SECTION I

Present Status of Resources Development

Present Status of World Geothermal Development

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ABSTRACT

Recent changes in the world energy situation are reviewed together with their effect on the course of development in the field of geothermal energy. An overview is given of the geothermal installations existing in various parts of the world categorized under the characteristics of the geothermal heat sources.

The paper surveys the status of new projects which are in the planning, exploration, or exploitation phases in different countries. In all, upwards of 50 countries have either commenced or are displaying interest in geothermal development in their territories. In many of these countries which lack significant deposits of fossil fuels, the use of geothermal energy as an alternative energy source is particularly attractive because of the opportunity it offers for making considerable savings in the foreign exchange required for the importation of fuel.

The present rapid rate of development of geothermal energy resources has been accompanied by difficulties associated with shortages of both equipment and suitable expertise.

INTRODUCTION

Although the use of geothermal hot water for balneological purposes has been known for hundreds of years, the utilization of geothermal energy for the production of electricity and the supply of domestic and industrial heat dates only from the early years of the twentieth century. For 50 years the generation of electricity from geothermal energy was confined to Italy and interest in this new and specialized technology was slow to spread elsewhere. In 1943 the use of geothermal hot water for space heating was pioneered in Iceland although it was not until 1969 that electricity was first produced from geothermal steam in that country.

During the decade following 1950, intensive exploration work was undertaken in New Zealand, Japan, and the United States, which led to the commissioning of geothermal power stations in 1958, 1961, and 1960, respectively. Thus, prior to 1950 there was comparatively little global activity in geothermal energy and despite the excellent prospects existing in many developing countries they were for the most part unaware of their potential in this field.

The decade to 1970 was marked by a greater realization of the benefits of geothermal energy, particularly following the United Nations Conference on New Sources of Energy which was held in 1961. This meeting, attended by representatives of many developing countries helped to publicize the possibilities of utilizing geothermal energy as an indigenous means of producing electricity. From 1964, rising interest in geothermal development was characterized by the starting of many preliminary investigation projects, particularly in developing countries. These formed the basis of many reports and scientific papers submitted to the United Nations First Symposium on the Development and Utilization of Geothermal Resources held in Pisa in 1970. The exchange of information and experience at this meeting provided a further impetus to the development of geothermal energy on a global basis.

A growing interest in the development of geothermal energy was the result of its demonstrated economic advantages over the utilization of fossil fuel alternatives. Geothermal power stations were seen to be more economical in small sizes and less capital-intensive than conventional plants and this was of particular interest to many developing countries having small electricity systems and many competing demands for their limited capital resources.

RECENT CHANGES IN ENERGY SITUATION

At the end of 1973 events took place which had a dramatic impact on the global energy scene. The restriction of oil supplies and quintupling of world oil prices abruptly changed the economic base which had hitherto governed the international energy economy. These conditions caused consequences of such magnitude that energy problems have since become a major concern both of governments and the international community.

It has been estimated by the International Bank for Reconstruction and Development that in 1973 developing countries spent $5.3 billion in foreign exchange for imported fuel oil, or 8% of the value of all imports. For the year 1974 these figures had risen to $14.9 billion and 20%. Over the same period, the cost of oil imports to developed economies rose from approximately $37 billion to $99 billion. In the light of this situation, strenuous efforts are being made throughout the world to develop those indigenous energy resources which will substitute for imported oil supplies. Geothermal energy is one such resource which in suitable locations now offers even more attractive economic possibilities for replacing oil in the generation of electricity and the supply of heat.

