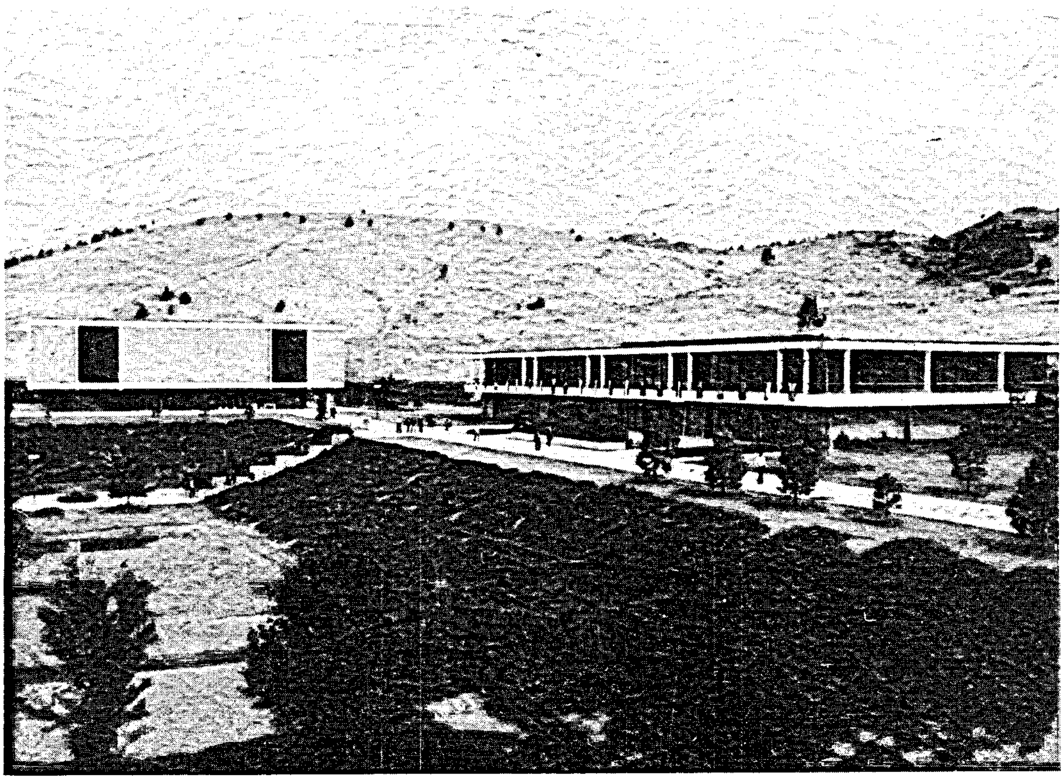
CONF-7410157--

MULTIPURPOSE USE OF GEOTHERMAL ENERGY

Proceedings of the International Conference on Geothermal Energy for Industrial, Agricultural, and Commercial-Residential Uses



MASTER

October 7-9, 1974

Oregon Institute of Technology

A geothermally heated campus

Klamath Falls, Oregon

DISCLAIMER

MULTIPURPOSE USE OF GEOTHERMAL ENERGY

Proceedings of the International Conference on Geothermal Energy for Industrial, Agricultural and Commercial-Residential Uses

Edited by Paul J. Lienau and John W. Lund

Sponsored by:
Oregon Institute of Technology
Oregon Department of Economic Development
Oregon Department of Geology and Mineral Industries
Klamath County Chamber of Commerce
City of Klamath Falls

Presented with a grant from the
Pacific Northwest Regional Commission

October 7-9, 1974
Oregon Institute of Technology
Klamath Falls, Oregon

Published by:
Geo-Heat Utilization Center
Oregon Institute of Technology

CONTENTS

GENERAL

FOREWORD

I am glad to have the opportunity to address the International Conference on Geothermal Energy. It seems to me that it is particularly appropriate to hold this vital conference here at Oregon Institute of Technology which gets much of its heat from geothermal energy. Klamath Falls is, of course, an important geothermal resource area, and the state of Oregon has great interest in geothermal energy since there are over 84,000 acres of known geothermal resource areas within its borders.

Present energy shortages also make this an especially appropriate time for a conference on geothermal energy. The embargo that the Mid East countries placed on oil exports last year and their subsequent attempts to restrict oil production and control oil prices have dramatized our energy problems. The nation's energy needs are surging ahead of the readily available supplies, and the prices of all forms of energy are rising rapidly. Since higher energy costs affect business costs, the higher energy prices are being passed on to consumers and are widely acknowledged to be one of the prime factors in the present two-digit inflation. This has slowed down our economic growth and job opportunities and the unfavorable results are now being felt on a wide scale of industrial, commercial, agricultural and residential activities.

It seems to me that we should proceed on all fronts to increase our sources of energy. This includes expanding the domestic output of the present big sources of energy--oil, gas and coal. However, we must also develop new sources of energy, including nuclear and solar energy and the subject of this conference, geothermal energy.

The amount of energy secured from geothermal sources today is relatively small, but the potential of these sources is huge and of particular importance here in the West. At present, worldwide generation of electricity from all geothermal sources amounts to about 1,000 megawatts, or about one-quarter of one percent of the U. S. electric generating capacity. However, according to estimates, which at this stage are understandably qualified, geothermal electric power in the United States alone could rise to a range of from 4,000 megawatts to 132,000 megawatts by 1985 and to a range of from 40,000 megawatts to 400,000 megawatts by the year 2000.

The major attention so far has been on geothermal dry steam, but I believe that there should be an exhaustive examination of all forms of this resource. This should include power development of wet steam and hot water, but also focus on direct applications of geothermal energy--which is what this conference will do.

While the development of geothermal energy for power usually requires fairly large initial expenditures for exploration and other costs, the available evidence indicates that it is competitive from a cost viewpoint with other energy sources. The total cost of electric power produced from geothermal hot water is not appreciably different from the cost of electricity produced from oil, fuels, hydro-electricity, or nuclear power. Actually, the cost of electricity produced by the Geysers in California, using dry steam power which unfortunately is rare, is substantially cheaper than the cost of production with most other sources of energy.

With all this enormous potential for the utilization of energy, the question arises as to why we have not already developed our geothermal energy to a greater extent. The answer in part lies in the difficult technical problems that still remain to be solved in bringing geothermal energy into actual use and in the difficulties of enlisting interest on the part of private capital and private enterprise toward this objective. Also, until fairly recently, there has not been the sense of urgency in government policies that is required to develop our geothermal resources.

The technology for converting dry steam deposits as exemplified by the Geyser is fairly well advanced--but unfortunately, as I have already indicated, dry steam fields are rare. Much is known about wet steams and hot water sources of geothermal power which are many times more plentiful than dry steam sources, but here the technology is not fully developed.

Our task is to find solutions to these technological problems--environmentally acceptable methods for the commercial production of electricity and other energy uses. In the long run, this means getting private industry and private capital interested in doing the job. In the short run--right now--it is up to the federal government to lead the way in the development of geothermal power, cooperating with private industry and providing the necessary incentives to get them off the mark at a running start.

Congress made a notable advance in adopting the Geothermal Steam Act of 1970 which authorizes the Secretary of the Interior to issue leases for the development and utilization of geothermal steam and related resources. Since a large part of the known geothermal resource areas exists on government land, this action was essential to get private industry involved in geothermal development.

A particular concern of mine has been to see that public utility companies, which supply about 20 percent of our energy needs, have an active role in the evolution of this new energy source. Because highly competitive bidding on known geothermal resource areas has kept them in the background in leasing activity so far, I--and Congressman Mike McCormack--have sponsored an amendment to the original Act, which guarantees them a fair share of the leases of K.G.R.A.'s on federal lands. If this amendment is approved by our Congressional colleagues, those organizations directly engaged in the sale of electrical energy will have a two-month preferential period to make application for one-quarter of any known geothermal resource area offered, before the Secretary considers bids from any other source. It is my intention to see that the resources of these publicly owned lands are made available to the public as rapidly and reasonably as possible, and I believe that this amendment will be a valuable reinforcement of the public interest.

Finally, up to now, Federal budgetary aid for the development of geothermal energy has been altogether inadequate. Only $4 million was budgeted for Federal research and development on geothermal energy in fiscal 1973 and only $11 million in fiscal 1974. Although it is most essential to control overall government spending, I believe that we cannot afford to stint the development of geothermal energy in this way. I am glad, therefore, that budget authorizations for this purpose for fiscal year 1975 have risen to $45 million, and I am hopeful that adequate funds will be made available for this vital purpose in the future.

As a cosponsor of the original bill, I was also pleased to see the enactment last month of The Geothermal Energy Research, Development and Demonstration Act of 1974. This legislation represents a substantial advance towards realizing the potential of geothermal energy. It provides for effective coordination of the many different government agencies which work on geothermal energy, and coordinates national geothermal energy research, development and demonstration programs. The Act seeks improved techniques to locate, evaluate, extract, and utilize geothermal resources and will develop policy alternatives for commercial utilization of geothermal resources. This is most important since once the advanced technology is achieved, private capital and private industry can be expected to flow into the geothermal energy development at an ever increasing rate. Moreover, the new legislation helps to attract needed private capital for geothermal resource development by adopting a Federal loan guarantee program covering up to 75 percent of the aggregate cost of geothermal projects.

In view of the importance of geothermal power, we should continue to explore additional ways to accelerate the movement of private enterprise and private capital into this promising field. There are possible tax approaches which might be considered as incentives. For example, development could be mitigated by lengthening the carry-back and carry-forward periods in such areas.

Another possible approach to generate needed capital might be to allow stockholders in corporations engaged primarily in geothermal energy development to defer payment of income tax on dividends received from and reinvested in such corporations.

Finally, additional study should be given to the desirability of stimulating geothermal energy development through percentage depletion. I believe that Congress should consider making clear that geothermal energy of all types--including wet steam, dry rock, geothermal pressured fields as well as dry steams--is eligible for a percentage depletion rate.

It is obvious that geothermal energy holds great promise as a source of power for the essential needs of the nation. It is up to all of us to help turn this promise into reality.

Al Ullman
U. S. Representative for
Oregon, Second District

Klamath Falls
October 7, 1974

INTRODUCTION

These Proceedings originated from the papers presented at the *International Conference on Geothermal Energy for Industrial, Agricultural and Commercial-Residential Uses* held at Oregon Institute of Technology October 7-9, 1974, in Klamath Falls, Oregon. The conference was organized to review the non-electric, multipurpose uses of geothermal energy in Hungary, Iceland, New Zealand, the United States and the USSR. The international viewpoint was presented to provide an interchange of information from countries where non-electric use of geothermal energy has reached practical importance.

The program chairman, Mr. R. G. Bowen, called upon experts in the field to present papers based on experience gained from actual working installations rather than on theoretical models. The non-electric applications of geothermal energy, and especially that of warm water, have numerous potentials for immediate development and use. Instituting these methods will do much to help solve our short-range and long-range energy and food production needs.

Governor Tom McCall of Oregon stated at the Conference:

"Like most states with known geothermal resources, we have done little to take advantage of this source of energy. By having the international conference here, perhaps the push for geothermal development will grow much more powerful...

"Oregon economic geologist, Richard Bowen, says geothermal heat can be used to dry lumber, cure concrete, cook potatoes, heat homes and business buildings, freeze-dry foods, provide refrigeration, and produce electricity. Where hot water excess to the principal need is discovered, it can add to the municipal water supply, and irrigate farms.

"The uses of the resource--he says rather grandly--are limited only by our imagination...

"Turning specifically to geothermal, we find impressive values. Energy from that source can come at low dollar cost; it is a relatively inexhaustible resource; it can be developed at small cost to the environment; and--at least in the West--most of the known geothermal resource areas are in lightly populated districts. I personally regard the latter as an advantage because of Oregon's need to disperse industry and population..."

The Conference was held at Oregon Institute of Technology as the campus is heated by geothermal hot water. Almost half a million square feet of floor space is heated with 192°F water from three wells adjacent to campus. The annual savings in fuel is over $100,000. Dr. W. D. Purvine's paper details the use on the Oregon Tech campus.

Field trips were taken through the City of Klamath Falls where over 400 geothermal hot water wells are used for space heating and other industrial applications. This resource has been in use for over half a century and incorporates many unique developments and applications.

Dr. I. M. Dvorov of the Academy of Sciences of the USSR, Moscow, was scheduled to speak at the Conference; however, due to complications, he was unable to attend. He did send a copy of his paper which is included in the proceedings. The multipurpose uses of geothermal energy are best expressed by him in the introduction to his paper:

> *"The northern town of Teplogorsk situated not far from the polar circle is considered the cleanest town in the world. Despite rigorous climate, the town does without coal, oil, gas, peat and wood. Perhaps you think that the town of Teplogorsk is heated by electric energy produced by atomic power stations. Nothing of the kind. The town is heated by deep heat of the Earth. Here great amounts of thermal water and steam-water jets outflow from the Earth.*
>
> *"The streets of the town are perfectly clean, the houses are light colored, and pavements and roadways are not covered by thick snow despite abundant snow-falls (up to 2-3 m) in winter, as pipelines pass under them.*
>
> *"A geothermal power station has been constructed in the suburbs of the town. Its turbines are put in motion by the energy supplied from the Earth's interior. Such a station does not need the production and transportation of fuel. Neither does it need cumbersome equipment consuming the fuel, boiler shops, access roads, or storage facilities for fuel, etc. A geothermal power station provides the town with the cheapest electric energy.*
>
> *"Pipelines diverge into all directions from the geothermal power station. Waste, but yet warm water, its temperature being 100-110°C, runs through the pipelines towards the town. The water heats living houses and commercial enterprises, satisfies the requirements of the population for hot water, warms street pavements and roadways, heats green-houses and swimming pools.*
>
> *"When entering the town, one can see a huge white cloud in the distance: here is the central town swimming pool in which citizens swim all the year round. Besides this swimming pool there are many others in the town.*
>
> *"Aside from the central swimming pool, massive glass windowed buildings are seen. This is the Central Park of Culture and Rest with evergreen trees, bushes and flowers of all kinds collected from all parts of the Globe.*

"Long and wide glass covered corridors stretch in all directions from the main valley of the park. These are green-houses where two to three harvests of cucumbers, tomatoes, onions and other vegetables are gathered every year. Bananas, grapes and other subtropical cultures grow in Teplogorsk too. So, the inhabitants are provided with fresh vegetables and fruits all the year round.

"We haven't said a word about the quality of water. As it has sulphate-hydrocarbonate sodium composition, it is successfully used by inhabitants of the town for treatment of the alimentary canal, liver and other organs, as well as disturbance of metabolism. It is astonishing, but there are no hydropathic establishments in the town. If necessary, patients take a bath of a certain temperature at their homes. As the water is slightly mineralized and alkaline, it is used at home for various domestic needs.

"A reader will certainly say that such a town does not exist at all, that it is merely an imagination of the author. Indeed, we do not have such towns in our country yet, but they will appear on the Kamchatka and Kuril Island, in the regions of permafrost on the Chukotsk, in West Siberia and many other places of the USSR.

"Such towns and settlements may appear in the nearest future in Alaska and other states of North America."

As a result of the Conference and the increased interest in the non-electric applications of geothermal energy, the Geo-Heat Utilization Center was established on the Oregon Institute of Technology campus. Funding for the establishment of the Center was approved by the Pacific Northwest Regional Commission of Vancouver, Washington. The Center will disseminate information to potential users of geo-heat, as well as write applied research proposals using geothermal energy. A quarterly newsletter on the progress and development of geothermal energy will be published.

Those involved in the Conference felt it was a success, with over 200 registrants and many local drop ins. Attendees represented over seven foreign countries and 20 states. We express our appreciation to Ardelle Godfrey for typing the manuscript.

Paul J. Lienau
John W. Lund
Editors

Klamath Falls, Oregon
August, 1975

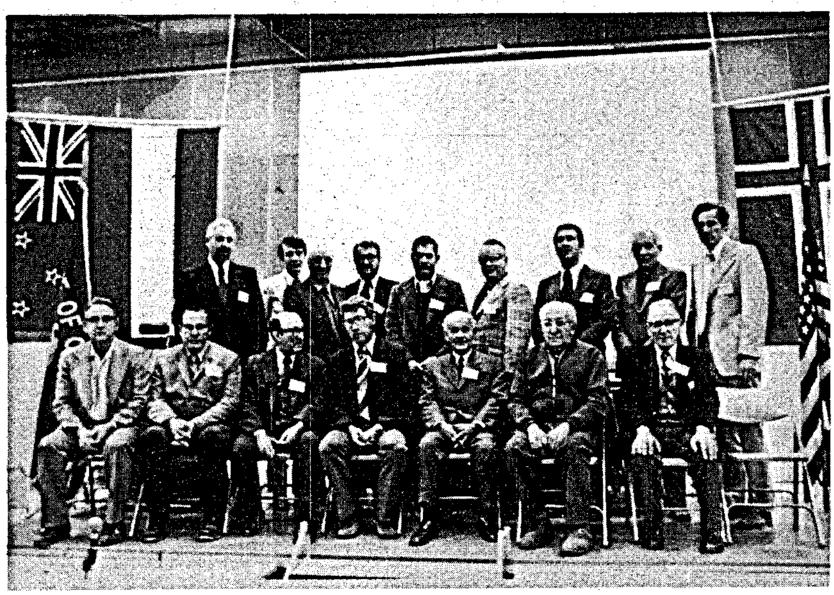


Figure 1. Conference Speakers.

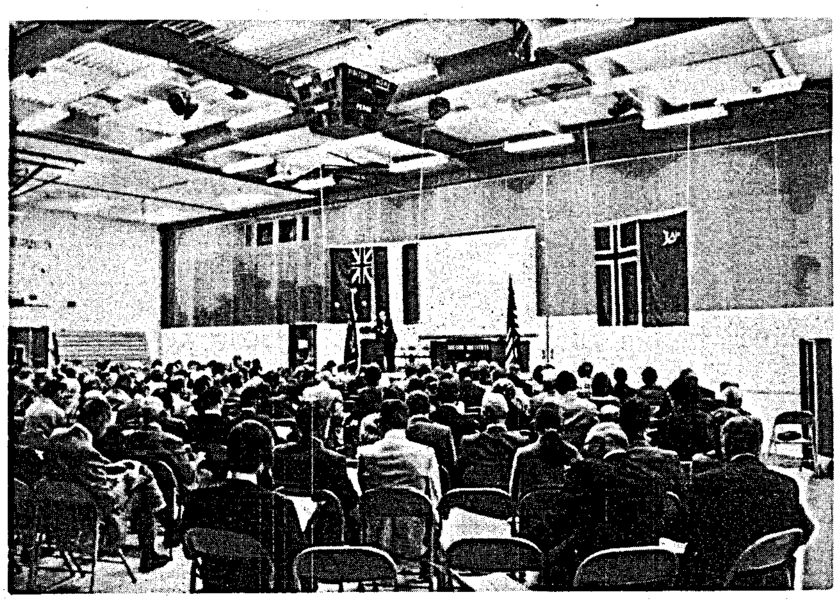


Figure 2. Conference Hall.

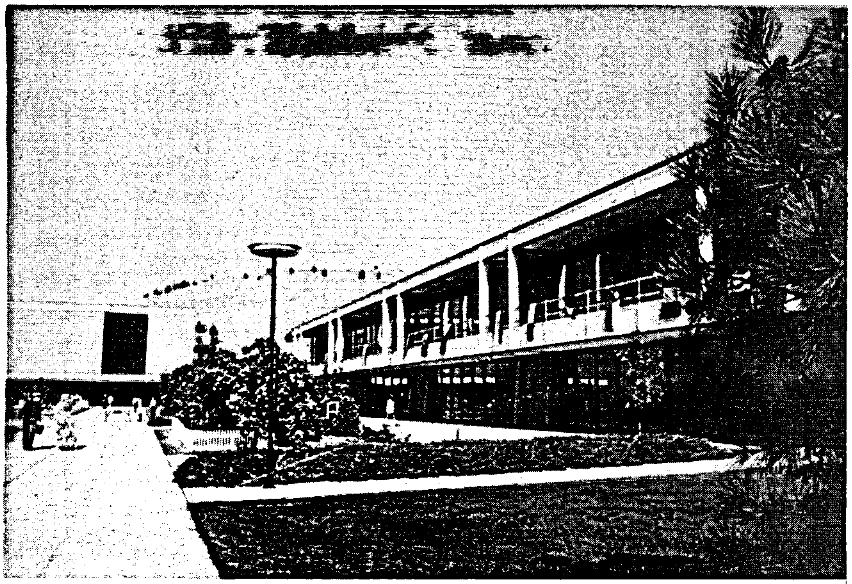


Figure 3. Oregon Institute of Technology.

Figure 4. Exhibit Area.

ORGANIZING COMMITTEES

Oregon Institute of Technology

LIENAU, PAUL J., Coordinator
Associate Professor, Physics

CHITWOOD, PAUL
Professor, Computer Systems Tech.

CONNORS, THOMAS
Associate Professor, Medical Tech.

KORZAN, DAVID
Assistant Professor, Biological Sciences

WOGAN, S. FRANZ
Associate Professor, Industrial Tech.

LUND, JOHN W.
Assistant Coordinator
Professor, Civil Eng. Tech.

CLARK, BILL
Director of Information

HEFTY, DONALD
Assistant Professor
Electronics Engineering Tech.

KURTZ, EARL
Professor, Physics

Oregon Department of Economic Development
317 S. W. Alder St.
Portland, Oregon 97204

WILLIAMS, WALKER, Coordinator
Research Director

BUDROW, NANCY
Business Manager

DENNY, JOHN
Publicity

HENDRICKS, KAREN
Registration

Oregon Department of Geology and Mineral Industries
1069 State Office Building
Portland, Oregon 97201

BOWEN, R. G., Program Chairman
Economic Geologist

Klamath County Chamber of Commerce

BRENNE, FRED
Manager

STEVENSON, DANI
Registration and Reservations

City of Klamath Falls

VEATCH, ROBERT, Mayor
Klamath Falls, Oregon

SPEAKERS AND PANELISTS

ANDERSON, David, N., Panelist
Public Policy, State of California
Division of Oil and Gas
1416 9th Street
Sacramento, California 95814

BARNEA, JOSEPH, Speaker
Economics of Multipurpose Use of Geothermal Energy
71-11 Juno Street
Forest Hills, New York

BOLDIZAR, T., Speaker
Geothermal Energy Use in Hungary
Technical University
H-3515 Miskolc - Egytemvaros
Hungary

BREWER, WILLIAM, Panelist
Public Policy Director
Washington Energy Policy Council
4220 East Martenivas Street
Olympia, Washington 98504

BURROWS, BILL, Speaker
Utilization in Rotorua
33 Nikau Street
Rotorua, New Zealand

DVOROV, I. M., Paper
Study and Use of the Earth's Deep Heat in the USSR
Geothermal Institute
USSR Academy of Sciences
ZH. 17 Ayzhevsky Querelok 7
Moscow, USSR

EARLY, BILL, Panelist
Forest Products Industry
1929 Park Street
Klamath Falls, Oregon 97601

HALL, KIRK, Speaker
Public Policy to Encourage Development of Renewable Energy Resources
Research Assistant for Rep. Mike McCormak

HOWARD, JOHN, Speaker
Status Report on the Com. on the Challenges of Modern Society Geothermal Pilot Study Non-Electrical Project
University of California
Lawrence Livermore Laboratory
Livermore, California 94550

LINDAL, BALDUR, Speaker
Geothermal Energy for Process Use
Verkfraedistofa Baldurs Lindal
Hofoabakka 9
Reykjavik, Iceland

LINTON, MURRAY, Speaker
Agricultural Uses of Geothermal Energy in New Zealand
254 Old Taupo Road
Rotorua, New Xealand

LUND, JOHN W., Speaker
CULVER, GENE, Speaker
SVANEVIK, LARS, Speaker
Utilization of Thermal Energy in Klamath Falls
Oregon Institute of Technology
Klamath Falls, Oregon 97601

McCALL, TOM, Speaker
Remarks by Governor Tom McCall
Salem, Oregon

OGLE, WILLIAM, Speaker
Alaskan Non-Electric Geothermal Energy Needs and Possibilities
3801 B West 44th Avenue
Anchorage, Alaska 99503

PARKER, ANDY, Panelist
Agriculture, Oregon Desert Farms
Lakeview, Oregon

PITTS, DON, Speaker
Director of Geothermal
Room 1229
1800 G Street NW
Washington, DC 20545

JOHNSON, SAM, Panelist
Forest Products Industry
Oregon State Representative
Salem, Oregon

PURVINE, W. D., Speaker
Utilization of Thermal Energy at Oregon Institute of Technology
President, Oregon Institute of Technology
Klamath Falls, Oregon 97601

SCHATZ, JOEL, Speaker
Geothermal as Part of Oregon's Energy Mix
Director of Office of Energy Research and Planning
Salem, Oregon

STOREY, ELDON, Speaker
STOREY, DAVID, Speaker
3847 Hope Street
EE Storey Well Drilling
Klamath Falls, Oregon 97601

ULLMAN, AL, Speaker
Public Interest in Private Geothermal Development
US Representative for Oregon, 2nd Dist.
Chairman, Ways and Means Committee
US House of Representatives
2410 Rayburn House Office Building
Washington, D.C. 20515

WEHLAGE, ED, Speaker
Geothermal Energy for Heating and Cooling in Food Processing
10707 E. Orange Drive
Whittier, California 90606

WILSON, R. D., Speaker
Use of Geothermal Energy at Tasman Pulp and Paper Company
Tasman Pulp and Paper Company, LTD.
Kawerau, Bay of Plenty
New Zealand

ZOEGA, JOHANNES, Speaker
District Heating in Reykjavik, Iceland
Hitaveita Reykjavikur
Reykjavik Municipal District Heating Service
Reykjavik, Iceland

GEOTHERMAL ENERGY USE IN HUNGARY

By

Dr. T. Boldizsar[1]

ABSTRACT

The Hungarian Plains is a subsistense basin which contains immense quantities of geothermally heated water, oil and natural gas. About half of the territory of Hungary has the potential to produce geothermal energy or geothermally heated water. Deep wells are drilled and lined with perforated casings. The hot water goes from the wellhead to concrete tanks where $CaCO_3$ deposits as flakes. The hot waters are alkali with about 1800 to 2500 ppm soluable ions. Periodic descaling is performed on the upper casing. Combustible gases are separated and used. The 131 wells in Hungary have about a 770 MW peak potential. District heating and greenhouses utilize the resource at about one-third the cost of using coal. Substantial gas and oil deposits have been revealed while drilling for geothermal resources. Detailed procedures for drilling, casing and descaling wells and diagrams of district heating systems are included in the paper.

INTRODUCTION

Geothermal energy in the form of low enthalpy thermal water has been in Hungary since 1962. The present author proposed to the government of Hungary the large scale exploitation of this new form of energy in 1958, after investigating the geothermal characteristics of the Hungarian Basin. The UNO-Congress on New Sources of Energy in Rome in 1961 gave an impetus to the development of the geothermal energy as the most important one among the "new sources" including solar and wind energy. Curiously these "new sources of energy" are the most ancient forms of energy used by mankind, but geothermal energy, mainly in the form of hot water springs had been used only for balneological establishments before the development of the Larderello steam field.

From the practical point of view, geothermal energy is a very slight fraction of the internal heat of the earth, which can be used for practical purposes. The amount of the internal heat of the earth is at least 10^{33} cal and is more than ten times as much as the added calorific value of all exploitable fossil energy on the earth, and the nuclear energy of fissionable materials to be obtained by mining. As a matter of fact, geothermal energy is essentially nuclear energy of the big natural nuclear reactor shell situated in the crust and mantle of the earth. The nuclear fuels are the K^{40}, $T^{24\ 2}$, and U^{238} atoms dispersed chiefly in acid crustal rocks.

The amount of geothermal heat of the earth is not only immense, but it is well isolated and only a small fraction is conducted over the

---

[1]Professor, Technical University, Miskale Egyetem, Varas, Hungary

surface into space. The heat accompanying volcanic activities is negligible compared to conductive heat. It may be, that radioactive heat production is even more than the heat loss and the earth is actually heating up itself.

The connection of hydraulic systems and hyperthermal rocks under suitable circumstances may give the possibility of commercial geothermal fluid production either in form of superheated and saturated steam or by hot water. Hyperthermal territories exhibit higher than normal heat loss either by local concentration of steam and hot water vents or by elevated regional terrestrial heat flow. In the first case convection takes foremost part, in the second one conduction is the main agency of the transport of surplus heat.

The presence of the following main simultaneous factors are prerequisites of geothermal areas:

1. Warm or hot rocks near to the surface owing to relatively recent volcanic or subvolcanic activity, hyperthermal areas.
2. Energy transporting agent, in most cases water, filling the fissures and pores of the heated rocks, hydraulic systems.

Thermal springs, geysers fumaroles, solfataras are the natural openings of the hydrothermal-hydraulic systems. In most cases, the amount of energy produced is moderate but these natural manifestations are very important in the discovery of commercial geothermal fields.

Large scale exploitation of geothermal fields is solved technically by drilling steam and hot water wells. Porosity, permeability and the amount of the water to be mobilized are the most important characteristics of the hydraulic systems.

At present two types of productive geothermal energy systems can be distinguished:

1. Volcanic or subvolcanic processes in connection with recent or Quaternary activities, producing superheated steam or hot water.
2. Subsidence basins or depressions with higher than normal heat flow filled up with porous, fractured sediments, containing hot water under high pressure.

The first type has been considered, up to now, more important owing to the higher concentration of energy.

Along the worldwide Alpine orogenic belt the main locations are: Larderello, Monte Amiata in Italy, Denizli-Aydin in Turkey, Indonesia, Philippines, New Guinea, New Britain, New Hebrieds, Fiji, Wairakei and Waiotapu in New Zealand, Taiwan, Japan, Paushetsk in Kamchatka, The Geysers in California, Cerro Prieto and Hidalgo in Mexico, San Salvador, Guatemala and northern Chile. The geothermal areas in Iceland are connected to the Mid-Atlantic ridge which is also a Tertiary feature of the oceanic orogenesis. Some areas in Africa are connected to the tectonic system of rift valleys. All these locations are well described in the international literature and the exploration for other geothermal locations of this system has not always been successful, since the evolution of a steam deposit depends on peculiar geothermal, hydraulical and thermodynamical conditions.

The second type of geothermal systems are more widespread and are also located along the Alpine orogenic system. Few of them are known and even less are exploited for practical ends, although 90 percent of the prospects for superheated steam produce actually hot water instead. The surplus heat, manifesting itself in higher than normal heat flow, takes its origin in subcrustal magmatic processes, which are in connection, or perhaps are the cause of the evolution of the continental crust and the growing of the continental masses.

These hyperthermal territories have been subsiding since the beginning of their formation and have been filled by sediments having been eroded from the emerging mountains in the surroundings. These hyperthermal regions in most cases are not connected to volcanic manifestations. The higher than normal terrestrial heat flow causes a rapid increase of temperature versus depth. In the Hungarian basin the gradient of temperature is between 50-70°C/km, which means that at 2000 meters depth, the temperature of water is 110-150°C and outflow temperatures may be a few degrees less than the boiling point of water under atmospheric conditions. The high permeability of the sandstones enables the production of great volume rates, consequently the amount of energy produced by a well is enough for practical aims.

The most important example, and at the same time the most intensively explored and exploitated subsidence territory, is the Hungarian basin which will be described later in detail. Another important location, where development is in an advanced stage, is the Piedmont region of the Caucasus, where at Krasnodar, Stavropol and Mahachkala, important hot water deposits are stored in the porous sediments. Temperature gradients are between 40-50°C/km and commercial production is said to have been started.

At the northern slope of the Pyrenees, in the Arzacq basin, the temperature gradient is about 60°C/km. From the Lacq-field, hot water production is possible but not practiced.

In the Paris basin, where the heat flow is normal, hot water production for district heating is considered as an economic alternative.

In Western Siberia an immense sedimentary basin, with moderate heat flow, can produce hot water for heating. The climate is very cold, but the population is sparse. In the future geothermal heating will surely play an important part since important oil and gas fields are being developed for transporting outside this territory.

In the Great Artesian Basin in Queensland at Springleigh, temperature gradients of about 50°C/km have been observed. At a depth of 1740 m, the virgin rock temperature is 110°C.

The Salton Sea geothermal area presents an interesting mixed type with both volcanic and subsidence effects. The structural trough in the vicinity of the Salton Sea is 120 kms wide. It is filled up by Neogene sediments. The fill is more than 6000 m thick at the center of the depression. Volcanic domes and recent mud volcanoes indicate that the thermal anomaly of this depression is in connection with Pleistocene volcanic activities. Hot brines of exceptional high concentration of dissolved material characterize this unique geothermal area.

A high heat flow value was measured in the Hungarian basin in 1954, Boldizsar, 1956, and further measurements have confirmed that the Hungarian basin which lies within the Carpathian arc and the Dinarics is a geothermal high with terrestrial heat flows between 2.0 and 3.4 $\mu cal/cm^2$ sec, Boldizsar, 1964. The average heat flow is about, 2.4 $\mu cal/cm^2$ sec and this high heat flow causes high temperature gradients everywhere in the sediments of the basin. The observed gradients are generally between 50 and 70°C/km.

Intensive exploration for oil deposits in the tertiary sediments of the Hungarian plain have revealed the topography of the subterranean surface of the Paleozoic-Mesozoic bedrocks and supplied reliable figures on virgin rock temperature. The Hungarian plain is in the center of the Carpathians. The Paleozoic-Mesozoic bedrock is elevated along a southwest-northeast fracture line forming the mid-Hungarian Mountains which rise to 1000 m above sea level. These elevated, mostly Mesozoic strata divide the Hungarian plain into two basins, a smaller one in the northwestern direction and a greater one to the southeast. The depressions are filled with tertiary porous sediments; about half of their thickness consists of lower Pliocene, Pannonian, strata. The maximum depth of the depressions are about 6000 m below the sea level; the average depth of the tertiary basins is about 3000 m. The porous and permeable sandstone strata contain immense quantities of water, oil and gas deposits of commercial value having been found in about 50 traps.

The volume of tertiary and younger rocks is about 160,000 km^3. The volume of porous rocks with porosity over 10% is about 20,000 km^3. More than 4,000 km^3 of hot water of 60 to 200°C is stored in the pores of the rocks that are deeper than 1000 m; most of it can be recovered by drilling wells with hot water capacities of 1 to 2 m^3/min. If the temperature is dropped to 40°C, this immense quantity of heat will amount to 2.3×10^{19} cal, which is about 50% of the calorific value of the known petroleum deposits in the entire world. Each well of 1000 to 2000 m deep can produce 1 to 2 m^3/min. of water at a temperature of 60 to 100°C for decades. About half of the territory of Hungary is potentially productive as shown in Figure 1.

It is of interest to note, that outside the Carpathian arc, in the Vienna-basin, in Czechoslovakia, Poland and Ukraine, the value of terrestrial heat flow is normal, less than half of the value within the Carpathian basin; consequently, the temperature gradient is also normal or less than normal with values between 35 to 10°C/km.

PRODUCTION METHODS

Standard procedure of opening up of the Upper-Pannonian reservoir is made by putting down a 1600-2400 meters deep borehole with a suitable rotary drilling rig. According to the local stratigraphy, the first 50 to 60 m is usually drilled with 19 1/2" bit and cased by 13 3/4" tube. After cementation the drilling continues with 12 1/4" bit down to about 800 m. After casing with 9 5/8" tube and cementation, 8 1/2" bit goes down to 2000 m. Drilling proceeds with bentonite based drilling mud with specific gravities between 1.1 to 1.4.

After finishing the 8 1/2" hole, a suitable electric logging sonde is lowered and resistivity, further SP (self potential) logs, are made and the location of porous and permeable layers are determined. If necessary, gamma-ray and neutron logs are also made. For determining the virgin rock temperature at the bottom, careful temperature measurement is made, but most reliable values are obtained later, at the deepest inflow of hot water.

The next step is to lower the 6 5/8" casing tube down to the bottom of the hole. After cementation jet perforation follows. Depth of the perforated sections are determined according to the interpretation of the loggings. Usually 12 or 24 perforations per meter are made. Perforation is started at the first suitable permeable layer nearest to the bottom. After perforating two or three layers a production test is made. If the production rate is less than 1200 to 1500 liters/min, higher layers are perforated and again a production test is made with all the perforated layers. Generally three to six permeable sections are perforated. The overall length of the perforated sections are between 30 and 100 meters along a casing length of 100 to 200 m according to the given circumstances, Figure 2.

The virgin rock temperature of the upper perforated layers are less than that of the deepest layer. Since the cooling of the water in the upper cold section is very sensitive of the volume rate, the increase of volume by perforating the cooler layer, up to a certain length, increases the outflow temperature.

The wells are equipped with a wellhead armature suitable for the production of 1 to 3 cu. meters per minute. The hot water, after flowing through a gas separator, is stored in a reinforced concrete tank, where CO_2 is separated and the Ca CO_3 deposits as flakes. In the heating system no scale deposit was observed. Corrosion is no problem, since the water is free of oxygen. Hot water production is controlled by four 6" gate valves. After shutting down completely, it takes a certain period of time until the water column in the hole cools down to the geothermal temperature of the layers. After a long shutting down period, the production cannot start by itself and an airlift is used to start production for which suitable connections to the 100 psi compressor are available.

Along the upper 30 to 80 meters, scale may deposit on the casing. Periodically, yearly once or twice, descaling is made by mechanical or acid treatments. The upper portion of the hole may be equippped with a plastic liner which can easily be exchanged.

The Upper-Pannonian hot waters are mainly alkali-hydrocarbonate waters of about 1800 to 2500 ppm soluble ions.

A typical chemical analysis at a well in Szentes is as follows:

Ca	6.5 ppm
Mg	2.2
Na, K	594.8
HCO_3	1575.0
Cl	23.4
SO_4	23.0
Others	2.0
	2226.9 ppm

The gas-water ratio is generally between 0.2 to 1.2 Nm^3/Nm^3 at atmospheric pressure; mainly CH_4 and CO_2 can be found. In most cases the gas is combustible and after separation will be used in the geothermal project.

ECONOMIC CONSIDERATIONS

There are at present 131 geothermal wells in Hungary, Figure 3. Total output of all of them is 11,760 cu.m/hour with an energy capacity of 380 x 10^6 kcal/hour. The average production of a well is about 80 to 90 cu.m/hour, the average energy about 4.4 x 10^6 to 5.0 x 10^6 kcal/hour. The energy of the wells is computed from the difference of outflow temperature and the off-flow temperature, the latter is considered as 20°C. Total energy production of the 131 wells amounts to about 770 MW which is considered as the peak load. If in addition to the heating of flats, industrial and agricultural uses, warm water is also used for washing and bathrooms, only 30 to 35 per cent of the continuous heat output can be utilized for the latter since heating is unnecessary in the summer from May to October. If in the summer months warm water supply is needed for agriculture uses in drying and cooling processes, municipal, industrial, and agricultural uses can be coordinated and utilization may be higher than 35 per cent.

If one-third of the full capacity is taken into account, the optimal useful production capacity of geothermal energy, in the form of hot water, at present, is about 260 MW. The geothermal energy production is expected to double within six to eight years.

An average geothermal well produces 80 to 90 cu.m/hour hot water of about 85 to 90°C temperature. Such a well can supply district heating for 1200 flats and complementary municipal and public buildings, swimming pools, schools and kindergartens including warm water supply for washing and bathrooms. The length of the severe peak heating load period is normally not more than two weeks. If the peak load is carried by complementary oil or gas overheating, the number of flats supplied by one well can be increased to 1800.

The geothermal district heating plant in Szeged, Southern Hungary, comprising 1200 flats, each consisting of two living rooms, a dining room, kitchen and a bathroom, was economically a very successful project. Actual heating cost, including the amortisation, was 1500 Forints/10^6 kcal, compared to 550 Forints/10^6 kcal with coal fired district heating plants of the same heat output, approximately 5 resp. 18 dollars/10^6 kcal. An additional advantage is, that the geothermal hot water supply takes off the load from the water works, since cold water is used in small amounts only for drinking and cooking which amounts to no more than 10 per cent of the domestic water consumption.

In agriculture the use of geothermal energy is very economical. During the six month heating season, night air temperatures are frequently under the freezing point and from the end of November to the beginning of March, the soil is frozen. During cold spells in January and February air temperatures may sink frequently below -20°C. The geothermal hot water is used for heating greenhouses, milking rooms, cattle stalls and pigsties, chicken houses, further all auxiliary rooms and premises, machine shops, garages, bureaus, service houses etc. In summer drying and cooling pressures are important heat consumers. An average well can supply hot water to all installations of a modern 7000 acre farm. The price of the heat unit is 7 dollars/10^6 kcal with geothermal system, 17 dollars/10^6 kcal with coal or oil firing.

At the end of 1973, the geothermal greenhouse area was about 1,200,000 sq.m. Geothermal heating for animal husbandry projects is also increasing and from 1965 up to now 60 wells of about 6 to 8 x 10^6 kcal/hours individual capacity were made for the cooperative agricultural units. The number of wells in agriculture is increasing yearly by 8 to 10.

Geothermal heating of hospitals, municipal buildings, factory premises and swimming pools in towns is also being made, but priority is given to agriculture because geothermal energy in agriculture increases the volume and variety of production. Geothermal heating of small towns and agricultural villages are being considered. It should be mentioned, that in 1966, a geothermal borehole in Tape near Szeged discovered the biggest oil and gas field of Hungary. The well after perforation produced through the 6 5/8" casing 5400 barrels of oil a day. After shutting down, the oil and gas field has been developed by drilling up to now 300 production wells. This strike increased the Hungarian oil production capacity by a yearly amount of seven million barrels and doubled the natural gas reserves of the country.

Cooling by geothermal hot water is possible by various processes and is very economical since the summer load is small or nil, and the hot water can be used to supply cooling plants. In Hungary geothermal cooling is used in agriculture for food storage.

Drying of grain, haystock, tobacco, paprika and other products found successful application. Geothermal hot water supplies heat to exchangers and the warm air of 50 to 60°C temperature is blown into the drying chamber by an electrically driven ventilator.

EXAMPLES OF GEOTHERMAL HEATING

The length of the heating season is 4,460 hours per year. Figure 4 illustrates the duration of the average daily outdoor temperature. The indoor temperature is +20°C. The ordinates are proportional to the heating load. The full capacity of the well can be used if minimum heating load equals to the heat capacity of the well. In this case an additional oil or gas fired boiler is necessary. At the beginning of hot water production, the district is small, and at first the peak load is carried by the well. Later, with the development of the district, the number of flats increases and either a new well will be drilled or a boiler installed. In most cases, the peak boiler plant carries the peak load during 700 to 800 hours.

The daily variation of the outdoor temperature is equalized by hot water storage in concrete tanks. In any special case the proper solution is selected after economic considerations among various alternatives.

Figure 5 shows the first district heating installation in Hungary. In 1962, the well produced 1500 liters/min. of hot water at a temperature of 90°C. This well nowadays supplies a district heating unit of 1800 flats, several municipal buildings, schools, shops, and kindergartens. The off-flow gives warm water to the district and to the municipal swimming pool. The peak load is carried by a gas fired boiler from the nearby gas field discovered by our geothermal investigation. The figure shows the district heating before peak boiler installation six years ago. The four room flat unit needs 5,000 kcal/hours peak heat supply, the yearly total heat required is seven million kcal.

In figure 6 the use of a gaseous geothermal well is shown supplying a cooperative farm, swimming pool and village houses with methane separated from the hot water and with hot water. Methane is used in kitchens for cooking, hot water is used for heating and the 40 to 50°C hot water leaving the plant is used for warm water supply.

In Budapest a thermal well supplies 5,000 flats in the central part of the town with warm water. 600 to 700 m^3 thermal water of 69°C temperature is needed daily for interruptible warm water supply of balneological quality.

Scaling takes place in the upper 30 to 80 m portion of the well and in the main line to the concrete tank, where CO_2 is separated and $CaCO_3$ deposits. Scaling can be prevented by using wellhead pressures of more than 2.5 atmospheres. This is being done by throttling. This procedure is simple and in the well no scaling takes place. Throttling diminishes hot water flow and this method can only be used with wells of high shut-off pressures, more than 7 to 8 kg/cm^2. The average starting wellhead pressure is generally between 4 to 6 kg/cm^2 and by throttling the quantity of hot water is not enough in most cases; moreover, throttling diminishes outflow temperatures.

Scaling is removed generally by drilling out of $CaCO_3$ with roller-bits of the rotary drilling system, or by acid treatment. It is important, that by using acid treatment a thin protecting stratum of 3 to 4 mm thickness should remain to prevent acid corrosion. Both drilling and acid treatment is used at regular intervals depending on the amount of production. There are wells where scaling must be removed weekly, other wells require removal once or twice a month, some need only a yearly treatment; however, more than 50 per cent of our wells requires no treatment at all. Generally wells with the highest temperatures and higher dissolved solids, present scaling problems. Hot water originated from Mesozoic limestone and dolomite bottom rock causes more scaling difficulties than Pliocene porous water.

<u>Text of Figures</u>

Figure 1. Geothermal energy potential of Hungary

Figure 2. Perforated sections and hot water production from a typical 1935 m deep well.

Figure 3. Location of geothermal wells in Hungary

Figure 4. Temperature--duration curve of the heating season in southern Hungary

Figure 5. District heating scheme in Szeged

Figure 6. Heating and gas supply of an agricultural village from a gaseous geothermal well.

REFERENCES

1. Boldizsar, T., "Measurement of Terrestrial Heat Flow in the Coal Mining District of Komlo." ACTA Technical Academy of Science Hungary, pp. 219-228, 1956.

2. Boldizsar, T., "Heat Flow in the Hungarian Basin." Nature, London, pp. 1278-1280, 1964.

3. Boldizsar, T., "Geothermal Data from the Vienna Basin." Journal of Geophysical Research, Vol. 73, pp. 613-618, 1968.

4. Boldizsar, T., "Terrestrial Heat Flow and Alpine Orogenesis." Bulletin Volcanologique XXXIII, pp. 293-298, 1969a.

5. Boldizsar, T., "Geothermal Energy Production from Porous Sediments in Hungary." Geothermics Special Issue Part I, pp. 99-109, Pisa, 1970.

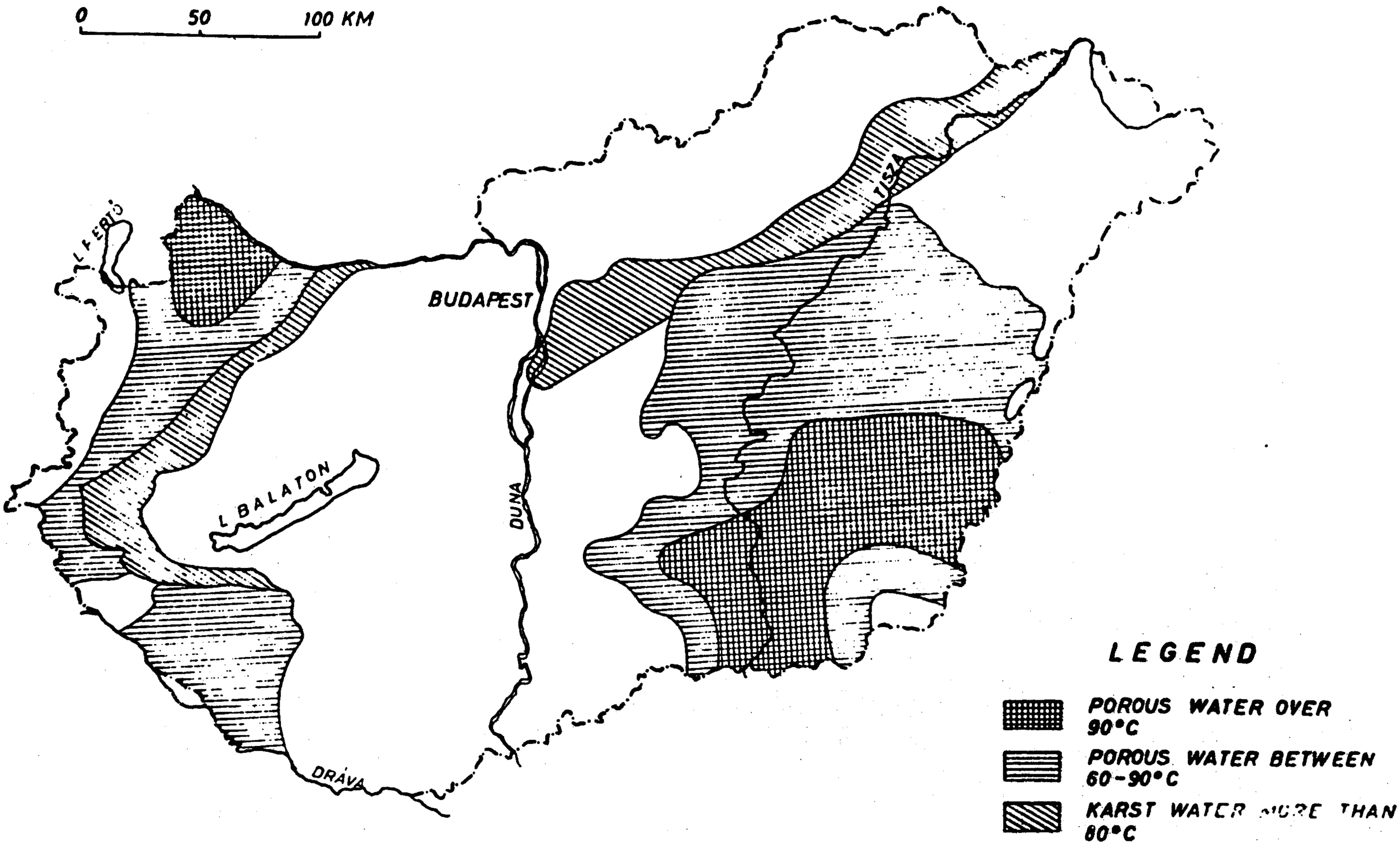

0
50
100 KM
L. FERTŐ
BUDAPEST
L. BALATON
DUNA
TISZA
DRÁVA
LEGEND
POROUS WATER OVER 90°C
POROUS WATER BETWEEN 60-90°C
KARST WATER
THAN
80°C

Fig. 1

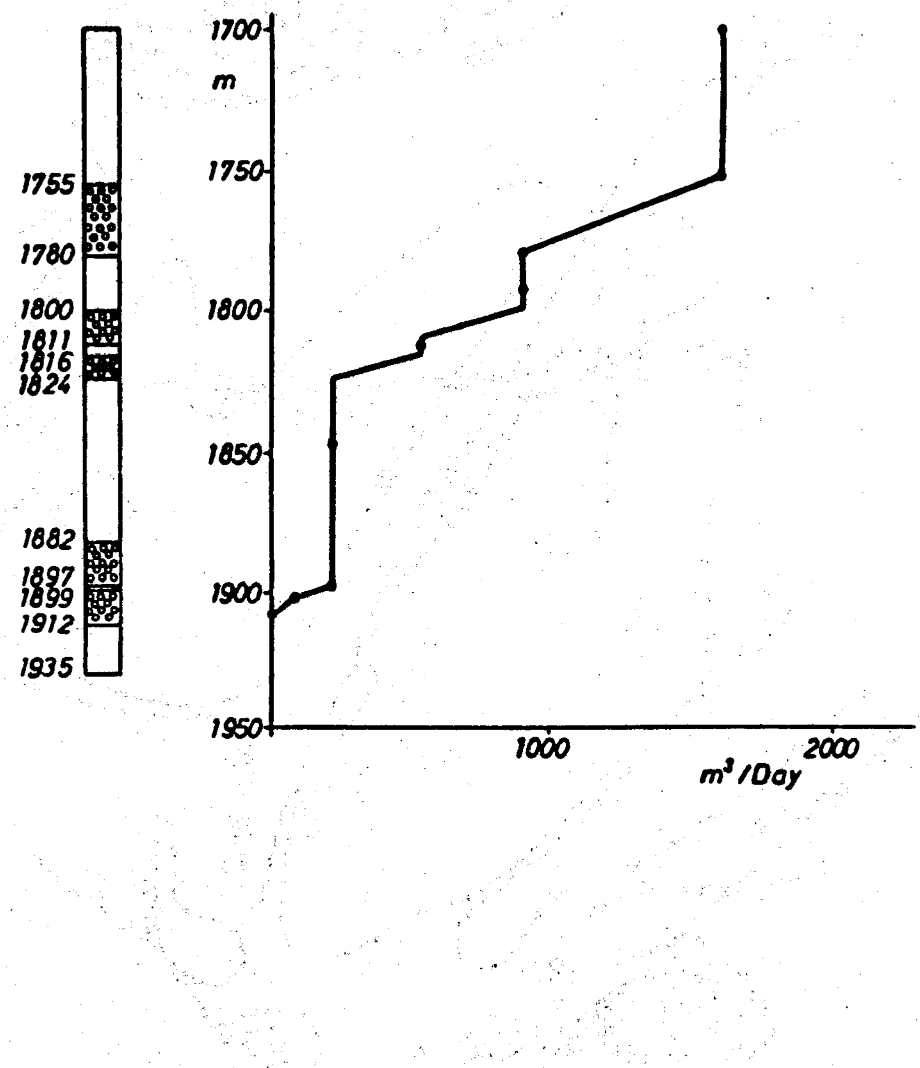

1755
1780
1800
1811
1816
1824
1882
1897
1899
1912
1935
1700
m
1750
1800
1850
1900
1950
1000
2000
m³/Day

Fig.2.

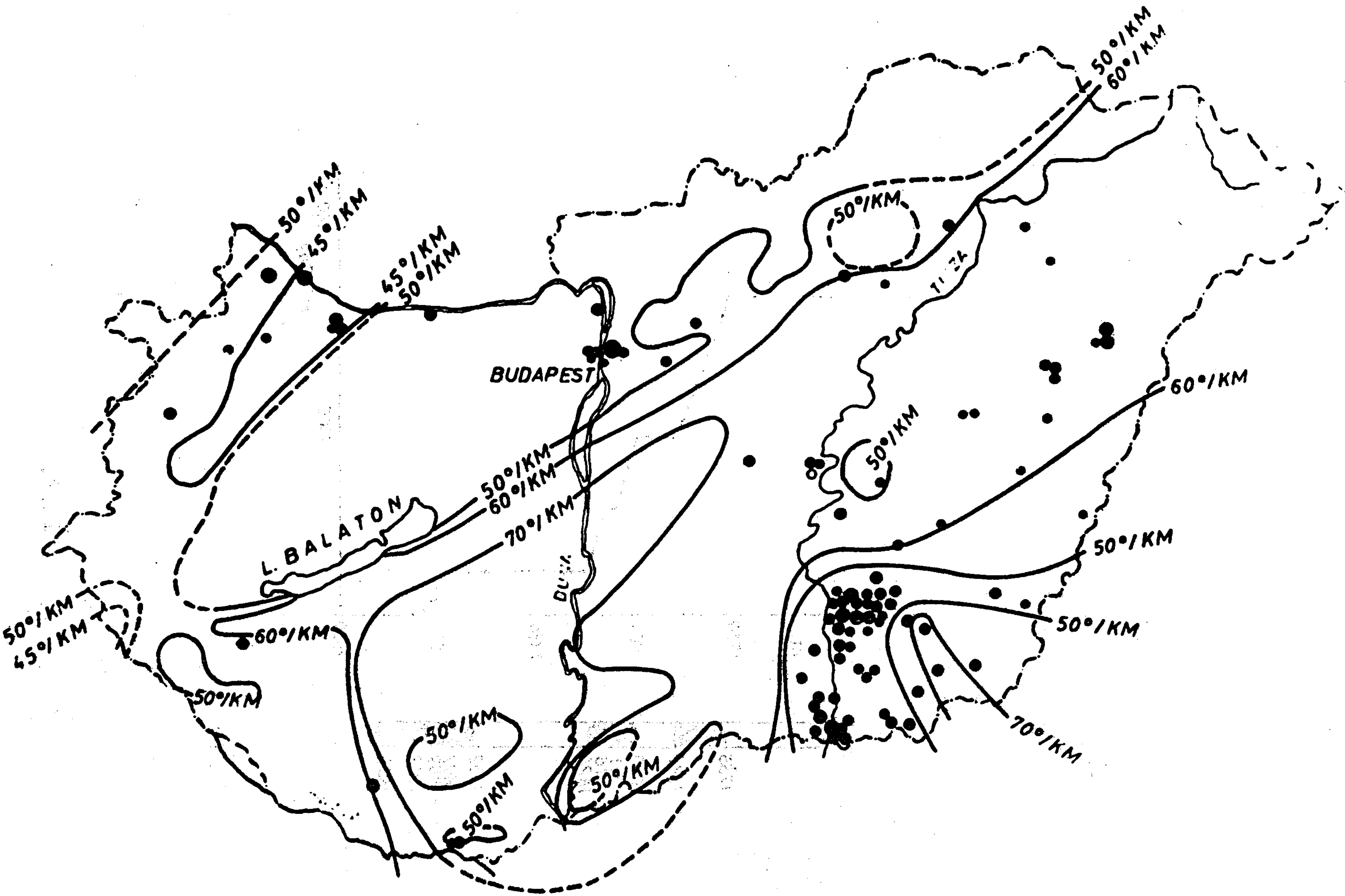
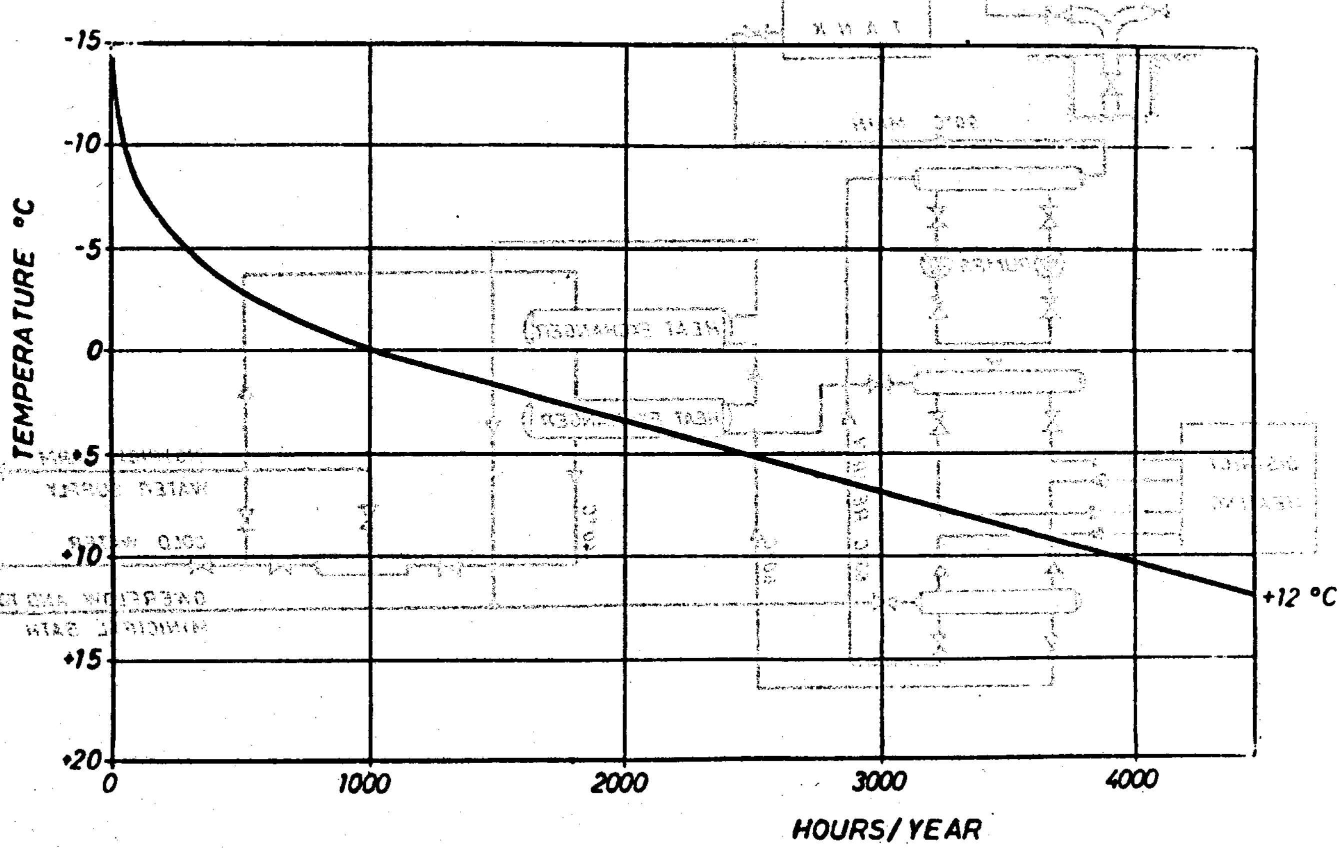

50°/KM
60°/KM
50°/KM
45°/KM
45°/KM
50°/KM
BUDAPEST
50°/KM
50°/KM
60°/KM
70°/KM
L. BALATON
60°/KM
50°/KM
60°/KM
50°/KM
50°/KM
45°/KM
50°/KM
50°/KM
50°/KM
50°/KM
50°/KM
70°/KM

Fig. 3.



TEMPERATURE °C
-15
-10
-5
0
+5
+10
+15
+20
0
1000
2000
3000
4000
HOURS/YEAR
+12 °C

Fig. 4.

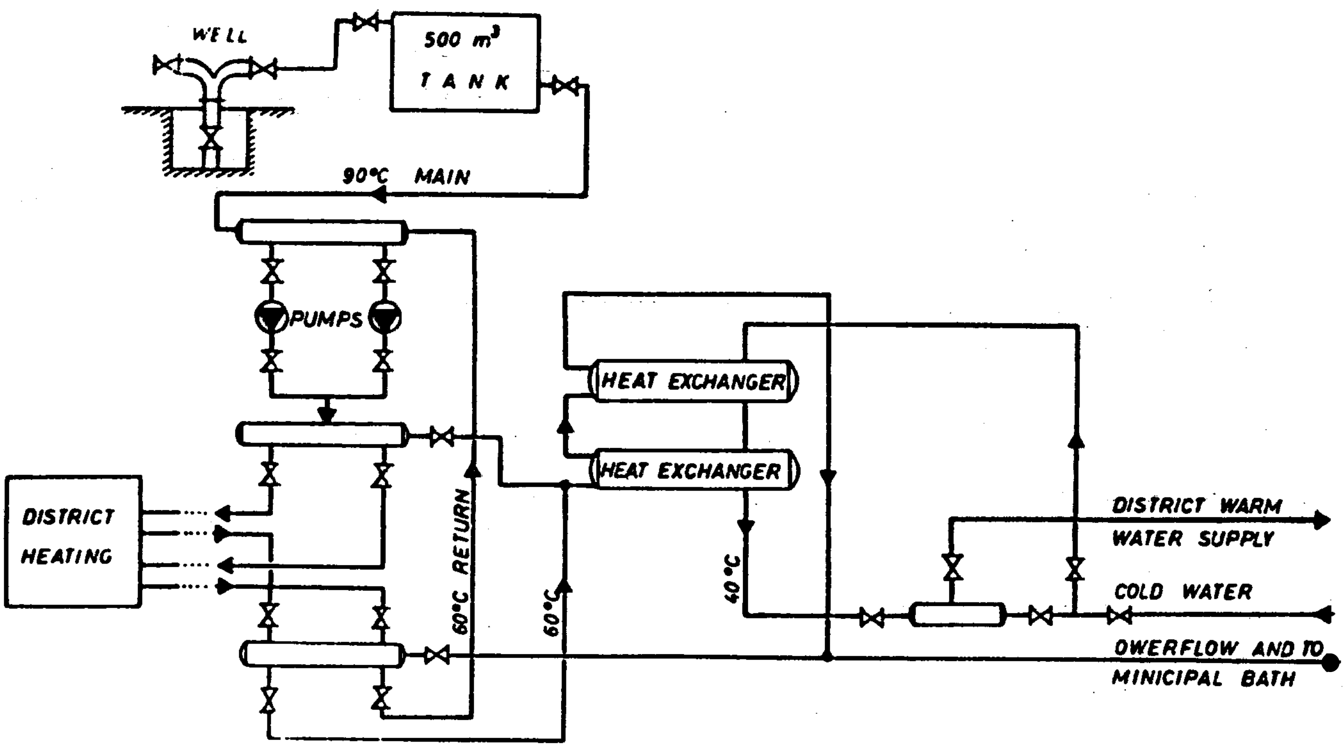

WELL
500 m³
TANK
90°C MAIN
PUMPS
HEAT EXCHANGER
HEAT EXCHANGER
DISTRICT
HEATING
60°C RETURN
60°C
40°C
DISTRICT WARM
WATER SUPPLY
COLD WATER
OWERFLOW AND TO
MINICIPAL BATH

Fig.5.

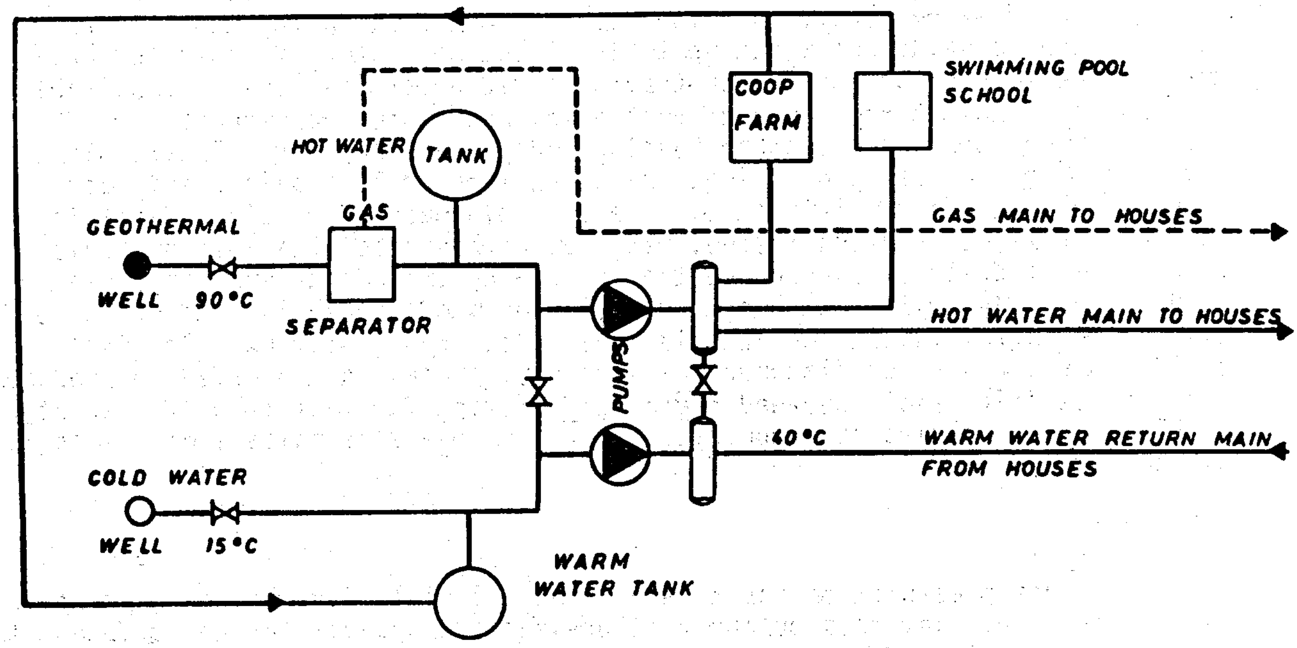

SWIMMING POOL
SCHOOL
COOP
FARM
HOT WATER
TANK
GAS
GEOTHERMAL
WELL
90°C
SEPARATOR
GAS MAIN TO HOUSES
HOT WATER MAIN TO HOUSES
PUMPS
40°C
WARM WATER RETURN MAIN
FROM HOUSES
COLD WATER
WELL
15°C
WARM
WATER TANK

Fig.6.

GEOTHERMAL ENERGY FOR PROCESS USE

By

Baldur Lindal[1]

ABSTRACT

The industrial processing fields in Iceland uses both hydropower and geothermal energy with potentials of 35,000 GWh per year and over 70 x 10^6 Gcal per year respectively. The use of geothermal energy has increased in recent years using wet steam up to 185°C and hot water at lower temperatures. The temperature of the geothermal fluid determines the most suitable process use. Multipurpose use of geothermal energy is recommended including electric power production, space heating and process heating. Entire plant complexes for chemical processing, which are more or less self sufficient in heat, power, and raw materials, have been planned. Corrosion of metals in the systems must be considered, with low carbon steel the most suitable. Established industrial uses of geothermal energy include greenhouses, seaweed drying, hay drying, washing and drying of wool, seasoning and drying of timber, drying of insulation material and stock drying of fish. At Myvatn 24,000 tons per year of diatomaceous earth are processed and dried to produce a diatomite filteraid. Seaweed drying and milling for meal is performed at Reykholar using a five deck conveyor dryer. Recovery of salts from brines is planned.

INTRODUCTION

This presentation has a rather general title for the purposes of this conference. Yet this author will present the subject for the greatest part from the point of view of his home country, Iceland. The reasons are the greater familiarity with the Icelandic developments, and also that any developments concerning geothermal energy for process use, are particularily dependent on local conditions. It is the authors intension, however, to present the subject in such a manner that the account may be as instructive as possible to others who may work with related projects.

Developments in Iceland in the process industrial field date back about 50 years. Fishing and farming being the traditional occupations of the people for many centuries; major industrial activities, at first, concerned fish products and the industrially useful products of the farms. Industrial plants based on the use of the local hydropower resources were established 20 years ago, where ammonium nitrate fertilizer is produced at one hand and portland cement at the other. Minor uses were also made of geothermal energy for process heating at an early date.

These developments reflected the fact that Iceland has very important resources besides grassland and rich fishing grounds. But, it was in 1968 that major industrial plants were completed for exploitation of both hydropower and geothermal energy for process use.

[1]Consulting Engineer, Reykjavik, Iceland

The hydropower potential in Iceland is considered 35,000 GWh/year. At the present only about 7% of this energy has been harnessed. The important use in the industrial field is by a 74,000 ton aluminum plant. At the present time, a ferrosilicon smelter is in the planning stage.

The economically useful geothermal potential of Iceland used to be considered the equivalent of 70 x 10^6 Gcal/year, which corresponds to roughly twice the hydropower energy potential. Recent geothermal explorations have indicated however, that useful geothermal energy may be even of greater magnitude than previously assumed. At any rate, it is now clear that in spite of the impressive water power potential Iceland has, the potential geothermal energy is several times greater. The most important process use of this so far is made by a diatomite plant in northern Iceland. But still only a tiny fraction of the geothermal energy has been put to use, even when counting all other uses.

The high temperature geothermal areas are found in a belt of recent volcanic activity, ranging from the Reykjanes Peninsula in southwestern Iceland, through the southern and central part and then reaching to the northeastern part of the country as shown in Figure 1. This belt has many areas of reservoir temperatures ranging from 200 to 300°C.

Towards the flanks of this high temperature belt, there are a multitude of low temperature occurrences where the reservoir temperatures are often about 100°C, but are, of course, lower or higher on many occasions. Such thermal occurrences are very common throughout the western and northern part of Iceland and in southern lowlands.

Both types of geothermal activity are of interest in process use. Thus, both the geothermal fluids from the high temperature areas and the low temperature areas are to some extent used industrially. The high temperature areas yield wet steam of pressures which may generally range from 5 to 11 atmosphers at the plant site, and have condensing temperatures of 150 to 185°C. The low temperature areas yield water which is often in the range 80 to 100°C.

CONSIDERATIONS REGARDING PROCESS USE

Geothermal energy may be used in a number of ways in the industrial field. This may be simply process heating, or drying, distillation or refrigeration may be involved. Deicing or tempering in various mining and manufacturing operations are performed. In some cases the geothermal fluids may also furnish raw materials which can be made useful by means of the energy these fluids carry.

In considering geothermal energy for process use, there are perhaps two fundamental ways to go about it. The first is to adjust to a prearranged pattern which has been lain in view of other ways of heating, and the second is to plan a new undertaking which takes view of geothermal energy as an essential industrial utility, accounting for all the special considerations which coincide with geothermal fluids in a successful heating application. Since the first approach has more often limited success, the second one will be considered here as the basic one.

Equipment and Process Design

In selecting equipment for a specified operation or in judging the viability of a project, it is perhaps most important to have a thorough knowledge of the state of the available heating agent. This may be steam at different pressures, or this may be water at different temperatures, and all of these may carry different amounts of chemical elements. The cost of these geothermal fluids may also differ greatly from one place to the other.

Having determined what heating conditions are available, the equipment must be selected and the feasibility assessed. Fortunately there is generally some selection of equipment which will fit reasonably in any one situation, but the best selection may sometimes be way out of the ordinary. Geothermal energy is in fact a new source which requires equally new engineer-responses. In Table 1 some examples are given of process design features which have been found useful.

The temperature level available with the geothermal fluids is as a rule more or less fixed in each specific case. This is a very important consideration which must be accounted for. As shown in Figure 2 most process heating requires the higher range of temperatures available with geothermal fluids. Yet it will be found, that by a suitable design, conventional temperature levels may in many cases be changed a great deal, without a noteworthy detrimental effect on the process involved.

Geothermal fluids for heating are, as a rule, very inexpensive close to the source. Such costs are more often less that 20% of the corresponding fossil fuel costs, so that process design for geothermal energy may be heavily influenced by the low prices in many cases.

The cost of energy plays a major role in most process designs. As an example, this will determine the number of effects in a multiple effect evaporator, the rejection temperatures for the heating medium etc., so that the complexity of an installation and the size of heat transfer surfaces are influenced greatly. Thus, if the cost of the geothermal heating medium is low, savings may be made in investment.

The savings in investment, plus the very low cost of these fluids close to the source, establish a major new potential for the development of secondary resources where geothermal fluids may be made available. Major industrial applications exist which have been established on these premises, even by using raw materials, which would otherwise have been worthless.

Criteria for Potential Use

It is of interest to consider here some common factors affecting the viability of the exploitation of geothermal energy for process use. In this respect, perhaps the three most important questions are:

1. What products may utilize the heat in the geothermal fluids?

2. What are the potential savings or advantages compared with the competitive conditions?

3. If there is a disadvantage involved in the site location, can this be offset by the cheap energy?

The present day technology is largely tailored to the use of fossil fuels and, therefore, no conclusive answers may be sought directly from present practice. Yet it may be helpful to begin a search by studying the conventional processes which use fossil fuel generated steam. Some such examples are listed in Table 2, together with the amount of steam which is conventionally used by fossil fuels. But there are many cases where geothermal fluids may be used with an advantage even in cases where no steam is used in the conventional processes by common practice. Some examples are:

1. The use of indirect heating in a process instead of direct contact heating. Thus, for instance, a steam tube dryer may be used instead of a direct fired one.

2. There may exist a choice of several processes for any one specific objective. One process may permit the use of geothermal energy with a great advantage, while another may not require any heat.

3. The availability of geothermal energy may call for a completely new process.

Some broad fields of potential major use are listed in Table 3.

The economic importance of the geothermal energy in a specific process may be judged by the share it has in the value of a product. This may sometimes be roughly evaluated in terms of the steam or the amount of fossil fuel which would otherwise be required. The effect of a different design, and hence investment, can also be accounted for in such cases. Many cases are known where the equivalent share of thermal energy may be 5 to 20% of the value of the product.

Where there is the question of a major use of geothermal steam, it is often more economical to transport the raw materials, than it is to transport the steam. Major process plants have, therefore, been built quite close to the steam source.

Ultimately there is the economic competitiveness of the project, as compared with the more conventional ones in any specific field. In such cases the savings which may have been made by the use of geothermal heat have to be balanced against some extra costs which may come about due to the limitations in site selection.

The major industrial plants which are in existence have amply demonstrated that geothermal energy is a very versatile source of energy. Thus process heating, space heating, and electrical power production have been integrated into the same system.

Due to the fact, that conditions and economic features vary greatly from one place to the other, there is no tailor made answer to the question of what should be done. Every source of geothermal energy must be studied by itself.

There are perhaps three main categories of utilization, which will serve as the main purpose of an exploitation plan. One is electric power, the second space heating, and the third process heating.

When electric power is the main objective there are, as a rule, ample opportunities for uses of waste heat, at least with plants using wet steam. Here geothermal water may be rejected at elevated temperatures, which may serve important purposes such as space heating, fresh water production or even industrial applications.

When space heating is the main objective a secondary electric power generation is possible in some cases. Applications for greenhouses, soil warming, swimming pools and a multitude of other low temperature applications may be made.

In cases of process heating being the main objective, electrical power will usually be involved for plant uses, and even for outside purposes. And as a rule there will be ample opportunities for any kind of secondary uses for heating purposes.

Entire plant complexes for chemical processing, which are more or less self sufficient in heat, power, and raw materials, have been planned. It is quite likely that such integrated and combined uses of geothermal energy may be common place in the near future.

Corrosion in Heating Systems

Low carbon steels are by far the most significant material of construction for geothermal heating systems although various metals and alloys may be used for special purposes. An excellent survey of surface corrosion rates in the high temperature range was made recently by the New Zealanders Marshal and Braithwaite (1973). For steel they reported the values shown in Table 4, where these are compared to results from Namafjall area, Iceland (Diatomite Plant) in this paper.

It will thus be clearly established through direct measurements and practical experience, that the surface corrosion rates of low carbon steel is usually within the normal limits for process use. The same thing applies to most engineering alloys with the possible exception of copper-base alloys.

Corrosion rate for mild steel in contact with low temperature geothermal water of the sodium chloride type, is usually low, providing that oxygen is kept absent. In Table 5, some specific cases are reported according to A. Einarsson et al. (1974). There is some pitting, as a rule, and this will determine the useful life of the structure in question, together with the wall thickness. Ordinarily pipes of mild steel may last 30 years or much longer. Major amounts of dissolved oxygen will however enhance corrosion greatly as shown in System 9, Table 2. If appreciable chloride is present, complete elimination of dissolved oxygen is essential. Yet there are exceptional cases, where high rates of corrosion are found, without any apparent explanation. It is, therefore, advisable to make corrosion rate tests in every case of a projected use of a new source of low temperature geothermal water.

Fouling in Geothermal Systems

While several minor elements in geothermal water may cause fouling in heating systems and supply mains, there are largely two components which may cause very rapid scaling, for example, silica and calcite. The non-condensible gas in the geothermal steam may also accumulate, if it is not vented out of the heating systems.

In a geothermal reservoir the water will dissolve silica from the rock according to the solubility being slightly higher than that of quartz. Upon cooling of the water, which will coincide with any thermal utilization, concentrations of silica which are above the solubility limit of quartz or chalcedony will be reached. But silica will not readily precipitate as quartz polymerize and may precipitate if the solubility limit of the much more soluble opaline form is reached.

Figure 2 shows the solubility of quartz and opal in pure water. Guide lines in the diagram show how flashing of the water influences the limit of opaline saturation. High pH values of the water will somewhat increase the value for total silica required for the saturation limit due to the disassociation of silicic acid. For more details see Arnorsson, 1974.

When reservoir temperatures are less than 160°C, and if quartz equilibrium was involved, the maximum silica will be 150 ppm. Referring to Figure 2, it will be found that opaline silica may begin to form by cooling to 25°C, or if flashing down to 100°C was involved, cooling to 34°C. Comparable figures for original equilibrium with chalcedony are 44° and 52°C. If high pH values were also involved these limits would be somewhat lower still. Since these temperatures coincide with the lower limits for most heating applications, self-induced precipitation of silica is not usually found with heating systems using water from such low temperature geothermal reservoirs.

Yet silica may accumulate slowly in these low temperature systems. Thus coatings of zinc (galvanized steel) are to be avoided, because silica will come down on their corrosion product, silica will also come into the corrosion products of copper, and into the corrosion products of steel. But fortunately satisfactory corrosive conditions for steel can usually be avoided by good oxygen control. It is most often satisfactory to keep the oxygen content below 0.05 ppm in systems which work at maximum temperatures of 100°C.

In Table 5, geothermal water heating systems 1 to 6 exhibit mild scaling conditions, and the water is used directly in the radiator systems except in No. 5 where the silica is on the high side.

A high rate of scaling is found in systems 7 and 9 in keeping with the high rate of corrosion. It is of interest to note, however, that a slow scale formation in such systems is sometimes believed to be beneficiary, since this will retard oxygen corrosion somewhat.

In water systems of reservoir temperatures above 160°C, it is of importance to take due account of the limit for opaline silica precipitation. The precipitation of silica and coincident fouling above the opal solubility limit, may be extremely severe in some cases.

Calcite fouling is generally associated with the calcium bicarbonate type of water only. When carbon dioxide is released from such a system, the pH is increased and calcium carbonate may precipitate. This will usually occur in the supply system itself. But if such water is used for heating purposes, a dilution with fresh water may be advisable in order to avoid fouling.

Upon the condensation of geothermal steam in a heating system, the non-condensible gas will concentrate. And since non-condensible gas will affect the heat transfer coefficient adversely, this must be vented out.

In order to preserve a high heat transfer coefficient, the steam is not condensed fully. At the end of the path of condensing steam, the gas along with a small part of the original steam charge is vented out. This may coincide with the discharge of condensate, and the steam trap will not ordinarily work properly except by direct bleeding of this kind.

Since geothermal gas includes hydrogen sulfide, any leaks of steam or the more concentrated non-condensibles may be harmful for the exterior of equipment and cause difficulties for the personnel. Such leaks are common for instance with the stems of valves and other equipment which may use packings of glands. Since it has proven to be very difficult to prevent such leaks completely, the system involved in use of primary natural steam, should be compact if possible, and a good ventilating has to be secured.

ESTABLISHED INDUSTRIAL USES IN ICELAND

The Initial Developments

Counting the trial developments, geothermal energy has been used for industrial purposes for some 25 years in Iceland. These initial uses were made in the Hveragerоi area where a new town was emerging in the 1940's due to the availability of geothermal steam. Although the steam was essentially used for greenhouses in Hveragerоi and this became the most flourishing green-town in Iceland, significant beginnings were made in the industrial field.

These pioneering developments included seaweed drying, hay drying washing and drying of wool, seasoning and drying of timber, and drying of insulating materials. Deep freezing by using geothermal steam for ammonia absorption was tried and tests were made for producing electrical power by steam. One of the predesessors for industrial use of geothermal energy was a stock fish drying plant which made use of the hot water from Reykjavík Heating System.

These initial attempts in Hveragerоi were made on a very small scale and some did not last at the time. Yet one of the biggest wool washing stations in the country is situated in Hveragerоi and most of the other functions are practiced on a larger and more economic fashion elsewhere in Iceland.

Myvatn Diatomite Plant

The first major process use of geothermal energy in Iceland was in the diatomite plant by Myvatn in Northern Iceland. This plant was built in 1966-67. It has been working successfully and with a yearly increase in capacity since.

The Process

The diatomaceous earth occurs as an underwater deposit in lake Myvatn. This raw material is dredged out of the water by a suction dredge and then pumped as a slurry through a 3 km long pipeline to the plantsite. This dredging takes place during the summer time only, so that the diatomaceous slurry is placed in reservoirs for storage at the plant. These reservoirs make a supply to the plant possible all through the winter.

The daily supply to the plant is obtained from a second dredge which is operated on these local reservoirs. A slurry from this local dredge containing 11 to 12% solids is pumped to a receiving tank at the plant. The slurry is drawn from this tank at a constant rate, heated to 80 to 90°C by direct injection of geothermal steam, and then fed to a filter after pH adjustment. Vacuum filters operating on the hot slurry produce a cake containing about 74% moisture. This cake is fed to rotary steam tube dryers, which operate on geothermal steam at a pressure of 11 atmospheres. This system is shown in Figure 4.

The dried diatomaceous earth is processed further, and thus commercial diatomite filteraids are the end products of this plant. Approximately two tons of the stored diatomaceous earth on the dry basis are needed for one ton of filteraids.

