Summary of Section IX
Space and Process Heating

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INTRODUCTION

Until a few years ago there was a widespread tendency to think of geothermal development in terms of electric power only, or at least primarily. This was understandable, because of the versatility, ease of transport, and ready marketability of electricity. Nevertheless, it is important to remember that geothermal power generation is essentially an inefficient process owing to inescapable thermodynamic restraints, and that the lower the temperature of the heat source, the lower will be the efficiency of power generation. On the other hand, the direct use of geothermal heat for space heating and domestic hot-water supply, industrial processes, or for husbandry can be highly efficient, since the losses incurred are not imposed by the laws of thermodynamics but only by such imperfections as must inevitably arise from insulation losses, drains, and terminal temperature differences in heat exchangers. These imperfections can be controlled within economic constraints; they are not dictated by natural laws. Another important fact is that the sources of high-enthalpy natural heat at present accessible to man and which are suitable for power generation are believed to be far less abundant than those of lower-enthalpy fluids which can be used for other purposes. Furthermore, practical applications can be found to cover a very wide spectrum of temperature extending down to about 30°C for balneology, biodegradation, and fermentation, and even down to about 20°C for fish hatcheries. Finally it should not be forgotten that a very large proportion of the world's energy consumption is in the form of heat, rather than electricity. In short, geothermal energy is far too versatile an asset to be used for power generation only. It is also very much less polluting than heat produced, as is mostly now done, by the combustion of fuel. There is encouraging evidence that these facts are becoming more widely recognized.

The Icelanders have never overlooked these factors. Just as Italy led the way in geothermal power generation, so did Iceland pioneer the use of geothermal heat for space heating and domestic hot-water supply on a large scale. The island's economy and climate were important factors that influenced them in so doing, for they lacked fossil fuels and timber, while their weather was never hot. On the other hand they did possess large reserves of geothermal energy. Other countries also, such as Japan, New Zealand, and the USSR, have not neglected the "nonpower" application of geothermal heat, and yet more countries are beginning to show interest in such developments. Nevertheless, it is generally true that electric power has been, and still to a large extent is, the prime goal of geothermal development in most parts of the world.

At the UN Geothermal Symposium at Pisa in 1970 the importance of widening the scope of geothermal application was stressed, and it is now becoming clear that the message is reaching more of those people who are in a position to influence the direction of geothermal development. The rapid rise in fuel prices since 1973 has provided, and will continue to provide, a powerful stimulus to the continued advance of all forms of geothermal exploitation and to a widening of its application. Moreover, the growing public awareness of environmental considerations in many countries will also encourage the development not merely of geothermal power but (even more) the exploitation of low-enthalpy fluids which are generally far less polluting and far more widespread than high-enthalpy fluids. A city of about 90 000 inhabitants such as Reykjavik can be almost fully supplied with all its domestic and commercial heating requirements without smoke and by means virtually innocent of any other form of pollution. This is an advantage that is shared by no other form of heat supply except hydroelectric and solar energy.

Space heating and domestic hot-water supply form the principal subject of the papers submitted in Section IX at San Francisco, but other nonpower uses have not been altogether neglected.

SPACE HEATING AND HOT-WATER SUPPLY

Iceland

The volume of building space in Reykjavik heated geothermally has increased from 10.3 million m^3 in 1968 to about 15 million m^3 in 1974—an average growth rate of about 6.4%/yr. The city is now virtually "saturated" with geothermal space heating, only about 1% of the buildings do not have it. The Reykjavik area alone has a thermal load demand of about 385 MW, and the sales of heat energy in 1973 amounted to more than 1.5×10^9 kWh, equivalent to an annual load factor of about 44.5%. These and other figures are quoted by Einarsson (p. 2117) who sketches the 45-yr history of the Reykjavik city heating system from its humble beginnings in 1930 up to 1975, by which time 11 000 buildings and about 90 000 people enjoyed this public service. Although new thermal areas have been brought in to meet this tremendous growth, the originally exploited fields are still producing at undiminished capacity after nearly half a century.