In many developing countries, electricity systems are still too small to support nuclear power stations large enough to be economical and this alternative cannot, therefore, be pursued. However, the exploitation of geothermal energy in those small developing countries situated in volcanic regions may assume greater relative importance than in larger and more developed nations. In addition, the comparatively small size of geothermal power stations is better suited to the present scale of electricity supply systems in most developing countries. For the foregoing reasons, the exploitation of geothermal energy in suitable developing regions of the world is likely to assume increasing importance. At the present time, as will be seen from the following survey, the utilization of geothermal resources is taking place mainly in developed countries. However, it can be anticipated that, under the stimulus of current conditions in the international energy field, the transfer of appropriate technology and experience to developing countries will proceed on an urgent basis and will result in rapid progress.

The exploitation of geothermal energy can be reviewed by subdividing it in accordance with the basic characteristics of the heat source. Thus, the following status review of geothermal energy resources can be conveniently considered by placing them into the categories of: (1) dry steam fields; (2) wet steam fields; and (3) hot water fields.

DRY STEAM FIELDS

Although dry steam fields appear to be much less common than wet steam fields, they account for the greater part of the electricity now being produced geothermally.

Italy

The use of dry steam for electricity production was pioneered at the Larderello geothermal field and development in Italy had resulted in an installed generating capacity of 384 MW, as reported at the Pisa Symposium in 1970. The use of large quantities of geothermal steam over a period of many years, particularly in the boraciferous region near Larderello, has necessitated a continuous well drilling program to maintain the output from existing power stations. In view of the difficulties encountered in increasing steam supply from the Larderello and Monte Amiata areas, considerable attention is being given to enhancing electricity production by replacing atmospheric turbines with condensing units. These will have lower specific steam consumptions and allow more electricity to be generated from the available steam. As part of this program, a new 15 MW condensing turbogenerator was added to the Serrazzano power station at Larderello during March 1975. Any substantial rise in the use of geothermal energy in Italy must depend upon the discovery of new fields and, to this end, the State Electrical Power Board and National Research Council are participating in joint efforts to explore promising areas (Leardini, 1974).

During the course of such an exploratory program at Travale, 20 km southeast of Larderello, a well was drilled in 1972 having a production capacity of 15 MW. In 18 months, this well was coupled to a 15 MW atmospheric turbine and has operated continuously as a remote-controlled base load power station.

In 1973 a new discovery of steam was made near Mt. Volsini, 50 km southeast of Monte Amiata, and deep drilling is proceeding with a view to the installation of a 15 MW turbogenerator similar to that installed at Travale.

The drilling of five wells at Alfina, 110 km north of Rome, has established the presence of a water-dominated field, and a water-steam separation plant is now under construction.

Further exploration will begin shortly in the pre-Appenine belt lying between Larderello and Naples and it is expected that at least 10 wells will be drilled annually for the next five years (Tongiorgi, 1974, personal commun.).

The total installed capacity of geothermal generating plants in Italy now stands at 420.6 MW.

Japan

Japan has considerable geothermal resources which, while consisting mainly of wet steam, include an important dry steam field at Matsukawa. Japan's first geothermal power station was commissioned at this location in 1966 with a capacity of 22 MW. After overcoming various problems it is now operating successfully as is evidenced by its 1973 generation load factor of 94%. Plans have been made to extend the capacity at Matsukawa to 90 MW.

During the course of a recent survey the Electric Power Development Company of Tohoku located a dry steam field at Onikobe on the island of Honshu. Production at this field is being obtained from 10 wells at a depth of only 300 m and work is under way on a power station installation of 25 MW capacity which should be in service during 1975.

USA

The only dry steam development in the United States at present is The Geysers field in California and this is being rapidly exploited. The speed of development can be gauged from the installed generating capacity which was reported to the Pisa Symposium in 1970 as 78 MW and now stands at 500 MW, making it the largest geothermal power plant in the world. The rapidity with which plant capacity has been increased is due to a considerable extent to the use of the largest sizes of geothermal turbogenerators to be found anywhere. Six have been installed with capacities of 53 MW while the latest unit commissioned in January 1975 has a capacity of 103 MW (Worthington, 1975, these Proceedings). Rapid progress has also been assisted by gearing development to the reservoir study results which have been accepted, thereby avoiding the empirical well testing previously carried out over long periods.

