GL01447

Rec 8/10/90 [illegible]

Department of Energy
Washington, D.C. 20585

July 20, 1990

Dr. Paul Lienau, OIT
Dr. Howard Ross, UURI
Dr. Leland L. Mink, IWRRI
Dr. Gordon Bloomquist, WSEO

Dear Folks,

The Geothermal Division of the U. S. Department of Energy has been asked to respond to a proposed research agreement with the Hungarian Hydrocarbon Institute as part of a wide ranging research and development agreement between the U.S. and Hungary. I have enclosed some of the materials I received and the response from the Geothermal Division to the DOE Office of International Affairs.

My understanding of our requested participation in this agreement is sketchy. The Hungarian geothermal researchers want access to our researchers for the purpose of collaboration on, and review of their research work. They feel isolated from the research community and want to pursue areas of joint interest with U.S. colleagues. I received several copies of one paper published in 1985 in the Journal of Petroleum Engineering. The Hungarian researchers would like U.S. coauthors to help them publish in major journals (at the same time improving their status).

Congress is expected to appropriate $1 million/year for all joint research with Hungary, and ours will be a small part of that. I expect there will be a "project development" trip of two or three people from the U.S. to define joint projects. These trips should be paid for by the State Department. Then Hungarian researchers want to visit our researchers and see our facilities. Hopefully, the expenses of visiting Hungarians will be paid by State Dept. or some other agency.

All of this is problematical at this time; but, since your groups would be logical for collaborative research, I would like you to think (not too hard) about what could be done with Hungary. I will contact you as soon as I receive more information.

Sincerely yours,

Marshall

Marshall Reed, Program Manager
Geothermal Reservoir Technology
Geothermal Division

N. Reed Rec 8/10/90 lhr

DOE F 1325.8
(8-89)

United States Government **Department of Energy**

memorandum

DATE: JUN 14 1990

REPLY TO
ATTN OF: CE-122

SUBJECT: Interest of Geothermal Division in U.S. - Hungary Cooperation

TO: Moustafa M. Soliman, IE-12

The Geothermal Division has a research commitment to the characterization and utilization of low- and intermediate-temperature (up to 150°C) geothermal resources. Your suggested involvement of the Geothermal Division in the Agreement for Scientific and Technological Cooperation with Hungary fits well with our ongoing research. The geothermal resources of Hungary are of major historical significance, but their characteristics are only known to DOE researchers through the scientific literature.

Because of other funding priorities, the Geothermal Division will be dependent on the funding to be appropriated for this Agreement by Congress to pay the expenses of U.S. researchers visiting Hungary or for Hungarian researchers to travel in the U.S. Hungarian researchers will be welcome to visit the several research groups participating in DOE-funded geothermal research.

From the material you attached to your memorandum, it seems that the Hungarians have very limited interests for cooperation. The letter from Dr. Arpasi Miklos only mentions an interest in the generation of electricity, and we could provide contacts in industry with experience in using 100°C water to operate 2MW to 5MW geothermal power plants. Additional fields for cooperative research immediately come to mind. The high concentration of carbon dioxide in the water from some Hungarian geothermal systems indicates that the deposition of calcium carbonate scale could be a problem. We have solved the scale formation problems in several geothermal systems and could share this technology. In addition, several U.S. research groups are developing computer models of geothermal systems to predict the response to production and to estimate the useful lifetime of a resource. Many more areas for cooperation could be developed during visits by Hungarian researchers as they receive a first hand understanding of U.S. geothermal research.

Ted

John E. Mock, Director
Geothermal Division
Conservation and Renewable Energy

DOE F 1325.8
(8-89)

United States Government | Department of Energy

memorandum

DATE: May 25, 1990

REPLY TO ATTN OF: Moustafa M. Soliman, IE-12
6-5904

SUBJECT: U.S.-Hungary Cooperation in Science & Technology

TO:

Miles Greenbaum, FE-13
R. Loose, CE-34
J. Mock, CE-341

The United States and Hungary have entered into an Agreement for Scientific and Technological Cooperation. This Agreement is similar to those agreements the U.S. already has with Poland and Yugoslavia.

