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GEOTHERMAL TRAINING PROGRAMME
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COOPERATION BETWEEN THE UNITED NATIONS UNIVERSITY GEOTHERMAL TRAINING PROGRAMME AND THE UNIVERSITY OF ICELAND

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1. INTRODUCTION

This presentation describes the author's vision of the future of the United Nations University Geothermal Training Programme and how this programme should expand in the light of increasing interest in developing geothermal energy resources. Today fossil fuel accounts for almost 90% of the global annual energy usage. Fossil fuel is a non-renewable energy resource. Within few decades it is likely that both crude oil and natural gas will be exhausted to such an extent that their price will go up much. Coal will last longer. It has been established without doubt that combustion of fossil fuel has caused much atmospheric pollution and will cause major climatic changes. For all these reasons, it is very important to develop new and preferentially renewable energy resources that are friendlier environmentally than fossil fuel, such as geothermal energy.

Growing interests to develop geothermal energy resources call for research to further knowledge on these resources and advances in technology to harness them. It is considered that the United Nations University Geothermal Training Programme should increase its research efforts on geothermal resources by further co-operation with the University of Iceland and other universities. The purpose is to stimulate such research in developing countries.

It is beyond the scope of this contribution to provide a comprehensive assessment of important research on geothermal resources. Only three examples will be discussed. One is advance in geochemical modelling of geothermal fluids and of water-rock interaction. The second concentrates on the sustainability of geothermal energy utilization, the renewability of geothermal systems and the birth, development and extinction of such systems. The third and last example focuses on research on the roots of volcanic geothermal systems. It is anticipated that a lot of heat is stored there that may be harnessed, either in a conventional way, if permeability is sufficient, but if not as hot-dry-rock systems.

2. ESTABLISHMENT OF UNU-GTP

The United Nations University (UNU) convened an international workshop in Iceland in 1978 to discuss the needs for a Geothermal Training Programme (GTP) to be hosted by the National Energy Authority (NEA) of Iceland ensuring that such a programme would not duplicate already available geothermal courses in Italy, Japan and New Zealand (Fridleifsson, 2003). The general consensus of this meeting was that the most important training for developing countries with geothermal potential, was practical, that is a man-to-man training, rather than a conventional study at a university. It was envisaged that such training was most likely to result in effective build-up of know-how for geothermal development in these countries. The main argument for having the UNU-GTP hosted by NEA was that this government company was engaged in research on geothermal resources as well as in geothermal development and investigations including geological, geochemical and geophysical surveys and well testing with good facilities for all such studies. Also, there was easy access to many geothermal fields in Iceland with very different reservoir temperatures and therefore varied potential usage. The training started in 1979 and was based on an intensive six months programme.

3. THE NATIONAL ENERGY AUTHORITY

Since the establishment of the United Nations University Geothermal Training Programme (UNU-GTP), Orkustofnun - the National Energy Authority (NEA) has undergone major structural changes. The government budget for research was reduced much after 1986 and at the same time the workload of the staff of NEA was diverted more to investigations paid for by companies and other bodies within and outside Iceland who were involved in geothermal development or needed monitoring studies of geothermal fields that were already in use. In 2003 the Geoscience Division of NEA became a new government owned company, Iceland GeoSurvey (ISOR). Its principal role is to conduct investigations on potential energy resources, invent, develop and adapt methods and equipment to study Iceland´s energy resources and teach and supervise Fellows attending the UNU-GTP. Today, ISOR may be essentially regarded as a commercial organization focusing on consultancy and investigation of energy resources, both within and outside Iceland. The new NEA became an advisory institution the Ministry of Industry on energy-related matters. When the Geoscience Division was separated from NEA, the new NEA hosted the UNU-GTP.

4. INCREASE OF STUDY NEEDS

With build-up of know-how on geothermal resources in countries supported by the UNU-GTP, the Board of this Programme began to discuss as early as 1990 the needs to expand the function of the UNU-GTP by offering graduate studies in the various subjects considered to be important for the development of geothermal resources, including the resource itself as well as technology.