Present plans envisage the installation of a further 406 MW of generating plant by 1978, bringing the total to over 900 MW. Since The Geysers plant is linked to a large interconnected electricity network, there will be no difficulty in operating it at a high load factor. This will result in the maximum savings from displacing the output of power stations burning expensive fuel oil.

WET STEAM FIELDS

Wet steam fields occur more frequently than dry steam fields and although hitherto they have been less important for the production of electricity, it is anticipated that the current upsurge in geothermal development on a global scale will discover many such fields and thereby increase their relative importance.

Japan

Japanese experience with the production of electricity from wet geothermal steam dates from 1967 with the commissioning of the Otake power station in Kyushu. Geological conditions throughout the country are particularly favorable for the occurrence of geothermal energy resources, and the impact of the present world energy situation has provided a strong developmental stimulus to further exploration.

The 13 MW Otake power station was followed by a 10 MW installation in 1973 at Onuma which supplies electricity for the use of the Akita factories of the Mitsubishi Company.

Kyushu Electric Power Company has begun an exploration project at Hatchobaru near the existing Otake power station. Wet steam has been found at a depth of 1000 m and seven wells are in production. A geothermal power station of 50 MW capacity is under construction and is expected to be in service during 1976. Present indications are that this field will be able to support a generating plant totaling 200 MW.

Further development has been indicated at Katsukonda which is situated between Matsukawa and Onikobe. Exploration has been successful and the 50 MW power station which is in the course of construction will be commissioned during 1977. It is expected that this field will eventually be capable of supporting a 200 MW installation.

It must be added that considerable attention is being focused at present in Japan on environmental quality and the development of geothermal energy is consequently taking place against a background of environmental constraints.

New Zealand

Following the successful development of the geothermal resources at Wairakei and Kawerau, exploration was extended to other areas of New Zealand. Of these, the most promising was found to be situated at Broadlands where maximum temperatures of up to 295°C were found, together with high well yields. The development of this geothermal field for electricity production was delayed by the discovery of a large natural gas field which was utilized in preference to geothermal steam. Under the changed conditions which have prevailed in the overall energy field during the recent past, priority has now been given to the development of Broadlands up to a capacity of 120 MW (Bolton, 1975, these Proceedings).

Mexico

Geothermal exploration commenced during 1960 in the Cerro Prieto region of northern Mexico. Production wells were subsequently drilled to an average depth of 1300 m and each produces the equivalent of 5 MW of power. Following the successful testing of the field, two 37.5 MW steam turbogenerators were installed in March 1973. Although some degree of calcification has been experienced with the production wells, this has not been excessive and operating experience with this installation has been good.

Work is now proceeding on the drilling of further wells designed to double the size of the power station. During the course of this drilling program steam has been located at a depth of 2000 m at a temperature of 344°C. It has been estimated that the area at present being exploited by producing wells is capable of supplying up to an ultimate capacity of 400 MW.

Iceland

Present conditions in the international energy field have focused renewed attention on geothermal exploration and a new steam field has been located at Svartsenti in southwestern Iceland as a result of an exploration project which started in 1972.

In the northeastern part of Iceland at Krafla, a steam field has been evaluated from the results obtained by drilling exploration wells. As a result of these preliminary tests it has been decided to commence drilling production wells during the summer of 1975 with a view to the construction of a power station consisting of two 30 MW generators. Although the detailed timing of this development must necessarily depend upon the results obtained with the production drilling, it is hoped that it will be possible to commission the new plant during 1977 (Palmason, 1975, these Proceedings).