The capital city, however, is not the only Icelandic area to be served with geothermal heating. Eleven other independent areas serve about 13 500 additional people with domestic heat, while a further 26 000 people will be served during the year 1975/76; and a system is being planned to provide more than 10 000 additional people with heat in the Reykjanes Peninsula under the Svartsengi project. By the time these plans have been executed, more than 137 000 people will be served with geothermal heat in their homes and the total heat load will be equivalent to nearly 680 MW. By then, more than half the population of Iceland will enjoy the benefits of this service, and it is aimed to extend the proportion to 60 to 65% within a few years thereafter.

Einarsson (p. 2117) states that the district heating schemes of Iceland use geothermal waters at 80 to 120°C, though in one case that has been operating for 30 years, the temperature is as low as 56°C. Such low- and moderate-enthalpy fields are preferred to high-enthalpy fields, as the fluids generally have much lower mineral and gas content. The Svartsengi project, however, will have to use high-enthalpy saline steam and hot water at 167.5°C. A dual-purpose power-heating project is under consideration for Nesjavellir; this project will use a high-temperature field (260°C bottom-hole temperature) and will produce 69 MW of power (net). Einarsson also examines the economics of district heating and shows a parametric graph of costs based on water temperature, pipe diameter, and transmission distance. This shows a range of costs (presumably at 1975 levels) from 4.3 to 15 mill/kWh (thermal); the lower figure represents 150°C water at the wellhead (no transmission), and the higher value represents 100°C water transported over 39 km in a 10-in. pipe. Intermediate temperatures, larger pipe diameters, and shorter transmission distances would produce intermediate cost figures. The costs generally compare favorably with fuel oil heating except perhaps where the temperature is low, the pipe diameter small, and the transmission distance great. On average, the price of geothermal heating in Iceland was 50 to 60% of that of oil heating before 1973 and is now 25 to 30%. Geothermal energy now supplies Iceland with about 2200 GWh (thermal)/yr for space heating; this saves Iceland about 300 000 ton/yr of imported fuel oil. Einarrson also technically describes the heat supply systems of Iceland and examines the climatic factors and means of improving load factor, either by short-term fuel firing or by heat storage. He also touches briefly upon institutional problems and stresses the importance of good building insulation and the effects of high cold winds.

Arnórsson et al (p. 2077) give a technical description of the Svartsengi district heating project for supplying a few population centers in the Reykjanes Peninsula and also the Keflavik International Airport. This project will represent a thermal load of 80 MW (100 MW, according to Einarsson). The wells at Svartsengi produce highly saline water together with steam at about 210 to 230°C, and this is chemically unsuitable for direct heating. Fresh water is therefore heated by the geothermal fluids and is transmitted hot to the load centers, thus obviating most of the chemical problems. It is hoped to complete the scheme by 1977 and to supply heat at about one-third of the cost of oil heating. Four different heating cycles were studied, but one in which steam and fresh water are mixed in two stages and subsequently heated and flashed, so as to degas the mixture, has been chosen as the most suitable. Fifteen kilowatts of electric power for auxiliary supplies is a by-product of the process.

Thorsteinsson (p. 2173) describes the redevelopment of the Reykir hydrothermal system, which has been exploited since 1944 for district heating in Reykjavik, 15 to 20 km distant. Before 1970 this area produced about 300 l/sec at 86°C by free flow and was the principal source of heat of the integrated system until 1959. After the development of two other areas within the city limits, Reykir's share of heat production fell to 38% of the total. Now the Reykir field is being redeveloped by drilling larger bores (22 to 31 cm) to depths of 800 to 2043 m, and equipping them with submersible pumps. Production had already increased to 850 l/sec at 83.5°C by January 1975, and is expected ultimately to exceed 1500 l/sec, with a fall in water level of 60 to 70 m from the 1970 steady-state level. Drawdown tests have been performed and the characteristics of the aquifer deduced. The effects of tides and earthquakes have also been studied.

