Application Report

Energy from deep underground

Protection against explosions in modern drilling equipment

by Thorsten Arnhold and Andreas Steilen

Figure 1: HERRENKNECHT derrick with the ›pipe handler‹

Mankind is facing a turning point in its history and is becoming conscious of this fact. The time of unrestricted worldwide economic growth at the expense of the environment appears to be nearing its end.

A radical rethink, particularly in relation to how energy is obtained and used, is becoming ever more urgent if the future of today's and future generations is not to be jeopardised.

While spring temperatures in the middle of January in northern and central Europe may have a certain appeal at the moment, an increasing portion of mankind is becoming more and more conscious that these temperatures are unfortunately no longer a pleasant whim of nature. Indeed, it is a sure sign of general global warming with long-term, destructive and, unfortunately, often irreversible consequences for the natural world in which we live. If efforts in the coming years at effectively and sustainably rectifying the causes of this change are unsuccessful, a lasting increase of several degrees Celsius can be expected to the average temperatures on Earth.

The scale of the related changes to the living conditions on Earth only becomes truly apparent if you consider that the three ice ages of the Pleistocene Period with their dramatic changes to the Earth were triggered by a change in the average temperature of around only three degrees Celsius. A change in the temperature in the opposite direction time would result in the melting of the polar ice caps and an increase in sea levels of several metres, combined with the loss of land that is currently densely populated. Pathogens currently not present in central Europe would torment the people there, the number of devastating storms would increase dramatically and there would be many other problems. The low-pressure system, ›Kyrill‹, which raged through Europe in the middle of January, and cost the lives of fourteen people in Germany alone, may have been a gentle harbinger of such a development.

Even if mankind were not to be brought to its senses by these alarming prospects and were to continue with the extensive exploitation and combustion of fossil fuels, the finite nature of the reserves available worldwide will set a foreseeable limit to their usage; this limit is between 35 and 70 years away depending on the estimations. Even the controversial usage of nuclear power does not provide an adequate, long-term alternative if you consider that the current contribution of this energy source towards total energy needs is in the single-digit percentage range, and the availability of raw materials is again limited to the coming 50 to 70 years.

However you look at it, there is no way round the extensive development and utilisation of new, non-polluting sources of energy with long-term availability. If you consider all the renewable sources of energy known today, it unfortunately becomes clear that their practical use in the provision of energy is a long way from that necessary to replace fossil fuels. For this reason, it is important to make a wide range of these alternative energy sources usable, to perfect the technical systems for the conversion of these forms of energy into usable energy, and to continuously increase the efficiency of all technical systems so as to minimise energy losses. If all these points are achieved, it would be possible to cover the energy needs of mankind over the long term, as theoretically the combined amount of energy available from all known alternative forms of energy is more than sufficient.

Alongside solar power, wind power and water power, the utilisation of the natural heat in the ground (geothermal energy) is a method of tapping energy largely unknown to the public. The frequent lack of attention by the majority of the public bears no relation to the potential offered by this form of energy: with the reserves of geothermal heat that are currently stored in our planet, mathematically and theoretically it would be possible, in principle, to cover worldwide energy needs for more than 100,000 years.

This article will provide an overview of a few known geothermal techniques and specifically address modern deep drilling rigs manufactured by HERRENKNECHT. These rigs are used for tapping geothermal heat.

The company, based in southern Germany, has been well-known for many years as a world market leader for tunnel boring machines, and has revolutionised deep drilling technology with a series of inventions from its new HERRENKNECHT Vertical division.

The topic may be very interesting, but the question of the relevance to protection against explosions must be asked and answered in the Ex-Magazine: Even though in the field of geothermal energy, contrary to fossil fuels, inflammable substances that involve a risk of explosion are not used, in certain circumstances comprehensive protection against explosions is also required here. How this protection is implemented on deep drilling rigs is also described.

Geothermic energy

When our Earth came into existence more than four billion years ago through the collection and compaction of material, this process was accompanied by the conversion of kinetic energy into heat. Due to the low thermal conductivity of rock this thermal energy is still present today and can be considered residual heat dating back from the time the Earth came into existence. This thermal energy represents a significant 30–50 percent of geothermic energy. The main portion – that is 50–70 percent – comes from radioactive decay processes in the interior of the Earth. Near to the Earth's surface, there are also contributions from solar radiation and from thermal contact with the air.