The rate of production of diatomite filteraids is at the present 24,000 tons per year. There are four steam tube dryers, having a total evaporating capacity of 150,000 tons of water per year. The capacity of each dryer is roughly 5 1/2 tons of water per hour.

The steam tube dryers are of ordinary steel construction including the tubes themselves.

Since good gas-bleeding is especially important with geothermal steam, the bleed is of a special design. These are straight tube dryers so that each steam tube has a bleeding outlet at one end of the dryer. There each tube is connected to a peripheral collecting tube, which in its turn has four gas-bleeding valves which discharge to a hood at the end of the dryers. The gas is then sucked out of this hood and blown out to the atmosphere through stacks on the top of the dryer shed. Steam traps of stainless steel are used and there again minor gas-bleeding arrangement is necessary in order to ensure faultless performance.

As with the dryers, steel is the main material of construction for all the equipment and tubing which has to do with the natural steam. Stainless steel is used for special purposes. Copper and copper alloys are avoided in every case.

In this plant ballvalves with Teflon packing have been very successful for small diameters. Otherwise gatevalves are used.

The Function of Geothermal Energy in the Plant

Lake Myvatn is situated at the edge of the Namafjall geothermal area in Northern Iceland, at an altitude of 277 meters above sea level. There, the temperature will stay below freezing six and a half months of the year and, in fact, freezing may occur any time of the year.

The lake is normally frozen during the winter season, but warm springs which outcrop at the edge of the lake help somewhat in prolonging the ice free dredging season during the summer. Besides this warm spring water is mixed in with diatomaceous slurry from the dredge before the pumping through the supply pipeline takes place. This helps in maintaing a trouble free operation whatever the weather conditions are.

The raw material reservoirs at the plant contain settled diatomaceous earth covered with water, which could normally be frozen the greater part of the year. The daily raw material supply to the plant takes place by suction dredging in the reservoirs, and a freedom of movement for the dredge is needed all through the year. Up to 20 liters per second of water is heated to 85°C by direct steam injection for deicing around the dredge and the flooding pipeline during the winter season. Freezing conditions in the raw material storage tank at the plant are also avoided by geothermal heating.

The operation in the plant begins by injecting live geothermal steam into the diatomations slurry which will raise the temperature to 80 to 90°C before filtration takes place.

The greatest amount of steam is, however, used in the drying process. About 1.4 tons of steam is needed for evaporation of 1 ton of water so that the dryers alone require 31 tons of geothermal steam per hour.

Furthermore the geothermal steam is used for preheating fuel oil for the kiln in the plant and also for space heating around the plant.

The above uses of geothermal steam for process heating is summarized in Table 6, as this is in 1974.

The plant has an installed electrical power supply of some 2.5 MW, although this is not used fully. A steamturbine generator of 2.8 MW is operating independently in this area supplying power to the local power grid. The arrangements for geothermal steam supply may be seen in Figure 5.

Space heating in a nearby village which is occupied largely by plant personnel, takes place by the use of the water phase of the flashed discharge from the boreholes in the area.

Operating Experience with the Steam

The Myvatn diatomaceous earth deposit is, as far as we know, the only water covered deposit which is being exploited at present. The process for recovery and the drying technique is also novel and adapted to these particular conditions which exist where ample and inexpensive geothermal energy may be obtained.

Since diatomaceous earth is ordinarily recovered from relatively dry mines where the moisture content of the ore ranges from 55 to 65%, and direct fired fuel oil dryers are used instead of steam tube dryers at Myvatn, it is clear that the Myvtn plant owes its existence to geothermal energy. Without geothermal energy, the production of diatomite would not be economically attractive. The operation of this plant has been very instructive since it is both technically novel by the process and in the use of geothermal steam. Understandably a lot of improvements have been made in the process of development.

By the first set of dryers which were installed the pressure of the steam was around 7 atmospheres, by installation of the additional sets this was raised to 11 atmospheres for all of them. The higher pressures increase the output of the dryers and in this case the geothermal reservoir proved quite capable of such pressure loads (reservoir temp. around 280°C).

The inside corrosion due to the steam and condensation is much like that predicted by tests which were performed beforehand. The corrosion will thus generally correspond to 1 to 2 mills, even by accounting for the rotating steam tubes on the inside. However, leaks of values and steam coming into open due to other faults, has proven to be much more serious than expected. Such leaks have in the long run caused considerable corrosion in the steel structure of the building which is used for dewatering equipment, and the hydrogen sulfide in the steam has had adverse effects on most automatic electrical equipment in this part of the plant. The hydrogen sulfide has occasionally been difficult for the personnel operating this part of the plant. Some redesigning is still needed in order to take care of these difficulties.

The gas-bleeding with geothermal steam on a rotary steam tube dryer was also more difficult than expected in the beginning. And although these problems have been solved, it should be emphasized that troubles with stoppages in gas-bleeding caused a lot of difficulties in running this equipment in the early days of operation. There were also difficulties with the steam traps which were partly due to the accumulation of non-condensible gas.

The general conclusion regarding the use of geothermal steam is, however, that while it is necessary to account for major differences in regard to some design and operational features, from those with ordinary steam, such differences need not affect the economics to any significant extent.

The geothermal energy used by the diatomite plant is supplied to the plant by the National Energy Authority while the plant itself is owned by the Icelandic Diatomite Company. The charge for this energy by the N.E.A. is based on the amount of steam supplied and is at present $0.42 per ton of steam. This price is roughly 10% of the equivalent energy cost of fuel oil in this area at the present time.

The Seaweed Plant at Reykholar

Some of the coasts of Iceland are rich in seaweeds. This is especially pronounced in parts of the southeast where lavas of recent origin extend into the sea and form favorable sheltered lagoons, and in the Breidafjordur area in the western part where shallow and sheltered areas exist separated from the open ocean due to a number of islands.

One of the greatest use for seaweeds is for the manufacture of alginates, since they are rich in alginic acid. Ascophyllum nodosum may be harvested for this purpose.

In order to achieve a satisfactory economic result from the collection of such seaweeds, the operation must have considerable capacity and be highly mechanized. For these reasons a major seaweed harvesting operation is being organized in the Breidafjordur area where the seaweeds will be collected to single plant with some processing taking place.

A plant for drying and milling of the seaweed is now under construction at Reykholar where geothermal water is available as the source of energy. This plant will commence operation next spring (1975).

The process involves the chopping of the fresh Ascophyllum nodosum weed into bits, the drying of this material and finally the milling and bagging of the resulting seaweed meal.

The seaweed is received at a moisture content of about 80% and is discharged at 12% moisture. The rate of production will be 2.44 tons per hour of milled seaweed, which involves the evaporation of 6.6 tons of water per hour. It is estimated that 6,685 tons may be produced this way per year requiring some 24,700 tons of fresh seaweed.

At Reykholar where the plant is being erected, geothermal water of some 110°C is available. It is assumed that 180 tons per hour of this hot water will be delivered to the plant where this drying takes place. In the heat exchangers of the dryer this water will cool down to some 45°C, and be discharged after that.

A single five deck conveyor dryer will be used. A counter current drying system is obtained by introducing the wet feed to the top conveyor belt and hence the seaweeds descend from one belt down to the other and finally being discharged from the bottom one. Hot air at around 75°C is introduced below the bottom belt and is made to ascend up through all of the other belts, and is released after going through the fresh charge on the top belt. Since a somewhat greater air velocity is permissible with the wetter material on the uppermost belts, some additional hot air is introduced to these.

Since the seaweed, and most other materials, have a much lower drying rate as the process of drying approaches the final stages and also since this final rate is temperature dependent, thus indicates how important this counter current drying system is where the possibility for high air temperatures is nonexistent. Thus in this case, the hottest air comes to the part of the charge where high temperatures are most important for rapid overall drying results. It is a coincidence in this case that this seaweed might be damaged by any higher temperatures in the final stage of drying, and it is believed that this way of drying takes good advantage of the limited possibilities which the low temperatures air may have.

There are plans for using these same kind of dryers for hay drying with geothermal water and for drying some other material of organic origin. The principles of the multideck conveyor dryer is shown in Figure 6.

FUTURE DEVELOPMENTS

In the past a considerable emphasis has been placed on the study of new projects involving the use of geothermal energy for process use in Iceland, beyond what has been implemented. This includes the recovery of heavy water, the production of alumina from bauxite, processing of mineral oil and many other possibilities. But the one process scheme, which at the present time stands closest to implementation is definitely the Sea-Chemicals Complex, or at least the basic part of it.

The Sea-Chemicals Complex

As shown schematically in Figure 7 the Sea-Chemicals Complex consists of many interconnected plants, which base their activity on the availability of geothermal energy, electrical power, salt and seawater.

This activity has been planned in the Reykjanes peninsula in southwestern Iceland where ample geothermal resources exist together with favorable local conditions for such developments. The Reykjanes peninsula is shown in Figure 8 together with the geothermal areas, population centers and communicational aspects.

The fundamental unit in this geothermal industrial complex will be a plant for the processing geothermal brine, which may be obtained in the Reykjanes area. In this part of the complex the most important product will be sodium chloride (common salt) which may in its turn be used for products such as caustic soda and chlorine, magnesium chloride and soda ash etc., many of these requiring geothermal energy for process use. These basic chemicals could finally be upgraded by the aid of the ample hydropower resources. The National Research Council of Iceland has been responsible for extensive studies in this respect in recent years. These developments are considered economically feasible.

Reykjanes Salt Plant

Geological studies and test drillings have shown that major quantities of saline geothermal brine may be obtained in the Reykjanes area. The most favorable site for a brine porcessing plant is believed to be at the tip of the Reykjanes peninsula where geothermal reservoir temperatures of up to 190°C have been found.

The geothermal fluid which may be obtained at Reykjanes at depths beyond 1000 meters is believed to be altered seawater. But even though the chloride content is that of seawater, some components are widely different due to reactions with the rock. Thus there is an important enrichment in potassium and calcium while magnesium is absent and sulphate has decreased to minor amounts. This change in composition is important in respect to the economic value of the brine.

Since the reservoir temperature is high, the brine gets more concentrated due to flashing, before it reaches the plant. Yet considerable further evaporation has to take place before the fluid obtains saturation in respect to the salt. This is achieved through the use of the steam which resulted from the former auto evaporation.

The preconcentrator in this plant will be a three effect forced circulation evaporator made of low carbon steel. Most of the primary geothermal steam will be used at about 10 atmospheres for the first effect. Then clean secondary steam for the remainder of the processes in the plant may be drawn from any of the evaporator steps.

The remaining process steps involve the crystallization of sodium chloride, the recovery of potash and bromine and the recovery of calcium chloride. An almost total recovery of these is scheduled. A flow sheet is shown in Figure 9.

The production rate of 250,000 tons of sodium chloride per year has been found suitable as a basis for a complete processing unit. This would also involve the production of 25,000 tons of potash, 60,000 tons of calcium chloride and 700 tons of bromine per year.

Since it is possible to build this plant independently of the rest of the units in the Sea-Chemicals Complex, this development has been planned for the very near future.

Long Range Considerations

In spite of considerable process use of geothermal energy in Iceland already, and further plans in this field, it is believed that in the next decade much more widespread applications will take place in order to replace fuel oil in the fishing industry and elsewhere. A special study is being conducted regarding the possibilities for a major expansion of the greenhouse activity and impressive recreational facilities. Counting also the space heating activities domestically it is likely that geothermal energy together with hydro-electrical power, where the former is not possible, may replace most uses of fuel oil for stationary purposes. Yet there will be a remaining field, where fossil fuel will still reign, that of transportation.

At present more than half of all fuel imported to Iceland is used in the field of transportation such as for automobiles, aircraft, fishing vessels etc. This use is expanding rapidly, and has already become one of the most important items of import to the country. Like elsewhere, the prices have risen greatly since the recent oil crises, so that a fresh look at the situation is needed in a country which otherwise has such abundant energy resources. Thus the question has risen in what way these may serve transportation.

Apparently there is no single answer to this question regarding all such fuel requirements, but for people having geothermal steam, the question of methanol production for use as motor fuel, is of considerable interest.

Methanol has many of the same transport, storage and usage characteristics as gasoline, and may be used in an internal combustion engine in a similar way. During the Second World War gasoline used to be mixed with up to 30% of ethanol in Sweden for economy and similar experience exists for methanol. Cars are even reported to run better that way.

Methanol may be made from one molecule of carbon monoxide plus two of hydrogen. This in its turn, is often made from steam and carbon in the form of coke or coal. These gas reactions are endothermic, so that a considerable outside energy is needed. Ordinarily this energy is derived from the combustion of some extra carbon, so that much more than the theoretical amount is needed. This will mean that it is possible to reduce the amount of carbon to the theoretical minimum required by the introduction of another source of energy.

At present the price of fossil fuels in Iceland is approximately equivalent to the cost of production of electric power in terms of energy. This might mean that it would be economically attractive to use electrical power and this even produced from geothermal energy. At any rate the energy furnished to the system by direct use of geothermal steam would count significantly. This may thus turn out to be a worthwhile consideration.

The same principles would apply for the production of pure hydrogen for use either in ammonia production for fertilizers or if liquid hydrogen will find some uses in the transportation field. Thus the study of these gas technological questions may easily become one of widespread interest.

REFERENCES

1. Arnorsson, S., (1974), Application of the Silica Geothermometer in Low Temperature Hydrothermal Areas in Iceland. In press.

2. Einarsson, A., Elisson, G., and Hermannsson, S., (1974) Private communication.

3. Marshall, T. and Braithwaite, W. R. (1973), Geothermal Energy, UNESCO, pp. 151-159.

Table 1

EXAMPLES OF PROCESS DESIGN FEATURES FOR GEOTHERMAL STEAM AND WATER

Operation	Geothermal Steam		Geothermal Water	
	Type	Examples	Type	Examples
Drying	Indirect heating	Steam tube dryers drum dryers	Indirect heating	Multideck conveyor dryer
Evaporation	Primary heat exchangers accessible	Forced circulation evaporators	Counter current heaters	Preheaters
Distillation	Steam distillation	General equipment	---	---
Refrigeration	Freezing	Amonia absorption	Comfort cooling	Lithium bromium absorption
De-icing	---	---	Direct application Indirect heating	Dredging aid Pavement de-icing

Table 2

THE CONSUMPTION OF STEAM AND STEAM USED PER $ VALUE IN SOME ESTABLISHED FUEL BASED PROCESSES

Product and Process	Steam requirements Kg steam/kg	Steam per unit product value Kg steam/$ value 1
Heavy water by hydrogen sulfide process	10.000	151
Ascorbic acid	250	45
Viscose rayon	(70)	42
Lactose	40	130
Acetic acid from wood via Suida process	35	159
Ethyl alcohol from sulphite liquor	22	142
Ethyl alcohol from wood waste	19	123
Ethylene glycol via chlorohydrin	13	45
Casein	13	10
Ethylene oxide	11	33
Basic Mg carbonate	9	37
35% hydrogen peroxide	9	23
85% hydrogen peroxide from 35% H_2O_2	4 3/4	--
Solid caustic soda via diaphragm cells	8	121
Acetic acid from wood via solvent extraction	7 1/2	34
Alumina via Bayers process	(7)	106
Ethyl alcohol from molasses	7	45
Beet sugar	5 3/4	26
Sodium Chlorate	5 1/2	28
Kraft pulp	4 1/5	32
Dissolving pulp	4 1/5	--
Sulphite pulp	3 1/2	26
Aluminum sulphate	3 1/2	79
Synthetic ethyl alcohol from athylene	3	20
Calcium hypochloride, high test	3 1/3	50
Acetic acid from wood via Othmer process	2 3/4	13
Ammonium chloride	2 3/4	21
Boric acid	2 1/4	20
Soda ash via Solvay process	2	60
Cotton seed oil	2	9
Natural sodium sulphate	1 4/5	54
Cane sugar refining	1 2/3	8
Ammonium nitrate from ammonia	1 1/2	20
Ammonium sulphate	1/6	5
Fresh water from seawater by distillation	1 1/2	227

Table 3

SOME POTENTIAL FIELDS FOR APPLICATION

1. Geothermal desalination
2. Pulp and paper manufacture
3. Sugar processing and paper manufacture for bagasse
4. Gasification of coal and other carbonations materials
5. The processing of mineral oil
6. The recovery of various salts and minerals
7. The recovery of valuable trace elements from geothermal sources and elsewhere
8. Textile processing
9. Heavy water recovery
10. Fish processing
11. Agricultural and related uses: crop drying, canning, refrigeration, spray drying product, extensive horticultural uses and greenhouse applications
12. Products of fermentations: ethyl alcohol, butanol acetone, cetric acid, etc.
13. Freeze drying of foodstuffs: fish, meat, coffee, etc.

Table 4

SURFACE CORROSION RATES OF STEEL IN HIGH TEMPERATURE GEOTHERMAL SYSTEMS

	Marshall & Braithwaite mils/year	Namafjall mils/year
Geothermal steam, 100 - 200°C	0.3 - 6	0.9 - 2
Condensate, ~70°C	3	4
Water, ~ 125°C	0.3 - 0.5	
Steam and water		1.2
Airated steam	20	18.3

Table 6

GEOTHERMAL STEAM FOR PROCESS HEATING A DIATOMITE PLANT, ICELAND

Uses	
1. For Drying	31
2. Slurry heating	7
3. De-icing in reservoirs	6[x]
4. Slurry tank, fuel oil heating and miscellaneous	1
Total	45 tons/h

[x]Only in winter

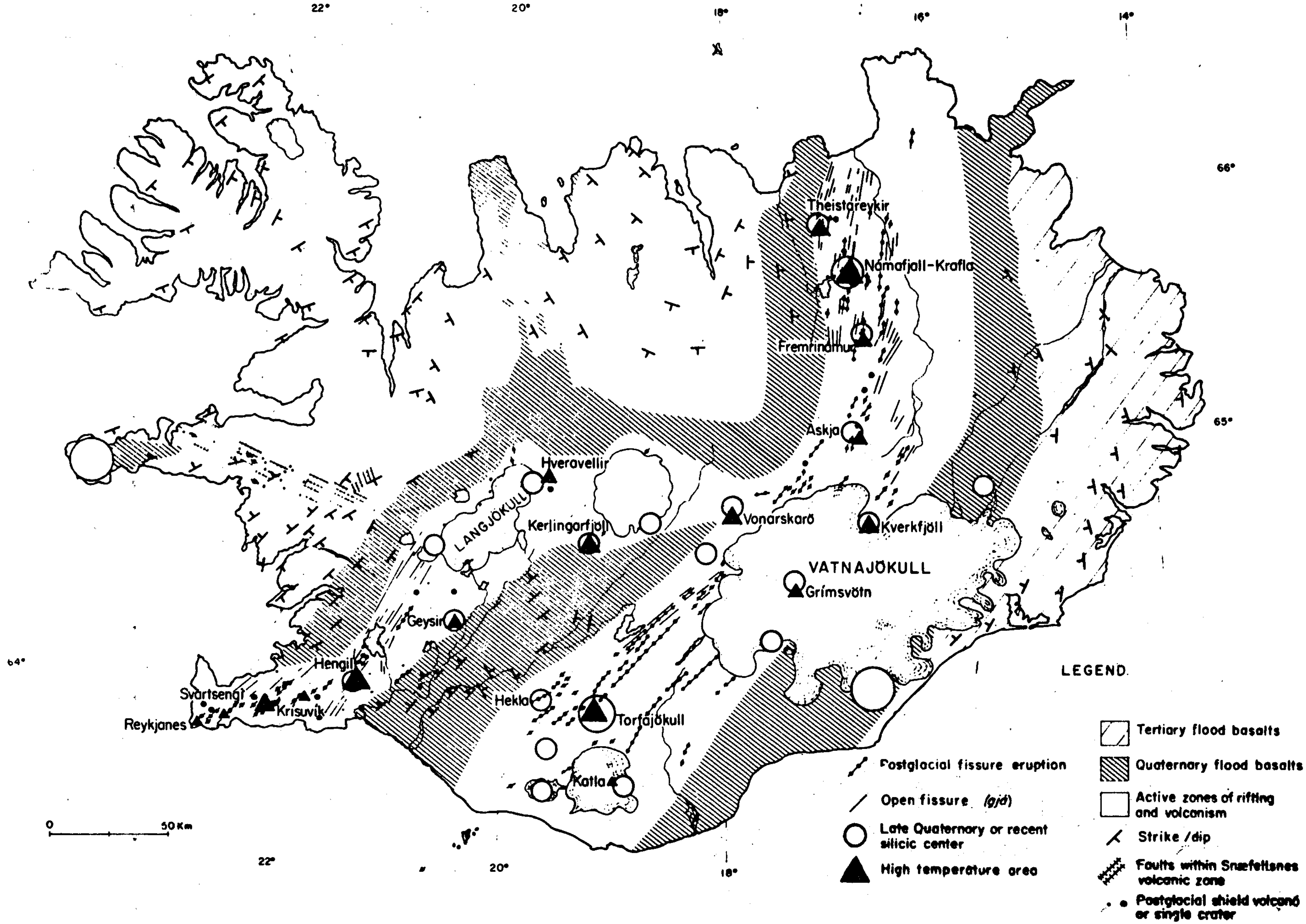


Figure 1. Iceland geologic map.

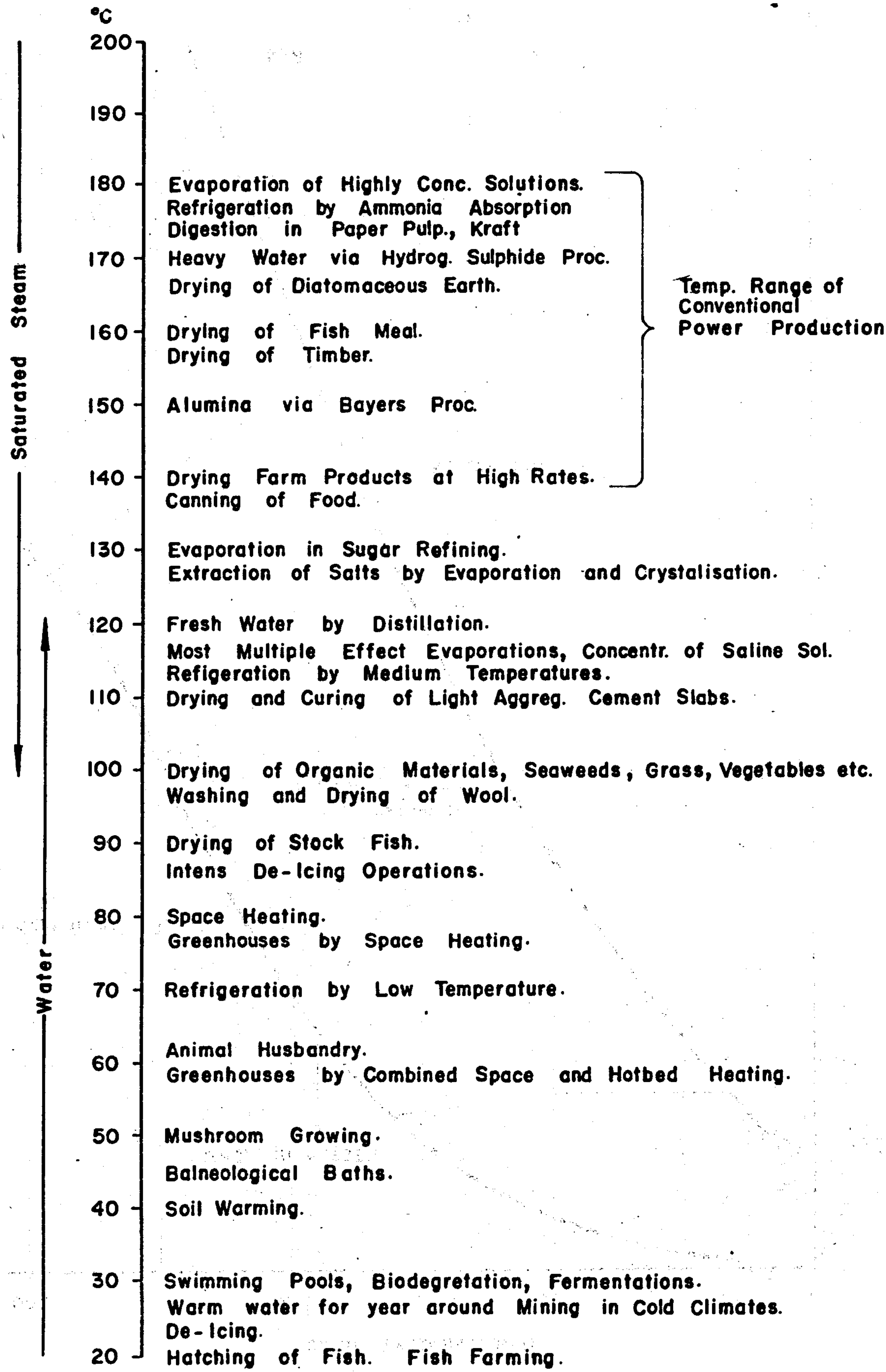


Figure 2. The required temperature of geothermal fluids approximate.

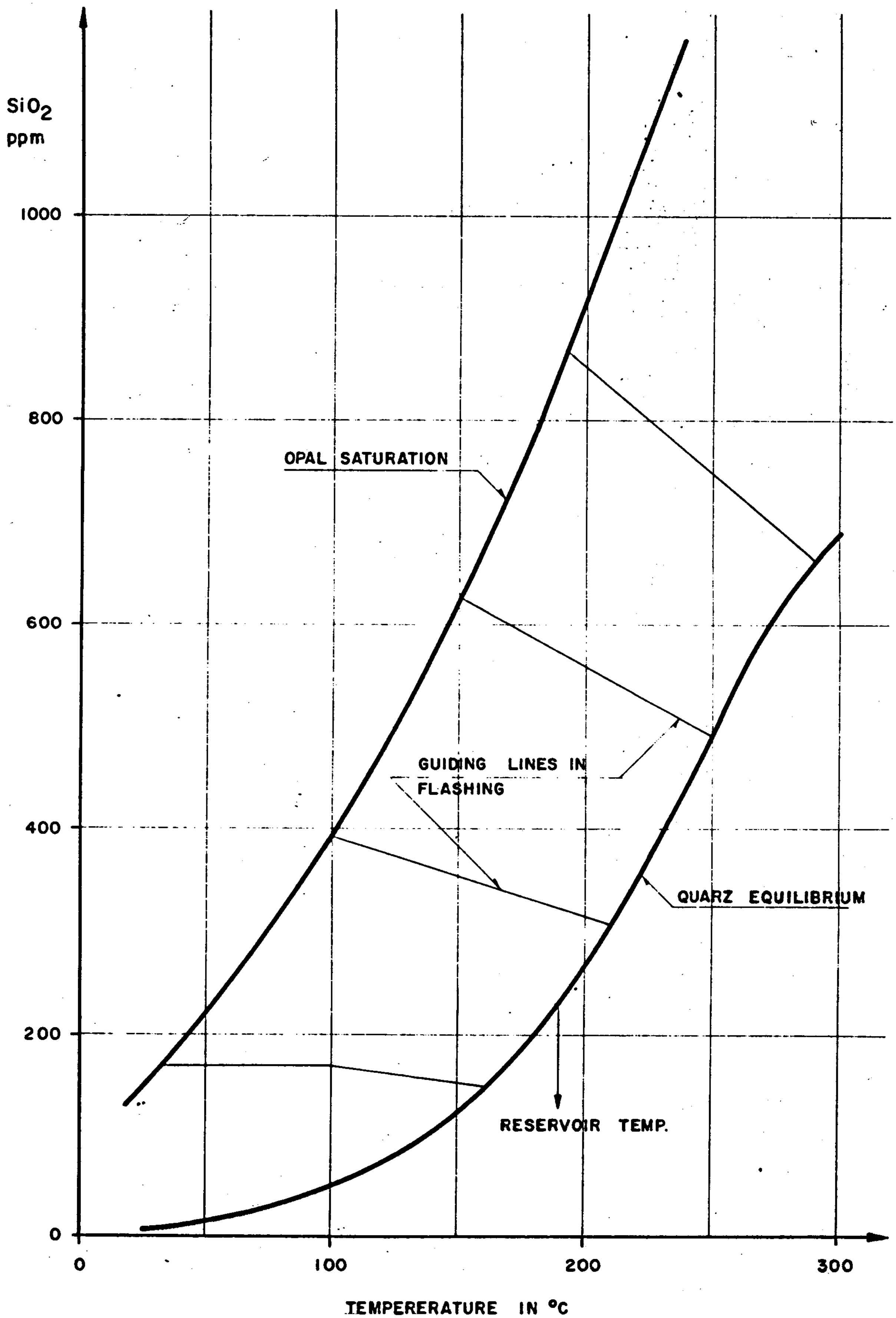


Figure 3. The solubility of Quarz and opal in water.

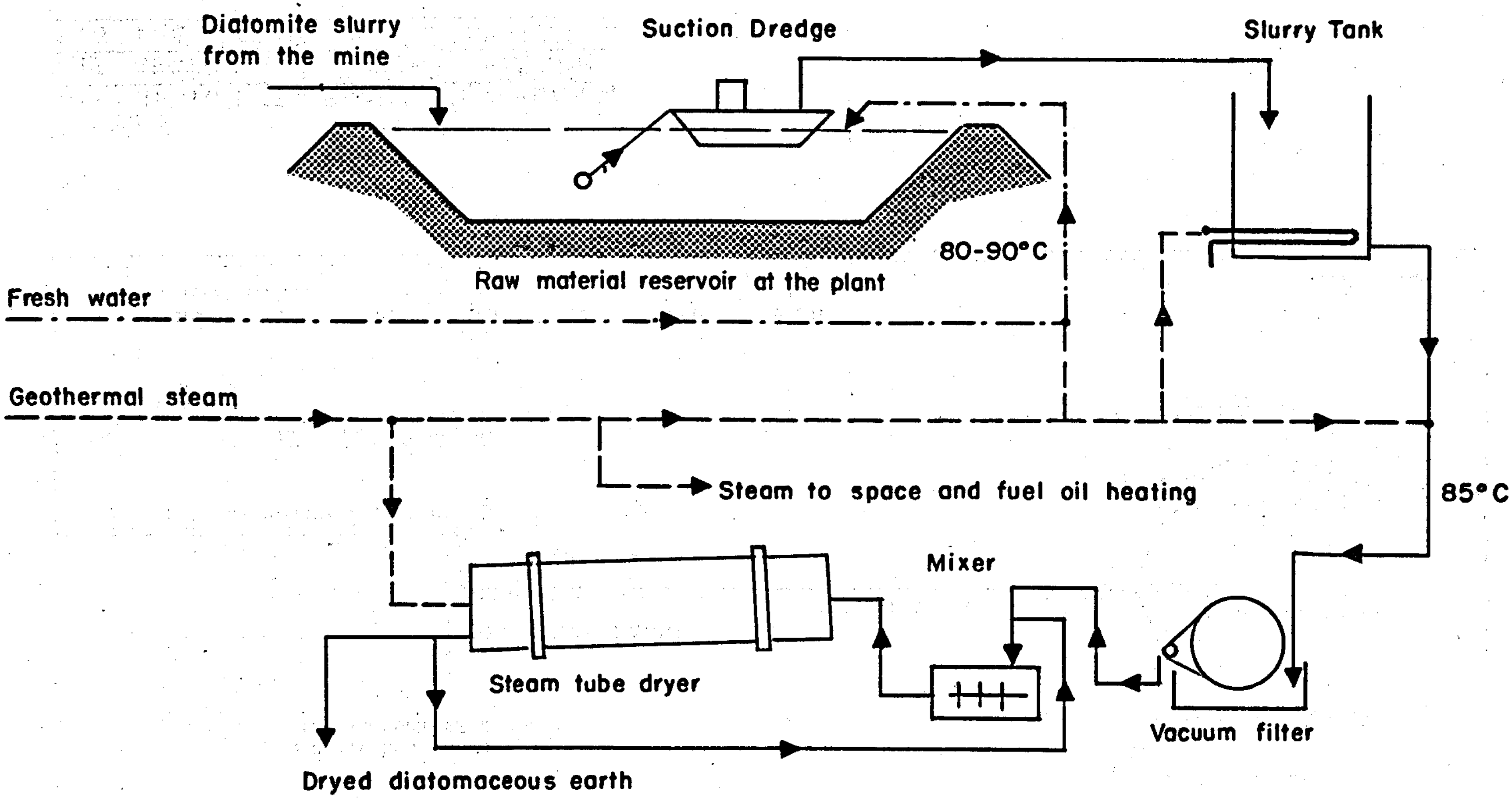


Figure 4. THE UTILIZATION OF NATURAL STEAM IN A DIATOMITE PLANT.

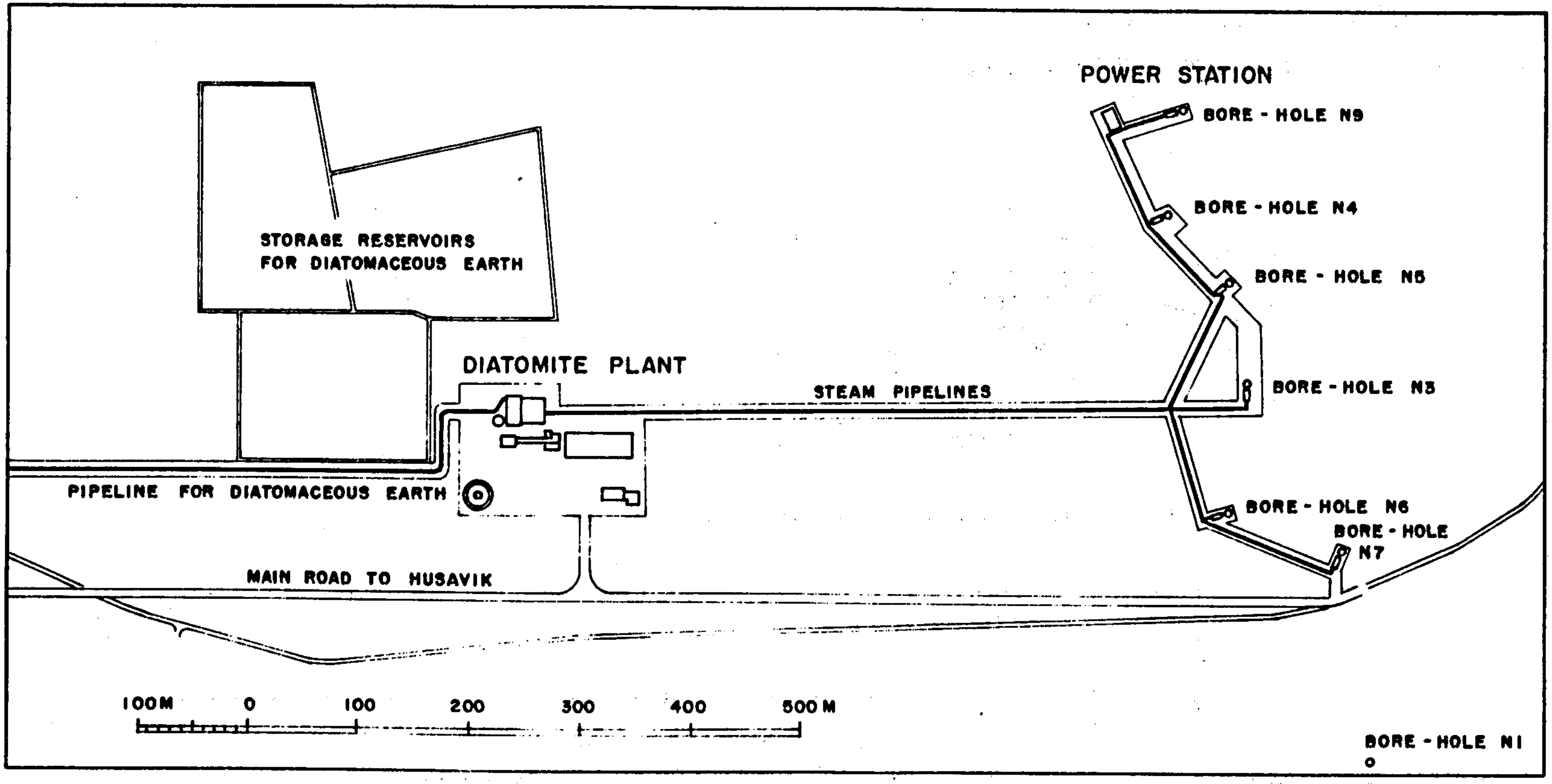


Figure 5.
<u>THE DIATOMITE PLANT IN ICELAND, THE GEOTHERMAL POWER STATION AND THE STEAM SUPPLY SYSTEM.</u>

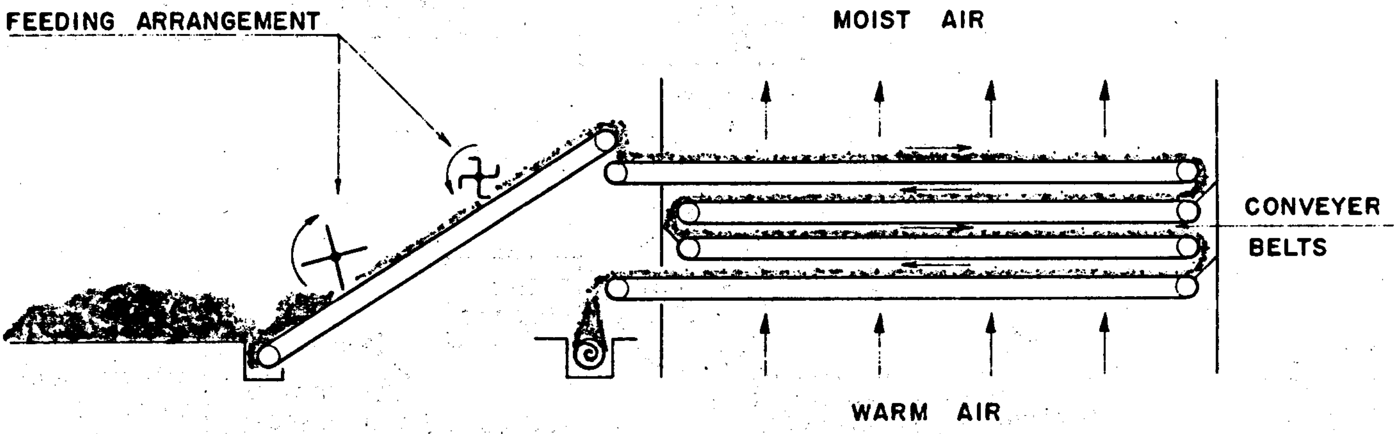


Figure 6.

A MULTI - DECK CONVEYER DRYER AS PROPOSED FOR HAY - DRYING.

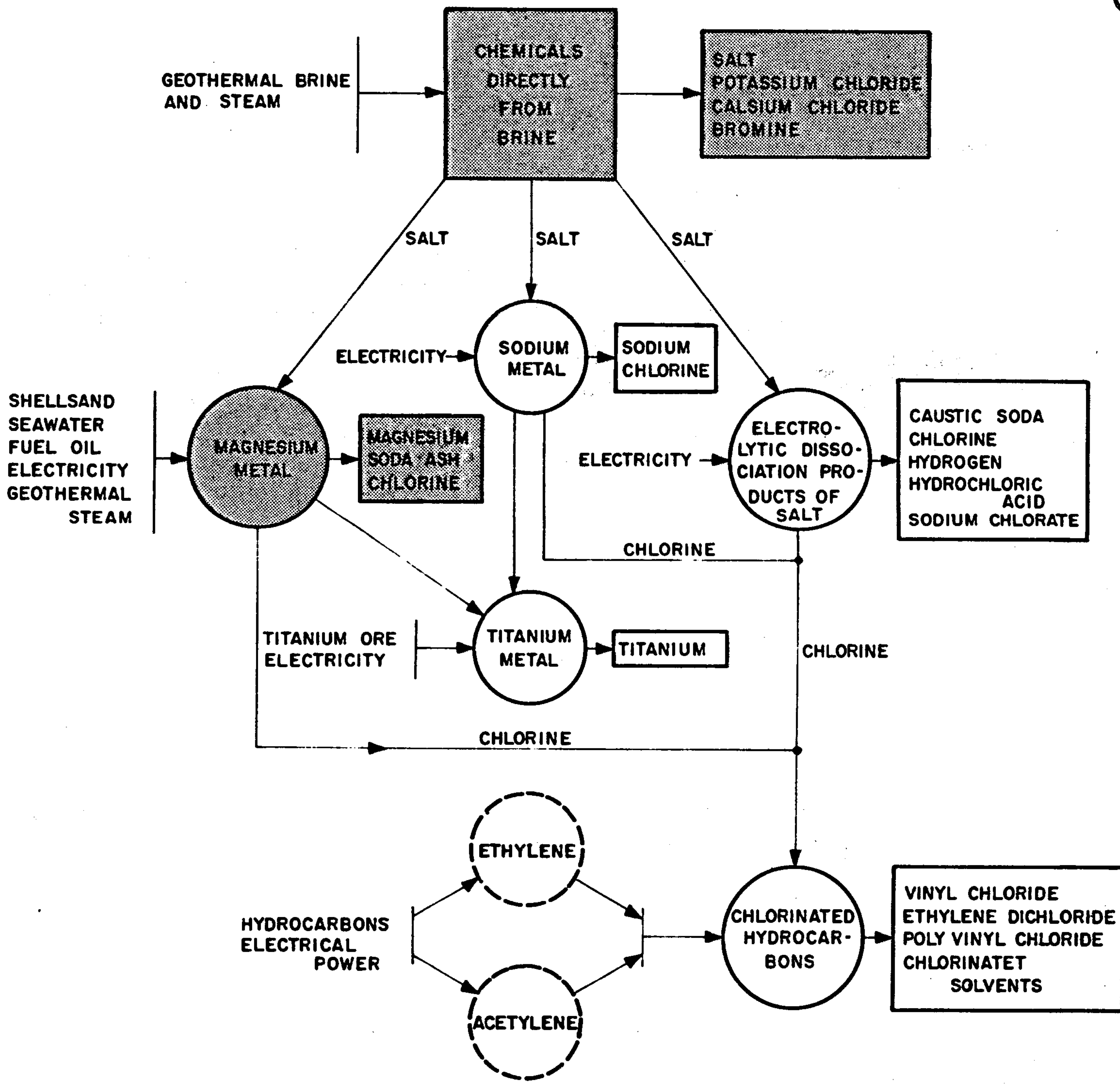


Figure 7. ORGANIZATION OF THE SEA CHEMICALS PROJECT.

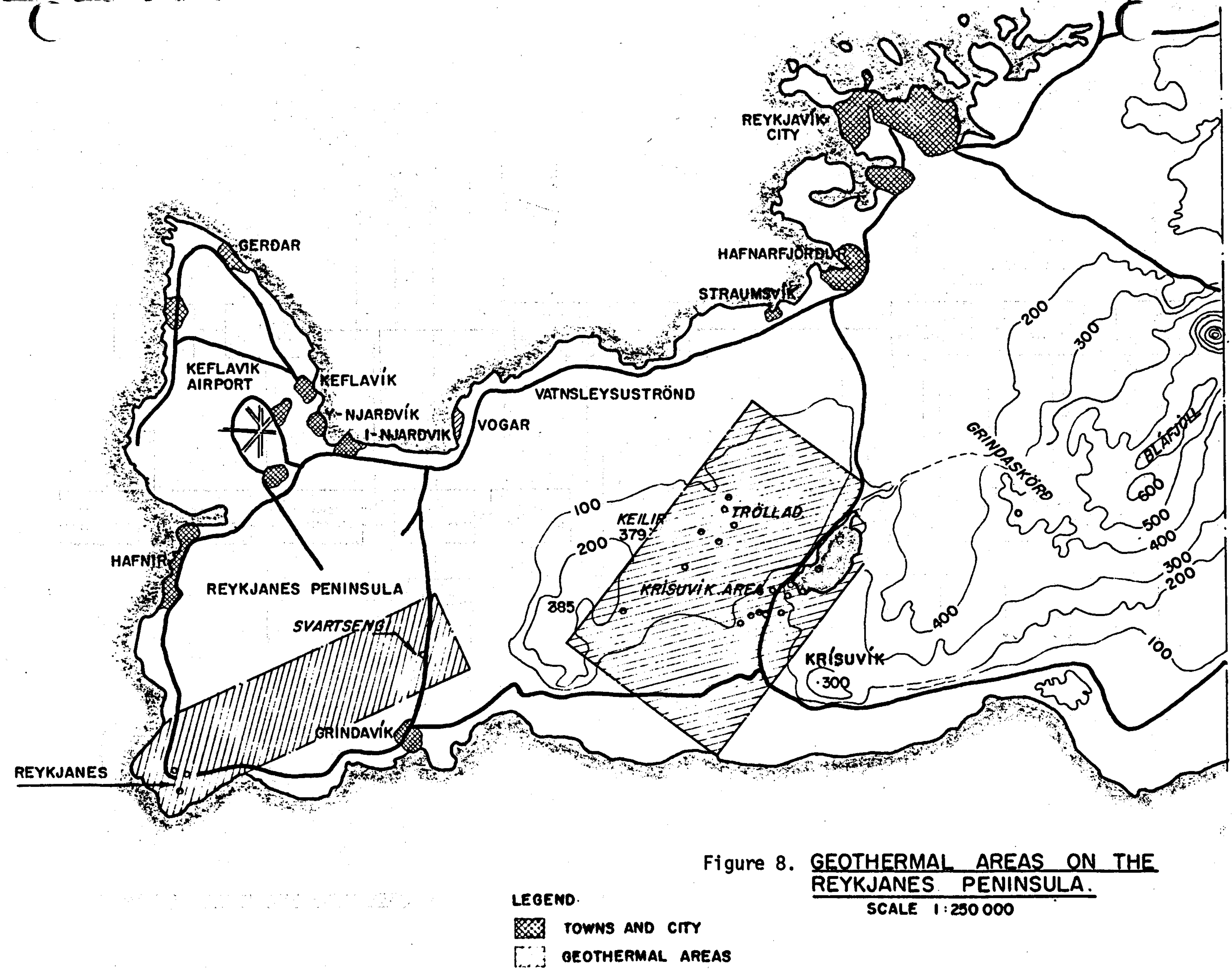


Figure 8. GEOTHERMAL AREAS ON THE REYKJANES PENINSULA.
SCALE 1:250 000

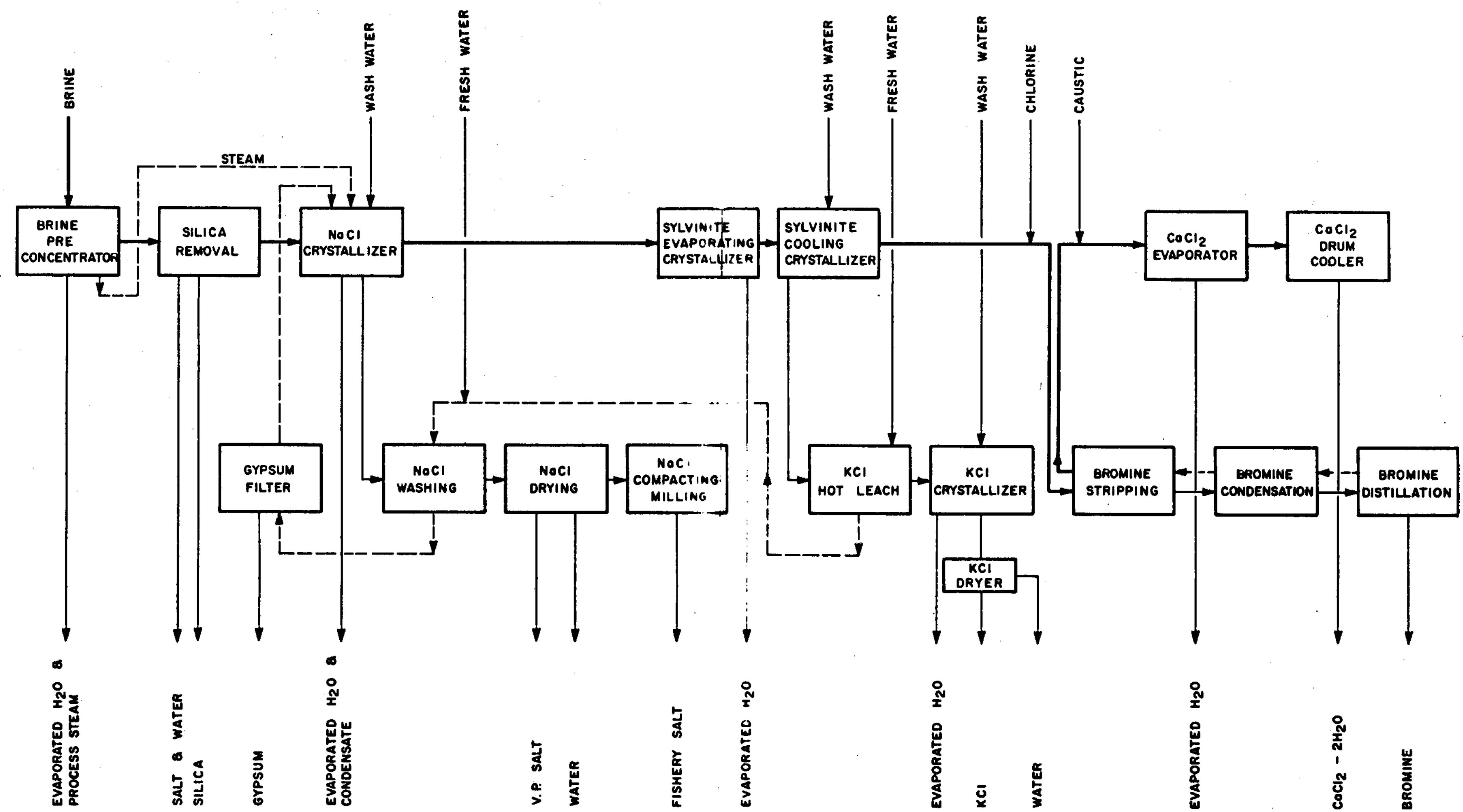


Figure 9. Process Diagram <u>REYKJANES SALT PLANT</u> (DSS Eng. 1973)

53083

UTILIZATION OF GEOTHERMAL ENERGY IN ROTORUA, NEW ZEALAND

By

William Burrows[1]

ABSTRACT

The uses of geothermal energy in Rotorua, New Zealand come from over 700 registered geothermal bores. Effluent disposal is accomplished by boreholes with a six-inch casing to a permeable strata. Heat exchangers involving combinations of contra-flow units are very efficient and increasing in numbers. A relatively low output bore can be made to do a large job by means of a storage-type exchanger used on a mixed secondary circuit in conjunction with a time switch. Geothermal control valves presented a real problem until Satchwell M. H. valves were used; however, due to a scarcity of this valve, motorized versions of ball-type valves are now being brought into use. The Forest Research Institute uses geothermal energy for timber drying kilns, space heating and cooling of a laboratory complex. A 2000 foot long transmission line is used to supply fluid to the Institute. The Queen Elizabeth Hospital has 200 beds, out-patient service, and a cerebral palsy unit. The hospital has a physiotherapy wing and a full hydrotherapy wing consisting of two pools. A generous source of geothermal energy is used to supply heat for this hospital.

GEOTHERMAL ENERGY UTILIZATION IN ROTORUA, NEW ZEALAND

The Geothermal Bore Register started in Rotorua by N. Modriniak of the New Zealand Geological Survey Branch of the Department of Scientific and Industrial Research, and referred to in his published paper in the New Zealand Journal of Science and Technology, 1945, has been used as the base for the present Register which was used to continue the recording of the 60 bores recorded by him to the present listing of over 700 registered geothermal bores in the Rotorua area.

The Rotorua City bore field is about two and a half miles long and almost a mile wide, with bores from 50 feet to 1,200 feet in depth, in size from 2" to 6" production cases, and from 120°F to 350°F in temperature at the bore head.

The first recorded geothermal bore was drilled in 1935 and produced a flow of boiling water from a 37 foot deep 2-inch casing. This was numbered 38, shown in zone 1 on the attached Rotorua City plan (Figure 1). In this locality are many similar shallow bores with temperatures between 150° and 211°F.

Bore 219 was drilled over 20 years ago and from a depth of 495 feet produces 12 million BTU/hr of heat above 180°F, with a total heat of 26.8 million BTU/hr at 320°F and has been in constant use, apart from an annual 24 hour shut-down for silica removal from the production casing. This bore

[1]Retired public works inspector of geothermal uses, Rotorua

supplies the Rotorua Boys High School heating system and swimming pool with heat. The steam water effluent is passed through approximately 4,000 feet of 3" pipe to supply two-two pass tubular heat exchangers for space heating and another exchanger for heating the swimming pool. This is at present the best producing bore in zone 1.

The public hospital is also in zone 1 and in steam terms the present consumption of geothermal energy for heating would be the equivalent of 2,500 lbs. of steam per hour at 150 p.s.i.g. from three bores, with another six bores now being sited to supply the equivalent of a further 16,000 lbs. per hour of steam at 150 p.s.i.g. The present bores are all below 25 p.s.i.

As may be expected in Rotorua, which has been subject to much volcanic activity, drilling conditions may vary considerably within quite close distances. Along the indicated eastern fault line bore 507 strikes no rhyolite and is in relatively unstable country with hard mudstone layers, layers of soft mud, pumice layers with occasional layers of sand. These conditions tend to carry right along this fault.

In the city commercial center, in zone 2, rhyolite is likely to be struck at quite shallow depths, with unstable conditions again being encountered in the area around bores 493 to 219, 548 and the area adjacent to the lake.

These conditions necessitate a sound knowledge by the well drillers of local factors and geology and the enforcement of safe standards in well drilling and well specifications.

Problems have been encountered where production casings are penetrated from the outside by acidic water layers, and again by presumed underground lateral movement when a section of the open hole may move sideways. This latter is not common but has occurred several times.

Bore 507 is described in the section on the Forest Research Institute and is in "difficult" country on the very edge of a highly active thermal area.

Two main factors considered in this bore were protection from surface corrosion of the production casing and anchorage to the country in a manner to prevent migration.

Bore 549 at the Queen Elizabeth Hospital presented another problem that occasionally arises. The estimated depth of this well before drilling was 300' to 350'. The country was gassy at the surface with sulphur depositing at small surface gas vents.

A 14" hole was drilled, with no problems, to 25 feet and a 9 inch casing lowered and grouted to the country.

On setting of the grout a 9" hole was commenced and water at 55 feet was a temperature of 190°F encountered. There was a total water loss and in view of this it was decided to reduce the drill size to 6 1/2" and drill to enter casing. After a few feet, 65 feet of casing was set up on the rig and driven to resistance.

A strong flow of H_2S and CO_2 between the casings presented a grouting problem. To overcome this, another hole 4 inches in diameter, was drilled and cased to the gas level 4 feet away and water forced down the annulus between the two casings to be grouted until a strong gas discharge came from the 4" hole. A fitting was made to allow grout to be forced between the two casings and grout pumped in until resistance was reached and the fitting inlet then valved off. This means of discharging the gas proved successful and enabled the bore to be satisfactorily completed.

Effluent Disposal

This is an important design feature.

City Council regulations forbid the discharge of geothermal effluent into storm water drains or sewage lines. The water authorities look with a prejudiced eye on disposal into streams or lakes, so it is now accepted that effluent is best returned to the ground whenever possible.

To achieve this the original practice was to dig a large pit, fill it with stones and roof it over with timber. This was not particularly successful, so the present practice of sinking a six-inch cased hole to a permeable strata is generally considered the most satisfactory.

These soak bores rarely give trouble provided they are adequately vented and that provision is made to separate steam and gases from the water.

In many cases, 24" or 36" holes to 15' or 20' are used in domestic systems. These are usually fitted with concrete liners, a concrete lid, and a vent but quite often allow discharge of steam and gas into the surrounding country causing damage to lawns and gardens.

Heat Measurement

For bores supplying steam for power generation, full calculation of steam fraction is necessary where steam and water separation is carried out. As it is not necessary to separate steam from water for our uses, a very simple calculation sheet has been accepted as a local standard, a copy of which is attached.

A simple calorimeter is used, made from a 400 gallon tank mounted on a towed vehicle with a divided feed line allowing either full by-pass or full injection of bore effluent into a predetermined quantity of cold water. The average is taken of three, thirty second runs at full discharge. The change in temperature and increased volume of the water is measured. For some applications more calorimeter readings are necessary to assist the design engineer particularly where further load extensions are envisaged and control valves could be affected.

While the Rotorua waters vary in pH from 4 to 9^+, the water from bores is almost always about pH 9. Very little if any internal corrosion takes place, on the contrary, deposits of silica--a very loose term--can build up in the pipelines and completely choke or close them, rendering the bore inoperable.

To combat precipitation, or at least to ensure that it does occur where access is easy, centrifugal separators are often fitted at the well head, and the first 25 feet of delivery pipe made accessible for removal and replacement.

This latter precaution I feel is most important as in restricted areas the bore may be very close to the calorifier room and considerable trouble could be experienced cutting out sections of the pipe with possible damage to a structural and building walls in the process of pipe renewal.

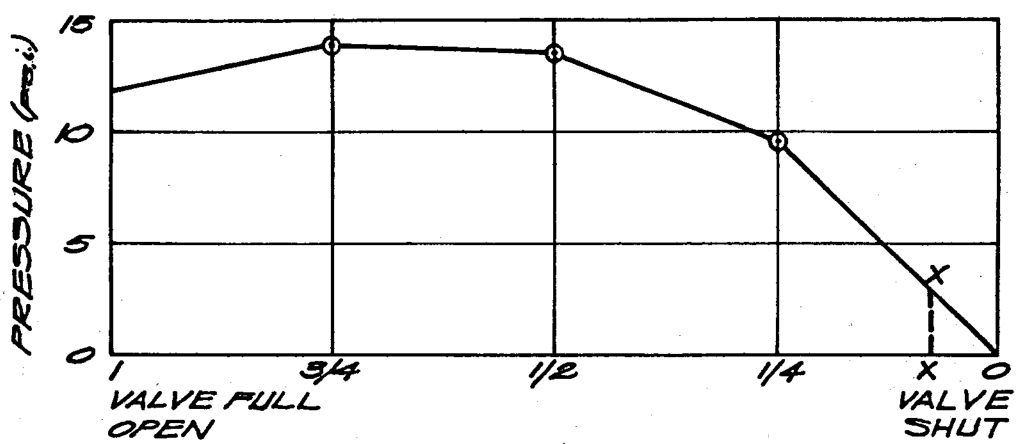
Assuming that the design has correctly determined the overall heat requirements of the project, heat exchanger design is the next consideration.

The Geothermal Energy Act and Regulations specifically state that geothermal energy shall be used economically. It is safe to say that fifty percent of the installations in Rotorua are of low mechanical efficiency on the primary side.

The types used range from the early hot sleeve type with a constant flow of town water through them and the radiators, to the nearest drainage point, to tubular and plate type exchangers. There is quite a variety, many of them extremely well designed for economy and maintenance.

I shall return to the subject of heat exchangers after considering the difference between the bore output and the required heat load.

It is obvious that to put the full discharge of a bore producing say, 1.0 million BTU/hr through a sleeve type heat exchanger to supply a system requiring in the vicinity of 100,000 BTU/hr is extremely wasteful, and produces a problem of disposal.



TYPICAL LOW PRESSURE BORE

FIG. 1

POINT X IS A VARIABLE AT WHICH POINT THE BORE CEASES TO PRODUCE AND WHICH IS AFFECTED BY GROUNDWATER LEVELS, SYSTEM RESISTANCE AND OTHER FACTORS.

It will be clearly seen that to use the bore efficiently and dispose of effluent at a compatible temperature a series of calorimeter tests is advisable, finally locating the ideal design point.

The most common problem in geothermal systems, is that of disposal of effluent and is almost always caused by returning waste into the soak bore at an excessive temperature. Steam locking occurs and various means are used to force the discharge into the ground by restricting vent pipes.

This can also create another problem in soak pits, or shallow large diameter soak holes. Local migration can cause surface damage. An ideal design is when heat can be extracted and effluent returned at between 160°F and 200°F.

You will have noted the shut down point (Figure 2) which indicates a restriction that is sufficient to stop the bore producing and will need restarting. This does not apply to all bores as some are naturally artesian and will start producing unaided from a cold condition.

When a system is controlled automatically it is obvious that something has to be done to prevent closing down when a change in heat demand causes the regulating valve on the calorifier primary circuit to close.

This is usually done by fitting a manually operated by-pass which is set by closing off the system and gradually operating the by-pass until the bore is operating through it at just above the shut down point. A variation to this is the fitting of orifice plates downstream of a valve as gate valves used on geothermal control should be either wide open or shut.

Another variation was to install a small electrically driven control valve on the by-pass which opens when the main control valve reaches a given point in its travel towards the fully closed position. This periodically gave trouble and was discontinued.

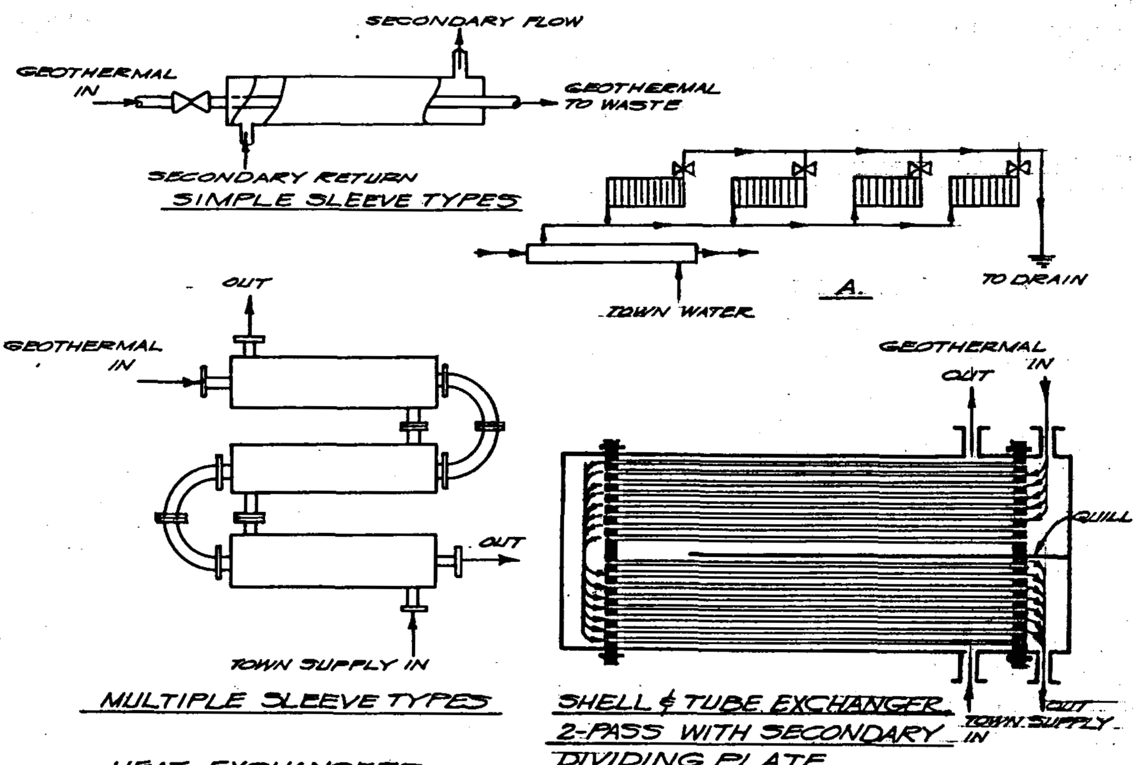
The main disadvantage of the manually set by-pass valve and orifice plate is that at all times a percentage of higher temperature water and flashing steam is passing to the soak bore which can cause locking problems and quite often a spray of condensing steam across buildings and roads.

This problem has been successfully overcome, apart from the waste geothermal energy, by discharging effluent and by-pass effluent into an expansion chamber where any remaining steam flashes off and finds its way at low pressure through an adequately sized vent pipe, and allowing the water to flow by gravity into the soakage bore. Later system designs also allow for higher secondary temperatures and the use of mixing valves which in turn permits the permanent by-pass to be put through the heat exchanger instead of around it.

Heat Exchangers

The first known heat exchanger consisted of a pipe coil connected to the town water supply being placed in a hot pool, and from there led to a tap at a suitable point giving, in fact, a continuous hot water supply much as the modern quick recovery domestic hot water system does. This naturally led to the sleeve type, which consists of a jacketed section of geothermal pipe as in sketch A, (Figure 3) having a constant water bleed through the radiators.

It would appear that at this time local enthusiasts were taking big risks by sinking their own bores and developing and installing their own systems. No doubt many systems were illustrated. (Figure 3).



HEAT EXCHANGERS
FIG. 3

Most of the early systems were in shallow levels and had to be constantly pumped. In these cases adequate sized exchangers were made and installed.

I would assume that about this time hotels and one or two public buildings were converted from low pressure hot water heating systems using coal or coke fired boilers to geothermal systems by replacing the boiler with a heat exchanger. Whakarewarewa Maori School still has its boiler connected in with the heat exchanger, and many old boiler houses are now clean plant rooms.

It was these low pressure hot water systems that led to the disuse of the constant bleed system and sleeve type exchangers (Figure 3) were put to a more economic use, quite large capacity units being built.

It was found that in places where a change in direction of flow takes place, particularly in the lower temperature pumped bores, a build-up of silica took place. This necessitated the use of straight through tubes, rather than the more commonly used return tubes, with detachable end covers to facilitate tube cleaning.

In view of this secondary or tertiary precipitation some engineers were loath to design to a primary drop in temperature below boiling point in the exchangers, but in very few cases has this presented any problem.

Some systems are working to a drop from 235°F to 150°F with no apparent drop in efficiency. However, cleaning access is there to be used if necessary.

It has been noted that in areas where bores are generally dirty, tubes of less than 2" diameter should not be used.

From straight through multi-tubular exchangers two-pass, three-pass and multi-pass exchangers developed.

Combinations of banks of contra-flow units as illustrated (Figure 3) are now very efficient and are increasing in numbers.

Much, however, can be said in favor of the large volume or storage type exchanger used on a mixed secondary circuit in conjunction with a time switch, where a relatively low output bore can be made to do a large job.

The recovery period is arranged for night time when heat losses to the building are less, due to much less frequent air changes caused by open doors and windows, and the passage of people from one room to another.

It has been found that with a relatively light bore a further recovery period can, on most days, be arranged for between 11 a.m. and 2:30 p.m.

Valves and Controls

The tendency for calcium and silica carbonates to precipitate under given conditions makes the careful selection of valves essential.

Any reversal in direction of water, turbulence, sudden changes in velocity tend to cause blocking of valves or whatever the piece of equipment that is bringing about the condition. For this reason cast iron (spheroidal graphite) full way gate valves were once used. "Everlasting" sliding gate boiler blow down valves also, but trouble with spindle glands in the first type, lack of provision for lubrication, and price, in the second, brought about the acceptance for local use of a lubricated plug type valve.

These were the best valves for local conditions until superseded by ball type valves with either stainless steel or chrome balls and Teflon seals. These are now the most used on-off valves.

Geothermal control valves presented a real problem until the Satchwell M.H. valve was discovered. This valve has a stainless steel body and an axially moving carbon piston with carbon bushes on a chromium alloy actuating crank and shaft driven by a small electric modulating motor which is thermostatically controlled through a special control box. We have had these running continuously now for 14 years. Unfortunately these valves are now very difficult to obtain. Any leak, even if not visible, of H_2S and other gases through a gland soon makes itself evident by a white encrustation of silica salts which left, will soon render a valve inoperable.

This is also evident where separated steam is used, however there is a most important difference; whereas in using high temperature hot water with a steam fraction of say 7 to 10% which is now almost standard practice where heat transfer only is involved, the use of straight through valves is important, it has been found that Drayton valves are quite satisfactory in separated steam for use in temperature control.

Due, as previously mentioned, to the scarcity of Satchwell M. H. valves, motorized versions of ball type valves are now being brought into use. A particular valve with a stainless steel shield over the P.T.F.E. seat gives protection against seat creep and also damage by abrasion when used as a modulating valve.

Ball valves have been used on our jobs for the last nine years following tests at the Queen Elizabeth Hospital, the only failures being where a valve has been used in adverse conditions in a partly open position.

The desirability of keeping H_2S away from electronic control equipment has resulted in the use of carbon filters in conjunction with ventilating and in conditioning systems. One unit developed by the Post Office Engineers consists of a standard vacuum cleaner with the bag replaced by a container containing activated carbon, and the speed reduced to the required air flow. These are fitted directly onto control panels ensuring clean air at all times.

Finally, when considering a geothermal heating system in conditions similar to ours in Rotorua, attention should be given to:

1. Make sure effluent disposal is possible first.
2. Make sure when you have drilled and tested the bore that the design engineer has all the test information you can give him.
3. Make sure that servicing access is adequate.

The Department of Scientific and Industrial Research has released information indicating that the potential of the Rotorua City area is in the vicinity of 100 megawatts.

THE FOREST RESEARCH INSTITUTE

The Forest Research Institute is a research division of the New Zealand Forest Service, and is situated just outside the Rotorua City boundary. It is devoted to scientific research in all phases of timber genetics, preservation, physical testing, paper testing, incubation, tree growth studies and pest control and is sited beside an active geothermal area.

It is staffed with scientists recruited from all over the world who experiment continuously to produce the best trees possible and give a first class service to our timber, building, pulp and paper making, by-products and allied industries.

Planting of exotic forests in New Zealand commenced early in this century, receiving added impetus in the depression years when cheap labor was available. Selective seed collection and improved nursery techniques followed in their natural sequence.

The first use of geothermal energy by the Institute goes back some twenty-five years when small experimental timber drying kilns were installed, heated from a shallow geothermal bore.

Some buildings were heated by direct geothermal effluent and a mineral bath built, supplied from the cooled discharge.

Until a few years ago when Stage I of the new institute building was built the major use of the old building's complex geothermal system was for space heating of the many individual buildings and laboratory blocks and heat for twin drying kilns for a seed extraction unit. This unit which for many years operated on a twenty four hour basis, uses raw geothermal effluent through a heater battery closely controlled by Satchwell M.H. valves.

The first geothermal bore failed because of casing perforation. This was not surprising as it appears that it was a single medium thickness galvanized steel pipe, sunk by the old cold water drilling methods of drill and drive.

A second bore, double cased, with a concrete grout annulus between the outer case and the ground and pressure grout between the production and anchor case was drilled in 1953. Black steel well casing was used for both casings.

This bore produces 8.4 BTU/hr. useful that is above 180°F. The pressure is 60 p.s.i.g. and the temperature is 300°F., water flow being 5,800 imperial gallons per hour. This is an interesting bore in that it is unusually clean, having at no time shown any signs of calcite build-up. A further interesting point on this installation was that the initial distribution main was beautifully designed--even to the extent of installing steam traps. A further unusual characteristic is that when load conditions, in this case light loading, caused the well head pressure to stabilize at 40 p.s.i.g. and remain in that region for some considerable time, (usually during summer when the space heating load is off) the well is reluctant to readjust to increased demand when winter load is added again. This peculiarity crept in almost unnoticed until further summer time loading by extensions to buildings and usage, still well within the bore's capacity, made the position most noticeable. It was thought that calcite deposits must have built up in the production casing, as can be quite usual. A drill rig was set up on the well and a cutter passed right down the bore to the bottom without locating any build-up. The bore was then air pumped to start and left discharging to atmosphere at 40 p.s.i. Two hours later a milk color was noticed in the effluent which gradually increased, and with it, the pressure, until in another two hours the pressure was 60 p.s.i. Then the effluent cleared to its former color. This is the only case experienced where a build-up or fall out of calcite has apparently taken place outside the bore, for example, in the ground supplying the steam. Our chemists have not yet got around to analyzing or fully explaining this phenomena.

In view of the increased anticipated loading when new institute buildings were proposed and designed, another supply bore was drilled on the edge of a very geothermally active area, one which is still undergoing almost constant surface thermal variations. This bore, No. 507 in the Rotorua register, was drilled by a local geothermal well drilling contractor, to Ministry of Works specifications. Forty feet of 10" casing was lowered into a 16" hole and grouted into the country and allowed to set from Friday to Monday.

A ten-inch hole was then drilled to a mudstone cap at a depth of 150 feet. A six-inch casing was lowered and lightly driven into two feet of a 6 1/2" hole drilled at the bottom of the 150 foot deep hole. The two casings, the 10" and 6", were pressure grouted together. Six-inch drilling commenced and a further cap reached at 300 feet, again a pilot hole was drilled to 302 feet and the casing driven into it. This production casing was grouted to the country and anchor case and when set, drilling of 4" diameter was carried out to 450 feet. The ground appeared tight with a little water loss, but on opening up after a week's spell from drilling, following fitting of well head gear, the bore artesianed and within a couple of hours was producing on full discharge, 75 p.s.i. and later, a calorimeter test indicated 13.8 million at useful heat and 7400 gallons per hour.

The designed exchanger capacity for supplying heat to stages 1 and 2 of the Forest Research Institute laboratory complex from the bores was for four exchangers of 1.5 million BTU's, each with two water to water calorifiers of 400 imp. gallons capacity, total 800 imp. gallons capable of raising the contents from 50°F to 150°F in 60 minutes from a primary flow to 180° with a 20° drop in the return.

The transmission line from bore 507 is 6" in diameter and approximately 2000 feet long, rising from 980 feet above sea level at the well head to 1020 feet above sea level at the highest point, approximately 1000 feet from the well head, then dropping to 1000 feet at the plant room point of entry.

It has never been our practice in Rotorua to separate water from steam. If we need steam we generate it. In view of this it was anticipated that certain problems in transmission could arise due to the three most noticeable factors, for example, (1) opening out from a 4" bore casing into a 6" line, (2) the hump in the distribution line giving a twenty foot drop to the point of entry, (3) the steam fraction of approximately 10%.

The first indication of a problem was in the early stages when one exchanger was commissioned to provide heat to the physical testing laboratory and to one D.H.W. calorifier. It was noticed that a cyclic pressure build-up and drop was taking place on a regular rhythm with further periodic intermediate peaks, accompanied by a water slug. The line was shut off and a 24 hour pressure record taken of the well head being discharged to atmosphere. It recorded uniform production. The old bore, No. 375, was put into the line to check the supply circuit. A similar pattern developed, without the slug, but the rise in back pressure closed the bore down in the early hours of the morning. This pattern continued for bore 375, which had also showed a steady discharge to atmosphere under test recording.

A low level bleed from the transmission line near 375 of 1" drain point, was found to prevent the self shut down, but it was then found that bore 375 could not hold the physical testing lab to its minimum working temperature against a 10°F frost. Meanwhile certain tests carried out on bore 507 showed an unusual pattern of pressures while the bore was discharged to atmosphere through different orifices. These orifices were varied by fitting various diameter tubes. First a 12 foot length of 1/2 inch pipe was fitted. After stablization the pressure read 60 p.s.i. This was repeated for different diameter tube orifices with the following results:

3/4"	pipe	72 p.s.i	1 1/4"	pipe	95 p.s.i.	2 1/2"	pipe	105 p.s.i.
1"	pipe	84 p.s.i.	2"	pipe	118 p.s.i.	3"	pipe	97 p.s.i.
						4"	pipe	84 p.s.i.

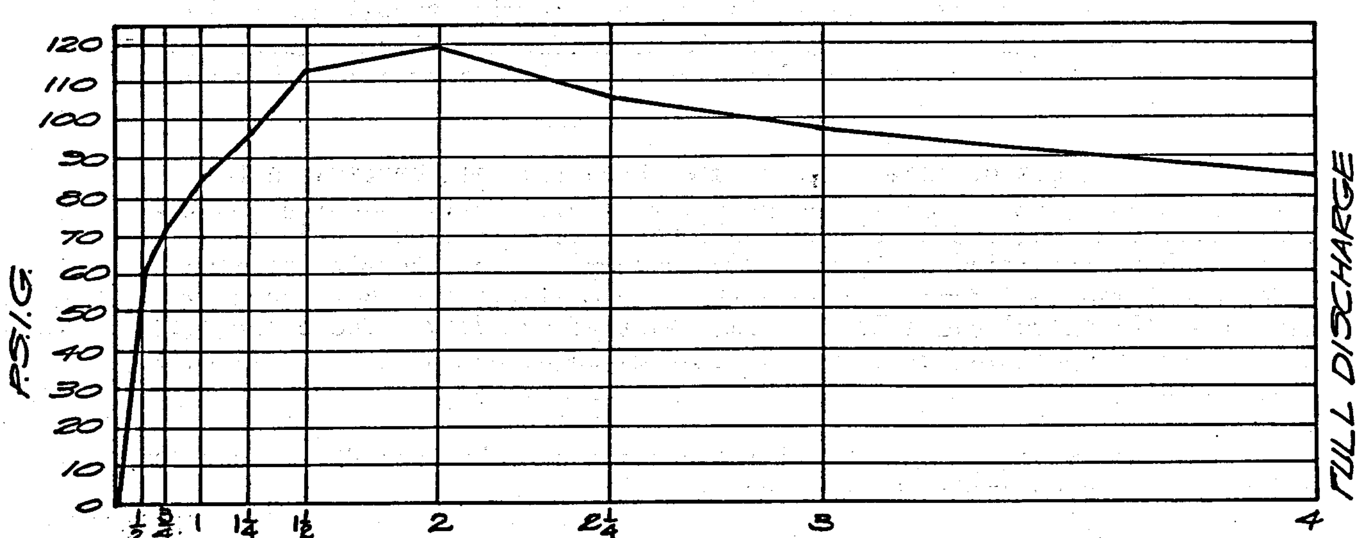


FIG. 4

From this check two things became apparent:

1. The country had heated up and increased supply to bring open discharge from 75 to 84 p.s.i.
2. That any change in density in the pipe due to flashing to steam or condensing, could have similar effects to altering back pressure on the well head by means of valves.

It was decided to put in a by-pass around the exchanger direct to discharge. A 1 1/4" Satchwell M.H. motorized valve was selected which was wired to open as the exchanger control valve closed. The valve did eliminate slugging but only after being put on manual control. This gave a constant bleed which could be reduced in cold weather.

The pressure cycles continued but were finally cut back by balancing bore pressure to the load.

This, in trial form only, but still in use, consists of a series of ball valves ranging from 1" to 3" around the line distribution valve at the well head, so that any valve from 1" to 3", or any combination of them may be opened and fed into the line around the closed 4" isolating valve.

A brief run through the equipment serviced by geothermal heat from four 1.5 million B.T.U. heat exchangers.

Floor area of laboratories and workshop is 65,500 square feet. All pipe work consisting of D.A.V. at 150 F, constant temperature hot water for air conditioning plants at 180 F. and low pressure hot water system water regulated by pilot controls, is run in a service tunnel under the floor, with air, vacuum low pressure steam, condensate, high pressure cold water, fire sprinkler mains, chilled water and all electrical services and glass wastes.

The types of heaters are: downthrow fan unit heaters in the high buildings, consisting of the products wing, physical testing lab and paper test section, and continuous wall convectors in laboratories and offices where conditioned air is not necessary. Five laboratories have independent fan coil conditioning units each of about two tons capacity with a ∓ 2°F control and a 50% maximum relative humidity. The paper test laboratory is operating continuously controlled within ∓ .5°F and 1% relative humidity.

The two other main conditioned areas are the Tree Physiology suite and an area around the incubation rooms.

With the exception of five cool rooms and the paper test laboratory, all cooling is by chilled water coils. Two 120 ton centrifugal chillers handle the chilled water.

The Physiology suite is built around three growth rooms, each with a moving platform on which 4 feet high young trees in tubs may be placed and the platform gradually lowered as the trees grow. The movement is 20 feet.

Each unit has its own light rig, light rig ventilating system, and its own air conditioning system, using constant temperature hot water in its heating circuits, through modulating valves.

The duties of these plants is to maintain any settings ∓ 1°F between 50 and 95°F and relative humidity to 70% ∓ 5%.

The light rig is separated from the growth room by a ceiling of 1/2" armour plate glass.

It is conceivable that with further development of the bore field, some thought could be given to heat absorption refrigeration units. At the time of writing, a steam generator has left the drawing board which, at this stage, could replace a packaged steam boiler in use at present.

Further development of the bore field has brought in bore No. 599 which is a replacement standby for 375. The attached chart shows how different it is in character from 507 which is about 150 feet away.

The design engineer was given the information available, that is to say, the calorimeter sheets plus down hole temperatures against depth and boiling point for depth curve, further variables crept in, mainly in the transmission phase.

In sharp contrast with this, most private geothermal enterprises in Rotorua supply the pressure and temperature to the design engineer who has to make the best of it.

It is evident that in most projects, be it a household system or an office block, if any economy measures are necessary, the services are pruned, or the lowest possible tender accepted.

I have included bores 599 and 375 to show how three bores, 599 is 150 feet from 507 and 75 feet from 375, vary so much.

THE QUEEN ELIZABETH HOSPITAL, ROTORUA

This hospital was built during the war for U. S. Servicemen and eventually was developed by the Department of Health as a national hospital for the treatment of rheumatic diseases. Medical and physiotherapy staff were transferred from the old Goverment Bath House in Rotorua which was built as a spa in 1908. The hospital has 200 beds, an out-patient service and a Cerebral Palsy Unit. As one of the important ingredients for the treatment of rheumatic diseases is heat and warmth, the hospital is ideally sited over a generous source of geothermal heat, on the lake front and quite close to the city amenities.

The first two bores drilled to provide geothermal heat for this hospital were single cased holes producing at 15 p.s.i.g. These provided water for an exercise pool, and were the first stage in L.P.H.W. heating of one wing of the hospital and a ward. The exercise pool was later taken off the mineral water and town water used, a heat exchanger of the sleeve type and a filter plant installed.

The remainder of the hospital was steam heated by two 15 h.p. underfired multi-tubular boilers which also provided sterilizing steam, steam in the kitchen and D.H.W. heating.

A nurses' home was built later and a bore sunk which produces at 60 p.s.i. This home has its own plant room and services. Two heat exchangers supply heating and priming hot water to a D.H.W. calorifier. This is a conventional system and the exchangers are two pass shell and multi-tubular types.

This system has given an almost trouble free service since its installation over 20 years ago and running costs are very light indeed.

The few problems encountered were external corrosion of the underground geothermal mains which were solved by replacing them with new above ground mains with a ramp across for access. The original control was a capsule actuated mitre valve which, though satisfactory in separated steam, proved quite unsuitable in geothermal high pressure hot water (sometimes referred to as two-phase transmission, or as Lawrence Livermore expresses it, "total flow"). After some years the M.H. valves and controls were installed and have proved satisfactory.

A test bore sunk adjacent to the main hospital boiler house to a depth of 850' had a hot section at 300' but a falling temperature gradient from 325'. Tests on the bore proved that it had struck an extremely dirty stream of underground water and on full discharge the casing built up solid in two weeks. When discharged through a 2" pipe the build-up period extended to six weeks. In view of this problem, it was decided to investigate another site about 100 feet away. This bore was given ample corrosion protection by an outer concrete annulus around a 6" case 63' deep, and a 4" production case was set in and grouted at 296 feet. On commencing drilling open hole, the well had a total water loss at 300 feet. This, I would say, would be the least amount of open hole of any bore in Rotorua.

This bore, numbered 223 proved to be the one that the Health Department's financial people had been waiting for. Money was made available for a standby bore within 40 feet which came in at almost the same pressure, 60 p.s.i.g. 300°F, 10 million BTU/hr useful heat.

Design was then commenced on the heat exchangers and modifications to provide for a progressive take over of the boiler load. This exchange of heat source had to be done without interfering in any way with the working of the hospital.

Four inch flanged and welded geothermal mains were run from both bores into a header in the plant room. Lubricated plug type valves were installed at all isolation points. These were the only valves available which could be guaranteed to shut off when required, as steam valves create turbulence and cause salts to be deposited inside the valves restricting their operation. Bronze or brass valves, according to composition, tend to become unserviceable due to chemical attack. Cast iron and steel valves, unless provision is made for lubrication, tend to seize up.