In 1995 a contract was made between UNU-GTP and the University of Iceland (UoI) which basically incorporated that the six months study of the UNU-GTP was evaluated as 30 credits for a study for a M.Sc. degree at UoI (a full academic year is 60 credits). Fellows financially supported by UNU-GTP need to apply for graduate studies at the UoI just as any other student interested in carrying out such studies. So far 16 UNU-GTP Fellows have completed M.Sc. studies at UoI, another 5 have started their studies and 4 more have just been accepted for a study for a Ph.D. degree.

If the success of the mentioned graduate studies at the University of Iceland is to be maximized, it is important that an infrastructure exists in the developing countries which will allow the doctorates to continue research on geothermal energy when they return to their home country. Continued research may either be carried out at universities or by geothermal companies.

5. THE FUTURE OF UNU-GTP

There is no question in my mind that the UNU-GTP has been extremely successful. This is reflected in the high percentage of Fellows who have been active and prosperous in the geothermal industry since completion of their studies in Iceland. There are several reasons for the success of the UNU-GTP. One is how this programme was structured in the beginning; another is adequate financing of the activity and the third the splendid guidance of Dr. Ingvar Birgir Fridleifsson, as Coordinator of the Programme.

With the recent structural changes of the NEA, and possibly privatization of ISOR in the near future, the decision in 1978 to place the UNU-GTP with the new NEA needs to be re-considered. Also, increased role of geothermal research within the GTP should be addressed. Certainly, engagement in geothermal investigations provides experts with important experience and also further understanding of geothermal resources. Such investigations, however, neither provide experts with the opportunity to ask fundamental questions about this resource nor do they provide the experts with the money needed to try to answer these questions. When it comes to geothermal resources, it is essential to allow scientists to ask some fundamental questions and to provide them with the money needed to try to answer them. It is my vision that the role of the UNU-GTP should be expanded in the light of increased worldwide interests in geothermal energy utilization due to increased prices of oil and the environmental consequences of fossil fuel combustion. It is my firm belief that the most important future role of the UNU-GTP should be to encourage advancement of geothermal energy development and utilization in developing countries. One way of doing this would be to establish closer links with the University of Iceland and other universities.

6. THE WATCH CHEMICAL SPECIATION PROGRAMME

Studies of Fellows attending the training course organized by UNU-GTP and graduate studies at the University of Iceland do not only include transfer of knowledge through teaching but also provision of tools for handling and interpretation of data collected from geothermal fields. One such tool will be mentioned here, the WATCH chemical speciation programme. Every Fellow attending the UNU training course receives a copy of this programme, which is specifically adopted for calculation of individual species activities and mineral saturation of geothermal waters. WATCH also allows calculation of the composition of aquifer fluids producing into wet-steam wells from analytical data on water and steam samples collected at the wellhead.

It is a long time since this programme was initially written (late 1970´s) and much progress has been made since with respect to modelling aquifer fluid compositions from wellhead data from wet-steam wells. This includes modelling of possible presence of vapour in the reservoir fluid under natural conditions and modelling the causes of changes in fluid enthalpy between initial aquifer fluid and wellhead fluid. WATCH is not specifically suited for such modelling. At present, however, a new programme is being written that will replace WATCH.

Many speciation programmes were written in the 1970´s and later. Geochemical modelling has, however, advanced much since these early days of computers by incorporating, in addition to speciation calculations, mass transfer calculations associated with primary mineral dissolution and secondary mineral precipitation and lastly by bringing time as a variable into the modelling by considering reaction rates. I believe that modelling of this kind will be important for improving understanding of geothermal systems. It may, however, be too advanced for the six month UNU-GTP course but not for a graduate students programme.