The temperature in the inner core of the Earth is, based on varying estimations, 4,500 °C to 6,500 °C. Almost the entire planet – specifically 99 percent of its volume – has a temperature above 1,000 °C, and even the majority of the vanishingly small rest has a temperature or more than 100 °C. These facts make it clear just how massive the energy reserves are inside the Earth. In comparison, the amount of energy contained in all fossil fuels is very modest! The heat from the deeper parts of the Earth is predominantly transported by thermal conduction to the depths that can be reached for its usage; however it is also transported by convection. ➔

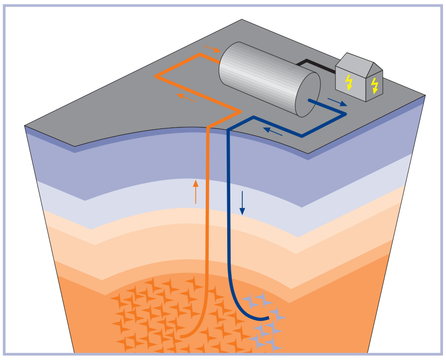

Figure 2: Principle of the ›Hot Dry Rock‹ technique

Energy from deep underground

Due to the relatively low heat flux density, it is the energy stored in the Earth's crust that is utilised for geothermic energy and not the energy flowing out of the interior of the Earth. This factor is important because in its current form we are not dealing with another finite source of energy. The exploitation of this source must be dimensioned such that the cooling of the related formations only progresses slowly, and the achievable service life of the plant permits economic operation. Due to the many negative experiences that have resulted from the extensive utilisation of fossil fuels in the past and in the present, all the possible consequences for the environment must be considered right from the start of widespread utilisation of geothermal heat!

The ground at a depth of a kilometre has a temperature of 35 °C to 40 °C almost everywhere. In specific geological conditions, e.g. in areas of active or past volcanic activity, however, even at shallow depths the temperature can reach several hundred degrees Celsius.

On the utilisation of geothermic energy as a source of energy for the generation of heat and electrical power, a differentiation is made between

- geothermic energy near the surface for direct utilisation using heat pumps and
- deep geothermic energy for direct utilisation or for the generation of electrical power.

A further differentiation is made between high enthalpy and low enthalpy reservoirs as a function of the reservoir temperature.

To tap the sources of energy stored deep in the Earth it is necessary to drill deep boreholes in almost all cases. These boreholes as well as the complete finished system fall under the scope of mining law in Germany. Despite refined seismological prospecting methods, it is not possible to completely determine the characteristics of the layers to be passed through by the borehole. Smaller reservoirs with inflammable substances cannot be detected from a certain drilling depth and can represent a potential hazard for the people involved with the borehole, as well as for the local population, particularly if one considers that geothermic plants will certainly be built in the immediate vicinity of populated areas.

For this reason German mining law specifies explosion protection for drilling rigs from a drilling depth of 400 m. From this limit the term ›deep geothermic energy‹ is used. In the following we will limit ourselves to the description of the technologies used for extracting heat.

Deep geothermic heat probe

The deep geothermic heat probe is a sealed system for extracting geothermic heat. The medium for absorbing the geothermic heat (mostly water) is pumped into the borehole through a 2,000 to 3,000 m long coaxial pipe in contact with the outside edge of the borehole, and during this process absorbs geothermic heat from the exterior. The heated fluid is then pumped up through a thinner suspended riser. At the surface the heat absorbed is extracted using a heat exchanger and fed to local and district heating networks, or is used as process heat in industry and for generating electricity. The advantage of this method is that the circuit is sealed and no interchange of materials with the ground takes place; as a result geochemical processes are avoided. This situation makes it possible to build such a geothermic plant almost anywhere. A disadvantage is that the small contact area between the carrier fluid and the heat sources severely limits the amount of heat absorbed. A further disadvantage is that a large amount of the heat absorbed is lost on the journey to the top of the borehole. As a result the extraction temperature of such a plant is only a few hundred degrees Kelvin.

Hydrothermal energy

For hydrothermal geothermic energy, naturally occurring reserves of thermal water, so-called hot water aquifers (water-bearing layers), are tapped. The hot, deep ground water is pumped to the surface using one or more boreholes. Here heat is extracted in heat exchangers and the cooled water is then returned to the ground water.

Up to 5 MW of electrical power can be generated from water at depths of up to 3,000 m and with temperatures of 100 °C to 150 °C.