Another early problem encountered when the pools were filled was ventilation. Initially adequate ventilation, proved, under some air movement conditions, to be inadequate and fairly high H_2S readings were recorded in scum channels. To counteract any possibility of concentrations of H_2S in excess of 10 p.p.m., a heat exchanger consisting of four modular units was designed and installed and fan coil units installed to sweep each pool, assisted by extract fans at low level.

During this stage various makes of ball type valves became available and several different makes were installed, from 4", all one make, to 1". The idea was to try to achieve standardization by sizes.

All these valves and cast steel bodies with stainless steel balls and P.T.F.E. seats and seals. All gave good service provided they were either full open or fully closed. Some seals crept or failed when the valves were used as regulating valves.

The geothermal system settled down well and saved the hospital well in excess of $30,000 per year.

The plant room is checked daily but operates untended from 5:00 p.m. to 8:00 a.m. weekdays and from 5:00 p.m. on Fridays to 8:00 a.m. on Mondays. The worst that could be anticipated to happen, would be for a generator to run dry. This could cause no damage, but a low water alarm signal would be transmitted to the Public Hospital a half mile away.

The low pressure hot water systems and D.H.W. load is 9 million BTU/hour.

Use of Rigid P.V.C.

The necessity for pipework within walls in the hydrotherapy wing led to the use of rigid P.V.C. pipework and valves. This is also used for piping under pressure, Priest water from a hot sping situated outside the eastern boundary of the hospital grounds and approximately 1500 feet from the Priest water bath. The 2" pipe of this line is laid in a sand filled trench, and as the water is at a temperature of 145°F, provision in the form of sliding joints is made from expansion. The pipe also runs under the hospital from east to west, supported throughout this section on timber. The temperature is well within the capacity of this pipe so no troubles have arisen from its use, other than stretching of the P.V.C. bolts on valve flanges. These have all been replaced by stainless steel bolts.

Some trouble was encountered with the pumps used for this particular water but eventually a centrifugal pump with a gunmetal case and impellor with the shaft adequately sleeved with gunmetal proved most satisfactory. This pump has been in operation for eight years and has required only a few easily replaced parts in its maintenance.

This hospital complex, initially our test bed of geothermal use in Rotorua, has been sufficiently successful to convince anyone that properly designed and installed geothermal systems, properly maintained, are a most reliable and economic means of providing building services under the conditions and requirements pertaining in Rotorua.

As part of the initial changeover, flow and return mains were installed from a header in the boiler room to the section already on geothermal heat from the original bore at the west wing, and connected in through isolating valves. A two unit multi-tubular exchanger was installed for the low pressure hot water system and a single unit exchanger to the D.H.W. service. These were thermostatically controlled to 180° and 100°F respectively through two Satchwell 2" valves which are motor driven modulators. They are of high chromium stainless steel casting, flanged, with well designed axial flow controlled by a crank actuated carbon piston driven by a modulating electric motor.

The old exchanger was taken out from the west wing and the new exchangers commissioned in the main boiler room.

On commissioning, it first appeared that the calculations had been wrong and that the exchangers were undersized. It was also noted that the temperature drop across the primary side of the exchangers did not appear to be correct. A decision to reduce velocity through the primary sides by installing a manual control valve down stream of the exchangers, had the desired effect, and by trial and error a setting was achieved to satisfy all load conditions.

A further problem became evident with failure of valve shafts on the M.H. valves. This was overcome by replacing the 2" valves with 1 1/4" valves with a manually operated 1" valved by-pass around them.

From this the following points were made:

1. Always arrange for control on discharge with a smaller valve than is needed for maximum load, with a manually operated by-pass.
2. Make sure that the pressure drop across the valve is within the manufacturers recommendation.

Following the successful change over, the remainder of the hospital was changed from steam to low pressure hot water heating, and consideration given to effluent discharge to a common point from any of the systems in use.

Two more bores were brought in. One of 25 p.s.i. which means that any of the six bores could be used, and two at a time in divided circuits. The next move was to be steam generation.

From an early conceived idea, Departmental Mechanical Engineers designed the first steam generator. The actual duty of the generator is to produce 445 lbs. of steam per hour at 30 p.s.i. No condensate is returned and towns water at 55°F is fed into the preheaters at mains pressure after treatment.

The hospital operated for another two years with one boiler on standby, during which period the steam cooking units and autoclaves were operated by the steam generator and during this period all formerly electrical sterilizers were connected to steam supply. At the end of this period both boilers were removed and an additional generator installed.

A point of interest is that the preheat section of No. 2 generator is built round a plate exchanger which allows feed water in excess of boiling point to be fed into the generator.

Due to enlargement of the hospital and services required, a third generator to the same design is to be installed in the very near future.

During this development, an old residential wing on the western boundary was demolished, a physiotherapy wing rebuilt and a full hydrotherapy wing, including doctors consulting and examination rooms and all amenities were built. These amenities consist of two pools with pressure douches, the pools at 100°F and the douches at 120°F, using what is locally called "Rachel" water, which is bore water with a Ph of about 9 at the well head, and a similar pool with "Priest" water, which is acid with a Ph of about 3.5 to 4. Next is the mud section where hot mud packs are applied, and two mud baths. The volcanic mud is kept heated, and a liquid mud tank, maintained at a correct temperature by direct injection of geothermal effluent. A mens and womens Aix massage section, each of two tables using Rachel water at 115°F under pumped pressure through cruciform nozzle holders are in constant use and a steam cabinet using generated steam is used for "sauna" type treatment in each of the Rachel pool areas under control of the pool attendant therapist.

The initial brief as to geothermal water requirements led to the installation of a water cooler using lake water as the cooling medium. In actual practice it was found that the water demand was in excess of the original requirement.

The main problem was that to cool the Rachel pool with towns water would lead to a very rapid discoloration and clouding of the water. If left in the pool overnight, even with a 1" hose of straight mineral water running into it, the mixed water in the pool would appear to be festooned with rope-like spider webbing next morning.

The problem was solved by an Inspector from the Department of Health, who identified the cause as Beggiota Alba, a sulphur inhibiting bacteria which, while quite harmless, multiplies rapidly in the right conditions, which are of course, sulphur in water at a high Ph and a temperature around 100°F. The problem was overcome by building large concrete cooling vats out in the open, into which the effluent from all heat exchangers was discharged and additional quantities added as required direct from spare geothermal bores.

Layering, initially troublesome in the vats, was overcome by circulating the water in the vats. A pump house was built and return mains installed above ground level, insulated and aluminum clad, carries cool effluent back to the hydrotherapy section.

The rebuilt and new wing has its own bores and exchangers but may also be serviced from the main plant exchangers. Tiled floors are heated to 96°F while the adjacent physiotherapy wing is radiator heated from the same exchangers.

STUDY AND UTILIZATION OF THE EARTH'S THERMAL ENERGY IN THE USSR

By

I. M. Dvorov[1]

ABSTRACT

The USSR has enormous geothermal reserves with 50 to 60 percent of the country underlain by hot water suitable for commercial use. These hot water reserves have temperatures from 40 to 200°C, mineralization up to 35 g per liter and exist at depths up to 3500 m. The total reserves have been evaluated at 19.75 million m^3 per day. Geothermal hot water is used for space heating by direct use and in peaking boiler plants. Heat pumps are also used for heating and refrigeration. Vegetable growing in the ground with protection uses geothermal hot water from 35 to 200°C, with the most efficient lowest temperature for greenhouses at 35 to 80°C, depending upon the outside temperature. Geothermal waters are regarded as a source of energy and as a source for minerals such as iodine, bromine, lithium, cesium and strontium. Presently investigations are being made into the use of geothermal energy for thawing frozen ground for placer mining; extraction of heat from bedrock by fracturing with explosives and injecting cold water to be heated in high temperature gradient areas; heating concentrates at ore mills and moistening air in mines; and for balneological purposes. Reservoir depletion, corrosiveness of the hot water and environmental problems must be considered, and many of these problems are presently being investigated.

INTRODUCTION

The USSR has enormous reserves of thermal energy in the earth. In many regions of the country geothermal surveys have been carried out, methods of geothermal mapping have been developed, the principal regional distribution of thermal waters throughout the USSR territory have been established, and the most significant deposits of thermal waters for practical use have been located. We can now calculate the probable extent of natural heat in the earth in the same way as we estimate the reserves of oil and gas. The only difference is that this kind of heat has proved renewable.

The estimates of thermal water reserves are based on data relating to amounts included in gravity waters, the volumes in the water bearing horizons and on the transmission properties of the bedrock, and takes into account the alignment of beds, the composition of waters, etc. All of these factors have become apparent in drilling for oil, gas and thermal waters.

Thermal water reserves are present in the pores and fissures of the water bearing horizon and are estimated to have temperatures from 40 to 200°C, mineralization up to 35 g per liter and to occur up to depths of 3500 m from the surface.

[1]Scientific Council on Geothermal Research, Academy of Sciences of the USSR, Moscow

Estimated production rates of the thermal reserves in the USSR have been evaluated at 19.75 million cubic meters per day (Table 1). But the known reserves are by no means fixed, so that their estimates will vary. The known reserves will certainly increase, as the earth's deep heat become the focus of attention by scientific and industrial institutions.

It has been established, for instance, that 50 to 60% of the USSR is underlain by thermal water suitable for some commercial purposes (that is, thermal waters having slight mineralization).

Deep drilling (7-10-15 km from the surface) offers promise of penetrating into higher temperature resources of heat. At such depths the temperature may be 250 to 350°C and over. In such cases the predicted reserves of the earth's deep heat will increase considerably.

Among the above mentioned estimated reserves of thermal waters are exploitated reserves, such as, those that are being utilized at present for commercial purposes. Exploitated reserves of thermal waters have temperatures of 50 to 200°C, depth of occurrence up to 3500 m from the surface and mineralization from 0 to 10 g/l. These reserves have been estimated at 7.9 million m^3 per day. A greater part of them (about 70%) are at depths of up to 2000 m from the surface.

RESERVE ESTIMATIONS

Some explanation on the method of estimating the reserves of thermal waters in relation to their thermal-physical properties in actual practice is necessary. The following assumptions have been adopted: (a) for hot water supply 0.05 g cal per m^3 of thermal water is used (assuming heating hot water supplies from +5°C). In so doing the average temperature of thermal water was taken as 55°C, whereas it is actually 65 to 70°C; (b) in heating living and industrial buildings 0.02 g cal per m^3 thermal water is used (average temperature of thermal water being 65 to 70°C).

The estimations made allowances for using 50% of the thermal water reserves for hot water supply, and the remainder for heating.

Thus, the total amount of heat that can be obtained from thermal waters is as follows:

3.6×10^9 m^3 x 0.05 g cal = 180×10^6 g cal (hot water supply)[1]
3.6×10^9 m^3 x 0.02 g cal = 72×10^6 g cal (heating).

The total amount of heat available will then be 252×10^6 g cal per year.

One ton of conventional fuel will yield 7 g cal, and considering the efficiency of large boiler plants, will produce 7 g cal x 0.7 = 5 g cal per ton. Since the total amount of energy available from known thermal waters is 252×10^6 g cal, 5 tons of thermal water will be equivalent to 50 tons of conventional fuel.

It is evident that these estimates are conservative, since we have not taken into account the multi-stage use of the thermal waters to increase the efficiency of utilization of the availalbe energy.

---

[1]Table 1, column 2 total: 7.2×10^9 m^3/year

Table I

DISTRIBUTION OF THERMAL WATER RESERVES IN THE USSR[1]

REGION	Temperature - 40-200°C Mineralization - up to 35 g/l			Temperature - 50-200°C Mineralization - up to 10 g/l		
	10^6 m^3/day	10^6 m^3/year	Economy of fuel and heat per year 10^6TCF[2] / 10^6 Gcal[3]	10^6 m^3/day	10^6 m^3/year	Economy of fuel and heat per year 10^6TCF / 10^6 Gcal
1. Caucasus and Fore-Caucasus	1.95	712.75	5.0 / 25	0.78	280	1.95 / 9.8
2. Crimea and Fore-Carpathians	0.57	208.05	1.5 / 7.5	0.23	90	0.62 / 3.1
3. Other regions of the European part of the USSR	0.50	182.50	1.3 / 6.5	0.20	73	0.51 / 2.5
4. Middle Asia	1.48	511.95	3.5 / 17.5	0.55	200	1.40 / 7.0
5. Kazakhstan	1.20	438.00	3.0 / 15	0.48	175	1.20 / 6.0
6. West Siberia	10.75	3924.00	27.2 / 136	4.30	1570	10.90 / 55
7. East Siberia and Far East	1.65	602.25	4.2 / 21	0.66	240	1.67 / 8.3
8. Kamchatka, Kuril Islands, Sakhalin	1.70	620.50	4.3 / 21.5	0.70	252	1.75 / 8.7
Total	19.75	7200	50.0 / 250	7.90	2890	20.0 / 100

[1]Dvorov, 1972

[2]TCF - Tons of Conventional Fuel

[3]Gcal - giga calories = 10^9 calories

HOT WATER UTILIZATION

Four different methods have been suggested for using thermal waters for hot water supply: direct use of thermal water; with peaking boiler plants; increasing the temperature of geothermal heat; and a combination of the above methods.

The important factors in geothermal procedures are the efficiency of heat transfer from the boreholes and the temperature drop of thermal water during extraction. The following is a brief explanation of some of the procedures.

The most profitable methods involving in the direct use of thermal water are: A system of double-step parallel connections of hot water supply and heating; a system of series connection of the systems of panel and radient heating by the hot water supply. These methods provide for deep cooling of thermal water, the heat power factor of a borehole, however, being very low. The low efficiency can be explained by a variable annual heat load. The direct use circuit of thermal water is characterized by its exceptional simplicity and possibility for automation (Figure 1). This fact is and will be of great importance for solution of problems of geothermal supply in agricultural regions. The direct use of thermal water is possible only in cases where the temperature of the water meets the requirements of the consumer. In older buildings that are equipped with heating radiators, the temperature of the water should not be below 90°C, whereas in newer buildings with heating devices using the direct circuit, water can be used with temperatures of 60 to 70°C (Figure 2).

If the temperature of the thermal water does not meet the requirements of the consumers, the following system can be used: peaking boiler plants with a combination of the above two systems. During heavy heating demands these boiler plants can operate when the outside temperature is low, even though the temperature of the thermal water in the boreholes is not high. Besides heating a heat transfer fluid to the required temperature, the peaking boiler plants permit an increase in the efficiency of heat transfer from the borehole. A geothermal borehole is used in this case as a basic source with a uniform annual output. The most profitable method is a combination of the above two systems of direct use of thermal water with peaking boiler plants.

There are also applications using heat pumps. Heat pumps prove economically efficient provided they are used the year round: in winter for hot water supply and in summer for refrigeration. The use of heat pumps for heating proves unprofitable in most cases since it is not efficient to use heat pumps as peaking devices. Heat pumps use waste fuel, and are thus most efficient for covering the basic loads.

Combined systems of geothermal heat supply involve the following conditions. The system that includes a geothermal borehole, a heat pump device and a peaking boiler plant is an example of a combined system. Commercial efficiencies of such a system are rather high. Below are listed the economic efficiencies of various types of geothermal heat supply systems.

Table 2

Types of Systems	Required Temperature of water (°C)		Water Utilization Temperature (°C Average)	Borehole Heat Transfer Efficiency (%) Southern USSR
	Old Buildings	New Buildings		
Direct use of thermal water	90	50-70	30-40	0.1-0.2
With a peaking boiler plant	50-70	50-70	30-40	0.2-0.4
With a heat pump	30	30	10-30	0.2-0.4
Combined systems	50-70	50-70	10-30	0.3-0.6

Some words about the commercial aspect of using thermal waters for heating and hot water supply follow. Natural heat can be used for heating large residential regions of towns and settlements. Sixty percent of the hot water supply of the town of Makhach-Kala comes from thermal waters the year round.

In the town of Kizlar of the Dagesta Republic of the USSR, five deep boreholes were drilled with the temperature of the water at 105°C. and a total production of 17,340 m^3 per day. Four smaller boreholes were drilled in another geological horizon with slight mineralization, giving a temperature of 60°C. and a production of 16,950 m^3 per day. At present all the new buildings are heated and supplied with hot water utilizing geothermal waters. In the near future the inhabitants of this town will fully satisfy their requirements by means of geothermal waters.

Another example of the use of geothermal waters is in the province of Georgia. The capital of Georgia, Tbilisi, began to receive thermal water not only for balneological purposes, but for heating and hot water supply as well. At a distance of 10 km from the center of Tbilisi, in the vicinity of the Lake Lisi, a borehole was drilled that produced thermal water with temperatures of 60°C and a productivity of 2500 m^3 per day, with mineralization corresponding to the quality of "drinking water" (Figure 3). The inhabitants of a new district of Subartalo now receive hot water the year round. Thermal water runs by gravity from an artesian borehole (as seen in Figure 4) into a distribution tank (there are several) from which the hot water is distributed by gravity to residences. The loss of heat from the borehole to the consumer is 1.5°C. Similar boreholes will soon be put into operation in Tbilisi (Figure 5). The use of thermal waters in agriculture is of great significance for our country being used mainly for the growing of vegetables under protection and for cattle raising. The natural heat is characterized by relatively constant output and temperature of the thermal waters, with wide distribution of the latter at low cost.

Vegetables growing in the ground with protection can use thermal waters directly at a wide range of temperatures (from 35 to 200°C), since cultivating equipment and the necessary microclimate are available. Depending on the growing period, climatic peculiarities of a locality, solar illumination intensity, estimated variation in temperatures and some other factors can be correspondingly adjusted. In the heating systems, heat transfer fluids of various temperature ranges can be used (Figure 6).

The available experience and estimates enable us to establish the limits of the lowest temperatures of heat transfer that are economically profitable in heating systems of different construction with an estimated outside air temperature of -25 to -35°C. These temperatures are respectively equal to: for winter greenhouses 70 to 80°C, for spring greenhouses 60 to 70°C, for hotbeds with heated ground 35 to 40°C.

In areas with higher estimated temperatures the lower limits of temperatures of heat transfer fluid will be lower. For instance, in the region of the North Caucasus with an estimated temperature of about -12°C. the yearly economic efficiency obtained by the use of thermal water at 60°C for heat supply of winter greenhouses gave surprisingly good results, as compared to conventional fuel.

The Paratunka greenhouses (Kamchatka) covering 60,000 m^2 may be an example of the economic cultivation of a large area of ground with protection using the heat of thermal waters to produce a desired climatic zone. Tomatoes, cucumbers and other thermophilic cultures do not ripen naturally because of climatic peculiarities of the Kamchatka (Figure 7).

At present slightly mineralized thermal waters are used in the USSR for heating greenhouses by direct procedures: from a borehole the water runs directly into the heating systems made of common metallic tubes, usually with finned radiator.

It is worth noting that many deposits of thermal waters in the USSR have a high degree of mineralization (up to 20 g per liter) and their chemical composition is responsible for considerable corrosiveness relative to metals. When the phase equilibrium of thermal waters (change of temperature, pressure, gas composition, etc.) is broken, precipitation of sediments can occur on internal surfaces of metallic pipes and heating components.

The testing of various materials for corrosion resistence showed that there is a group of materials that can withstand the corrosive effect of highly mineralized chemically active thermal waters. Hence, when using thermal waters in agriculture, high corrosiveness cannot be a technical obstacle in the heat supply system.

When it is not possible to use the thermal waters directly in the heating system, a system with a water heat exchanger can be adopted. There are many examples of such use. In the North Caucasus in the town of Nalchik there is a complex application of thermal waters. Water with a temperature of 78°C and mineralization of 18 to 20 g per liter runs from the boreholes into a heat exchanger of the "pipe in pipe" type, using domestic water. Hot water goes through an air eliminator into the heat exchanger. From the heat exchanger domestic water is transported to residential and industrial buildings for hot water supply for technological uses, and into greenhouses where various vegetables are harvested twice a year. Finally the thermal water, cooled in the heat exchanger to 37 to 38°C is supplied to baths and showers of balneological hospitals (Figure 8).

CHEMICAL COMPOSITION OF HOT WATER

During recent years both in the USSR and abroad thermal waters are regarded not only as energy, but as a source of iodine, bromine, lithium, cesium, strontium and many other chemical components. It is known that thermal chloride brines, as well as slightly mineralized thermal waters contain a large complex of metallic and non-metallic microcomponents.

Below is a brief analysis of typical deposits of thermal waters of commercial importance in the USSR. Twelve water bearing horizons have been exploited for thermal waters in the Cheleken iodine-bromine deposits for ten years. Besides a high iodine (26.3 mg/l) and bromine (578.7 g/l) content, there are a number of other components.

The chemical analysis of the Cheleken deposit of 11 horizons showed a high content of microcomponents (mg/l): lithium--7.8; rubidium--0.65; lead--3.24; zinc--3.7; copper--2.4; cadmium--1.48; arsenic--0.36; strontium--715. Using the average yearly output of boreholes, one can extract (in tons) according to preliminary data: lithium--over 100; rubidium--about 10; lead--300-350; zinc--48-50; copper--24-35; cadmium--18-24; arsenic--6-8; strontium--7200.

In zones of recent volcanism the chemical and mineralogical composition of the bedrock has undergone especially great changes. In some areas of the Kamchatka the rocks are rich in aluminum and sulphur. They are situated near the Pauzhetka hydrothermal power station. The content of aluminum oxide reaches 20-30%, that of sulphur up to 10%. Their reserves are estimated as ten million tons. The mineral concentration in the raw material is low, and from the viewpoint of industrial value, its exploitation may prove unprofitable. Yet, with cheap electric energy produced by a geothermal power station, extraction of aluminum and sulphur can be considerably increased. Such a complex could be the beginning of a geothermal ore industry in the Kamchatka.

Geothermal waters of the Kamchatka contain boric acid, lithium, rubidium, cesium and other elements. Thus, for instance, the Pauzhetka deposit contains (mg/l): boric acid--250, lithium--4.4, cesium and rubidium--0.4 each, etc. It is easy to calculate that in a possible discharge of 200 l/sec of hot water from a geothermal power station we loose annually (tons): boric acid--1600, lithium--25.2, cesium--2.4 and rubidium--2.4. When calculated in rubles, the total sum will be 5.52 million rubles per year.

Along with the engineering application of thermal waters, we can extract very valuable raw materials for industry without any significant expense (these can also be raw materials for the chemical industry). As an example, thermal waters of the North Caucasus contain large concentrations of chemical components.

OTHER UTILIZATIONS OF GEOTHERMAL HEAT

At present, the scientists of the USSR are working on the problems involved in searching for methods of extraction and the practical utilization of the heat accumulated in bedrock using the present available technical method of drilling in the regions of the extreme north and northeast of the USSR. The tasks of accelerated economic exploitation of these vast areas in general, and further development of mining industry in particular, requires an urgent solution to the problem of hot water supply for industrial and residential areas. The extraction of commercial minerals in these regions involves enormous expense. The open mining of deposits, especially placer ores, is possible only in summertime, when the upper layers of ground are thawing. Draglines, hydroelevators, washing equipment and other devices do not operate during many months of the year. On some deposits an artificial thawing of frozen ground is effected by heating the water to 6 to 10°C; this makes their exploitation considerably more expensive. The traditional solution of this problem at the expense of increasing the production of heat in boiler plants under conditions of the northeast appears scarcely practical, even if we consider the exploitation of new deposits of coal, oil and gas. Regardless of the extent of the deposits under exploitation, difficulties related to transportation of fuel in the vast territory of the northeast will, as in the past, remain the major cause of high heat costs in most regions not directly adjacent to fuel bases. Under such conditions the search for new reserves of heat energy is an urgent task of great industrial value. Water temperatures from 20 to 30°C is quite sufficient for increasing the rate of thawing frozen ground.

Search for cheaper reserves of heat energy is a task of paramount importance. The solution of this problem lies in using the earth's deep heat that can be obtained through drilling boreholes to extract the heat from bedrock with the help of a heat conveyor such as water, and increasing the transmission properties of bedrock by the help of explosions. Extraction of heat from bedrock at considerable depth in areas with normal geothermal gradients may prove most efficient in engineering and economic respects, especially in places with high demands and favorable conditions for using the thermal energy of the earth.

The particular geothermal conditions of various regions can be characterized by evaluating the specific geothermal reserves of one km^2 of the area. Estimations show that geothermal reserves of bedrock in a relatively small interval of depths yield tremendous values. The geothermal gradient in the regions of the extreme northeast of the USSR varies within 1.5 to 4.0 times the normal gradient per 100 m, with thermal reserves ranging from 3.5 up to 7.0×10^{13} kcal/km^2, this being equivalent to the heat from burning 5 to 10 million tons of conventional fuel[1].

---

[1]One kilogram of hard coal yields 7000 Kcal.

Extraction of a small portion of these reserves would make it possible to satisfy the technical requirements of any mining enterprize for a period of many years. The development of circulation systems to extract the heat of the earth is directed toward these tasks. The productive capacity of the system, duration of operation, and temperature are determined by the requirements of specific mines and their industrial and domestic facilities. Analysis shows that in most cases such systems require one to two boreholes with depths from 2000 to 4000 m. They will have to provide continuous heating of 50 to 400 m^3/hr of water up to 20 to 80°C over 10 to 30 years, with heat output being within 1.5 to 10 Gcal/hour.

The following are possible variations of the thermo-circulation systems. In principle each system consists of two main elements: underground heating and extraction through water extracting canals (Figure 9).

Two deep boreholes are drilled at a specified distance from each other. They hydraulic connection between them is made by opening lateral branches using inclined drilling with a subsequent use of explosive charges to form connecting zones of fracture. Paired lateral branches in the boreholes produce longitudinal zones of fracture and fissure formation in a bed of impermeable bedrock of a workable horizon.

As it travels through the wells and branches and during filtration in longitudinal and connecting zones of fracture, the pumped river water is heated as a result of heat exchange with a high temperature mass of bedrock then drawn upwards through the hole to the surface and finally reaches the consumer. The number of boreholes depends on the requirements for hot water.

It can be assumed that sudden introduction of cold water into deep deposits of bedrock will rapidly cool the deep interiors of a given region. Calculations show that in cooling one km^3 of bedrock at a depth of 3 to 5 km by only 1°C, 10 billion kcal heat can be obtained. It follows from this example that rapid cooling of deep deposits with heat exchangers is not significant.

According to estimations in two boreholes drilled to the depth of 3 km the circulation systems with longitudinal zones of fracture under conditions of the northern region will provide for continuous heating of 15 to 50 l/sec of cold water up to a temperature of 40 to 60°C over several decades.

A method has now been developed, and hydrodynamic calculations have been carried out on the process of heat carrier filtration of the underground heat boiler with heterogenous permeable bedrock. An evaluation of the economic effectiveness of heat extraction has been made. Engineering efficiencies of the circulation systems for extracting of the earth's deep heat under conditions of the USSR northeast have also been determined.

These studies have laid the foundation for planning and experimental industrial development. The solution of this problem will make it possible to thaw out frozen formation and protect basins against winter freezing. The layer-by-layer stripping of rocks by means of bulldozers will be replaced by excavators. This will make it possible to process gold, diamonds, tin, tungsten and other precious mineral resources in the vicinity of permafrost regions not only in summertime, but the year round.

With the availability of warm and hot water, the heating of concentrates at mills (increasing the effectiveness of flotation of ores) will become possible, as will the conditions for heating and moistening the air in mines. This in turn will lower the incidence of respiratory ailments among miners and the dust content in pits. Hot water will solve the problem of hot water supply to residential and industrial buildings and greenhouses. All this will radically change the nature of the mining industry in the vast and rich regions of the USSR northeast.

In the USSR we already know of 127 deposits of thermal waters with a production of about 150,000 m^3/per day suitable for balneological purposes. The composition and physical properties are determined by the extent of precipitation.

In the USSR the bottling of thermal waters is performed at 21 locations, 14 of which are located together with balneological enterprises, and 7 at mills that exploit thermal water deposits separately.

For medical purposes thermal waters are used with mineralization from fractions of a gram per liter to highly mineralized brines of various basic ionic, gas and microcomponent composition with temperature from 37°C and over.

Four types of thermal waters are widely distributed in the USSR: (a) nitric thermal waters with mineralization up to 2 g/l, various ionic compositions, carbon dioxide content over 50 mg/l and high alkalinity. (b) nitric, nitric-methane and methane thermal waters with mineralization up to 25 g/l and higher bromine and iodine content. (c) nitric and methane sulfide waters of chloride or chloride-hydrocarbonate sodium composition with mineralization up to 35 g/l. (d) carbon dioxide hot springs with mineralization up to 10 g/l with CO_2 content up to 10 g/l. All these four types of thermal waters are widely used for balneological purposes.

SUMMARY

This is a brief analysis of some aspects of scientific studies and practical application of natural thermal energy of the earth. It is of course not possible to give a detailed description of the related problems in this short paper.

Unlike other sources of energy, the utilization of thermal waters has certain inherent difficulties. Geothermal deposits differ considerably from one another in chemical composition, depth of occurrence, temperature, production, etc. Their exploitation should be preceded by thorough investigations. Natural deep waters are mineralized and gas saturated to a lesser or greater degree. Being in contact with bedrock, they dissolve some mineral substances, thus one can frequently encounter sodium chloride (salt), potassium chloride, calcium carbonate (gypsum), nitrates, etc. The gas composition of thermal waters comprises nitrogen, carbon dioxide, hydrogen sulfide, ammonia, hydrogen, methane and other hydrocarbons. They each affect the corrosion intensity differently. The most corrosive thermal waters are those containing hydrogen sulfide and carbon dioxide.

Many geological factors are responsible for successful drilling and obtaining the necessary amount of geothermal heat. It is rather difficult to determine beforehand how many boreholes should be drilled at each location. In cases with water in fractured rock, the drilling of boreholes at a short distance from one another can provide good productivity and offer a positive economic benefit. We believe that the most efficient distance between boreholes is that capable of providing the least production cost to obtain thermal waters. Thus, for example, in Iceland there are three boreholes situated on one line with spacings of 220 and 38 m. In New Zealand (Wairakei region) no interaction between boreholes was observed even in the case when they were about 30 m from one another. Two boreholes drilled at a spacing of 18 m did not influence one another, giving a high and constant production. Each case depended on the geological conditions of the thermal water deposit. Another case was recorded where the borehole fluid of one borehole appeared in the next borehole situated at a distance of 61 m from the former. It should be mentioned, however, that when both boreholes were exploited, their output did not decrease.

In the Soviet Pauzhetka deposit of thermal waters (Kamchatka), 12 experimentally utilized boreholes were tested simultaneously. After half a year of the trial pumping the output was 15.8% less as compared to that estimated during individual testing (Figure 10). The maximum decrease in the output of a steam water mixture was observed in the northern part of the deposits where the boreholes are located at a distance of 100 to 125 m from one another. The southern part of the deposit was not affected by the change in the output recorded in the northern part. During the simultaneous use of only six boreholes in the southern part of the deposit the reduction in output was minimal.

Decrease in output was naturally followed by decrease in pressure and heat content. Thus, for instance, in individual tests of the boreholes in the northern part of the Pauzhetka deposit the yield of the steam water mixture was 161 kcal/kg, the heat outflow was 14,170 kcal/sec, and at the end of the experimental industrial tests in the same part of the deposit--160 kcal/kg and 10,159 kcal/sec respectively. The same picture was observed in the southern part of the Pauzhetka deposit.

The average period of operation for the borehole is 25 to 30 years. Many geothermal boreholes in Italy are known to be under operation for over 30 years. Some boreholes in the town of Makhach-Kala (USSR) have been used for over 25 years, and no deviations in the output, temperature and chemical composition have been observed.

As has already been stated, some deposits of thermal waters contain great amounts of mineral salts forming plentiful sinter in the zone of transformation not only inside the boreholes, but on their surfaces and pipes as well. There are a great many such cases in the world's experience. Thus, for instance, the Bolshe-Bannoe deposit of thermal waters on the Kamchatka, calcium carbonate deposits in the boreholes prevented this deposit from being used. The measures to be taken against scaling in the boreholes is a very important question in the problem of using the earth's deep heat in practice. This question has had minimal study by scientific and industrial institutions. Solutions to the scaling of boreholes is carried out by many methods: new drilling of boreholes down to the zone of steam formation; dissolving of sinter by sulphuric, hydrochloric and boric acids; filling of a borehole with calcic solution forming an artificial protecting layer, etc. It is necessary to examine the possibilities of removing the residues in each case, considering hydrogeological, hydrochemical and utilization factors.

Corrosion of metallic pipe lines and equipment is a serious difficulty in the use of thermal waters, especially those containing dissolved oxygen. However, there are a number of methods for the control of corrosion. There are special devices available for removal of boric acid from the steam water mixture before the latter comes into a turbine or pipe lines. This is a profitable procedure as boric acid is a valuable product, and it also prevents corrosion.

Thermal waters of the Pauzhetka deposit are known to have a higher arsenic content (0.5-0.6 mg/l). This fact prevents the use of these waters for hot water supply. At present a system is being worked out to treat the thermal waters for arsenic by means of ionic--exchange resins and non-organic ionites.

If the thermal waters are corrosive and have high mineralization, they will contaminate the environment. This problem still remains unsolved. Indeed, where can we dispose of waste waters? We must not discharge them into the rivers and water reservoirs, as they are mineralized and gas saturated. We face the problem of pumping these waters into deep aquifers and slightly saturated permeable lenses of sandstones through a pressure system of injection and exploitation boreholes. Waste waters can be pumped into any water bearing formation: dry or slightly saturated permeable lenses of sandstones, porous and fissure rocks. The possibility of creating an artesian borehole has been confirmed in practice by reinjection in the oil boreholes of the Bashkir and Tatar Republics. The experience has been obtained through filtration and subsequent heating of cold water pumped under pressure from the surface through a specialized system (Figure 11).

Let us imagine that two deep boreholes have been drilled at a distance of 600 to 1000 m from one another with the depth to the bed and the temperature being known. Water is pumped into a bed of a borehole, thermal water being extracted from the other one. The pumped water moving radially in all directions will push hot water in the strata and acquire the temperature of the environment at the same time. Deep seated bedrock formations are carriers of such heat. The necessary number of injection and exploitation boreholes is determined by capacity of a bed. Boreholes can be arranged in a square, triangular or circular pattern.

The success of the above measures will depend on the geothermal conditions of a region, lithological features of a water system, depth of occurrence, arrangement of injection and exploitation boreholes, as well as the volume of water pumped.

Experience shows that cold or waste thermal water pumped into bedrock is heated to the temperature of a surrounding formation. Bedrock in the faces and adjacent zones of injection boreholes will be the coldest. At a distance of some hundred meters from them the temperature of the pumped water will approach that of the bed. This can be fully confirmed in practice by the flooding of oil beds where a prolonged pumping of river water does not cause any significant changes of temperature of the bedrock. The construction of artificial thermal artesian reserves will prove profitable only if the amount of heat obtained exceeds the energy expended in pumping the water.

REFERENCES

1. Dvorov, I. M. "Hot Breath of the Earth," Journal Nauka i zhizn, No. 6, 1960.

2. Dvorov, I. M. "Heat of the Earth," Znanie, 1969.

3. Dvorov, I. M. "Deep Heat of the Earth," Nauka, 1972.

4. Lokchine, F. A., Dvorov, I. M., "Application Experimentalis et Industrielles de l'Energie Geothermique in USSR," U.N. Symposium on Geothermal Energy, Pisa, 1970.

5. Tikhonov, A. N., Dvorov, I. M. "Development of Geothermal Studies in the USSR," Vestnik, Akad. Nauk USSR, No. 10, 1965.

6. Tikhonov, A. N., Dvorov, I. M. "Development of Research and Utilization of Geothermal Resources in the USSR," U. N. Symposium on Geothermal Energy, Pisa, 1970.

7. Tikhonov, A. N., Lyobimova, E. A. and Dvorov, I. M., "Utilization of Underground Heat in the USSR," Geothermal World Directory, 1972. Katherine F. Meadows Editor publisher.

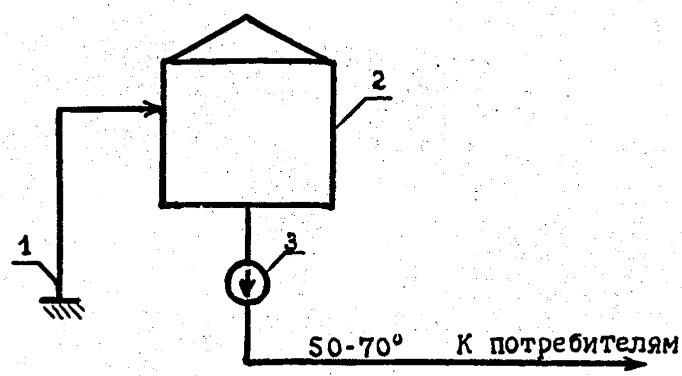


Figure 1. Diagram of direct use of thermal waters, (1) Bore-hole, (2) Holding tank, (3) Pump

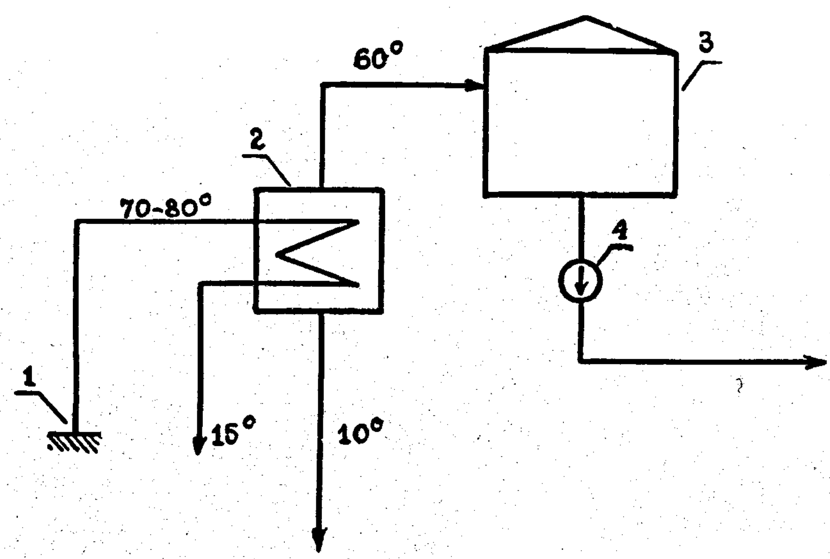


Figure 2. Diagram showing the use of heat exchanger with thermal waters (1) Bore-hole, (2) Heat exchanger, (3) Holding Tank, (4) Pump for heat supply

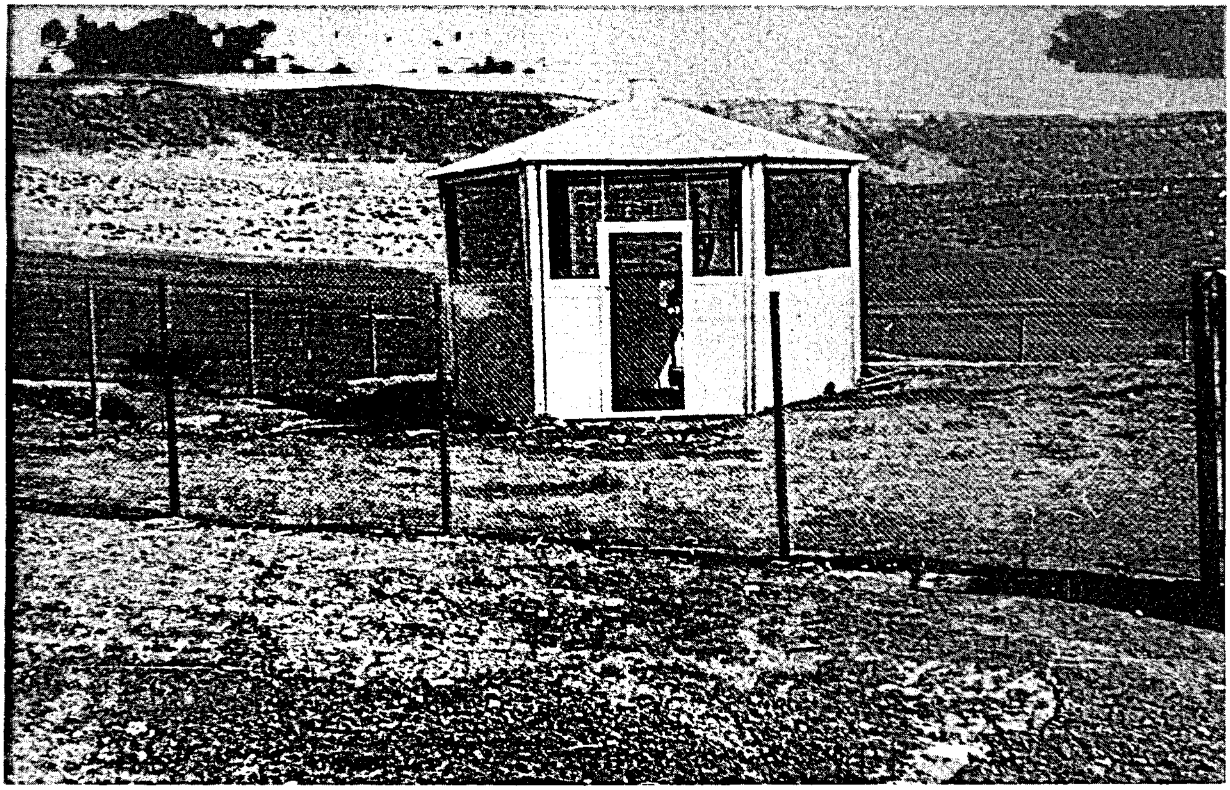


Figure 3. Geothermal bore-hole in the vicinity of the Lake Lisi in Georgia (photo by I.M. Dvorov).

Figure 4. Hot water pipe-line at Lisi-Tbilisi (photo by I.M. Dvorov).

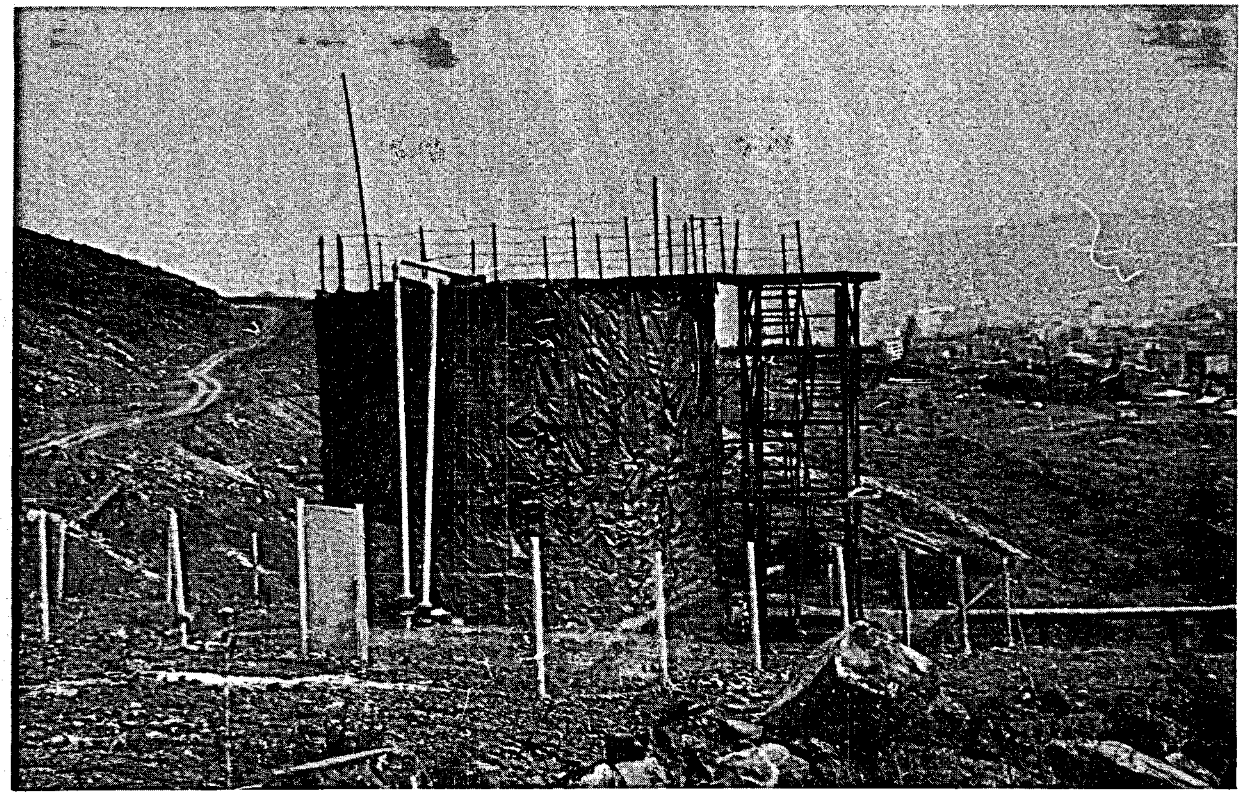


Figure 5. Distribution tank supplying hot water to consumers under pressure (photo by I.M. Dvorov).

Figure 6. Greenhouses heated by thermal waters at Makhach-Kala (photo by I.M. Dvorov).

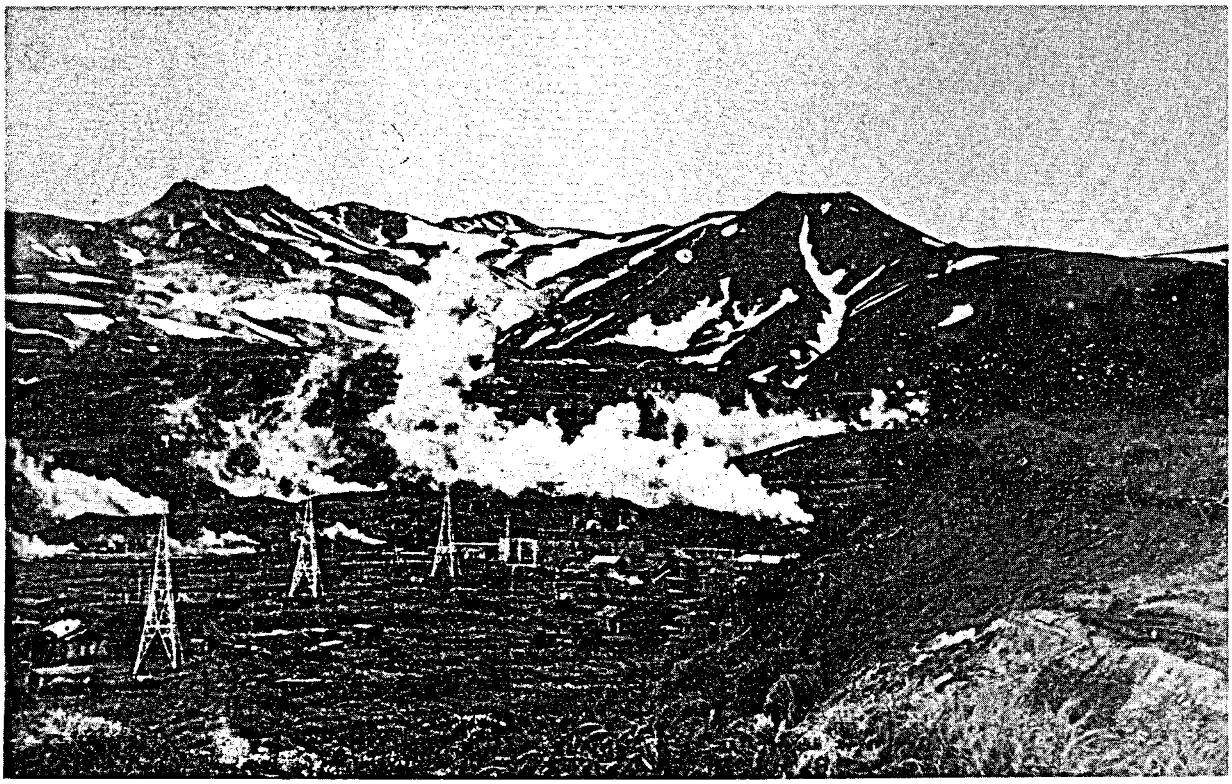


Figure 7. General appearance of the Pauzhetka geothermal field on Kamchatka (photo by I.M. Dvorov).

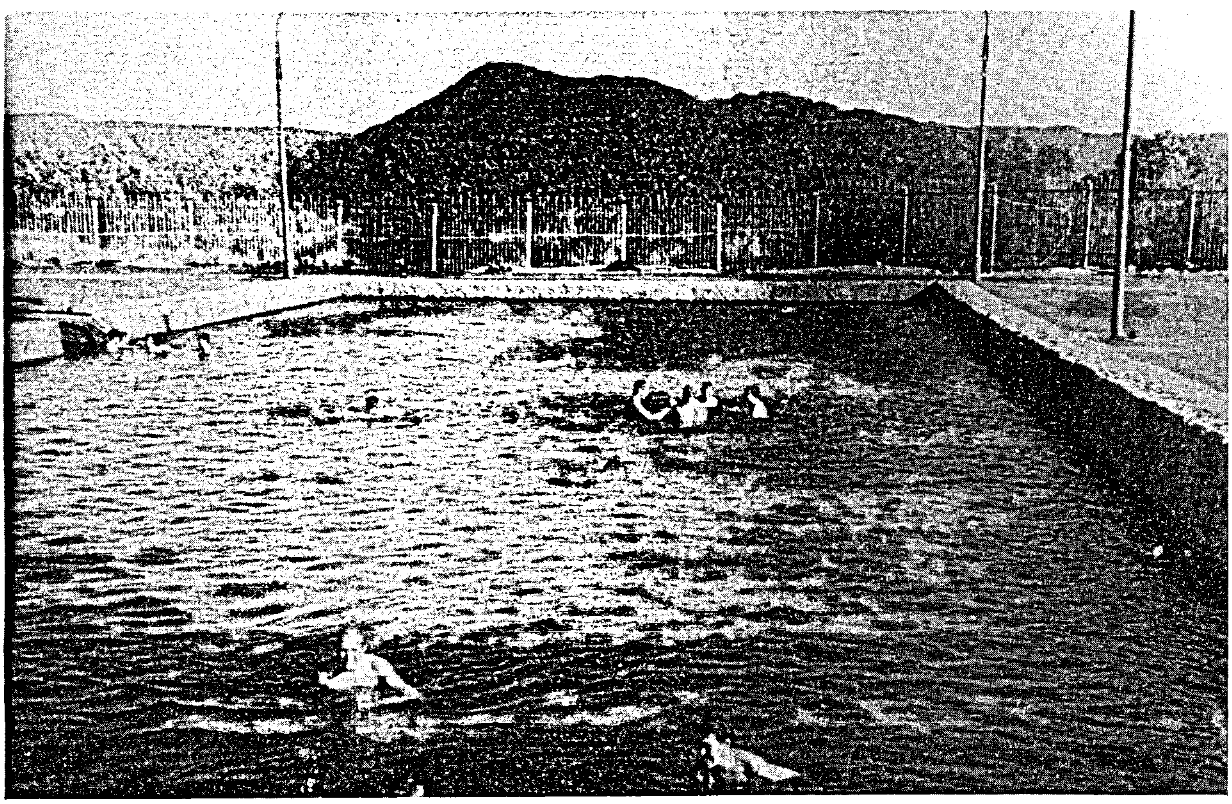


Figure 8. Typical year round operation of swimming pool on Kamchatka (photo by I.M. Dvorov).

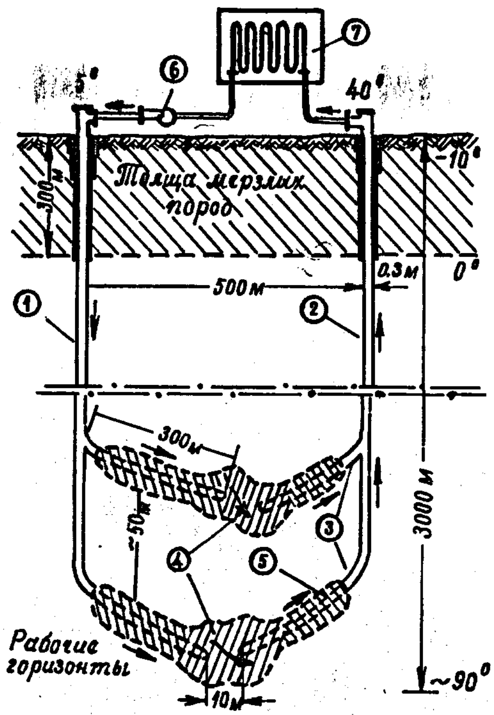


Figure 9. Diagram showing the extraction of heat accumulated in bedrock. (Yu.D. Dyadkin), (1) Injection bore-hole with cold water, (2) Extraction bore-hole with hot water under pressure, (3) Connecting fracture zones, (4) Opening of branches, (5) Elongated zones of fracture, (6) Circulation pump, (7) Hot water supply to a consumer

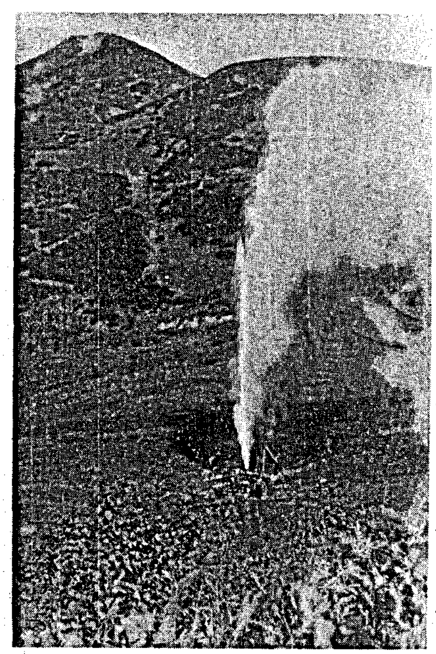


Figure 10. Testing of a bore-hole at the Bolshe-Bannoe deposit of thermal waters on Kamchatka (photo by I.M. Dvorov)

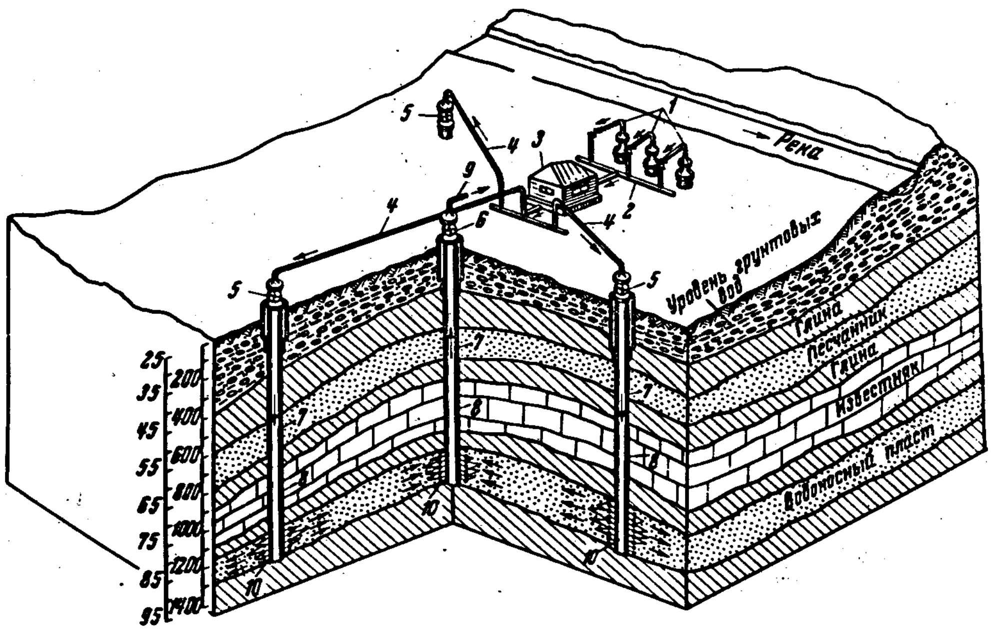


Figure 11. Diagram of hot water extraction under pressure by pumping water into deep aquifers. (1) Ground water bore-holes for cold water supply, (2) Suction collector, (3) Pumping station, (4) Supply lines, (5) Injection bore-holes, (6) Extraction bore-holes for thermal water, (7) Cement ring, (8) Well casing, (9) Pipe-line for hot water, (10) Filter

53,085

USE OF GEOTHERMAL ENERGY AT TASMAN PULP AND PAPER COMPANY LIMITED NEW ZEALAND

NZ

By

R. D. Wilson[1]

ABSTRACT

The sites for the integrated newsprint, pulp and timber mills of the Tasman Pulp and Paper Company Limited and the associated town of Kawerau, were selected in 1952 in close proximity to an area of thermal surface activity. Investigation and subsequent drilling in the area produced usable quantities of geothermal steam. The steam water mixture produced by the geothermal bores is generally separated at the well heads into its two fractions. The steam is piped to the mill and hot water discarded.

Geothermal energy is used by Tasman for timber drying, black liquor evaporation, pulp and paper drying and for electric power generation.

Recent surveys of the area and an investigation drilling program planned by the Ministry of Works and Development to commence in 1975, if approved, are expected to determine the extent and future development of the Kawerau field. The present energy crisis has placed further emphasis on the important part geothermal energy plays in Tasman's operations.

The site (Figure 1) of the integrated mills of the Tasman Pulp and Paper Company Limited producing newsprint, kraft pulp and sawn timber, and the town site of Kawerau, were selected from several alternatives in 1952 because of the close proximity of the mill site to an active hydrothermal area then known as Onepu Springs and now known as the Kawerau geothermal field. The Tasman mills have undergone two major expansion programs since production commenced in 1955. The second of these programs will be complete with the commissioning of No. 3 newsprint machine in mid 1975. This will bring the mills annual production capacity to 345,000 long tons of newsprint, 160,000 long tons of kraft pulp and 80 million board feet of timber.

Completion of this expansion program will increase the mills demand for process steam to approximately 820,000lb/hr. This steam will be supplied from two entirely different sources: 620,000 lb/hr will be generated in a conventional steam plant comprising two chemical recovery boilers and four power boilers. These six units will burn black liquor, hog fuel and oil to produce steam at 650 lb/in^2 gauge[2] and 750°F.

The remaining 200,000 lb/hr of process steam requirement will be supplied by a group of steam bores located approximately three quarters of a mile from the mill, producing wet saturated steam at 120 lb/in^2 at the well heads.

---

[1]Engineer, Tasman Pulp and Paper Company Limited, Kawerau, New Zealand

[2]Steam pressures stated throughout this paper are gauge pressures.

This paper describes the development and use of this source of geothermal energy in the Tasman mills where it plays a very important part in the economics of mill operations.

LOCATION OF MILL AND BORE FIELD

The Kawerau geothermal field, like the areas of geothermal development at Wairakei, Rotorua and Taupo, lie within the main volcanic belt of the North Island of New Zealand (Figure 2) stretching for approximately 150 miles in a northeasterly direction from the volcanoes Ruapehu and Ngauruhoe in the center of the North Island, to the volcanoe White Island off the Bay of Plenty coast.

An investigation of this geothermal area commenced in 1952, immediately after selection of the mill site, with a survey by the Department of Scientific and Industrial Research (D.S.I.R.), followed by test drilling by the Ministry of Works geothermal group. During the periods September 1952 to October 1955, three four inch investigation bores, Numbers 1, 4, and 5 (Figure 3) were drilled to depths of 1,476, 1,640 and 1,407 feet respectively.

The results of this investigation were so encouraging that the Tasman Company decided to continue investigations on a larger scale and immediately purchased a T32 drilling rig, capable of drilling to 5,000 feet.

Kawerau Geothermal Field

Figure 4 is a cross section of the Kawerau field based on geological data compiled during drilling, mainly below the 2,000 foot level. It is assumed to present a reasonable facsimile of the geology of the field.

This cross section shows several layers of differing materials. The rhyolite, andesite and ignimbrite are the most impervious layers which water penetrates mainly through faults and cracks. The breccias are porous or granular layers of pumice, sandstone and other materials through which water can move with relative ease.

In drilling for geothermal steam the object is to at least penetrate these breccias and, if possible, the principal faults. The main problem is to locate the faults at drilling depths of around 3,000 feet. Most of the Kawerau bores appear to be fed from the andesite layer.

The fault shown to the west of the field in Figure 4 was located by D.S.I.R. geologists from surface observations. Bores 16 and 17, drilled in 1967, and bore 19 drilled in 1971, were sited as near as practicable to this fault to give a reasonable chance of good production, as well as to obtain geological data to assist in planning future drilling programs. All three of these bores were successful, particularly No. 19 which, with an initial mass output of 960,000 lb/hr, has the largest output of any bore drilled to date in the Kawerau field. Number 8, the previously largest bore to the east of the field, drilled in 1956, is still the second best bore with an average output of around 85,000 lb/hr between cleaning operations. This bore, because of its past high output and the analysis of the water discharged, is believed to have penetrated a fault or be close to one.

Kawerau bores, the depths of which are shown in Figure 4, like all geothermal steam bores in New Zealand, are essentially hot water bores. On entering the bore casing at depth, the pressure of the hot water is reduced causing a percentage of the water to flash into steam. Some flashing may also take place as the water migrates toward the bore. The resultant steam rises up the bore casing carrying hot water with it, final flashing taking place at the surface in the separator.

Composition of Bore Water

Water discharged from the bores at Kawerau contains a variety of minerals, the concentrations of which vary from bore to bore (1). The only two which cause any real concern are calcite ($CaCO_3$) and silica. Calcite tends to deposit inside the bore casing at lower levels where most of the steam flashes from the water. This gradually restricts bore discharge. Silica, on the other hand, tends to remain in the water until the water is discharged at atmospheric pressure and corresponding temperature when heavy deposition occurs in pipes, channels and weirs and at leaking glands or joints. Calcite concentrations, while generally below 1.0 ppm, have been recorded as high as 2.0 ppm. Silica concentrations range from 250 to 770 ppm.

The steam from the Kawerau field contains approximately 2.5 percent by weight of non condensible gases (1) 91 percent of the gases are carbon dioxide, the remainder being largely hydrogen sulfide with some hydrogen, nitrogen and hydrocarbons. The presence of these gases, particularly hydrogen sulfide, has created problems in mill plant utilizing steam. It necessitates special sealing of glands to prevent the escape of the gas and, also, prevents direct use of the steam in certain mill equipment.

No trouble has been experienced with corrosion while the gas is confined with the steam in pipe lines and vessels. However, when the gas combines with oxygen in the air, highly corrosive conditions arise. Carbon steels have proven to be very satisfactory for all equipment handling geothermal steam but such items as glands, gland studs, valve seats and spindles are usually made from type 316 or 304 stainless steels. The most severely attacked of the common metals is copper, with a corrosion rate in geothermal steam of 0.017 inches per year compared with 0.0038 inches for mild steel and 0.0001 inches for type 316 and 304 stainless steel under the conditions applying at Kawerau.

DRILLING TECHNIQUES

Drilling and Testing of Bores

Equipment and techniques used in drilling for geothermal steam at depths around 3,000 feet in New Zealand are similar to those used by the oil well drilling industry, with some modifications to suit the peculiarities of geothermal steam.

Prerequisites to drilling a 3,000 foot steam bore are a minimum water supply of 500 gal/min, a level site approximately 200 feet by 150 feet, a concrete cellar and consolidation of the area surrounding the cellar.

Figure 5 is a cross section of No. 16 bore site, and is typical of geothermal bores drilled to 3,000 feet. The cellar is required to accommodate the main well head valve and blow out prevention equipment below the drilling rig. The area surrounding the cellar, about 80 feet square, is pressure grouted to depths of up to 100 feet. This consolidation grouting is necessary to safeguard against the possibility of an eruption should the bore come under pressure in the early stages of drilling. The 16, 11 3/4 and 8 5/8 inch steel casings are all cemented into the country and into one another. The 11 3/4 inch casing carries the casing head flange on which is mounted the main well head valve and on top of this, during drilling, the blow out prevention equipment. The 6 5/8 inch casing in the bottom 1,000 feet of the hole is slotted over most of its length to allow the hot fluids to flow into the casing. This casing is not cemented and may be withdrawn for cleaning or repairs at any time. Usually it is suspended with a hanger inside the 8 5/8 inch casing; the hanger also serves to close the annulus between the two casings.

During drilling, fluid mud containing bentonite, oil, sand and gelling material is circulated down the center of the drill pipe and bit, and returned via the annulus around the drill pipe to a storage tank and cooling tower. This mud cools and lubricates the drill string and bit, flushes cuttings from the hole, consolidates the walls to prevent caving in and, due to its density (70 lb/in^3), prevents hot fluids entering the hole during drilling.

Failure of the mud to return to the surface results from drilling into porous strata. At levels above 2,000 feet, porous areas are cemented up whenever possible. Below 2,000 feet in the prospective production zones, circulation loss is a welcome sign. Then the mud is often dispensed with and drilling continued while pumping as much water as possible into the bore.

On completion of the drilling of a bore, water loss runs are conducted to determine the location of the porous zones from which production will probably be obtained. A water loss run is made by pumping water down the bore at a steady measured rate of up to 400 gal/min, recording well head pressure and measuring temperatures at intervals down the bore using a geothermograph lowered into the bore on a wire line.

Where a porous zone is encountered outside the slotted casing, some of the water being pumped down the bore is lost. This is indicated by a rise in temperature of the water immediately below the porous zone. This information is used for comparison with subsequent measurements which may be made to check the behavior and future life of a bore. Stable conditions in a bore are indicated when temperature measurements, taken at regular intervals over several weeks, are steady with the bore closed.

Under stable conditions pressures may be measured at intervals down the bore with an amarada gauge. The measurements may be repeated at intervals to determine whether there is any reduction in water pressure and, hence, the level of feeding aquifers. This again is valuable information in assessing the probable life of a bore and the potential of the field for future drilling.

Usually during shut periods there is quite a build-up of gas pressure at the well head. For example, during a shut period of two months, No. 16 bore reached a pressure of 720 lb/in^2. Such a gas build-up is useful in starting the discharge from a bore since it forces the water level down to the high temperature zone. On release of the gas pressure the water flashes to steam and discharge commences (Figure 6). In cases where sufficient gas has not accumulated, compressed air may be used for the purpose. A pressure of at least 300 lb/in^2 is required to ensure success.

The output from a new bore is measured by using a sampling calorimeter which collects and evaluates samples from the steam water mixture as it discharges from the blow pipe at high velocity. A more recently developed method enables the mass flow, steam and enthalpy to be calculated from the measured water flow over a weir and the lip pressure of the discharge pipe (2).

Water and steam outputs from bores 7A, 8 and 14 in Figure 7 show typical bore characteristics. A knowledge of the enthalpy of the discharge is also of extreme importance when studying performance over a period of time to determine trends. The enthalpy of Kawerau bores has ranged from 624 to 430 BTU/lb with maximum downhole temperatures after drilling ranging from 285°C at bore 8 to 258°C at bore 10. Constancy of these figures with time characterizes a good bore.

Well Head Equipment

The well head equipment (Figure 5) includes the main 8 inch ASA 900 series valve, two 8 inch valves on the blow line to the silencer and the line connecting the bore to its separator. The separator is a pressure vessel 42 inches in diameter by 15 feet 6 inches high into which the steam water mixture from the bore discharges tangentially to separate the two phases by centrifugal force. It also allows the final flashing of steam to occur. Number 19 bore well head arrangements for "two phase flow" is similar except that the separator is located approximately 1,500 feet from the bore and at 100 feet lower elevation. Steam is led away from the separator by a central 12 inch pipe extending almost to the top inside the vessel, while water is discharged from two outlets into a 6 inch pipe at the bottom. Steam is piped to steam mains and the water discharged into a silencer where the pressure drops from the operating pressure of 120 lb/in^2 at the separator to atmospheric pressure. Steam again flashes off and is discharged to the atmosphere while the water is discharged usually via an open flume to waste.

The water level in the separator, which is provided with a gauge glass, is controlled by the setting of manually operated gate valves in the water discharge line. These have generally proven more satisfactory than the automatic air operated level control valves originally installed, since the control valves tend to bind, due to silica deposition in the packing glands. Following the successful operation of an electrically operated rotary plug valve on a small bore in the town, it is now proposed to fit a similar high pressure valve for a trial on No. 19 bore in the near future.

Excessive pressure build-up in the separator is prevented by a safety valve on the 12 inch steam line adjacent to the separator.

Figure 8 shows the separator installation at the discharge end of the two phase line from bore 19. This type of separator, the design of which is basically similar to the earlier type separators, has been in use at bore 16 since 1967. Mass flows of up to 1 million lb/hr have been successfully handled by this type of separator with a steam dryness of 99.9 percent.

PROGRESSIVE DEVELOPMENT OF THE KAWERAU FIELD

Following encouraging investigations in 1952, a well drilling contractor was engaged to drill production bores using the Tasman T32 rig. In the period April 1956 to February 1957, seven 8 inch diameter bores were drilled to depths of 1,917 to 2,046 feet. The output from these bores (Nos. 7A, 8, 10, 11, 12, 13, and 14) was about 400,000 lb/hr of steam at 150 lb/in^2 at the well head.

Engineering commenced immediately on the utilization of this steam in the mill, resulting in the connection of No. 8 bore to the timber drying kilns and wood preparation plant via a 12 inch main with a capacity of 80,000 lb/hr at 220 lb/in^2. The early operation of this line provided valuable information on water separation at the well head, corrosion, and the effect of geothermal steam on mill plant.

A second steam main with a capacity of 320,000 lb/hr at 100 lb/in^2, with well head separators at the bores, was scheduled to utilize the steam from four of the other bores (Nos. 7A, 10, 11 and 12) in early 1960. This main was intended to supply two steam generators and a 10,000 kW turbo alternator at the mill. In the meantime, these bores had been left blowing to atmosphere with restricted discharges.

Late in 1958 a considerable decline in bore outputs was noticed and the Ministry of Works geothermal group was called in to investigate (3). Downhole measurements were made by lowering various diameter cylinders (go-devils) into the holes on a wire line. The tests indicated that three of the five bores had calcite deposits on their casing walls. These bores were subsequently reamed out using a truck mounted rotary drilling rig working through a steam gland with water circulation to flush out the cuttings.

In spite of this work all bores except No. 10 ceased to produce steam at the minimum pressure of 100 lb/in^2 required for the low pressure main which had been almost completed by this time. Number 10 bore, which continued producing about 30,000 lb/hr, was connected urgently to the high pressure main to provide a much needed steam supply at the mill woodroom.

Following further temperature measurements and a re-appraisal of data by the Ministry of Works, bores 7A, 8, 12 and 14 were deepened to 3,000 feet in 1960. Number 8 bore when reopened discharged at a well head pressure of over 530 lb/in^2, and at 200 lb/in^2 produced 145,000 lb/hr of steam, the greatest output of any bore in New Zealand at that time (Figure 7). Bores 7A and 14 produced well, while No. 12 was unsuccessful.

Number 10 bore, which had not been deepened, together with 7A and 14, were now connected to the low pressure main while No. 8 bore was reconnected to the high pressure main. Bore 14 ceased to discharge after three months but, following a rest period of ten months, again produced usable steam. This pattern, for which no definite explanation was found, persisted until 1970, with operating periods up to 18 months. A rapid decline has since made the bore unusable. Number 7A, which commenced at 50,000 lb/hr, will still produce about 20,000 lb/hr at 100 lb/in^2 at the well head.

Calcite deposits gradually reduced the output from No. 10 bore until useful production ceased in 1967. These deposits were reamed out on four occasions between 1960 and 1967. Although the immediate output increased each time, it did not return to the level recorded after the preceding cleaning. The decline was due to deposits behind the casing and in the casing slots. These deposits could not be removed by reaming and, unfortunately, the casings in the early 2,000 feet bores were not removable.

Cleaning of the slots in the top section of the casing was then attempted with inhibited hydrochloric acid. Fifty-four hundred gallons of ten percent acid was pumped down the bore after blocking the casing below the slots with drillable cemented plugs. The operation resulted in very little change in output and finally the bore was shut down.

The output from other bores which were deepened in 1960 (Nos. 7A and 8) have also decreased with time due to calcite deposits. Cleaning of these bores by reaming or renewing the slotted casing has restored their steam production, but each time the output does not return to the same level as prior to the previous cleaning. Number 8 bore is now requiring reaming at approximately six monthly intervals but, even so, still has an average output of around 85,000 lb/hr.

<u>1967 Drilling Program</u>

Experience had shown that, if geothermal steam were to be used to supply future mill expansion programs, any new bores would need to be given a trial period of at least three years to determine bore characteristics and reliability.

In view of the success in deepening earlier bores it was decided in 1966 to deepen No. 10 bore also to 3,000 feet and to drill three new 3,000 feet bores in the area west of the Tarawera River (Figures 3 and 9). The Ministry of Works and the D.S.I.R. had recommended this area, believing it to be nearer to the center of the heat for the field. For the expenditure to be justified it was estimated that the output from each new bore would have to average at least 40,000 lb/hr of steam at 120 lb/in^2.

Preparation of the new drilling sites, cellar construction, roading and drainage were undertaken by the Tasman Company while the Ministry of Works undertook the drilling using a T12 rig. The program commenced in November 1966 with the deepening of No. 10 bore and continued with the new bores Nos. 16, 3 and 17 drilled in that order. The site for bore 17 was chosen by D.S.I.R. geologists after a study of water and core samples from Nos. 3 and 16. Number 3 was drilled on a site which had been prepared complete with a cellar in 1955 and required only enlargement of the site to accommodate the T12 rig.

Bores 10 and 3 both exhibited low permeability during drilling. This was confirmed by tests after the completion of drilling. Numbers 16 and 17 were drilled into much more permeable formations, particularly 16. These observations have since been reflected in the performance of the bores. Their initial outputs are shown graphically in Figure 10.

Steam output from the three bores well exceeded the required target of 40,000 lb/hr average per bore. The outputs of Nos. 16 and 17 bores have varied since being connected to the steam system in April 1968. Number 16 has been as high as 163,000 lb/hr at 127 lb/in^2 and is now producing 65,000 lb/hr. while No. 17, which initially produced about 50,000 lb/hr, appears to interact with bore 16 and will now only discharge at approximately 90 p.s.i. well head pressure or at higher pressures when 16 is shut down.

The deepening of bore 10 was not a great success. The discharge varied above and below an initial 50,000 lb/hr but finally fell to zero approximately 3 1/2 months later. The bore has since lost all pressure and is now completely dead.

High outputs from bores 16 and 17 immediately after drilling were so encouraging that engineering was commenced on steam mains and well head separators to connect these two bores to the geothermal system. In the meantime, the bores were discharged continually into silencers. The output from No. 3 bore (15,000 lb/hr) was considered too low to justify connecting it to the system until it has been given a much longer trial period. Eventually number 3 was connected into the system in 1970 and still produces 15,000 to 20,000 lb/hr.

<u>1971 Drilling Program</u>

Further drilling was planned in 1970 for the mill expansion program. Three sites, Nos. 18, 19 and 20 were selected in the area west of the Tarawera River, and one bore, No. 19, was drilled in 1971. The other two sites were reserved for future drilling to replace existing bores as these deteriorate, or until such time as further bores can be drilled over a wider area outside Tasman's present property boundaries.

Tasman again prepared the site and the Ministry of Works undertook the drilling as in 1967. This bore exhibited high permeability throughout most of its depth (3,652 feet) which was again verified by the completion tests and by its high initial mass discharge of 960,000 lb/hr at 220 lb/in^2 from an 8-inch straight vertical blow pipe. The enthalpy was 560 BTU/lb and the steam fraction, 205,000 lb/hr.

A diversion from the usual drilling techniques was an attempt to block off a zone of total circulation loss with wood chips. Extreme permeability, possibly a cavern, had been anticipated from experiences at Nos. 16 and 17 bores, at about 500 feet, and a four-inch gravel pump and feed chute were set up in readiness. After attempts with the usual cementing and gelling materials had failed to block off the loss zone, a total of about 90 cu. yards of wood chips were pumped down the bore. Although flow down the bore was stopped by this method on several occasions and the zone cemented, each time circulation was again lost shortly after drilling recommenced. Eventually, as a last resort, drilling proceeded without circulation and casing was run through the permeable zone as in 16 and 17 bores.

STEAM MAINS

Steam from the bore field is delivered to the mill through two steam mains (Figures 3 and 9). One is a 12-inch diameter high pressure main, 4,200 feet long with a capacity of 80,000 lb/hr at 200 lb/in^2 in carrying steam from No. 8 bore, the only high pressure bore in the field.

The other main, 4,100 feet long and 24 inches internal diameter (3/8-inch wall thickness), is rated at 320,000 lb/hr at 100 lb/in^2. It carries all low pressure steam from the field to the mill. Steam from bores (Nos. 3, 16, 17 and 19) is fed into this main through 3,200 feet of 24-inch line which was put into service in April 1968.

Because of the decline in No. 8 bore, the 12-inch high pressure line will eventually also be operated as a low pressure main.

The 12-inch high pressure main is lagged with asbestos and 85 percent magnesia and is aluminum clad. It is built with a series of 18 feet by 100 feet loops, with an anchor point in each loop, to take up the expansion. Although this design largely avoids the use of expansion devices, it is expensive in pipe and fittings and has not been repeated in either of the 24-inch mains.

The original 24-inch main is fed by an 8-inch line from 7A bore and a 16-inch line, originally from No. 10 bore (Figures 3 and 9), also serves as a pressure control line releasing surplus steam into the river through a submerged tee. The quantity of steam released is controlled by a 10-inch air diaphragm motor operated valve receiving an electric and pneumatic signal from a pressure controller at the mill end of the main.

This 24-inch main and the feeder lines are also insulated with asbestos and 85 percent magnesia and all are aluminum clad. These pipes are supported on pairs of rollers, each pair set in a 90°V and spaced at 20 to 60 foot centers along the line, thus locating the pipe laterally and allowing expansion in opposite directions from the anchor points. Hinged bellows type expansion joints are located at right angle changes in pipe direction to permit free movement of the pipe. The maximum movement allowed for at any point in the line is 23 inches.

A 12-inch line connects the high pressure and low pressure mains together at bore 8. This permits surplus steam from the high pressure main to be used as low pressure steam. The flow into the low pressure main is controlled by a manually operated valve in this 12-inch cross connection. A second cross connection of 8-inch pipe, with a 6-inch automatic control valve, is installed between the two mains at the mill end of the lines. This valve automatically controls the pressure in the high pressure main at the mill by allowing surplus steam to pass into the low pressure main.

The 3,200-foot section of steam main from bores 3, 16, 17, and 19 also is constructed from 24-inch I.D. by 3/8-inch wall pipe. This latter line is fabricated to B.S. 3601, the older pipe line to B.S. 806. The feeder lines are all A.P.I. 5L Grade B seamless pipe.

A second, 16-inch diameter, blow off line with a 10-inch control valve, working in parallel and under the same pressure control as the original blow off line at bore 10, has been provided. This is connected to the later 24-inch main at the downsteam end of the river crossing and again discharges into the river through a submerged tee.

Air for the diaphragm operated blow off valves and steam flow and pressure recorders at each bore, is provided at 100 lb/in^2 by two air compressors. One, a 100 ft^3/min. compressor, is electrically driven, the other, a 65 ft^3/min. standby compressor, is driven by a diesel motor with automatic starting.

The later lines are all insulated with 2 inches of fiberglass bonded with resins for a maximum working temperature of 422°F and are clad with 22 gauge sheet aluminum. The separators at bores 3, 16, 17 and 19 are also insulated with these materials.

The 16-inch pipe from bore 17 to its separator and the 24-inch main are supported on simple single horizontal rollers fabricated from 12 inches of 3-inch schedule 80 pipe with ferobestos bushes running on one inch diameter stainless steel pins. In the case of the 24-inch pipe line, these rollers are spaced at 40 feet centers and at 30 feet centers along the 16-inch line, the pipes being kept on line by guides (Figure 11) at 200 and 150 feet centers respectively.

Expansion in this 24-inch line is catered for by two, 150 feet radius bends (Figure 9), allowing for a maximum movement of 46 inches at the commencement of the upsteam bend. An anchor is provided between the two bends with trunnions in the vertical axis on the pipe center line to permit the bends to pivot about this point as the two long pipe runs expand. The 24-inch pipe is anchored at the two ends remote from this 150 feet radius S bend. The supports under these two large radius bends are simple 3/8-inch stainless steel plates screwed to the concrete foundations on which rests supports faced with 3/8-inch tufnol sheets. These materials have been used in other locations where sliding supports or guides have been required. Pipes carrying the mixed flow at high level from the well head separators are suspended with counterweights.

Expansion in the feeder pipes is catered for by a combination of hinged type expansion bellows and pipe flexibility at right angle changes in pipe direction. The later 24-inch main is carried over the Tarawera River on a single 225 feet span, Callender Hamilton, 15 feet by 16 feet through type, prefabricated bridge. This bridge also provides access to the east side of the bore field for operating personnel with light vehicles, and provision has been made for at least two similar mains to be added in the future.

Two Phase Flow Main

The 16-inch line (Figure 11) from No. 17 bore to its separator at 16 bore is Tasman's first "two phase flow" line. This line is 450 feet long rising 20 feet in elevation from the bore to the separator. The line, construction details of which are given earlier in the paper, has operated very satisfactorily since its commissioning in 1967.

A second and much larger "two phase flow" line (Figure 12) was put into service in 1972 to carry the steam water mixture from No. 19 bore to its separator located at a convenient point adjacent to the 24-inch steam main. Design for this line was based on information provided from experiments conducted by the Ministry of Works and D.S.I.R. on "two phase flow" and the experience gained in operating the 16-inch line from No. 17 bore.

This line commenced operation carrying the mass flow from No. 19 bore of 960,000 lb/hr at 220 lb/in^2 at the well head without any problems, and has continued to operate very satisfactorily.

The line is 1,460 feet long from the bore site to the separator and is constructed from 18-inch API 5L Grade B pipe, insulated with 2 inches of fiberglass, aluminum clad and is supported on rollers all similar to those described earlier in the paper. No deterioration was found during inspections made at several points in the line in September, 1974, after 2 1/2 years of operation. Wear was, however, found at the sleeve of an 8-inch expansion compensator at the well head, necessitating its replacement. This is no doubt due to the high velocity of discharge from this bore. The separator, also described earlier, was transferred from No. 17 bore which now discharges into No. 16 separator. The only unusual feature observed in the operation of both lines has been a slow fluctuation in the water level in the separators. This fluctuation, which has a cycle of several minutes, is of no consequence, except for possibly the loss of a small amount of steam through the water discharge valves when the water in the separator falls to its lowest level.

EQUIPMENT UTILIZING GEOTHERMAL STEAM

9,000 lb/hr of the high pressure steam is used directly in jump cylinders operating log handling equipment in the wood preparation plant.

Because of the presence of hydrogen sulfide gas in the steam and its detrimental effect on equipment (particularly electrical equipment), the glands of these cylinders are sealed with boiler steam at 150 lb/in^2. The cylinders are operated with 100 lb/in^2 geothermal steam supplied from the high pressure main through a pressure reducing station.

Other direct users of high pressure geothermal steam are the recovery boiler shatter sprays and liquor heaters (consuming 5,000 lb/hr) and the timber drying sheds (3,000 lb/hr) with line losses of 11,000 lb/hr.

The most important use of geothermal steam at Tasman is in the steam generators (Figure 13) producing clean process steam at 150 lb/in^2 and 50 lb/in^2 used principally in the kraft pulping process and in the pulp and paper machine dryers. The largest steam generator in use at the present time is designed to consume 65,000 lb/hr in its heating coils in a closed vessel to generate 55,000 lb/hr of clean steam at 150 lb/in^2. At present this unit is being used to produce 50 lb/in^2 process steam. Eventually, when high pressure steam is no longer available, this unit will be used only as a low pressure steam generator. A second, low pressure, steam generator, produces 45,000 lb/hr of process steam at 50 lb/in^2 from geothermal steam at 100 lb/in^2.