7. IS GEOTHERMAL ENERGY A RENEWABLE AND SUSTAINABLE RESOURCE?

Many countries have estimated the size of their geothermal resources. For example in Iceland, the resource size (stored heat down to 3 km depth) of high-temperature geothermal fields has been estimated as equivalent to some 3,500 MW_e for a production period of 50 years (Palmason et al., 1985). This estimate is based on many simplifying assumptions and if taken literally, it implies that a geothermal field is a mine of heat that will be depleted in proportion to its utilization. There are many questions that arise when it is stated that geothermal energy is a renewable and sustainable resource. Can geo- thermal energy be utilized in a sustainable way? My answer to this question is no! Geothermal energy utilization always has some impact on the environment, both the resource itself as well as the surroundings. Probably, the environmental impact of most concern is changes induced in the geothermal reservoir by fluid extraction from it and chemical pollution of the external environment from spent geothermal fluid, both by airborne and waterborne pollutants. Airborne pollution from geothermal power plants is, however, much less than from fossil fuel plants (Figure 1).

To date geothermal development essentially has involved drilling into permeability anomalies to prove fluid (steam or water) and subsequent prediction by numerical simulation of reservoir performance. The principal aim of the simulation has been to evaluate whether the reservoir will last long enough for depreciation of all cost involved in erecting a power plant and in operating it. This economic view has dominated geothermal development rather than effective and environmentally benign use of the resource. Almost always siting of wells is skilful, based on exploration surveys and understanding of the geological structure of the geothermal system being drilled. In some cases exploitation plans may require drilling of boundary holes to prove the areal extent of the geothermal reservoir. Most often, however, this is not so in which case every well is (or should be) sited with the purpose of maximizing well output.

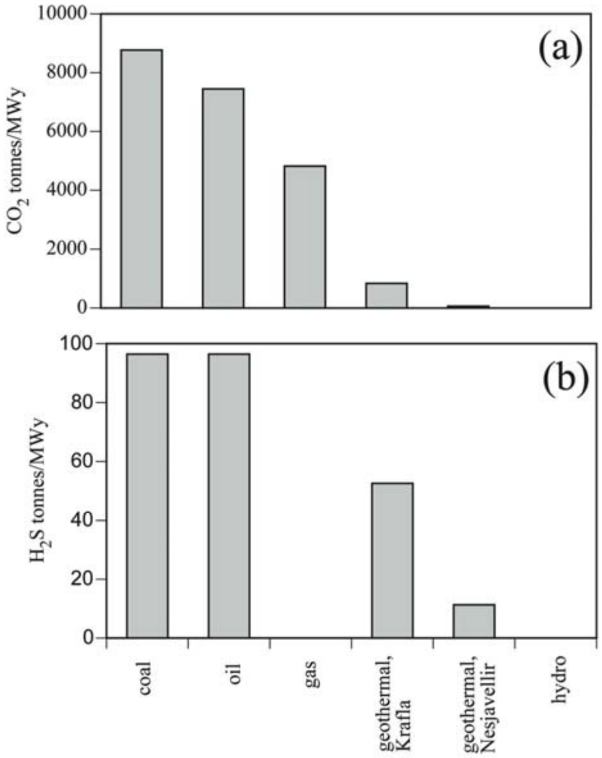

FIGURE 1: (a) Carbon dioxide (CO_2) and (b) hydrogen sulphide (H_2S) emissions from some power plant types; based on Armannsson and Kristmannsdottir (1992) and Gislason (2000)

In the light of present worldwide awareness of the environment and the fact that Earths resources are limited, it is evident that there is a need to save as much as possible on our energy resources and enhance the development of new ones that are renewable. Some of us may be driving a Mercedes but our children will be riding a house and our grandchildren a camel or simply travel by walking along sheep paths if we continue to behave the way we have in the past.

