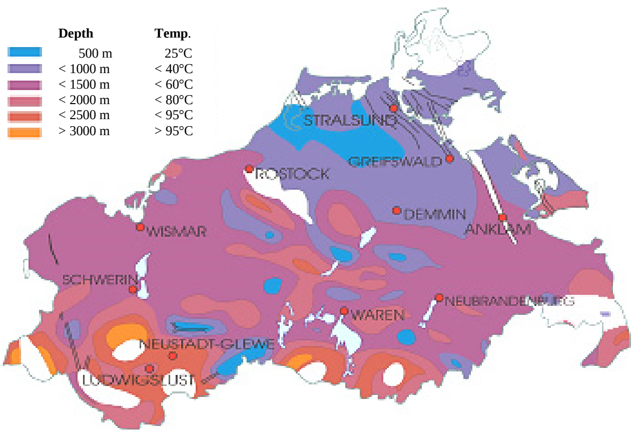

Figure 2: Geological conditions Neustadt-Glewe

Landau

Supported by national universities and state-aided organizations (BMU) the ORC powerplant nearby Landau was developed. With its high low enthalpy temperature of 160°C 3 MW_{el} are produced.

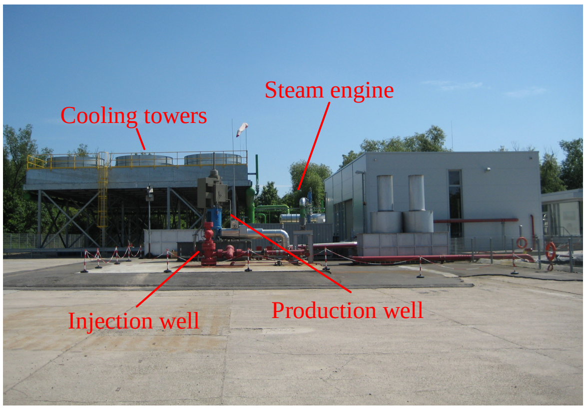

Figure 3: Geothermal powerplant Landau (a)

Landau is located in the geological anomaly zone called Oberrheintalgraben. Because of that anomaly a geothermal gradient of about 4.7°C/100m could be reached. That meant a bottomhole temperature of 160°C at a depth of about 3,300 m. The geothermal powerplant Landau was the first economical powered geothermal powerplant in Germany.

Figure 3: Geothermal powerplant Landau (b)

Groß-Schönebeck

Groß-Schönebeck is located in the north-eastern region of Berlin. Initialized by the GFZ a georesearch-research center for geothermal purpose was raised upon a former petroleum gas drilling.

The aborted drilling was reactivated in the year 2000 and deepened to its final depth of 4,309 m. The geological conditions and the given geothermal gradient are shown in the figure 4.

The geological conditions of Groß-Schönebeck correspond to most European low-enthalpy regions. Therefore Groß-Schönebeck was predestinated for a research program to develop stimulation methods for low-enthalpy regions to a suitable geothermal power generation.

At site of Groß-Schönebeck a research program for hot-dry-rock (HDR) geothermal powerplants was started. Besides stimulation methods the sustainability and the long-term values of a geothermal reservoir were developed.

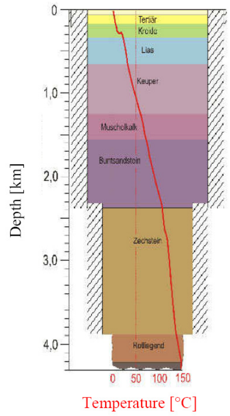

Figure 4: Temperature profile Groß-Schönebeck

Unterhaching

Supported by national universities and state-aided organizations, the Kalina-cycle powerplant nearby Unterhaching was developed. Gathering 120°C of hot water from an aquifer at 3,500 m, about 4 MW_{el} and 30 MW_{th} are produced. An overview of the most important information gathered during the process of the development is shown.

Unterhaching is located next to Munich. The geological, hydrogeological and geothermal conditions of Munich are quite different to the previously mentioned projects next to Berlin (Groß-Schönebeck), northern Germany (Neustadt-Glewe) and the Oberrheingraben (Landau). With this fourth geothermal powerplant located in Unterhaching, the main geological homogeneous regions suitable for geothermics are investigated and researched by pilot projects.

5. SHALLOW GEOTHERMAL PILOT PROJECTS

Besides these deep geothermal pilot projects shallow geothermal research is also promoted in German institutes of sciences. Actual projects of shallow geothermal systems supported by German institutes of sciences are pointed out.

5.1 Geothermal Investigation

While for smaller geothermal systems up to 30 kW of heating / cooling power the conductivity can be estimated it is necessary for larger systems to define the conductivity in detail. This investigation is performed by geothermal investigation methods.

The most common geothermal investigation method in situ is the thermal response test (TRT).

To define the effective conductivity in situ a constant heat power is set to the fluid of a borehole heat exchanger (BHE). Before, during and after this heating period the temperature of this fluid is measured. Therefore it is possible to figure out the conducted heat energy of the surrounding ground. As a conclusion the effective conductivity in situ can be defined.

Disadvantage of this well probed geothermal investigation method is that the effective conductivity can only be defined for the whole BHE. The varying of the conductivity according to the change of geological and hydrogeological conditions is neglected and cannot be defined.