Two additional steam generators (Figure 14) are included in the current mill expansion program. These units each have a rated output of 60,000 lb/hr of process steam at 50 lb/in^2 and will consume geothermal steam from the low pressure, 100 lb/in^2 main. They are "two pass" horizontal generators (Figure 15) fitted with straight tubes and a floating internal tube plate and header. Steam is collected and discharged through two steam domes fitted with demisters to ensure a steam dryness of at least 92 percent. Demisters were added to the two original generators some time after they went into service.

Facilities have been provided in this new installation to superheat the 50 lb/in^2, 297°F saturated steam from all four generators by injecting 150 lb/in^2, 475°F boiler steam, under automatic temperature control into the mains from the steam generators. Thus the generator steam will be raised to the same temperature (315°F) as the process boiler steam with which it mixes in the mill steam mains. Drying and superheating the steam has been found necessary to avoid temperature variations which on occasions, under certain steam flow balances, have adversely affected drying operations on the paper machines.

The presence of gases in the steam from the generators, from occasional leaks and also from breakdown of carbonates carried into the generators in the feedwater, has also caused paper machine dryer problems. The new installation and selection of the generators has been engineered to avoid these problems in the future.

The presence of gas in the steam can now be detected with small steam sampling condensers, one for each generator, each discharging into a filter flask containing water. The presence of gas can be observed by bubbles rising in the flask and a simple gas test determines whether the gas is sulphur dioxide indicating a leak, or carbon dioxide indicating carbonates present in the generator feedwater.

Feedwater previously pumped from the boiler plant hot well and supplemented with raw mill water, will now be supplied from the dealkalizing stage of a new demineralizing feedwater treatment plant, primarily for the supply of additional feedwater to the boiler plant. The dealkalized water will be fed through a deaerator to the generators hot well. Feedwater is delivered to the steam generators under three element level control and is heated by the geothermal condensate, from the generators in stainless steel lamella type feedwater heaters. In supplying steam to the process, valuable condensate is produced for boiler plant feedwater make-up.

Output from the steam generators is controlled by the pressure in the mill process mains operating pneumatic pressure controllers with air diaphragm motor control valves in the geothermal steam lines feeding the generators. An over-riding feature, on the two new generators, cuts out this pressure control feature if the geothermal mains pressure falls rapidly due to the turbine switching to speed governing (described below).

Geothermal condensate discharge from the generators is controlled automatically from the levels in receiver tanks. The non-condensible gases pass through the generators and are vented to atmosphere through a gas line to the top of the turbine exhaust stack. Gas venting is automatically controlled by the water level in a gas separator tank in the condensate discharge line from each generator.

Geothermal Turbo-Alternator

Low pressure geothermal steam which is surplus to the requirements of the steam generators, is fed to a 10,000 kW turbo-alternator set. This machine is designed to generate full load when consuming 319,000 lb/hr of steam at 100 lb/in^2 at the throttles. It exhausts to atmosphere at 1 lb/in^2

back pressure through a 5 feet diameter by 190 feet high, aluminum sprayed, steel stack. Glands on the main shaft of the turbine and on all valve spindles are sealed with 150 lb/in^2 boiler steam to prevent the escape of non-condensible gases into the turbine room, in which are also located two extraction back pressure turbo sets operating on boiler steam.

Up to 100,000 lb/hr of exhaust steam from the turbine is fed to a black liquor pre-evaporator to raise the black liquor solids from 15 to 21 percent at a flow of 500 gal/min. The steam is condensed in this unit and the non-condensible gases only are discharged into the turbine exhaust stack.

The turbo set normally operates in parallel with other mill turbo sets and with the New Zealand Electricity Department power system. Normally the turbine is controlled by a steam pressure governor, which permits only the use of geothermal steam which is surplus to the mill process requirements and, in so doing maintains a constant pressure at the mill end of the steam main. In the event of a failure of the State supply the turbine reverts automatically to speed governing, power generation then taking preference in the demand for geothermal steam.

The turbine was designed to permit the addition of a condenser and three further sets of fixed and rotating blades. With the full complement of blades, the turbine could produce 10,000 kW exhausting into a 23.8 inch vacuum and would consume only 185,000 lb/hr of steam.

It has been very doubtful, until the present time, whether the addition of a condenser could be justified since the capital cost would be greater than that of drilling a new bore. The position is, however, now being restudied along with the possible further use of geothermal energy in the mill processes which could fully load the geothermal steam mains.

MAINTENANCE

Relatively little maintenance has been required over the fourteen years of operation of the geothermal system. Reconditioning bores by reaming or withdrawal of the casing is by far the major item, involving the use of a light truck mounted rig for reaming or the heavier T12 rig for casing withdrawal. This work, like the drilling of bores, is carried out by experienced technical staff and drilling crews from the Ministry of Works at Wairakei.

All other maintenance, involving mainly the overhaul and annual statutory requirement of surveys of all pressure vessels, is carried out by the Tasman Company.

The average annual maintenance cost for the past four years for the whole of the geothermal system, excluding the turbo set, is $NZ84,000, of which almost 50 percent has been expended on bore maintenance. Overhaul and surveys of pressure components account for the major part of the balance.

COSTS

The Tasman Company's total investment in development of geothermal energy since its inception, including bores, pipe lines and equipment to use the steam, will amount to approximately $NZ5.0 million on completion of the present expansion program.[1]

The cost of drilling three new bores in 1967 was $NZ145,000 per bore which included access roading, site preparation, drilling and provision of silencers for testing the bores. Well head separators, connecting piping and the 24-inch main (including the river crossing) amounted to $NZ315,000. In 1971, the cost of No. 19 bore was $NZ264,000 and $NZ190,000 was the cost of the two phase line, separator and silencers. The two new steam generators, their ancilliary equipment and a new condensate disposal line will amount to more than $NZ500,000. The total expenditure in 1967 of $NZ750,000 provided the mill with an average of 170,000 lb/hr of steam at 100 lb/in^2 and the 1971 expenditure of $NZ454,000 provided an average of a further 90,000 lb/hr.

On completion of the present expansion program, geothermal energy will reduce Tasman's purchased fuel costs for steam by approximately 70 percent of $NZ3.2 million per year, based on the present price on fuel oil.

The apparent advantage of geothermal energy must be tempered to some extent by the degree of reliability involved in its use, when it is recalled that the mill still has only six useful bores out of a total of 11 drilled, and two bores (Nos. 8 and 19) are producing 60 to 70 percent of the steam from the field. Greater reliance can, however, be placed on geothermal energy as the demand and, hence, the number of active bores in the field increases. Tasman's policy has been to provide boiler capacity to cover the greater part of the mills steam demand and to use geothermal energy to make the greatest possible reduction in the consumption of purchased fuel.

FUTURE GEOTHERMAL DEVELOPMENT

The 24-inch steam main completed in 1968 and 16-inch "two phase flow" line from 19 bore have been designed and tested for maximum working pressures and temperature of 300 lb/in^2 and 422°F. This pressure is much higher than the operating pressure (100 lb/in^2) dictated by mill equipment. This design pressure level was chosen with a view to the future possibility of piping the whole "two phase flow" from the bores to separators and heat exchangers as near as possible to the mill end of the line.

Estimates based on study and experiments by the Ministry of Works and D.S.I.R. at Wairakei indicate that, in transmitting "two phase flow" over the distances at present involved with geothermal pipe lines at Kawerau, it is possible to increase the available geothermal steam from the bores by as much as 15 to 20 percent and to increase the available heat, by passing the mass flow through heat exchangers, by as much as 90 percent. Therefore, it is possible that "two phase flow" could almost double the life of bores supplying geothermal energy to the mill. Deposition of silica in the heat exchangers and discharge piping is the main problem still to be investigated before a decision can be made on "two phase flow" to the mill. Although tests by the D.S.I.R. at Wairakei and elsewhere have shown deposition to be a minor problem, tests must still be made with Kawerau bore water as a basis for heat exchanger design.

The full potential of the Kawerau geothermal field still remains to be established and only further drilling can determine its extent.

---

[1] Approximate exchange rate: $US 1.36 = $NZ 1.00

A Relatively shallow, 240 foot deep 4-inch bore drilled in November 1968 in the town of Kawerau, approximately two miles from the Tasman bores, has produced 42,000 lb/hr mass flow at 50 lb/in^2 at the well head. A recent resistivity survey (4) of the Kawerau area, conducted by D.S.I.R., indicates this area to be part of the Kawerau field. The Ministry of Works and Transport (previously Ministry of Works) are planning, for Government approval, an investigation drilling program for commencement in 1975, in an endeavor to determine the magnitude of the Kawerau field. It is expected that the data from this program will form the basis for future development of geothermal energy at Kawerau, and to what extent the field can be used for power generation as well as supplying the pulp and paper industry in the area.

ACKNOWLEDGEMENTS

The author wishes to express appreciation to the Governor and the State of Oregon for the opportunity to present this paper and to the Management of the Tasman Pulp and Paper Company Limited for permission to use the material. Appreciation is also expressed to the Ministry of Works and Development, D.S.I.R. and those colleagues who assisted with the material.

REFERENCES

1. Report for Tasman Pulp and Paper Company Limited, on Geothermal Survey at Kawerau, 1962, D.S.I.R., New Zealand.

2. James, R., New Zealand Engineering, 21:437 (1966).

3. Dench, N. C., New Zealand Engineering, 17:353 (1962).

4. Report No. 62, Geophysics Division, D.S.I.R., New Zealand

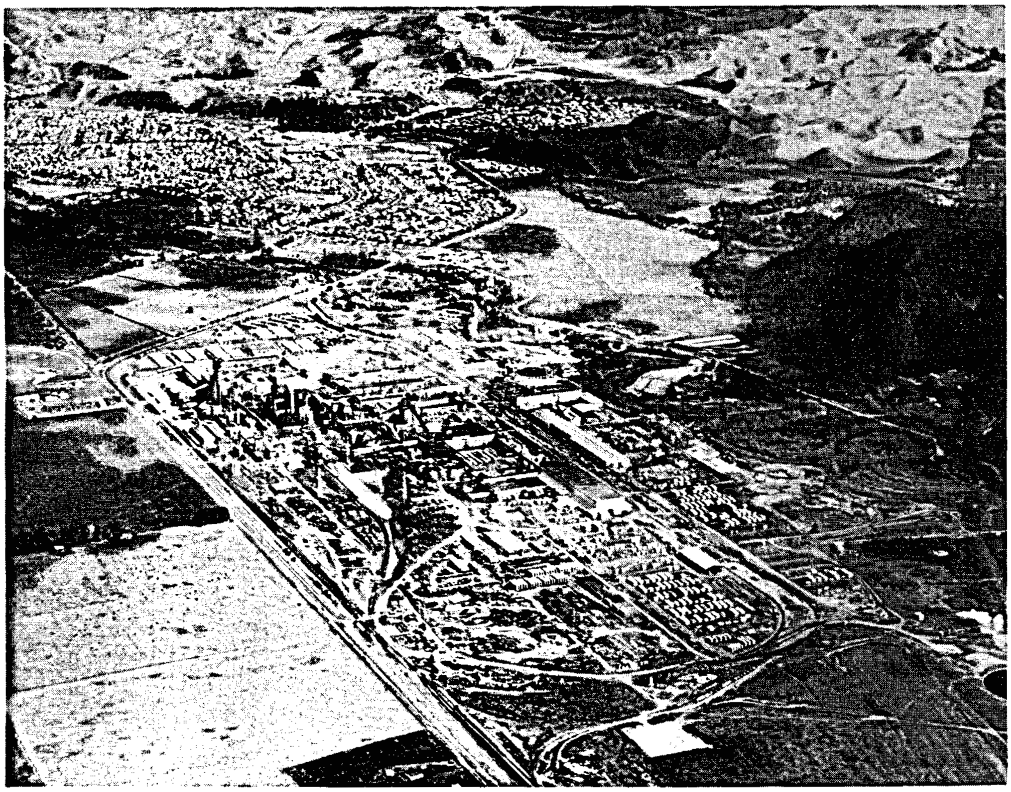


Figure 1. Mill site with town of Kawerau in background, part of geothermal field right foreground.

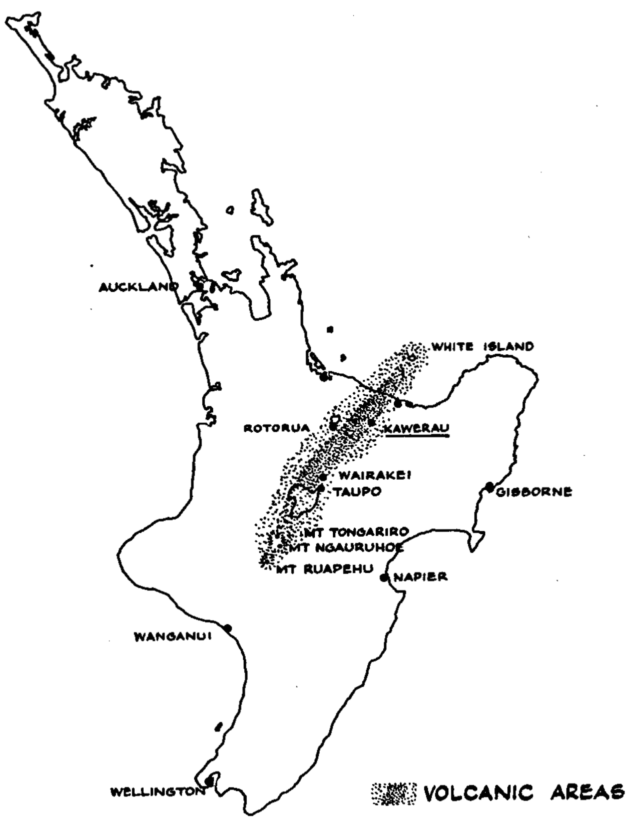


Figure 2. Volcanic belt, North Island of New Zealand.

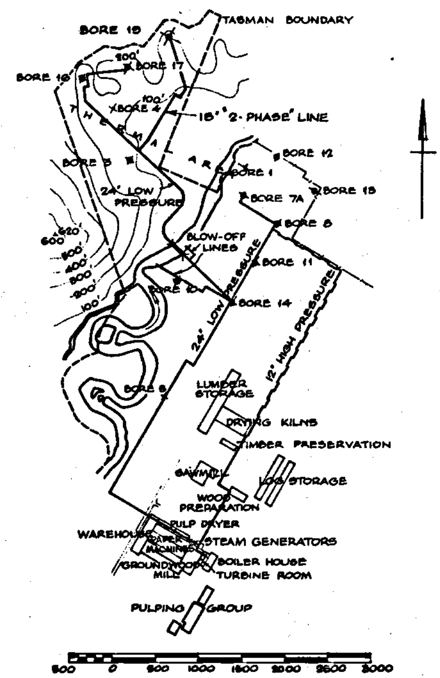


Figure 3. Layout of bore field and system.

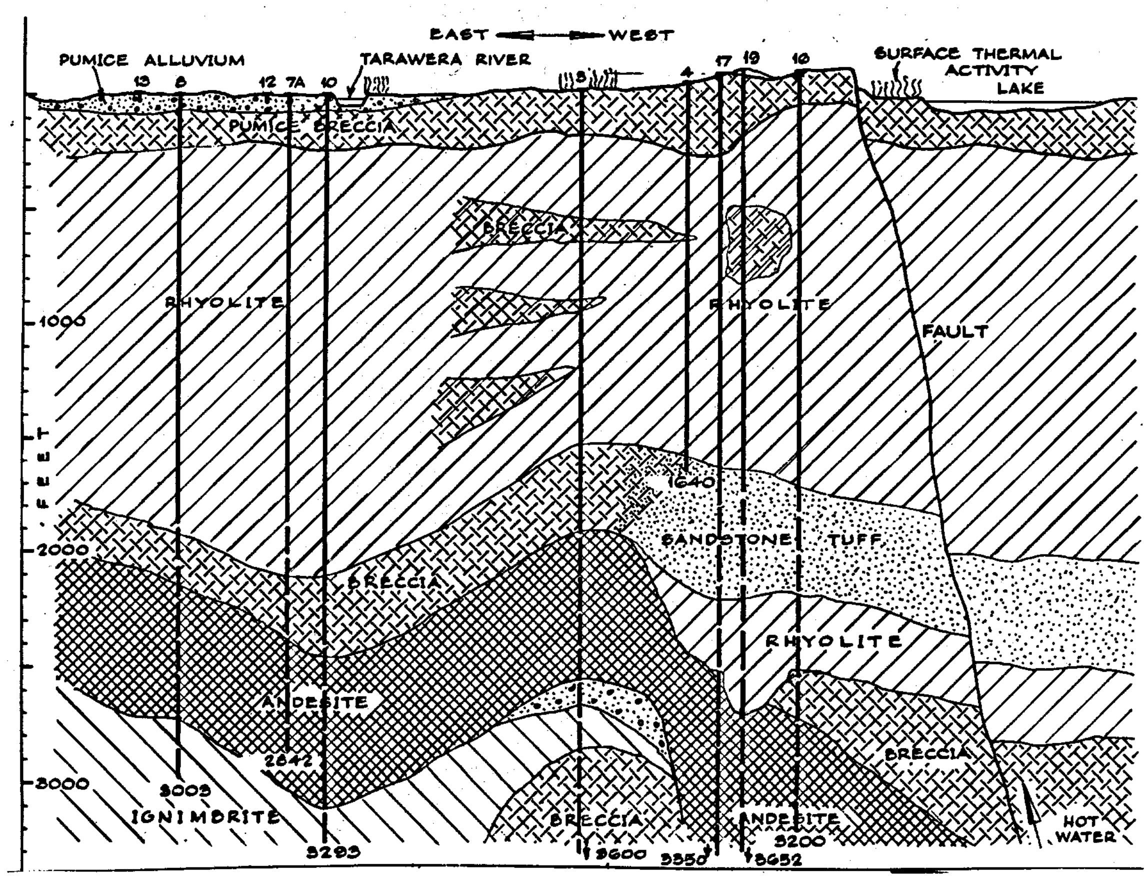


Figure 4. East-west section through Kawerau thermal field.

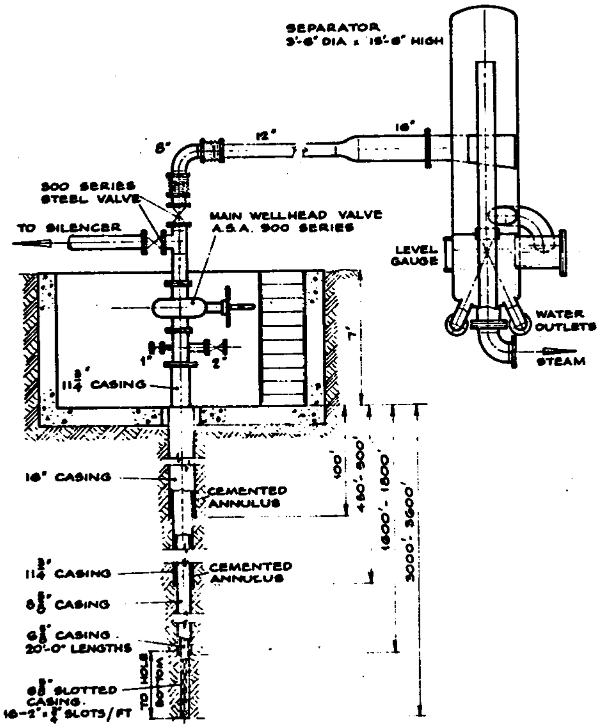


Figure 5. Typical bore and wellhead equipment.

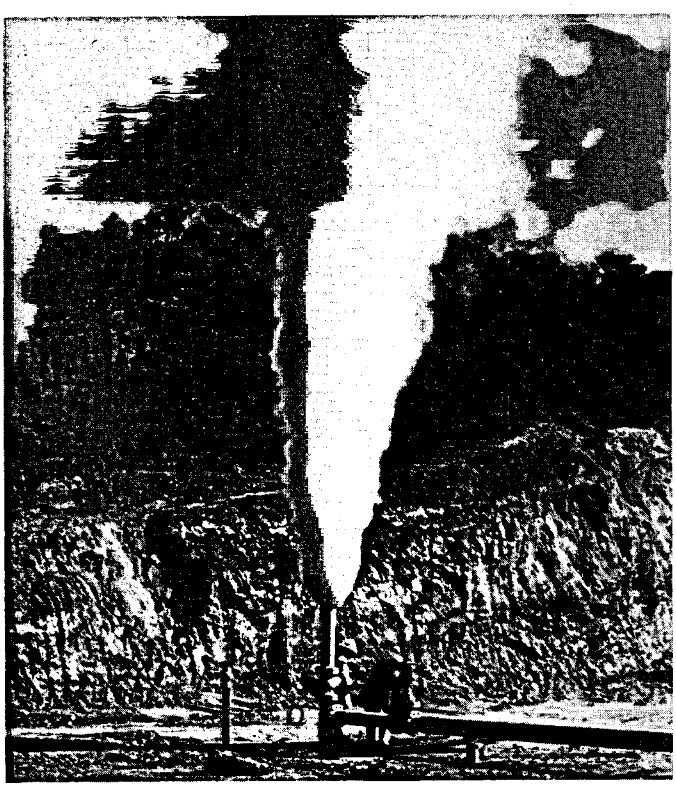


Figure 6. Initial discharge from No. 19 bore. (960,000 lb/hr at 220 lb/in^2)

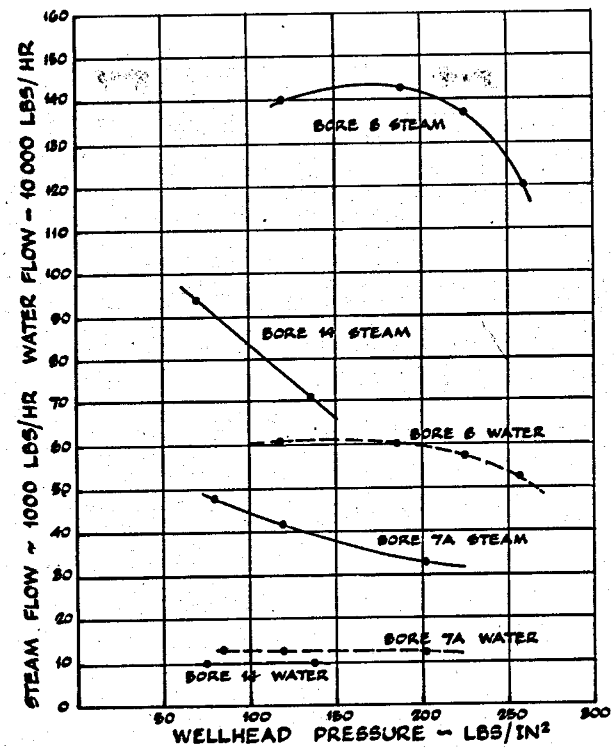


Figure 7. Outputs after deepening bores in 1960.

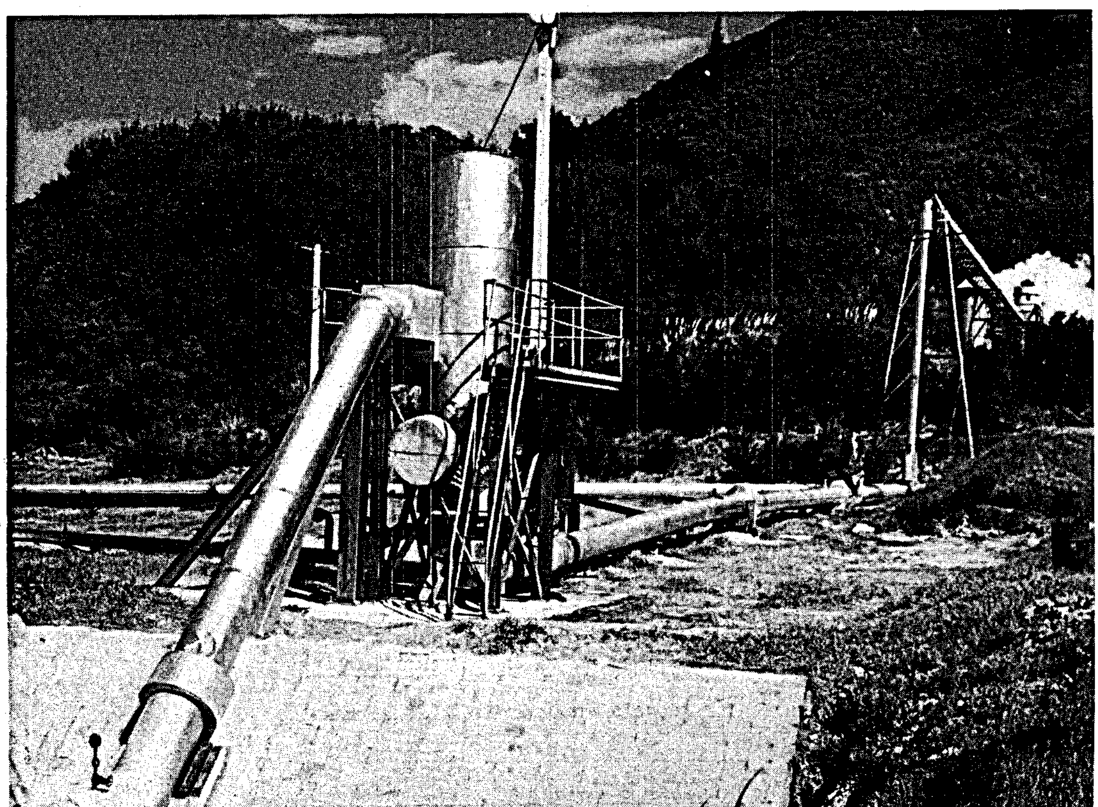


Figure 8. Typical separator, with 18 inch two phase flow line from No. 19 bore in foreground. Silencer and separator at No. 3 bore in background.

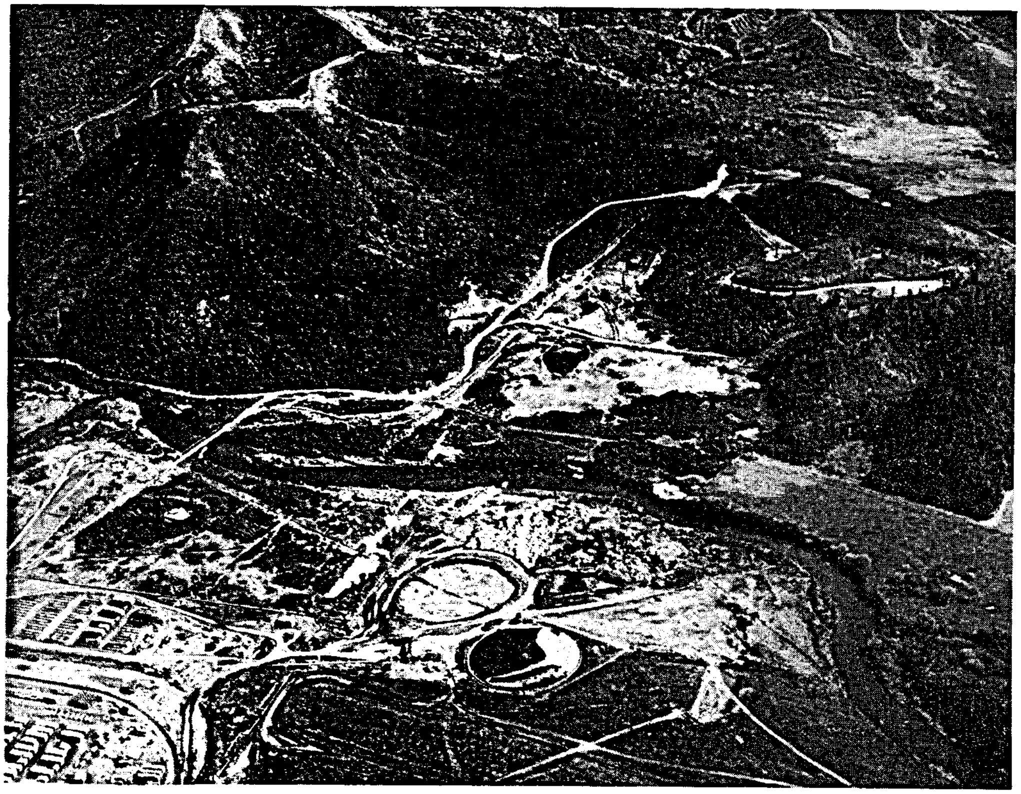


Figure 9.   East to west view of borefield.

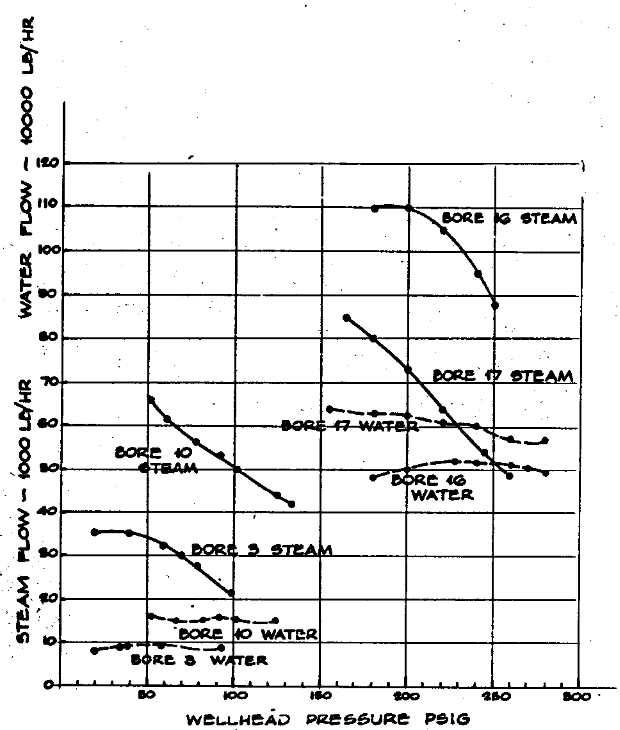


Figure 10.   Output from bores drilled in 1967.

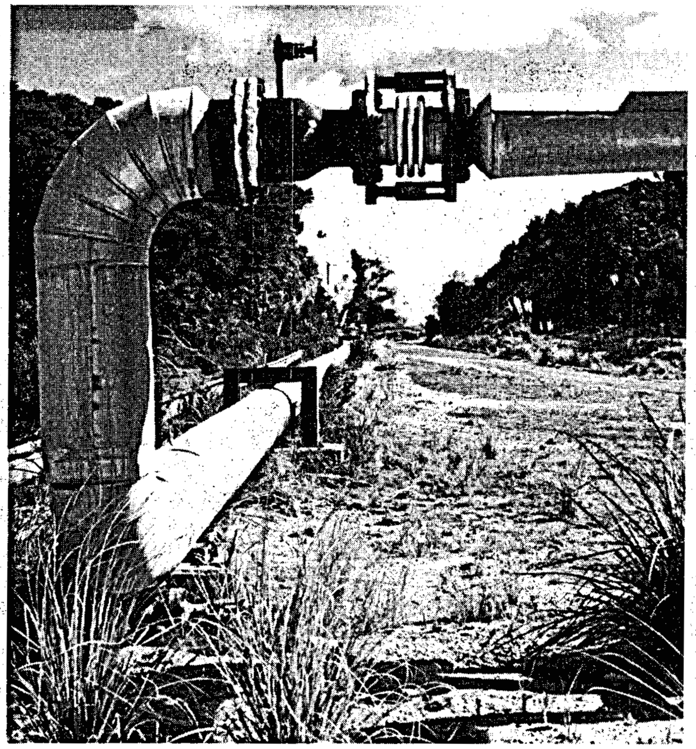


Figure 11. 16 inch two phase flow line from No. 17 bore. Typical expansion compensator, roller support and guide.

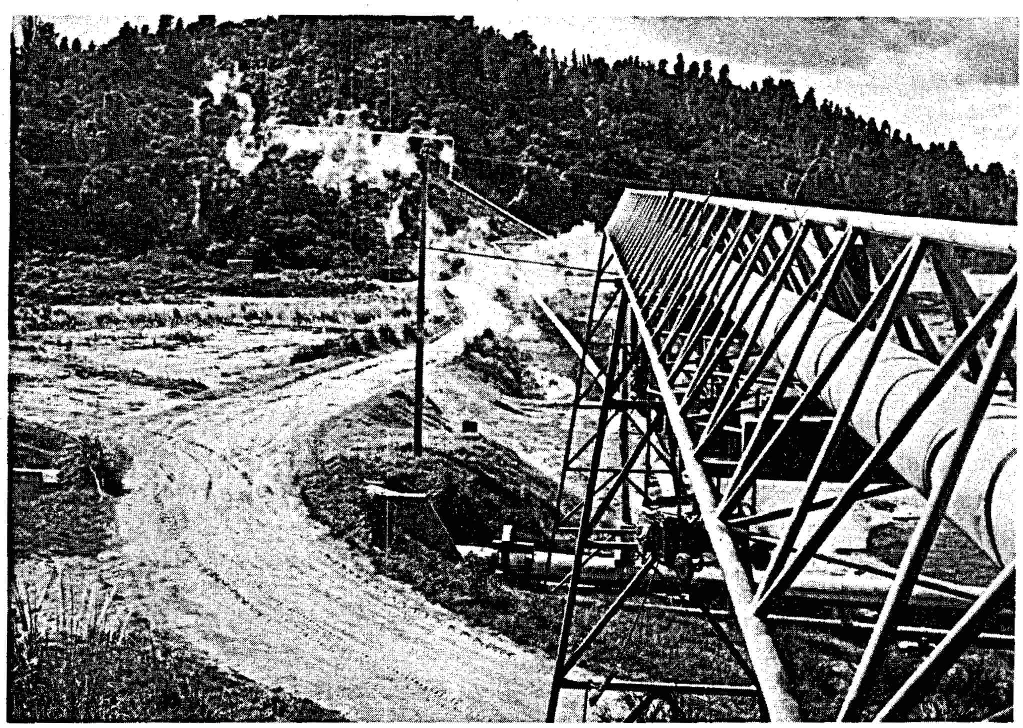


Figure 12 18 inch two phase flow line from No. 19 bore in background. 6 inch steam pipe from No. 3 bore to 24 inch steam main in foreground.

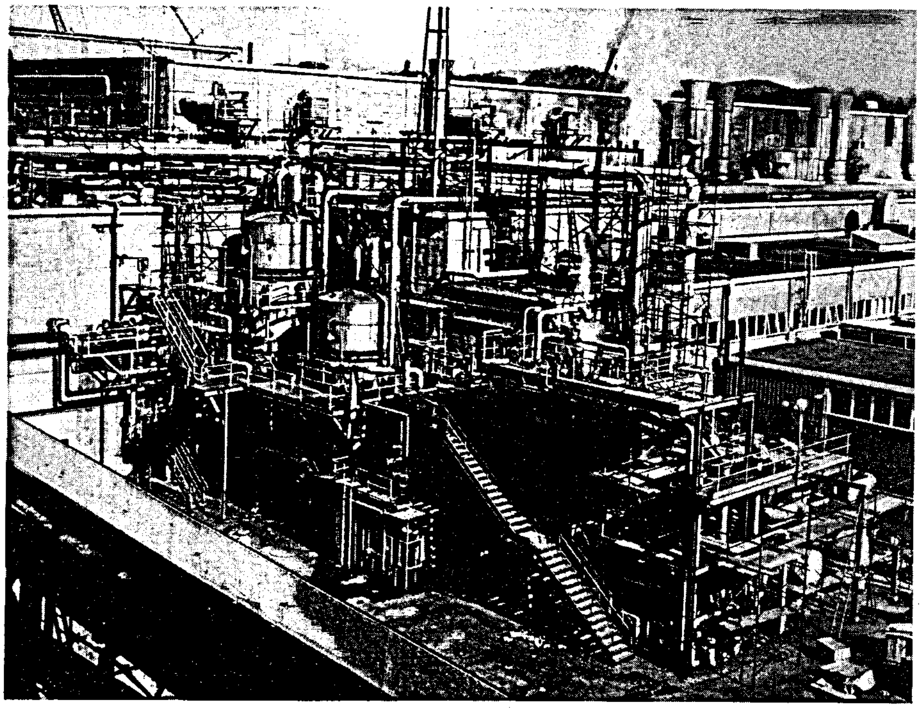


Figure 13. Geothermal steam generators. Original HP generator far left with LP generator. De-aerator center. Two new generators bottom right.

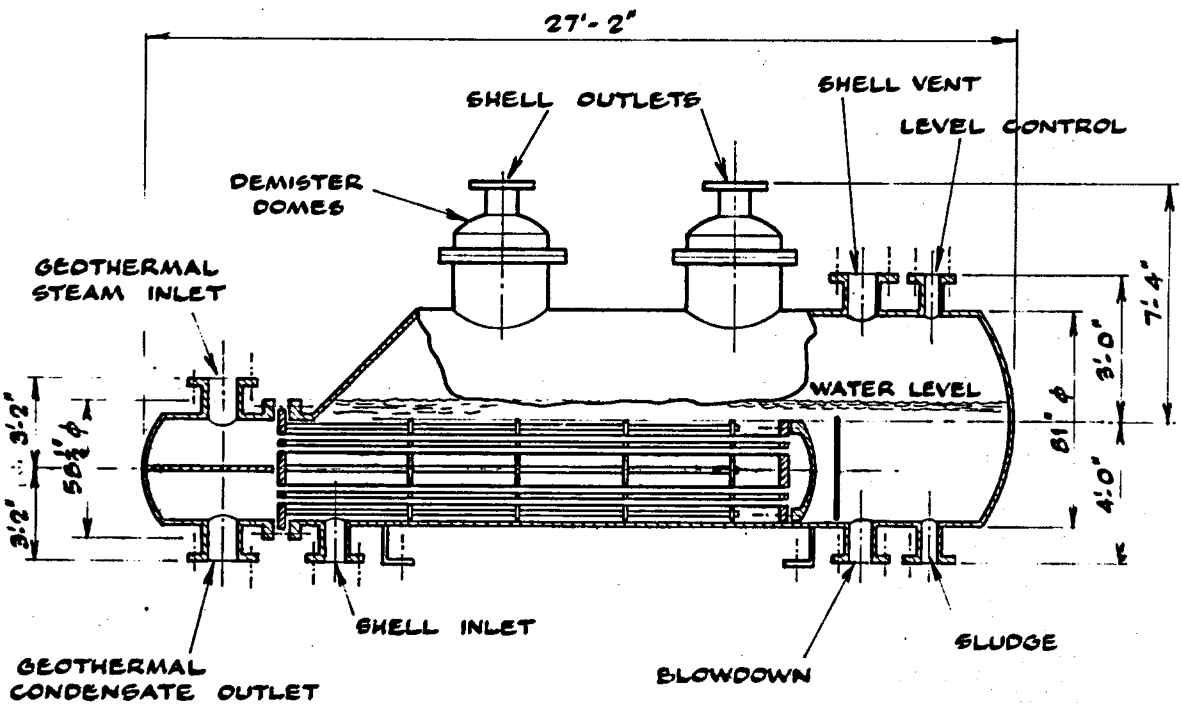


Figure 14. Geothermal steam generator. (output 50 lbs/in^2, 60,000 lbs/hr)

GEOTHERMAL ENERGY'S POTENTIAL FOR HEATING AND COOLING IN FOOD PROCESSING

By

Edward F. Wehlage[1]

ABSTRACT

Geothermal heat applied to food processing has a potential for relieving part of any strain resulting from crises in energy and food. The term "geo-heat" is applied to simplify reference to process heat derived from geothermal sources. Indication of the available geothermal heat to parallel food processing temperatures is included. Direct production of refrigeration effect, by-passing electric generation, is possible at +4 or minus 60°C. Technology for food processing is well advanced beyond any equivalent technology for applying geo-heat. More research in several fields will be needed for full utilization of geo-heat to process food wherever such heat potential exists.

INTRODUCTION

This extremely exciting and fascinating idea that geothermal energy may now be effectively applied to the production, processing, preserving and storing of food, opens so many novel avenues for social, political, economic, environmental and engineering discovery, that it becomes difficult to follow a purely objective course of reasoning. Our entire society is currently being threatened with such serious dangers that we must shudder at the possible loss of our traditional energy supplies and the danger of famine. These hazards to our basic need for warmth and food can produce a strong emotional reaction in those of us here who work today, and dream about our future world with geothermal energy at work.

One simple fact, that geothermal energy may now participate in the fulfillment of a significant part of the food processing industry's emergency need (and future potential needs) for both heating and cooling, must assume substantial importance for each and all of us in the Western United States--and other places on this globe that have been given an abundance of the earth's residual heat that is made manifest with geothermal energy.

A MATTER OF NECESSITY

We have to dry, can, and freeze food if we want to survive, eat reasonably often and maintain any desirable level of nutrition. In our Western World you will not make it otherwise. Many of us think of the "good old days," but we usually only think back a few years--not really far enough back. It has been shown that even two hundred years ago, the winter storage of food was so inadequate that spring fatigue, just before the planting time when the most strength was needed, was very common because of inadequate winter nutrition. This began to change with the development of better transportation, and changed greatly with the advent of a wider range of food

[1]Consultant, Whittier, California

preservation with more and more diversified products. Today, we can joke about "spring fever," but it was no joke for our ancestors at winter's end.

A TECHNOLOGY...AND ITS LACK

Today, we do not have a geothermal technology that has developed to match our food manufacturing technology which is the best mankind has ever known. It may be fashionable in some quarters of our society to denigrate its commercial application, but food technology is a science that will be flexible enough to be guided into many useful future paths. So far we have not developed a corresponding geothermal application technology.

There is a need for geothermal practice which can be readily integrated into both food technology and food plant engineering practice. This could become one of the more important undertakings of geothermal people during the next 25 years--while a realization, or lack of materialization, of those terrible forecasts unfold and become history. We should study and get ready.

A PROCESS VS. POWER

No consideration has been given in this paper to any possibility that eventually there can be in-plant generation of electric power in a self sustaining energy operation; nor has there been any consideration that a food processing operation could be an auxiliary industry for a power station. Two of the most successful geothermal industrial operations in the world already operate with back pressure turbines generating electrical power and simultaneously supplying industrial process steam.

PROPOSING A SIMPLIFIED TERM

At this point, it appears desirable to introduce a new term proposed for this paper (although used before) to simplify the description of geothermal energy for direct application in some system, such as food processing, rather than for the generation of electrical power for system distribution.

The term is "geo-heat." It is brief. It can readily indentify the direct application of geothermal heat, rather than electrical power derived from geothermal energy. Geo-heat seems especially applicable for the plan in which we "mine" and use the earth's available heat while residual pressure is dissipated and the "spent" convecting fluid is returned to the earth, or otherwise disposed of as a rejected waste material.

In this paper, reference will be made to geo-heat for that fraction of geothermal energy applied to process work.

FEW KNOWN APPLICATIONS

Should one of the Maori ladies who lives in a New Zealand thermal reserve walk into her backyard with a basket of food for steaming in the fumarole there, she will be preparing food with geo-heat. If you cook a few eggs in a hot spring at 99.8°C, you are preparing food with geo-heat (process geothermal). The nearest thing to commercial geothermal food processing could well be the bread baked in the earth ovens of Iceland--a long and slow process--commercial because it is served to the tourists. In a sense, cleaning up a plant with warm well water is the same. It is known that other industrial and food processing uses for warm water utilization have existed, and probably are still in use.

A GEO-HEAT "THERMOMETER"

An interesting parallel exists between those temperature ranges available in existing geothermal sources and the requirement for a broad spectrum of temperatures used in the preparation and storage of foods. A comparison of the temperatures used and those available is made with the "Geo-heat Processing Thermometer" shown in figure 1.

The heat now produced from fossil fuel sources for a food process operation closely follows the range available from recognized geothermal sources. Therefore, there must be an opportunity for the use of geo-heat in any food processing industry. Geo-heat may be a substitute for fossil fuel consumption in such service. Not utilizing such potentials, even in a relatively minor quantity, may lead us into an economic ice age where technology would be useless.

WHERE DO WE GO?

When he wrote "Harvesting The Earth," in 1973, Dr. Georg Borgstrum said: "We Westerners cannot expect to remain seated comfortably at ringside while this tragedy unfolds on the world scene. Our food deliveries have been

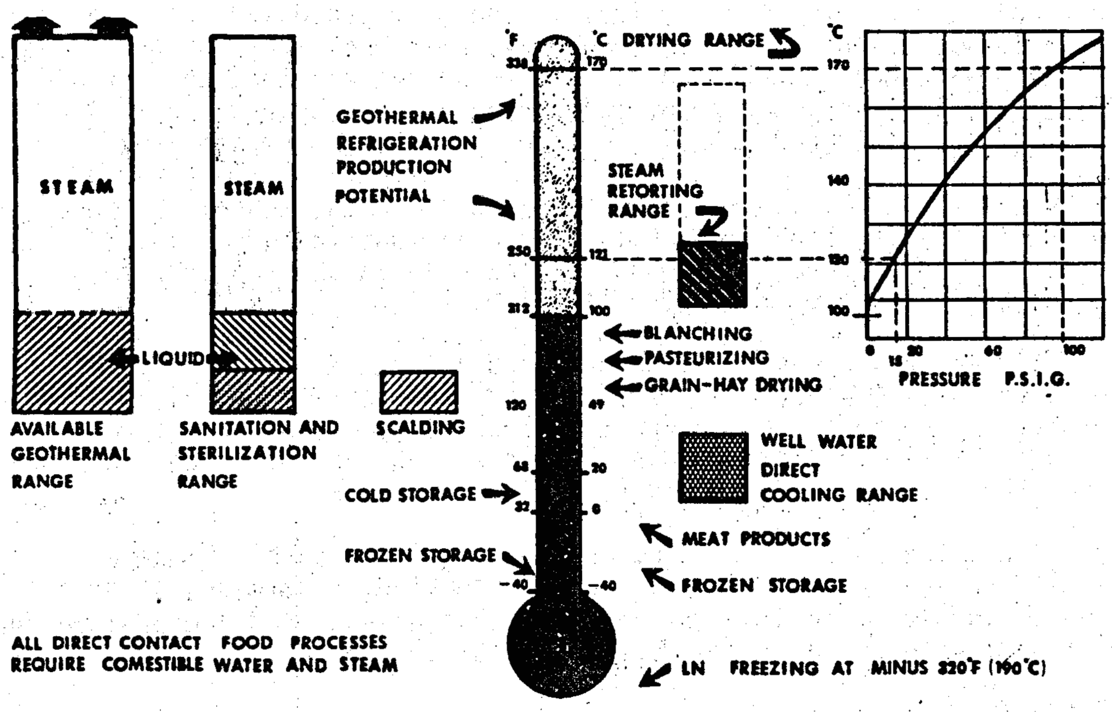


FIGURE No. 1.

from: "FOOD FOR THE FUTURE WITH GEO-HEAT"

GEO-HEAT PROCESSING 'THERMOMETER'

mostly like crumbs falling from the rich man's table. Far more extensive measures, both in time and size, are needed to stem the tide and reduce the enormous dimensions of human misery, not the least in the terms of food."

There are estimates indicating far more food value is lost prior to today's processing than is packed. If all of this were to suddenly become available for packing and distribution, the needs of the industry would suddenly double and so would the requirements for fuel in an already troubled energy market. This will probably be one demand that could develop. If we enter any wide-ranging crash program for energy, where does the food processing increment fit in? Geo-heat may have to match it one day.

There must be a way. Only by acting now can we learn if we have the slightest chance of moving into the next century knowing how well geo-heat may be used for added food output.

A FORE-RUNNER OF AN INDUSTRY

When the Reverend Thomas Robert Malthus (1766-1834) conceived his essay with the idea that mankind, like hungry termites, could eat its way off the earth, there is little chance he dreamed geothermal energy in 1974, might influence his conclusion two centuries later. It is equally unlikely he was aware of the "Art of Appertizing" that grew from Napoleon's call for food preservation methods unknown in 1790.

France, in 1790, had a crisis. It was at war. Famine was abroad. Feeding people and an army was difficult. The only processed food that was transportable was dried--no canning, no freezing. When Nicholas Apert began experimenting with heat and closed containers he learned that decay could be arrested. After ten years spent in proving his discovery, Apert was awarded the prize of 12,000 francs promised by Napoleon for the process.

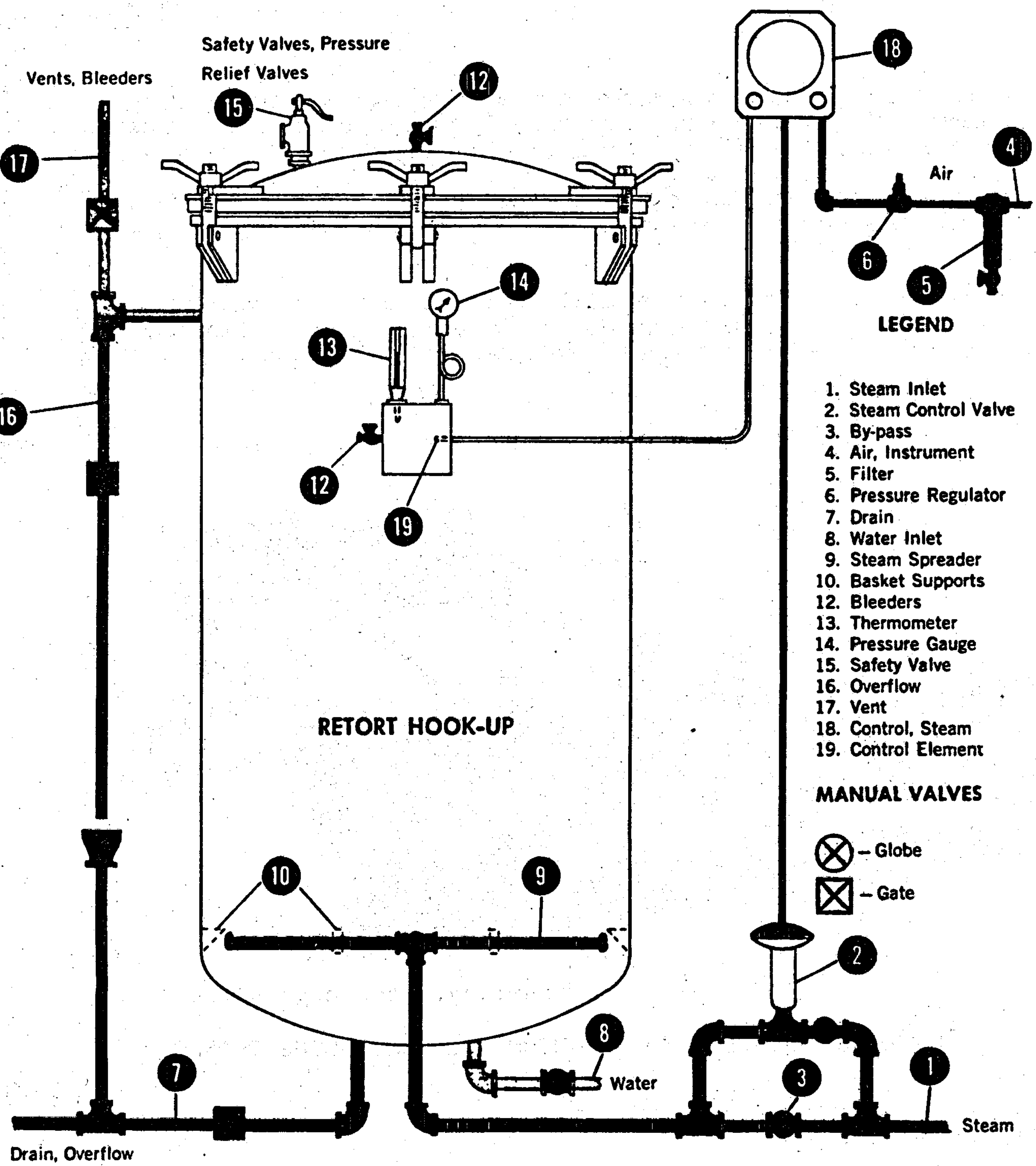
In 1810, a British patent was issued for metal and glass containers and closures. A metal can with a hole in the lid was invented in 1823, a principle still followed today when an open hole in the top of an evaporated milk container is soldered shut after filling.

Sterilization was still an art, and not yet a science, for more than 50 years until Pasteur discovered the idea of controlling microorganisms--the one that is the basis for modern food technology. The idea of heat controlling bacteria and enzymes was slow in coming, now with heat in abundance from the earth, we are surely ready for a new use.

Thermal processing of food and sealing it in cans to make a hermetically sealed product is often termed "cooking, retorting, or processing" and it involves the application of heat at a specified temperature for a specified time to produce a commercially sterile product.

THE STEAM RETORT

Probably the greatest single technical development in the entire field of food preservation is the steam retort that is a closed pressure



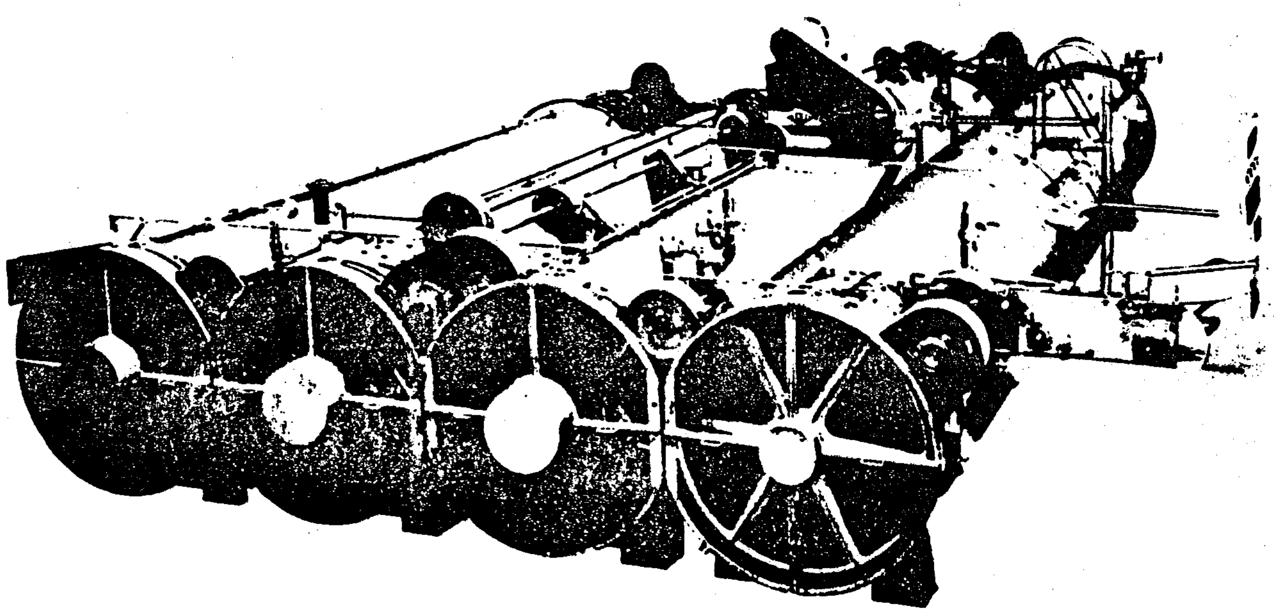
Courtesy: Continental Can Co., Inc.

FIGURE NO. 2. SIMPLE VERTICAL STEAM RETORT DIAGRAM SHOWING BASIC PROCESS WITHOUT PRESSURE COOLING.

vessel using pure steam or superheated hot water to heat food in the closed containers. Its use is an art, and it probably contributed more to the safety of our food supply than any other factor, mechanical, chemical or otherwise.

Under the right conditions geo-heat can take over this very important job as well as fossil fuel produced steam. It is natural and reasonable in geothermal territory.

The rather simple automatically controlled batch retort in figure 2 has developed from a humble beginning to the complex automated continuous cooker and the automatic sterilizer illustrated by figures 3 and 4.



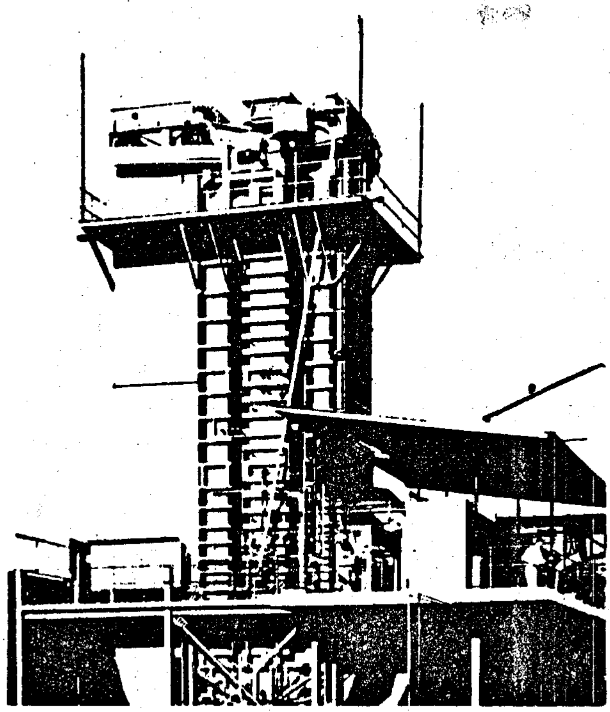
Courtesy: FMC Corporation

FIGURE No. 3. FOUR SHELL AUTOMATIC CONTINUOUS COOKER

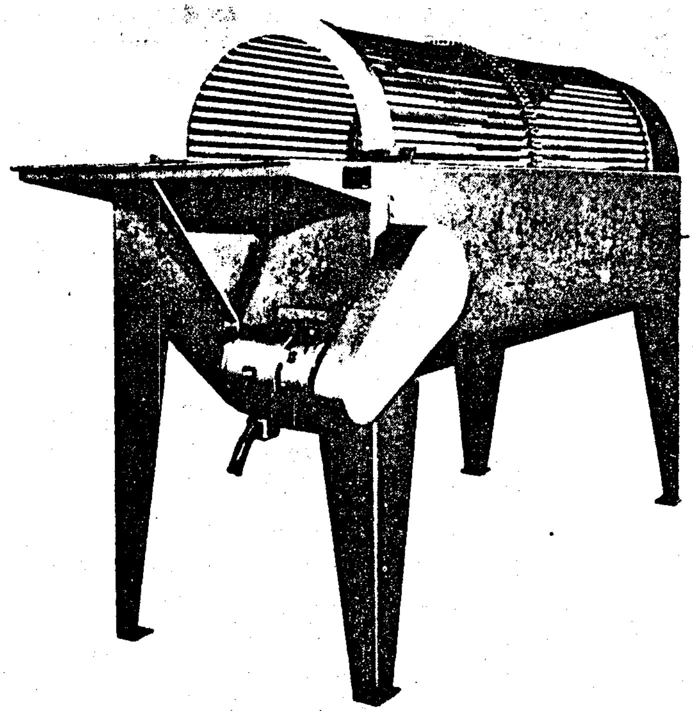
AGAIN, OUT OF A CRISIS?

An important point is that out of a crisis we got a new industry preserving food with heat. Can we achieve greater strides with just another source of heat from the earth?

It may be possible that each new crisis, whether in 1790 or in 1990, will encourage growth and that now our understanding of heat leaves us better equipped to handle energy oriented problems. We are on the threshold of new discoveries. We do not need to know the names of each kind of bacteria to realize that adding or removing heat from a food is essential to processing, and that if done properly, it can be done with geo-heat.



(A)



(B) *Courtesy: FMC Corporation*

Figure No. 4. Virtually all food processing machinery requires a substantial volume of water, hot and cold. (A) A large continuous sterilizer. (B) A simple reel washer may use hot or cold water depending on product.

GEOTHERMAL REFRIGERATION

The relative absence of heat can also be utilized to preserve the food after it has been adequately cooked and sterilized.

Where geo-heat is available at the proper level, it is also capable of supporting the operation of a food freezing operation without the conversion of energy into electrical power to be the force in a compression-expansion system.

Refrigeration systems for operation at +4°C (40°F) are now a real capability for geothermal operation. Such systems are already designed, except for the variable primary exchangers that change with each brine condition. The author's office is now at work on preliminary investigations for a plant capable of delivering minus 60°C (-50°F).

WE HAVE THEM...SO WHAT?

If we have the sources of geo-heat, why are we not using it for food processing now? Must we continue using fossil fuels in boilers? What can geo-heat do in the food processing fields?

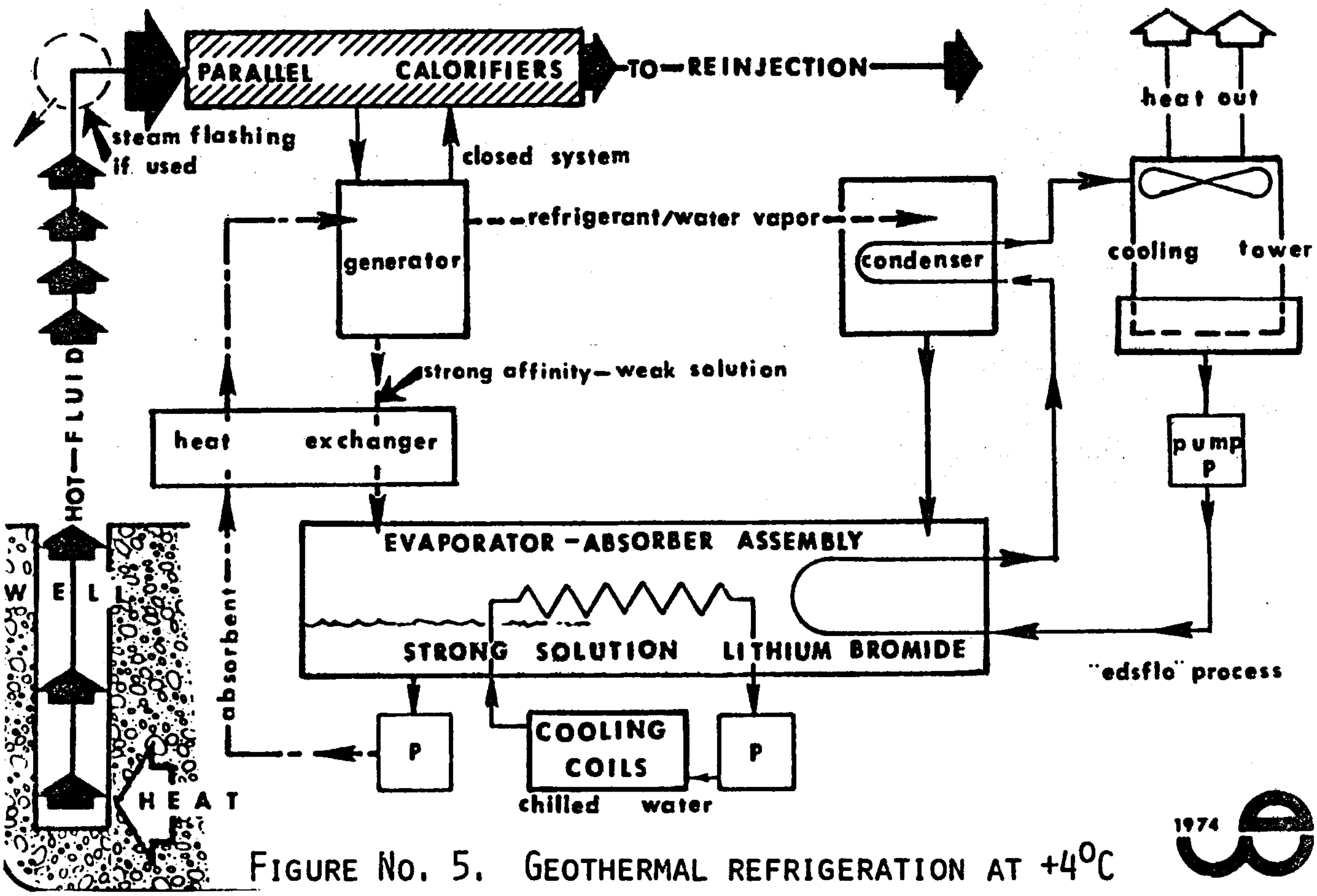


FIGURE No. 5. GEOTHERMAL REFRIGERATION AT +4°C

There are many reasons. Fossil fuel can be transported almost anywhere. It has not been extremely scarce. It can be held in storage. Geo-heat must be used where it exists.

A canning plant does not have to be located in the center, or beside an orchard or spinach field, but it has to be close to raw products and a market for the product handled.

Until recently the only available sources of geo-heat were low temperature hot springs. The potential has changed now that new geothermal discoveries and the drilling techniques can deliver adequate temperatures for processing.

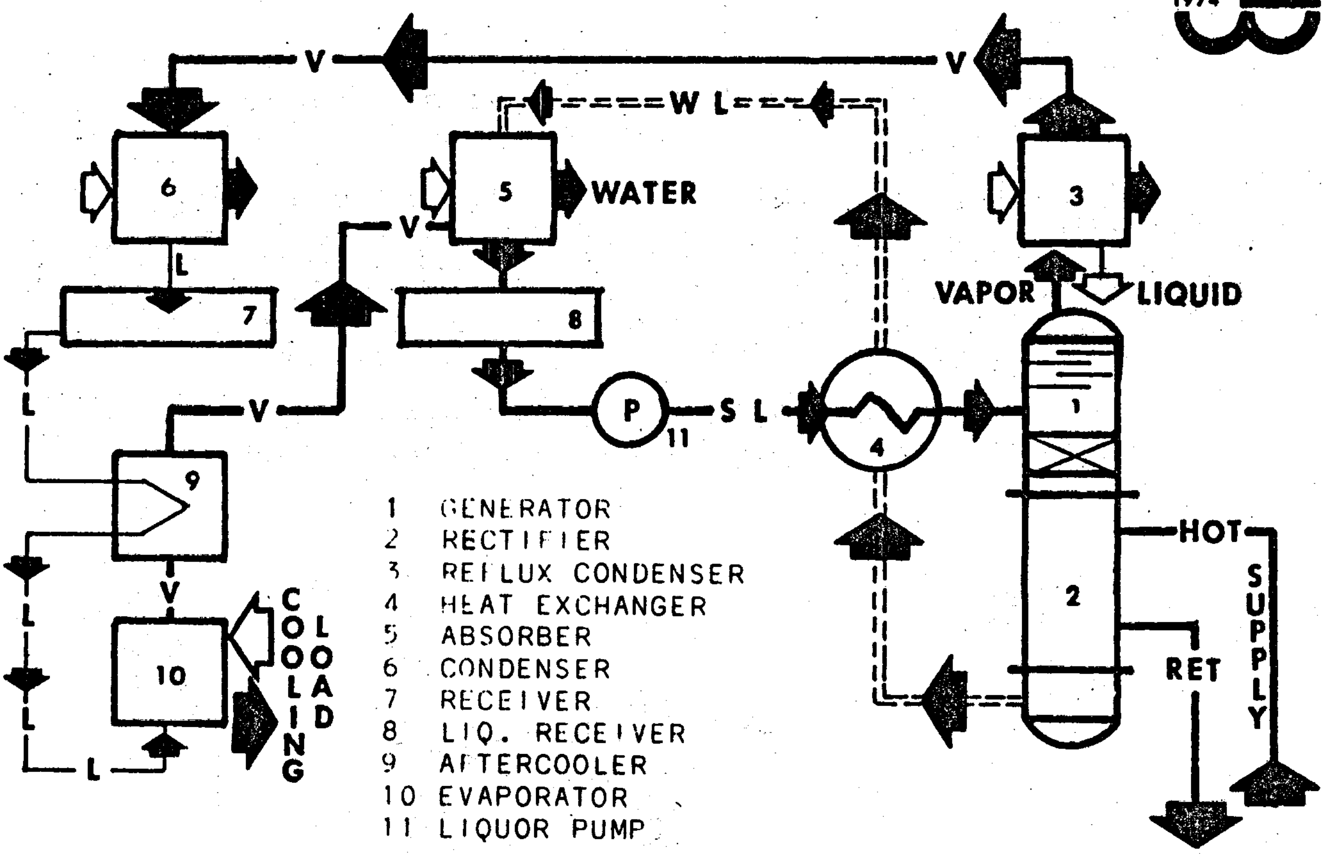


FIGURE 6. BASIC SINGLE-STAGE FLOW DIAGRAM FOR MINUS 60°C GEOTHERMAL REFRIGERATION SYSTEM PROPOSAL.

SOME LOAD AND DEMANDS

In one specialty canning plant familiar to the author, the typical daily production was 50,000 dozen five ounce containers per 16 hour day with year round operation. Daily steam consumed was 400,000 pounds (±180,000 kg) at 160 psig and a demand of approximately ten tons per hour.

Comparison with the data from one of the wells at the Otake field in Japan shows how capacity from certain wells compares for a plant source. Well No. 8 was partially completed when its output was 11 tons of steam per hour at 2.1 ata, enough to meet the demand, but not hot enough for plant requirements.

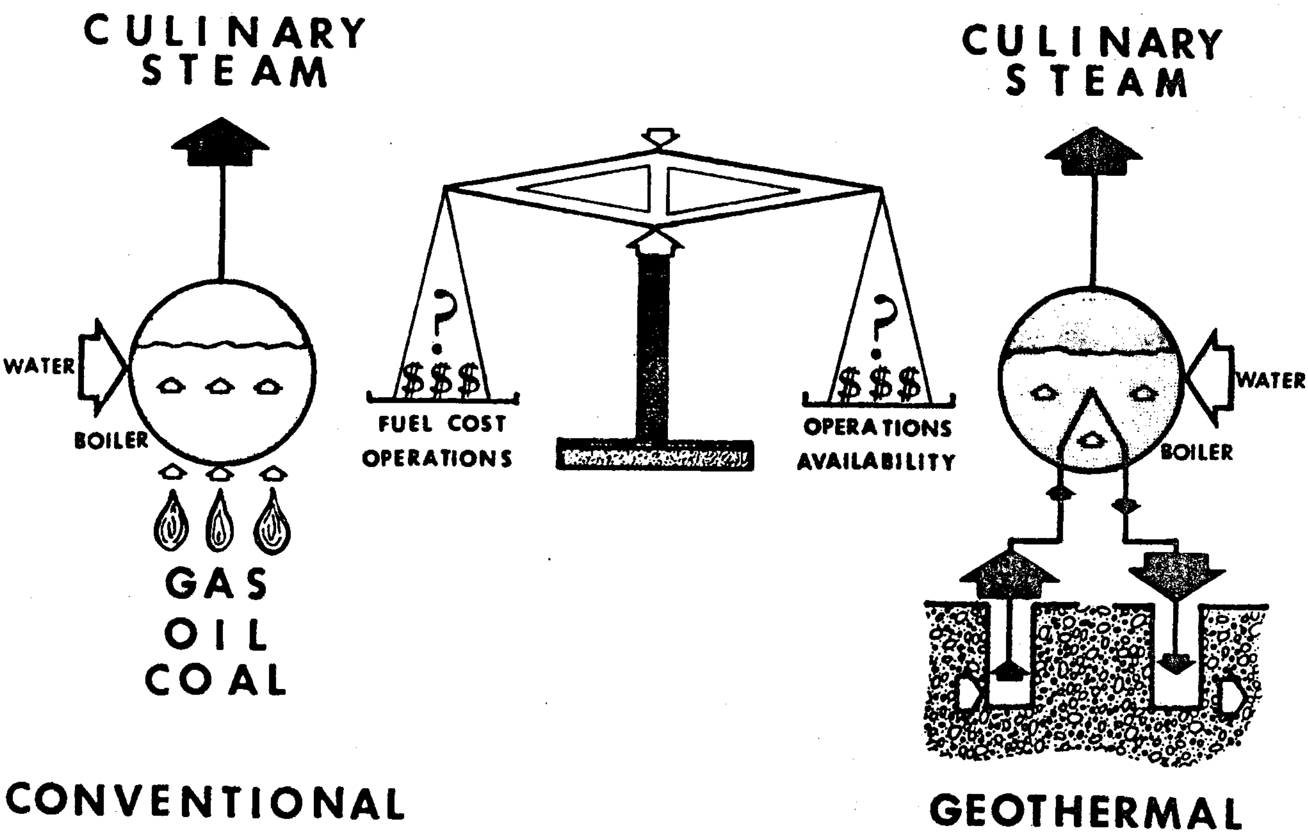
Another well at nearby Hatchobaru, No. 3, delivers about 46 tons of steam and 143 tons of water per hour and pressure level of 7.0 atg--far in excess of the canning plant requirements and at a satisfactory pressure for sterilization.

ECONOMIC BALANCE

If costs are nearly equal, plant managers will be reluctant to switch from a tried operation using automatic steam boilers.

Geo-heat may be plentiful, but convincing plant managers that it is desirable will require proof that there is a proven economic advantage, that fuel is not otherwise available, or that legal and social requirements will be imposed. Fuel does not occupy such a major part of the plant budget that a substitute is likely to be sought out without compelling reasons. Research on the economic balance is essential for the ultimate changeover.

Certain operating problems will also arise over an economic balance. Here again, research and study will benefit the industry and guide future applications.



ECONOMIC BALANCE?
from: "Food for the Future With Geo-heat"

Figure No. 7. A wide range of items will affect the required economic balance required to influence competitive application of geo-heat in a food processing plant.

Food processing plants share one common point of technology with geothermal operations--a mutual concern with the disposal of relatively large quantities of rejected materials and water.

It is not possible to make a blanket prediction of the analysis of geothermal fluids and steam. Contaminants will be the source of many difficulties. Some of them will include these:

Solids carryover	Salinity/acidity
Calcium	Ammonia
Sodium	Arsenic
Potassium	Mercury
Boron	Hydrogen sulfide
Iron	Silicon
Magnesium	Nitrogen
Trace minerals	Carbon Dioxide

None of these will have any particular appeal for quality control people in the food industry. Pure steam of "culinary" or "comestible" quality is mandatory where steam is used for direct contact processing. It is likely that a geothermal boiler or exchanger will prove to be a mandatory requirement. This is in no way impractical since this type of boiler functions quite satisfactorily in the paper mill operation for the Tasman plant located in New Zealand.

FUTURE PLANS FOR STUDY

There may be other obstacles and problems. This is an untrodden path. A continuing program of investigation is indicated from the proposed geothermal applications to the food processing industry.

A program of investigation is suggested that may very well follow the outline that follows, including:

Locating sites with adequate temperature and pressure
Locating sites to match raw product availability
Determine marketing potential from geothermal areas
Development of direct refrigeration
Acceptability by investors and government
Economic desirability of geo-heat in processing food
Environmental aspects of geo-heat in processing food
Matching geo-heat temperatures with operations
Elimination of impurities
The possibility of container corrosion and etching
Designing new "calorifiers" and exchangers, etc.
Training prospective plant operators
The social need to replace fossil fuels

CONCLUSION

Without adequate fuel for heat the canning industry is going to encounter trouble and geo-heat can help us in the Western U.S.A. We will surely face a demand for more processed and transportable food. There will be new problems because this is a new approach, but there is no activity in the geothermal field today where there is a greater challenge because there is the power we need in our geothermal reserves.

REFERENCES

1. ASHRAE Guide and Data Book, 1972, Chapters 13 and 14.

2. ASHRAE Guide and Data Book, 1974, Applications, 23 through 41, Food Industry Practices.

3. Borgstrom, Dr. Georg, Harvesting the Earth, Abelard-Schumand, 1970.

4. DeRosier, Dr. Norman W., The Technology of Food Preservation, The AVI Publishing Company, Westport, Connecticut, 1970.

5. Kubota, Katsundo, "On the Development of the Otake Geothermal Field," Manuscript No. 31, Fourth International Group Training Course in Geothermal Energy at Kyushu University, 1973.

6. Livestock Environment, Proceedings International Livestock Environmental Symposium, American Society of Agricultural Engineers, 1974.

7. Retorts for Canning, Chicago Technical Center, Metal Division, Continental Can Company, Inc.

8. Wehlage, Edward F., "Geothermal Refrigeration," Geothermal Energy Magazine, June 1974, Vol. 2, No. 6.

9. Wehlage, Edward F., "Non-Electric Cooling at +4°C From Geothermal/Hydrothermal Heat Sources," 1974 Transactions, International Society for Geothermal Engineering, Vol. 1, No. 1, pp. 1-7.

10. Wehlage, Edward F., "Geothermal or Hydrothermal Heat Source Refrigeration Versus Electric Power and Fossil Fuel Sources for Process and Air Conditioning," IEEE, Transactions on Industry Applications, July/August 1974, Vol. 1A-10, No. 4.

INNOVATIVE GEOTHERMAL USES IN AGRICULTURE

By

A. M. Linton[1]

ABSTRACT

Geothermal heat has been used for agricultural purposes since the late 14th century at Rotorua. The wells produce both steam and hot water. A good four inch geothermal bore produces from 10,000,000 to 12,000,000 BTU/hour. About 350 bores are in existence, many heat several residences besides being used for horticulture. The hydrogen sulfide and sulfur dioxide in the fluid and steam aid in controlling fungus diseases. Horticultural crops grown in the warm atmosphere are orchids, carnations, mushrooms, tomatoes, french beans, lettuce and others. Pineapples and bananas are grown in areas where temperatures may fall below -10° Celsius. Alfalfa is processed for protein by using geothermal heat in the processes. Development of the dependable resource is progressing rapidly and, when completed, will aid the country to be more nationally self-sufficient for energy sources.

INTRODUCTION

The Oxford dictionary defines agriculture simply as the cultivation of the soil. In our country, agriculture has by common usage come to mean the science of farming and cultivating the broad acres, and the word horticulture is more normally used to denote the cultivation of the soil in a more intensive manner, generally in smaller areas. However, despite this local distinction, it is fair to suppose that the term 'agriculture' can be used to mean the cultivation of the soil in both large and small holdings, and indeed in intensive cultivation where buildings of one sort or another are an accessory to the activity.

In this paper, reference will be made principally to what we would call in our country horticultural activities. The reason for this is simply that because it is a small country, lying generally in a north-south direction between latitudes 34 and 47 south with a long coastline exposed to the ameliorating influence of the sea, it is possible to find considerable frost free areas within reasonable distance of most centers of population. Because of this, large scale farming has tended to neglect the availability of the geothermal heating potential over a fairly considerable area of the country. It has been left to the more intensive users to develop in this field.

HISTORY

To get to the beginning of the innovative use of geothermal heat in agriculture, it is necessary to go back to a time about 100 years before Columbus discovered America.

---

[1]Former Mayor of Rotorua, New Zealand

The great migration of seven canoes from the mythical Hawaiki--thought now to be the Tahitian group of islands--is reckoned as having taken place in 1350 A. D. The leading canoe was the Arawa canoe under the command of Tama-te-kapua, with the tohunga Ngatoro-i-rangi as navigator. Ngatoro's grandson, Ihenga, discovered Rotorua and its hot springs.

The canoes brought the kumara or sweet potatoe to New Zealand, and in the course of the voyage much of the precious seed was lost. This was, according to legend, because Tama-te-kapua, known to be an amorous individual, paid more attention to the wife of the tohunga or high priest than he should have. As an act of revenge, the tohunga called down the wrath of the storm gods and the canoe was almost engulfed. In time the tohunga relented and called off the storm, but a great part of the provisions and much of the kumaras were lost overboard. However, despite great privation, enough seed kumaras were kept, and because of this the kumara is highly valued by the Maoris.

Following the discovery of Rotorua and its hot springs, the Maoris were not slow to learn that the kumara would sprout much quicker if the tubers were placed in a warm soil around the hot springs. They found also that in areas where the soil was warmed by geothermal heat they could grow kumaras, whereas frosts of up to -10 or -12 degrees celsius, over most of the surrounding area, caused it to be unprofitable kumara ground because of the short growing season.

Insofar as the growing of kumaras was concerned, the main areas around Rotorua were confined to the highly thermal regions around Whakarewarewa and Ohinemutu, and on Mokoia Island, which is about a square mile in area, and roughly in the center of Lake Rotorua.

Warm pools are located on the southeastern side of the island, and on the flat land north of these were the old kumara fields. Here, too, is a curious stone, known locally as the Kumara God and believed by many to have been brought from Hawaiki and regarded as 'tapu' by the Maori people.

Maoris planted by the phase of the moon, and the tohunga was always present to give the appropriate "karakia" or incantation to ensure the success of the crop. However, I should imagine that the real ensurer of success was the geothermal heat which warmed the ground, but more importantly, kept at bay the early and late frosts which are the bugbear of agriculturalists in our district.

The practice of sprouting kumaras alongside warm pools is still carried on, and the plants made available are then transported back to the coast, into an almost frost free climate, for growing. Energetic people can, in this way, grow nearly three crops of kumaras in a year. Under ideal conditions, each crop takes just a little longer than four months to mature.

GEOTHERMAL UTILIZATION

In more recent times there has been a great deal of effort, perhaps more correctly trial and error, put into the use of geothermal heat resources.

Over much of the area around Rotorua, a good geothermal bore on a 4" pipe, which is the usual size, would produce 10,000,000 to 12,000,000 BTU/hour. One of the features of our use of this form of energy is its wastefulness. In all, throughout the town, there are about 350 bores. In Maori villages, considerable use is made of the more readily available heat obtained by passing the town's supply of water through a pipe some 20 feet of which is immersed in a hot pool. In many cases, the surplus heat is used to grow vegetables planted along the line followed by the pipe to the house or bathing pool which is to be heated.

While the geothermal bores number about 350, the number of premises heated is unknown; the greatest number of houses on a single bore that I know of is about 30, and that particular source of supply could easily supply six times that number.

However, it is in the field of organized and professional horticulture that the greatest use is made of geothermal heat. The range is very considerable, from orchids to mushrooms, and considerable fortunes have been made by those who had the ability to get into this activity before the competition became too great.

A description follows of some of the more common uses:

<u>Orchids</u>

Probably about fifty home gardeners include in their activities the growing of orchids. Most people generally grow one or two plants in suitable locations within the household; however, in this instance, they grow anything up to 100 plants with considerable success. Some of the more energetic have entered the local market for orchids, and some have even succeeded in getting into the export field.

I have asked a considerable number of these growers to comment on the reason for becoming involved in this activity. Almost without exception the comment has been along the line: "We had a glasshouse and we had the surplus heat available, so why not make use of it." Here is a situation where the motivation was not a desire to grow orchids, but rather to use a product that was readily available--geothermal heat in a readily usable form, and easily regulated.

<u>Other Flowers</u>

It is not common practice to grow roses under cover in New Zealand--indeed it is most uncommon. However, certain types of flowers are profitably grown on a commercial basis. Probably the most extensively cultivated is the carnation, and the quality of the blooms produced mainly in the winter season, exceeds that of the best growers growing in the open in the more favorable season.

It is generally recognized that the best carnations are grown in an open, sunny situation, and it would be reasonable to suppose that off season cultivation in a closed house would have its problems. It seems, however, that good results are not difficult to obtain.

It may be that in addition to providing heat in an easily managed form, a geothermal bore, at least in Rotorua, has other advantages. Hydrogen sulfide is one by-product, and in our case, sulphur dioxide is frequently another.

It is well established among rose growers around London that the British Clean Air Act, while widely acclaimed and very effective, had some not so welcome side effects. Without exception growers report a marked increase in the incidence of black spot and other fungus diseases, unquestionably due to the absence of sulphur dioxide in the atmosphere. There is no doubt that where sulphur dioxide is a side product of a geothermal bore, the incidence of many fungus diseases is lessened. This form of heat really encourages people to make use of it.

Much of the foregoing comment deals with the use of geothermal heat by what would normally be non-commercial users. In the commercial field, development is much more evident, and over the years growers have come and gone, most having been able to retire on the results of a comparatively short working period. Typical of these are those who have made the growing of mushrooms their occupation. A growing demand, an assured market and a quick turnaround, coupled with a cheap and reliable means of controlling temperature and himidity have resulted in unfailing success.

Mushrooms, of course, do not require very much heat, but the important feature is the ability to grow them when the field ones are not available and prices are high. Recent years have been good for field mushrooms, and school boys have been selling them in season on the roadside, for as little as 10 cents per pound. It is in the remaining ten months of the year that the geothermal growers come into their own.