The advantage of this method is that the hydraulic conditions underground remain unchanged and the heavily mineralised water is not released into the environment. The disadvantage is that the technique is limited to selected areas with special geological conditions. In Germany the necessary hydrothermal conditions are relatively rare and limited to the Upper Rhine Basin, the Molass Basin in southern Germany and the basin in northern Germany.

Petrothermal systems

Rocks at large depths have a high temperature (hot dry rock). At depths of 4,000 to 6,000 m the temperature is up to 200 °C. To tap these energy-rich layers, first water is pressed into the deep-lying hot rock at a high pressure using an injection borehole (Figure 2). As a result any existing cracks and gaps are expanded to produce channels of adequate proportions.

Using this technique, called ›hydraulic fracturing‹, the overall permeability of the rock is increased and, in the process, the necessary surface area for exchanging heat is created. A heat exchanger with a physical size of many cubic metres is produced.

Then a second borehole, the so-called production borehole, is sunk. The water pressed through the injection borehole into the deep, hot layers of rock heats up in the immense natural underground heat exchanger and is then pumped through the production borehole to the Earth's surface. Here the hot fluid is cooled in an industrial heat exchanger to generate electrical power and useable heat.

By using mixtures of ammonia and water for the working medium, the boiling point of the liquid is set such that it is possible to directly couple the circuit to steam turbines for generating electrical power (Kalina process).

The advantage of the hot dry rock technique is that there is greater freedom of choice in location than that of hydrothermal energy. A disadvantage is the necessary changes to the geological structure of the deep-lying layers of rock. In some circumstances these changes can place the local population and environment at serious risk, as occurred recently with a borehole in the Basel region that on 8 December 2006 triggered an earthquake with a magnitude of 3.4 and subsequent after shocks. Fortunately hardly any damage was caused, but it made clear just how much care is required during the preparation and implementation of the installation of petrothermal systems. In general, however, the experts are in agreement that the technique itself does not involve any risk of triggering earthquakes of such magnitude. Other unfavourable geological conditions must be present; these conditions can be detected during the prospecting phase and taken into account.

Deep drilling rigs for tapping geothermic heat

As mentioned above, before energy from deep underground can be used for extracting heat for generating electricity, several boreholes at depths up to 6,000 m must be drilled. The underlying technology is not new: after all drilling through the layers of the Earth near to the surface, either on land or on the sea bed, has made it possible to extract crude oil and natural gas for many decades. However, the boundary conditions that must be taken into account when designing drilling rigs for tapping geothermic energy sources are significantly different.

The most important difference is that the boreholes for a geothermic plant often need to be drilled in the immediate vicinity of densely populated areas, and that a very large number of such boreholes are required to cover the energy needs. While technological development for fossil fuels is focussed on tapping reserves in increasingly extreme places, such as at a depth of several thousand metres under the surface of the ocean or in the Siberian permafrost region, in the case of deep drilling techniques for geothermic energy the emphasis is primarily on a high level of work safety and working at high speeds to keep the burden on the environment as low as possible. In this respect it was an obvious step for the German company HERRENKNECHT, which has been a technological leader and ➔