Chile

Geothermal exploration in Chile began in 1967 under the aegis of a United Nations technical assistance project and reconnaissance surveys were carried out in the three areas of El Tatio, Puchuldiza, and Polloquere. As a result of this reconnaissance, detailed geological, geochemical, and geophysical exploration surveys were undertaken in Puchuldiza and El Tatio. Following this work the El Tatio area was selected for exploration drilling, and from 1970 to 1972 six 4-in. diameter wells were completed to 600 m. The highest temperature encountered was 240°C and the maximum steam production was equivalent to approximately 1 MW per well.

This slim hole exploration program was followed in 1973 by the drilling of seven 8-in. production wells to a maximum depth of 1800 m. These wells encountered permeability problems and although two produced steam equivalent to 7 MW each, the performance of the others was disappointing.

At the end of 1974 exploration was resumed at Puchuldiza and geological, geochemical, and geophysical surveys are now in the course of completion. It is anticipated that following these surveys, drill sites will be selected and two exploration holes will be drilled during 1975.

During 1974 a feasibility study was commissioned, directed toward the construction of a 15 MW power station to utilize the steam which is at present available. It is hoped that further drilling will enable the plant capacity to be increased to 20 MW. In view of the need for potable water in Chile, arrangements were made with the government of the United Kingdom to finance a pilot desalination plant which was connected to one of the small exploration drill holes. This plant is being used to evaluate the possibility of corrosion and scaling problems arising in large-scale desalination plants based on geothermal hot water (Lahsen, 1975, these Proceedings). The government of Chile has set up a National Geothermal Enterprise to be responsible for controlling the production and commercial aspects of geothermal energy development.

El Salvador

A geothermal survey was started in El Salvador in 1965 under a United Nations technical assistance project. In 1969, work was concentrated on the Ahuachapan geothermal field where the highest temperature located was 237°C. In this phase of the project five wells were drilled which proved to have sufficient steam for a 30 MW power station.

Water disposal posed a problem at this site since use could not be made of the Paz River because of the quantity of effluent envisaged for a large-scale development of the field and the downstream use of the river for crop irrigation. Considerable attention was therefore given to the question of reinjecting well effluent into the reservoir and a suitable reinjection system was constructed and successfully tested in December 1970 to take the full output of one of the production wells. Continuous reinjection at a rate of 91 l/sec was carried out for almost six months during 1971 without noticeable silica deposition inside the well or interference with the temperature of producing wells located only 400 m away.

A reservoir study carried out in 1971 estimated the Ahuachapan reservoir at 40 km^3 with a minimum energy reserve of 5000 MW years based on single stage flashing. As a result of this evaluation it was recommended that the field be initially developed in three stages of 30 MW each. It was also considered feasible, on the basis of the field tests, to reinject into the local reservoir at 150°C.

In 1971 a power station feasibility study was prepared and recommended the initial installation of a 30 MW geothermal power plant. The first machine will be commissioned during June 1975, and the government of El Salvador is planning to install a second 30 MW unit during February 1976, followed by a third in 1979 (Valiente, 1975, these Proceedings).

Turkey

In 1967 a geothermal exploration project was commenced in Turkey under the United Nations Technical Assistance program. Initial scientific surveys carried out under this project identified nine geothermal prospects in Western Anatolia. During the course of more detailed investigations a deep borehole drilled in 1968 revealed the existence of a wet steam field at Kizildere. Twelve other wells were subsequently drilled in this area between 1968 and 1971, directed toward the evaluation and development of the field. Of these wells, eight were suitable for production and the highest temperature encountered was 206°C.

Unfortunately, the flashing of the hot water during its passage up the well bore released carbon dioxide causing calcium carbonate to deposit as scale in the well and in the surface equipment. The rate of scaling was so rapid as to restrict steam flow over a short period of time and prevent economical operation of the wells for power production. In view of the importance of this problem, special tests were carried out with a view to the establishment of some practical operating regime which would allow the field to be used for power production. The best suggestion was directed toward keeping the geothermal fluid in a liquid phase by pumping it out of the well at a pressure high enough to avoid flashing. However, this solution would have required the use of deep-well pumps operating at a depth of 400 m. Since this was beyond the scope of current experience, the idea has been abandoned until such time as future progress in this field improves its feasibility.