A feature of geothermal heating is its reliability, its ease of adaption and regulation to meet almost any situation, and its freedom from power failures, and in our present situation power shut downs. Three years of drought have been too much for a power generating system relying on water potential and neglecting an enormous geothermal potential.

The winter production of tomatoes, french beans and lettuce all have their devotees. In particular, the last two have great possibilities and show good returns, and there are good reasons for the popularity of these crops. Under the ideal conditions provided by a uniform and regulated system of growing, the rotation time of these crops is within the range of eight to ten weeks, enabling the grower to use these catch crops between raincrop plantings. The widespread use of frozen vegetables has not lessened the demand for the fresh grown product. Indeed, if anything, consumers appear readily to tire of the frozen product, and are willing to pay prices which make the production of fresh vegetables on a year round basis economically very satisfactory.

One of the most enterprising of users of geothermal heat was an individual who grew some 200 pineapples each year in his own backyard. They were excellent pineapples, of large size, and were grown under the propagating benches on both sides of the house, and did not in any way interfere with the usual occupation of the owner, who raised seedling plants, mainly annuals, for local gardeners. The pineapples were a sideline, and

I doubt if any were sold, but instead were handed out to friends of the family of which I was fortunate enough to be one. This again demonstrates the versatility of geothermal steam, and also is an indication of what an enterprising individual can do in raising unusual crops, a type of activity easily capable of commercial introduction. This same grower was also the first to commence a service to gardeners which has since been carried on by a commercial nursery.

This latter enterprise commenced operation with three larger than average glasshouses, engaged in a single crop activity. This was growing tomatoes to ripen right through the winter

Later the owner came to realize that this one crop activity was not making use of the full potential, and somewhat gradually he extended his premises; he went out of tomato growing and became a commercial nurseryman. In this field he has been highly successful and well on the way to affluence.

Over recent years, probably the greatest development in the horticultural field has been the increase in the growing of indoor plants. Perhaps this has been due in some measure to the change in housing patterns.

New Zealand had established a reputation as being the place above all others where every house stood on a fifth or quarter acre lot--810 m^2 or 1012 m^2 in modern terms.

Seven years ago, flats formed only 11% of the total house units built. Now they form, in some areas, 50% of the total house units built. The home dweller must now garden indoors more and more, and this means a greater reliance on house plants.

One of the essentials for a nursery raising bedding plants, perennials, shrubs and trees from seeds and cuttings, is a supply of sterilized soil. It is essential also for home gardeners growing house plants.

Our nurseryman has capitalized on his cheap heat, following the earlier example of the pineapple grower, and sterilization of soil in quantity is one of the services he provides. The local gardener in our town can fill his trailer with soil, run down to the nursery, push a three quarter inch perforated pipe along the floor of the trailer under the load, cover it with a polythene sheet, and over all a tarpaulin, turn on the steam, and in half an hour he has a load of sterilized soil--enough to last for months.

The Rotorua City Council's nursery is another facility which relies on geothermal steam from a single bore which, for the past 30 years or so, has carried the load at little or no annual cost. Annually the Council raises its total requirements of bedding plants, and in addition holds in continual stock 30,000 to 40,000 pot plants.

Several innovations can be found in this long standing installation. In a small propagating house, a single load would be around 10,000 cuttings packed tightly. Up to 4,000 of these are frequently rhododenrons which grow superbly in Rotorua. Under these ideal circumstances, most cuttings root in three to six weeks.

Humidity control, in most similar circumstances, is usually by sophisticated and costly electrical equipment. The Council's system is simple--indeed almost primitive--one or more 1/16" holes are bored into the steam pipe, allowing the steam to sizzle away to achieve 100% humidity. With the right bottom heat, sterilized material and correct humidity, the cuttings cannot fail and the result is a remarkably economical and continuous supply of trees and shrubs for streets, playgrounds and public parks.

As I sit at my office desk, I can look out over the grounds of a local church and on into the backyard of an accommodation house. Here I see a group of trees which under normal circumstances should not be growing as they do grow, within 500 miles of this particular location. They are a group of bananas which year by year ripen large bunches of good fruit.

As well as the banana trees, the small yard holds the geothermal bore and the heat exchanger which supplies the accommodation house with the whole of its heating requirements. There is a good deal of steam about and I have a suspicion that this bore is one of those which we describe as problem ones. Some give very little trouble and go on and on for years; others seem too overloaded with silica which, unless the water and steam are kept flowing, tends to choke the bore. However, the steam seems to suit the bananas.

These particular bananas are not an isolated instance. For several years, the City Council had a very energetic and innovative director of parks. Periodically when Councillors arrived for the formal monthly meeting, they found on the table in front of them a hand of bananas or a pineapple.

The bananas were grown in the palm house, a facility built of odds and ends, without the formal approval of the Council, and without much cost to the city. It was, however, so successful that a short description of it is merited.

Twelve foot posts at twelve foot centers each way were set in the ground. The material used was tree ferns, many of which seem to take root when so dealt with, and once growing last for a very long time. Over the tops of the posts, bearers were placed, and this was the only material to cost any money.

The walls and top were then covered with laths about two inches wide at six inch centers. Face cuts from the local sawmills recut on a small saw bench, and treated with a coat of timber preservative sufficed.

Heat was supplied by a two inch steam pipe lying on the ground, around the outer walls, and twice at intervals across the house. There was no total covering at all. Everything was grown in tubs. For bananas, tubs were about two feet by two feet, and one and a half feet deep. They shared the space with luxuriantly growing philodendrons, monsteras and assorted palms.

There is no reason at all why this primitive, though innovative type of activity could not be expanded to almost unlimited size, and given an adequate supply of geothermal heat, bananas as well as other crops are a commercial possibility.

The pineapples, which occasionally graced the Council table, were a side line from a thoroughly insulated house used mainly for crotons and caladiums.

In dealing with the growing of bulbs of the narcissus family, one of your own gardening books has this to say: "There is no spray or satisfactory treatment for bulbs infected with the narcissus fly, except for immersion in hot water at 110° to 112°F for two hours, with the temperature held constant over that period. Below 110°F the treatment is not effective, above 112°F it will ruin the bulbs. It is easier to burn the bulbs and buy more."

The writer does not live in our town. It is a comparatively easy exercise for us to have a large receptacle such as a farm water trough and, by adjusting a valve, hold the temperature at a constant level as long as is desired. All of these and more uses are everyday occurrences in a town where geysers play all day, and sulphur dioxide and hydrogensulfide permeate the air we breathe.

A rather interesting parallel to the ability to hold a large quantity of water at a fairly constant temperature arises from time to time in the form of a controversy over the efficacy of mineral hot baths. There are some who hold they are no more effective than a hot bath in your own home. Naturally with hundreds of hot pools in private homes there are a great cloud of witnesses to say just the opposite. Perhaps the truth of the matter lies in the fact that the home bath is too small to maintain a constant temperature, whereas the mineral pool is capable of doing this, and herein lies its virtue.

CONCLUSION

So we are back to where the Maori began, and annually we start growth in our early kumaras in geothermal steam heated houses or in beds alongside a hot pool.

The wider use of geothermal steam is only a matter of time. As the population increases, food growing requires more intensive cultivation, and the development of artificial climates (greenhouses), permitting two or three or more crops per year in the place of the usual one or two, is a certainty for the future. Perhaps one day we may see major heat producing geothermal plants playing a greater part in our agricultural activities, for while the resource seems rather endless, the main feature of our present use of geothermal heat and energy is its wastefulness. We need to start now, using it more effectively, and this means planned use in larger plants rather than the dozens of scattered small ones we have now.

The total resource extends over an area about 150 miles long and in varying width from 5 to 20 miles. We could well make greater use of it.

Finally, I mention a development which moves into the wider and true agricultural field. I refer to the establishment about 35 miles south of Rotorua of a plant for the processing of lucerne. You would no doubt refer to this material as alfalfa. Numerous industrial plants already exist throughout the country, but this will be the first operating entirely on geothermal energy.

Lucerne, as we call it, grows well in our deep pumice soils, and up to now in our part of the country, has been harvested as hay for winter sheep and cattle feed and occasionally for horses.

In New Zealand we have not for many years grown sufficient wheat for our own use, and in fact, grains of all sorts except corn have periodically been in short supply. This is an especially serious problem for poultry farmers, and to some extent, pig farmers who are dependent on grains for their feed supply.

Only a limited part of the country as a whole is good grain country, perhaps, because the climate is too wet. Our pumice soils do not grow good grains, wet or dry, but they do grow good lucerne.

The use of cheap geothermal energy for the recovery of the high quantity of protein in lucerne, making as it does a highly nutritious livestock and bird food, provides for the development of an economic product.

It means that nationally we become more self sufficient. It means too that our production from the land becomes more diversified, and that is always a useful development.

Perhaps some day we shall learn to make more extensive use of this abundant commodity.

53,085

THE REYKJAVIK MUNICIPAL DISTRICT HEATING SYSTEM

By

Johannes Zoega[1]

ABSTRACT

The Reykjavik District Heating System uses natural heat resources, found in the city and its vicinity, to heat 11,000 houses, serving some 88,000 inhabitants. (Figure 1).

The natural hot water used is obtained by drilling in known thermal areas, and in areas found by various geophysical methods to be promising.

The water used is chemically clean, directly potable and contains only a small amount of dissolved solids, it is also non-corrosive to steel, and ordinary black steel pipes are used throughout in the system. Load density in the city is low, the average being 20 MW/km^2 and 1.9 MW/km of distribution mains.

The maximum heating load is 350 MW and the available energy 370 MW including a 35 MW oil fired heat peak power plant.

The climate in southern Iceland is mild considering latitude, the mean temperature in July being 11°C, and in January is 0.4°C, and the consumption in January is only two to three times that of July; thus, due to the relatively cold summers and warm winters, the equivalent hours at peak power for natural heat alone are 4500 hours per year. (Load factor 51 percent). Water meters are used for billing and the cost of heating averages 30 percent of the cost of individual fuel oil boiler heating.

The growth of the city, as well as the supply of neighboring communities having 26,000 inhabitants, will in the near future necessitate exploration and development of thermal areas further from the city where high temperatures (up to 280°C) have been found. This project enables combined production of heat for the district heating system and electricity.

It is shown that the production cost of both electricity and heat is lower than it would be in separate plants. The heat cost will be lower than from the present fields due to higher borehole temperature and larger size of the projected plant.

INTRODUCTION

Hot springs have been known in Iceland since the time of the first settlers, late in the ninth century; the name of the city is derived from hot springs, but the use of this natural heat was for the first thousand years limited to washing and bathing. At the beginning of this century, use was first made of it for heating of dwelling houses, and some years later

---

[1]Director, Reykjavik Municipal District Heating Service

for heating greenhouses.

In 1928, the first boreholes for hot water were drilled close to hot springs in the eastern part of the city; 14 boreholes were drilled to a maximum depth of 400 m and yielded 50 m^3/hr. of water at 87°C. In 1930, a distribution system was built, serving some 70 houses together with an open air swimming pool, a swimming hall and a schoolhouse.

These undertakings promoted further interest in the utilization of these natural resources, and in 1933 the city authorities purchased drilling rights in a hot spring area at Reykir, some 15 km east of the city, and drilling started that same year. In the years 1939 to 1943, collecting mains and a pumping house were built, together with a main pipeline to the city, storage tanks (Figure 12) of 8000 m^3 capacity and a single pipe distribution system for the main part of the city, (Figure 13) as it was at that time; this system was put into operation in 1943 and served 2300 houses. In 1947, additional drilling rights were bought, 3 km north of Reykir, and drilling commenced the same year; the area was developed in the years 1949 to 1950 and extensions to the distribution system in the city followed.

In all 72 boreholes were drilled in these thermal areas, down to a maximum depth of 770 m; and the total yield amounted to 1200 m^3/h of water at a temperature of 86°C. In 1958 the municipality, in cooperation with state authorities, purchased a large drilling rig which has until this time been used widely in southern Iceland, mainly in the city, drilling to a maximum depth of 2200 meters. Scientific methods of exploration were used, such as systematic temperature measurements in boreholes already drilled, and mapping of temperature gradients in these boreholes, measurements of gravity and magnetic field, and electrical resistance of rock foundation. Results were obtained in a field inside the city limits, and the field was connected by a pipeline to the existing system; two new districts were added to the system in 1957 to 1961, and drilling continued.

Since 1958, the result of drilling in this field has been 1100 m^3/hr of 128°C water together with 600 m^3/hr of water at 102°C from a second more recently developed field, also within the city limits.

Since 1970, drilling of deep boreholes in the Reykir area has been in progress and it is expected to bring the yield of this field up to at least 6000 m^3/h of water at 80 to 90°C. From the year 1969, all planned districts in Reykjavik have been served by the District Heating System.

The number of houses connected to the District Heating System today is 11,000 (99% of all houses in the city) with a total volume of 15 million cubic meters, representing a heating load of 350 MW including some outdoor (Figure 14) and indoor swimming pools and greenhouses.

In 1972 and 1973 agreements were made with three neighboring communities with 26,000 inhabitants to extend the district heating network to their areas. This service will be provided on the same terms to the consumer as in Reykjavik City. This work is now in progress and is expected to be finished in 1976. The extension is about 25% of the present size of the system. An oil fired peak boiler plant of 30 Gcal/hr capacity has been added, and storage capacity increased to 26,000 m^3

The system's heat resources today are summarized in the following table:

1.	Reykir area 3600 m^3/hr at 80°C	170 MW
2.	Reykjavik area 1700 m^3/hr at 119°C	155 MW
3.	Peak power plant	35 MW
4.	Electricity Authority peak plant[1]	25 MW
	Total	385 MW

THE DISTRICT HEATING SYSTEM (FIGURE 5)

Development of Thermal Areas

As stated in the previous chapter, the geothermal areas yield water at different temperatures and the following methods are employed in utilizing these areas. The water is pumped out of the boreholes with deep well pumps inserted about 120 meters down the boreholes, connected by drive shafts to surface mounted electric motors, through collecting pipelines to the area's main pump house.

The purpose of using deep well pumps is to lower the water level in the boreholes and thus increase the inflow of water and secondly maintaining the pressure of water exceeding 100°C over a certain minimum to avoid boiling in the system. The hot water contains a certain amount of gaseous nitrogen which has to be expelled; it will otherwise collect in the radiators of the highest situated houses where pressure is lowest, and block the circulation in the houses' heating systems. The nitrogen is removed by piping the water, on arrival at the main pump house, through a de-airator, which is a horizontal steel tank with a relatively large surface. The pressure is relieved and the water allowed to boil slightly at the surface; the gas freed by this process is then led to the atmosphere, and the water piped to the suction side of the lower situated pumps, which pump it through high temperature mains to the various district stations in the city.

In the areas with water temperature below 100°C an open cistern replaces the de-airators described above. Pumping is regulated by air operated valves on the discharge side of the pumps, controlled by a level control in the de-airators and the cisterns. The main pumping plants are each equipped with three to four pumps, one functioning as stand-by. All pumps are driven by squirrel cage induction motors. The total pumping power in the four main plants is at present 4750 hp, and in the 44 boreholes in all areas is also 4750 hp.

District Pumping Plants

The city is divided into a number of districts, each served by its own district pumping plant (Figure 15). In the oldest part of the system, completed in 1943, the distribution system is a single pipe one. It is fed directly from the storage tanks situated on a hill, which then was higher than any structural feature in the city; it does however require booster pumps to take care of higher loads, the pumps adding a lift of 20 MWC.

The pumps are regulated (speed regulation) by a pressure controller at a selected point in the distribution system. In order to utilize water

[1]Available only at electrical off peak hours.

systems, so that direct connection is nearly always employed (Figure 5). Hot domestic water is also supplied directly, and water meters are therefore included in the supply pipe.

Inferential water meters are used, with magnetic coupling between water wheel and register mechanism. The District Heating System supplies water to each consumer at a certain minimum pressure in a single pipe system, or in a double pipe system; it maintains a certain minimum pressure difference, keeping the return mains pressure within reasonable limits, to supply sufficient back pressure without overloading the house systems.

A minimum of automatic control equipment is mandatory to ensure proper utilization of the water, and supply is limited by sealed maximum regulators, according to the heat requirements of each consumer. Generally the control equipment consists of a solenoid valve, connected in series to a room thermostat, and a high limit temperature switch mounted in the return pipe from the radiators. In the last few years, individual thermostatic valves fitted in the return of each radiator have become popular.

OPERATING CONDITIONS AND COSTS

Heating Load

The total of houses heated by district heating in the city in terms of volume is 15 million m^3, and the corresponding heating load based on -10°C outside and +20° inside temperatures is 350 MW, or approximately 23 W/m^3.

Load Density

The load density of the system is rather low, as many of the houses in the city are single family houses standing in rather large grounds. The average density is 120 MW/km^3, and 1.9 MW/km when referred to mains length. House connections from street mains are not included in the latter figure; these are also comparatively long.

Heat Production

Figure 3 shows the yearly heat production of the system since 1944, and its division into geothermal heat and that produced by oil boilers. This figure also shows the growth of the system as described in chapter 2; the heat production has trebled in the past 12 years, from 490 GWh/year in 1961 to 1500 GWh/year in 1973.

Climate and Yearly Load Distribution

The climate in Reykjavik is very suitable for district heating, especially geothermal, as the available heat is constant and the variable production costs are a very small part of the total production costs.

The mean temperature of the year is 5°C (41°F), the mean of July being 11.2°C (52.2°F) and that of January -0.4°C (31.3°F). Figure 6 shows the monthly mean temperatures.

The difference between the mean temperature of the hottest and the coldest months is only 11.6°C (20.9°F). Figure 7 shows the relatively even distribution of load through the year, the January load being only two to three times that of July.

These figures reflect the island climate prevailing in the south-western coastal area of Iceland, and the influence of the Gulf Stream balancing the temperatures. Due to the low summer temperatures, the heating season lasts throughout the year. On the other hand, the weather in Reykjavik is very unstable, as indicated in Figure 8, which shows the daily mean temperatures during the winter months of 1968-1969, which were exceptionally cold. Wind velocity is no more stable than temperature and can become very high. On an average, we have 14 days of storm (wind velocity above 40 knots) each year. Very low temperatures with high wind velocities do not last long at any one time, and days with temperatures below -5°C (23°F) are, on an average, fewer than 10 in any one year.

As the District Heating System obtains its energy in the form of hot water from the ground, storage tanks can be used to carry it over short periods of cold weather, lasting for a few days only. These tanks are also used to supply peak demand during daytime, which is 15 to 30 percent over the mean load for the 24 hours, the maximum amount produced hourly being even.

Due to these facts described, the number of equivalent hours at full load (load factor) is very high for this system as compared to current figures in Europe or North America, the average figure being about 4000 hours per year, or 46 percent. The capacity of the system's oil fired peak boiler plant is approximately 10 percent of its total capacity and the load factor of the geothermal heat alone therefore becomes 4500 hours/year or approximately 51 percent.

Investment Costs

It is practical to divide the construction cost of the District Heating System into three main parts, which breakdown as follows:

Heat Production

1. Consessions and Research
2. Drilling
3. Borehole development
4. Collecting Mains

Transportation

1. Main Pumping Station
2. Supply Mains

Distribution System

1. Distributing Pumping Station
2. Street Mains
3. Service Branches
4. Consumers Connections

The cost of each part is variable. In the first group it varies with the capacity of the thermal area, the number and the distribution of the boreholes in the area and the temperature of the borehole water.

In the second group cost varies with the distance of the area from the distribution station, the soil conditions and whether it is necessary to lay the pipeline underground or not.

In the third group the cost varies with the size of the distribution systems, their load density, type of ground in the districts etc. As the borehole water is piped directly into the distribution system, it is possible to build a part of it as a single pipe system with the water having spent its heat in consumers' radiators being returned to the drains. This makes the distribution network cheaper, as the cost of a single pipe network is only about 70 percent of a two pipe system.

With the present day methods and equipment, the average construction costs come out as follows:

Heat Production	25.27 \$/kW
Transportation	32.01 \$/kW
Distribution System	111.02 \$/kW
Total	168.30 \$/kW

The total replacement value of the District Heating System today amounts to approximately 59 million dollars. The maximum capacity is 350 MW.

Operation Costs

The yearly operation cost is the sum of the capital cost, for example, repayment and interest of invested capital and direct operation cost, for example, wages, power for pumps, repair costs, etc. The rate of interest and the lifetime of a district heating plant will not be discussed in this paper, but it is assumed that 7% per annum is a reasonable rate of interest based on the replacement value of the system and that its lifetime is 25 years. The yearly capital cost is calculated as an annuity, for example, equal annual payments. So the annual capital cost is 8.58 percent of the investment cost.

The direct costs are variable, mainly depending on the size of the system. In the past years these costs have been approximately 4% of the revalued investment costs. So the total yearly operation costs will be 12.6 percent of the investment cost. According to this the unit prices will be as follows (load factor 0.46 or 4000 hours per year):

Heat Production Cost: $\frac{2527 \times 0.126}{4000} = 0.080$ K/kWh[1]

Transportation Cost: $\frac{3201 \times 0.126}{4000} = 0.101$ K/kWh

Distribution Cost: $\frac{11102 \times 0.126}{4000} = 0.350$ K/kWh

Total Cost 0.530 K/kWh

[1] \$1 = 118.70 K, Icelandic kronur

at 120°C and higher, and yet maintain the water supplied to the houses at a suitable temperature for heating and domestic use (80°C), combined single and two pipe systems have been built, making possible mixing of the high temperature water with return water from the two pipe system while at the same time draining the system through the single pipe part of the system.

The piping arrangement in pumping stations serving these combined districts is such (Figure 2), that only the return water is pumped, the high temperature water being led into the supply main on the pressure side of the pumps.

Temperature of the supply water is regulated by an air operated regulating valve in the high temperature pipe, controlled by a temperature controller in the supply pipe. Pressure in the system, both in the supply and return pipes is regulated by valves controlled by pressure regulators at suitable points in the system. Each district pumping station is equipped with two pump units, one of which is sized for 100 percent capacity, the other for 70 percent. All pumping stations, apart from borehole pumps, are fully automatic; they do, therefore, not require constant control, but are looked after by five engineers visiting each station several times a day. An electronic system enables remote supervision of all pumping plants and borehole pumps from a central control room; a number of other operations can also be controlled, such as the starting and stopping of pumps. Automatic data-logging is also included for all stations, recording, for example, temperatures, pressures and amount of water pumped by each station. A full 24 hours watch is maintained. The total number of district distribution stations is 10 with an overall pump rating of 2926 hp.

Distribution Network

The pipes used in the system are longitudinally welded black steel pipes to standards DIN 2440 up to 6" and to DIN 2458 above 6". Street mains larger than 3", supply and collecting mains, are laid in buried concrete channels, and insulated with rockwool (Figure 4). The channels are placed on a bed of pebbles in which concrete drain pipes are buried. Minimum inclination of channels is kept at 5%. At street junctions, the channels meet in concrete chambers, containing valves, fastening bolts, expansion joints, etc. These chambers are ventilated, and either drained from the bottom or, if that is not possible, they have a pump pit. Smaller street mains and house connections from street mains are insulated with polyurethane foam insulation, protected by a water jacket of high density polyethylene. These pipes are prefabricated in lengths of 6 m, the PE jackets joined by sleeves of PE, sealed at both ends by rubber rings, and foamed in situ.

Figures on pipeline lengths are as follows:

Collecting mains	21.0 km
Supply mains	46.0 km
Street mains	146.6 km
House connection	157.4 km

Consumers Connections

Central heating has been a general rule for all housing in the city for the past 40 to 50 years, the vast majority having radiator heating

Comparison of Different Heat Sources

Other heat sources for space heating in Iceland are light fuel oil and heavy fuel oil (only for large houses) and electricity from hydroelectric power plants.

The following table shows unit prices for heat from these heat sources:

District heating	0.53 K/kWh
Light fuel oil	2.18 K/kWh
Heavy fuel oil	1.04 K/kWh
Electricity	1.44 - 2.91 K/kWh
Surplus electricity (night tariff)	0.91 K/kWh

FUTURE UTILIZATION OF A HIGH TEMPERATURE FIELD, NESJAVELLIR PROJECT

The District Heating Service owns a thermal field some 30 km from the city, this field is now subject to studies. In deepwells, already drilled, the inflow temperature at 1800 m is about 280°C. Inflow temperatures of at least 260°C can certainly be assumed in this field and the preliminary projecting is based on that assumption. It is planned to produce electricity as well as heat for district heating from the borehole fluid. Due to precipitation of silica, cooling below 40°C is not considered feasible. As the borehole fluid contains various other dissolved chemicals (minerals) that make it unfit for human consumption, it has been decided to use cold shallow ground water to be found in abundance in this field, and heat it using the hot borehole fluid. After heating this ground water above boiling point, dissolved air is removed in de-aerators before the water is pumped to the city.

As the discharge temperature of the houses' heating systems is about 40°C, the heat used to raise the temperature of the ground water from approximately 5°C to about 40°C is not usable and is inevitably wasted. The diagrams (Figure numbers 9, 10 and 11) show different possible methods of utilizing the geothermal heat. They are of course simplified, as the main purpose here is to compare feasibility of different methods of utilization. It is, for example, more practical to use staged evaporation of the separator fluid instead of a surface heat exchanger shown on the diagram because of probable silica scaling on the exchanger surfaces. It is assumed that 10% of the electricity produced is used up in electric plant auxiliaries.

Figure 7 shows a plant for heat production only (method I). In Figure 8, electricity is produced using separated steam but all the heat of the condensate and the separated water is used for district heating (method II). Figure 9 shows the use of a cooling tower for further cooling of the condensate to increase the electrical output.

Apart from this the plant is similar to that of Figure 8. In all cases the district heating water is heated to 108°C before going to gas separators and from there it is piped to the city's distribution network.

As the water is cooled down to 40°C in the house systems the useful heat for district heating purposes is only 108-40 = 68 kgcal/kg. In all examples the amount of borehole water is assumed to be 3000 tons/hour. A Comparison of these three methods, based on the conditions already described is as follows:

	I	II	III
District heating output	531 MW	505 MW	289 MW
Electrical output	0 -	42 -	69 -
Total output	531 MW	547 MW	358 MW

In cases I and II all the boreholes heat is utilized. The difference in total energy figures is due to the fact that in case II the turbine condensate is mixed with the district heating water. In case III electric production is increased at the expense of district heating as part of the heat of condensation is wasted in the cooling tower.

The electric power load for domestic and small industry use varies widely during the 24 hour day with a peak load for several hours at mid-day up to 45% above the average for a short period. The heat load for house heating on the other hand is regulated by storage tanks in the distribution area. The most likely choice is, therefore, a combination of methods II and III such a way that most of the time method II is used and cooling water and condensate bypasses the cooling tower, but at peak electric demand, all the water, or part of it passes through the tower and the turbine back pressure is lowered as necessary.

Building cost and unit prices of energy are shown in Table I.

Table I

	Heating	Electricity
Power output (variable)	279/505 MW	69/42 MW
Output on which cost analysis is based	415 MW	69 MW
Cost Analysis: (in million US$):		
1) Drilling	1.68	1.68
2) Collecting mains	0.42	0.42
3) Heating exchangers $ pumps	0.84	
4) Housing for three	0.34	
5) Cold water bores and mains	0.51	
6) Turbine, generator, condenser		6.84
7) Cooling tower, mains $ pumps		2.91
8) Electrical network		1.92
9) Plant buildings		1.20
10) Plant hoisting machinery		0.29
11) Employeer lodgings	0.15	0.15
12) Road construction	0.11	0.11
Total	5.02	16.49
Unit cost $ per kw	12.10	239.00

Table I (continued)

Equivalent hours at full load per year   4000

Unit prices of power as delivered at plant site

Electricity: $\frac{23900 \times 0.126}{5000}$ = 0.60 cents per kWh

Heat for district heating: $\frac{1210 \times 0.126}{4000}$ = 0.038 cents per kWh

Heat transmission cost to distribution network: $\frac{2639 \times 0.126}{4000}$ = 0.083 cents per kWh

In this case investment cost for the pumps and the pipeline is 26.39 $ per kW.

The distribution cost is the same as quoted above (see operation costs) 0.350 K/kWh.

The total cost to consumers is then 0.038 + 0.083 + 0.350 = 0.471 K/kWh.

This is 11 percent less than the present cost. The cost to the distribution areas, for example, production and transmission cost is 33 percent less than the present cost, the main reasons being the larger size of this plant and higher temperature of the borehole fluid. A plant producing electricity alone in this area, and assuming the same conditions, would have a power output of 70 MW or about 13% of the total output of the combined plant projected. The unit price of electricity would in that case be about 0.69 cents per kWh.

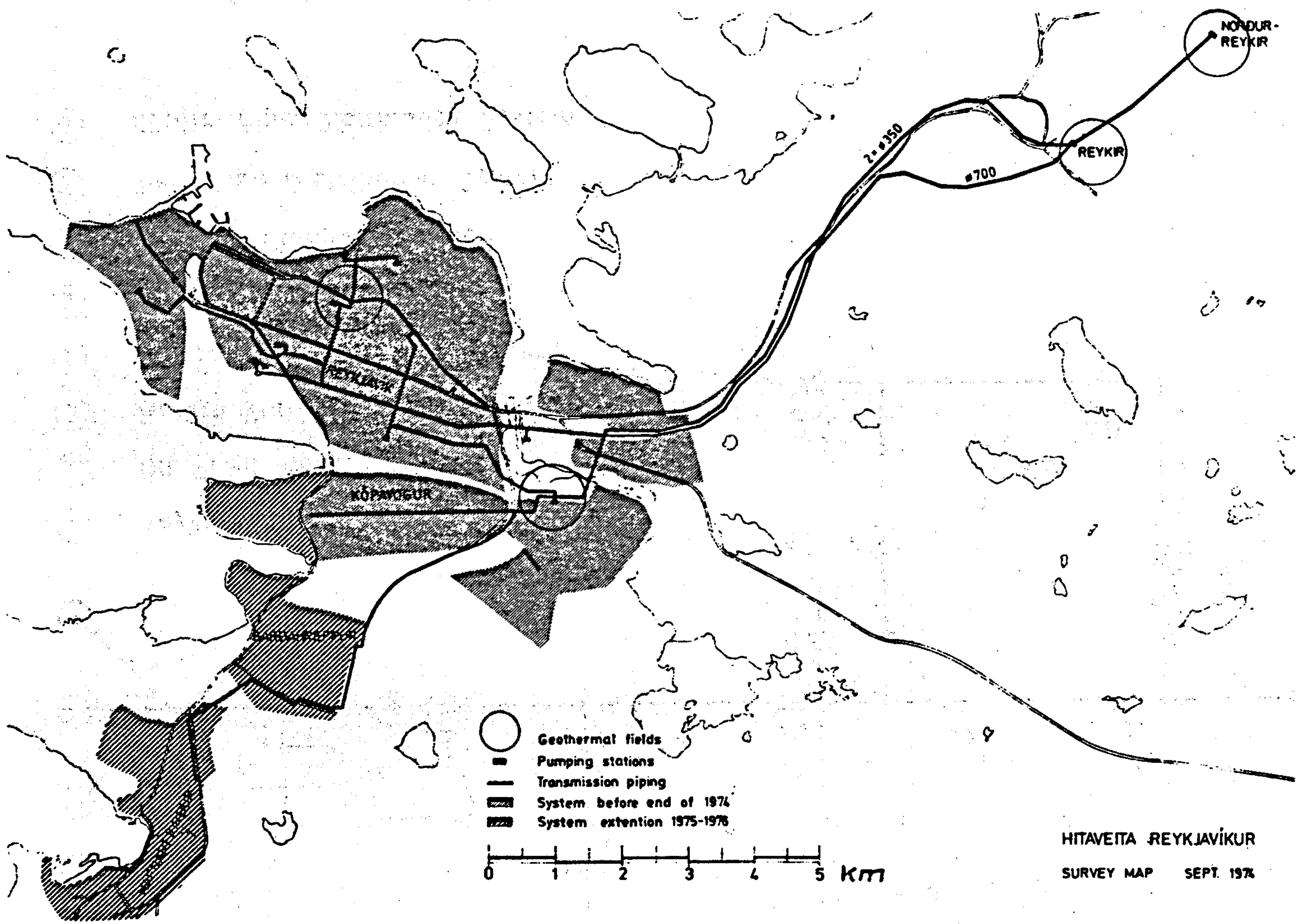
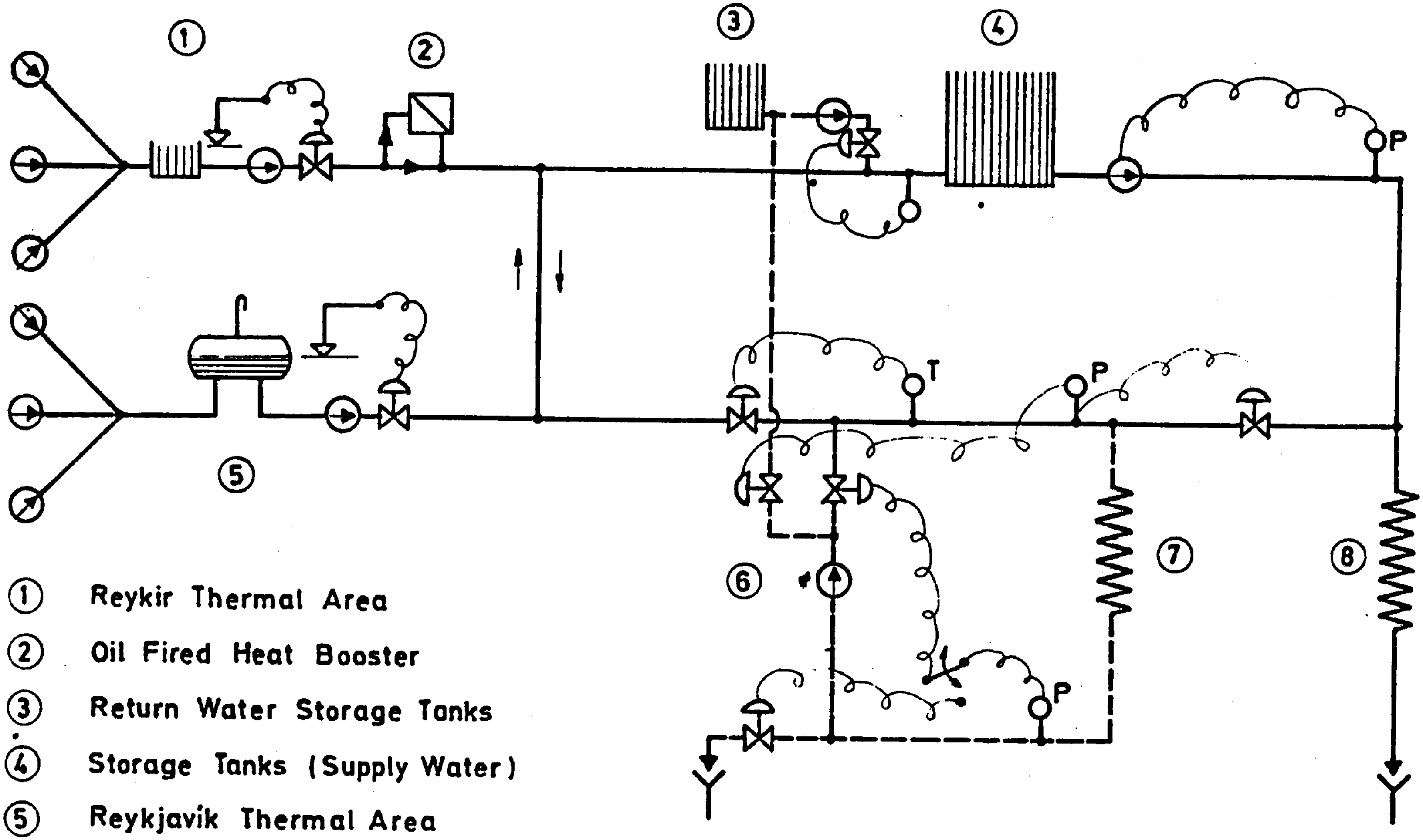

NORDUR-
REYKIR
REYKIR
2×ø350
ø700
REYKJAVIK
KÓPAVOGUR
Geothermal fields
Pumping stations
Transmission piping
System before end of 1974
System extention 1975-1976
0 1 2 3 4 5 km
HITAVEITA REYKJAVÍKUR
SURVEY MAP SEPT. 1974

Fig. 1



① Reykir Thermal Area

② Oil Fired Heat Booster

③ Return Water Storage Tanks

④ Storage Tanks (Supply Water)

⑤ Reykjavik Thermal Area

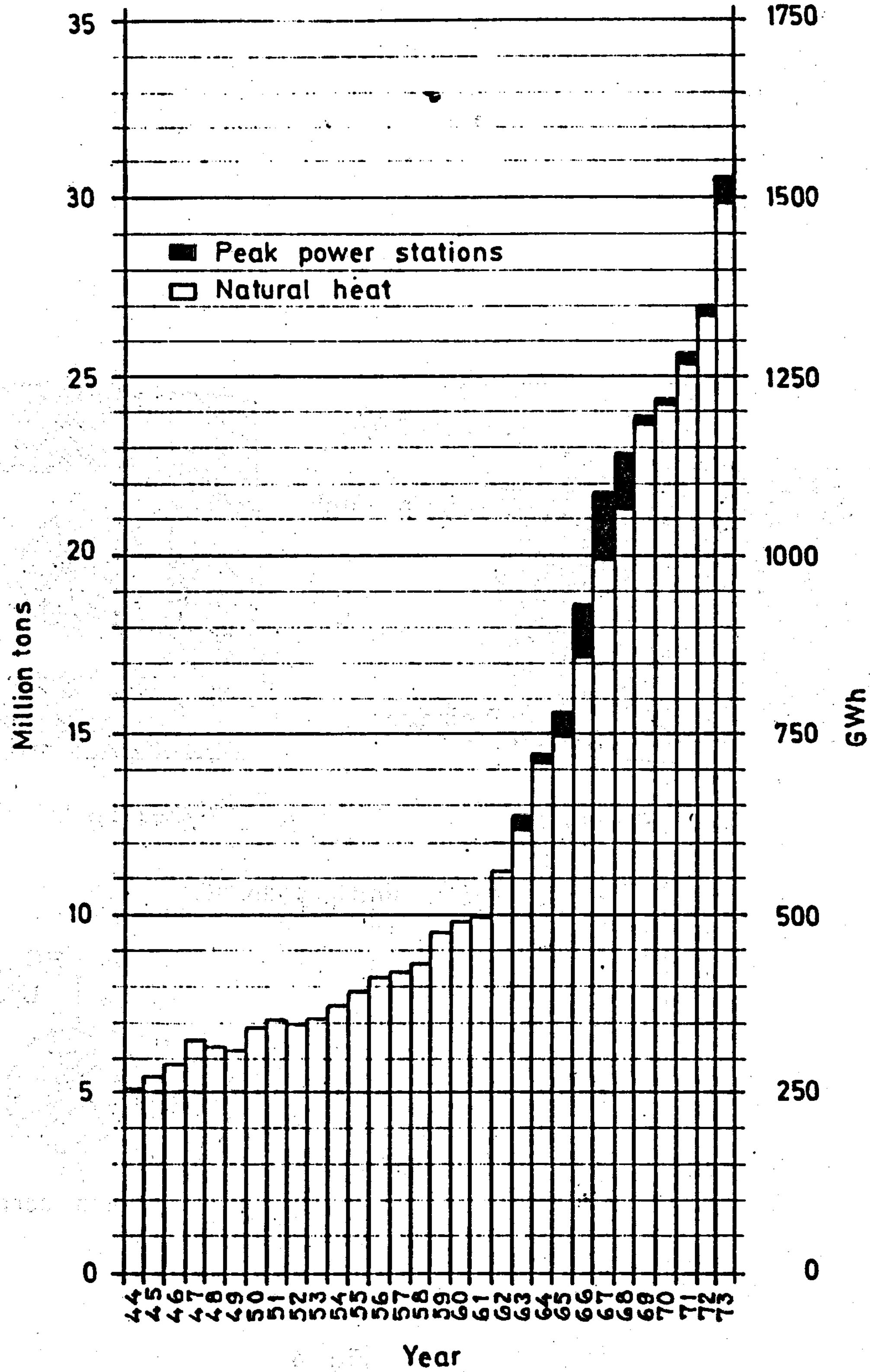
⑥ District Pumping Station

⑦ Two Pipe Distribution System

⑧ Single Pipe Distribution System

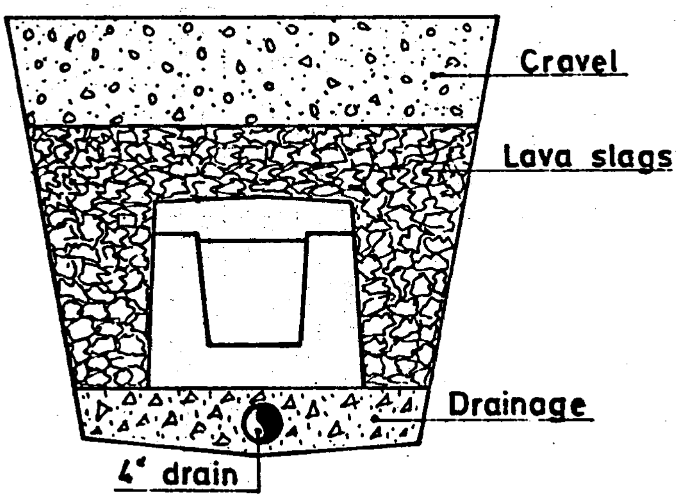
SCHEMATIC DIAGRAM OF SYSTEM

Fig. 2

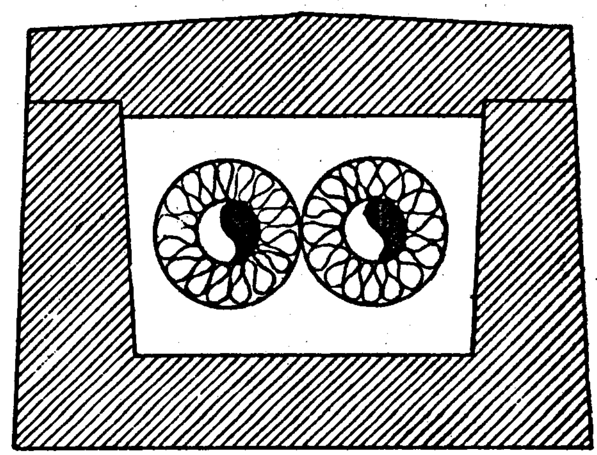


YEARLY WATER PRODUCTION 1944-1973

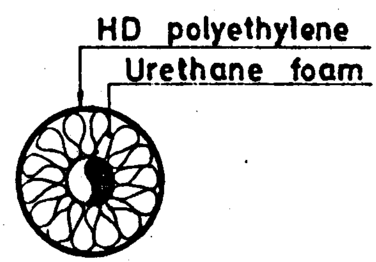
Fig. 3



Buried channel

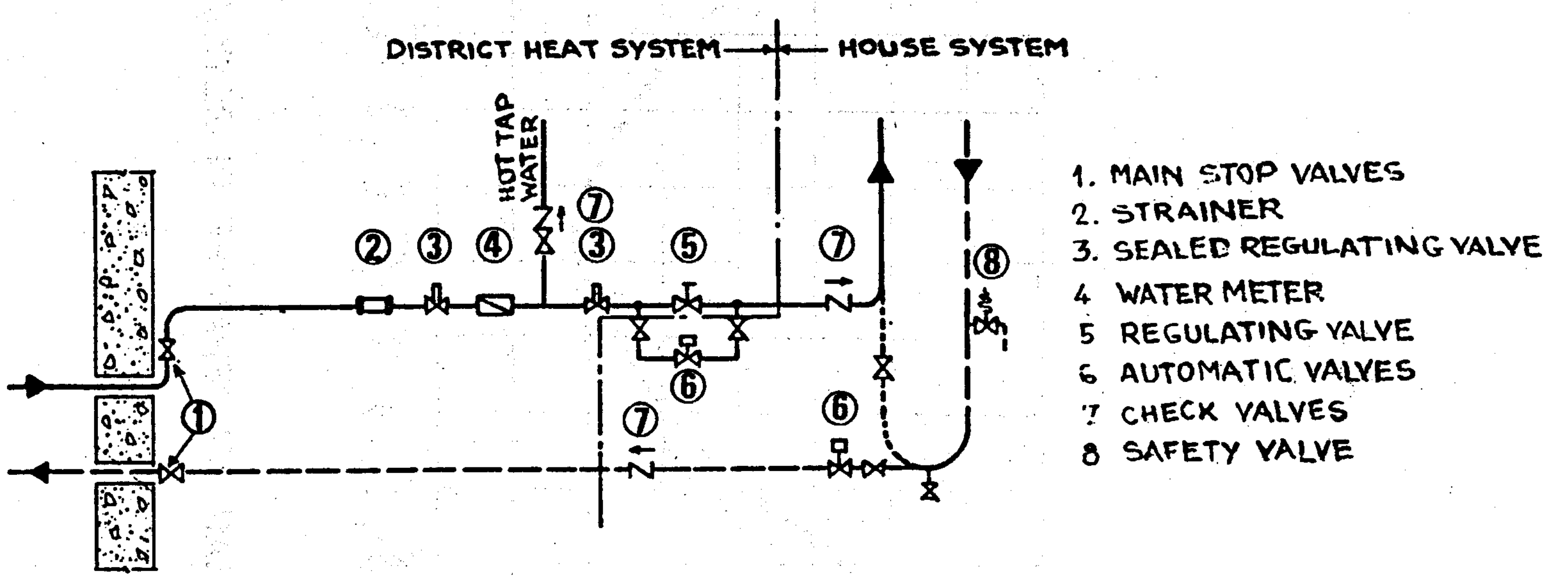

Rock- or Glass Wool insulation

Street main channels



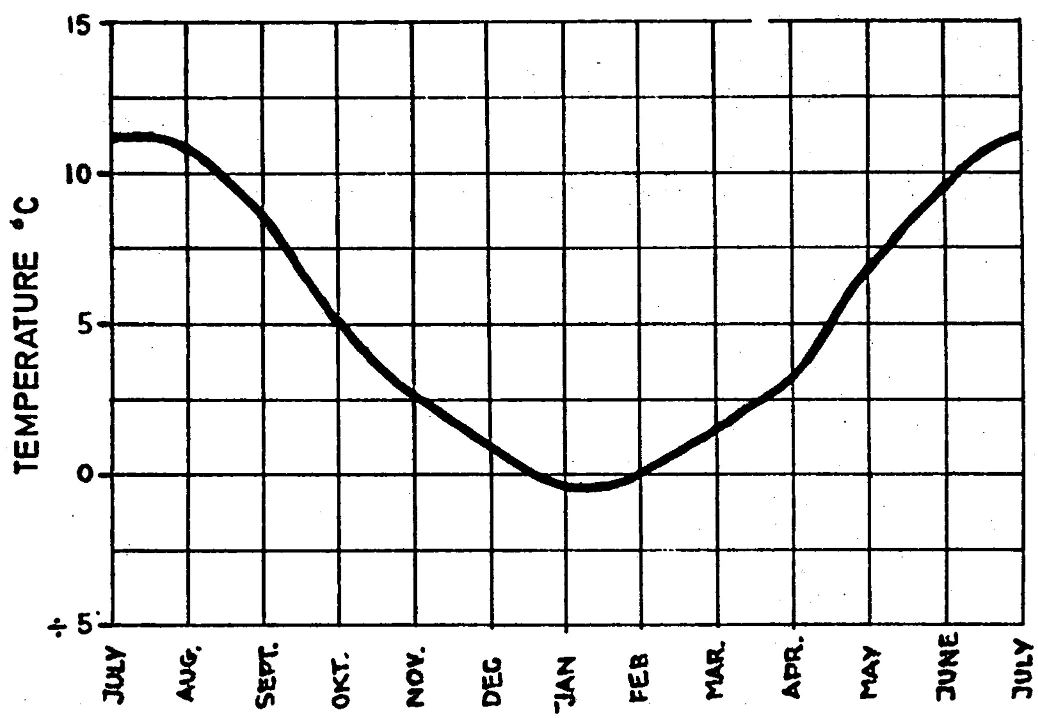
House connections

Fig. 4



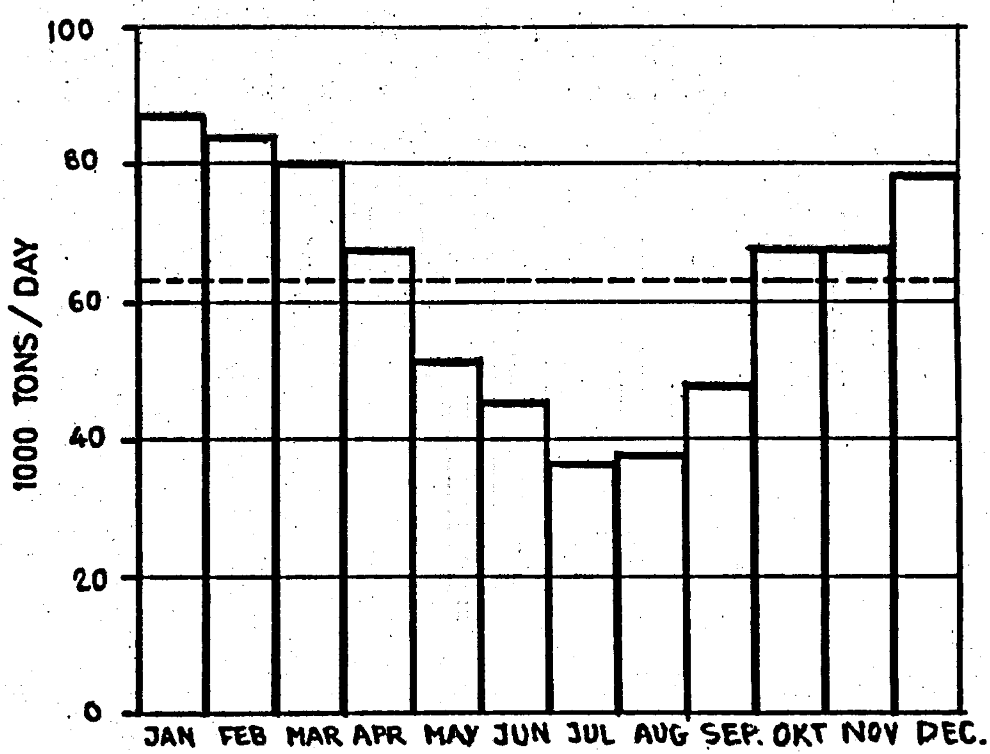
HOUSE CONNECTION

FIG. 5



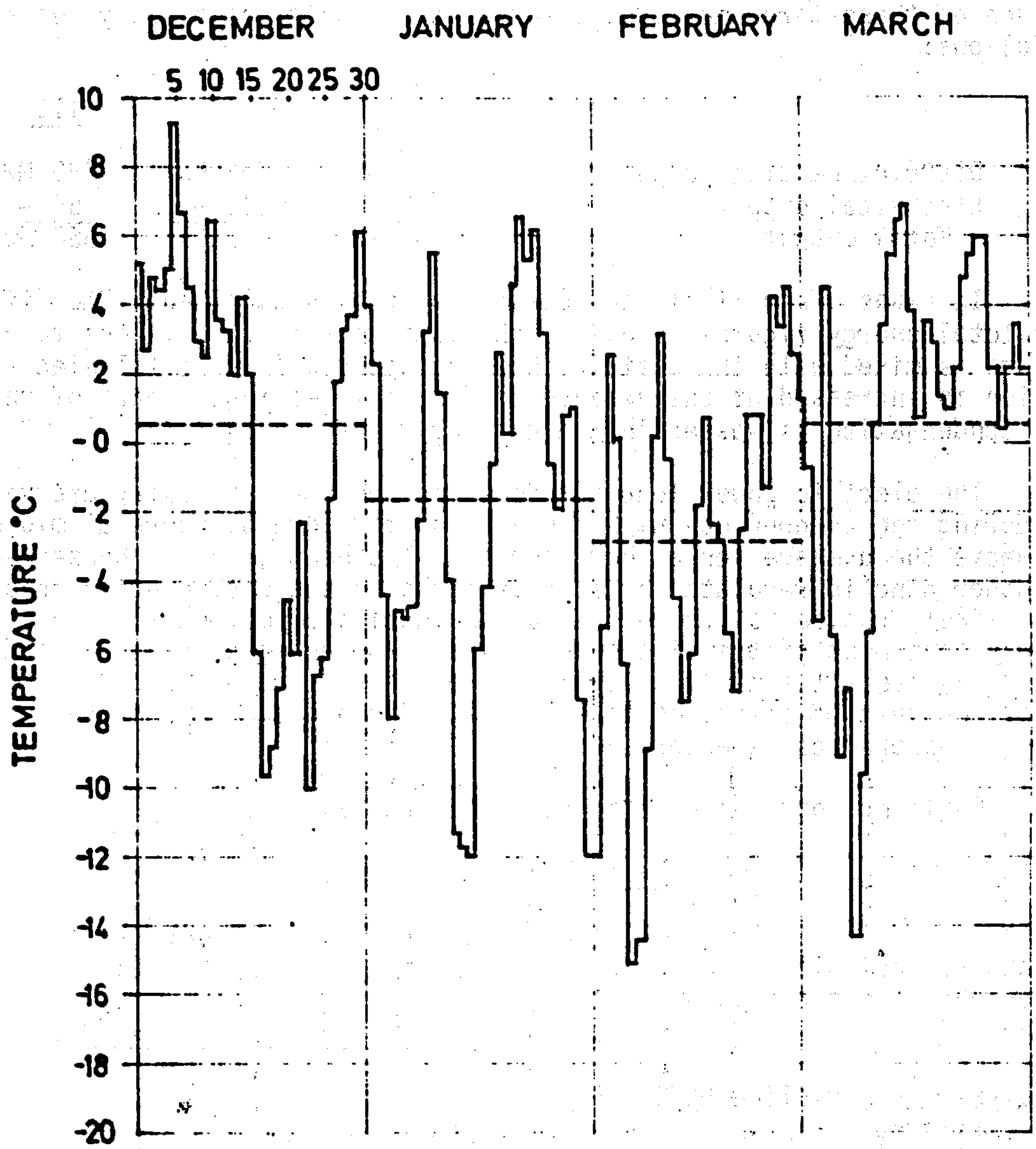
MONTHLY MEAN TEMPERATURE IN REYKJAVÍK 1931–1960

FIG. 6



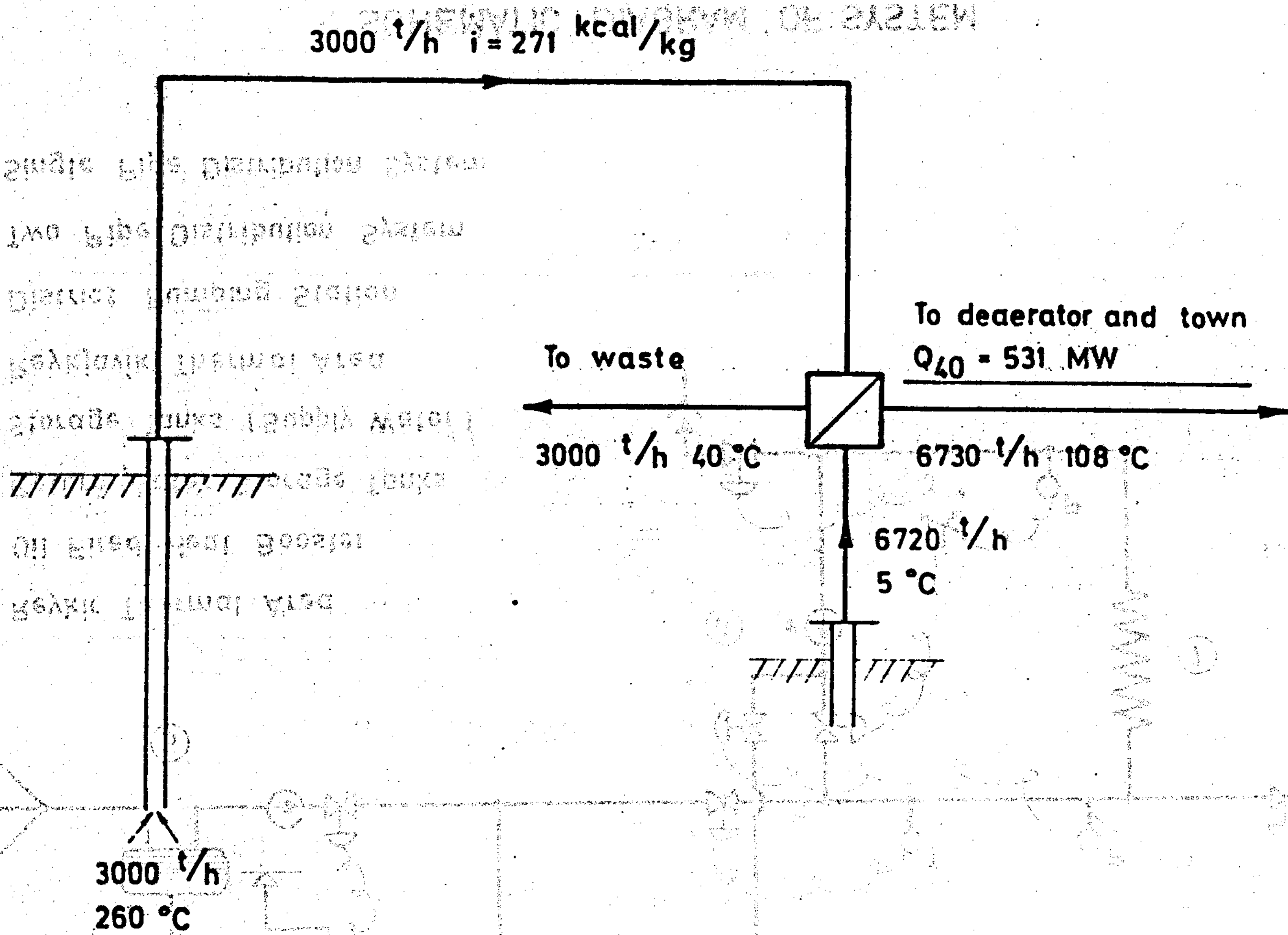
MONTHLY WATER PRODUCTION 1968

FIG. 7



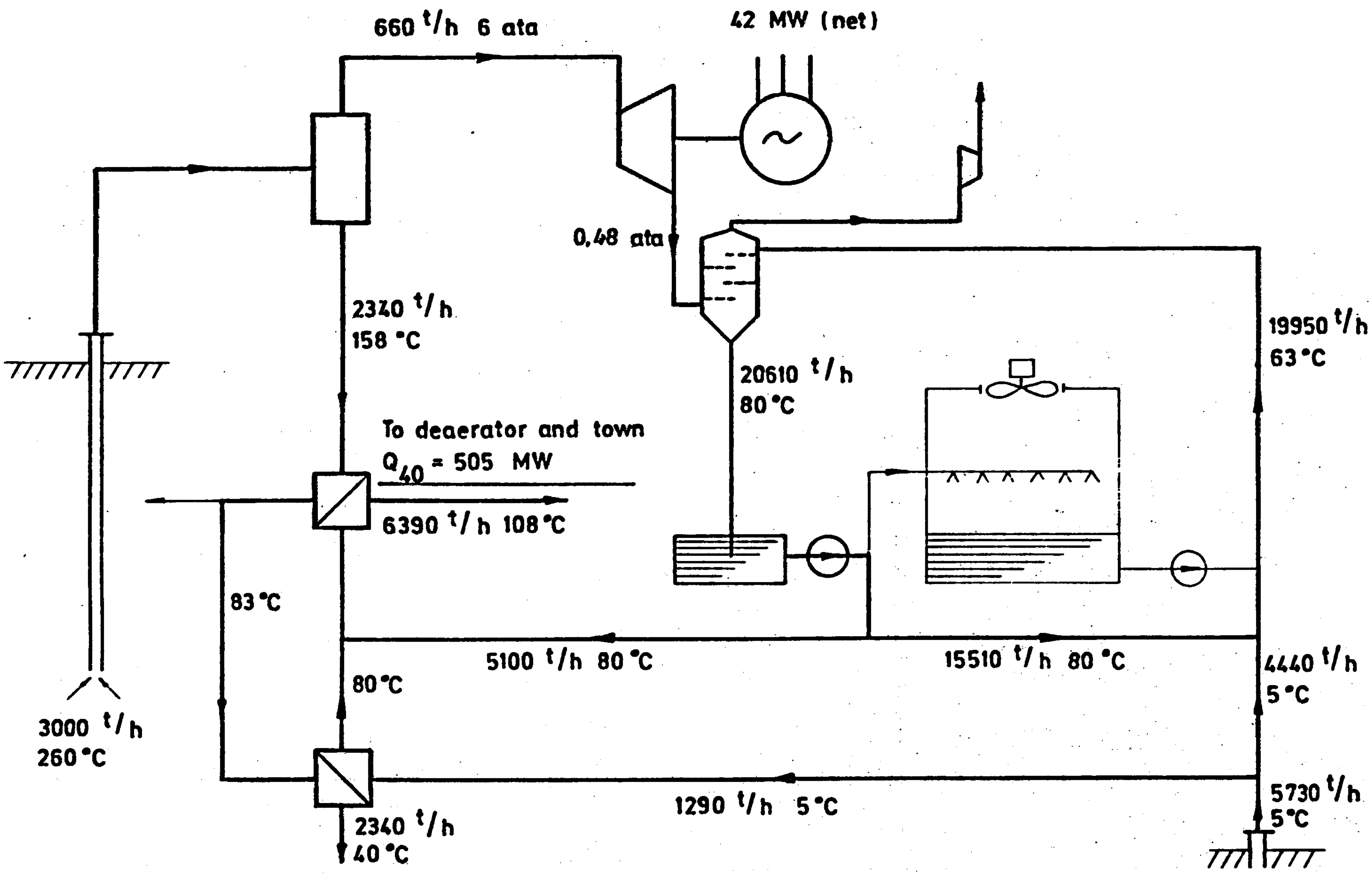
DALY MEAN TEMPERATURE DEC-MARCH 1968-69

Fig. 8



'NESJAVELLIR PROJECT I
District Heating only

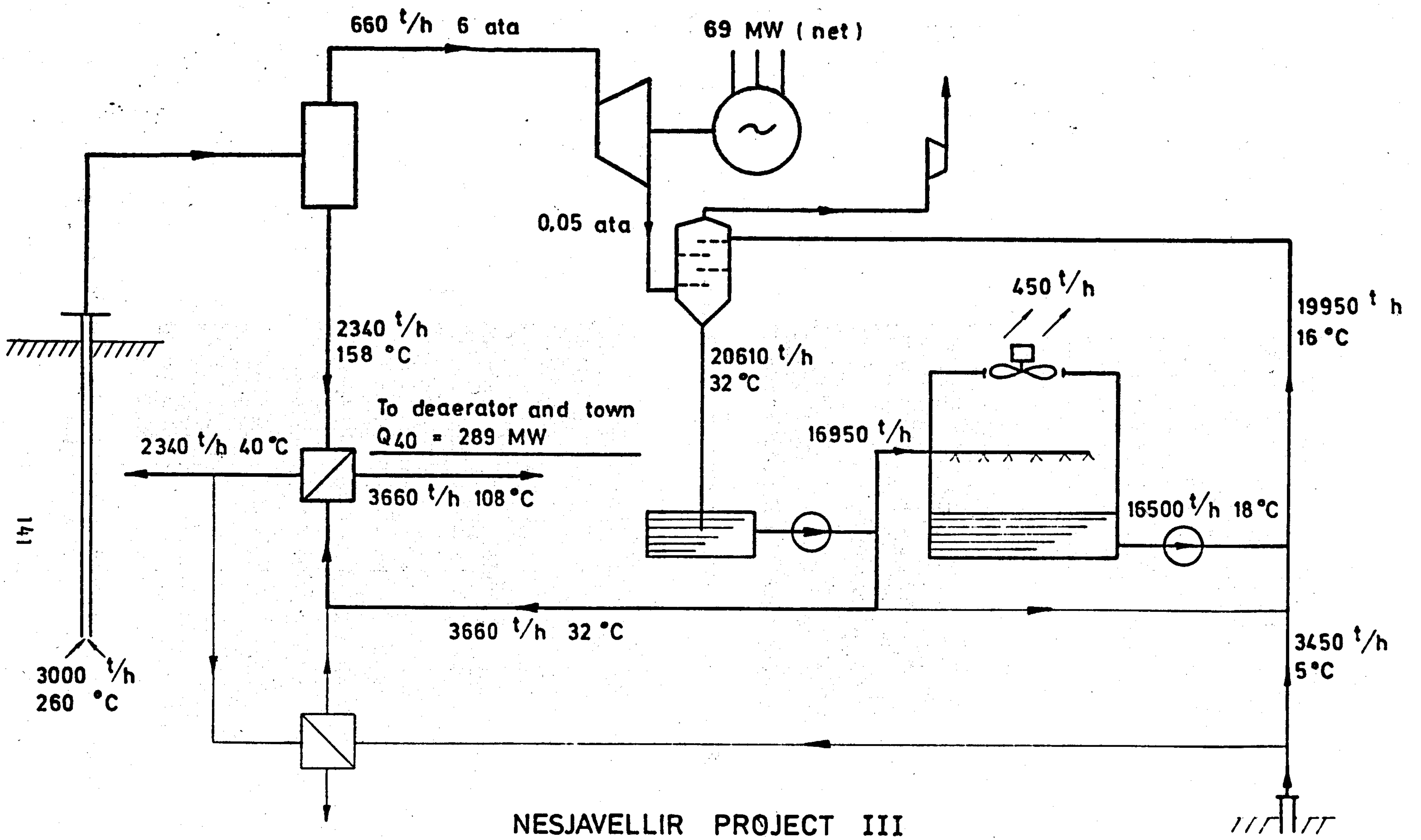
Fig. 9



NESJAVELLIR PROJECT II

District Heating and Back Pressure Turbine

Fig. 10



NESJAVELLIR PROJECT III
District Heating and Turbine
with Low Pressure Condenser

Fig. 11

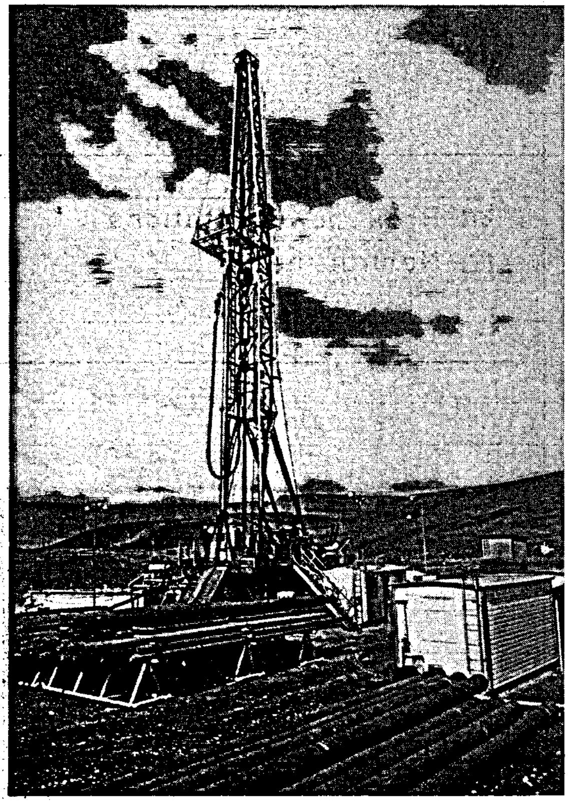


Figure 12. Geothermal drilling at Reykir.

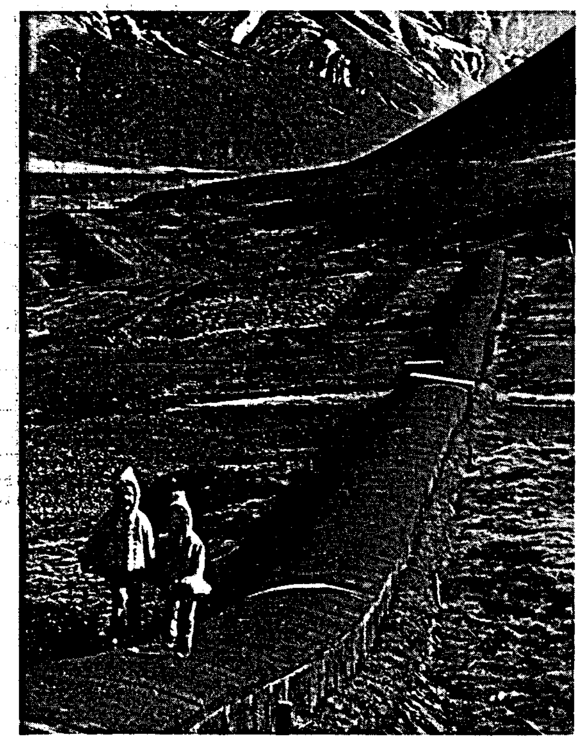


Figure 13. Pipeline conduit from Reykir to Reykjavik, 10 miles of 2" X 14" pipe.

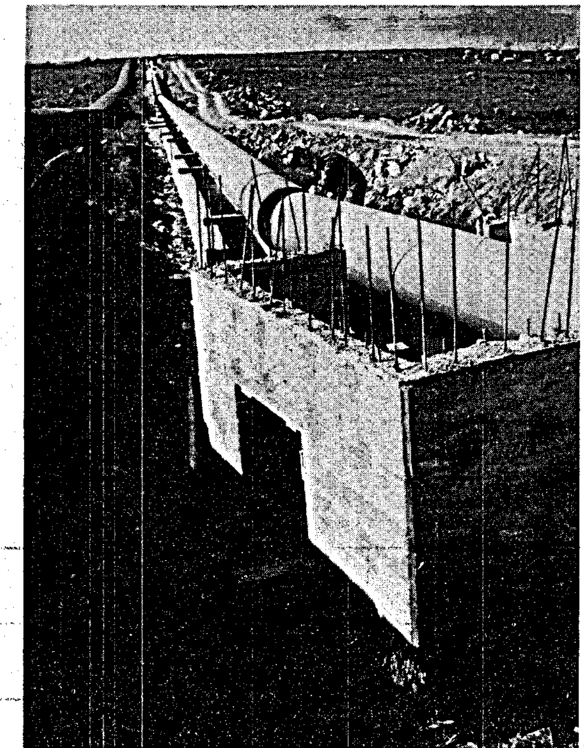


Figure 14. New pipeline from Reykir to Reykjavik 28" diameter pipe in concrete conduit.

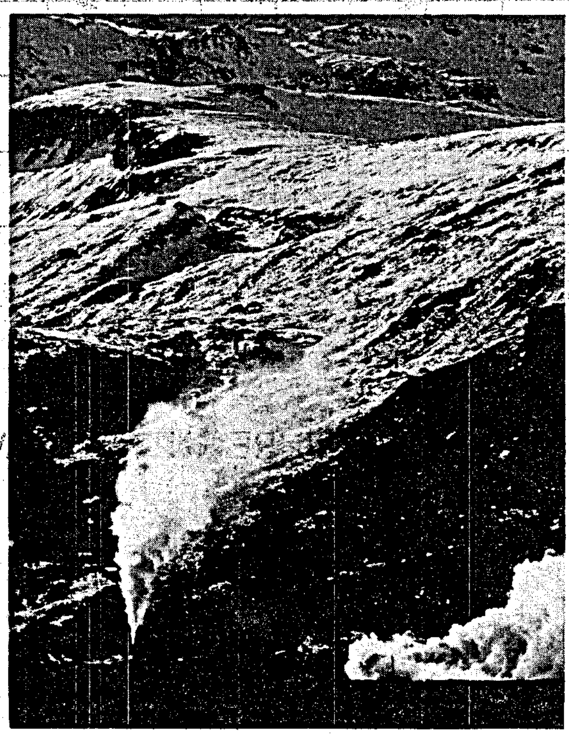


Figure 15. Steam boreholes at Nesjavellir. Temperature 260° to 280° C.

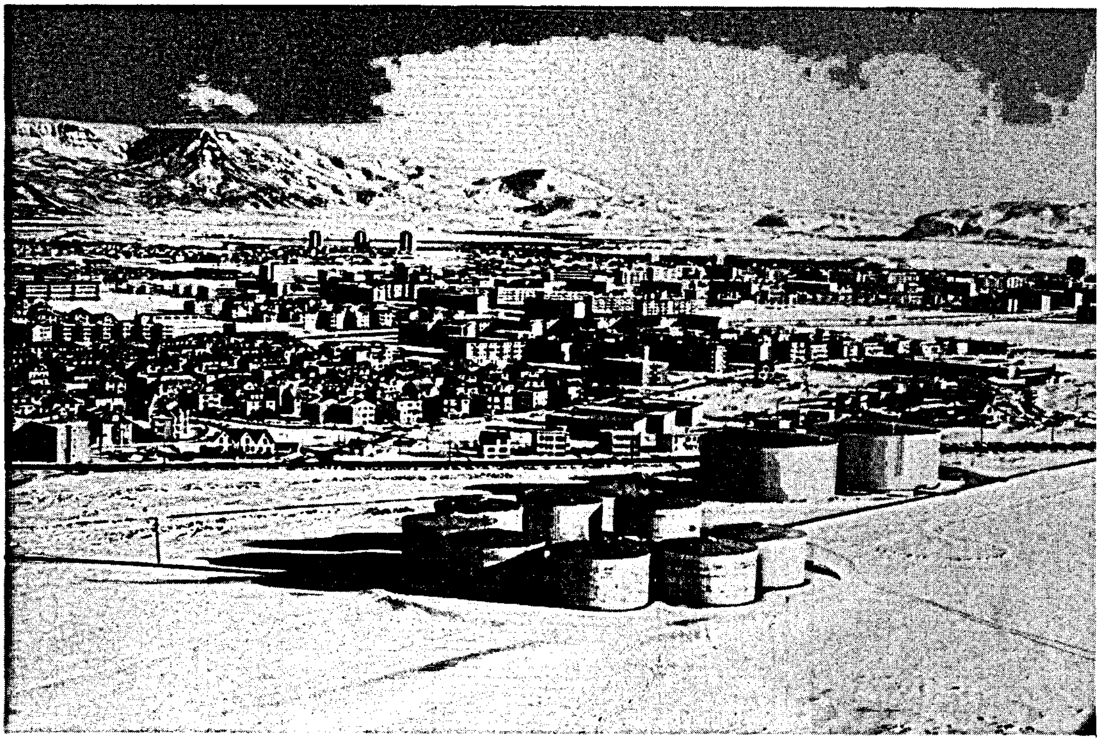


Figure 16. Winter view of Reykjavik, hot water storage tanks (26,000 Tons.) in foreground.

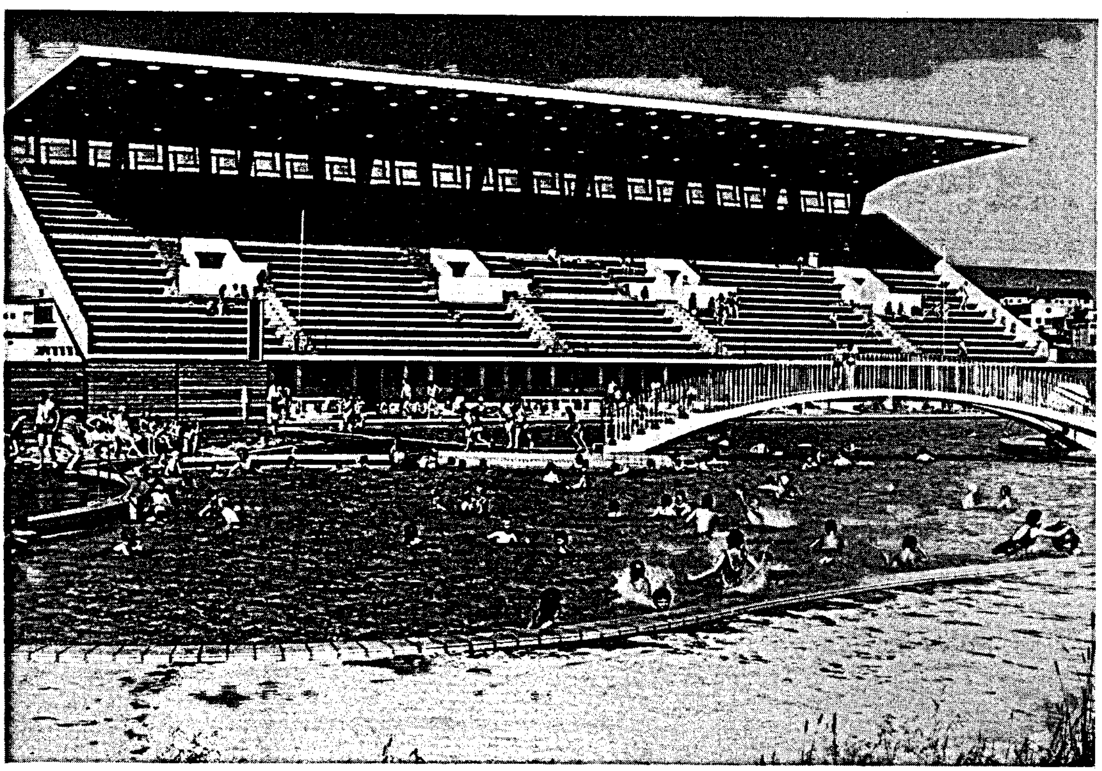


Figure 17. Open air Swimming Pool in Laugardalur, open to the public all year around.

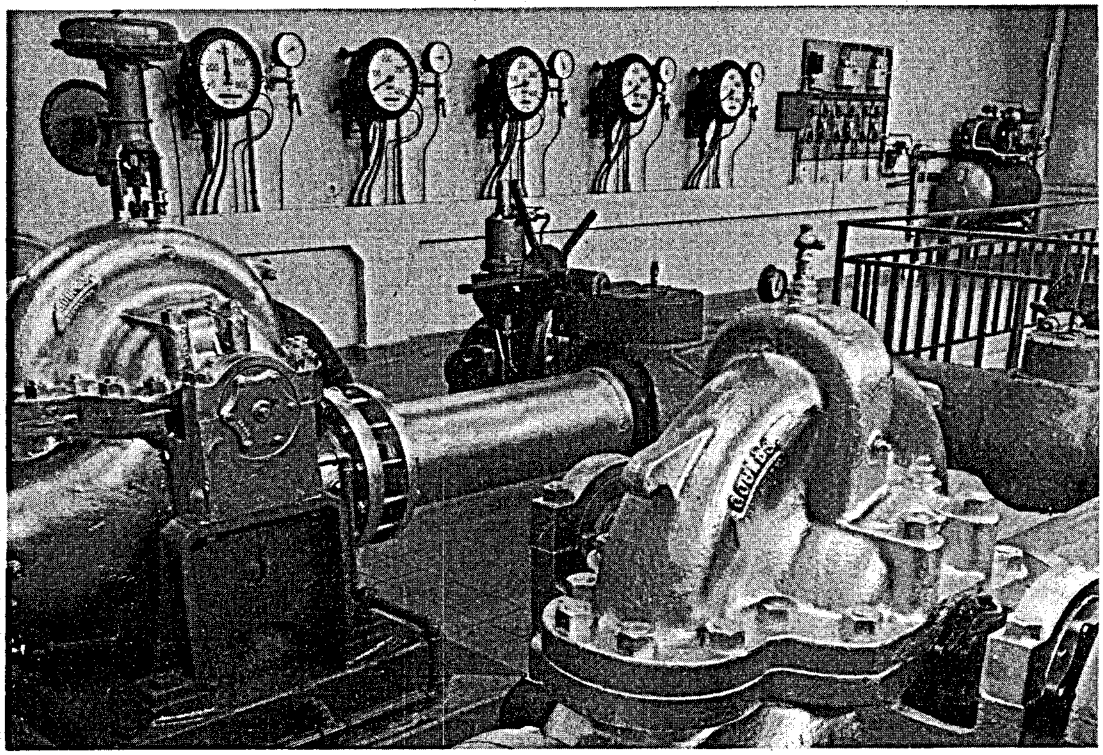


Figure 18. Pumping plant at Stekkjarbakki, a combined borehole booster and district circulating pumps.

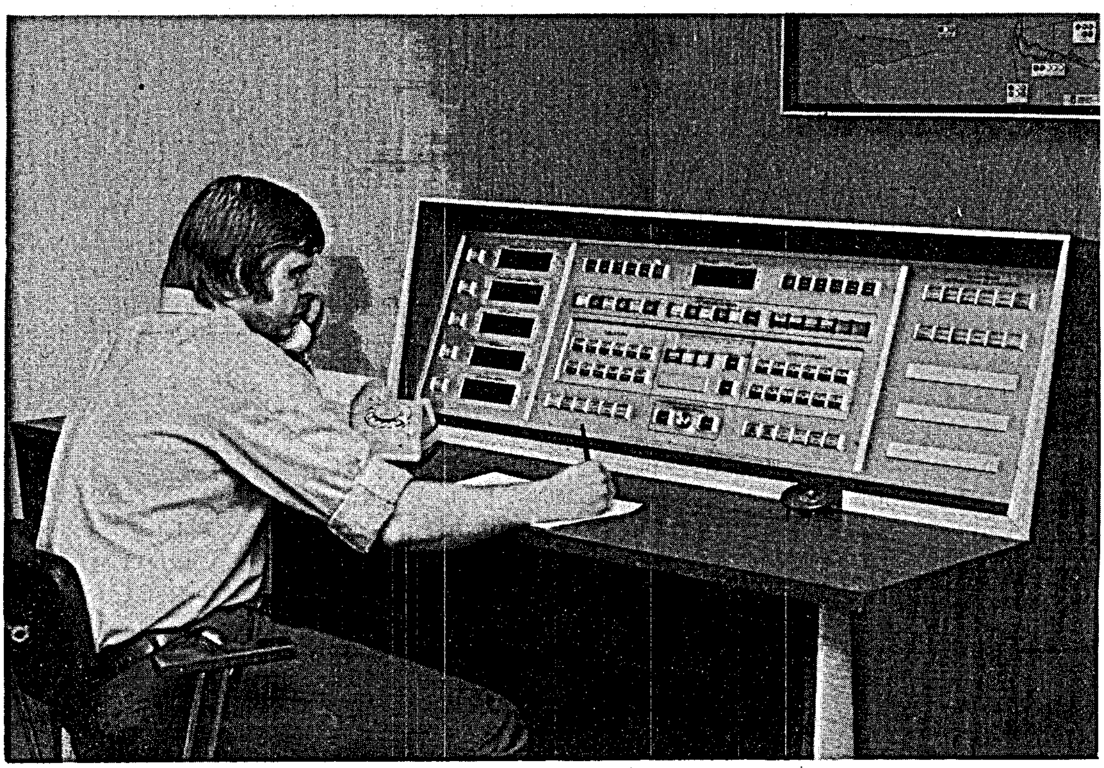


Figure 19. District heating monitor console, 24 hour supervision of all pumping plants and borehole pumps.

UTILIZATION OF GEOTHERMAL ENERGY
IN
KLAMATH FALLS

By

John W. Lund[1]
G. Gene Culver[2]
Larsen S. Svanevik[3]

ABSTRACT

Klamath Falls, Oregon, is located on a Known Geothermal Resource Area (KGRA) which has been used by residents, principally in the form of hot water for space heating, at least since the turn of the century. Approximately 400 shallow depth wells ranging from 27 to 580 meters (90 to 1900 feet) in depth are used to heat approximately 500 structures. This utilization includes the heating of residences, schools, businesses (including a creamery for milk pasteurization), heating swimming pools and melting snow from pavements. Seventy-five locations were selected for detailed study and documentation during the summer of 1974.

Well water, which ranges from 38°C (100°F) to 110°C (230°F), has been used directly in heating and drinking water systems, however, present practice is to use down-hole, hair-pin, heat exchanger with city water as the circulating fluid. Well water chemistry indicates approximately 800 mg/l (ppm) dissolved solid, with sodium and sulfate having the highest concentrations. Calcium and potassium concentrations are very low. Some scaling and corrosion does occur on the down-hole heat exchangers (black-iron pipe) which is related to the Langelier Saturation Index.