Funds will be appropriated by Congress for this cooperation in FY91 in the amount of $1 million which will be matched by Hungary in Forints. Energy will receive 14% of the total budget while Agricuture, NSF, EPA, NIST, and DOH will receive the rest. Thisbudget is expected to increase in the following fiscal years.

These funds will be used to fund joint research projects, seminars, workshops, and project development trips. Proposals will be reviewed by responsible DOE programs to determine programmatic interest. A program announcement describing the overall U.S.- Hungary S&T program and explaining the procedure and format of the proposals will soon be available for distribution to Hungarian and U.S. research institutions , universities and national laboratories.

During the first US-Hungarian Joint Board meeting in Budapest on May2-4, 1990, I had the opportunity to visit a number of research institutes to explore potential areas for energy R&D cooperation that can be developed under this Agreement. I have found a number of excellent opportunities in the fields of coal technology, enhanced oil recovery, geothermal energy, renewable energy , energy conservation, basic energy sciences, high energy and nuclear physics, fusion, and nuclear safety. Attached, please find the material I have gathered in your program area during these meetings.

Considering the lead time involved in developing research proposals which are of interest to us in DOE, I request that you review these documents and relay to me any specific topics that may be pursued in our future contacts with the Hungarians. Please keep in mind that in certain areas we may have to fund some project development trips before we can develop meaningful research proposals that can benefit the Hungarians as well as DOE domestic programs.

Attachments

SZKI

<u>The possibilities of geothermal energy utilization for generation of electricity in Hungary.</u>

1. <u>Geothermal energy reserves and occurances in Hungary.</u>

A typical characteristic of the area of Hungary is the strong geothermal overheating. The measurements have shown that the heat glow density makes some 100 mW/m^2 and the geothermic gradient 0.05 K/m in contrast to the world average of 63 mW/m^2, and 0.03 K/m, respectively. Beneath the surface of Hungary the earth's crust is thinning out and the elevated position of the mantle explains the higher heat content of the sediments, filling up the basin. (See Fig. 1).

The geothermic energy reserves are composed partly of the heat content of the subsurface rocks, and partly of the heat content of the thermal waters filling the porous rocks.

The geothermal energy reserves contained in the subsurface waters makes some 53.10^{18} kJ in the depth interval from 0 to

MOHO-HEAT FLOW (mW/m^2)