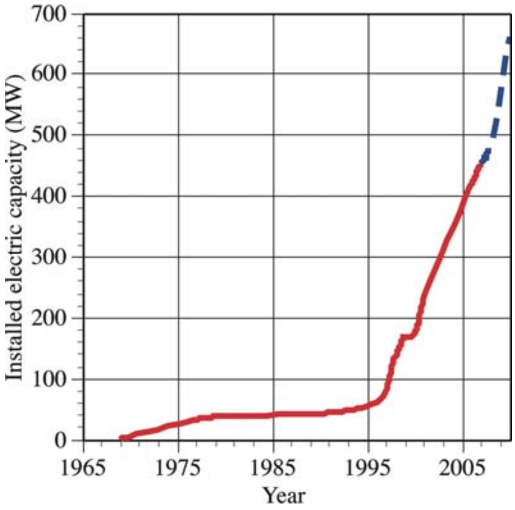

FIGURE 2: Production of electric power by geothermal steam in Iceland. The solid line represents installed capacity by April 2008 and the dashed line additional capacity from a power plant presently under construction

Some countries, such as Iceland and New Zealand, have enhanced development of their geothermal resources for electricity production in response to increased oil prices (Figure 2) by erecting conventional geothermal power plants. My view is that too much rush may in effect be a drawback in the long run, cause loss of money by wild-catting rather than skilful drilling, lead to poorer economy, and the most benign use of the resource will not be experienced.

Research is needed to improve our understanding of the birth, evolution and extinction of individual hydrothermal systems, whether volcanic, tectonic or of other types. Such an understanding will influence our way of thinking about geothermal energy utilization. Is inefficient utilization of the resource justifiable, even if economic, if it will only last for 25 years? Research should also help answering many technical questions: What can be done to make use of hot-dry-rock systems economic? Where should we look for such systems? How long do tectonic systems last (Figure 3)? How rapidly does hydrothermal alteration occur? Is there any self-sealing cap that separates geothermal systems from the enveloping cooler ground water? How is the heat source renewed in volcanic geothermal systems (Figure 4)? What is the mechanism of heat transfer from magma to the fluid circulating in volcanic geothermal systems (Figure 5)? How deep does permeability go? We could ask many more questions. Manpower, infrastructure, instrumentation, know-how and money are all needed to try to answer these questions. My impression is that the geothermal community worldwide is mostly occupied by continued development of geothermal fields in the same way we have been doing during the past few decades and efforts to further knowledge are apparently limited.

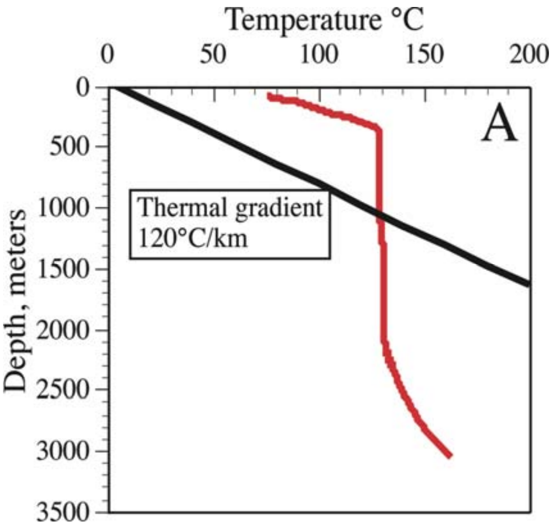

FIGURE 3: Temperature profile for the deepest well drilled within the Laugarnes low-temperature field in Reykjavík; from Arnorsson et al. (2008). The profile shows that water convection has transferred heat from deeper to shallower levels. Evidently, the heat source is hot rock at depth. The high gradient towards the bottom of the well might indicate reduction of permeability