Cost analysis for capital and annual operation costs are presented and compared with alternate forms of energy (electricty, natural gas and fuel oil). For a single residence, at today's costs, heating using geothermal water appears to be somewhat competetive; however, when several structures use the same well, the savings are substantial. District heating, similar to that in operation in Iceland, is proposed. The average annual energy utilization is only 5.6 megawatts. It is felt that only a small portion of the area's potential is being utilized, with speculation that a high temperature steam area exists below the known shallow reservoir.

INTRODUCTION

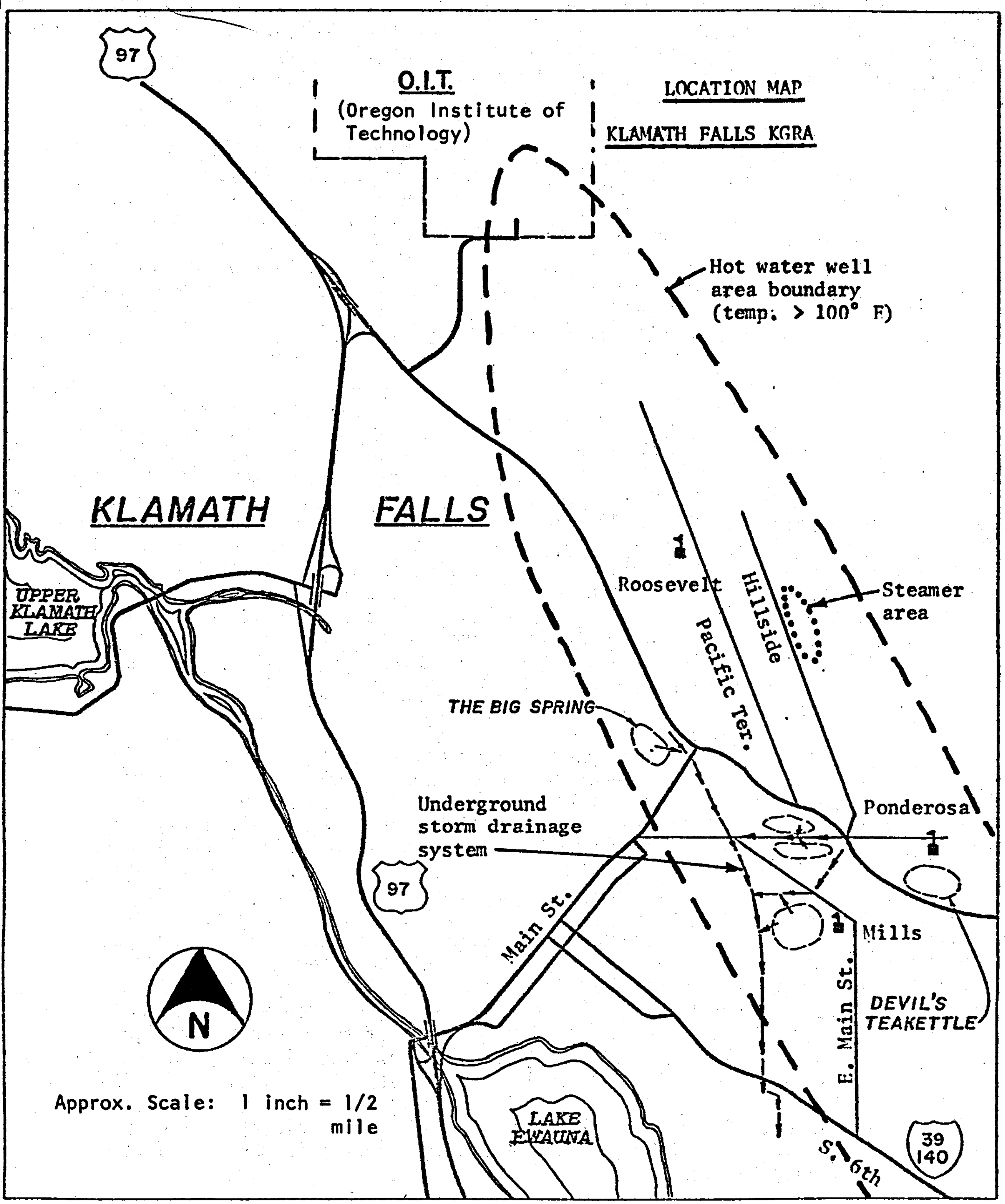
Klamath Falls, Oregon, is located on a Known Geothermal Resource Area (KGRA) (Koenig, 1973) and the residents have made use of the resource, principally in the form of hot water for space heating, at least since the turn of the century. The local use appears to be somewhat unique; however,

---

[1]Professor of Civil Engineering Technology, Klamath Falls, Oregon

[2]Associate Professor of Mechanical Engineering Technology, Klamath Falls, Oregon

[3]Associate Professor of Chemistry, Klamath Falls, Oregon


97
O.I.T.
(Oregon Institute of Technology)
LOCATION MAP
KLAMATH FALLS KGRA
Hot water well area boundary (temp. > 100° F)
KLAMATH
FALLS
UPPER KLAMATH LAKE
Roosevelt
Hillside
Pacific Ter.
Steamer area
THE BIG SPRING
Underground storm drainage system
Ponderosa
97
Main St.
Mills
E. Main St.
DEVIL'S TEAKETTLE
N
Approx. Scale: 1 inch = 1/2 mile
LAKE EWAUNA
39
140
S. 6th

only limited reporting and documentation has been made by others (Peterson, 1967 and 1970). Based on the uniqueness of the utilization in the United States and the lack of specific information, a detailed investigation was initiated during the summer of 1974 to study residential, public building, and commercial geothermal heating systems in Klamath Falls (Culver, 1974).

It is estimated that Klamath Falls has approximately 400 hot water wells for space heating of approximately 500 structures, thus 75 locations were selected from these for detailed documentation. These locations were chosen to represent a cross section of the usage and geographic distribution in the Klamath Falls area and included 38 single family residences, eight multiple residences using a single well, six apartment complexes, seven schools, three churches, four public uses (including the city swimming pool), and nine commercial locations. Included in the study were well temperatures profiles, chemical analysis of water samples, analysis of heating systems, and operational costs.

HISTORICAL DEVELOPMENT[1]

Surface hot springs and mud pots were present before the settlement of Klamath Falls and had been used by Indians and sheepherders before the turn of the century. Five specific spring areas were known during this time; the most noted ones were the "Big Springs" located in the present Modoc Field adjacent to the high school and "Devil's Teakettle" located in the present Ponderosa Field behind the City School Administration buildings. Other locations were one on either side of Main Street in the vicinity of the present City swimming pool and Klamath Medical Clinic and one between Mills School and the railroad passenger depot. The latter area was a swamp and excellent duck hunting area for many years. Today these areas are the location of artesian or near surface artesian wells. These natural spring areas were used by residents for scalding hogs and poultry and as temporary residence for many transients. Figure 1 gives the locations of the above areas.

In the 1890's local sheepherders dug holes in the ground to obtain hot water in areas adjacent to the artesian springs. Around the turn of the century homes were heated by direct use of the artesian water, and both hot and cold water (after cooling in tanks overnight) were used for drinking and bathing. In 1925, residents started drilling wells using cable drilling methods in the area near the lower end of Pacific Terrace and Hillside Avenue. During the period from 1920 to 1932, plunger pumps were used on the dug and drilled wells due to the lack of knowledge concerning principles of "thermo syphoning" or the natural convection movement of hot water in heat exchangers. The last plunger pumped well (at Alameda and Esplanade) was abandoned in 1937. The first down-hole heat exchanger (locally called a "coil") was placed in 1929 at 519 Pacific Terrace utilizing the thermo syphoning principle. In 1928, Butler's Natatorium was constructed on the location of the present day high school swimming pool. It had a swimming pool and hot mineral baths. Greenhouses have also been used since the early 1900's but only to a limited extent.

Today most of the eastern portion of the city of Klamath Falls is heated by hot water. The principal heat extraction system is the closed loop down-hole heat exchanger utilizing city water in the heat exchangers.

---

[1]Based on personal communications with local residents.

Prior to 1960 there were no restrictions on the discharge of hot water into the city sewer system. Ordinance No. 5149 was adopted in 1960 controlling the drilling of hot water wells and the discharge of hot water into the sewer system. This ordinance requires a permit to drill a hot water well within the city limits and a license for the discharge of hot water into the sewer system. The discharge of hot water is limited to a flow of two cubic feet per minute per single-family residence and to two cubic feet per five thousand cubic feet of building area for commercial use. Any excess flow can be approved by the City Council with a fee of $10.00 for each additional cubic foot of discharge per minute charged to the owner on an annual basis. The building inspector is to keep the records of well locations and discharge rates.

Most of the present wells for residences vary between 90 and 900 feet (27 to 274 m) in depth with 200 to 300 feet (61 to 91 m) being most common. Commercial establishments and schools, requiring a great heat output, increase the well depth to over 1800 feet (550 m) with 1000 to 1300 feet (305 to 396 m) common. Depth to the water surface varies from artesian (surface) to 350 feet (107 m) with 50 to 100 feet (15 to 31 m) most common. Down-hole heat exchangers will generally extend to near the well bottom with a minimum of 100 feet (31 m) below the water surface.

Four "steamers" are located along the middle of Hillside Avenue. These are sources of natural steam that were encountered during the course of drilling at very shallow depths (approximately 90 feet, 27 m). These are in the 300 to 400 block of Hillside Avenue and due to the high temperature gradient in this area, grass and wildlike (frogs and quail) can be seen all winter. At one location, a subtropical Mimosa tree is growing. No water is present in these wells, and the steam is used to heat the city water in the heat exchangers.

Present uses of the hot water heat include residences, almost all of the city schools, Oregon Institute of Technology, a creamery (for heating and milk pasteurizing), melting snow from a state highway pavement, keeping a floor from freezing and frost heaving in a cold storage plant, accelerated curing of concrete, direct use in a laundry, and for heating swimming pools. Several locations make use of waste hot water discharged into storm sewer lines.

GEOLOGY (Peterson, 1967 and 1970)

The Klamath Falls KGRA is located near the east side and center of Klamath Basin, a northwesterly oriented graben approximately 50 miles (80 km) long and 10 miles (16 km) wide extending from Medicine Lake highland to the south to the Crater Lake caldera to the north. The area is typical of the basin and range country of horst and graben structure located to the east, with Upper Klamath Lake being the largest body of water in this basin. The area is drained by the Klamath River to the south into California. The Cascade Mountains are located to the immediate west and the high desert country to the east. Evidence of recent volcanic activity is shown by Mt. Lassen to the south (erupted in 1914-1917), Mt. Shasta (a composite volcano), Crater Lake (formerly Mt. Mazama which erupted approximately 6500 years ago), and Lava Beds National Monument (with lava flows as recent as 500 years ago).

The steeply dipping normal faults that form the graben has estimated vertical movements of 1700 feet (518 m) with several of the fault scarps being exposed in the basin (i.e., Rattlesnake Point and Stukel Mountain). The main hot water well area is located adjacent to the fault scarp over fault blocks that are slightly tilted and raised over the central portion of the graben. The principal geologic formations are lava flows, volcanic breccia including lapilli and locally designated "cinders," and extensive deposits of lacustrine diatomite and tuffaceous siltstones and sandstone. Many of the above deposits are intermixed making divisions difficult to define. All of the above are underlain by Cascade lava flows of andesites and basalts. All deposits are Pliocene or more recent. Figures 2 and 3 illustrate the geology of the area.

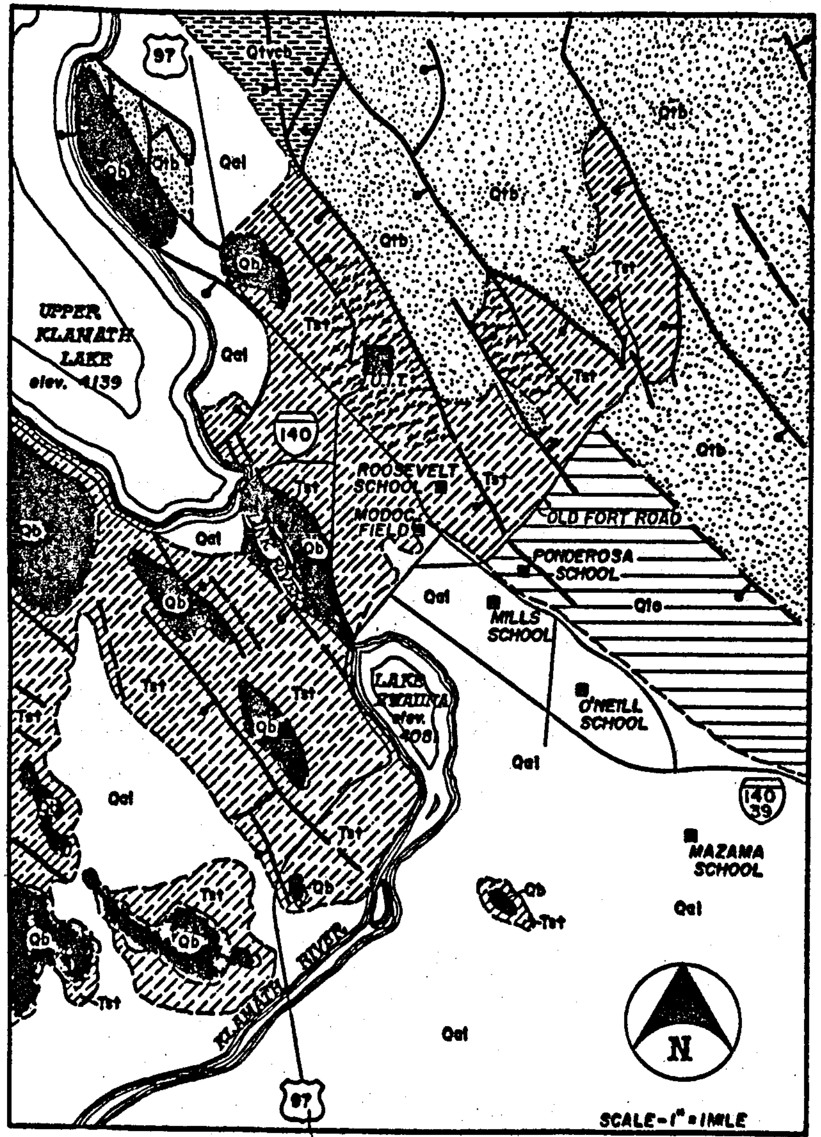
In general, the fractured basalts and cinders are highly porous, being capped by a nearly impervious zone of diatomite and tuffaceous sediments locally called "chalk rock" (Tst on the geologic map) which varies from 30 to 150 feet (9 to 46 m) thick in the area. In very localized areas (as seen behind the new hospital), this "chalk rock" has been hydrothermally altered to various siliceous deposits, locally called "hot springs agates."

The hot water probably originates as seepage from the Cascades to the west, Crater Lake to the north and in part as seepage from Upper Klamath Lake and the "hog backs" to the east. These latter two sources probably contribute most of the cold water near the surface of the area. Two main geothermal reservoirs probably exist, a lower area with temperatures in excess of 250°F (121°C), with heat and water being transferred by convection cells to the upper reservoir in the form of steam and hot gases along fault zones. The upper reservoir has temperatures less than 250°F (121°C), with the upper portions of this zone being cooled by the downward seepage of cold ground water. Wells generally intercept the hot water in specific stratas of porous material (fractured basalts, andesites and cinders). Water generally flows in these layers and can be indentified by the lack of drilling cuttings when bailing a well. These layers can be from 2 to 20 feet (0.7 to 6 m) thick with impervious layers in between. The general circulation pattern in both the upper and lower reservoirs is probably along fault zones vertically and porous layers horizontally. No well drilling has encountered the lower reservoirs, thus its existence and the associated live steam can only be the subject of speculation and interest for future drilling. Figure 4 illustrates a hypothetical section of the graben and convection cells.

The permeable layers of hot water appear to be somewhat channelized, as in several cases a well drilled in the vicinity of several "good" wells with active flowing zones, was unable to intercept these zones. These latter wells often have high rock temperatures; however, without the free flowing water to provide an adequate transfer medium, additional depth is required to allow for added heat exchanger pipe length. These wells are known locally as "mud" wells. At one location a well over 1000 feet (305 m) deep was drilled within 250 feet (76 m) of one only 220 feet (67 m) deep. This 1000 foot (305 m) well was essentially dry, even after attempts to fracture the rock at the bottom with dry ice and explosives.

DETAILS OF THE UTILIZATION

Well Construction Characteristics



GENERALIZED GEOLOGIC MAP OF KLAMATH FALLS & VICINITY

GEOLOGIC MAP EXPLANATION

Holocene

Qal — Alluvial deposits including diatomite and peat

Pleistocene

Qlo — Fluvial terrace and lacustrine deposits

Qb — Basalt flows

Pliocene

Tst — Lacustrine & fluviatile tuffaceous siltstones, sandstone, ashy diatomite, basaltic tuffs and breccias, few thin basalt flows.

Qtb — Basalt flows, pyroclastic breccia, and agglomerate; of uncertain stratigraphic relationships; may in part be contemporary with Tst, Tb, and Qb.

Tertiary-Quaternary

Qtvcb — Basalt eruptive centers

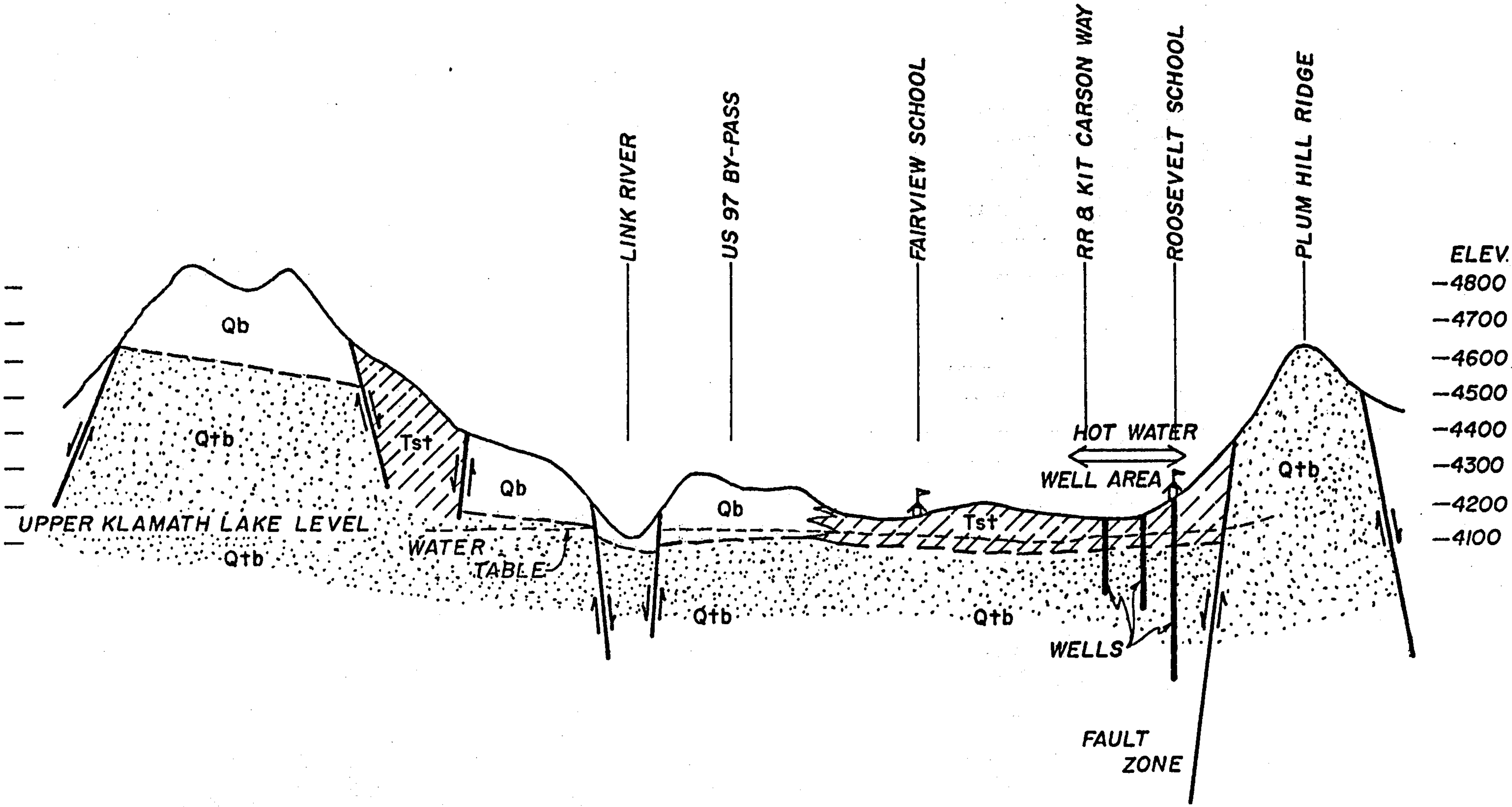
SYMBOLS

- Known fault location, ball on downthrow side
- Approximate or inferred fault location
- Contact location
- Zone of hydrothermal alteration

Reference:

1. Peterson, Norman V. and Edward A. Groh, "Geothermal Potential of the Klamath Falls Area, Oregon - A Preliminary Study, The Ore Bin, Vol. 29, No. 11, State of Oregon Department of Geology and Mineral Industries, Portland, November 1967.
2. Peterson, Norman V. and James R. McIntyre, "The Reconnaissance Geology and Mineral Resources of Eastern Klamath County and Western Lake County, Oregon," Bulletin 66, State of Oregon Department of Geology and Mineral Industries, Portland, 1970.
3. Personal contacts with Dr. Murray C. Gardner, Geothermex, Berkeley, California, 1974.

Figure 2.



GEOLOGIC CROSS SECTION B·B

VERTICAL SCALE: 1" = 400'
HORIZONTAL SCALE: 1" = 2000'

Figure 3.

TYPICAL SECTION OF EAST SIDE OF KLAMATH GRABEN

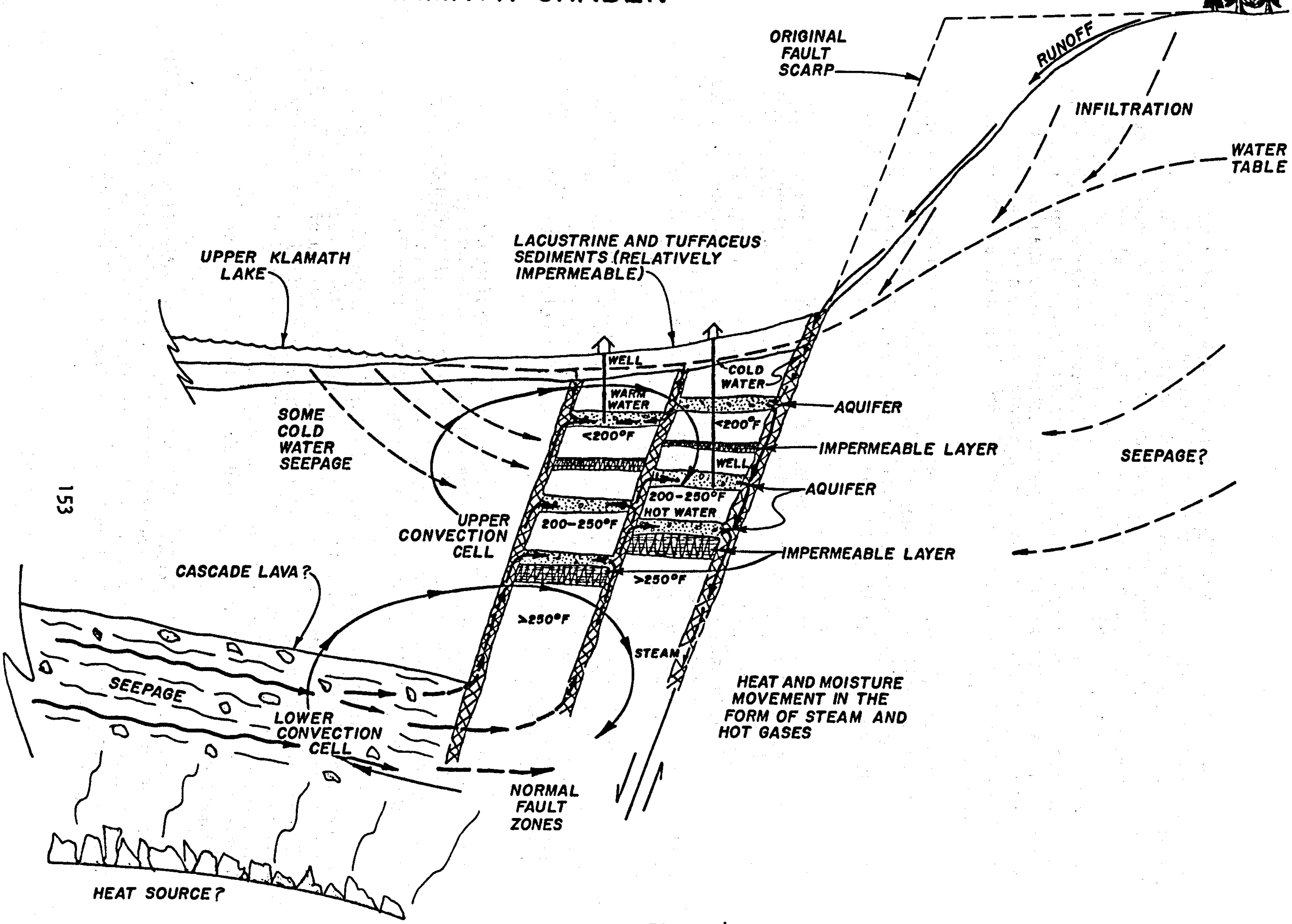


Figure 4.

Most of the wells in Klamath Falls are drilled with cable tool drilling equipment. Early wells were relatively shallow mainly because of the location in the better geothermal areas. Casing of these early wells was only deep enough to case off surface cold water and to prevent caving near the surface. The casing length was around 30 feet (9 m) and in many cases only 1/8-inch (3 mm) wall thickness. As a result caving would often occur below the casing, filling in the lower portion of the well and causing the temperature of the water to cool. Cleaning was required every 8 to 10 years, and casing life was extremely short, estimated less than 15 years. Electrolysis would develop between the down-hole heat exchanger and the well bore below the casing, causing replacement of the heat exchanger pipe in less than 10 years.

Recent well drilling practice is to still use cable drilling rigs or to use rotary drilling rigs to depths near expected live water flows and then finish the drilling with cable drilling tools. Drillers feel that there is some danger of sealing off the flow of live water with the rotary drills.

The usual construction of newer wells is shown in Figure 5. The well bore is typically 12 inches (30 cm) in diameter and the casing 8 inches (20 cm) in diameter. Well depth is determined by a sufficient section of free flowing water, high temperature, and the length of coil required to supply heat for the structure. Heating system contractors consider 24 inches (61 cm) of free flowing water near 190°F (88°C) as the minimum to provide sufficient heat for a typical 1600 to 1800 square foot (150 to 170 m^2) home, with longer sections more desirable.

Free flowing water seams are geologic structures where there presumably is a high flow rate of water, commonly found in fractured lavas and pyroclastic material such as cinders. In drilling a well these strata are identified by the lack of drilling cuttings when the well is bailed every two to three feet of drilling depth.

Once a sufficient length of free flow at satisfactory temperature is obtained, drillers prefer to continue drilling 10 to 25 feet (3 to 8 m) even though the extra depth may not be required for the heat exchanger pipe. This extra depth provides space for a mud leg and a volume to hold debris that may otherwise slough into the well and cover the lower flow.

Once the well bore is complete, casing is started down the hole. Perforations are cut in the casing as it is lowered so that free flowing water can enter the casing. The casing extends to the bottom of the bore and, by Oregon law, must be set in a solid formation. If required, a packer may be installed to block off cold water flows. Packers are generally made by securing burlap to the casing in the desired position as the casing is lowered. After the casing is set, grout is placed above the burlap to provide a permanent seal.

Since the bore is larger than the casing, live water flows at several depths are usually encountered, and the perforations allow circulation. It is believed that a convection cell is established within the well. How effective this cell is in providing good circulation after many years is open to some question.

TYPICAL HOT-WATER WELL SECTION

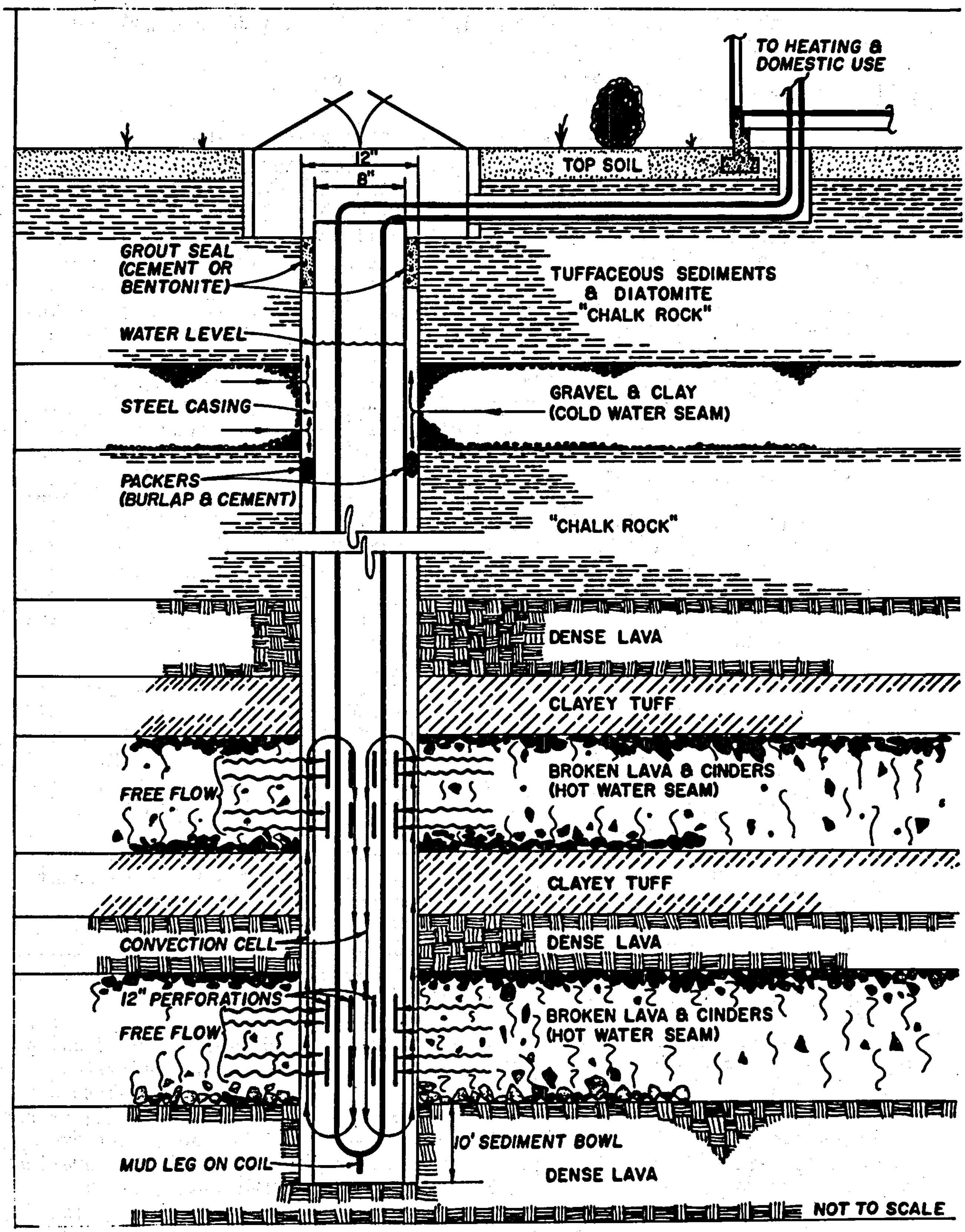


Figure 5.

Present casing thickness is 1/4 to 5/16 inches (6 to 8 mm) and the expected life is well over 50 years.

Well Temperatures and Chemistry

Well water temperatures vary from 70°F (21°C) at the top to over 220°F (105°C) at the bottom. The low surface temperatures are generally caused by cold surface water cooling the surrounding formations. Rock temperatures in drill holes have been measured as high as 250°F (127°C) but once water enters the hole, the temperature will drop to the 220°F (105°) range. During the course of the study temperature profiles were determined for many wells in the area with a thermistor probe. Based on this information two main high temperature areas were noted in Klamath Falls. The main one, shown in Figure 6, is in the vicinity of Roosevelt School and includes the steamer area as well as the area to the north and west of the school. The second area is in the vicinity of the original artesian springs and presently the location of many artesian and near surface artesian wells. This area extends from Modoc Field to the south. Well profiles are somewhat difficult to obtain for artesian wells as most of these are capped. Temperatures were determined in many cases based on pumped temperatures at the surface; however, based on the results from three that were profiled, the temperature change from top to bottom varies from 10° to 20°F (6 to 11°C). Average water temperatures in the hot water area vary from 100°F to over 210°F (38 to 99°C). Temperatures below 100°F (38°C) are generally not considered to be adequate for space heating. Water temperatures outside of this area vary from 100°F (38°C) to 70°F (21°C) as the location is further removed from the hot water region.

Temperature gradients have also been determined for the area; however, these are greatly influenced by the chilling effect of surface cold water causing the gradient to be larger than normal for shallow depths. In general, the higher gradients of 20° to 35°F per 100 foot of depth (37 to 64°C per 100 m) are associated with the Roosevelt School and Hillside Avenue high water temperature area. With depth the gradient tends to approach zero.

The well water is generally characterized by high concentration of sodium and low concentrations of potassium, having Na/K mass ratio of about 42 (atomic ratio of about 71). The water hardness of these samples is generally low and results principally from calcium ion. On a mass basis, sulfate is the principal negative ion of these waters. The alkalinity values indicate the major contributor to pH is bicarbonate ion and that these waters are highly susceptible to downward pH shifts.

The Langelier Saturation Index (Langlier, 1936) was computed using the nomogram to Sisson (Sisson, 1973) for 13 well samples, three of which were artesian. The index in all cases was positive ranging from 0.02 to 0.88 indicating that water in these wells tends to deposit calcium carbonate rather than dissolve it. It is of interest to note that a well having a heat exchange pipe repair frequency of approximately five years has a low saturation index of 0.02 while non-artesian water with large positive index values between 0.45 and 0.75 have repair frequencies of 10 to 20 years. Artesian wells, on the other hand, having saturation index values between 0.45 and 0.75 have repair frequencies between 29 and 34 years.

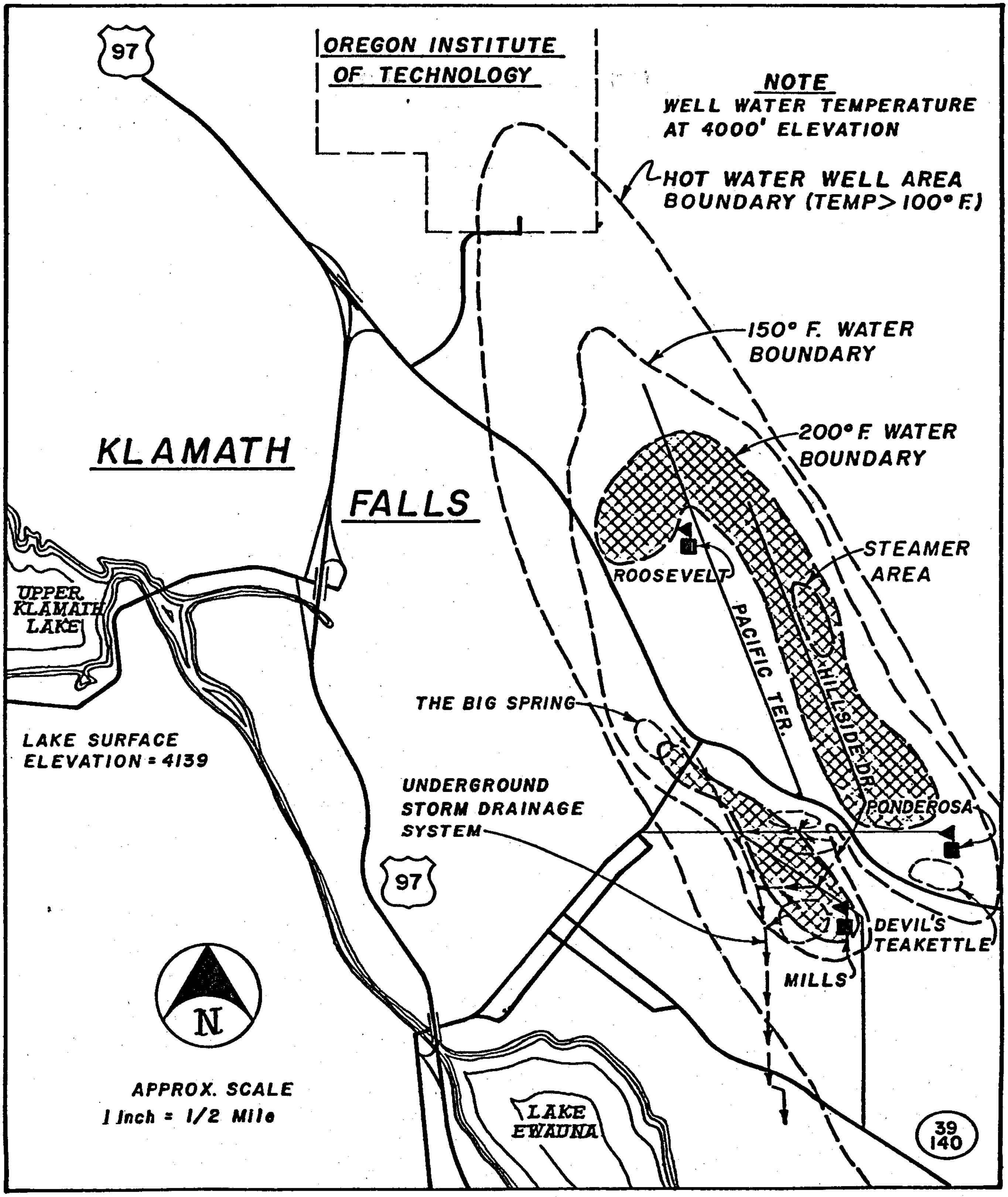


Figure 6. Well Water Temperature at 4000' Elevation

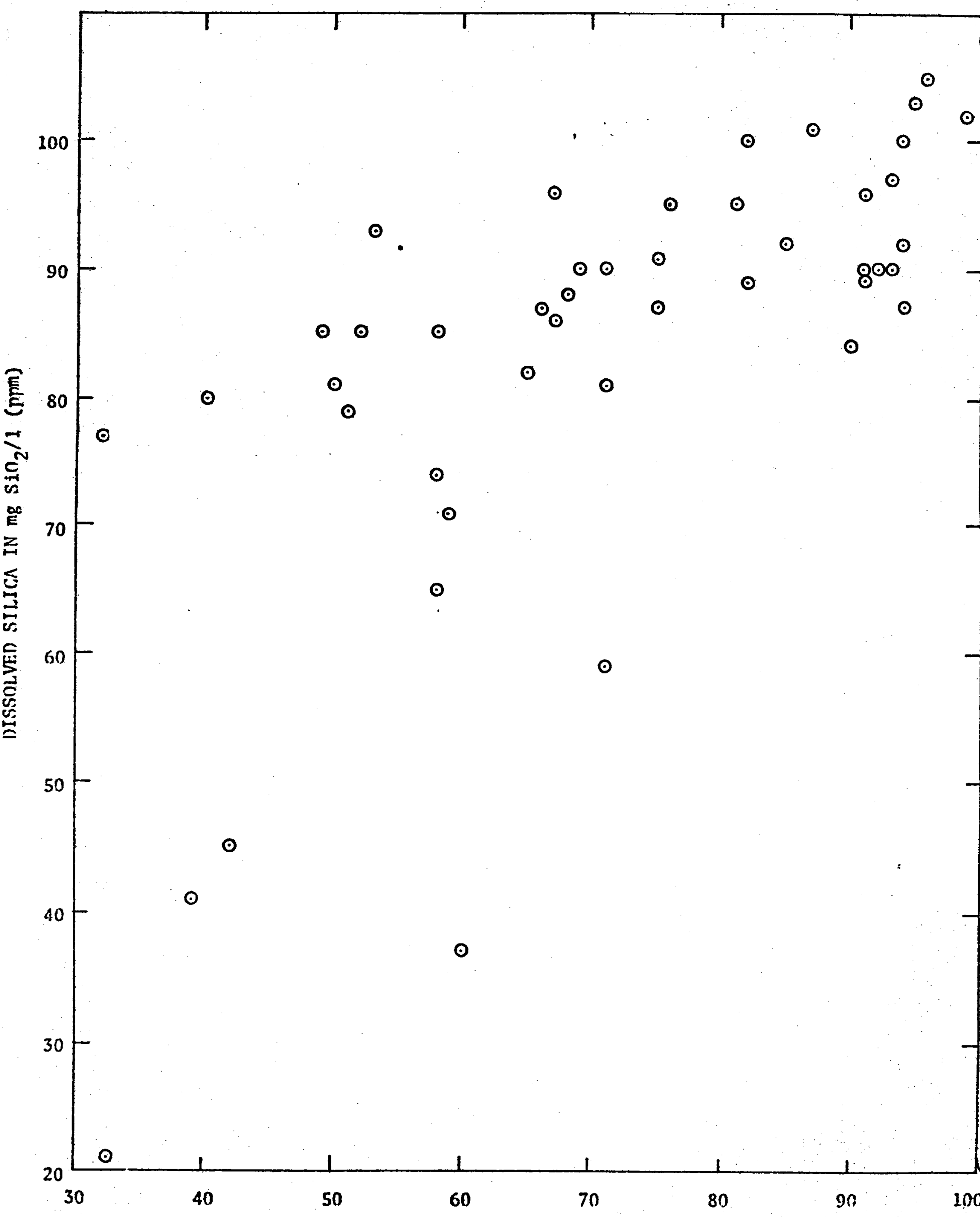

DISSOLVED SILICA IN mg SiO_2/1 (ppm)
100
90
80
70
60
50
40
30
20
30
40
50
60
70
80
90
100
SAMPLING TEMPERATURE IN °C

Figure 7.

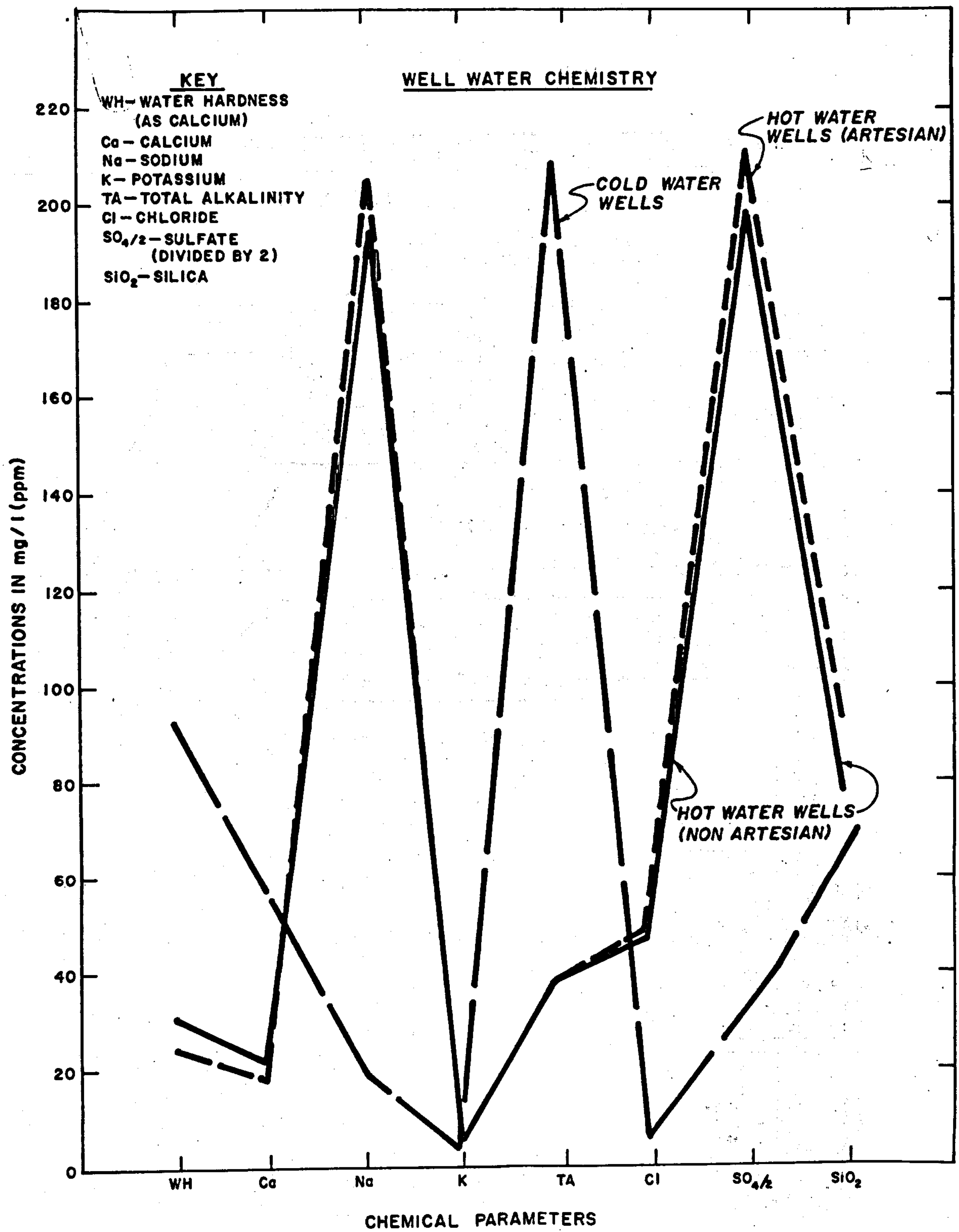
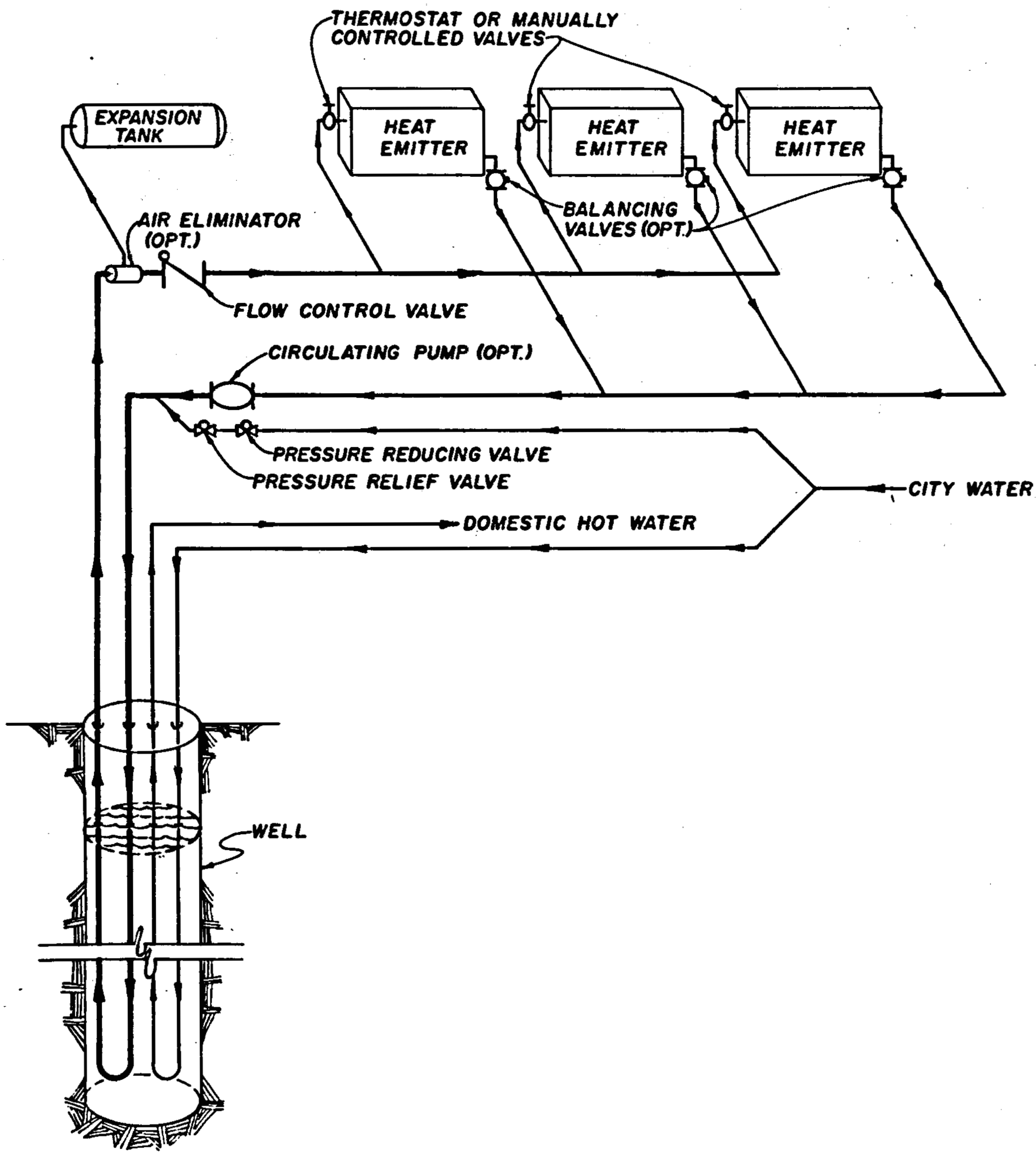

WELL WATER CHEMISTRY
KEY
WH - WATER HARDNESS (AS CALCIUM)
Ca - CALCIUM
Na - SODIUM
K - POTASSIUM
TA - TOTAL ALKALINITY
Cl - CHLORIDE
SO4/2 - SULFATE (DIVIDED BY 2)
SiO2 - SILICA
HOT WATER WELLS (ARTESIAN)
COLD WATER WELLS
HOT WATER WELLS (NON ARTESIAN)
CONCENTRATIONS IN mg/l (ppm)
0
20
40
60
80
100
120
140
160
180
200
220
WH
Ca
Na
K
TA
Cl
SO4/2
SiO2
CHEMICAL PARAMETERS

Figure 8.

TYPICAL HOT WATER DISTRIBUTION SYSTEM



DOWN-HOLE HEAT EXCHANGER SYSTEMS

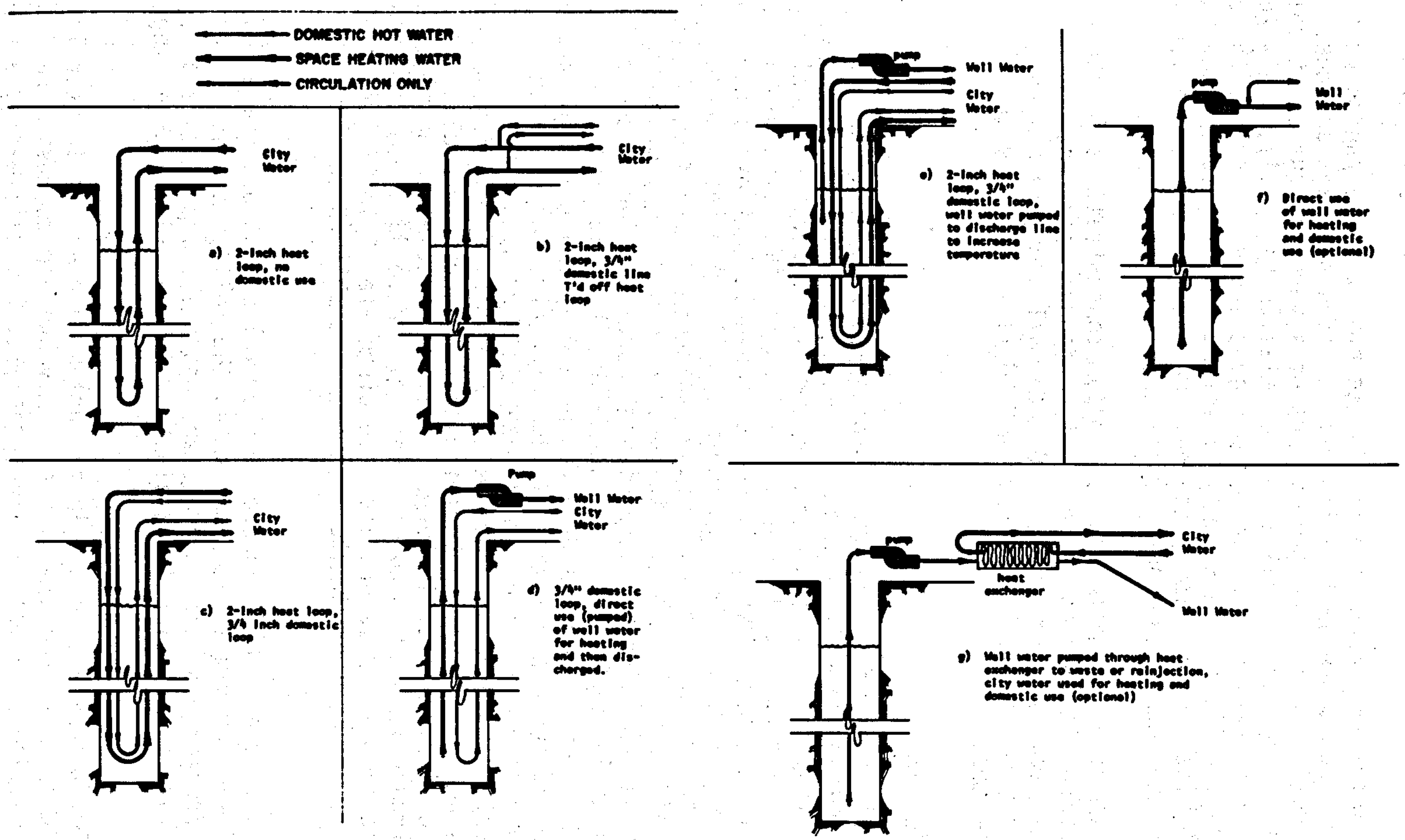


Figure 10.

The silica concentration typically is 70 to 90 mg SiO_2/l which exists principally in these waters as bisilicate ion. Figure 7 diagrams the silica concentrations obtained as a function of sampling temperature.

Wells which are adequate heat sources have a cation/anion pattern notably different from those wells which are not adequate heat sources. Figure 8 illustrates three patterns, one the average of several adequate hot wells, and a second the average of several adequate artesian hot wells, and a third the average of several wells known to be poor heat sources. All of the adequate heat sources, while having notably different sampling temperatures, each share certain chemical composition patterns. Most notably in comparison between adequate and inadequate heat source chemical data are:

1. High water hardness and low sodium concentrations in the inadequate sources compared with adequate sources.
2. Low total alkalinities, ∿ 40 mg$CaCO_3$/l adequate sources, and high alkalinities ∿ 200 mg$CaCO_3$/l in the inadequate sources.

<u>Heat Exchange Systems</u>

Since the turn of the century, geothermal well water has been piped through spacing heating systems in Klamath Falls. Even though the water in the area is unusually pure for geothermal water, it corroded and scaled plumbing systems of the era so that in a relatively short time, systems had to be repaired or replaced. About 1930, the first down-hole heat exchanger, locally known as a coil, was installed in a geothermal well. The heat exchanger coil consists of two strings of pipe connected at the bottom by a reverse bend. The temperature of the well water and the predicted heat load determine the length of pipe required. Based on experience, local heating system contractors estimate approximately one foot of coil per 1500 BTU (0.38 g cal) per hour required. The coil pipes are connected to the supply and return of the distributing piping and the entire system filled with city water. Figure 9 illustrates a typical system. The "thermo-syphon" (or gravity feed in standard hot water systems) process circulates the domestic water, picking up heat in the well and releasing the heat in the radiators. Circulation pumps are required in cooler wells or in larger systems to increase the flow rate. Thermo-syphon circulation will provide 3 to 5 psi (2 to 35 kg/cm^2) pressure difference in the supply and return lines to circulate 15 to 25 (57 to 95 liters per minute) gallons per minute with a 10° to 20°F (6 to 11°C) temperature change.

There are several older and/or cooler wells that are pumped directly into the storm sewers or canal. In most cases the well is pumped in order to increase the flow of geothermal waters and raise the temperature of the well to a level locally considered satisfactory for use in space heating, about 140°F (60°C).

In a few instances, mostly in the artesian area, well water is pumped directly through the heating system. Advances in corrosion resistant materials and knowledge about maintaining pressure, and eliminating air inclusion, tend to reduce internal corrosion. Higher pressures and flow rates tend to reduce scaling. Both of these techniques have extended the life of these systems. The most common down-hole heat exchanger systems presently used in Klamath Falls are illustrated in Figures 10a through 10g.

As hot water heating technology developed, systems were improved; more sophisticated distribution systems with automatic zone control, baseboard convectors, and hot water forced air systems with air conditioning were incorporated. Small quiet circulation pumps of 1/12 to 1/6 h.p. are now almost standard. By-pass circuits may be installed to provide continuous circulation of the water in the coil and usually are included in the domestic hot water supply to provide quick hot water. Figure 11 through 11c illustrate the most common heating systems presently in use.

The down-hole heat exchanger system is economical, minimizes corrosion problems, probably conserves the resource, and eliminates the problem of waste water discharge.

The most common failure of these systems is corrosion of the heat exchanger pipe at the air-water interface. Other areas of failure are where pipes touch the side of the casing or due to twisting where they rub or touch each other. Most heat exchanger pipes are standard black iron pipe, although a few are double strength near the top in deep wells to reduce stresses, or at the water line to provide longer corrosion resistance. The average life of standard black iron pipe in the wells investigated was about 14 years. Other materials have been tried for use at the water line including brass and lead; and based on limited information, these appear to extend the life of the system. The most common, economical, and apparently effective method of reducing corrosion is to pour used motor oil or paraffin in the well. These materials either reduce evolved gases and water vapor, or provide a protective coating on the coil surface, or both. Several types of corrosion resistant paints have been tried with questionable results.

ECONOMIC ANALYSIS

Capital and Operation Costs

During the investigation an attempt was made to determine the cost of hot water heating system operation. This included the cost of the initial installation such as drilling, casing, heating pipes, and the annual operation and maintenance cost such as taxes, electricity for pump motors, well maintenance, and heating pipe replacement and repair cost.

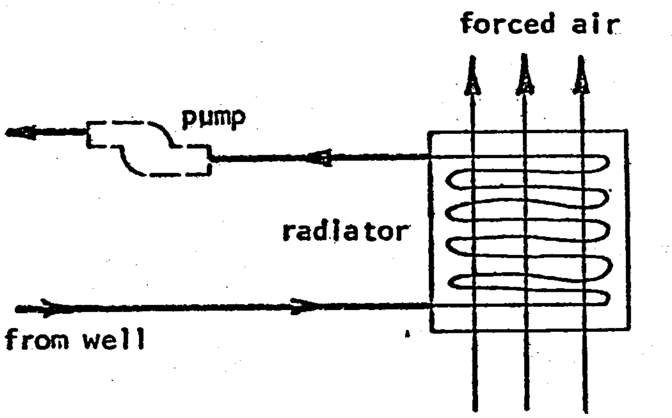
We were able to document the frequency of repairs for heat exchange pipe at 21 locations which gave us sufficient data to estimate the average. The averages obtained were:

1. Frequency of pipe repair for a residence--14 years
2. Average cost of repair for this 14-year frequency--$560
3. Frequency of repairs for artesian wells--32 years
4. Average cost of repairs for the artesian wells--$1500
5. Estimated frequency of repairs for wells cased to the bottom--over 50 years.

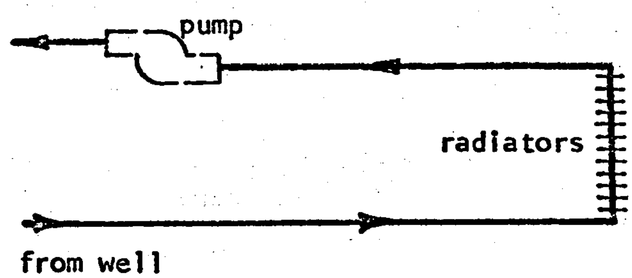
Based on 1974 prices, the various items would cost:

1. Hard rock drilling--$20 per foot for 12-inch diameter hole
2. Soft rock drilling--$10 per foot for 12-inch diameter hole
3. Steel casing--$9 per foot for 8-inch diameter
4. 2-inch diameter heat pipe--$1.65 per foot
5. 3/4 inch diameter water pipe--$0.56 per foot

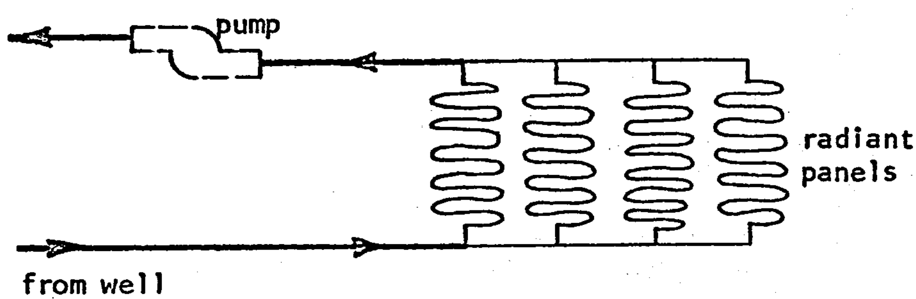
HEATING SYSTEMS



a) City water or well water circulated through radiator with forced air used to circulate heat.



b) City water or well water circulated through cast iron or finned radiators.



c) City water or well water circulated through radiant heating pipes in floor or ceiling.

FIGURE 11.

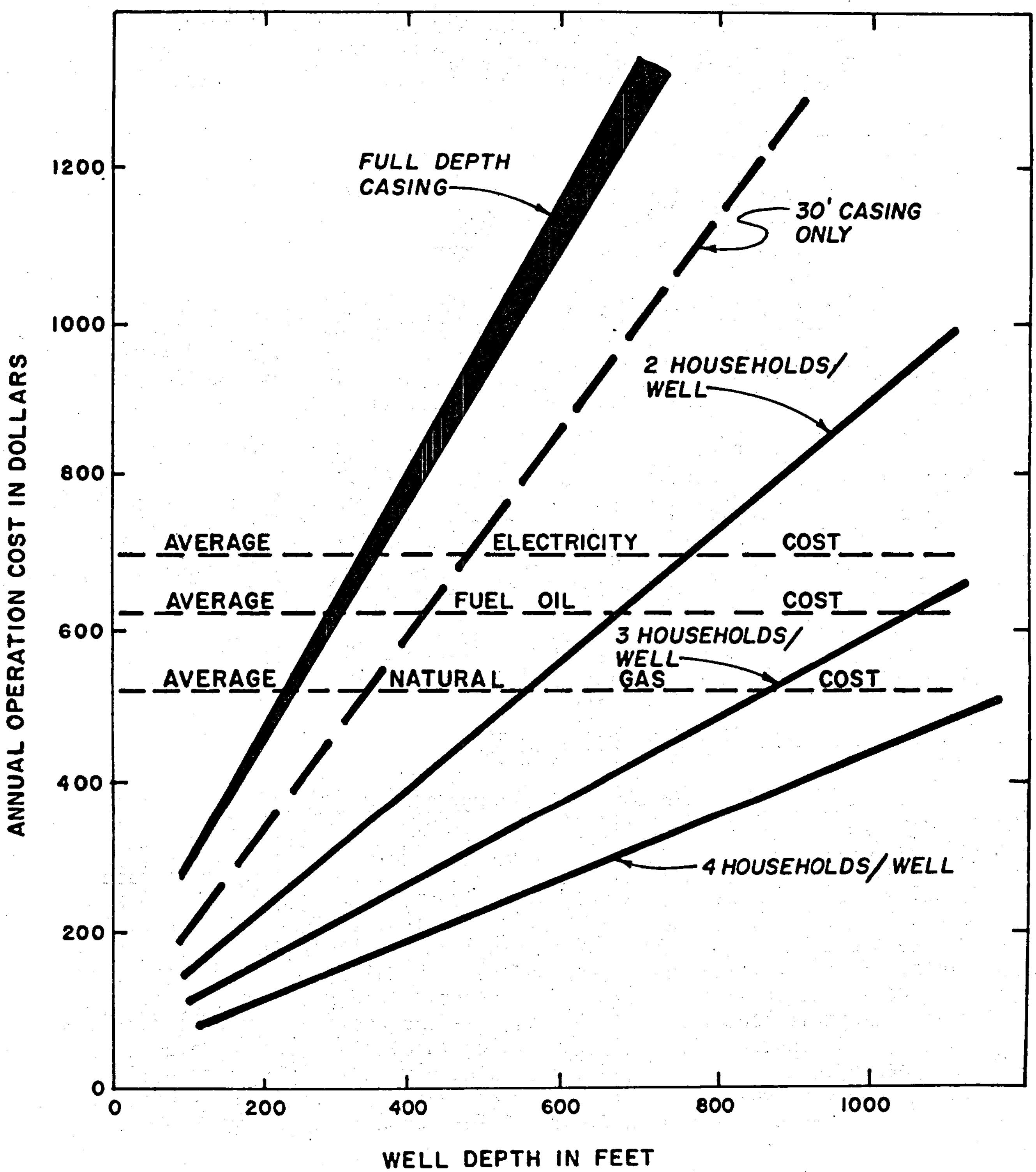

FULL DEPTH CASING
30' CASING ONLY
2 HOUSEHOLDS/ WELL
3 HOUSEHOLDS/ WELL
4 HOUSEHOLDS/ WELL
AVERAGE ELECTRICITY COST
AVERAGE FUEL OIL COST
AVERAGE NATURAL GAS COST
ANNUAL OPERATION COST IN DOLLARS
WELL DEPTH IN FEET
0
200
400
600
800
1000
1200

Figure 12.

Using a 7 percent rate-of-return, the following total costs can be estimated:

1. 150-foot deep well with casing and heating pipe--$3830
2. 300-foot deep well with casing and heating pipes--$7549
3. 600-foot deep well with casing and heating pipes--$16,000
4. Annual operating costs for maintenance, electricity and taxes--$64.

Thus, the total annual cost comes to:

1. 150-foot deep well--$336 per year
2. 300-foot deep well--$603 per year
3. 600-foot deep well--$1142 per year

There will obviously be some variations in these estimated costs due to the amount of hard rock encountered and variations in labor costs. A graphical plot of annual cost vs. well depth is shown in Figure 12 with the band allowing for the above mentioned variations. The costs will be essentially the same for non-artesian as for artesian wells.

A similar comparison was made for a well cased only to a depth of 30 feet as has been past practice. This method would save on casing cost but would require more frequent maintenance and pipe repair due to electrolysis below the casing. The results are also plotted in Figure 12 and show a reduction in annual cost; however, several intangibles should be recognized, such as a gradual reduction in heat available from the well as sloughing occurs and the difficulty of estimating the actual maintenance costs.

Included in Figure 12 are lines indicating the annual cost for a well if two, three, or four households share the same well. As can be seen, the reduction in cost is substantial.

Comparative Costs with Alternate Energy Forms

There are three main alternate energy sources available for heating in Klamath Basin (excluding fireplaces). These are electricity, natural gas, and fuel oil. Comparison of annual heating cost per year was made on several typical locations and is shown in Table 1. These figures are based on approximate heat loss calculations for the particular structure and are only estimates. The geothermal cost is obtained from the graph of annual cost vs. well depths for the depth of the well at the location. As can be seen, in all cases, natural gas is the most economical of the three alternate energy sources, and this agrees with local practice and recommendations. In some cases, electric heat can be competitive if the residence has thermopane windows and good construction with extra thick insulation. These calculations are based on a design temperature loss at +70° to -10°F (21 to -23°C) and 6300 degree-days below 65°F (18°C) for the year. Average annual heating costs for a residence is shown in Figure 12 for comparison with geothermal costs.

The comparison with geothermal heat in Table 1 indicates that it is below or competitive with the most economical alternative source. For a smaller home, alternative heating costs would be less, and the geothermal

ESTIMATED ANNUAL HEATING COSTS FOR SAMPLE LOCATIONS IN KLAMATH FALLS
(Based on September 1, 1974, prices)

Description	Electricity ($0.015/KWH)	Natural Gas ($0.173/therm)	Oil ($0.379/gal)	Geothermal[2] (Figure 12)
Grade School[1]	$ 10,000	$ 3,500	$ 8,330	$ 4,500 (3 wells @ 800')
Older, well constructed residence	439	240	392	300 (124' deep)
Apartment Complex	4,614	2,523	4,120	600 (278' deep)
Newer Residence	790	433	710	340 (140' deep)
Average Age Residence Well Abandoned, Used as Check on Estimates	857	468	765	800 (Based on estimates of drilling well to proper depths of approx. 400' deep)

[1]Fuel prices for a school or somewhat less: $0.0125/KWH, $0.1964/therm., and $0.3621/gal for PS 300 fuel oil.

[2]Based on present well depth and cost if well had to be put in at today's prices.

Table 1.

cost would be more as the latter is independent of the size of the residence and dependent upon the well depth.

All of the alternative heating sources costs are based on rates as of September 1, 1974. Indications are that natural gas rates will be increased from 9 to 30 percent this coming winter, and fuel oil may be difficult to obtain. Thus, there is a strong indication that alternative heating sources will increase greatly in price and may, at times, be difficult to obtain, especially if last winter was any indication. Geothermal costs will also increase, mainly due to increased prices for steel casing and heat exchanger pipe. However, these costs will probably increase at a slower rate than other fuel costs, making geothermal heat more economical.

SUMMARY AND CONCLUSIONS

The Klamath Basin KGRA has been utilized primarily for space heating for over 70 years. The most popular method of extracting the heat from the ground is by down-hole heat exchangers in hot water wells. A secondary method is to pump the water from the ground and pass it through a heat exchanger above ground and then waste or reinject the water. There are many variations in the specific configuration of the heat exchanger systems as shown in Figures 10 and 11.

The extent of the near surface hot water can be fairly well delineated with the area with temperatures greater than 100°F (38°C) shown in Figure 1. The temperatures of the near surface water appear to gradually diminish as the location gets farther away from this 100°F (38°C) boundary. Based on well drilling logs and conversations with local residents, the temperatures of the water outside this area decreases from 100°F to about 70°F (38 to 21°C) within half a mile to the east and west. The typical cold water well has a temperature of 70°F (21°C) in the basin. The areas to the northwest, beyond OIT, have not been explored; thus very little is known about the extent of hot water in this area. To the southeast the surface water gradually decreases in temperature as is illustrated by Mazama School (approximately five miles south of OIT). It appears that the hot water is deeper at this point and has been severely diluted by surface infiltration of cold water. The water table is extremely shallow in this area. Hotter water and steam probably exist a great depth under this latter area. Evidence of the continuation of the hot water can be seen in natural hot springs at Olene Gap to the southeast and the Klamath Hills to the south, approximately five to ten miles away.

The utilization of geothermal heat for space heating could be extended beyond the present area by considering radiant heating panels in the floor of a structure or two coils could be used in a well to provide greater area for heat transfer. The use of radiant panels in the floor is the most efficient heating system recommended for use in any part of the geothermal hot water area, however they are also the most expensive. Based on cost per BTU, baseboard radiators in parallel are the most efficient heating system. Forced air systems are slightly more expensive. Other considerations would be transporting hot water in piping systems to areas within the community presently without sufficient hot water temperature.

An estimate of the total heat utilization in the Klamath Basin KGRA is as follows:

1 municipal swimming pool @ 3 x 10^8 BTU/year	=	3 x 10^8 BTU/year
1 hospital @ 65 x 10^8 BTU/year	=	65 x 10^8 BTU/year
3 churches @ approx. average of 12 x 10^8 BTU/year	=	37 x 10^8 BTU/year
8 commercial establishments	=	200 x 10^8 BTU/year
11 apartments @ approx. average of 9 x 10^8 BTU/year	=	100 x 10^8 BTU/year
7 schools @ approx. average of 29 x 10^8 BTU/year	=	200 x 10^8 BTU/year
1 college (OIT) @ 250 x 10^8 BTU/year	=	250 x 10^8 BTU/year
468 residences @ approx. average of 1.75 BTU/year	=	819 x 10^8 BTU/year
500 locations using 400 wells = total of		1,674 x 10^8 BTU/year

The total heat utilization estimate is then 1,674 x 10^8 BTU/year (422 x 10^8 kg-cal) or 5.60 mega watts from hot water wells. This amounts to 5,300 BTU (1336 kg-cal) per second on the average for the year. This, of course, does not consider the potential of the area which is obviously greater but very difficult to estimate.

The cost of hot water well operation in Klamath Falls appears to be somewhat expensive for an individual homeowner. Initial investment of from 7 to 10,000 dollars appears to be usual at the present time. As can be seen in Figure 12, the cost of operation for two to four homeowners sharing a well appears to be far more economical and appears to work quite satisfactorily in the cases in Klamath Falls. The obvious conclusion is to consider some sort of district heating similar to that in Iceland. Alternatives that could be considered are a minimum of four homes sharing a well, an entire block sharing a well, or an entire subdivision sharing a well. The greater the number of homes on one well, the larger and deeper the well will probably have to be and the greater the overhead cost for maintenance and administration will be. Four homes to a well appear to be near optimum for cost and efficiency.

ACKNOWLEDGEMENTS

This work has been sponsored by Lawrence Livermore Laboratory, University of California, under their contract with the Atomic Energy Commission. The success of this investigation is due in part to the cooperation of many persons in Klamath Falls and the surrounding area. These include the many homeowners and business owners who allowed us access to their property for well and heating system information. Many firms directly involved in hot water well drilling and heating system installation provided us with technical information and opportunity to measure wells while they were being repaired. The assistance provided by the staff at OIT for equipment development, typing, and many other tasks is also appreciated.

REFERENCES

1. Culver, G. Gene, John W. Lund and Larsen S. Svanevik, Klamath Falls Hot Water Well Study. (performed for Lawrence Livermore Laboratory), Oregon Institute of Technology, Klamath Falls, Oregon, October 1974.

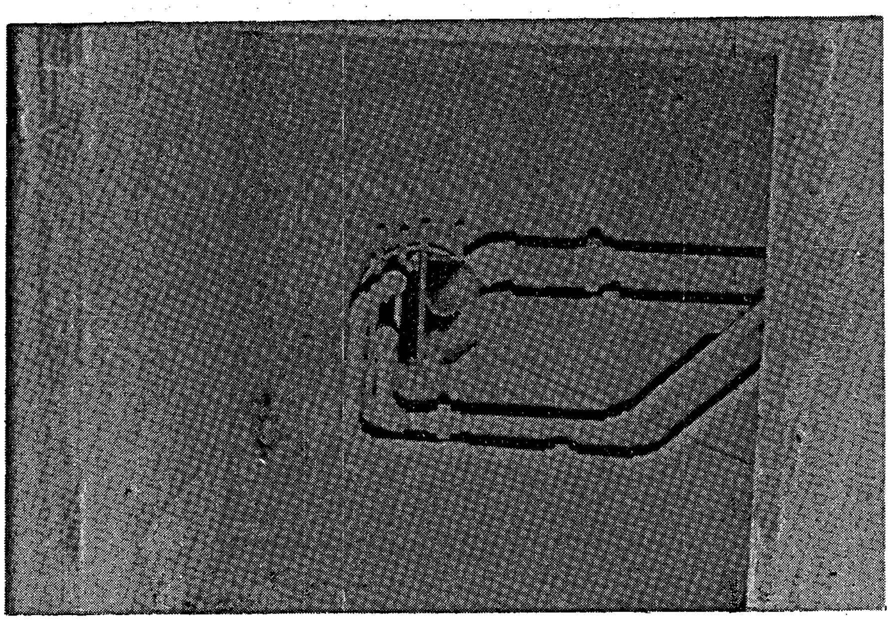
2. Koenig, James B., "Worldwide Status of Geothermal Resources Development," Geothermal Energy, edited by Paul Kruger and Carel Otte, Stanford University Press, Stanford, California, 1973, p. 15-58.

3. Langelier, W. F., "The Analytical Control of Anticorrosion Water Treatment," Journal of the American Water Works Association, Vol. 28, p. 1500, 1936.

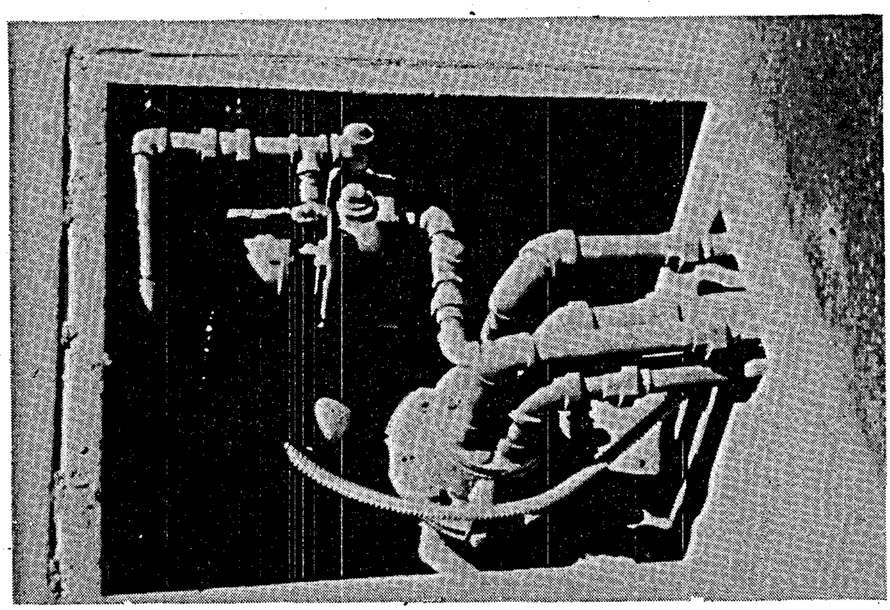
4. Peterson, Norman V. and Edward A. Groh, "Geothermal Potential of the Klamath Falls Area, Oregon--A Preliminary Study," The Ore Bin Vol. 29, No. 11, State of Oregon Department of Geology and Mineral Industries, Portland, November 1967.

5. Peterson, Norman V. and James R. McIntyre, "The Reconnaissance Geology and Mineral Resources of Eastern Klamath County and Western Lake County, Oregon," Bulletin 66, State of Oregon Department of Geology and Mineral Industries, Portland, 1970.

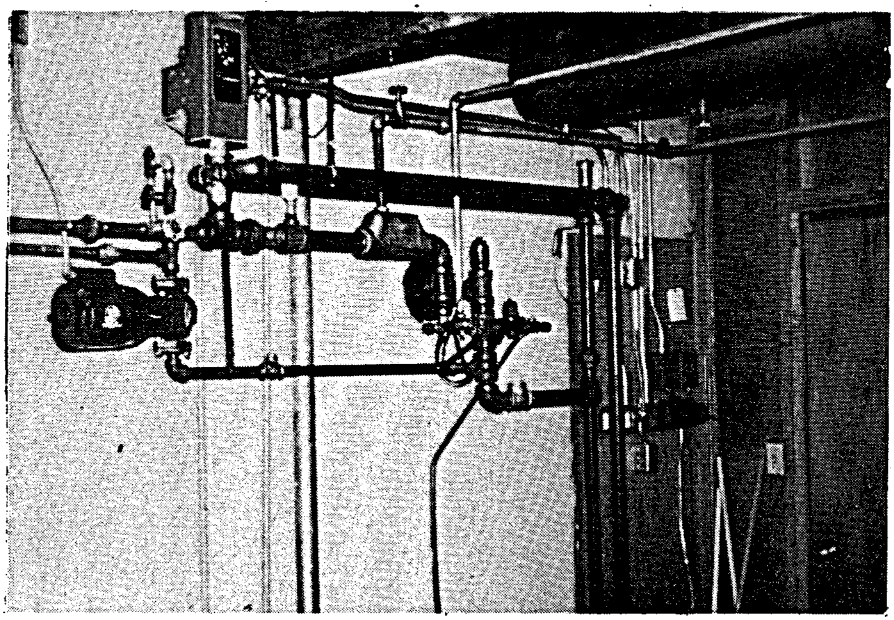
6. Sisson, W., "Langelier Index Predicts Water's Carbonate Coating Tendency," Power Engineering, p. 44, 1973.