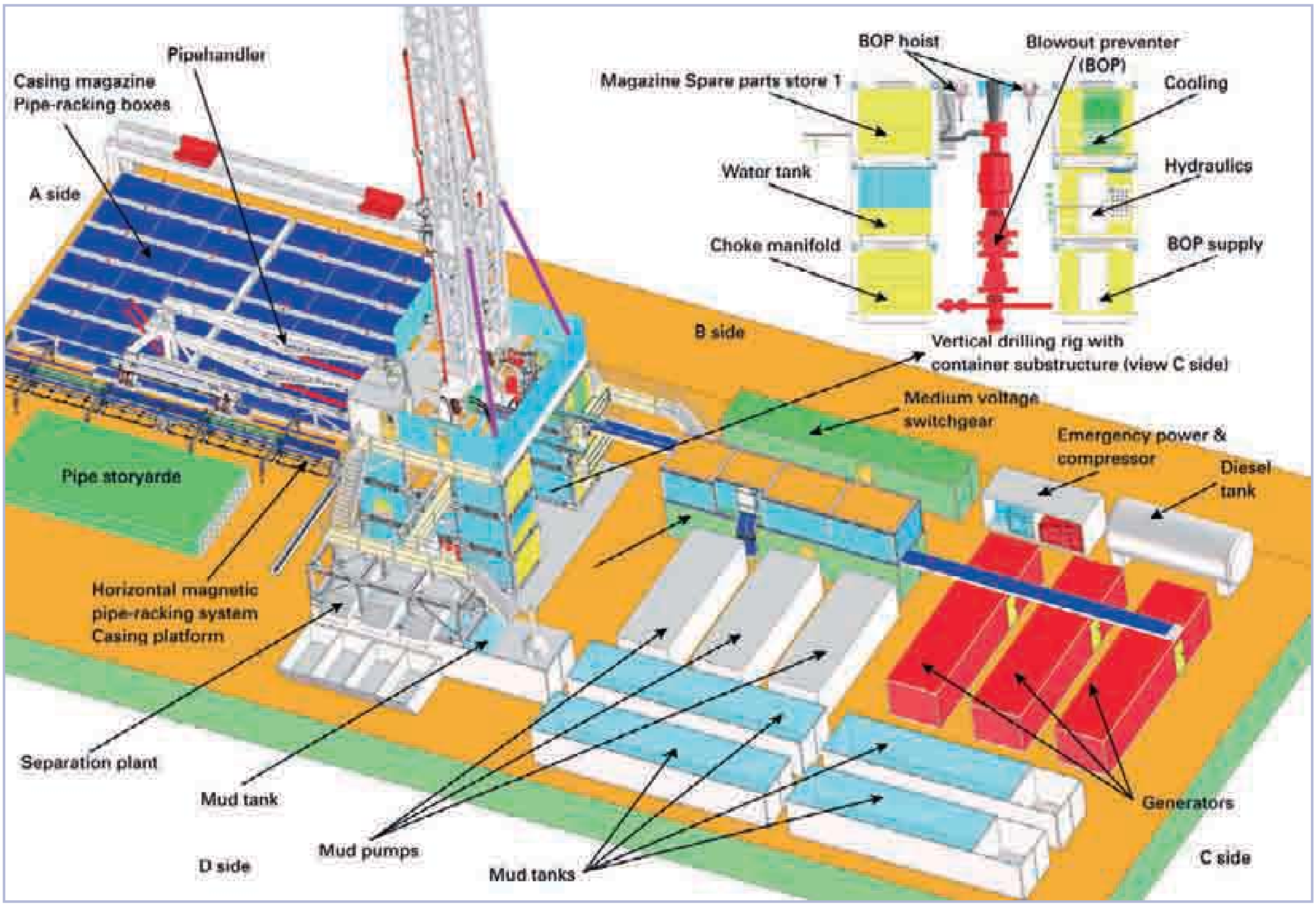

Figure 3: Drilling site overview, HERRENKNECHT Vertical core plant

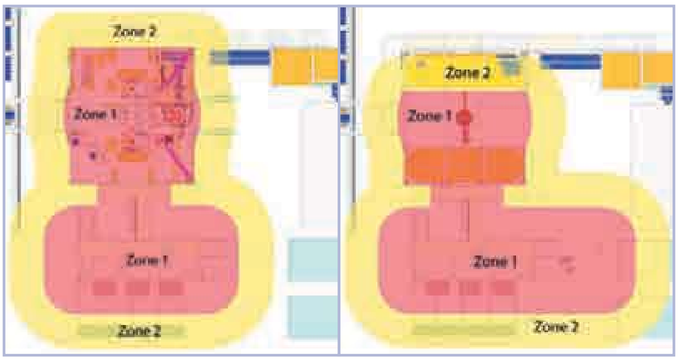

Figure 4: Zone classification of the working platform and sub-structure

world market leader in tunnel boring machines for many years, to move into deep drilling technology where the requirements are similar to tunnel building. The company HERRENKNECHT Vertical GmbH, founded in 2005, was able to apply technical achievements from tunnel drilling to the first rigs developed and built, e. g., an optimised safety concept (hands-off technology), flexible power management as well as technically refined concepts in the form of cylinder lifting gear and integrated measures for protection against noise.