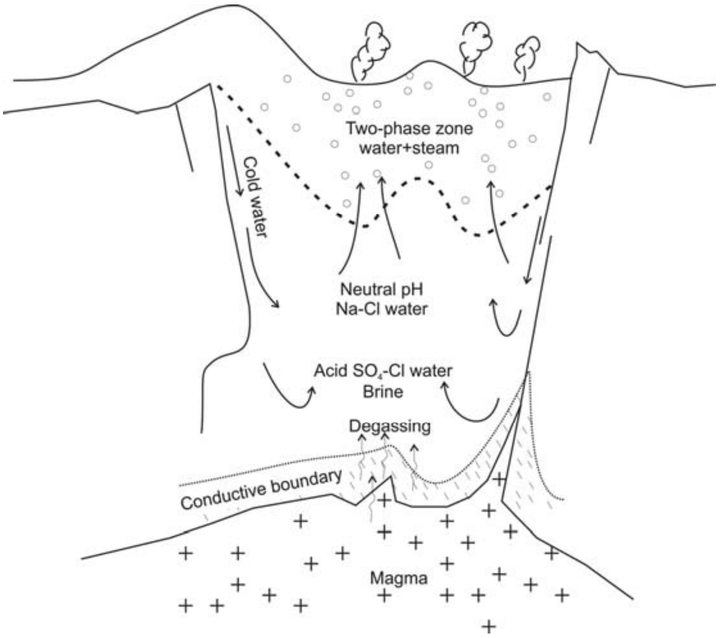

FIGURE 4: A schematic section through a volcanic geothermal system depicting fluid circulation above the magma heat source; from Arnorsson et al. (2007)

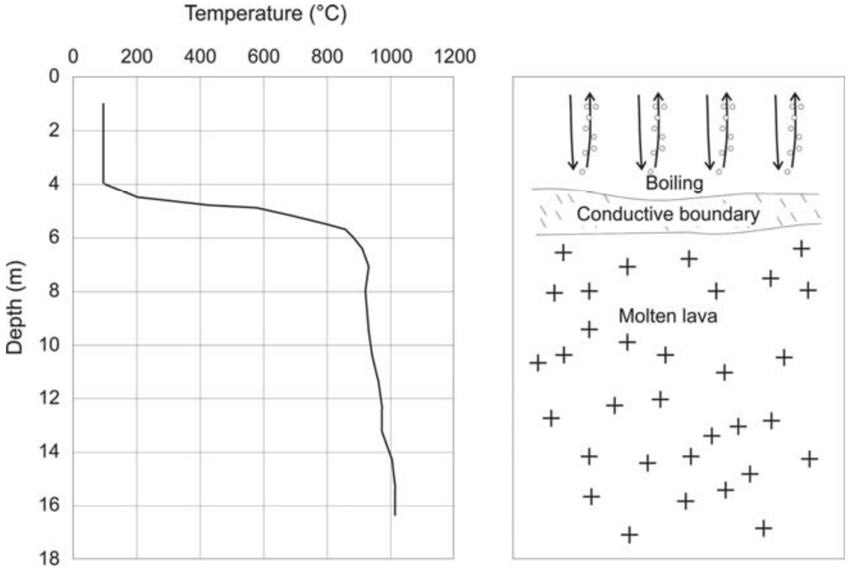

FIGURE 5: Temperature profile in a hole drilled into molten lava erupted in 1973 on the island of Heimaey off the south coast of Iceland. Seawater was pumped onto the lava. The water percolated to a depth of 4 m where it was converted into steam. The rising steam kept temperature above 4 m at 100°C. The temperature of the molten lava was ~1000°C. Heat was transferred conductively through the layer at 4-6 m depth to the circulating water. Magma intruded into brittle rock in the volcanic geothermal systems may cool by this mechanism through convection of ground water (from Arnorsson et al., 2007)

8. MULTIPLE INTEGRATED USE OF GEOTHERMAL ENERGY

The efficiency of the use of geothermal steam in conventional power plants is poor. Only about 10-12% of the heat in the steam is converted into electric energy, and in the case of high-enthalpy liquid-dominated geothermal reservoirs, the water brought to the surface through wells with the steam is not utilized. In contrast to conventional electric power generation, direct use of geothermal heat is efficient. A combined scheme that permits an efficient use of the energy from high-temperature reservoirs needs to be seriously addressed in the world of energy shortage. An example of integrated multiple use of a high-temperature geothermal resource is provided by the Nesjavellir and Svartsengi power plants in Iceland. In both plants, electricity is produced with steam and the condensate and separated water passed through heat exchangers to heat up fresh that is used for space heating. Additionally, at Svartsengi the hot water is used for bathing. Figures 6 and 7 depict a layout of a conventional geothermal power plant the plant at Nesjavellir, respectively. Many other possibilities exist to improve direct usage of the heat in conjunction with power production (Figures 8 and 9).

