GEOTHERMAL ENERGY

TECHNOLOGY DESCRIPTION

Geothermal energy is the natural heat that exists within the earth and that can be absorbed by fluids occurring within, or introduced into, the crustal rocks. Although, geographically, this energy has local concentrations, its distribution globally is widespread.

The amount of heat that is, theoretically, available between the earth's surface and a depth of 5 km is around 140×10^{24} joules. Of this, only a fraction (5×10^{21} joules) can be regarded as having economic prospects within the next five decades, and only about 500×10^{18} joules is likely to be exploited by the year 2020.

Three main techniques are used to exploit the heat available: geothermal aquifers, hot dry rocks and ground-source heat pumps.

Geothermal aquifers

Geothermal aquifers exist where heat from the earth's crust is absorbed by groundwater that collects naturally in the deep porous rocks of certain geological structures. To exploit these aquifers as a source of energy, it is necessary to drill two boreholes: a production borehole to extract the naturally heated water and an injection borehole to dispose of the water once that heat has been removed by surface use. It is also possible to use a single hole configuration if the used water is discharged elsewhere – to the sea or to some other convenient sink.

Because of the poor thermal conductivity of rock and the low rates of natural fluid recharge, heat is usually extracted at a greater rate than it is replenished from the surrounding rock mass. Geothermal aquifers are not, therefore, "renewable" resources in the strict sense of the word, although they are usually placed in the renewables category.

The exploitation of geothermal energy has, to date, concentrated on these hydrothermal resources, most economically from aquifers in countries where seismic activity is high.

Hot dry rocks

The hot dry rock (HDR) concept was developed during the 1970s. Heat is extracted from the crust by injecting cold water deep into granite (crystalline) rocks or into metamorphic "basement" complexes. Water or gel is pumped down one well to induce hydraulic fracturing, thereby creating a reservoir. Water is then circulated under pressure through these fractures, where it absorbs heat before being pumped back to the surface via one or more production wells.

The concept was initially pioneered in the UK and the USA. More recently, the focus has switched to large-scale experimental work at France, under an EU co-ordinated programme, and in Japan. Alternative concepts, such as the direct exploitation of heat from magma bodies or energy extraction from geopressured formations, remain as longer-term options.

Ground-source heat pumps

Ground-source heat pumps use the ground within the immediate proximity of a building as a heat source and/or sink. The building is fitted with water source heat pumps that are connected to the ground loop arrays and provide heating and/or cooling. Internal heat distribution is achieved using conventional techniques. The only restriction is that the maximum heating output temperature is ~55°C. During the summer the ground is used as a heat sink for heat extracted from the building. In winter this process is reversed. Proponents of the system state that, for every kWh_e that is used to drive the circulation system, 2.5-3.5kWh of heat are extracted from the surrounding ground or from the building.

There are at least 15 installations connected to commercial or public buildings in the UK, including an office block in Croydon. These systems are rated at between 25kW and 280kW. There are also seven examples of individual ground-source heat pump systems in domestic buildings. The technology is widely used in the US, Canada, Switzerland, Sweden, Germany and Austria. Estimates suggest that between 40,000 and 50,000 systems are installed each year throughout the world.

MARKET

Geothermal energy can be used to produce steam for electricity generation, hot water for use in horticulture, fish farming etc, or heat for individual buildings and district heating schemes. Opportunities vary with the temperature of the water extracted. For instance, water from aquifers at temperatures in the 50-150°C range has applications in district heating, fish farming, horticulture and recreational facilities such as spas. Where water temperatures exceed 150°C, as in parts of the USA, Philippines and Italy, it is feasible to generate electricity, and steam of suitable quality can be used directly in back-pressure or condensing turbines. About 8240MW of electricity generating capacity (equivalent to an output of 48.5TWh/year) is currently installed around the world in locations where both steam and water are produced at temperatures above 200°C. Half of this capacity is located in the USA.

BENEFITS

The main benefit of energy from geothermal aquifers and ground-source heat pumps is the absence, or near-absence, of pollution. Gaseous emissions are usually negligible and noise is only a problem during drilling.

TECHNOLOGY STATUS

Geothermal aquifer technology is commercially developed and competitive in those regions of the world where high-enthalpy resources exist – usually in seismically active countries such as Greece, Italy and Japan. In the UK the aquifer resource has a lower enthalpy and the technology is, consequently, less competitive.

Ground-source heat pump technology is well established in North America and some continental European countries and is commercially developed. Although not widespread in the UK, a growing number of domestic and commercial buildings have had ground-source heat pump systems installed.

Geothermal HDR rock technology is neither commercially developed nor competitive, and the UK R&D Programme ceased about 10 years ago.

TARGETS FOR COMMERCIAL COMPETIVENESS

In the UK, the energy derived from aquifers and ground-source heat pumps needs to be commercially competitive with that provided by fossil fuels and off-peak electricity.

The geothermal aquifer resource within the Wessex Basin, under the Bournemouth area, appears to be the most attractive for possible future exploitation, but the commercial risks of speculative drilling remain high. At 3.5p/kWh or more, the cost of heat from the aquifer resource is still significantly higher than that from conventional industrial boilers (approximately 1.44p/kWh).

RESEARCH AND DEVELOPMENT ISSUES

There are significant commercial, institutional and technical constraints on the development of geothermal energy within the UK. These constraints vary with the individual technologies.