To increase the efficiency of geothermal investigation methods different aspects of geothermal parameters are analyzed in Germany. Therefore an enhanced geothermal response test (EGRT) was invented. Within this EGRT the conductivity of a given ground can be analyzed by depth for every single layer. Shallow geothermal methods can be adapted to the actual conductivity of each layer.

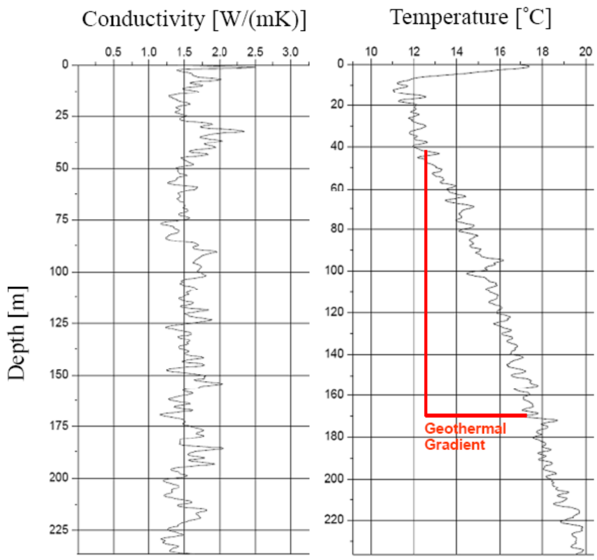

Figure 5: Example for an EGRT result

Besides these improvements in geothermal investigation methods in situ the standards for geothermal pre-studies were also improved immensely. Therefore the online-portal Geotis was developed. Geotis is a research project supported by the BMU and LIAG as well as the University of Berlin.

The Geothermal Information System (GeotIS) offers a voluminous database for shallow and deep aquifers in Germany suitable for geothermal usage. Geoscientific base data as well as current knowledge are provided and continuously complemented. The aim of the project is the minimization of risks in finding proper locations for geothermal installations, such as powerplants.

Therefore data of more than 30,000 drillings in Germany are combined to a geothermal 3D underground model. Geological structures as well as underground parameters like temperatures, geothermal gradients, porosities and permeabilites can be illustrated in horizontal or vertical sections.

5.2 Shallow Geothermal Exploration

In Germany different methods of withdrawing shallow geothermal energy are well probed. Famous examples of shallow geothermal projects are the house of parliament, Berlin (seasonal heat storage), the municipality Frankfurt (field of borehole heat exchangers) and different high-rise buildings for example Skyper, Frankfurt (energy piles) or WestendDuo, Frankfurt (groundwater usage).

Besides these well probed shallow geothermal systems a combination of common borehole heat exchangers and horizontal loop systems was invented in Germany. This combination of the advantages of the two most famous geothermal shallow systems is called geothermal radial drilling (GRD).

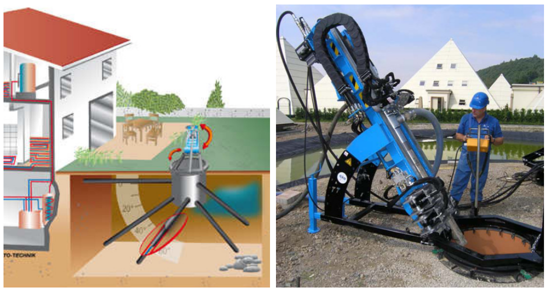

Figure 6: Geothermal radial drilling

With GRD different borehole heat exchangers can be installed to ground operating from one point of drilling. The borehole heat exchangers can be installed with angles from 15° – 60°. With that adaptability GRD utilises the building property‘s set-up in all aspects. Deep underlying drinking water levels remain untouched. In addition, the GRD technology is based on the need for minimal technical equipment and clearly reduces the overall expenditure for installing borehole heat exchangers.

6. CONCLUSIONS

Having no high-enthalpy regions, Germany is forced to perform research and improvements to produce geothermal power. The improvements shown in this paper are national pilot research projects. The lessons learnt from these projects could be adapted for international purposes. In that way an environmental friendly green geothermal energy production could be performed all over the world, not even in high-enthalpy regions. With that possible high number of decentralized geothermal power plants the world energy demand could be satisfied to a considerable extent by geothermal energy.

REFERENCES

Arslan, U. and Huber, H.: Application of geothermal energy. University of Istanbul, Yapistanbul No. 3 / 2008, Turkey (2008)

Arslan, U. & Huber, H. 2008. German Education and Training in Geo-Engineering Sciences. First International Conference on Education and Training in Geo Engineering Sciences. Soil Mechanics and Geotechnical Engineering, Engineering Geology, Rock Mechanics. Geotechnical Engineering Education and Training. Manoliu, Antonescu, Rădulescu (Eds.) Balkema, Rotterdam.

Arslan, U., Huber, H., Quick, H., Waldmann, A. 2009 Geothermieanlagen. Verieferarbeit am Institut für Werkstoffe und Mechanik im Bauwesen, TU Darmstadt (2009)

Huber, H., Grundlagen und Anwendungen der Geothermienutzung, Vertieferarbeit an der Technischen Universität Darmstadt, Institut für Werkstoffe und Mechanik im Bauwesen, Darmstadt, Germany (2006)

Huber, H., Numerische Methoden in der Geothermie am Beispiel des EGRT in der Forschungsbohrung Viernheim, Diplomarbeit an der Technischen Universität Darmstadt, Institut für Werkstoffe und Mechanik im Bauwesen, Darmstadt, Germany (2007)