Although it has not been possible to proceed with the development of the Kizildere field for the large-scale production of electricity, a pilot greenhouse scheme was started in October 1972. Under this project a 1000 m^2 plastic greenhouse was erected close to one of the production wells and heated by air blown through a radiator through which borehole water was circulated under pressure to prevent scaling.

More recently, geothermal exploration work has been carried out in Turkey close to the city of Afyon. A short distance from the city, wells drilled into the Omerli hot springs have located water at 100°C. In view of the possibilities of using this hot water to supply heat to the city of Afyon, a deep drilling program was commenced during 1974. The first well drilled under this program resulted in the production of 20 l/sec of water at 100°C.

HOT WATER FIELDS

It has been established that some parts of the world contain considerable deposits of hot water which form large reservoirs of low-grade heat. Although in many cases this heat cannot be used economically for the direct production of electricity, it can be a cheap source of space heating where climatic conditions enable it to be used at sufficiently high load factors. It is becoming increasingly recognized that the use of geothermal water for space heating is to be preferred to the burning of a highly refined petroleum product at 1000°C in a power station boiler if the end-product is to be air at 21°C.

In view of the climatic conditions needed for the development of space heating, the exploitation of geothermal hot waters has so far been concentrated in Iceland, Japan, USSR, Europe, and the USA.

Iceland has a long history of utilizing geothermal hot water for space heating and this interest has been maintained during the course of the last five years. Space heating for the city of Reykjavik is now supplied completely from geothermal sources. In addition, the hot water supply system is at present being extended to three communities totaling 75 000 people in the vicinity at Raykjavik and it is anticipated that this work will be completed within the next two or three years.

In addition to a history of the balneological use of geothermal hot water extending over hundreds of years, Japan has used this heat source widely for hothouses, fish farming, and animal raising.

It has been estimated that hot water may be found in over 20% of the area of USSR territory. Considerable development of this resource has already taken place and geothermal hot water is being used to supply district heating, domestic hot water, greenhouses, and animal husbandry installations. In addition, the use of the binary cycle for the production of electricity from hot water was pioneered by the USSR with the commissioning of the Pauzhetka power station in 1967.

The considerable deposits of hot water in the sedimentary Hungarian basin have been utilized for many years for district and industrial heating schemes as well as hothouses and animal rearing.

In some instances hot geothermal water has been located as a result of drilling oil exploration wells; examples are Romania, Czechoslovakia, and the Paris basin. In Romania, geothermal hot water is being used on a pilot basis for greenhouses and the methane obtained from the water is being utilized to supply peak heating demands. In Czechoslovakia, geothermal hot water is supplying a pilot greenhouse installation and the United Nations has given advice on proposals for using geothermal heat in district heating. This proposal is of particular interest in that it involves an examination of the feasibility of feeding geothermal hot water into the existing district heating scheme of Bratislava.

In the United States a small geothermal district heating scheme has been in operation for many years at Klamath Falls, Oregon. At Boise, Idaho, a detailed study is now in progress on the feasibility of supplying geothermal heat to the State Capital Building and several large office buildings.

OTHER EXPLORATION PROJECTS

Ethiopia

During 1970 a geothermal exploration project commenced in Ethiopia under the United Nations Technical Assistance program. The first phase of this project was directed toward identifying hydrothermal areas in the Ethiopian Rift system and assessing their relative technical prospects for detailed exploration and subsequent development. During the course of the survey many gas and water samples were collected and analyzed and the results were presented in the form of a technical report.