USA

Although there are no sizable towns or cities in the USA that use only geothermal heat, there are nevertheless some interesting developments in the western states of Idaho and Oregon. Kunze et al. (p. 2141) point out that nearly 20% of the total energy consumed in the USA is used for space heating, so the market is immense if suitable geothermal resources can be found. They think it not unreasonable to expect that about one-third of this market might ultimately be supplied geothermally. The authors mention that in Boise, Idaho, a small geothermal space heating scheme was established in the Warm Springs residential area as long ago as 1890. At one time this scheme supplied about 400 homes and businesses, but it has recently declined to 170 homes fed with 77°C water pumped from two wells 130 m deep. Now, a study is in progress for establishing a Demonstration Space Heating Project, sponsored by the Energy Research and Development Administration (ERDA) and under the direction of the Idaho National Engineering Laboratory (INEL) and in collaboration with Boise State University and the Idaho Bureau of Mines and Geology, for geothermally heating a group of public buildings in the city of Boise. At present, the annual fuel bill for heating these buildings is $225 000, and this figure is expected to rise. The two wells now feeding the Warm Springs area have shown no decline in productivity in more than 80 years, and the chemical quality of the water is good. The study will cover environmental and chemical aspects, the conversion of existing installations, and various methods of waste disposal including infiltration through sand and gravel pits, reinjection wells, discharge to the existing irrigation system, discharge into the Boise River, and cycling to greenhouses, fish hatcheries, and so on. The cost of the study is estimated at about $2 million.

Lund, Culver, and Svanevik (p. 2147) describe the exploitation of the geothermal waters at Klamath Falls, Oregon—a project which has provided space heating since the turn of the century. About 400 holes of depths ranging from 27 to 580 m are used to heat about 500 buildings (and incidentally, swimming pools, a milk pasteurization plant, and snow melting facilities for roads). Some of the wells are artesian, with a pressure of about 5 psi. The total heat load is about 5.6 MW. Estimated costs are given for different numbers of households per well and are compared with fuel and electrical heating as alternatives. Initial investment for a single well is usually from $5000 to $10 000, and the annual operating costs are less than $100. Where several householders share the same well, geothermal heating is shown to be competitive. A large-scale district heating project on the lines of the Reykjavik system is being studied, as it is obvious that only a small portion of the total local heat potential is being tapped. Additional uses for the heat, for husbandry and industry, are also being considered. The well temperatures vary from 38 to 110°C. Downhole "hairpin" heat exchangers are commonly used in order to minimize corrosion, with city water as the circulating fluid; circulation is usually effected thermosyphonically. Four steam wells have been struck, and these too are used with heat exchangers.

France

Coulbois and Herault (p. 2099) state that the French administration is seeking to encourage the use, for domestic heating, of hot waters discovered in the French sedimentary basins in the course of oil prospection during the last 20 years—in particular in the Dogger aquifer near Paris. Since the depths at which these hot waters occur range from 1.5 to 1.8 km and the temperatures vary from 55 to 70°C, it would appear that the areas of interest may be regarded as "nonthermal," having temperature gradients (assuming surface ambient temperature of 15°C) only of the order of 30°C/km, which can be regarded as "normal." The water salinity varies from 8 to 30 g/l (NaCl) and traces of H_2S are present. Heat exchangers are therefore considered necessary so that clean secondary water may be used as the heating medium. Reinjection is necessary in order to avoid surface pollution from the saline well waters after having yielded up their heat, and also to conserve both fluid and heat for recharging the aquifer. The authors examine the problems theoretically from the economic and technical aspects, stress the high capital cost of geothermal heating, and suggest that geothermal energy is suitable for background heating to be supplemented with another heat source for boosting at times of high demand. Their presentation is sometimes rather obscure, and their conclusions could have been stated more clearly.

New Zealand

Shannon (p. 2165) tells us that the extraction of geothermal heat in Rotorua for domestic heating purposes has steadily increased since the first successful bore was sunk there in 1935. There are now more than 700 registered bores in that city, ranging from 50 to 1200 ft in depth and from 2 to 6 in. in casing diameter. Temperatures vary from 49 to 177°C, and pressures are experienced up to 175 psig (which is hard to understand, as this pressure exceeds the saturation pressure at 177°C). These pressures are sufficient to ensure delivery to the places required without pumping. Chemical deposition has been something of a problem, but deep bores generally give less trouble than shallow. After the heat has been extracted from the geothermal fluid, the cooled waters are disposed of in soak bores, vented at high level to dispose of the H_2S. Heat exchangers are obligatory in view of the noxious ingredients in geothermal fluids which could escape from valves and pipe joints. The author discusses the choice of suitable materials for the various component parts of the heating system, presents drawings of some of these parts, and discusses controls. He also gives particulars of a scheme for heating a complex of government buildings, representing a total thermal load of nearly 14.6 MW. Finally he gives some interesting cost data which show that although the capital cost of geothermal heating is 16% and 44% higher than for coal- and oil-fired heating respectively, the annual running costs are 30.5 and 71% lower respectively at present fuel price levels. Geothermal heating thus "pays for itself" in 15.5 and 39.5 months when compared with oil and with coal heating respectively.