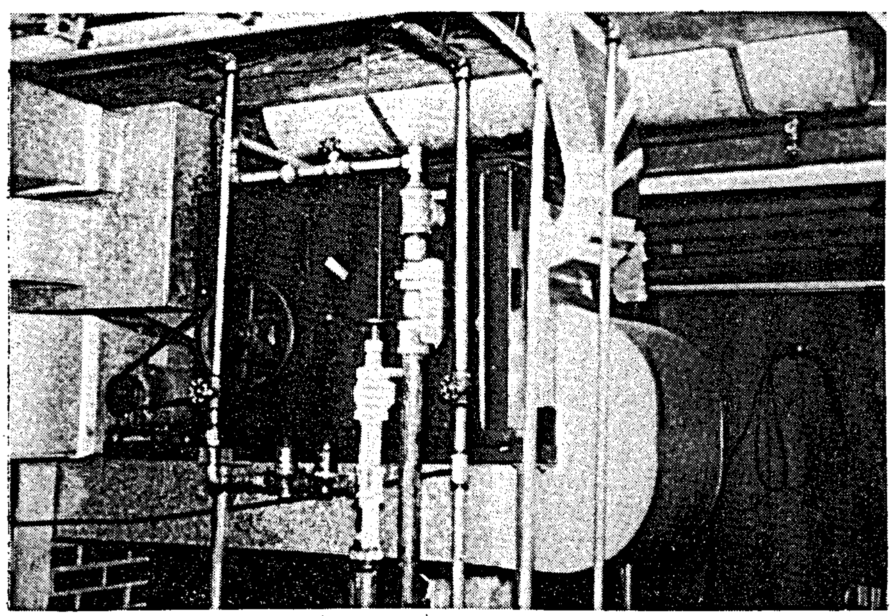
PHOTOGRAPH 1. Typical Well with Heating and Domestic Water Heat Exchangers



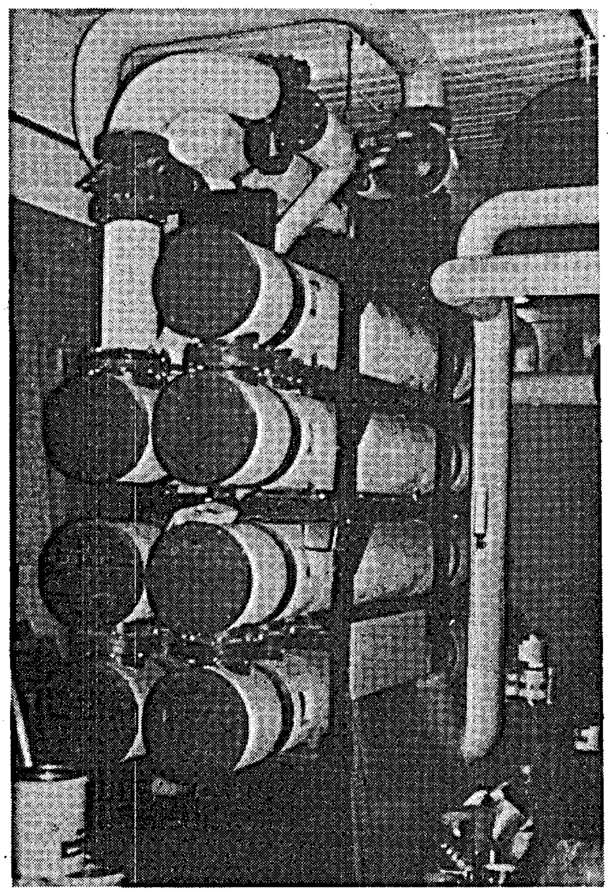
PHOTOGRAPH 2. Typical Well with Heat Exchangers and Pump for Circulation



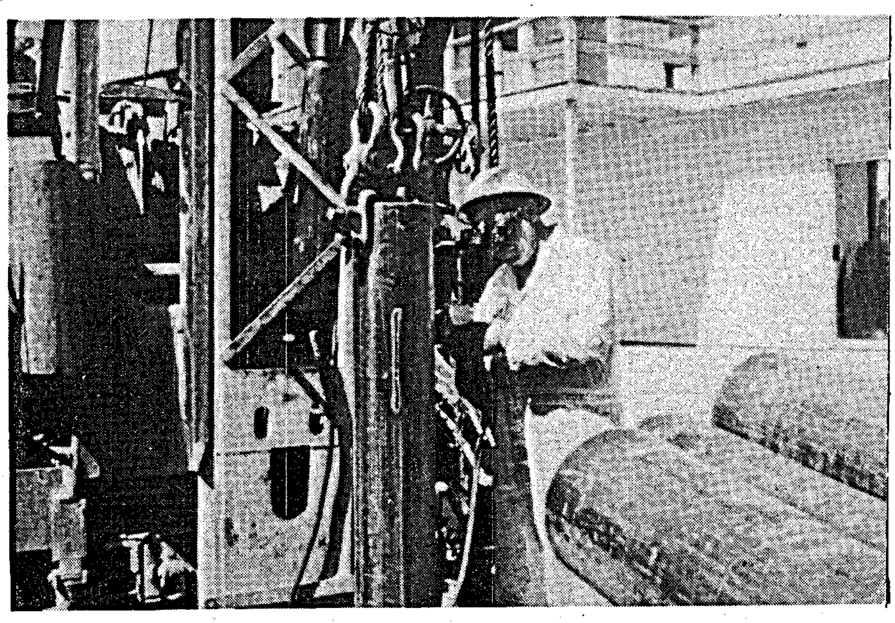
PHOTOGRAPH 3. Typical Piping System for Hot Water Radiators



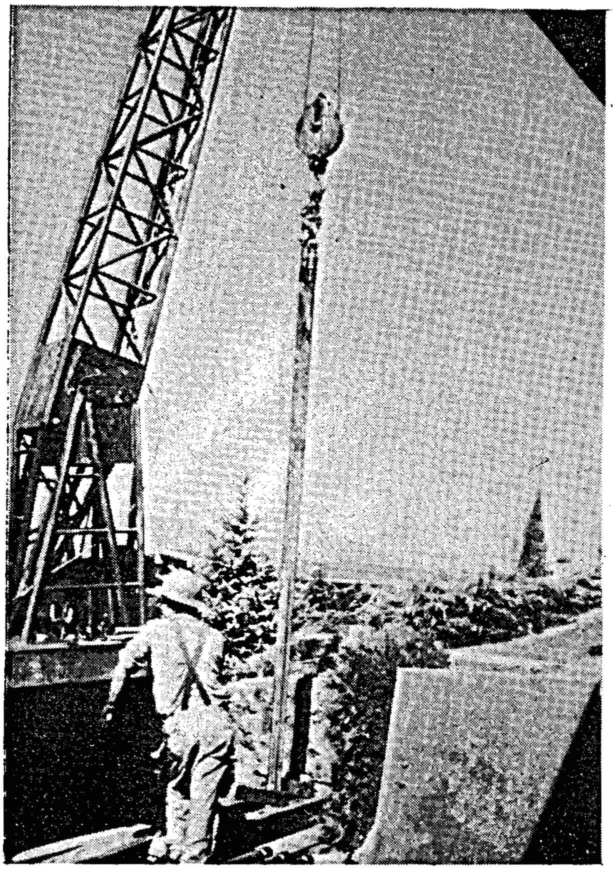
PHOTOGRAPH 4. Typical Piping System for Forced Air



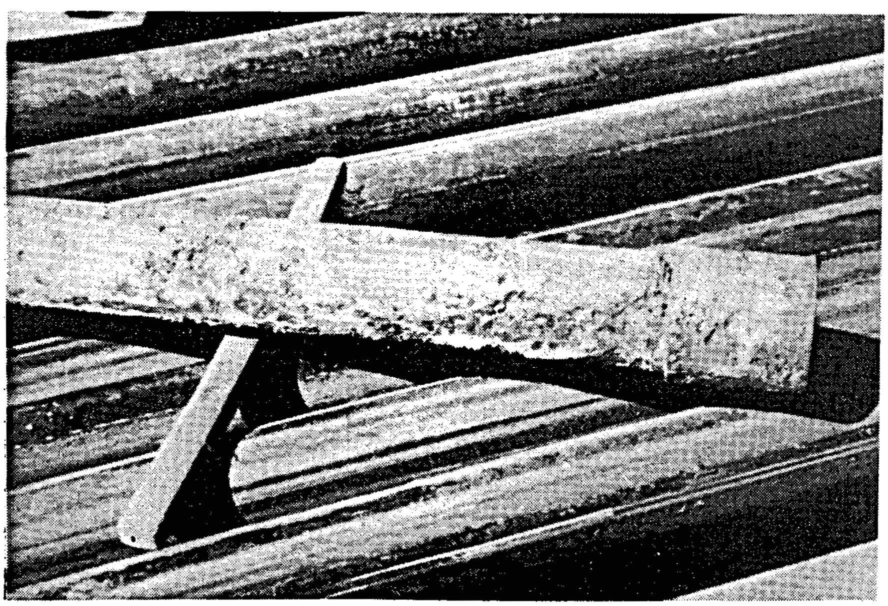
PHOTOGRAPH 5. Heat Exchangers at Mazama Mid High School



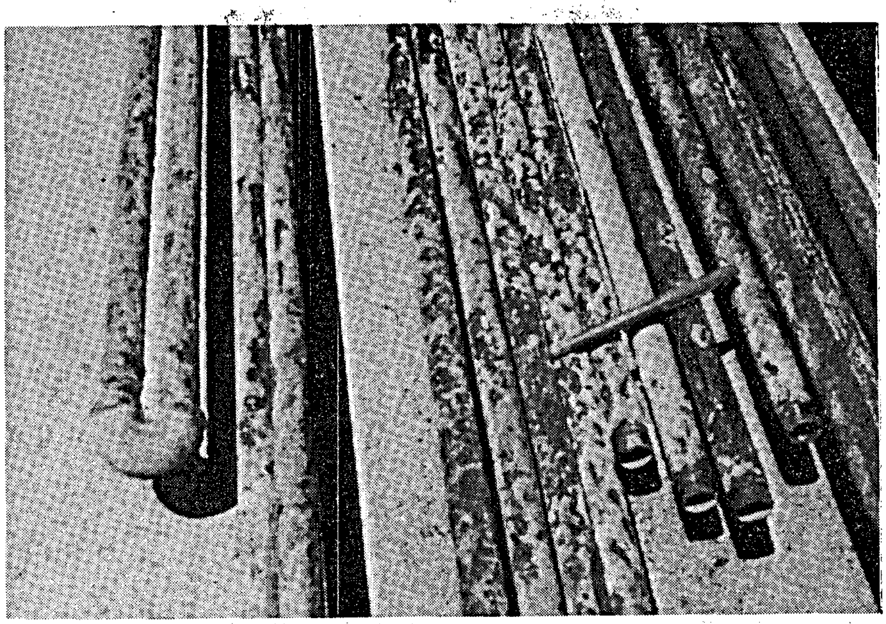
PHOTOGRAPH 6. Cutting Perforations in Well Casing



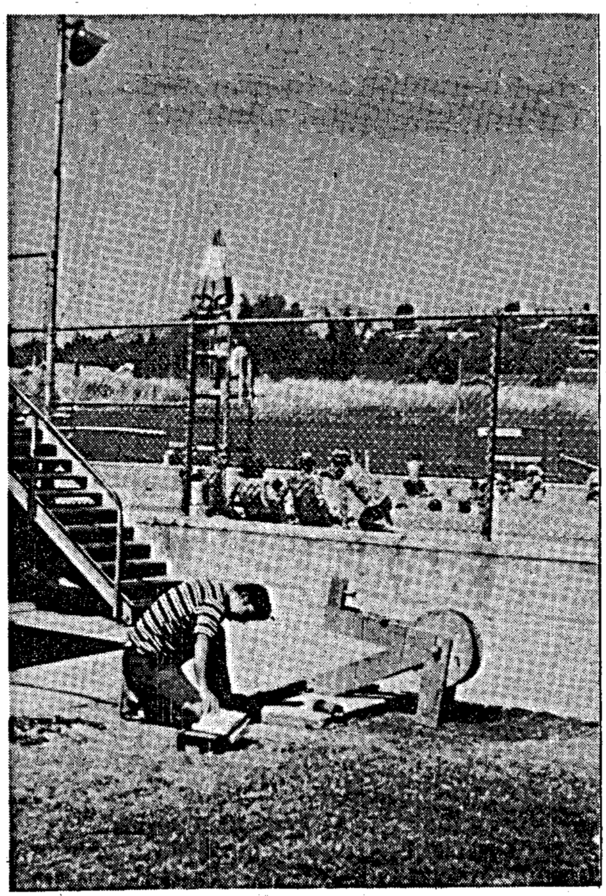
PHOTOGRAPH 7. Pulling Heating Pipes for Repair



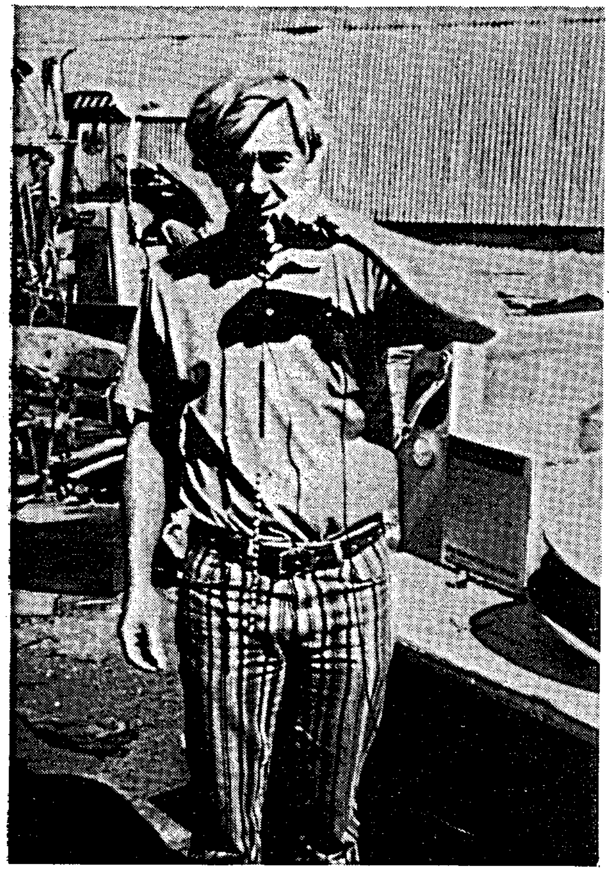
PHOTOGRAPH 8. Typical Heat Exchanger Pipe Corrosion



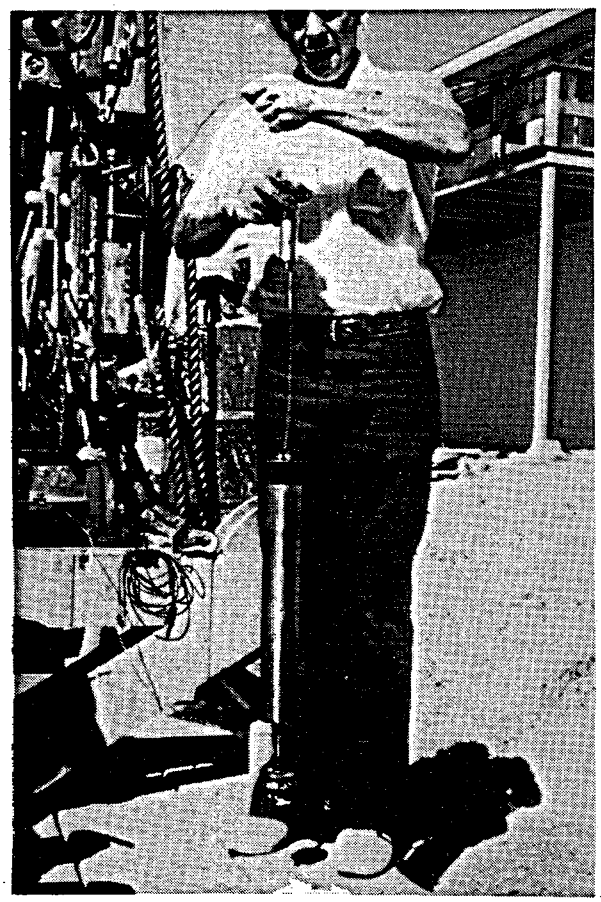
PHOTOGRAPH 9. Typical Domestic Water Pipe Corrosion Showing Reverse Bend



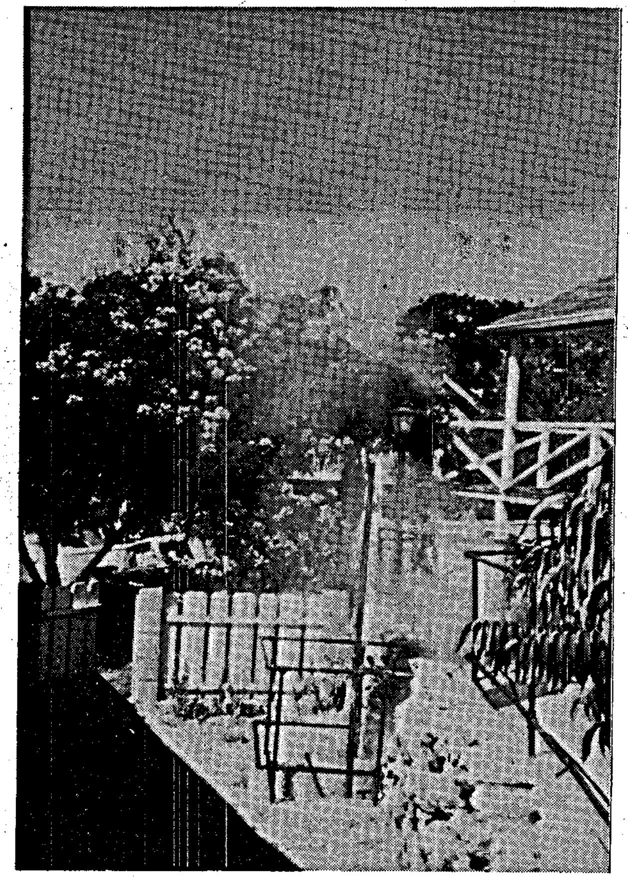
PHOTOGRAPH 10. Temperature Profiling of City Swimming Pool Well



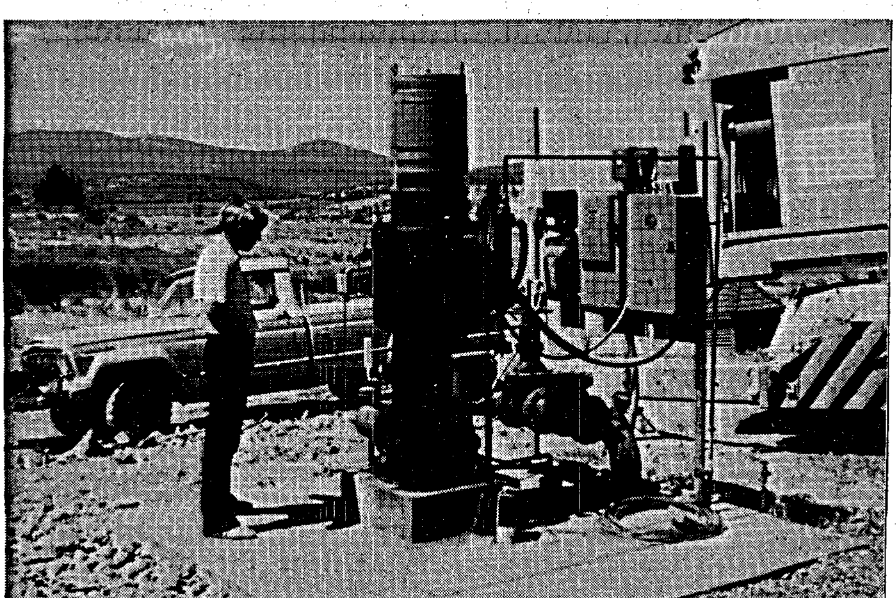
PHOTOGRAPH 11. Thermistor Temperature Probe with Lead Weights



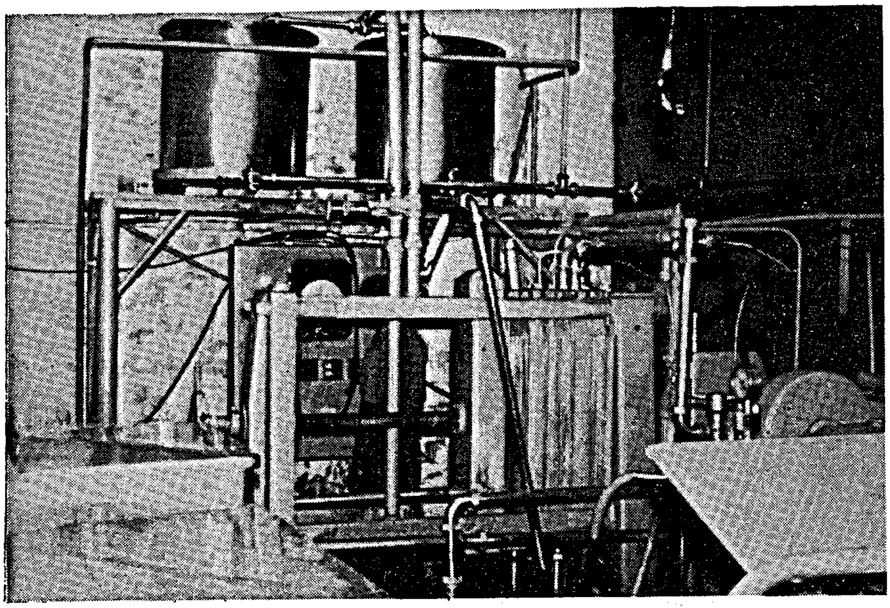
PHOTOGRAPH 12. Large Water Sampling Device with "Messenger" for Depth Sampling



PHOTOGRAPH 13. "Steamer" Well with Mimosa Tree on Hillside Avenue



PHOTOGRAPH 14. Oregon Institute of Technology Pump and Well Head



PHOTOGRAPH 15. Medo-Bel Creamery Pasteurizing Equipment

PHOTOGRAPH 16. CPI/Midtown Datsun Horizontal Heat Exchangers Using Waste Water

53,090

UTILIZATION OF THERMAL ENERGY AT OREGON INSTITUTE OF TECHNOLOGY KLAMATH FALLS, OREGON

By

W. D. Purvine[1]

ABSTRACT

The Oregon Institute of Technology campus was relocated in 1959 to make maximum use of potential geothermal hot water for space heating of approximately 440,000 square feet of floor space (40,900 square meters). Based on observations of early morning frost and snow melting, and conversations with local hot water well drillers, six wells were sited along a major fault zone adjacent to the proposed campus. Depending upon the exact location with reference to the fault line three cold and three hot water wells were located at depths from 1200 feet (366 meters) to 1800 feet (550 meters). The cold water wells produced water at approximately 78°F (26°C) and the hot water wells produced water at approximately 191°F (88°C), with the latter producing up to 750 gallons per minute (2839 liters per minute). The water is piped from the hot water wells and passed through forced air and hot water radiators within the buildings on campus. An average of 2.8 million BTU per hour (0.705×10^9 gcal per hour) with a maximum of 24.8 million BTU per hour (6.25×10^9 gcal per hour) is used for the campus, at considerable savings from the heating of the old campus using conventional fuels.

INTRODUCTION

The State Board of Higher Education was awarded a 1959 appropriation of $150,000 for use in exploration incident to the selection of a new campus for Oregon Institute of Technology. The old campus was a military facility. These funds were to be appropriately used in the overall master plan for the buildings and for the exploration to determine the availability of geothermal water for heating. Since the Board of Higher Education wished this to be a decision based on good information, a study was made as to the locations of hot wells, hot springs, faults, and other factors useful in determining a potential location. One of the things determined early was the existence of a broad faulted zone running from Ft. Klamath south of Crater Lake in Oregon to north of Alturas in northern California. At various locations along this broad zone there were hot springs and there had been some hot wells drilled. The fault zone seemed to be the source of the subterranean hot water which was surfacing at the hot springs and provided the source of the well water.

Well drillers were interviewed who had experience in the drilling of geothermal wells. All well drillers active in the locality were interviewed since we felt we should consult every source. These individuals testified from their experience as to surface indications and relationship to the fault as places where the wells were either warm or hot. The well drillers described the two different kinds of water found in the hot wells in and near the City of Klamath Falls. Some well water was corrosive so that iron or galvanized pipe would be eaten away in the waterline area.

[1]President, Oregon Institute of Technology

It was theorized that this water had been in contact with magmatic conditions. If Oregon Tech wells were corrosive in water content, a heat exchanger would be needed. Other well water was bland which brought opinions that it was normal ground water. The theory was advanced that this water was heated by contact with hot rock warmed by magmatic water. Thus, the rock was said to act as an underground radiator. Should Oregon Tech wells tap such a source, the water could be used directly through the heating system without heat exchangers.

In addition to conferring with the well drillers, a visit was made to the State Engineers Office for conferring with officers there who had information relevant to hot wells. That office had, at that time, a proof map of geological study that had been made by the U.S. Geological Survey which was there for suggested corrections. This seemed to indicate that the formations lying west of this generally north-south fault had been broken up by faults that trended to be north and south as well as east and west, so that it was more an area of faults than a single fault.

One of the surface indications that would lead us to surmise that hot well drilling might be successful was the occurrence of early-in-the-day melting of frost and of the rapid melt of light snowfalls. We looked around inspecting the possible places where a new campus could be located. We found that there were some areas where frost would be melted off by as early as 8:30 to 9:30 a.m., which was too soon for the sun to have had much influence in the melting of the frost. This was assumed to indicate that the soil had been warmed by subterranean waters. We discarded those areas where the frost would stay on until noon or later as unlikely to overlay hot water.

WELL DRILLING AND CHARACTERISTICS

Having made such preliminary studies over a period of time, we determined the locations at which we wished to drill test wells to determine the suitability of the selected area for a campus. The first well was drilled in an area which was west of but close to the major fault line, and we obtained a cold water well. This well was on the order of 1200 feet (366 meters) deep and provided a flow of approximately 510 gallons per minute (1930 liters p.m.) at 78 degrees F. (26 degrees C.) which was basic to a domestic water supply.

The next well was drilled further west and south within the projected borders of the new campus. This well was of approximately the same 1200 foot depth (366 meters) and produced hot water at 176 degrees F. (80 degrees C.). In use as a heat well, this particular well produced 170 gallons per minute (or approximately 643 liters per minute).

Well number 3 was drilled at a distance from the other two and turned out to produce only 35 gallons per minute (132 liters p.m.) of water at about 65 degrees F. (18 degrees C.), and was thus judged to be inadequate for any use to the campus. Well number 4 was drilled between well number 1 and well number 2. This one turned out to be cool at 92 degrees F. (33 degrees C.) and was utilized as the second domestic well for supplying the drinking, cooking, and irrigation needs of the campus. Wells numbered 5 and 6 were then drilled and produced good hot water at a temperature of

191 degrees F., or 88 degrees C. These were located on a plot just south of our first hot well; the one numbered 2. Five acres of additional land was purchased (just over 20,200 square meters). Data on each well is listed in Table 1.

Figure 1 indicates a typical hot water well section. This type of well was started with a drill bit of 12 inches or 30.5 centimeters in diameter and was drilled for several hundred feet until a hard layer of lava was entered. The well casing of the 12 inch size (30.5 cm) was inserted against this rock and a packing was made that would stop the flow past it. A grout seal consisting of cement was poured around the casing to rest against the packing. The drill bit size was reduced to 10 inches (25.4 centimeters) and the drilling continued going down through various layers of chalk rock (tuff and diatomite), dense lava, clayey tuff, broken lava and cinders, and other layers. At a suitable point, the well diameter was again reduced now to 8 inches (20.3 centimeters). Finally, hot water was found in a broken lava and cinders layer. Most of these wells were drilled through a water table level of cool water which was in the order of 73 degrees F (23 degrees C.).

Figure 2 presents a cross section of the area in which the OIT campus is situated. The Upper Klamath Lake is shown in this area and faults that occurred near by are illustrated. The water table goes across at an approximate elevation of 3800 feet above sea level (1158 meters). The campus elevation is about 4100 feet above sea level (1250 meters). At the campus we then locate these wells which is well number 1, the cold well which was drilled slightly upgrade from the others, and in penetrating the soil crossed what we assumed to be the fault zone and penetrated into the foot wall of the fault. Well number 5 which is one of the deepest on campus is next and its penetration to over 1700 feet (about 523 meters), as illustrated in Figure 2. The well more recently drilled by the Presbyterian Intercommunity Hospital then is at this other location further west and was drilled to a depth of 1584 feet (483 meters) and had water of 196 degrees F., on test (91 degrees C.). Pumping tests lead us to believe that the hospital well is in the same hot water pool as are the Oregon Tech wells.

DISTRIBUTION AND HEATING

Figure 3 locates wells numbered 2, 5, and 6 in relation to the campus as a total. The water is piped from the wells through the building that was to be a heat exchanger building where it enters a settling tank for the removal of sand. It then follows a main pipe line past the residence hall out to the administration building, Snell Hall, and is distributed throughout the buildings on the campus. The residence hall is heated with hot air circulation in the corridors from a mechanical room in which a central unit is located where the hot water is run through large radiation with air fans providing forced air circulation. But it also has hot water radiators in the individual rooms. Several buildings, Snell Hall, the Library-Commons, the P.E. Building, Owens Hall, and Semon Hall are all heated by forced air from a single central unit in which the hot water heat is transferred to the air by radiators and ducted to the rooms. Unit heaters are utilized mounted high up for general circulation in Cornett Hall and in the Warehouse. The thermal water is used for heating the domestic hot water utilized in Semon Hall, Owens Hall, the Residence Hall, the P.E. Building, and in the Commons. However, in the Commons, due to the need for hotter water than would be produced from our geothermal sources, a small booster boiler is supplied to produce water of higher heat. When the thermal water has been reduced to a temperature of approximately 125 degrees F. (52 degrees C.), it is released at the discharge point of the system. This is where it flows over the land surface and down to Klamath Lake.

Figure 4 shows the pump and electric motor within the well housing at well number 2. The Residence Hall is in the background to the right. This illustrates the change made from the top unit sitting in a pit, to a better ventilated installation. This helped to avoid electric motor burnouts and rusting.

Figure 5 shows the well head with the housing removed so that the pump and piping and the control panel are available for view and pipe for the well, the water column is in the foreground.

MAINTENANCE

Figure 6 stays with well number 2 where the periodic maintenance procedure is shown in progress. The pump motor and well head have been removed and in the foreground we see the water column and pump shafting exposed. These have been withdrawn from the well and the piping part of the water column is what is used for bringing the water to the surface. The shafting is in the center of the column and carries the power of the electric motor down to the submerged pump which is located 550 feet (167 meters) below the surface. The pump drive shaft going down the center of the column is screwed together at each joint and therefore suspends the impeller of the centrifugal pump at the end of the column. The problem of keeping the bearings lubricated on the well shafting and in the impeller of the pump was solved by the introduction of a lubricant other than the water. As we started our operation of this heating system, the theory was that, as in other wells, a submersible pump and the pump line would be adequately lubricated by the flow of water. We found that hot water did not supply the same lubrication as cold water and therefore the providing of a petroleum lubricant was essential.

Figure 7, in addition to showing the well column, displays the submersible pump cylinder which is the last item to be withdrawn from the well. It lies in the foreground and its configuration shows that the pump impeller is divided into numerous segments. Each one of these segments has provision in it for the change in length of the pump drive line which occurs as the well shaft is heated to pumping. The allowance for this heat expansion is 5 1/2 inches, or 14 centimeters. As the pump starts up with the drive line cold, the impellers are at the upper end of each one of the cells or pump stages. As the shaft expands, the impellers are at the lower part of the pump stages. This is an essential specification. Visible to the right in this slide are the rear wheels and bed of a well rig which has been hired to carry on the job of preventive maintenance through pulling the well column, the pump rod and the pump unit out of the well for inspection and repair.

Figure 8 shows the well rig truck and the assembly for pulling the well column out of the well for maintenance. As the pipe column and the drive shaft are quite heavy, the equipment must be sturdy. Care is exercised to avoid dropping this column and shaft into the well. Periodic inspection is required to maintain reliable operation.

Figure 9 is taken from a greater distance to show well number 2 and the building that was expected to be a heat exchanger. It now contains an oil fired standby boiler in the case of well breakdown. The buildings of the entire campus are visible from the well site.

Figure 10 shows the discharge of the spent water from the heating system. Here, at the outlet to the surface, this figure taken of the water on a cold morning clearly showing the warmth remaining in the 125 degree F. (52 degrees C.) water.

COST AND UTILIZATION DATA

The geothermal heating system at the Oregon Institute of Technology is now a valuable operation. Our costs range from $12,000 to $14,000 per year to heat over 440,000 square feet (40,900 square meters) of building floor space. As a small school on the old campus, the cost was $94,000 to $100,000 per year at pre-inflation prices. The various kinds of adjustment that needed to be made in order to gain reliability in the operation of the equipment have been made. The original electric motors had insufficient ventilation and, therefore, we were troubled with burned out motors. In the beginning, these were set down in a sump and later on we found it necessary to raise them above the surface and to build housing, as you have seen, for improving the ventilation and to protect the equipment from vandalism. At first there were some troublesome periods during which the standby boiler was required. This has not been necessary during the past six years.

As friendly neighbors of the Presbyterian Intercommunity Hospital, the findings that we have made in the design of the pump bowl and in the installation of the column and the electric motor have been made available so that their installation would be successful. Our experience in this matter has shown us that, as in all things in technology, there are needed technological data that must be gathered and utilized in solving the problems. Normal heating needs are satisfied by hot water from only one of the three wells, with up to two being used during extreme cold weather (below 0°F (-18°C) temperatures) The third well is used for standby, and allows maintenance to be performed without interrupting the usage. Major repairs are required on the average every five years for each well/pump system. Presently maintenance is being performed every three years on each well to prevent major breakdowns. Using all three wells, a maximum flow of 750 gallons per minute (2,839 liters per minute) can be used. In terms of British Thermal Units (BTU) our average use has been at 2.8 million BTU per hour (0.705 x 10^9 gcal/hour). The potential available BTU between 191 degrees F., and 125 degrees F. (88 and 52 degrees C.), at pumping maximum is 24.8 million BTU per hour (6.25 x 10^9 gcal/hour), about ten times present use in cold weather. We feel now that it is successful and are pleased to find that a new kind of heating utilization has been made possible.

Table 1

OREGON INSTITUTE OF TECHNOLOGY
Well Data (1963)

Well Number	#1	#2	#3	#4	#5	#6
Surface Elevation	4,585±	4,409±	4,400±	4,450±	4,429±	4,429±
Depth	1,205 ft.	1,288 ft.	1,150 ft.	1,224 ft.	1,716 ft.	1,800 ft.
Dia. 14"	---	439 ft.	---	730 ft.	480 ft.	416 ft.
12"	---	---	---	295 ft.	335 ft.	432 ft.
10"	700 ft.	361 ft.	700 ft.	199 ft.	294 ft.	302 ft.
8"	505 ft.	488 ft.	450 ft.	---	607 ft.	650 ft.
Static Water	449 ft.	332 ft.	110 ft.	315 ft.	358 ft.	359' 4"
Maximum Volume Pumped	510 GPM	107 GPM	175 GPM	400 GPM	442 GPM	250 GPM
Temperature						
(pumped 1963)	78°	176°	65°	92°	192°	146°
(pumped 1974)	78°	191°	(abandoned)	92°	191°	191°
Level Pumped	532 ft.	550 ft.	355 ft.	550 ft.	393 ft.	540 ft.
Use	Dom. & Irrig.	Dom. Heat	Dom. & Irrig.	Dom. & Irrig.	Dom. Heat	Dom. Heat
Casing Used:						
12"	---	441' 3"	---	733' 0"	530' 3"	416' 4"
10"	---	---	---	315' 6"	814' 6"	867' 6"
8"	686' 0"	803' 0"	705' 7"	207' 7"	318' 6"	294' 6"
6"	544' 10"	515' 0"	---	---	648' 1"	677' 8"
Cost of Drilling	$10,038.00	$11,082.50	$ 7,418.00	$15,317.75	$20,322.50	$21,466.50
Cost of Testing	2,076.00	3,425.00	1,325.00	1,750.00	1,750.00	2,000.00
Cost of Casing	4,836.12	7,592.00	3,012.87	5,939.32	9,180.00	8,816.74
Total Cost	16,950.12	$22,099.50	$11,755.87	$23,007.07	$31,252.50	$32,283.24

SECTION OF AN O.I.T. GEOTHERMAL WELL

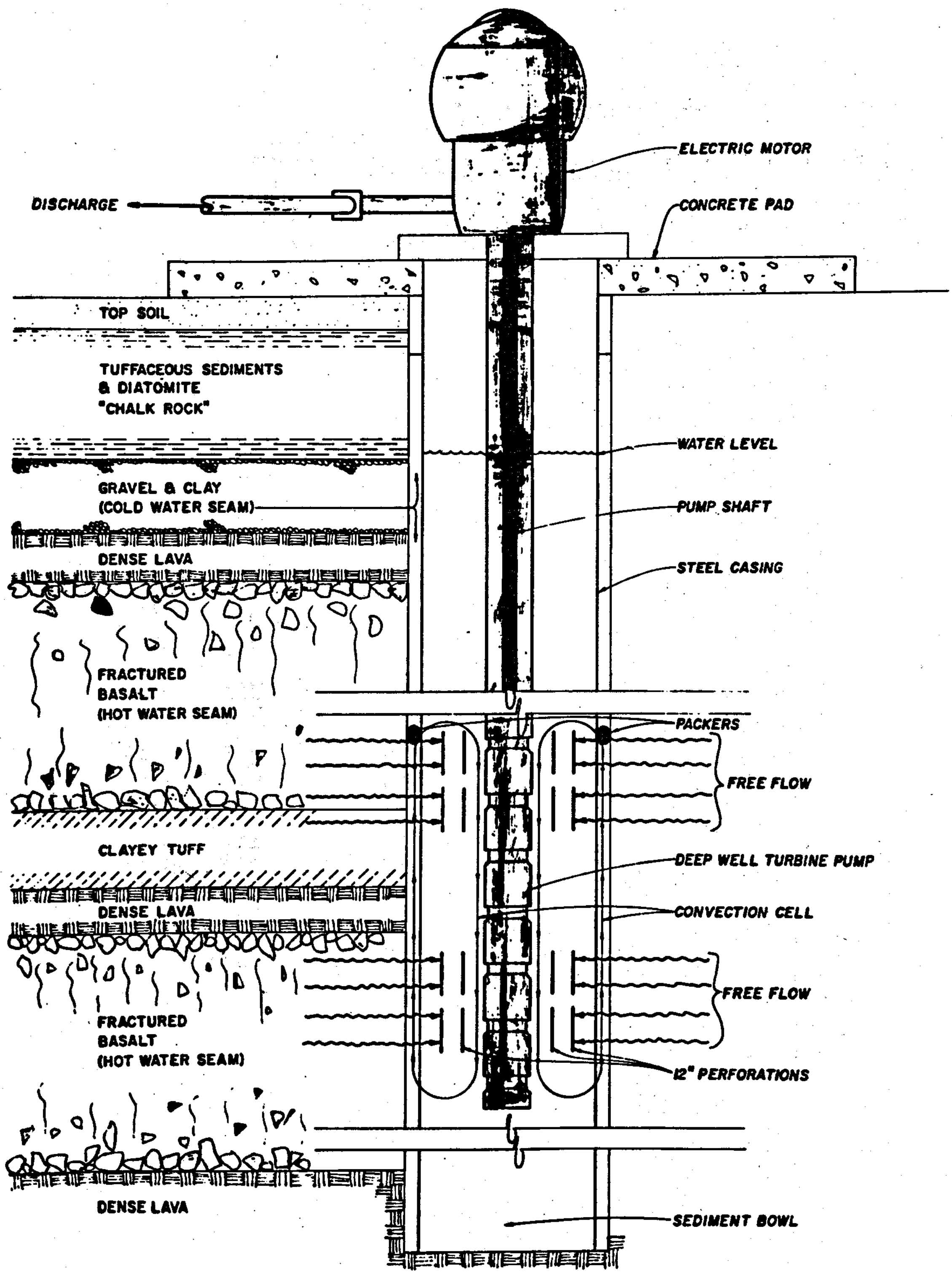
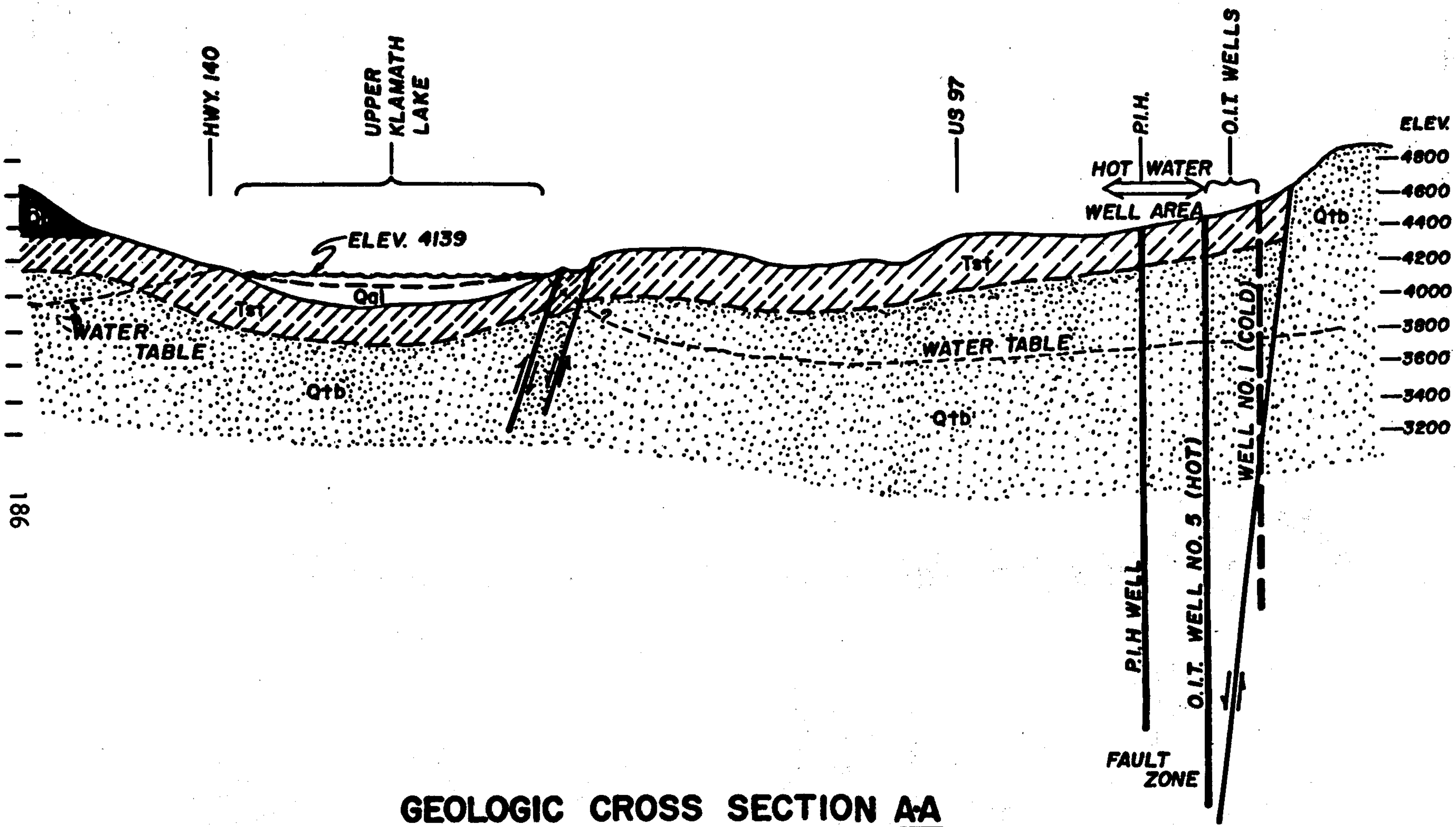


Figure 1. Section of an OIT Geothermal Well



GEOLOGIC CROSS SECTION A-A

VERTICAL SCALE: 1" = 800'
HORIZONTAL SCALE: 1" = 2000'

Figure 2. Geologic Cross Section Through the OIT Hot Water Well Area

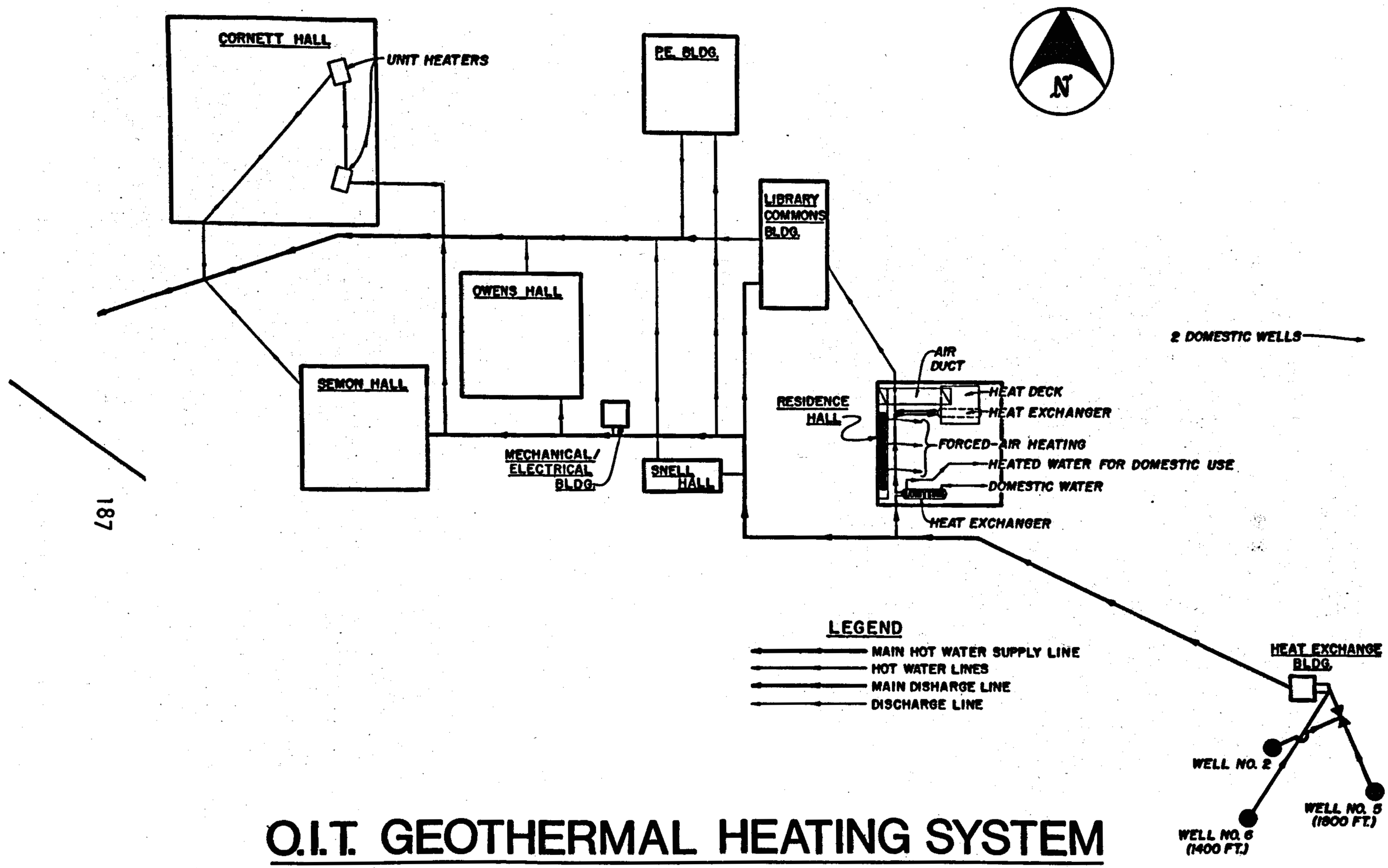


Figure 3. OIT Geothermal Heating System

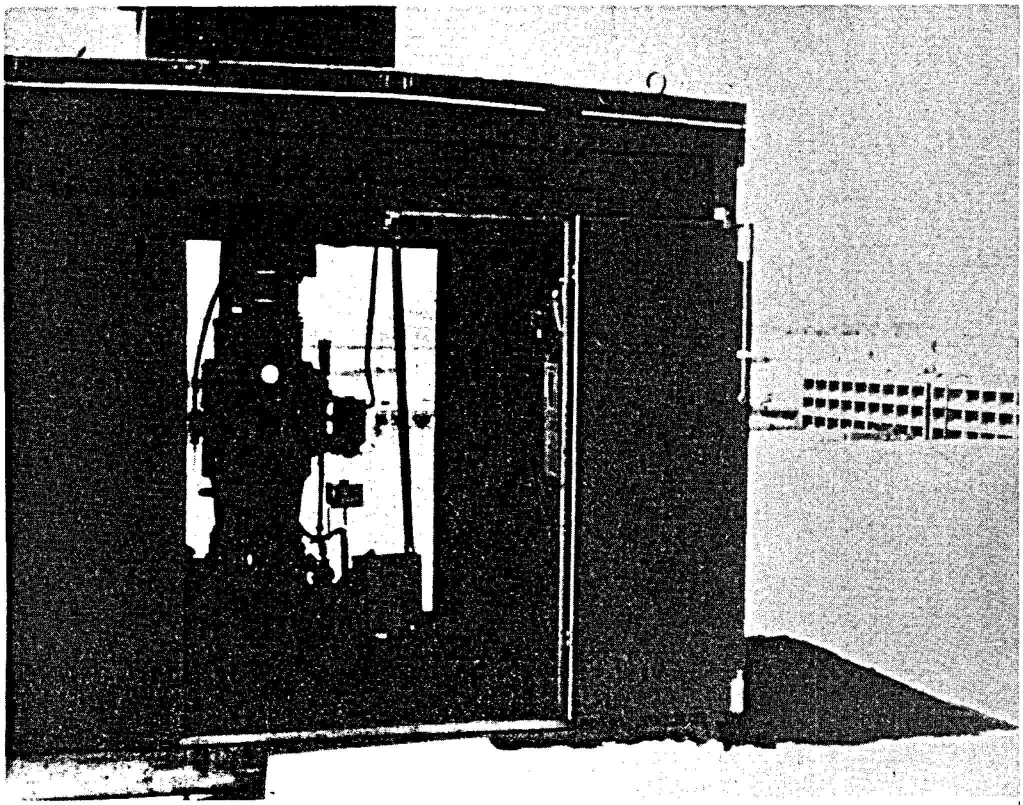


Figure 4. Pump and Motor at Well No. 2

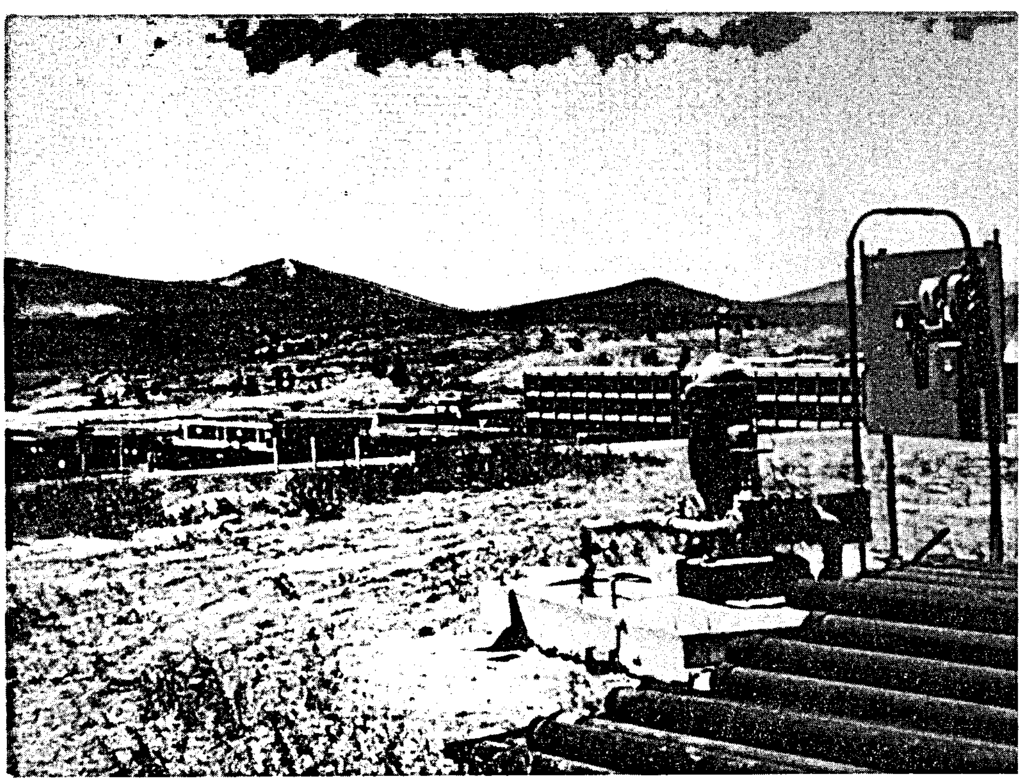


Figure 5. Well head, pump, control panel and piping

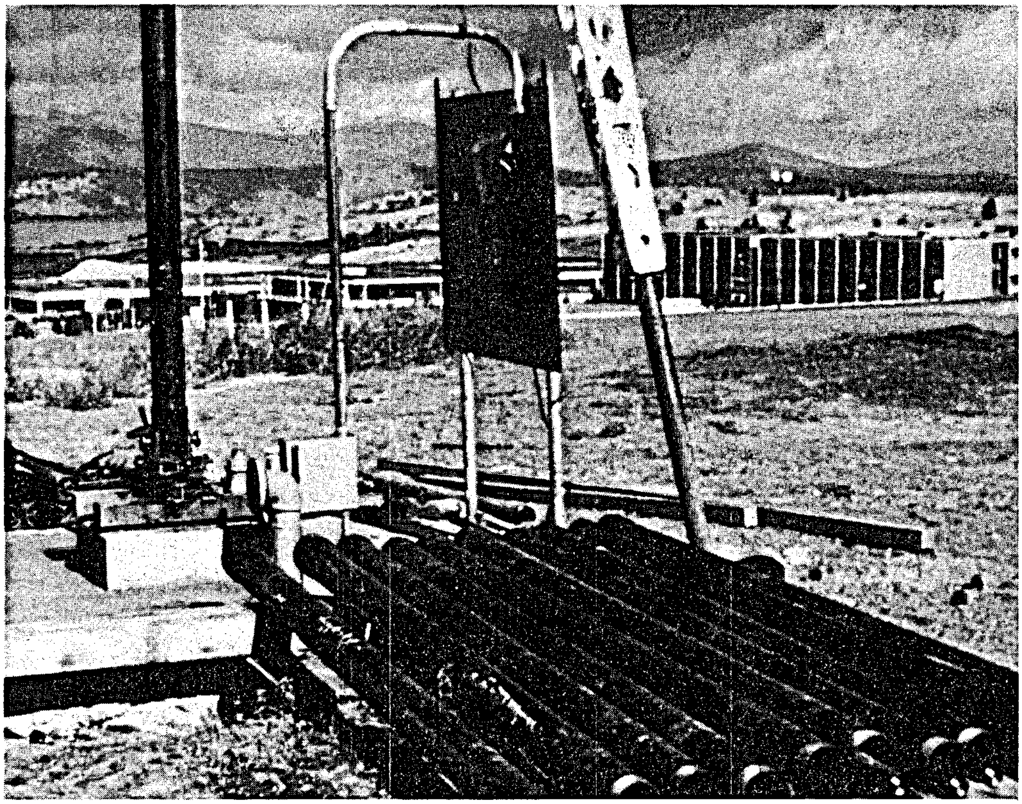


Figure 6. Well No. 2 during maintenace

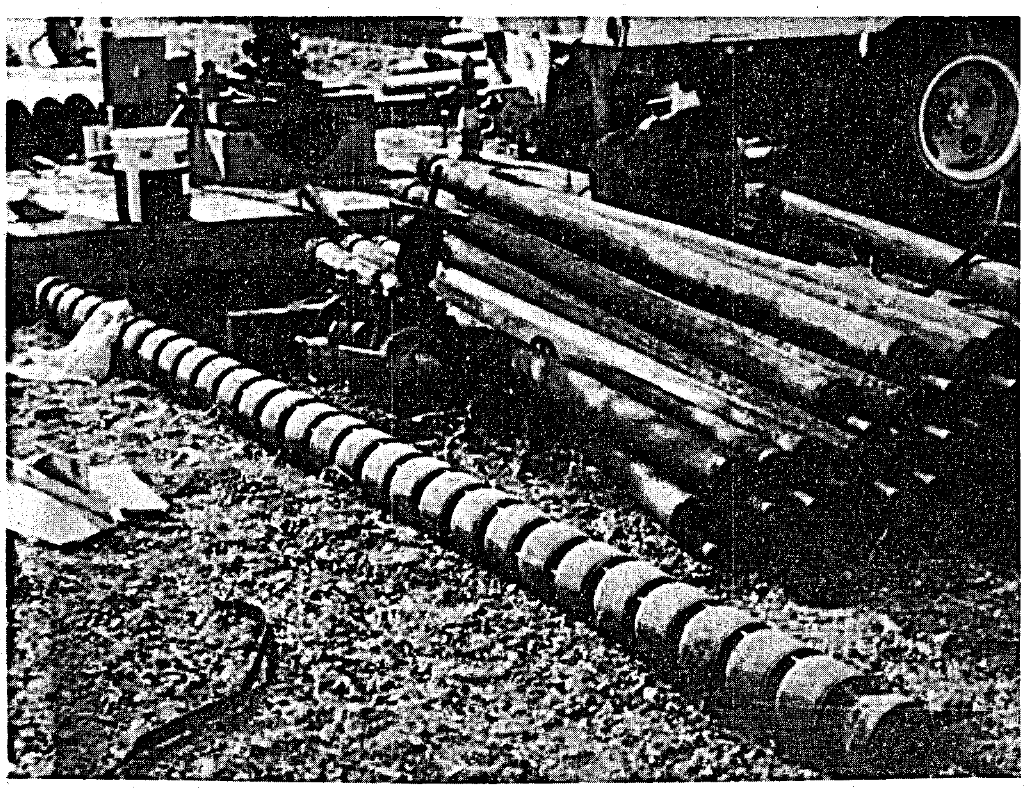


Figure 7. Close up of well column and submersible pump

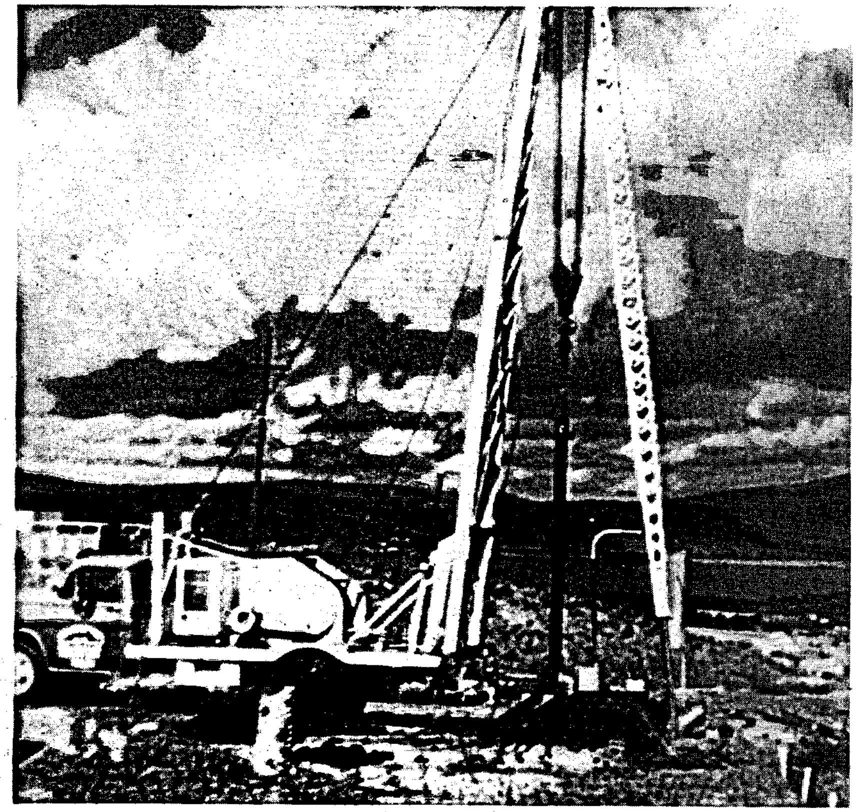


Figure 8. Well rig truck used to pull well column during maintenance

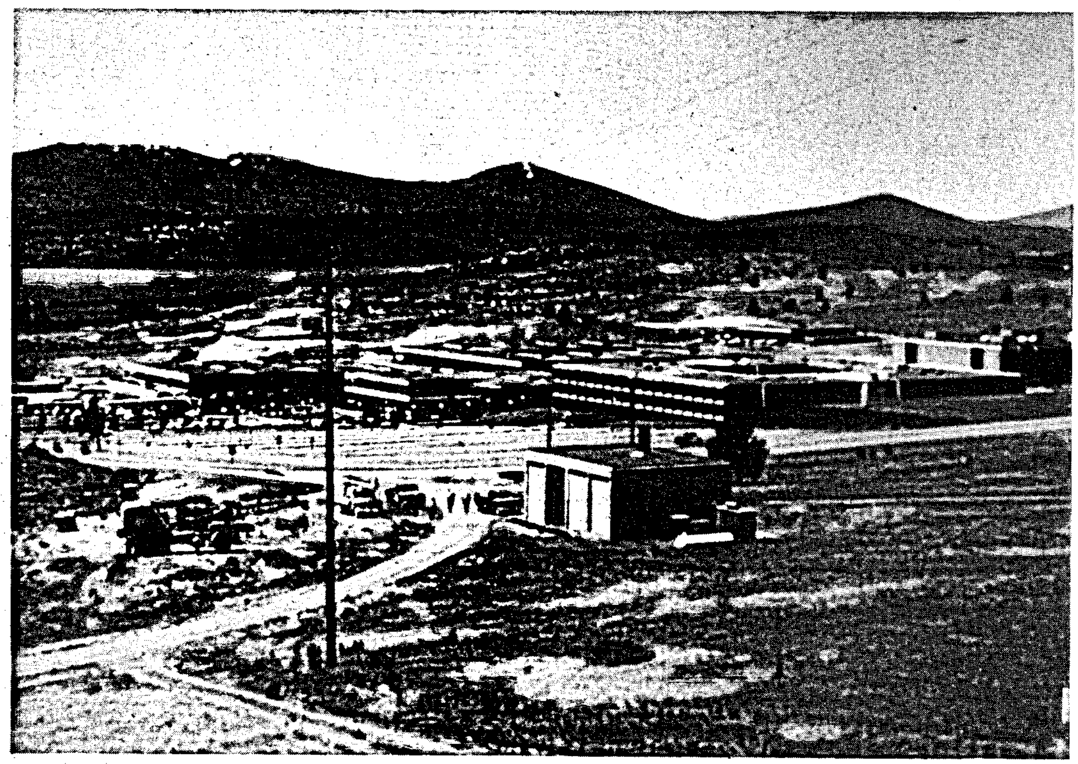


Figure 9. Well No. 2 and building housing standby oil boiler and sediment tank

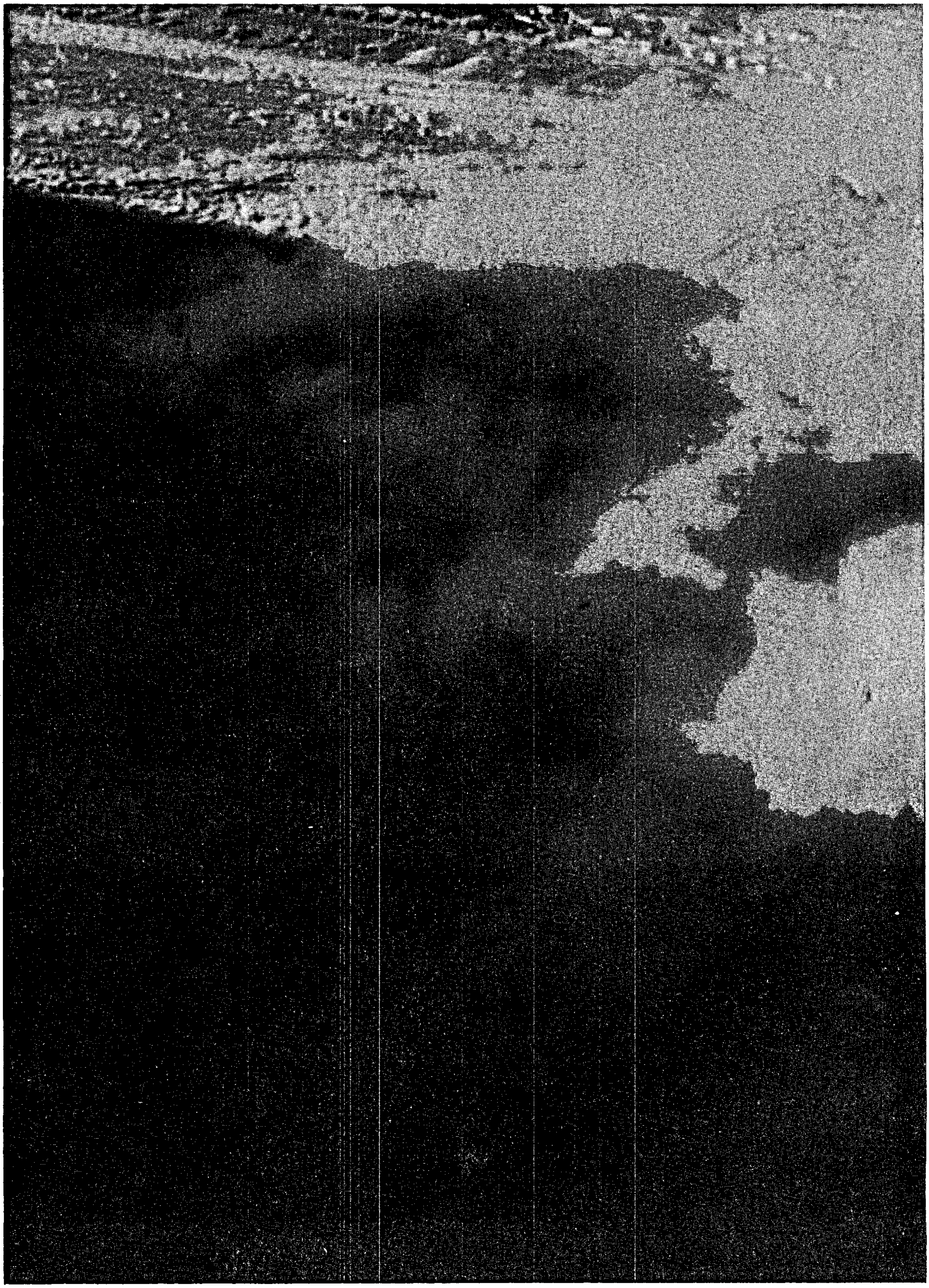


Figure 10. Spent water discharge

GEOTHERMAL DRILLING IN KLAMATH FALLS, OREGON

By

David M. Storey[1]

ABSTRACT

Geothermal well drilling in Klamath Falls is done by two methods, the percussion or cable rig and the air-rotary method. The air-rotary method is faster, however causing difficulties in the disposal of drilling cuttings and making temperature logging less accurate. The cable rig is preferred. Numerous commercial and residential wells have been drilled in the area varying from 150 to 1805 feet (46 to 550 m) in depth. The larger commercial wells in most cases pump the well water due to the large heat demands, whereas the residential wells use down-hole heat exchangers. Well construction includes casing the well with perforation in the casing to allow hot water circulation, and using wax at the water line to reduce the corrosion of the heat exchange pipes. Costs for residential wells range from $3,000 to $10,000, with commercial wells as high as $30,000.

HISTORY

The earliest log or record we have of hot water well drilling in the Klamath Falls area was in 1936. My father remembers hot water being drilled for as early as the 1920's. Not all drillers kept logs at that time and many of these have been lost. The state now requires a log to be sent to the State Engineer for every well drilled. My father started drilling hot water wells in 1946 when he first started his drilling business.

TYPES OF DRILLING RIGS

Air Rotary

The drilling of geothermal wells in the Klamath Falls area is done by two methods. The most widely used is the percussion or cable rig. The other method used is the air-rotary. This latter method uses a rotary machine by which the use of large air compressors force a large volume of air down the drill pipe to bring the drill cuttings to the top of the ground.

The air-rotary method has various advantages and disadvantages compared to the percussion method. It is 10-20 times faster than the cable rig. Where a cable rig will only drill one to twelve feet (1/3 to 3 1/2 m) per eight hour shift, the air-rotary will drill five feet (1 1/2 m), or better per hour! Formation changes can be detected much more accurately with the air-rotary.

The disadvantages of the air-rotary are: a) greater danger of getting burned from the hot water because the air from the compressors makes the water flow erratic as it is blown out of the hole; b) most of the drilling is done in residential areas where space is limited, therefore it is

[1]Klamath Falls, Oregon, Well Driller

difficult to construct a pit to confine the water and cuttings which come out of the well; c) transporting these effluents away from the well fast enough to keep up with the flow rate is cost prohibitive to the well owner; and d) accurate temperatures in the course of the drilling procedure cannot be kept when drilling with the air-rotary.

The air-rotary method has been used to start wells and continue down to a depth where the water becomes a problem to dispose of, or the temperature rises above scalding. A cable rig is then moved in to finish the well.

Straight Rotary

A straight rotary rig is one which circulates mud to remove the drill cuttings from the hole.. Although a straight rotary rig has never been used in local geothermal drilling, it would not be practical. There is no way to keep track of water temperatures encountered in the different aquifers as the drilling progresses. Also the mud being circulated in the well will cool any water encountered. Small stratas of water could be passed as the mud can cake them off. A flow of 2 to 30 GPM (8 to 114 liters/minute), or a combination of these small stratas, can yield a geothermal well, making them very important in the final completion of the well. Here again, because of the confinement of space there is very little room to construct a mud pit out of which to circulate mud.

The important thing in drilling these geothermal wells is being able to record accurately minute changes in water temperatures and water flows as the drilling proceeds. In addition, cold water flows have to be cased or cemented off, thus also requiring very accurate temperature records to be kept.

Cable Rig

The old-fashioned cable rig is still the best and most accurate for drilling hot water wells in this area. We are able to accurately determine the stratas of water, large or small, hot or cold, which is impossible to do with any rig. Exact temperatures can be taken in the hole at each strata of water. Less room is needed for equipment, less material is emitted from the hole, and cuttings can be hauled away at a more reasonable rate and cost. The main disadvantage of the cable rig is the slow rate of drilling in the hard basalt rock encountered in these geothermal areas.

COMMERCIAL WELLS

The construction of geothermal wells can be classed into two types of wells; those serving commercial facilities and those for residential use.

Commercial wells are used for heating large buildings in Klamath Falls, such as: (see map)

1. City School District Shops
2. Ponderosa Junior High School
3. Mazama Mid-High School
4. Boy Scout Building

5. Ponderosa Nursing Home
6. Main Fire Hall Station
7. Specialized Service (no longer in use)
8. Balsiger Motor Company
9. Municipal Swimming Pool
10. Several large apartment complexes (Main Street Apartments, Roosevelt Apartments)
11. Asphalt Paving
12. Presbyterian Intercommunity Hospital
13. Oregon Institute of Technology (three hot and two cold wells)
14. Mills Elementary School
15. Roosevelt Elementary School
16. Klamath Union High School swimming pool
17. Calhoun's Floor Covering
18. Doctors Clinics (several)
19. Klamath Ice and Storage. Here geothermal well water is used in a very practical way. After the ice is frozen in cans, the can is dipped in the geothermal water and the ice is released to be packaged and sold.
20. State Highway Department. Here geothermal water was put to a very unique and modern use. Heating coils were laid under the concrete paved roadbed so that during the winter no ice or snow will slow or stop traffic at the Esplanade underpass.
21. Medo-Bel Dairy. Who advertise as the only dairy using geothermal heat in their milk processing. Geothermal energy is used to heat the building and more importantly to pasteurize the milk delivered to Klamath Basin residents. The water flows at a constant 180°F (82°C), but the pasteurization process killing harmful bacteria is accomplished at 166°F (74°C).

Because of the large demand for heat for these commercial establishments, the water is actually pumped from these wells. The size of the wells are from 10 to 14 inches (25 to 35 cm), and the amount of water pumped is from 25 to 400 GPM (95 to 1514 liters/minute). Due to the size of the area to be heated, Oregon Institute of Technology is pumping the highest volume of water.

The geothermal commercial well is constructed approximately the same as any other large well with the exception of installing casing. A string of casing may have to be set in the hole and cemented in to case off a flow of cold water.

After the water is pumped from the well it is run through radiant radiators or forced air radiators. In some buildings the hot water is pumped through coils in the floor. After the water is used and has lost its heat, it is disposed of in the city storm drains. In the case of O.I.T., it is drained into Klamath Lake.

Some commercial buildings, public schools, apartment buildings, and nursing homes use coils in the well. The coils provide a source of heat transfer. This type of heating is also used in residential heating on a smaller scale.

The depths of commercial wells will vary from 400 to 1805 feet (122-550 m). The deepest well is at O.I.T., well number 6 at 1805 feet

(550 m). In starting the geothermal well the estimated final depth and temperatures to be reached are never known until the well is completed. In other words, the well next door or across the street may have entirely different drilling formations and temperatures. The reason for this being the broken stratas, faulted areas, and dikes that underlay these geothermal areas. A good example of this would be the wells at Oregon Institute of Technology and Presbyterian Intercommunity Hopsital. These seven wells are all within less than a quarter of a mile of each other, ranging from depths of 1,150 feet to 1,805 feet, with four hot wells, and three cold wells.

RESIDENTIAL WELLS

Residential wells will vary from 150 to 1,000 feet (46 to 305 m) in depth. They consist of drilling a 10 inch (25 cm) diameter hole to a depth where "live" or moving hot water is encountered. This hot water ranges anywhere from 140 to 250+ degrees farenheit (60 to 121°C). "Live" or moving hot water is necessary for a successful hot water well. High temperatures from drilling mud only in a well, are not sufficient to maintain the high temperatures needed.

Drilling does not cease until the temperatures in the bottom of the hole are 200+ degrees Farenheit (93°C). Temperatures of the water and hot mud are logged throughout the drilling of the well. A temperature is taken at the top of the water standing in the well, and one at the bottom of the well at the beginning of every shift. If a good flow is encountered, several temperature readings are taken at different levels during the day as the drilling proceeds.

Most residential wells have 8 5/8 inch (22 cm) OD casing installed to the bottom of the hole to accommodate two inch coils (5 cm), to accommodate large amounts of super heated water, and to reduce electrolysis on the coils. When the drilling has ceased it is determined where to perforate the casing. Depending on the well, the casing is perforated approximately ten to fifteen feet (3 to 4 1/2 m) under the static water level for a distance of twenty feet (6 m) and also the bottom twenty feet (6 m) of the casing is perforated. The perforations cause a thermosyphoning effect with the hot water. The cold water drops down through the casing to the bottom and the hotter water rises on the outside of the casing. The thermosyphoning effect of the water will raise the top temperatures of the water in the well after the casing is installed from ten to seventy degrees Farenheit (5 to 39°C). By perforating the casing and causing the thermosyphoning effect, the efficiency of the well is greatly increased.

The next step in construction is to set two strings of two inch (5 cm) steel coils in the well to a depth determined by the depth of well and water temperatures. The set of coils are connected at the bottom by what is called a mudleg. This consists of a two inch (5 cm) close return with a short two inch (5 cm) pipe welded on the bottom of the return. This is a catch-all for rust and corrosion in the two inch (5 cm) pipe when it is in service.

This type of a system is a closed return system. City water is used to flow in the coils in the well. As the heat is needed, the water is moved through the coils by a circulating pump. The water is circulated down through the coils and as it comes out of the well it is run through radiant radiators or forced air radiators which in turn heat the house. After the water has passed through the heating system, it is returned to the well to start another cycle. Through a series of valves and mechanisms, as the superheated water is used and some is lost through evaporation, automatic pressure gauges replace any lost water in the system.

It is important to know that in residential wells, or whenever possible, the actual water in the hot water well is not used due to its corrosive characteristics.

The popular types of heat exchange systems for residential wells are baseboard heating, coils in the floor or ceiling, and forced air radiant heating.

Domestic water which would replace electric or gas hot water heaters can be obtained in a number of ways from a hot water well. A three quarter inch (2 cm) coil is installed down the well alongside the larger two inch (5 cm) coils. Another method is tapping into the two inch (5 cm) coil and using that water. An alternate method is using a side-arm heater which is a tank and works on the same principal as a hot water heater.

DRILLING FORMATIONS

The formations drilled through to reach these geothermal stratas consist of shales and clays to hard basalt rock. Hot water is usually found in a strata of broken gray shale and creviced black or gray basalt. Usually the basalts are very hard.

HOW HOT WATER IS HANDLED

Precautions must be taken in drilling geothermal wells. One drop of hot mud or water will penetrate several layers of clothing. When bailing the well to remove the cuttings, if temperatures of mud or water are 215 degrees Farenheit (102°C) or above, great care must be taken in bringing the bailer to the ground surface. The bailer is held below the static water level for a period of five to thirty minutes for the mud, water and cuttings to cool. If the bailer is brought to the surface too rapidly, the mud and cuttings will explode out of the bailer. In new home construction or if drilling where mud and drill cuttings cannot be dumped into a holding pit, they must be hauled off in barrels to a landfill. Fences and retaining devices must be employed to protect spectators.

COMPLETION TECHNIQUES

In some cases, the geothermal water is very corrosive. When this condition is encountered, copper sections or double strength pipe are installed in the coils at the waterline.

There is a minimum amount of up-keep to hot water wells. To help prolong the life of the coils at the corrosive waterline, twenty or more pounds (9 kg) of candle wax may be placed in the well every year. This coats the coils and protects them from the corrosive water. Every three to twenty years, again depending on the individual corrosive action and electrolysis of water on the coils, the coils will need replacing.

COST

The cost of a residential geothermal well ranges from $3,000 to $10,000. A commercial geothermal well will cost up to $30,000 or more. In considering the economical value of a geothermal well compared to gas, oil, or electric heating systems, the cost must be compared over a period of five to ten years for a residential well, and fifteen years for a commercial well.

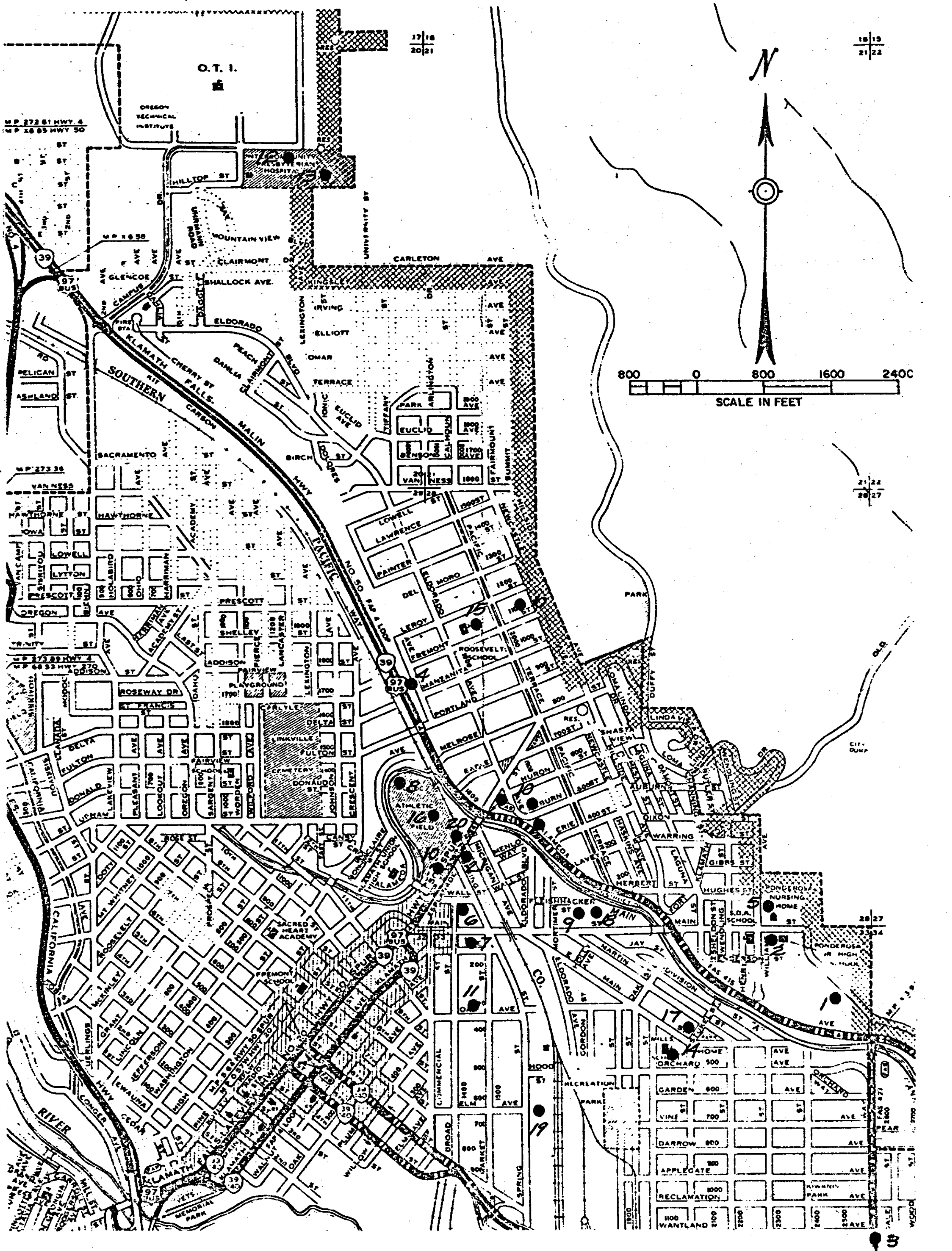


Figure 1. Location of major commercial uses of hot water in Klamath Falls

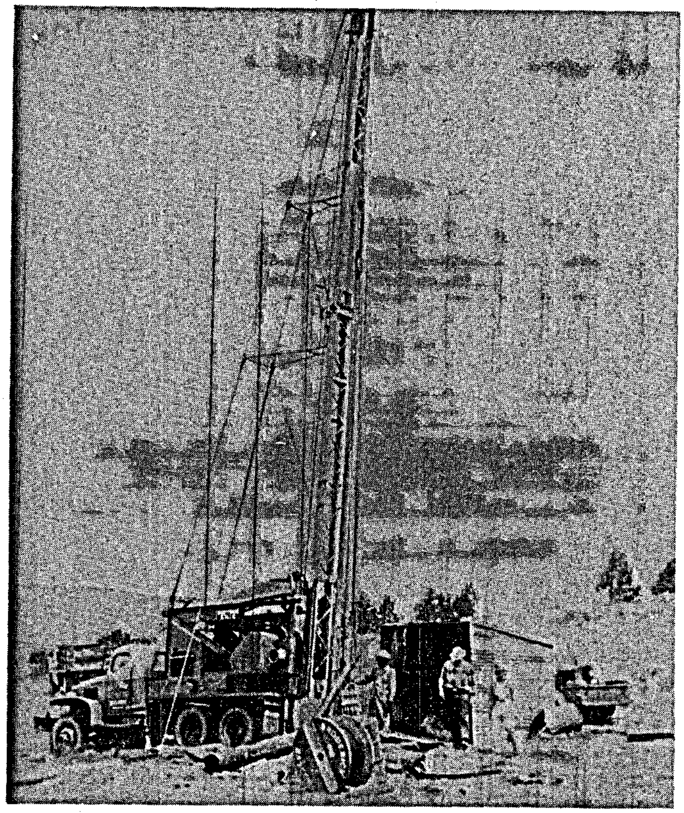


Figure 2. Cable drilling rig on the OIT campus

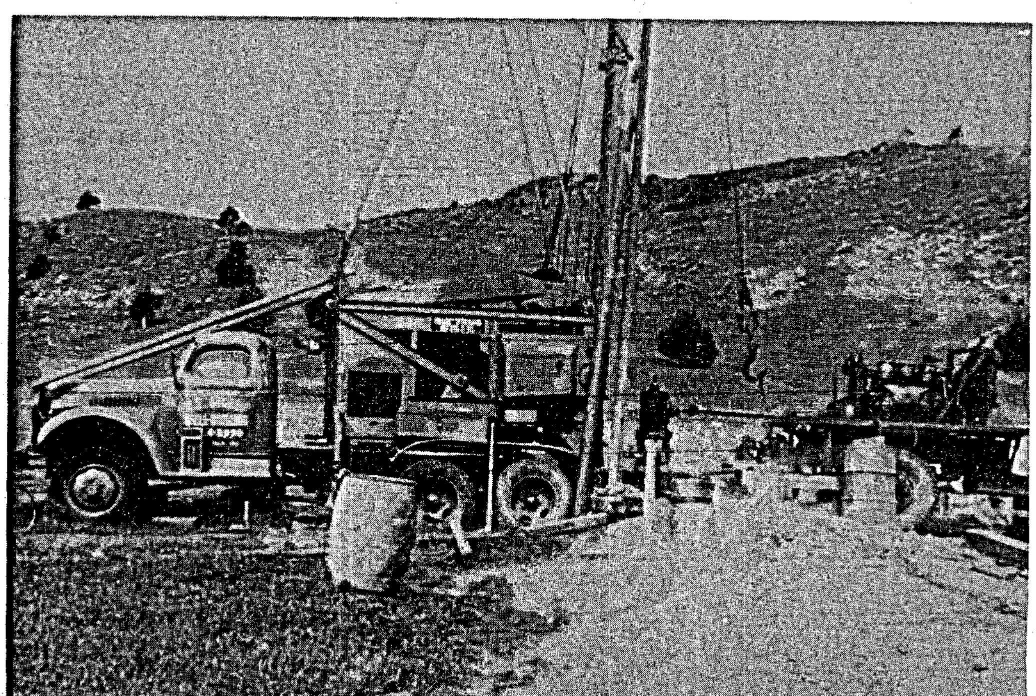


Figure 3. Pumping test on the OIT well

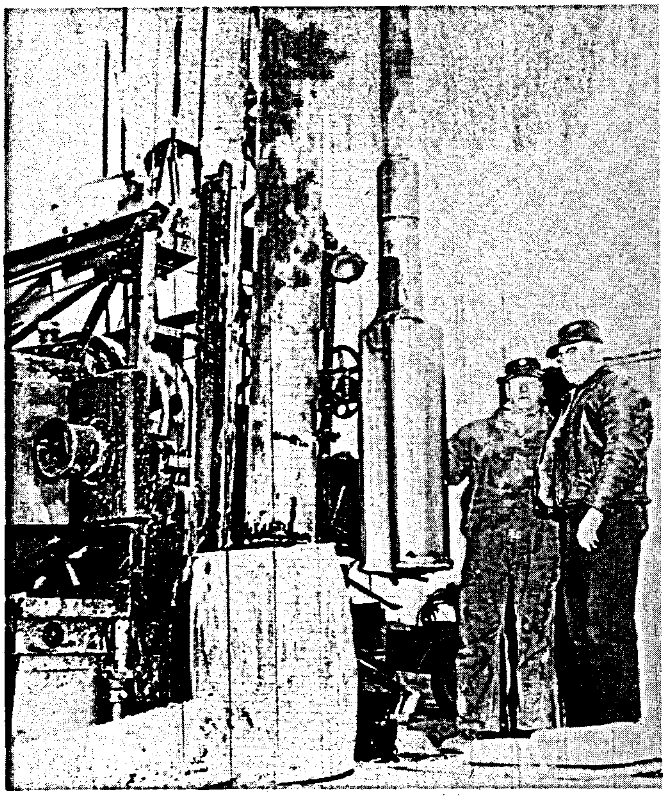


Figure 4. Close up of bailer (left) and percussion bit (right) during drilling of OIT wells

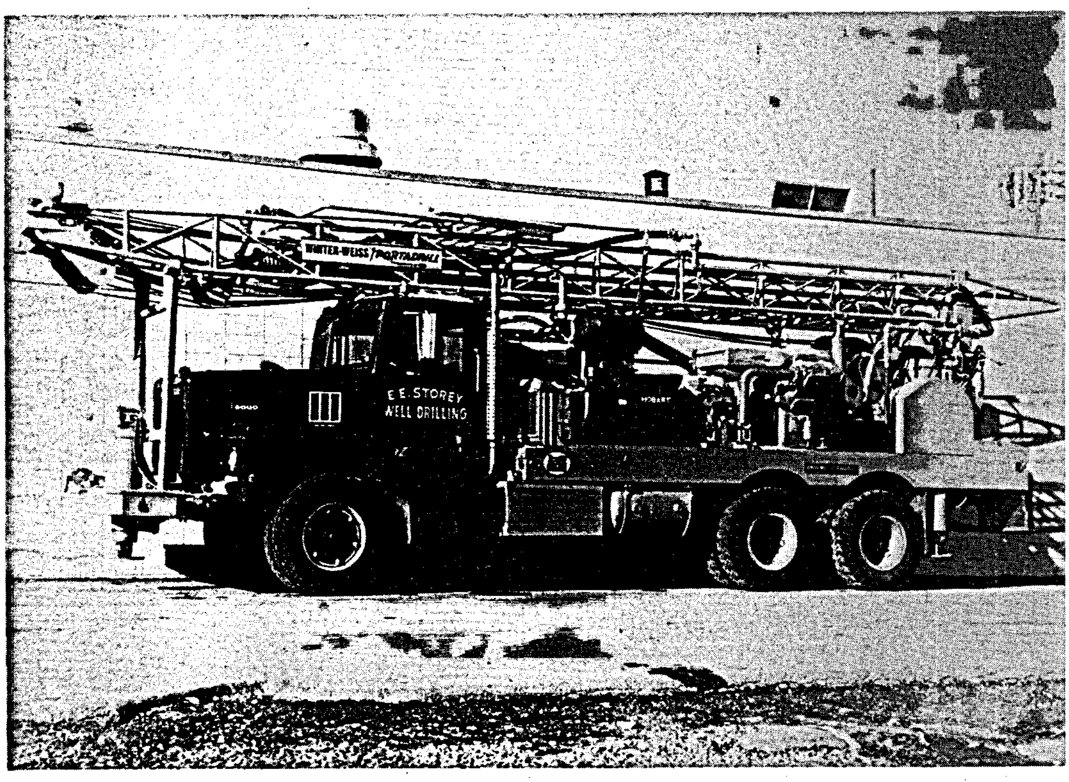


Figure 5. Rotary drilling rig.