Geothermal aquifers

- The resource close to the main areas of demand is limited.
- Only low-grade heat is available.
- There is a high technical and commercial risk, much of it associated with the drilling of unusable wells.
- Opportunities for development within the UK are limited to the Wessex Basin beneath Bournemouth and, possibly, the Grimsby area.

Hot dry rock technology

- In theory, there are accessible resources at a target depth of ~6km in the granite areas of south-west England, northern England (Weardale) and north-east Scotland.
- Evidence from the UK R&D Programme suggests that the technology would be uneconomic in the UK, even for the most attractive UK sites. The Programme drew the following conclusions:
  - A practicable method of extracting the energy from hot dry rocks is a long way off.

- There is no confidence that a commercial-scale system with a predictable lifetime can be developed.

- The level of technical development, the poor economics and the localised nature of the resource mitigate against development in the foreseeable future.

- Even if the technology does prove to be commercially viable in the UK, sites would be subject to the stringent planning regulations that apply to all industrial installations. These would take into account visual appearance, access roads and other infrastructure requirements.

- The technology is still technically unproven and must rely on long-term pilot-scale trials.

Ground-source heat pumps

- Ground-source heat pumps use a proven and reliable technology that can be commercially attractive in certain situations. Cost reductions and improvements in complete systems are likely to result from advances in established technology and system standardisation.

- Ground-source heat pumps can be installed anywhere, although site-specific conditions will determine detailed design and cost requirements.

NON-TECHNICAL ISSUES

Once developed, geothermal energy has few environmental impacts as long as the water extracted is re-injected. Geothermal power stations do have some visual impact. They also emit steam and, in some cases, gases that contribute to the greenhouse effect. District heating systems can be concealed or housed in imaginatively designed buildings that minimise their visual impact.

UK INDUSTRY STRENGTHS

The UK has companies that provide consultancy services for the development of geothermal energy. Their specialist expertise in areas such as reservoir modelling is directly applicable to both conventional (aquifer) and HDR geothermal energy. These companies originally developed their knowledge of geothermal energy from the UK's HDR R&D Programme. They have since diversified into conventional geothermal energy, ground-source heat pumps and high-temperature instrumentation. They also continue to provide expertise to the European HDR Programme. Two UK companies have developed specialised heat pump units for the UK ground-source heat market.

The overseas market for geothermal energy is dominated by established developers and foreign equipment manufacturers. The UK does have some drilling contractors, but most geothermal development relies on drilling contractors with an established presence in the industry's main markets. Five manufacturers (three Japanese, one Italian and one Israeli) dominate the generator equipment market, although one European manufacturer also produces for this market.

TECHNOLOGY ROUTE MAP FOR THE DTI PROGRAMME

Given the mature status of conventional geothermal technology, there are few areas that would benefit from additional government-supported R&D. Aquifers that produce a very low-grade heat (below 40°C) are unlikely ever to be exploited in the UK. Furthermore, although there appears to be a substantial resource producing heat at 40°C+ (estimated to be equivalent to 8,300TWh_{th}), the fact that the resource does not coincide geographically with areas of likely demand is a major constraint.

A detailed assessment of the heat requirements of several urban centres suggests that it is unreasonable to expect the development of more than 50 geothermal schemes in the UK. If it is assumed that each viable scheme produces a minimum of 26GWh of heat per year from its geothermal source, the theoretical accessible resource is 1300GWh/year. The likelihood of the resource being exploited on this scale is, however, low. To date, only one system has been developed in the UK. This is in Southampton where the geothermal aquifer provides 20% of the energy demand for a city district heating system.

There is a significant European R&D programme for HDR technology. The considerable technical risks associated with this technology were highlighted during the UK and US Programmes, and it is clear that any European pilot project must be adequately demonstrated at the 6MW scale to verify its technical and commercial viability. The European Programme is about to progress to deep-level (~5km) circulation tests. The decision to proceed reflects the more encouraging results achieved at the site. If the circulation tests prove successful, a small pilot plant will be built. Because of the experimental nature of the technology, the generation plant is likely to be developed in four 1.5MW increments, each using conventional Ormat turbines.

Support for the pilot project will, after 2002, come mainly from France and Germany, with the balance of funding being met by the EC and by an industrial consortium of two utilities and an oil company that has been set up to oversee future industrial development.

It should also be stressed that site-specific conditions may limit the application of HDR technology to countries like the UK where a target depth of ~6km is required.

The most promising geothermal market is the one for ground-source heat pumps, which can be commercially attractive in certain situations. In July 1999, a UK heat pump network was established, with support from DETR, DTI and the UK Heat Pump Association, to promote the technology. The technology would benefit from a study to quantify the benefits of ground-source heat pumps, particularly when used in conjunction with “green” electricity.

No allowance is made for ground-source heat pumps in the Government's Standard Assessment Procedure (SAP)[1] or National Home Energy Rating (NHER)[2] schemes. Furthermore, neither the technology nor the industry is accredited against recognised standards, although these could be adapted from existing European and/or North American ratings. More information on the technology and its integration with different types of building would help to promote its benefits, while technology transfer and export programmes could be developed in conjunction with the UK heat pump network.

[1] The Government's Standard Assessment Procedure (SAP) is presented on a scale of 1-100. The SAP is a means of calculating the energy used in the home to provide heating and hot water only. It does not take account of electrical use for lighting and appliances or the effect of climate variation throughout the UK.

[2] The National Home Energy Rating (NHER) is a measure of the energy efficiency of dwellings in terms of energy running costs.