As a result of this survey, areas of special geothermal promise were identified in the Lakes District, the Awash Valley and the Northern Danakil Depression. The second phase of this project initiated in October 1974 has been formulated to contain proposals for geotechnical studies in the Lakes District leading to the selection of drilling sites and the drilling of production wells sufficient to supply a pilot power station with a capacity of up to 10 MW. Since the Lakes District is comparatively close to Addis Ababa there will be no difficulty in absorbing the output from such a geothermal power station in the Addis electricity network. Concurrently, with the carrying out of detailed geophysical and geochemical investigations in the Lakes District, an economic feasibility study will be undertaken to assess the possible economic impact of developing geothermal energy in the other two regions. The cost benefit analysis obtained from this study will be of considerable assistance to the government in deciding on the priorities for subsequent geothermal development work.

India

Since 1973, geothermal investigations have been carried out in India at Puga Valley, Ladakh. As a result of this work steam and hot water at temperatures up to 130°C were found in some shallow wells from 30 to 90 m deep. To utilize this geothermal fluid and also obtain valuable operating experience, the government plans to install a 1 MW pilot geothermal power plant in the near future.

The United Nations will carry out a technical assistance project in geothermal resource exploration for the government of India, and an international staff is being recruited. In this project, further investigative work will be undertaken in the trans-Himalayan region as well as in the area of west India to the south of Bombay.

Indonesia

Since the Pisa Symposium, the compilation of an inventory of geothermal areas has been continued by the Geological Survey of Indonesia with technical assistance from New Zealand. As part of this program, six exploratory holes were drilled during 1972 at Dieng in central Java. In March 1974 the Indonesian State Oil Company (Pertamina) accelerated surveys in Java and Bali and these have now been completed in West Java at Banten, Kamojang, and Derajat.

At the end of 1974, deep drilling was commenced at Kamojang and two wells were successfully completed. On the basis of the results achieved at Kamojang plans have been made for the construction of a power station having a capacity of at least 30 MW. The deep drilling program is at present being extended to cover a more detailed investigation of the Derajat and Dieng areas (Akil, 1975, these Proceedings).

Kenya

A program of geothermal exploration was commenced in Kenya during 1970 as a United Nations technical assistance project. After preliminary exploration tests, a production drilling program started at the end of 1973 and continued for over a year. Of the four wells drilled in this phase, the first did not produce but the second had an initial flow equivalent to approximately 6 MW. The output from the remaining two wells was low, in the range of 1 to 2 MW, and the general indications are that permeability may present a problem at this location.

The present position is that testing is being carried out on wells 2, 3, and 4 with a view to obtaining detailed information on reservoir behavior. The government of Kenya has bought a drilling rig and intends to continue a reservoir assessment program.

The present high cost of generating electricity from oil-fired power stations in Kenya has improved the competitive position of geothermal energy and it is anticipated that a geothermal power station would be economical even with comparatively modest well outputs. However, a firm decision on the advisability of building a power station is now awaiting the results of the reservoir evaluation.

Philippines

Exploration projects have been carried out by the Union Oil Company of America in the Tiwi and Los Baños areas of Luzon. Both projects have been successful in locating steam, and production wells are being drilled. On the basis of results achieved to date the government has placed firm orders for the supply of four 50 MW turbogenerators which will be commissioned in two separate power stations during 1977.

Concurrently with developments in Luzon the government of New Zealand is providing assistance with geothermal exploration at Leyte. Present indications are that it may be possible to generate up to 100 MW from this geothermal area.

INDUSTRIAL USE OF GEOTHERMAL STEAM

At present, geothermal steam is being used for industrial processes in two countries—Iceland, which possesses a diatomite drying plant, and New Zealand, where geothermal steam is used for a wood pulping mill, several small industries, and a hotel air conditioning system. Despite the present conditions in the energy field occasioned by fuel oil price rises, there does not seem to be any pronounced upsurge in interest for the industrial use of geothermal steam.