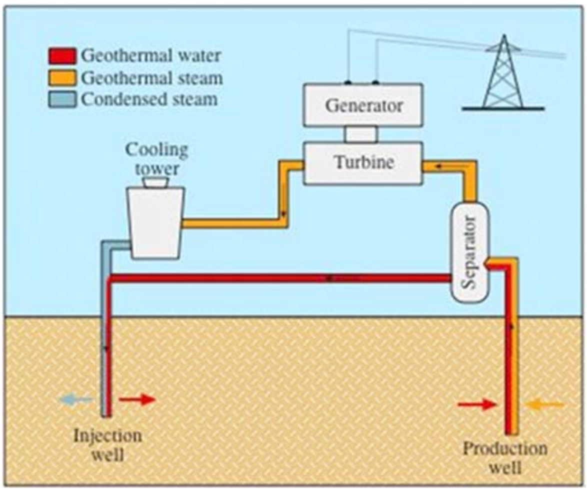

FIGURE 6: Simplified schematic layout of a conventional geothermal power plant. In such plants utilization of the thermal energy brought to the surface through wells is poor. The liquid is wasted and only 10-12% of the heat in the vapour is converted into electric energy (from Arnorsson, 2004)

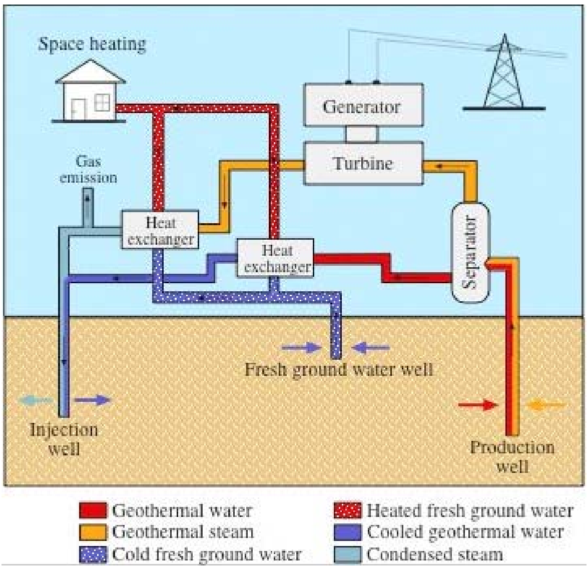

FIGURE 7: Simplified schematic layout of the Nesjavellir geothermal plant in Iceland. The installed power capacity is 120 MW and thermal power (hot water production for house heating) is 300 MW

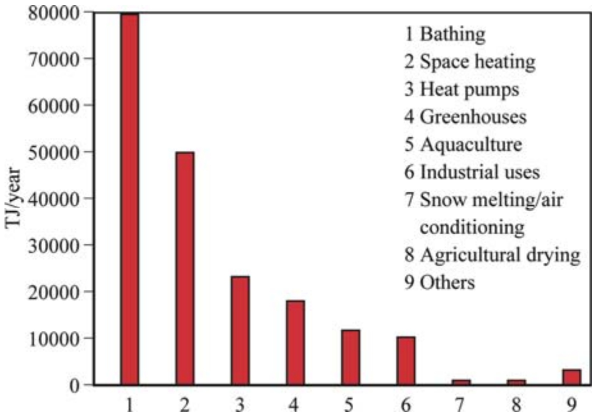

FIGURE 8: Direct worldwide use of geothermal energy in 2000 by type (based on Lund and Freestone, 2001)

A problem, which discourages efficient use of the heat energy brought to the surface through wells, is that no value is put on the resource. It is taken to have indirect value only, profit, which is the difference between income and expenditure for erecting and operating a geothermal plant. Because of this, it does not matter whether or not the resource is utilized in a benign way. It is important to focus more than hitherto on more effective use of the heat, for example by use the spent hot water and condensate from a power plant for house heating, greenhouse farming, bathing, fish farming, food processing or other purposes, depending on the local market. Spent geothermal fluid is often of poor quality chemically. It may therefore be necessary to use heat exchangers to heat fresh water for some or all of the mentioned uses, thus requiring ground water to be heated.