India

Although India cannot yet claim to be one of the countries in which geothermal space heating is practiced, some experiments are being conducted in two Himalayan areas. The occurrence of geothermal energy in Ladakh coincides with very severe climatic conditions, but unfortunately the natural heat is found at present only in some of the most sparsely populated parts of the world—in particular at Puga in southeastern Ladakh where the population density is only 0.8/km^2. Here, at a height of 4500 m above sea level, the winter temperature sometimes falls to −40°C. Nevertheless, steam and hot water are found at depths of only 20 to 30 m, and an experimental test rig has been set up to test the suitability of geothermal space heating. Behl, Jegadeesan, and Reddy (p. 2083) describe the local conditions, the test equipment, and the results hitherto obtained. Some empirical knowledge has been acquired from the tests regarding building insulation and the corrosive properties of the thermal fluids. At present the Ladakhis have to rely on kerosene heaters to make their dwellings habitable in winter. To relieve these people of dependence upon petroleum products would be most desirable; but it is not easy to see how geothermal space heating could become economical, even with such shallow wells, in such an underpopulated area, nor how a viable economy in such an inhospitable climate could be found to justify the establishment of settlements of a size that could be heated economically by geothermal means. Nevertheless, the authors explain how the Government of India has also conducted some successful greenhouse heating experiments at Chumathang, also in Ladakh; so perhaps it might be possible to establish greenhouse cultivation in new settlements of an economical size.

USSR

Dvorov and Ledentsova (p. 2109) recognizing the complexity of the variables which govern the economics of geothermal space heating, have presented an erudite paper in which the component cost factors are analyzed separately—borehole production, local heat distribution, waste disposal, heating systems, and longer distance heat transmission. Different secondary variables are considered in each case as may be applicable—drilling costs, bore yields, bore spacing, bore fluid temperature, pattern of demand, transmission distance, local fuel costs (in competition), climatic conditions, and so on. Different heat distribution systems, heating schemes, and devices are also considered. Graphs are given showing the interrelationship of some of these variables. The authors broadly conclude that simple local geothermal heat distribution schemes can at present be competitive with traditional fuel heating only when the thermal fluid temperature is 85°C or more, the temperature change does not exceed 45°C, the local distribution distance does not exceed 5 km, and the ambient air temperature is not less than −8°C. Borehole costs should not exceed 100 000 to 130 000 rubles, or 150 000 in rare cases. Long-distance transportation can be economical up to 35 to 40 km if drilling costs are exceptionally low—for example, 50 000 rubles per bore. Drilling costs in the range of 80 000 to 120 000 rubles per bore reduce the economical transmission distance to about 5 km—or perhaps 8 to 10 km under very favorable conditions of high well yields and very expensive fuel alternatives. The authors mention the enormous heat reserves in the Soviet Union but point out that in many areas the waters are highly mineralized and sometimes the temperatures are rather low. Different schemes are described for dealing with highly mineralized waters and for moderate-temperature waters; these involve heat exchangers and supplementary fuel heating. The authors also describe a scheme which makes possible the use of low-temperature fluids in combination with a heat pump, and a complex system involving both a boiler unit and a heat pump using the lithium bromide process which permits the use of air conditioning in summer. The possibility of recovering rare elements from highly mineralized waters, after yielding up their heat in heat exchangers, is mentioned. The authors stress the fact that high sophistication and complexity may adversely affect the economics of heating schemes and their reliability of operation.

Elsewhere

There are, of course, many other examples of geothermal space heating and hot-water supply to be found in various parts of the world—for example Japan, Hungary, and so on—but unfortunately no papers on these developments were presented in San Francisco.