Although geothermal steam and hot water are obtainable in abundant quantities, they cannot be transmitted over long distances and must therefore be used relatively close to the well head. Since industrial processes also need raw materials, their development in geothermal areas must depend upon the geographical coincidence of raw material and heat sources. In addition, the proximity of a market for the final product is also of considerable importance. These locational restrictions explain why geothermal steam has not been more widely used for industrial processes up to the present time.

It is clear from the foregoing that the industrial use of geothermal steam is dependent upon an integrated approach covering all the various aspects involved. In some instances, particularly in developing countries, it is possible to envisage such an approach. For example, the development of a geothermal field could result in the production of cheap power, which in turn would allow the use of pumped irrigation to support agricultural and animal raising industries. Such industries could then create a demand for industrial steam for crop drying and food processing.

RESEARCH AND DEVELOPMENT

The recent increases in world oil prices have caused many countries to reassess their energy programs with particular reference to the greatest possible use of their own energy resources. This new attitude is illustrated by the inauguration of "Project Independence" in the United States and "Project Sunshine" in Japan.

As an essential step in the encouragement of indigenous energy resource development many governments are expanding their commitment to research and development programs. In 1973 the government of Japan spent \$300 000 on geothermal research development, but increased this to \$2 million for 1974 and it is anticipated the total will rise to \$7 million for 1975. In the United States the government spending was \$1.5 million in 1973 and \$10 million in 1974. For the current year, an outlay of \$28 million is expected and it is anticipated that for next year the authorized appropriation might be as high as \$43 million. In addition to government expenditure, various private enterprises are also carrying out important work on geothermal problems.

Current research and development cover a broad spectrum of geothermal activities ranging from exploration techniques through new drilling and conversion technology to environmental and utilization aspects. At the exploration stage, research is being conducted to improve the geophysical and geochemical evaluation of geothermal prospects. To aid the exploration process, work is proceeding on the improvement of downhole instrumentation and the more accurate determination of reservoir capacity. In the drilling phase, investigations are being carried out to try to reduce costs by evaluating alternative drilling methods using turbine drills, erosion, and melting techniques (Rowley, 1974). In addition, consideration is being given to the development of new and improved muds.

Since in many geothermal developments output is limited by the permeability of the formation, investigations are being carried out into the possibility of fracturing aquifer formations by hydraulic, thermal, and explosive methods to increase permeability.

In view of the comparatively low temperatures found in many geothermal fields, as well as problems due to high salinity and mineral deposition, significant research is being directed toward the production of power from these fluids. The University of California is investigating a total flow system where mixed steam and brine could be used in conjunction with an impulse turbine (Austin, 1974). A further possibility which has already been demonstrated at the Mesa field in California is the use of the Helical rotary screw expander, and larger scale tests can be expected in the future (McKay and Sprankle, 1974). The need for suitable downhole pumps to maintain the geothermal water under pressure and thus avoid mineral deposition problems has already been mentioned with reference to recent developments in Turkey. This problem is the subject of current research aimed at developing downhole pumps suitable for operation under the conditions to be found in geothermal wells (Matthews and McBee, 1974).

The use of a binary cycle to produce electricity has already been demonstrated with the experimental plant at Pauzhetka in the USSR. Further evaluation of this system has been carried out by the University of California which recently prepared a design study for a 10 MW demonstration geothermal power plant to operate on an iso-butane binary cycle at a site in Nevada, USA (Holt and Brugman, 1974). It is anticipated that this machine will be commissioned during 1978.

The availability of heat and brine from the wells in geothermal wet steam fields has raised the possibility of producing desalinated water. Considerable experience exists concerning the desalination of sea water but since in some cases the quality of geothermal water differs greatly from that of sea water, there is a need for reliable data on the behavior of various construction materials under these conditions. As mentioned earlier, a small pilot desalination plant has been operated from one of the wells associated with the United Nations geothermal project in Chile. Experience to date has been satisfactory and indicates that a full-scale plant would be possible. This finding has been supported in the United States where a multi-stage flash and a vertical tube evaporating plant have been installed in the Imperial Valley of California (Suemoto and Mathias, 1974). The first results obtained from the operation of these two plants indicate no problem with carbonate or silica scaling.