53,092

GEOTHERMAL ENERGY POSSIBILITIES IN ALASKA

By

William Ogle[1]

ABSTRACT

Very little development and use has been made of geothermal energy in Alaska. Due to the high cost of oil used for heating, recent emphasis has been given to the exploitation of geothermal energy. Towns in the state are remote and of low population, thus natural springs and other local resources are being considered to avoid exploratory costs and drilling costs. Based on visible sources and USGS work, the main areas of interest are in the Seward Peninsular, near Fairbanks, on the southeastern Panhandle and on the Aleution Chain. Several projects are presently being considered for development--at Nome, just south of the Arctic Circle, and at Elim, about 150 miles east of Nome. The Nome project appears to be too costly to develop, either due to local drilling costs, or high transportation costs from Pilgrim Springs about 60 miles from Nome. Elim has some local hot springs of temperatures from 180 to 190°F (82 to 87°C), that can be used for space heating and are presently being investigated by the University of Alaska. Present usage of geothermal energy includes Manley Hot Springs where greenhouses and homes are heated by hot water. Other potential resources include many active volcanoes for electric power generation.

INTRODUCTION

It might be interesting to you to hear a little about the problems that we are having in Alaska in getting a geothermal program started and some of the considerations that we've been going through. About two years ago, Governor Egan instigated a small program to try to encourage geothermal development in Alaska and to try to determine what might be reasonable to do there.

Now before talking very much about what we're trying to do, I think it's necessary that you understand a little about Alaska. Probably the main consideration that one goes through in thinking about the problems of Alaska from a geothermal point of view, is the physical size of Alaska. If you plot, to the same scale, a map of Alaska on a map of the Lower 48 you will see that, if you put Anchorage on Kansas City, then Ketchikan is almost on the east coast and Shemya is off the west coast. The linear extent of Alaska is similar to that of the rest of the United States leaving out Hawaii, although the area is only about a fifth of the size.

Now in that area we have only about 300,000 people, most of whom are in the so-called "Rail Belt" between Anchorage and Fairbanks. By most I mean perhaps 150,000 to 200,000 of the 300,000. The last 100,000 is spread all the way from Atka in the Aleutians, to Barrow on the Arctic Ocean, to Ketchikan

[1]Consultant, Anchorage, Alaska

on the southeast panhandle. That kind of population obviously cannot support and has not been able to support a road system or railroad system. There is a highway from the end of the Kenai Peninsula to Fairbanks and back over into Canada. Coming into existence at this time is a road from Fairbanks to Prudhoe which will be open to the public in about two or three years. Beyond that there are no roads. Transportation, therefore, in Alaska is either by air, by small plane, by boat, by dog sled or Shank's mare. The result, and this is the pertinent point, is that when you get off in these regions which are a long way from the transportation system, fuel costs or energy costs, are rather fantastically high.

In western Alaska in the region of Bethel oil costs of $50 to $60 a barrel are very common. There are many towns there where oil is over $100 a barrel. I have talked to people in that region who are thinking of going back to living in native grass sod-type huts because of the heating costs for their modern houses. It costs around $70 a month to heat that nice small, modern house, and a common income is about $65 a month, so it seems wise to use some of their income for food.

Therefore, in thinking about the possible uses of geothermal energy in Alaska, one initially tackles the problems of those remote people. Well, that's a rather odd use of geothermal energy. The towns are in the region of 100 to 300 people. Those of you who have been playing this game are aware that you don't drill very many holes for the kind of money you can capitalize out of 300 people. You can't pipe water very far, either.

So, our thoughts have turned to the use of natural springs and other local resources to avoid the exploratory costs and drilling costs.

But let me come back to some specific applications in a moment.

ALASKAN GEOTHERMAL RESOURCES

From the point of view of geothermal application one must, of course, know something about the resource. The studies of the geothermal resources of Alaska have been rather minimal but they've been increasing over the last three years. The USGS has had a program during that period of time in which they have surveyed most of the springs in the state, leaving out the Aleutian Chain because the Aleutian logistics are too difficult for the type of funding they have had. Thus, they've looked at the order of 100 springs and determined the source temperature from those springs. They've also done other appropriate geological work to try to define the resource. The University of Alaska has also spent some effort on the subject.

To put a different aspect on that effort, it is my somewhat informed, but not completely informed, opinion that in the State of Alaska there are two people who work full-time, year in and year out, on geothermal. I know of, I think, about another eight or ten who spend maybe a tenth to a quarter time on the subject.

The USGS has looked at the resource and, to make a long story short, it appears that there is some resource in the Seward Peninsula and over toward Fairbanks but it's probably low temperature. Source indications are like 150°Centigrade at the source and there is no stated estimate to the amount of water that one might find there. There are some resources down in the Panhandle which appear to be of similar temperature. The Aleutian Chain and up through the Wrangells is, of course, a very long chain of volcanoes. We have something like 80 volcanoes there, of which 40 are intermittently active. I believe we have two quite active volcanoes erupting at the moment. So, if you happen to be a believer in geothermal energy from volcanoes, then we should have a tremendous source in that region. But, of course, except for the military, we don't have any people out there. The civilian population doesn't extend much beyond Cold Bay.

There are some present applications of geothermal energy in Alaska. Approximately half a dozen hot springs have been utilized for rather primitive hot house works; there are three or four swimming pools; and I'm aware of two locations in which there is some small heating of houses. To the best of my knowledge, there has been no production drilling in Alaska for geothermal--not one hole has yet been put down.

If you consider the size of Alaska, and you also consider the climate, you realize that our minds are turned very quickly to non-electric applications of geothermal energy. Our problems are space heating and agriculture. The same problem of transportation that leads to oil being $50 or $60 a barrel, in some places, leads to also high costs of food . . . especially fresh vegetables. In many of the regions, fresh vegetables are not available at all. Thus, we have considered space heating and local agriculture by greenhouses as perhaps the most outstanding application that we could come up with in fairly short time without too much investment.

We have been looking for specific projects that might warrant support by the Federal Government. Consider Nome, just a little south of the Arctic Circle. Nome is a town of approximately 3,000 people. Fuel costs there, strangely enough, are not tremendously high. Fuel oil runs between 35 and 40 cents a gallon. It is brought in over the beach during the summer in barrels. The cost would probably be reduced slightly if there were a way to pipe it ashore into storage tanks. There is, about 60 miles (97 km) from Nome, the so-called Pilgrim Springs about which not very much is known. The USGS says that the source temperature, again, is about 140 or 150° Centigrade. There is apparently a fairly large heat source, since it shows up as an area about three by five miles that is noticeably hotter as determined by observing snow melt, the plant growth and, for that matter, the temperature of the air within the surrounding region. There have therefore been some considerations of trying to get a demonstration project going which would bring hot water from Pilgrim Springs to Nome for space heating. Pilgrim Springs, early in the century, served as a small agricultural base, which could be started again. Conceivably one could talk of electric generation, although the temperature seems low.

We don't have much effort on the subject of studying this but Ralph Stephano made some preliminary engineering studies and came up with a cost of about $35 million to run a pipeline that distance with the proper flow to take care of Nome. That seems pretty unreasonable for a town of that size. They couldn't very well pay for it. We looked at the alternatives of developing electricity at Pilgrim Springs and running it across. We observe that if that is done the power line only costs about a million and a half or $2 million but, of course, the power plant will cost maybe 15 or more million in that region, so it isn't really clear where the balance is yet. Only one thing is clear, and that is Nome really doesn't have enough money to start either one. As a result of this we have started some consideration of trying to do here exactly the same thing that Jack Howard mentioned for Melun, France. That is, drilling straight down in a presumably normal gradient region, hoping to do as they did there--to get 70 or 80° Centigrade water at depths of a kilometer or so. We are told by the geologists that it's the wrong medium. Nome is on the edge of a granite pluton of some sort. That discouraged me very much until I observed the Marysville experience which makes it perfectly obvious that if you drill down in a granite pluton you get lots of hot water.

Pilgrim Springs was, at one time, a school for orphaned children. They had a fair agricultural growth simply because the ground itself is quite hot. Open water in ponds is visible in winter pictures, even though the air temperature may be many tens of degrees below zero. The water seems to come up all over the valley, so it doesn't hit the surface at very high temperatures, perhaps because of mixing with cold surface water.

Another project that we have been considering for the last year and a half or two years has to do with the village of Elim which is about 150 miles (240 km) east of Nome, on the coast. Elim is a small fishing village of between two and three hundred people. Near the village are two hot springs--one about seven miles away and one roughly 15 miles away. We have been trying to do the arithmetic of running a pipeline from those springs. They are fairly warm, a surface temperature of about 180 to 190° Fahrenheit (82 to 87°C). At the moment, due to a very small grant from the AEC, the University of Alaska is making some seismic measurements in the region of Elim.

One of the present practical applications is at Manley Hot Springs. There is a very nice greenhouse there and a couple of heated houses. The hot water supply system is quite unsophisticated, consisting of a primitive mixing chamber (an old wash tub), into which hot water from the springs is mixed with cold water from a stream. The mixture is then pumped to the greenhouse. However, the products are edible. In fact, the cantaloupes are about the best cantaloupes I've ever eaten. Chuck Dart, the gentleman that runs Manley, is not particularly interested in making money off of it. He wants to grow what he wants to grow so he's paid no attention to the economics of greenhouses and hence, he grows cantaloupes in them.

While we've been on the subject of non-electric uses of geothermal energy, which is the purpose of this meeting, I can't talk about Alaska without saying something about the electric possibilities. It does seem that there is not much sense in trying to use geothermal energy for the development of electricity over much of Alaska, although that may be questionable in some of the more remote regions. It is to be pointed out that even though we have a fairly low source temperature, we also have a low temperature sink. Thus, it may turn out to be fairly profitable to work from fairly low thermal waters to make small amounts of electricity. However, our largest resource, which may be the largest resource in the North American continent, is the string of volcanoes off the Aleutian Chain.

We've been considering the question of what we could do with all that if the hot-dry rock method that Los Alamos is working on, some of the work that is being done in Hawaii, should come to fruition. We are gently considering how we might make electricity in the Aleutians and transfer it by other means to the Lower 48. We don't particularly need it but the Lower 48 does. One path that is perfectly obvious is to deal with high energy intensive systems.

An outstanding possibility being followed in Iceland right now, is to treat bauxite to make aluminum. Now we've had some small conversations with the aluminum companies on this subject. They point out that they really only have two requirements. One is cheap electricity and the other is reasonable transportation. Transportation to the Aleutian Chain, if you ignore the weather, is fairly good. The harbors are good. So, if the methods that we are working on in many places in the world to develop electricity from the hot sources around volcanoes should prove out, then the use of that energy by such a technique might seem reasonable.

Of somewhat closer interest in Alaska is Augustine Volcano which is about 70 miles (113 km) from Anchorage and maybe 30 miles (48 km) from Homer. Energy developed here might actually be useful within Alaska. The University is doing a small amount of work there, seismic studies and some temperature measurements. There are no proposals that I am aware of to actually try to develop it as an energy source.

One of the major problems that needs to be addressed to further the use of non-electric geothermal energy in Alaska is, in the first place, resource assessment--we still know very little about that and we're very pleased that USGS is considering spending somewhat more effort in the future. The State Geological Survey has become interested--I don't know what they'll come up with. We need economic assessments, as must be completely obvious. In many of these places that I've been talking about for geothermal, wind may be a much more reasonable resource. The wind does occasionally blow in Alaska, especially out in the Aleutian Chain. By that I mean that it occasionally gets below 30 knots (56 km/hr).

We may have resources in somewhat different places than where the people are so we are certainly interested in the problems of the transport of hot water in pipes and, at the moment, are somewhat confused at the economics on that subject.

We need public education, sort of like we're doing right here. Public education on the value of geothermal energy, the process of getting the people who might put in money from the private sector interested in the subject.

We need front-end funding. Alaska, like so much of the rest of the country, would like to have geothermal development, but the small villages and the towns like Nome can't dig up the money in the first place to build a plant, even though they know it will save them money in the long run.

I would like to mention two other specific problems that we have had. We've tried to get some of these proposals into the Federal agencies.

Specifically, the AEC and NSF. At the time when national energy plans were being drawn up we ran into an interesting difficulty which I think I should mention to you because you may have the same kind of problem. We wanted to promote non-electric applications in the first place--which wasn't very popular a year ago--but our object is to help what amounts to 100,000 people. Well, when the national plans were put together one of the serious considerations was that anything considered must promise an appreciable affect on the nation's energy picture. Well, nothing we do with 100,000 people is going to show any affect on the nation's energy picture, so the proposals were by-passed. We feel that the kind of thing that we would like to do in Alaska can also be of value to many places in the northern part of the United States and in many other places in the world, and hence can affect the total energy picture. Some of this kind of work is going on in other places in the world. Iceland does have towns (of less than 300 people) that are heated by geothermal energy.

We have run into a second problem which I think the audience here might be able to do something about. A recent speaker might straighten it out or turn it around. The National Energy Plan as read, and of course the thing hasn't been approved by anybody, says something to the effect that we are going to develop 20,000 megawatts electric by 1985. Then in a phrase after that it says that we will also use waste heat and will look at non-electric applications. Well, I'm afraid the process by which we get funding out of Congress had emphasized the electric part in order to get the funding. The programs described to Congress are pretty well fixed so that a large proportion, at least in AEC and perhaps in the NSF, of that funding is not directed toward non-electric applications and it's going to be extremely difficult to turn it in that direction, because the basic thing the National Government is trying to accomplish--it says right there on paper--is 20,000 megawatts electric.

We can have spin-off, as was stated earlier, from some of the electric projects, but I would like to argue that when you're doing a project and you've got electricity in your mind, you will work somewhat different than you will if you're trying to develop the non-electric resources.

I, therefore, feel that, both from the point of view of Alaska and our very small use, but also from the point of the rest of us in the geothermal community, reconsideration of that philosophy in both the Federal agencies and, particularly in Congress, is due. I'm glad we have had Federal Government representatives here to perhaps turn some of that thinking around and emphasize, in the place where it will help, because they control the money, the value of non-electric geothermal energy to the country.

Let me mention the Navy base at Adak. This is the major northern Navy base of something like 5,000 people. In the first place, because of the cheapness of sea transportation their fuel costs are not high. However, the Navy is conscious not only of the energy costs at that base but of all their bases around the world. They are conscious of their very high use of oil and so they are looking into, and putting money into, geothermal and other energy resources that can reduce their oil use in fixed bases. Specifically, they have asked the USGS to make surveys in the region of Adak, which I think was started this summer, to see if it is practical to develop geothermal energy there. They are also encouraging the investigation of the use of wind there. The Navy has, in Iceland, considered converting to hot water at Keflavik.

With respect to local finances, we have explored the possibility of getting money from the State or from the tribal Indians to advance geothermal development.

Until very recently, the State has had all of its efforts on the pipeline. The pipeline has to do with their future financial health. The State Government is going in the hole very rapidly. So practically all extra State effort has gone into the oil pipeline. However, the situation should now change, since money will start coming in in the next few years.

Several of the Native organizations are looking into both geothermal and wind but are being very cautious and careful about it.

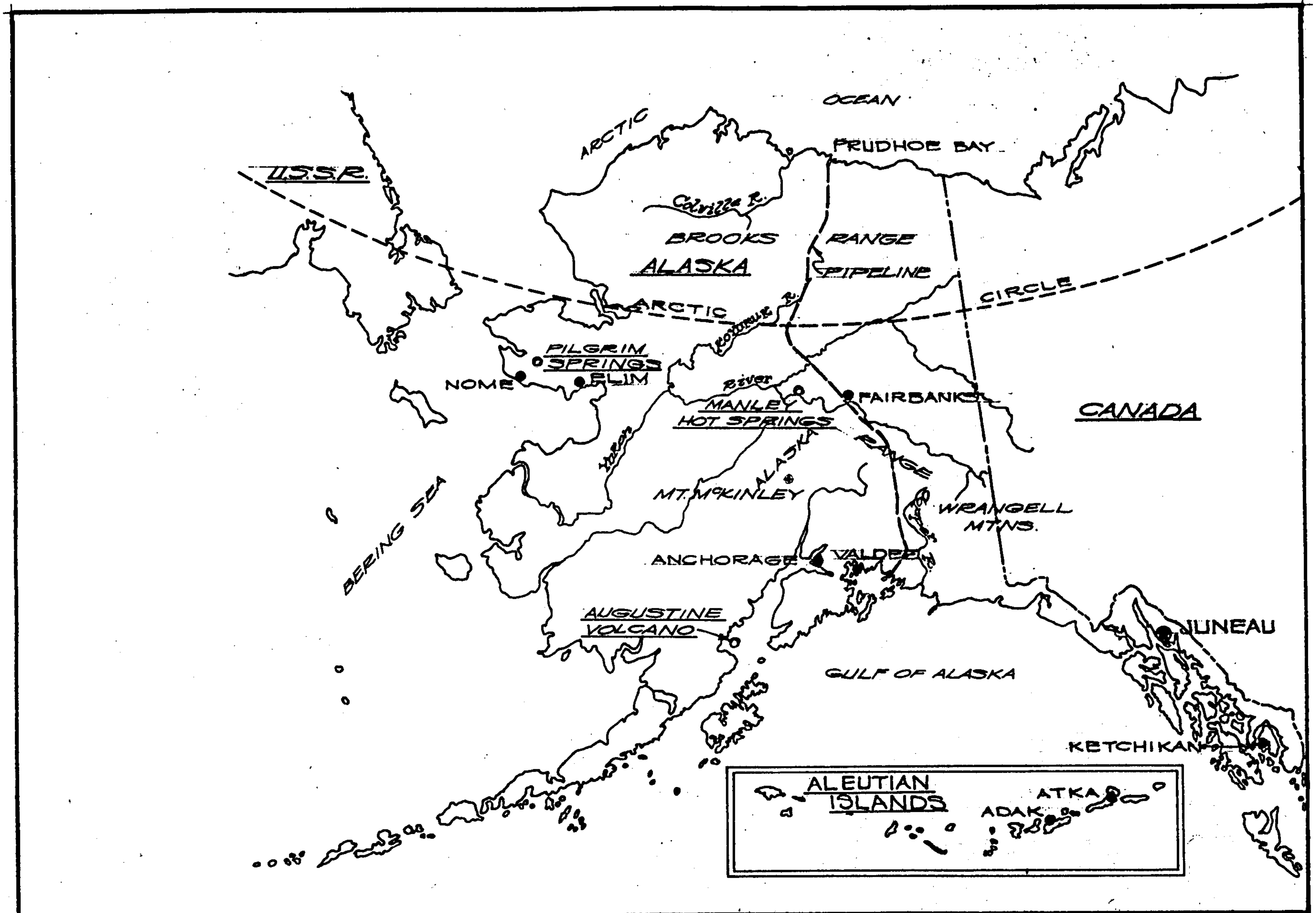


Figure 1. Alaska geothermal resource areas.

53,093

ECONOMICS OF MULTI-PURPOSE USE OF GEOTHERMAL RESOURCES

By

Joseph Barnea[1]

XU

ABSTRACT

A new definition is proposed for geothermal energy to include applications in addition to electric power production. Three basic factors should be considered in looking at geothermal resources: (1) the geothermal formation, (2) the geothermal constituents, and (3) the on-going geothermal processes. Sequential use, or the use of geothermal constituent in stages, each requiring heat at decreasing temperature, allows a multiplicty of utilization. The master plan for geothermal use requires a program which provides for full testing of everything found in the geothermal formation. The use of steam and hot water for power generations and non-electric uses can provide large cost savings. All geothermal resources can provide heating and/or other direct applications at costs which run to 1/10 and 1/20th of the corresponding cost of fuels which require a boiler system. Large scale food and fiber production in greenhouses using geothermal resources should be looked at as it can provide vast increases in yield, year round production and year round employment. Geothermal resources are the best resource base for modern agro-industrial complexes. They can provide the water for crops, fish and animals, the electricity needed, the energy for processing and refrigeration, and in certain cases even the fertilizer. Previous federal legislation provided a narrow definition of geothermal resources which is a serious handicap to the multi-purpose development of geothermal resources. The Geothermal Energy Act of 1974 provides a new definition of geothermal resources to include items other than geothermal steam. Changes in geothermal legislation is needed at the Federal level.

INTRODUCTION

This paper will attempt to offer a new definition of geothermal energy, one which more truly reflects the extraordinary potential of this resource and one which more accurately inventories its multiplicity of uses and applications for other than or in addition to electric power production.

The President of the United States may not have realized how prophetic his words could be when last month[2], in his address to the United Nations, he linked food and energy as two sides of the same coin, geothermal energy which is found in one form or another in more than 100 nations of the world is surfacing, if you will, as a vast and new source of energy and water for food on a global scale. Finally, I would like to direct attention to what I believe is a most urgent and critical consideration--

---

[1]Economist, United Nations Institute for Training and Research

[2]September, 1974

the need to re-examine existing Federal legislation on geothermal energy which, if I am correct, makes non-electrical utilization of geothermal resources on Federal lands difficult, if not virtually impossible.

GEOTHERMAL RESOURCES

We don't have, as yet, a clear and comprehensive definition of geothermal resources and perhaps it's a little early to arrive at any final formulation since we are still in the stage of discovering and characterizing new types of this resource. However, as a prelude to a new and more workable definition, let us agree on the types of geothermal resources which are identifiable today.

I would classify these into six types: the first three are geothermal resources with fields currently in operation and where the technology and economics are well known. These include dry steam fields, wet steam fields and low-temperature fields. The other three types I would characterize as potential geothermal resources, namely, (1) geopressure zones or geopressure fields; (2) hot dry rock areas; and (3) areas in and around volcanoes. With regard to geopressure zones, we are aware of the existence of many such areas as a result of data published by oil companies. However, at this stage further exploration is not indicated since we do not have the technology, as yet, to take advantage of it, even though we have considerable knowledge of the resource constituents present in geopressure zones. For hot dry rock areas the technology is currently under development but we do not know whether there are any large-scale clearly identifiable areas with hot dry rock characteristics given present knowledge. In hot dry rock areas future utilization will probably take the form of a one-commodity product, namely, steam. Areas surrounding volcanoes may now be classified as potential geothermal resources with the recent announcement by the USSR to build the world's largest geothermal plant of some 300 MW utilizing an area around a volcano as the source of heat. Each of these six types of geothermal field have specific differences in the composition of their geothermal constituents and this should be borne in mind when we make an effort to define geothermal resources.

In looking at geothermal resources we have to consider three basic factors: (1) the geothermal formation or geothermal field (the container); (2) the geothermal constituents, most of which fill the container or rock surrounding it (discuss in greater detail later); and (3) the on-going geothermal processes which generate natural heat and water re-charge. We find, therefore, in geothermal energy that we have a three-dimensional resource, and, in my opinion, it may be the only natural resource which can lay claim to such a three-dimensional character. Each of these various characteristics in turn has many possible applications. The geothermal formation is not only the holding tank for geothermal fluids but it can also be used for artificial re-charging and, in addition, it can be used by the geothermal processes themselves. I suggest, therefore, that we might re-define geothermal resources as geothermal formations which contain constituents and are constantly undergoing geothermal processes.

Let me now turn from the definition of these factors to a more detailed examination of what may be the single most important factor, namely, the constituents. These constituents include hot water, steam, minerals, gases and chemicals mixed in the water. They may also include gases in the steam and the water, precipitates and sinter in geothermal areas, minerals in geothermal host rock, heat in the geothermal formation and natural gas as well as energy found in compressed water. In this discussion today, I will not be able to discuss the economics of each constituent in a single purpose, dual-purpose or other applications or combinations. However, I assume that most of these facts have been collected from at least some of the various geothermal fields and springs that are known and need not be repeated here. It may be useful nevertheless to point out that precipitates around geothermal springs can prove to be very attractive. For example, Mr. B. G. Weissberg, in a study made in New Zealand, found precipitates which carry 85 parts per million of gold and 500 parts silver per ton (Weissberg, 1969).

Some research is also being carried out on the deposition of base metals by hot springs in host rocks, an area which may prove of significance in the future (Browne, 1969). Geothermal constituents allow a multiplicity of utilization and we might classify them under the following heading: (1) constituent use, and this in turn could be subdivided into full use for one purpose or into partial use for two purposes, or for sequential use and re-use.

The sequential use--and I believe this is a term I introduced four years ago at the Pisa meeting--means use of a geothermal constituent in stages each requiring heat at decreasing temperatures. This concept has recently been applied to solar energy under the name of energy cascading. I believe that geothermal energy is far more suitable for energy cascading than any other energy resources. (2) The second category of division involves single constituent use, dual constituent use, triple constituent use, quadruple, fivefold, sixfold usage and so on. Given the potential multiple applications only the ingenuity of the geothermal planner, the local conditions, and the characteristics of the given geothermal resource will determine what is the best and most economic use.

The variety of constituents and of factors, the variety of possible uses (such as full use for one purpose, use for two purposes, re-use, etc.) and the variety of local economic, climatic and topographic conditions probably allow hundreds of different combinations. Most of them have not been studied yet. This is the area of the geothermal planner or development planner, a function which is both new and important.

The master plan for geothermal use requires from the very onset a program which provides for full testing of everything found in the geothermal formation, not only the temperature flow but, for example, the composition of the water, of the gases, of the rocks and so forth.

The full testing of geothermal resources, insofar as it can be done before drilling, is equally important for the selection of geothermal exploration targets and for the success of geothermal exploration, and successful exploration is the base and foundation of geothermal planning. If exploration is not done well, and it is not yet done well here in the United States, we may endanger public support for geothermal energy. I hope that we will witness in the coming years a sharp improvement in geothermal exploration, and this will provide the foundation for a broad based multi-purpose development.

If we look at a geothermal formation and its primary characteristics, I think we will all agree that today heat and water represent the most important resource constituents. But given these conditons we have to ask again is it the most economical approach to look at geothermal resources only as a source of energy for electric generation or, in fact, is it more economical to look at the utilization of such energy resources for non-electrical purposes, and, specifically, I think we have to begin now to look at the contribution which the earth's warm or hot water can also make to the world food supply of the future.

Geothermal steam for electric power generation, including steam derived from a dry steam field, is low-temperature steam. As a result, we have low efficiency in the utilization of such steam for power generation. If we use geothermal steam, 24,000 BTU's (6.0×10^6 gcal) are required to generate one kilowatt hour, whereas if we use fuel oil only 9,000 BTU's (2.3×10^6 gcal) are required to generate one kilowatt hour (USGS, 1974). Fuels, therefore, seem to offer, purely from an efficiency point of view, a considerable advantage over geothermal steam. But let us take a look at comparative cost. If we take a barrel of fuel oil at today's prices of $14 per barrel, a million BTU's will cost $2.40 whereas one million BTU's of geothermal steam, assuming prices in effect at The Geyser field in California, will only cost about 17¢. Thus, in spite of its low efficiency, if geothermal steam is used for electricity generation, the BTU's required to generate one kilowatt will cost only 4 1/2 mills while the BTU's based on fuel oil will cost 22 mills per kilowatt hour, or five times more. Now, if we turn to the use of geothermal steam and hot or warm water for non-electrical application, we find that the situation from the point of efficiency has been reversed. The use of fuel oil to produce warm or hot water involves conversion losses ranging from 30% to 40% whereas the geothermal hot water or steam for non-electrical use shows virtually no conversion losses. Therefore, when it comes to non-electrical applications the efficiency advantage clearly lies with geothermal resources and not with fossil fuels. If we compare hot water or low-temperature steam produced for house-heating or air-conditioning we find everything else being equal, and based on the present prices of fuels, all geothermal resources can provide heating and/or other direct applications at costs which run to 1/10th and 1/20th of the corresponding cost of fuels which require a boiler system. There is, therefore, no need to go into detailed economic studies under present conditions in order to investigate the applicability of geothermal resources for non-electrical utilization. What is needed now, in my opinion, is to determine what are the technical applications for geothermal resources the location of the demand, the size of the demand, and the distance from the geothermal resource.

GEOTHERMAL UTILIZATION

Let me now turn to one of the utilizations of geothermal resources which I believe may in the future prove to be of great significance for all. The use of geothermal resources on a global basis to grow food or other agricultural crops in the controlled environment of greenhouses. The full utilization of geothermal resources for growing crops will often combine the applications of three geothermal constituents, namely, the heat, the water and the CO_2 content of geothermal formations. Greenhouses are being built in many places today because modern agricultural research has found that growing crops in controlled environments has the following advantages:

(1) it allows vast increases in yield; (2) it permits year round production; (3) it provides year round employment; (4) it provides protection from insects, pests, predators and frost. The addition, for example, of the CO_2 to the air of greenhouses can increase the yield of those crops so treated by 50% to 80%. Greenhouses can also be used for the raising of fish, already being done in Japan, and for alligators and other species.

A few months ago a report was issued on a five-year research program which was carried out here in Oregon in Corvallis on the use of thermal water for agriculture. The project sought a solution for the use of substantial quantities of warm water which would be generated in the future by large-scale nuclear power stations. The report, however, recognizes that the study should be followed by one much more relevant, namely the utilization of geothermal water for use in greenhouses (EPA, 1974). The tests discussed in this report were based on cooling water in the range of 90 degrees to 110 degrees F.(32 degrees to 43 degrees C.) which was made available from a power station operated by a big timber company (not infrequently stoppages at the power station lead to an interruption in the supply of this water, for example, during one winter an important crop was lost because of a failure at the power station). The report states and I quote: "As can be seen in the various figures no constant soil or air temperatures were maintained. The thermal water was used as it was supplied and probably represents a realistic view of what may be expected with a larger installation that relied on industrial waste thermal water." (page 114). In short, what they were saying was that interruptions in the supply of warm water could be expected routinely and that a continuous supply of warm water could not be relied upon in the future. Here we might add that a greenhouse supplied directly with warm water from a geothermal field would experience no such failures but would provide a degree of reliability which would not be obtainable from conventional power stations and even less obtainable from nuclear power stations. Further, in many instances a geothermal field will also provide a rich source of CO_2 and, in addition, all of the water needed for a greenhouse operation.

But let us return to the results of the study. The study shows that in the greenhouse production they were able to obtain, and I quote: "A gross return per year with selective cropping can be a minimum of $161,837 and a maximum of $288,809 during a nine-month operation." These figures refer to the return per year in a greenhouse covering one acre (0.405 hectares).

I believe that the world should begin to look at the application of geothermal resources to large-scale food and fiber production in greenhouses even if the financial yields are substantially lower and even if we apply the technology to crops of lesser value than those selected in the Oregon experiments. For example, even if we should realize a return of only 1/5th of what has been calculated in the Oregon study, and this, in my opinion, is an achievable goal for a large number of crops, the results could prove most significant. Now the question could be asked where will we get the water for the irrigation for crops in greenhouses. This is, of course, a question which could only be answered after a study is made of local alternatives available. But let me point out here that, on average, if we compare returns on a per acre basis, The Geyser field offers a return to its owners, and I am speaking of a gross return, of roughly only $10,000 per acre ($24,710 per hectare). Thus, in certain cases it may prove more economical for even a dry steam field to use the steam first for agricultural processing, including refrigeration, and the water in a second stage for greenhouse warming. If we now analyze in greater detail the sources of irrigation water which can be obtained from geothermal resources we begin to see the following results. In a dry steam field where we have a well producing, say, 100[1] tons of steam per hour, 75% of the water is required for evaporative cooling, and only 25% is left for outside use, that is providing that the water quality is satisfactory. If, however, brackish or saline water were available for power station cooling then all the steam produced could be used for irrigation. There is the further possibility of using such steam and mixing it with cold water if large quantities of warm water at a lower tempertue were required. Thus, the steam or part of the steam could also be used for the desalination of saline or brackish water in a given area although in most cases this alternative may prove uneconomic.

A wet steam field may produce as much as 400 tons of water per hour and, depending on the quality of the water and its economic utilization we may be able to use a large part of this output for agricultural purposes including the 20% or 30% which would otherwise be flashed when used for power production. One alternative is to flash 20% and assuming that the water is not potable, take what remains and run it through a desalination plant. A substantial additional quantity of potable water could then be produced, leaving a concentrated brine for processing or disposal. Water mixed with other available cold water is also possible and, therefore, substantial quantities of fresh water can be obtained depending on the economics in each case. There is still another possibility where the use of water can be maximized in a wet steam field. We flash 30% for power production, use the remaining brine for other heat utilization purposes, such as greenhouse heating, and, finally, use the cold brine as cooling water for the power station just as saline seawater is used for cooling water today at power stations. If this is done then all the condensed steam of roughly 120 tons per hour could be used as low-cost water for irrigation. 120 tons of fresh water per hour can give us almost one million tons of fresh water per year per well. A quantity of water which would be sufficient to irrigate 400 acres (988 hectares) of land, such as is required for citrus groves. The land could also be irrigated, if it is economically attractive, in greenhouses with maximization of output per unit of land with year round employment and vastly larger returns.

Geothermal resources are the best resource base for modern industrial complexes. They can provide the water for crops, fish and animals, the electricity needed, the energy for processing and refrigeration. In certain cases even some of the fertilizers can be provided by geothermal resources. In addition, the associated human settlements can be provided with safe water, electricity, heating and air-conditioning at low cost in a clean environment.

The somewhat more detailed discussion of the potential geothermal resources utilizing its water and heat constituents for growing and processing of agricultural crops has not been realized in the past. Not all geothermal resources will or can be heavy producers of water. Geopressure zones, on the other hand, may be able to produce more fresh water than even wet steam fields, but this is a type of resource which will only come into use in the future.

---

[1] 1 ton = 2000 lbs. = 907 kg

GEOTHERMAL LEGISLATION

Having thus sketched some of the vast possibilities of utilizing our geothermal resources for new applications, let us turn to the present legislation in effect in the United States as it applies to Federal lands. If we look at the "Geothermal Steam Act" of 1970--and I might add that I have previously called the title of this act into question--and the subsequent "Geothermal Regulations" which were published in final form on 21 December 1973, and which became effective on 1 January of this year[1], we find that the "Regulations" define geothermal resources as follows: "Geothermal resources means geothermal steam and associated geothermal resources which include... "(This is followed by an enumeration of the associated geothermal resources). The key element here is the words "geothermal resources means geothermal steam." Consequently, if we look at the detailed leasing terms, we find in paragraph 3203.1-3, and I quote: "If geothermal steam is produced or utilized in commercial quantities, within the primary term of a lease, that lease shall continue for so long thereafter as geothermal steam is produced or utilized in commercial quantities..." and so on.

In other words, the primary term of a Federal lease of ten years can only be extended if geothermal steam is produced or utilized.

In paragraph 3203.1-4, we read: "A lease which has been extended by reason of production, or on which geothermal steam has been produced, and which has been determined by the Secretary to be incapable of further commercial production and utilization of geothermal steam, may be further extended so long as one or more valuable by-products are produced in commercial quantities but for not more than five years." In other words, when the geothermal steam production ends a geothermal Federal lease may be extended only for five years.

This narrow definition of geothermal resources is a serious handicap to the multi-purpose development of geothermal resources. I urge that we address ourselves to the problems inherent in such definition, and to the consideration of those changes in the Federal legislation which would make it possible to fully develop Federal lands for multi-purpose usage other than electric power production. It may also prove useful to draw the attention to the fact that the present definition also excludes oil, hydrocarbons, gas and helium from geothermal resources, and I believe it will too require clarification when we seek to determine that there is natural gas dissolved in geopressure zones and helium found in geothermal areas in other parts of the world.

The very important Geothermal Energy Act of 1974 which I believe has been signed now by President Ford[2] uses a definition for geothermal resources which leaves out the words "means geothermal steam" and includes all resources. It should be noted too that this act is called "The Geothermal Energy Act of 1974" and not "The Geothermal Steam Act of 1974." We have, therefore, I believe, two different sets of definitions for geothermal resources now existing in Federal legislation and a study may prove most useful now to define geothermal resources for pending legislation by States. When

---

[1] 1974

[2] Geothermal Energy Research, Development, and Demonstration Act of 1974, PL 93-410, September 3, 1974.

we examine the "Geothermal Energy Act of 1974," one finds the Secretary of the Interior is authorized to guarantee loans for acquiring rights in geothermal resources, etc. "for the commercial production of energy from geothermal resources." This, presumably, means all forms of energy, not only electric energy. Moreover, in the second part of this "Geothermal Energy Act of 1974," authority is given to "enter into cooperative agreements with non-Federal utilities, industries and governmental entities for the construction, operation and maintenance of demonstration developments for the production of electric or heat energy water supplies, or minerals from geothermal resources."

Changes in geothermal legislation is not only needed on the Federal level. Some states now grant a reduction in property taxes for houses using solar energy for heating. Why should geothermal energy not benefit also from a reduction in property taxes?

SUMMARY

The energy crisis which we all witnessed, has highlighted the role of energy in our society. Its availability and cost are crucial for our economy and well being. We use energy in many different forms and for many different purposes. Geothermal resources can provide low-cost electricty and low-cost heat or about 75% of our energy consumption, the rest needs fuel for air transport and other transport. Whether geothermal resources will in the future provide a large part of our energy need will depend, given the growing support from Washington, on (a) our exploration ability which needs improvement; (b) our multi-purpose utilization of geothermal resources requiring geothermal resource planning; (c) financial support from geothermal end-users and (d) an accelerated program of training of geothermal experts of all types.

We have before us a challenging task worthy of all our efforts.

REFERENCES

1. A Demonstration of Thermal Water Utilization in Agriculture, United States Environmental Protection Agency, EPA-660/2-74-011, Washington, D. C., 1974.

2. P. R. L. Browne: "Sulfide Mineralization in a Broadlands Geothermal Drill Hole, Taupo Volcanic Zone, New Zealand," Economic Geology, Volume 64, 1969, pages 156-159.

3. "Water Demands for Expanding Energy Development," United States Geologic Survey Circular 703, 1974

4. B. G. Weissberg: "Gold-Silver Ore Grade Precipitates from New Zealand Thermal Waters," Economic Geology, Volume 64, 1969, pages 95-108.

53,09

ABSTRACT (HOWARD, HALL, BREWER, AND EISENSTAT) US

The following four papers deal with the current status of geothermal energy, the legislation and taxation affecting present and future development and utilization. Dr. Howard's paper explains the purpose and status of the Committee on the Challenges of Modern Society--Geothermal Pilot Study project (CCMS GPS). Mr. Hall's paper outlines some of the current congressional interests and legislation related to geothermal research and funding. Mr. Brewer's paper emphasizes why public policy must support geothermal development in order to utilize completely this new technology just as fast as it develops. Finally, Mr. Eisenstat relates geothermal development to the Internal Revenue Code as it applies to the depletion allowance.

STATUS REPORT ON THE COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY GEOTHERMAL PILOT STUDY NON-ELECTRICAL PROJECT

By

John H. Howard[1]

INTRODUCTION

A project on non-electrical uses of geothermal resources was initiated in October, 1973, at the organizing meeting of the Committee on the Challenges of Modern Society ("CCMS") Geothermal Pilot Study ("GPS"). CCMS is a working committee of the North Atlantic Treaty Organization ("NATO"). The U. S. Atomic Energy Commission Division of Applied Technology was asked to organize and lead the study. The University of California/Lawrence Livermore Laboratory is a prime contractor to AEC/DAT, and Lawrence Livermore Laboratory in turn was asked to be responsible for the non-electrical project. The Non-electrical Uses Project is one of five projects under this study.

The original charge for this particular project is given in NATO (North Atlantic Treaty Organization) Document AC/274-D/38 dated October 11, 1973, copies of which are available from the Technical Coordinator.

There are four purposes of the CCMS GPS Non-electrical Uses Project. They are as follows:

1. To bring together all "leads" which could be useful to anyone proposing to exploit a geothermal resource for non-electrical purposes. These include not only literature references, survey articles, etc., but also the names and addresses of individuals who are knowledgeable about particular non-electrical applications.
2. To summarize what has been done in the way of non-electrical applications (e.g., see Table 2).

[1]Lawrence Livermore Laboratory, University of California

3. To define the technical and non-technical problems (e.g., financing) which have affected and continue to affect non-electrical applications of geothermal resources.
4. To determine if enhanced development of non-electrical applications of geothermal resources is warranted and; if so, to recommend a course of action in order to realize such development.

Canada, the Federal Republic of Germany, France, Iceland, Italy, Mexico, New Zealand, Phillipines, Portugal, Turkey and the United States are members of this project. Mexico, New Zealand and the Phillipines participate in the project via silent consent.

Following the organizational meeting, Canadian, West German, French, Italian, Mexican, New Zealand, Turkish and United States representatives met in New Zealand on April 30, 1974, to discuss in a preliminary way the preparation of a report on non-electrical applications. Subsequent to the New Zealand meeting certain members of the Project toured sites of Italian and French applications and then convened in Iceland to see Icelandic applications. While in Iceland, the group formulated the outline for the report which is shown in Table 1. The consensus was that the report would be readable and useful in this format. It was also agreed, however, that individual articles might be included in an appendix if there were some reason that the article stand alone as well as be synthesized as appropriate in the main body of the report. It was agreed that named individuals would be responsible for certain sections of the report and that drafts of their sections would be prepared by late 1974 for review by members of the Project. The section on "Present Problems and Future Possibilities" is to be written jointly at a meeting to be held as soon as reasonable following assembly of a draft of the report.

CURRENT STATUS OF REPORT

The report is being contributed to by thirty individuals along lines reflected in Table 1 (Table of Contents). Two sections are in draft form: (1) agricultural and related topics and (2) Industrial. Individual contributions regarding the general status of non-electrical applications in their respective countries have also been received from participating countries known to be in some way exploiting geothermal resources. The AEC through its contractor laboratory, Lawrence Livermore Laboratory, has specifically financially supported for inclusion as appendicies to this report two special projects: (1) a review of space heating practices in Klamath Falls (Oregon Institute of Technology) and (2) a study of possible direct industrial uses of the geopressure resources (DSS Engineers Inc., Fort Lauderdale, Florida). The planned content of the principal chapters of the report is summarized below.

Finding the Exploitable Resource

A sketch and evaluation of geophysical and geochemical prospecting techniques and a selected bibliogrpahy of key references are to be included. Emphasis will be on (1) the finding of moderate temperature waters (80° to 100°C) and (2) the costs of exploration programs. Plans also call for assembling the names of international firms and of individuals providing geothermal exploration services.

Drilling, Extraction and Distribution

Costs of drilling and distribution are to be emphasized. Appropriate concepts of a general sort on the problem of energy distribution are to be included here, for instance, those that can be taken over from studies of solar power. Experience from municipal heating districts based on fossil fuel fired sources will be summarized, as appropriate, in this section. Prospects for greater distances of transportation of geothrmal fluids than is currently practiced is to be addressed.

Uses

This will be a short section listing the various non-electrical uses of geothermal resources and their importance when measured in terms of associated power. Any clear generalizations or well established themes about current non-electrical use of geothermal would be put in this section as opposed to the "Applications" section (see below). For instance, a theme that might be developed here is the fractional value of a product that energy costs represent. A discussion of the implications of cheap geothermal energy to overall product costs would be included here.

Disposal

Questions of major interest include (1) When does hot water become "waste" water? and (2) What might be done, if anything, to minimize costs of disposal? (3) Under what conditions can waste be put into the municipal disposal system? Environmental considerations are to be addressed and coordinated with the section on Regulations.

Applications

The section on Applications will be divided into three parts as noted in the Table of Contents. It is intended that this section be as up to date as possible. There is nothing widely written on the French experience at Melun, for example, and this application appears to be a highly significant development (normal earth temperature gradient heating). Agricultural applications are truly outstanding when measured in terms of square meters of greenhouse farming, for instance. The status of understanding of the beneficial effects of warm water and warm air on growth is well known and is excellently summarized in an Oak Ridge National Laboratory report (Yarosh, 1972). Industrial applications are few but the geothermal power associated with each is high. Thoughtful discussions of the practical problems associated with bringing the New Zealand pulp and paper mill on stream and the Icelandic diatomite plant on stream are being considered for inclusion in the appendix. This applications section of the report is to emphasize how to get into position for doing an application, e.g., to give the names of major agencies involved in the application. The report will not provide blueprints for applications, but the report is intended to be a guide to interested people with whom to get in touch; what the major practical problems are; pitfalls to avoid; realistic costs and schedules etc.

Economics and Regulations

This is an important section for practical purposes of development of geothermal in non-electrical applications. Emphasis will be on costs of drilling, transportation of fluids, disposal of fluids, and perhaps retrofitting of homes, greenhouses, etc. Some attention will be given to the problem of obtaining venture capital. Emphasis will also be on any themes of regulations, (common sense and first priority to first established user, etc.) if present, rather than a recitation of laws throughout the world.

Present Problems and Future Possibilities

This section is a most significant section because it can, if appropriate, be used as the basis for an administrative decision to undertake new applications. It will be put together by the entire Working Committee.

Literature Review

Work is well along on gathering references on literature on non-electrical applications of geothermal resources, and the value of such references is obvious.

List of Contacts

A list of contacts on different subjects, e.g., home space heating projects, is invaluable to potential non-electric users and will be assembled as part of this report. An important point here is that all contacts so named agree to respond to inquiries.

Appendix of Special Contributions

There are some especially good contributions and articles which can stand alone and should be included in toto in the report. An example is the summary by Yarosh et. al. on the benefits of warm air and water to agriculture.

Comments on Drafts Received to Date

The report is mainly a summary document and an example of the kind of output being assembled is shown in Figure 1 and in Table 2. New and significant ideas are also being gathered. A fine example here is the analysis of the questions of "substitutability" of geothermal resources which was investigated by Professor Gordon M. Reistad of Oregon State University. A diagram of his analysis will be discussed at the meeting. The analysis shows rather clearly the large potential if the resource is appropriately situated for use of geothermal in space heating and cooling. An appreciation and documentation of such ideas is one of the main reasons for this CCMS-AEC-LLL activity.

REFERENCES

1. Yarosh, M. M. et. al, 1972, Agricultural and Aquacultural Uses of Waste Heat: ORNL-4797, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 47 p.

GEOTHERMAL REGIONS OF THE WORLD

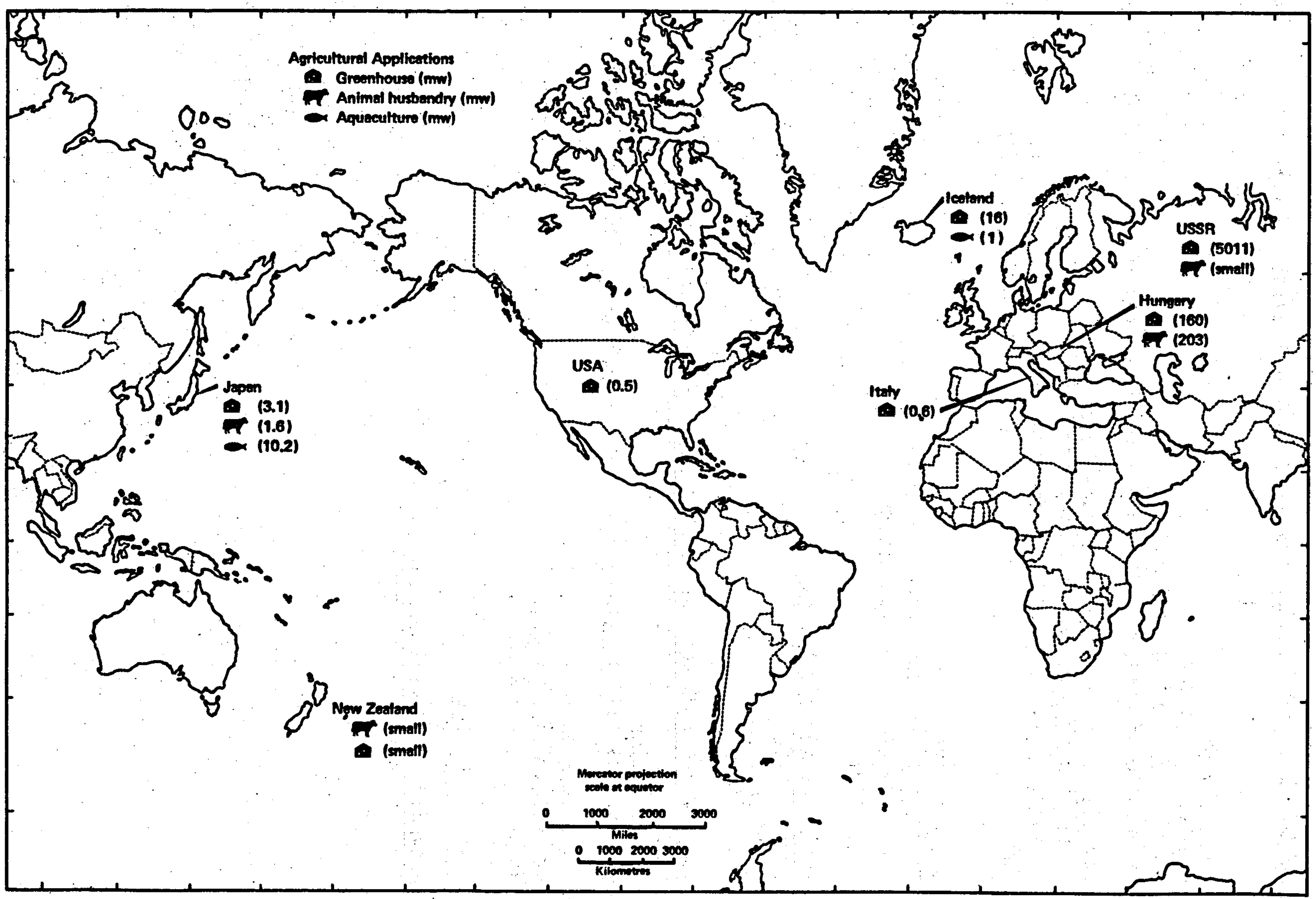


FIGURE 1

TABLE I

TABLE OF CONTENTS FOR CCMS GPS NON-ELECTRICAL APPLICATIONS PROJECT

AGRICULTURAL APPLICATIONS OF GEOTHERMAL ENERGY

Application	Country	Localities	Description of application	Power output	Assoc. power in MW	Comments	Reference
Greenhouses	Iceland	Various localities		120 T cal/year	*15.9	Glass greenhouses heated by natural steam and/or hot water. Heat use either direct or heat exchangers. **1/3 Flowers **2/3 Vegetables – tomatoes, cucumbers, lettuce Cost ~$3.80/G Cal. (1970)	Palmason, G. and Zoega, J. (1970) **Dragone, G. and Rumi, O. (1970).
	USSR	Makhach-Kala and other localities		25,000,000 m^2 56,000 m^2 of greenhouse	†5011.2	1,002,240 tons of tomatoes, cucumbers and other vegetables per year.	Tikhonov, A. N. and Dvorov, I. (1970)
	Italy	Castelnuovo		3000 m^2 of greenhouse	†0.6	Mild climate in Italy is responsible for low interest in heated greenhouses.	Dragone, G. and Rumi, O. (1970)
	Hungary	††Szentes and various localities		*800,000 m^2 of greenhouse	†160	†Typical greenhouse vegetables plus paprika. Typical horticulture	*Boldizsar, T. (1970) ††Belteky, L. (1972)
	Japan	Various localities		15,528 m^2 of greenhouse	†3.1	Horticulture – various species. Vegetables – tomatoes, cucumbers, papayas, melons, genana, eggplant. 3 types of greenhouse: glass, plastic, vinyl.	Komagata, S. et al., (1970)
	USA	Oregon		26,000 ft^2 of greenhouse	†0.48	Steel framed fiberglass greenhouse. 70°F year round – automatic environmental control system. Heat exchanger. Tomatoes.	Head, J., (1970)
	New Zealand	Various localities		Not mentioned		Mushrooms-soil is sterilized and heated by using geothermal fluids directly. Tree nursery-seedlings. Tomatoes.	Cooke, W. L. (1970) Burrows, W. (1970)

* Where 1 MW = 4.186 X 10^{-6} cal/sec.

† Where 2 X 10^{-4} MW/m^2 of greenhouse

†† Where MW = [temp of water °C – Discharge temp (35°C)] [rate of flow (ml/sec)]4.186 X 10^{-6} MW/cal/sec]

TABLE II

Application	Country	Localities	Description of application	Power output	Assoc. power in MW	Comments	Reference
Animal Husbandry	USSR	Lorinsk	Fowl runs	Small	Small	Part of the Chukotsk collective farm	Tikhonov, A. N. and Dvorov, I. (1970)
		Various localities	Needs of cattle breeding	DO.	DO.		
	Hungary	Various localities	Heating and cleaning animal shelters	25 wells at 7 X 10^6 Kcal/hr	*203	Heating and cleaning milk rooms, cattlestalls, pigsties, chicken houses	Boldizsar, T. (1970)
	Japan	Minamitzu,	Heating poultry houses, drying droppings	115°C water at 300 ℓ/min	††1.6	Yoshisawa poultry yard – heating below floor with pipes. 8000 chickens – drying droppings	Komagata, S. et al. (1970)
		Ueda, Bappu, Oita	DO.	Small		Nakamura poultry yard – DO. 1600 chickens – DO.	
		Higashusa, Shizuoka	Alligator crocodile breeding	105°C water at 2000 ℓ/min	††9.7	Alligators and crocodiles – 20 species. Geothermal water mixed with cold to attain 28° – 32°C.	
	New Zealand	Taupo	Pig farm-heating-sterilizing	Unknown but small		Geothermal steam- cook and sterilize garbage feed-warm piggeries floors at 85°F-hose pens-sterilize and concentrate waste manure-drying of sheep crutchings-boiling of sheep cuttings	Kerr, R. N. et al. (1961)
			Dry sheep crutchings	DO.			
			Dry wool cuttings	DO.			

* Where 1 MW = 4.186 X 10^{-6} cal/sec.

† Where 2 X 10^{-4} MW/m^2 of greenhouse

†† Where MW = [temp of water °C – Discharge temp (35°C)] [rate of flow (ml/sec) [4.186 X 10^{-6} MW/cal/sec]

TABLE II

Application	Country	Localities	Description of application	Power output	Assoc. power in MW	Comments	Reference
Aquaculture	Japan	Hokaibo and Kocoskina prefectures	Eel breeding	Unknown but small		Utilizing water from hot springs.	Komagata, S., et al. (1970)
		Shikabe, Makkaido	Experimental breeding station	70 1/sec at 70°C	††10.2	Hot water Hokkaido hatching center. Eels and Carp.	
	Iceland	Various localities	Experimental Salmon breeding station	7 1/sec at 70°C	†† 1	Kollafjord experimental fish farm. Rearing young salmon to the smolt stage	Matthiasson, M. (1970)
Related	Japan	Kannawa, Bappu, Oita	Drying rice	Unknown		Daily rice processing capacity = 180 Kg.	Komagata, S. et al. (1970)
	Iceland	Reykholar	Drying seaweed	80 ℓ/sec at 100°C	21.8	Drying seaweed for export	Matthiasson M., (1970)

* Where 1 MW = 4.186×10^{-6} cal/sec.

† Where 2×10^{-4} MW/m^2 of greenhouse.

†† Where MW = [temp of water °C – Discharge temp (35°C)] [rate of flow (ml/sec) [4.186×10^{-6} MW/cal/sec]

TABLE II

WHY PUBLIC POLICY MUST SUPPORT GEOTHERMAL DEVELOPMENT

By

William Brewer[1]

WHY PUBLIC POLICY MUST SUPPORT GEOTHERMAL DEVELOPMENT

Except for a few unusually attractive locations, the geothermal potential of the western states still remains largely unknown, unexplored and difficult to get covered in any effective development programs. While the essence of the Conference at Klamath Falls is an optimistic view, based on experience around the world, those of us working in public policy areas must realize that we are still at the level of small beginnings.

All the good things we say about geothermal development will be empty words unless and until we get public policy--and public money--behind sizeable programs which are keyed to utilization of new technology just as fast as it develops. Without criticizing the role of private, commercial development which is valid, most of us are aware that the proprietary and competitive nature of these operations tends to keep knowledge bottled up, and technology fragmented.

For some reason never made clear, we keep pushing geothermal development into the same category as coal, oil and gas, and other familiar mineral resources which are demonstrably better suited to private-enterprise development. As originally written, the Geothermal Steam Act of 1970 seemed almost ideal as a mechanism for limiting the diffusion of knowledge, duplicating expensive exploration and drilling, and preventing effective assessment of suspected resource concentrations on a unit or field basis.

Other papers in the proceedings have told us that some long needed improvements in the law are now at least being proposed, but the pace is far too slow. And to my knowledge we still do not have the concept being written into public policy of the geothermal resource being considered as a total resource including energy at several thermodynamic levels of utilization, water, brines, salts and minerals. My old friend, Dr. Barnea, made this point in his paper, and we would be well advised to heed his words.

The urgency of increasing both the pace and the scope of public programs stems from the essential lack of knowledge at present. We understand quite thoroughly the nature of fossil fuel resources, even the ones not yet in major commercial development, like kerogens and tars. The net available BTU's per known unit volume are defined, within known ranges. But with respect to the deeper, more diffused and more widespread types of geothermal resources, we don't even have legal definitions worthy of use. The ownership under non-federal lands is stalled at the level of state legislatures, and the publicly funded technical programs tend to be narrowly specialized at theoretical levels, or in specific site developments instead of

[1]Director, Washington State Energy Policy Council

regional assessments. Until these three constraints are removed, we will never be able to evaluate the total geothermal resource available for general public benefit.

And this is a state of affairs which cannot be allowed to continue. I do not have to instruct the reader on the declining nature of our traditional fossil fuel reserves, or on the bleak outlook for our economy if we continue to spend a billion dollars a month for foreign oil, or on the impact of high energy prices on every sector of American life, or on the severe environmental tools and secondary resource demands we face if we try to get more and more energy out of less and less of the traditional energy base.

These are some of the primary areas of concern in all public policy on energy. To the extent geothermal development can help resolve them--and as a professional geologist I believe it is a very appreciable extent--it must now become a policy matter. By this I mean there is justification for an aggressive, rather massive and completely "open-file" technical assault on the total problem, even if it doesn't pay its way, economically, in the beginning years. If we can make this case at the policy level, then we can drop the severe constraints and limitations now imposed by "ordinary" or "historic" attitudes prevailing in petroleum or mineral exploration.

The collective decision to have a successful, non-military space program was, I believe, founded on policy justifications no more urgent than the justification for a successful, national geothermal program.

By analogy, that means we have to put a difficult problem up against the wall and throw money at it. R & D money, money for deep drilling, money for the engineering of new materials and equipment, and money to upgrade the public technical agencies, state and Federal, who will assume leadership.

And it means we must take a hard look at, and make adjustments in, our institutions along the lines of legal definition, ownership and public access to technology that I have mentioned.

With each passing phase of the "energy crisis" and its social and economic upsets, I believe the justification gets stronger. Now I propose that we try to get out ahead of it in at least this one promising area. There was probably enough talent at the conference to make a good public program of technical development successful, if we can hammer out the basic policy decisions.

While I would like to have the time to discuss with you the details of how much, when and where new programs, this must be put off. But I would answer the question of "how much?" with "more." And "more of what?" with "everything."

PERSPECTIVE FOR THE 94TH CONGRESS

By

L. Kirk Hall[1]

Congress has always been the most public forum in the process of formulating national policy. Presently the Congress, the Executive, State and local governments, and other Nations as well are searching for a rational, far reaching energy policy.

This policy will provide the working arrangements and laws that will guide the development and utilization of new forms of energy and fuels. This policy must be able to make hard and difficult selections from among the many alternatives--selections which will determine our well being one year from now, five years from now and even fifty years from now.

Policy though, is not reached in a vacuum. It is the result of public pressure, adversary politics and information reaching the decision makers (information that can prove to be incorrect as easily as correct). What then is the scene that this country will have in 1975 when a new session of Congress convenes to tackle the policy questions dealing with our future resources of energy? It is useful, to review what has transpired to obtain indication of what will transpire.

New resources must supplant those that are being depleted. Even the most optimistic predictions agree that we have a finite limit of oil and natural gas--that we cannot depend on them indefinitely to underwrite our economy. As Congressman McCormack stated before the Project Independence Public hearings in Seattle, "I think it may have a salutory effect on our perspective to recognize that future historians will probably record that during the twentieth century, western man discovered and burned up as fuel virtually all of the earth's resources of petroleum and natural gas."

To provide our future energy needs, this nation is looking to:

1. Solar Energy
2. Geothermal Energy
3. Nuclear Breeders
4. Coal
5. Fusion
6. Oil Shale

---

[1]Technical Specialist, Science and Astronautics Committee, U. S. House of Representatives, Washington, D. C. The views expressed here are those of the author and do not necessarily reflect those of the Chairman of the Committee or any of its members.

Another area, while not a true resource, is most important: energy conservation. Unrestrained growth in demand in future years would outstrip the potential resources of many of these alternate sources. Efforts to conserve one percent of our available energy supplies will be more effective and much less costly than a technological effort to improve steam boiler efficiency by that same one percent. Large gains, by means of energy conservation, will take a correspondingly greater effort in cost and care. Yet by most estimates, they would remain less expensive than most high technology efforts to improve the production of energy resources in a short period of time.

Nuclear Breeders, Coal and Nuclear Fusion face many difficult technical (not to mention environment and social) tests before they become a major part of our economy. The program for Nuclear Breeders and Coal have been adequately covered in many other texts and will not be discussed here.

Nuclear fusion will need a conscious and intense effort of Federal aid to be achieved. The need for this effort has long been recognized. Prior to fiscal year 1975, the funding for research and development of nuclear fusion had reached a total of nearly 592 million dollars. The funding for this current fiscal year is 177.6 million dollars.

Oil Shale has been considered as an energy source many times since the advent of the petroleum based economy. However, the attractiveness of the resource has been primarily dependent upon the price of petroleum. With the recent price excursions, the resource has become quite attractive. Attractive enough that $210 million was bid by Standard Oil of Indiana and the Gulf Oil Corporation for the first lease of the Prototype Oil Shale Leasing Program. This lease was to develop 5,090 acres of public land in Northwestern Colorado. The leasing program is an outgrowth of a five-point oil shale policy enumerated by the Secretary of Interior in 1967, which culminated in a decision in June 1971, by the Department of Interior to start a prototype oil shale leasing program.

At the present time, no national policy exists on the integration of Oil Shale Development with the development of other forms of energy. No legislation has been enacted by Congress with regard to oil shale, though hearings have been held in both the House and Senate in the last year on the subject.

Recent Congressional activity on solar energy began in 1951 with the introduction of legislation to provide for research and development of wind energy systems. This legislation did not pass. The same fate befell a variety of bills dealing with solar energy introduced from 1951 until 1971. They provided forums for discussion but no specific federal policy was formulated. In 1971, funding for the first time topped one million dollars and began to appear as a federal research priority. In the last three years, it has increased substantially as shown in the following chart:

FEDERAL FUNDING OF SOLAR ENERGY--RESEARCH, DEVELOPMENT, AND DEMONSTRATION ACTIVITIES, BY PROGRAM AREA*
(In millions)

Program area	1971	1972	1973	1974 estimate	1975 budget request
Heating and cooling of buildings	$0.54	$0.10	$1.36	$8.20	$17
Solar thermal energy conversion	.06	.55	1.43	2.42	10
Photovoltaic conversion	.03	.41	.92	3.71	8
Bioconversion	.60	.35	.68	1.05	5
Wind energy conversion			.20	1.20	7
Ocean thermal energy conversion		.08	.23	.70	3
Workshop and program assistance		.19	.26		
Total	1.23	1.68	5.08	17.28	50

*Review of Selected Federal and Private Solar Energy Activities. Prepared by the General Accounting Office for the Subcommittee on Energy of the House Science and Astronautics Committee. June 1974, p. 2.

In the present Congress, 26 different solar bills have been introduced. Of this legislation, one can break the bills into three general categories: Heating and Cooling Research and Development; Comprehensive Solar Energy Research and Development; and Heating and Cooling Incentives, with the remainder covering a miscellaneous assortment of topics.

Congressional action has resulted in the passage of the Heating and Cooling Demonstration Act of 1974 (P.L. 93-409), which was signed into law on September 3, 1974, and the Solar Energy Research, Development, and Demonstration Act of 1974 which passed the Senate as S. 3234 on September 17, 1974, and the House as H.R. 16371 the following day. Currently a conference between the Senate and the House is underway to resolve the differences between these two bills.

The Solar Heating and Cooling Demonstration Act sets up a five-year program to demonstrate the commercial viability of solar heating and cooling in commercial buildings and private homes. The Solar Energy Research, Development, and Demonstration Act sets up the administrative mechanism for a coordinated Federal program in solar energy research, development and, where possible, demonstration. The program under the heating and cooling act would become a part of this overall program.

The Congressional interest in geothermal energy began in the Senate Committee on Interior and Insular Affairs in the early 1960's. In July and October 1963, the Committee held hearings on the national potential of geothermal steam resources. These hearings led to the introduction of a geothermal steam leasing bill which passed both houses. One of the major differences between the House and Senate versions was the omission of a grandfather clause in the version that passed the House. The retention of the grandfather clause was finally agreed to by the House. Over one year after the bills original passage by the Senate, the measure passed the Congress in October 1966. President Johnson opposed the grandfather clause and applied a pocket veto, which killed the bill. From 1966 until 1970 various attempts were made in the Congress and the Executive to work out the differences and pass leasing legislation that would be signed into law. This was accomplished on December 24, 1970, with the signing into law of the Geothermal Steam Act of 1970 (P.L. 91-581). The legislation authorized the Secretary of the Interior to implement a program to lease public lands for use in the development of geothermal resources.

Congressional interest has continued to the present where in this Congress, H.R. 14920 and S. 2465 were combined into the Geothermal Energy Research, Development, and Demonstration Act of 1974, which was signed into law on the 3rd of September (P.L. 93-410). This legislation provides for a loan guarantee program to stimulate the private sector's involvement in the development of geothermal resources and sets the policy for the Federal effort in resource assessment, research and development and demonstration of the various types of geothermal resources.

FEDERAL GEOTHERMAL ENERGY R. & D.

	Fiscal year--				
	1971 (actual)	1972 (actual)	1973 (actual)	1974 (actual)	1975 House appropriation)[1]
NSF	---	0.7	1.1	3.7	22.3
DOI	0.2	.7	3.5	2.8	10.2
AEC	---	---	---	4.7	12.7
Total	.2	1.4	4.5	11.2	45.2

*H.R. 14434, Special Energy Research and Development Appropriation Act, 1975, approved by House of Representatives Apr. 30,1974.

In 1971, the Congress began to feel the growing pressures from the lack of any coherrent energy policy. In teh Senate, "The National Fuels and Energy Policy Study," (Senate Resolution 45) passed in May. This resolution directed the Senate Interior and Insular Affairs Committee along with ex officio members from the Committees on Commerce and Public Works and the Joint Committee on Atomic Energy to conduct studies which would lead to the development of national fuels and energy policy. Subsequent hearings have been held on various energy resources.

Concurrently, the House Committee on Science and Astronautics was forming a Task Force on Energy to review the status of energy research and development in the United States. This task force worked through late 1972 and in December of that year published its findings in a report entitled Energy Research and Development. The conclusions and recommendations of the Task Force were:

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

During its year and one-half of intensive investigation on Energy Research and Development, the Task Force has become aware of the many complexities and interrelationships affecting present and future energy uses. Although recognizing the need for further careful study, the Task Force makes the following recommendations:

1. Now is the time to implement a greatly increased national energy research and development effort. Studies alone are not enough. Adequate funds and technical manpower must also be committed.

It is clear that a short-term energy crisis is upon us. But there is a long-term energy crisis which is just as real, and now is the time for making those decisions for action necessary for the long-term. Report-writing, discussion, and debate have gone far enough to identify where additional emphasis is needed. Research and development will have a great effect in solving these long-range problems, and adequate R & D programs must get underway now.

An appropriate agenda for research was developed in 1964 by the Interdepartmental Energy Study commissioned by President Kennedy. Most of the excellent recommendations from that report relative to such topics as nuclear power, substitutes for crude oil and natural gas, and environmental pollution abatement are still valid today--valid because so little action has been taken to implement them.

The total government and private funding for Energy R & D has remained at 0.15% of the GNP (about $1.5 billion now) during the nine years since the Interdepartmental report was written. This is inadequate to meet future energy needs and should be significantly increased. An additional one billion dollars annually for Energy Research and Development is needed now.

2. Organizational reforms are needed in the executive branch of Government in order to effectively coordinate and direct a greatly increased national energy R & D effort within the context of an overall national energy policy.

(a) A focal point for energy policy must exist in the White House.

This policy group should constantly review the energy situation--both short- and long-range problems--taking account of both international and domestic developments. It must take the responsibility for making policy recommendations to the President, and then overseeing the implementation of those policies (including research and development) which are promulgated. In addition to its responsibility for setting Energy R & D policy within the executive branch, if it is to be effective it must also be responsive to the Congress.

(b) An operating agency with responsibility for managing Government supported energy R & D should be established as soon as practicable.

This will require centralizing within a single organization the management of many energy R & D programs which now reside in various departments, commissions, and independent agencies. This operating agency would carry out, along with other executive agencies, the policies enunciated by the President acting upon the advice of the policy organization recommended above. The agency would answer to the Congress and its various legislative and appropriations committees in developing its specific responsibilities and in budgetary matters.

3. The issues of environmental protection and energy conservation must be paramount in any national energy policy and should receive greatly increased research and development support.

Energy consumption cannot continue to increase indefinitely into the future at its present rate, since our planet cannot cope with the vast amounts of thermal and material pollution which this would produce. Research programs directed toward more rational and efficient utilization of energy, health and safety of our people, and protection of the natural environment should have the highest priority.

Concomitant with the need for conserving energy and protecting the environment is the necessity for more careful utilization of our limited natural resources. Research and development offer great opportunities in accomplishing these goals through more effective resource recovery, and more efficient energy conversion, transmission, and utilization. Recycling of materials and the use of solid wastes as energy sources deserve substantial R & D support.

4. The Nation must set priorities among technological opportunities for investment in research and development. We cannot support all energy research and development alternatives at the levels which are suggested by their proponents. Evaluation of current data indicates the following areas of activity should have the highest priority.

(a) Basic Research

Since basic research is inherently cheap compared to applied research and development, and the basic knowledge obtained from it undergirds all advances in energy technology, the progress of basic research should be limited by scientific and technical barriers rather than financial ones. Scientifically sound research in unconventional as well as conventional fields of Energy R & D must be pursued at a vigorous pace.

(b) Materials Research

Materials Research and Devlopment including materials testing, should receive special emphasis since almost all technological progress related to energy is limited by the properties of available materials.

(c) Solar Energy

Because of its continuous and virtually inexhaustible nature Solar Energy R & D should receive greatly increased funding. Near term applicantions of solar power for household uses seem likely, and central station terrestrial solar power and satellite solar power are attractive long-term possibilities.

(d) Geothermal Energy

Because of the vast reservoirs of thermal energy located in the earth's underground water and rocks, and its widespread distribution, geothermal energy should have greatly increased R & D emphasis.

(e) Nuclear Breeders

The present effort to develop a safe, dependable Liquid Metal Fast Breeder Reactor (LMFBR) must be continued with its high priority. Breeder concepts alternative to the LMFBR must be pursued in parallel and have the same priority. Methods for safe, secure handling of nuclear fuels and safe, long-term disposal of radioactive wastes must be developed and implemented.

(f) Coal

Technologies to obtain clean energy from coal must be brough to commercial demonstration as rapidly as possible. Development of clean, economic coal gasification, liquefaction and solid coal combustion techniques would greatly reduce our dependence on oil and natural gas. Such R & D should be financed by both the public and private sectors at greatly increased levels.

(g) Fusion

Controlled thermonuclear fusion presents an exciting challenge to mankind. The enormous payoff from taming this virtually inexhaustible energy resource makes it mandatory to make the investment needed to overcome huge scientific and materials problems.

This Congress has seen a heavy traffic of energy legislation, but much of it has a piecemeal approach--resource by resource. Early in 1973, President Nixon in his second Energy Message noted this difficulty and soon after made the proposal for the Department of Energy and Natural Resources (DENR), an organization which would unify the energy programs of the nation. At about the same time, S. 1283 was introduced by Senator Jackson. Known as the "National Energy Research and Development Policy Act of 1973," this bill intended to coordinate the Federal effort in Energy Research and Development. Among its intended objectives was a determination of overall research priorities and the establishment of model corporations to demonstrate the feasibility of various energy technologies such as: coal gasification, coal liquefaction, and geothermal steam.

In an energy speech late in the Spring of 1973, President Nixon expanded on the concept of DENR with the addition of an Energy Research and Development Administration (ERDA) which would have the responsibility to direct and coordinate the Energy Research and Development programs of the Federal government. In June the President created the Energy Policy Office in the White House.

One outcome of this increased awareness was the report "The Nation's Energy Future" prepared for the President by Dr. Dixy Lee Ray, Chairman of the Atomic Energy Commission. This report was submitted on December 1, 1973, and presented a five-year, ten billion dollar Energy Research and Development Program considering nuclear fusion, fission, coal, geothermal, solar energy, oil shale, conservation, oil and gas.

This was a first in that it provided, in one document, an attempt to consider trade-offs and returns in a program that had an external total limit.

The Arab oil embargo transformed a problem into a crisis. In December of 1973, the President created the Federal Energy Office and soon called for the creation of a Federal Energy Administration to deal with the problems of allocation and supply-demand balance in the short term.

In January, 1974, the President presented a unified Energy R & D budget to Congress for the fiscal year 1975. This budget (an estimated 1.8 billion dollars) represented an 81 percent increase over the previous year, which was itself 30 percent larger than fiscal year 1973. Some areas of research went up by phenomenal amounts: Coal mining techniques: 467 percent, Solar: 262 percent, Geothermal 310 percent.

Congress in response to this unified request, considered the Energy Research and Development Appropriations as a separate unified entity--a consideration which cut across committee boundaries and jurisdiction. As a result the funding was appropriated quickly and signed into law by June 30, 1974.

These Executive actions were happening during the time the Congress was considering the proposed ERDA.

This legislation passed the House on December 18, 1973, and the Senate on August 15, 1974, in differing versions. A conference is now being held to resolve the differences.

This new agency would take the Research and Development arm of the Atomic Energy Commission along with the functions of the National Science Foundation dealing with solar heating and cooling and geothermal energy, and the Department of Interior's Office of Coal Research and those research functions of the Bureau of Mines dealing with fossil fuels, and the Environmental Protection Agency's work with advanced automotive propulsion systems and stationary power source emission control. It would also include the military weapons research functions of the Atomic Energy Commission. This organization would have five Assistant Administrators responsible for Research and Development in the areas of:

1. Fossil Energy Development
2. Nuclear Energy Development
3. Environment, Safety and Conservation
4. Advanced Research Systems
5. National Security

Running almost concurrently with the Congressional action on the ERDA legislation, has been the legislative history of S. 1283. This legislation was modified from the version introduced, during the mark-up in the Senate Interior Committee, and was passed by the Senate on December 10, 1973. The House version passed on September 11, 1974. As stated in the Floor debate in the House, this legislation would now set the policy for the non-nuclear research and development undertaken by the ERDA. The legislation creating ERDA, is merely a reorganization of governmental offices, and does not provide any specific statements of policy. While the Atomic Energy Act and its various ammendments provides the basis for policy for nuclear research, the fragmented manner of the research and development in other areas has not led to any clearly stated policy.

The Solar Heating and Cooling Act, the Geothermal Energy Research, Development and Demonstration Act, and the Solar Energy Research, Development, and Demonstration Act all have provisions that the functions to be carried out by each act will be transferred into ERDA (or any other agency having responsibility for Federal Energy Research and Development). This means that the policy enumerated in the legislation would also be transferred, thereby becoming the policy for the centralized organization.

While Congress has been considering this Executive reorganization, the House has been considering a re-organization of its own Committee structure. One of the great impediments to the development of sound policy is the fragmented manner in which energy legislation is treated by the Congress--in addition to the same sort of fragmentation existing in the Federal agencies.

The House created a special Committee on Committees to review the structure of the House and make recommendations for the reorganization if necessary. On Monday the 30th of September, the House will consider those suggestions.

The Federal Energy Administration is now in the final stages of preparation of the report on Project Independence. As stated by John Sawhill, Administrator of the FEA, in testimony this spring, "We will prepare the report by late next Fall outlining the legislation needed to achieve energy self-sufficiency and the new relationship that must be forged between government and private industry."

Legislators have been made keenly aware of the problems facing the nation in its search for alternate energy sources. Yet, presently this nation does not have an energy policy, not for renewable resources, not for conservation, not for regulation of depleting resources. The 93rd Congress will soon end. In 1975, the Nation and its leaders will have to resolve the need for the formulation of a national energy policy.

RECENT DEVELOPMENTS IN THE TAXATION OF GEOTHERMAL EXPLORATION

By

Samuel M. Eisenstat[1]

The tax consequences which flow from geothermal exploration and development still remain far from clear although certain provisions of the proposed amendments to the Internal Revenue Code should be helpful to the industry.

The basic question is a simple one: Do the provisions of the Internal Revenue Code relating to oil and gas which permit the expensing of intangible drilling costs and provide the depletion allowance apply to geothermal exploration?

There are only two reported cases on the subject and both treated geothermal exploration in the identical fashion as exploring for oil and gas. In Arthur E. Reich, 52 T.C. 700 (1969), aff'd. 454 F. 2d 1157 (9th Cir. 1972), the Tax Court found that both the depletion and intangible deduction provisions of the Code applied to exploration at the Geyers. This decision was affirmed by the Ninth Circuit Court of Appeals. In George D. Rowan, 28 T.C.M. 797 (1969), the Tax Court held that the intangible drilling deduction applied to geothermal exploration[2].

Despite these two defeats, the Internal Revenue Service continues to challenge geothermal exploration. In Charles J. Thornton, a case docketed in the Tax Court (No. 181-66) scheduled for trial in New York, the Internal Revenue Service was challenging the taxpayer's right to expense intangibles. This case was settled and discontinued. There appears to be at least one other matter presently pending involving geothermal tax treatment.

It should be clear that the Internal Revenue Service is not conceding the issue. The only way this question can be resolved is through Congressional action and amending the Internal Revenue Code to provide comparable treatment for geothermal exploration as is given to oil and gas exploration.

Congress has not come to grips with the problem. The Committee on Ways and Means of the House of Representatives has not focused on this question. It has, however, indicated a certain degree of sympathy for the industry in maintaining the depletion rate at 22% and not reducing it as is

---

[1]Counselor, Geothermal Exploration Company, New York

[2]For a discussion of these cases, see Eisenstat, Tax Treatment of Exploring and Developing Geothermal Resources, 22 Oil and Gas Tax Quarterly 76 (Matthew Bender, 1973).

the proposal for oil and gas.[1] In the proposed legislation, the Committee indicated that if depletion applies to geothermal energy, it will remain at 22% and will not be reduced. But it stops short of stating the depletion applies. The positive expression by the Committee and the acknowledged appreciation of the industry's need falls short--it is useless without an edict that depletion applies.

Another interesting aspect of the proposed legislation relates to the expensing of the intangible drilling deduction. The proposal would expand the deduction to include all geophysical and geological work. Under present law, expenditures for geophysical and geological work to evaluate a lease are not within the intanglible deduction. Only those geological and geophysical expenses relating to well site location come within the deduction.

Expenditures for general geological, geophysical and related work is significant in geothermal exploration. Much must be done in evaluating a lease and a prospect before a potential site location can even be contemplated. The ability to expense these items provides a welcome change--if the intangible deduction applies to geothermal exploration. Once again, the proposal is most interesting, but we cannot truly appreciate it since the big picture is not clear.

Private capital is necessary to develop our great geothermal potential. The same capital pool which has funded oil and gas exploration and development through joint ventures and limited partnerships is available for geothermal exploration. The recent promulgation of Rule 146 by the Securities & Exchange Commission provides an exciting vehicle for generating exploration capital on a private basis.

All of this awaits a clear simple statement that the intangible drilling deduction applies as does depletion to geothermal exploration. Only then will sophisticated investors be in a position to commit substantial funds to geothermal exploration. For only then will they be able to substantially reduce the risk in this very exciting but very risky effort.

---

[1]The proposals discussed herein are presently being considered by Congress. Although Chairman Wilbur Mills has expressed a strong desire to have the legislation enacted by the House of Representatives this session, it seems doubtful that he will succeed. In any event, it seems most unlikely even if the House passes the proposals that the Senate will act on them this year.