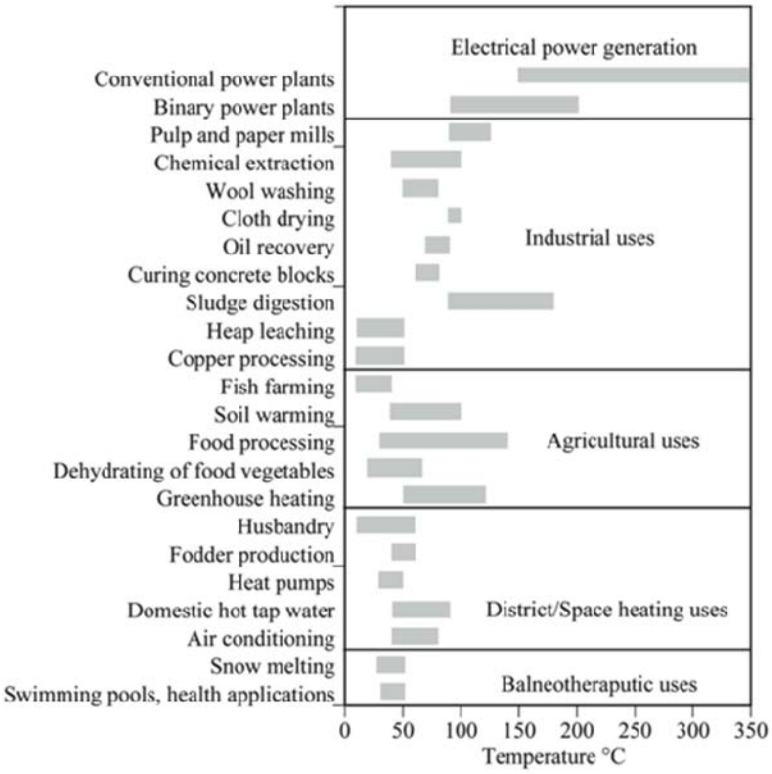

FIGURE 9: The Lindal diagram, which shows the potential uses of geothermal energy in relation to the temperature of the fluid. Taken from Arnorsson (2004)

Conventional power plants with cooling towers are not as environmentally friendly as plants that use water for cooling. Also, instead of wasting the heat by transferring it to the atmosphere, it is more attractive to use water cooling because this technology opens up the possibility of using the heat in the condensed steam.

9. THE ROOTS OF VOLCANIC GEOTHERMAL SYSTEMS

Deep drilling (up to 5 km) into active high-temperature fields in Iceland is under way. There is no question that a lot of heat is stored in the rock below presently drilled depths (~2.5 km) in these fields. It is considered that the success of deep drilling depends mostly on four parameters, permeability, temperature, the depth to the magma heat source and fluid composition, particularly with respect to its gas content and corrosion and scaling potential.

In general, permeability is expected to decrease with depth. In drilled high-temperature fields in Iceland, intrusive bodies dominate the succession below some 2 km depth. In extinct high-temperature geothermal systems, which have been exhumed by erosion, intrusions are abundant at depth levels of as little as 1-2 km. The intrusions have lower porosity, and presumably also lower permeability than the above lying lava sequences and sub-glacially erupted hyaloclastites. These shallow intrusions are typically considerably fractured.