Figure 3 shows a schematic overview of the deep drilling rig ›Hot Rock 1‹. Along with the mast, other basic components on the rig that can be seen are the power supply with the diesel tank, the generators and the switchgear. The soil and rock produced by the drilling process must be transported out of the borehole using a drilling fluid. The drilling fluid is stored in the mud tanks, then pumped into the borehole during drilling, and the material produced is removed again in the separation plant. For information on explosion-protected decanters for purifying drilling fluids, see also Ex-Magazine 29/2003, page 50. The many pipes necessary for drilling to a depth of several thousand metres are stored in the pipe yard (as an individual pipe is 19 m long, approx. 270 pipes are needed for drilling to a depth of 5,000 m). The zone classification of the hazardous areas is shown on the zone plan in figure 4. It can be seen that the area of the working platform with the mast, the separation plant, and parts of the mud tanks are classified as Zone 1. The area surrounding Zone 1 (approx. 5 m) is classified as Zone 2. The pipe yard, the unit for supplying power, and large parts of the storage tanks for the non-inflammable drilling fluid are outside the hazardous area.

The rig only requires a comparatively small drilling site that can then be used for other purposes once drilling is complete. It is designed for a hook load of 350 tonnes. Depending on the borehole diameter, boreholes up to 7,000 m deep can be drilled with a pulling rate of up to 500 metres per hour. For this purpose a drive power of 2,000 kilowatts is required that, depending on the situation, can be provided either solely from the electricity grid or from a generator, or from the grid with generator support.

The heart of the rig is the mast with the container sub-structure. This sub-structure contains the hydraulic plant, water tanks, cooling system, and the process control. While a conventional drilling rig operates like a crane with the new section of pipe pulled up to the top of the mast to then be manually aligned and connected to the drill-string, on the Hot Rock rig this process is completely mechanised and largely automated.

Figure 1 shows a view in the direction of the top of the mast. On the left in the picture the so-called ›pipe handler‹ can be seen, which is currently adding a new section of pipe. To create space for this piece of pipe, the top part of the mast is moved upwards using the cylinder lifting gear, which can be seen in the middle of the picture.

The pipe is connected at the top to the rotating head mounted on the load cross-member (›top drive‹) and aligned to suit the drill-string at the bottom using a special unit, the ›iron roughneck‹ (Figure 5), and then connected to the drill-string using a high torque. The drilling process can then be continued with feed provided by the cylinder lifting gear. A major disadvantage of conventional rigs is that the entire drilling casing extension process is manual. Lifting, aligning and attaching the additional pipe is physically demanding and dangerous work involving frequent accidents. This safety problem is no longer present on the Hot Rock rig. The operator sits in the control cabin and controls the process from there using a joystick and other operator controls (Figure 6).

Figure 5: Iron roughneck

Figure 6: Controlling the increase in the length of the pipe using a joystick and other operator controls

The entire process automation on the rig is undertaken using 4 Remote I/O systems of type IS1 manufactured by R. STAHL. These are installed locally in Zone 1 and control several hundred signals (Figure 7). The low voltage systems in the rig are controlled using various locally installed control systems and distribution panels (Figure 8).

As drilling work is frequently undertaken around the clock, value is also placed on the effective illumination of the rig. Figure 9 shows a view of the separation plant with explosion-protected EXLUX 6000 light fittings, floodlights, and the related explosion-protected distribution boards for the lighting installation.

The overall rig concept is focussed on safety aspects. Various operating modes integrated into the rig provide new, innovative process solutions, for example the ›pipe handler‹, for high process safety. Value was also placed on high borehole safety. Among other features, it is ensured that in the event of an accident, the uncontrolled release of hazardous substances from the interior of the Earth is prevented in fractions of a second by the safe and stable sealing of the borehole. Work safety has been significantly increased by widespread mechanisation and automation of the processes.

Outlook

In 2004 some 0.178 GW of power were obtained from geothermic sources in Germany. This is a very modest 0.04 % portion of total primary energy needs. In 2005 around 10,000 people were working directly or indirectly on the supply of geothermic energy in Germany, and annual growth of 14 % is expected in this sector. The development described at the start and other alarming scenarios will provoke further discussion on the need to rethink worldwide energy policies and accelerate the search for alternative sources to cover energy needs.

The fact that geothermic energy must be considered as a serious option is proven for example, in Sweden. Although geologically disadvantaged, thanks to coherent policies on the environmental and public relations work, a notable 1.14 GW of power is already used predominantly for heating.

If this development continues, there will be good prospects for geothermic energy and the related deep drilling technology from HERRENKNECHT Vertical with explosion protection from R. STAHL.

Figure 7: Process automation on the rig is undertaken using 4 Remote I/O systems IS1

Figure 8: Various locally installed control systems and distribution panels in flameproof enclosure

Figure 9: Effective illumination during drilling work with explosion-protected EXLUX 6000 light fittings for Zone 1