PROCESS HEATING

The expression "process heating" is used here very broadly to cover all nonpower uses of geothermal energy other than space heating and hot-water supply—even (paradoxically) refrigeration and air conditioning. As mentioned in the introduction to this summary there is far more low-enthalpy than high-enthalpy heat available in the world. (This point is brought out by Kunze, Miller, and Whitbeck in a paper in Section VIII, p. 2021, and is the subject of comment in the summary of Section VIII). Furthermore, a very large proportion of the basic energy needs of an industrialized country is for heating at low to medium temperatures.

Applicability of Geothermal Heat

Reistad (p. 2155) emphasizes these considerations and presents an interesting breakdown of the different uses of energy in the USA economy—electricity generation, residential, commercial, industrial, and transportation. The electricity is then reallocated to the other four sectors according to the requirements of each. Each sector's energy requirements are further broken down into the various applications such as space heating, cooking, refrigeration, process steam, and so on; and a final allocation is then made to one of two groups—"Potential Geothermal Use" and "Nongeothermal Use." The second group excludes all uses requiring temperatures exceeding 250°C; it also excludes transportation and such applications as cooking, which have intermittent demands. The author's final conclusion is that about 41% of the national energy requirements could be filled by means of geothermal energy, were it available. If the temperature limitation were dropped from 250 to 200°C, the proportion of energy requirements that could be met geothermally would scarcely be affected—a drop merely from about 41 to 40%—because very few processes use temperatures between 200 and 250°C. If the temperature limitation were further dropped to 150 and 100°C, the percentage of national energy requirements falling within the "Potential Geothermal Use" group would become about 30 and 20% respectively. This interesting analysis serves to show that the problem is one of geothermal availability rather than one of applicability, as the uses to which geothermal energy could be put, if it were available, would be enormous.

Howard (p. 2127) reports on the findings of the Committee on the Challenges of Modern Society Non-electrical Applications Project. The committee first emphasizes that very large resources of low-grade heat can probably be made available by methods already established. They cite the USSR, where it is believed that at least half of the Soviet Union is underlaid with fluids of 50 to 160°C that are industrially usable. They also state that there are many existing and potential applications for such heat, and support this with extensive tables. The committee believes that the economics of nonelectrical applications of geothermal energy are generally promising and likely to improve as fuel prices rise, but they warn that the disposal of used geothermal fluids can be a consideration of some importance. They stress that cheap energy does not necessarily imply a cheap product, as so much depends upon the energy intensity of a process. Finally they touch upon institutional and legal aspects of the matter. Much of the paper overlaps with the content of Reistad's paper.

Geothermal Heat for Process Steam

Valfells (p. 2181) points out that steam produced by fuel combustion now costs from $1 to $5 per ton according to the type of fuel and the location, whereas geothermal heat usually costs less than $0.50/ton. Temperature and location, however, impose restraints upon the use of geothermal steam. Valfells shows advantages, for a chemical process, of sequential flashing of the geothermal fluid from a wet field, whereby the condensate from each stage of flashing is mixed with the residual hot water from that stage, and the mixture flashed again at a lower pressure. He describes how the system must be optimized together with the heat exchange and recovery system of the plant. If the condensate from the last flashing stage can be sold for space heating, agricultural, or other useful purpose, the net costs would of course be lowered.

Farming, Refrigeration, and Balneology

Geothermal heat can of course be used for a variety of agricultural and horticultural purposes, for fish breeding, and for animal husbandry—all of which may loosely be termed "farming." Refrigeration is also closely related to farming as a means of preserving foodstuffs, and this too is a process that can be effected by means of geothermal energy. Much of the application of geothermal energy to farming is no more than a form of space heating, for example, greenhouse and soil warming. The word "balneology" too may be extended to cover its medical counterpart of "crenotherapy."

Behl, Jegadeesan, and Reddy (p. 2083) describe how the use of geothermal heating under glass has produced very promising results even in the inhospitable climate of Ladakh. The authors also state that a refrigeration plant is being planned to exploit the Manikaran geothermal field in the Parbati Valley, Himachal Pradesh, in the Himalayas. This district abounds in orchards and potato farms, and it is intended to install a 100-ton cold storage plant, using the ammonia-water absorption process, to preserve the local produce. The residual waters will be used for space heating and to warm swimming pools, as the area is frequented by tourists and by pilgrims. A small hydroelectric plant is to be included in the project so that the whole complex may be self supporting. A small pilot 10- to 15-ton refrigeration plant will form the first step in this project.