Injection tests on a geothermal well in New Zealand demonstrated that the injectivity was enhanced by cooling the aquifer by cold water injection (Clotworthy, 2000). Permeability can be created in hot-dry-rock by hydrofracturing and enhanced by cold water injection (Baldeyrou et al., 2004). Therefore exploitation of heat stored in the rock in the roots of volcanic geothermal systems need not depend on sufficient natural permeability. It can be created easily by cold water injection, at least if the rock has microfractures. One may speculate that drilling of deep wells (3-5 km) into the roots of volcanic geothermal systems, and injection of cold water into these wells, may lead to production of hot fluid at deep levels that could ascend by buoyancy into shallower production wells, thus contributing to their output and maintaining reservoir pressures. Such exploitation of the heat in the roots of volcanic geothermal systems would be expected to reduce recharge of cooler water into the reservoir from shallow zones, but at the same time it could improve the performance of producing wells and increase their lifetime. Also by impeding shallow cold recharge into a wellfield, the heat stored in the rock at shallow level might be better utilized in the long run.

One deep drillhole cannot be expected to provide information, which represents the drilled field, not to speak of the characteristics of other volcanic geothermal fields. The three dimensional distribution of permeability varies within and between fields. The same is expected to be the case for the depth to the magma heat source. In Iceland, much information on the nature of the roots of volcanic geothermal systems can be obtained from information on fossil systems which have been exhumed by erosion. They should be studied or re-visited with the purpose of collecting data relevant to the roots of presently active volcanic geothermal systems. Developers of geothermal energy need to be open-minded in this respect. Furthering understanding of a particular geothermal system need not be confined to collecting data from that system only.

As is the case with locating and developing subsurface Earth resources, including geothermal resources, a risk is always involved. If nobody is willing to come up with risk-money, there will be no progress. However, and understandably, those involved in financing geothermal exploration and development want to minimize the risk. It is my view that collection of information on the roots of volcanic geothermal systems with the aim of utilizing the heat, it best done in relatively small steps. One approach would be to gradually drill deeper in already existing wellfields. For example, if the presently deepest production wells are 2.5 km, a new well could be designed for a target depth of 3 km and it could be drilled as a make-up (replacement) well to recover fluid to counteract decline in output of existing production wells. If the drilling of this well verified the existence of producing aquifers below 2.5 km depth, the next replacement well could be drilled deeper, say, 3.5 km. The 3 km deep well could be put into production, if its yield was satisfactory, thus getting return on the investment involved in drilling it. Alternatively it could be used for injection. The important point here is that the purpose of drilling deeper is to gather information on the deeper levels of volcanic geothermal reservoirs implying that the study programme is of first priority, not the drilling of the well.

10. EPILOGUE

The geothermal energy stored in the uppermost few km of the Earth´s crust is enormous. With present-day knowledge, however, geothermal energy is only a usable resource in hydrothermal systems where hot fluid, water or steam, can be brought to the surface through drillings into these systems. The ultimate objective of applied research on geothermal energy and technological advances should be to make use of hydrothermal systems more efficient and to make a larger fraction of our geothermal energy a usable resource.

We live in a world of foreseen shortage of energy and increasing energy prices. Additionally fossil fuel combustion is polluting and is already leading to major climatic changes. Because of all this, every effort should be made to develop new energy resources that preferentially should be renewable as well as environmentally benign. Geothermal energy will probably not contribute much to today´s worldwide energy usage. It is and will, however, be of much importance to some countries, particularly those located in active volcanic regions.

The geothermal industry has developed sophisticated geological, geophysical and geochemical methodology to search for and characterize hydrothermal systems. Drilling techniques to recover geothermal fluids has also advanced very much as have studies aiming at predicting geothermal reservoir performance and longevity in drilled fields. The prevailing paradigm has been to locate and quantify the features characterizing hydrothermal reservoirs using well data and to emphasize the economy of the usage rather than its efficient and environmentally friendly utilization. Indeed, this way of thinking is beneficial for the present and the near future but not necessarily for the distant future.

A new paradigm for geothermal energy utilization is needed that should emphasize, as much as possible, efficient and sustainable use of geothermal resources. Also, we should strive to make progress that would turn more geothermal energy into usable geothermal energy resources. This requires research. The UNU-GTP should stimulate increased research on these lines in developing countries with geothermal potential.

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