Considerable interest was stimulated at the Pisa Symposium by discussion of the geopressure zones which have been located along the Texas and Louisiana coast in the United States. These zones contain hot water at great depth under high pressure. Since the water also contains considerable quantities of dissolved methane there are possibilities of obtaining energy from its pressure, heat, and methane content. Research is being continued into these geopressure areas with a view of a better understanding of the nature of this resource and its possible method of exploitation.

In some parts of the world, areas of hot rock exist in a dry state without containing the water which is the normal medium for bringing geothermal heat to the surface. The possibility of utilizing these hot rock zones is at present under review. Consideration is being given to injecting water into hot, dry, rock and returning it to the surface after heating.

The scope and complexity of current efforts in the field of geothermal research and development will be apparent from the foregoing remarks. The considerable infusion of resources which has recently taken place in this field can be expected eventually to provide answers to many of the problems which have hitherto restricted geothermal development. Quicker progress can therefore logically be expected over the course of the next few years. Although geothermal research and development will be almost entirely confined to those countries possessing the necessary financial and technological resources, it can be anticipated that the results will eventually be transferred to developing countries and will assist their geothermal programs.

CURRENT PROBLEMS

As has already been mentioned, global oil price increases have considerably heightened interest in the exploration and development of geothermal energy resources in many parts of the world. These conditions have resulted in a rapid escalation in the demand for experts such as geophysicists, geochemists, geologists, and drilling engineers with expertise in geothermal exploration. The supply of suitable experts possessing sound experience, acquired over many years, is limited and, as a result, difficulties are now being experienced in staffing new geothermal projects in various parts of the world. Although geophysics and geochemistry are scientific exploration techniques, they cannot alone be used to forecast accurately the occurrence of geothermal energy deposits. The most that can be expected from them is the provision of background information against which the decisions to carry out exploratory drilling programs may be made. It is clear from these circumstances that the success of geothermal exploration programs rests heavily on the interpretive skills of the field experts who must position exploratory wells on the basis of their analyses of all the available scientific data. In the last analysis, therefore, the success or failure of geothermal projects is greatly dependent upon the professional training and experience of the relevant experts. If the demand for experts exceeds the supply of suitably trained personnel the result can be expected to be a diminution in the success ratio of geothermal exploration projects. These conditions emphasize the urgent need to accelerate training in all the geothermal disciplines to meet the present demand for experts which is expected to increase substantially in the future.

The same economic conditions which have led to increased activity in the geothermal field have also resulted in renewed efforts being made for the exploration of new oil and natural gas supplies. The aspect which both these energy sources share with geothermal energy is that the exploration process is based upon well drilling. Thus, a demand for drilling equipment in all three fields has resulted in shortages and delays in supplying basic equipment. Drilling rigs have become scarce and subject to long delays in procurement, while shortages of items such as well casings have caused serious bottlenecks. It is to be hoped that manufacturers of exploration equipment will have sufficient confidence in the future to increase their production of these essential items and thus allow the full benefits of geothermal development to be reaped.

CONCLUSION

Due to recent changes in the international energy supply situation there has been an upsurge of interest in geothermal energy. This interest has extended, not only to exploration in suitable locations, but also to the possibilities of exploiting it in diverse forms. The present expansion of activity in the geothermal field can be expected to result in the rapid accumulation of experience concerning both exploration and exploitation under a variety of differing conditions. This experience, coupled with the results of the substantial research and development programs in progress, should result in considerable technical improvements which will further strengthen the position of geothermal as an energy source. The transfer of appropriate experience and technology to developing countries will be of particular importance since geothermal energy is expected to make a relatively larger contribution to their energy sectors than to the vast energy requirements of more developed countries.

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