Einarsson (p. 2117) briefly mentions agricultural and balneological applications of geothermal energy, and states that there are now 140 000 m^2 in Iceland under glass, geothermally heated. He also mentions space cooling, or air conditioning, and mentions that he has proposed the establishment of a district cooling system for Managua, Nicaragua, to be adopted while the city is being rebuilt after its destruction in the devastating earthquake of 1972.

Chiostri (p. 2091) devotes his paper to the medico-balneological applications of geothermal energy. The oldest geothermal "industry" in history is the use of natural hot or warm waters, for pleasure or for alleged medical reasons. The ancients of Greece and Rome made great use of warm and hot springs—and even of cold springs if endowed with certain mineral contents. Such waters were alleged to possess healing and prophylactic properties when applied externally, as in bathing, and sometimes when taken internally or used for douches. The Roman bath became an institution—not merely as a health center, but also as a kind of social club; and in the eighteenth and nineteenth centuries the idea was more or less revived at the many "spas" and "watering places" that sprang up all over Europe as gathering points both for invalids and for the world of fashion. In Japan, Mexico, and in Maori, New Zealand, thermal waters were also used for health and hygiene. The "hamams" of Turkey are much frequented to this day by sufferers from various ailments and by women hoping for fertility, and "Turkish baths" are to be found in countless cities all over the world. While some people remain sceptical of the therapeutic value of the waters, modern medical science treats the subject seriously and has coined the word "crenotherapy" as the technique of curing and alleviating diseases by means of thermal waters. For convenience, waters have been classified by the medical profession as follows: (1) cold, less than 20°C; (2) hypothermal, 20 to 30°C; (3) homeothermal, 30 to 40°C; and (4) hyperthermal, more than 40°C.

Natural waters vary in their gaseous and soluble solid contents, also in their degree of radioactivity. They are used for drinking, bathing, underwater massage, inhalation, douches, mouthwashes, saunas, and are alleged to cure, alleviate, or inhibit many complaints such as rheumatism, arthritis, skin infections, internal disorders, and diseases of the respiratory tracts. Since a large percentage of potentially useful human activity is frustrated by disease, and much suffering is caused thereby, these alleged properties could—if their efficacy is firmly established—be of immense value to mankind.

Chiostri broadly discusses the whole subject of crenotherapy and clearly believes that it is of very real value. He mentions that in Italy alone 15 million people were treated at more than 200 thermal clinics in 1971, and that in the USSR more than 10 million people are treated annually with thermal waters. Several other countries have also built up impressive "spa" industries. Chiostri points out that where very hot fluids occur, heat could first be extracted for some useful industrial or other purpose and the temperature thus lowered to tolerable body temperature for medical application thereafter. Apart from the health aspects of the matter, there is no doubt that thermal "spas" are responsible for having built up tourism on a large scale in many parts of the world. An international catalogue of all medicinal waters throughout the whole world is proposed.

Gutman (Section X, p. 2217), when addressing the symposium participants, stressed the value of geothermal energy in the food industry and described a hydroponic installation in northeastern California situated 4100 ft above sea level, where winter temperatures can fall to −27°F. The installation uses a natural artesian geothermal well yielding hot water at just below the atmospheric boiling point. An area measuring 3320 ft^2 is under "glass." Domed sheds are placed parallel to one another at 13-ft spacing so that they do not shade one another from the sunlight. Humidifiers are needed in the summer. Bradbury asked, during the discussion, whether the pliable bubble plastic technique had been considered as a means of constructing the sheds, and whether increased CO_2 content of the atmosphere had been tried in order to stimulate growth. To the first question Gutman said that high winds would preclude this method of construction, and that stiff corrugated plastic had been found satisfactory. To the second question he said that the idea was under consideration but had not yet been tried. Gutman also mentioned a proposal for developing a birth-to-death controlled-environment cattle-raising project.

Unfortunately no references were made at San Francisco to other nonpower applications of geothermal energy, although many such are to be found throughout the world.