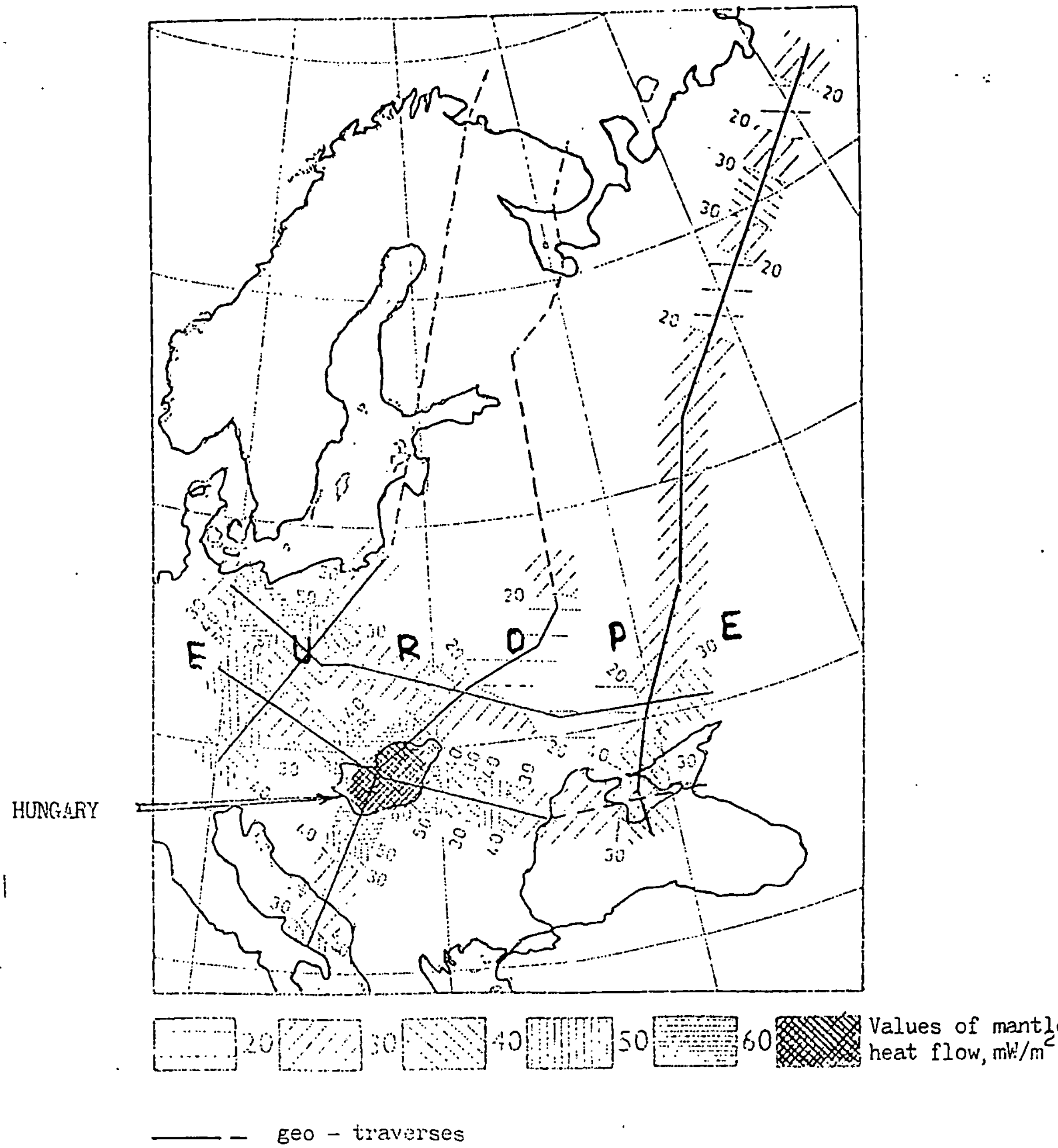

Fig.1. Regional variation of the mantle heat flow (in mW/m^2) along the considered geotraverses in Europe

3000 m. This is equivalent to $1.26x10^{12}$ tons-oil-equivalent (toe). If the interval between 3000 and 10.000 m is also considered, then the thermal energy reserves in place make some 500.10^{18} kJ corresponding 12.10^{12} toe (2). Naturally the total thermal energy in place can not be exploited fully. If 15% depletion ratio is taken into account then the recoverable thermal energy from the depth interval 0 to 3000 m makes 8.10^{18} kJ, i.e.: $0.189x10^{12}$ toe. Compared to the recoverable hydrocarbon reserves, estimated in 1976 for the same depth interval, it becomes that the thermal energy reserves are 1380 times more. This represents such a potential possibility the exploitation of which deserves much more efforts.

Geothermal energy is actually depleted from two reservoir systems:
1. regional big systems,
2. local small systems.

The two types of regional big systems, known in Hungary are as follows:

1.1. The upper pannonian sand and sandstone series of multiple horizons and reservoirs extending all over the Hungarian Great Plain (the Pannonian Basin). In the lower and middle section of the upper pannonian formations porosity may reach 20 to 30%, and in the upper section it may exceed even 30%. The reservoir pressure of the upper pannonian reservoirs is hydrostatic. The solution gas content of the thermal waters in the reservoir (hydrocarbon and CO_2 gases) is one of the most important driving factors. E.g. at Orosháza the GWR (gas water ratio) makes some 1.1 to 1.5 m^3/m^3, at Debrecen 1.2 to 1.96 m^3/m^3. The outflow temperature of the thermal waters goes up to 100 ^oC (especially in the southern, and sout-eastern part of the Great Plain). At 1600 to 2500 litre/min discharge outflow temperatures of 95 to 98 C have been often observed. The salt content in solution makes max. 2 to 4 g/lit. (mostly sodium hydrocarbonates).

1.2. Triassic fractured, fissured limestones and dolomites, sometimes partly karstic, showing vertical flow patterns. Thickness may reach 4000 to 5000 m. The fissure-fracture system is locally and vertically very variable, it can not be characterized geometrically. The formation has secondary porosity and permeability, areally varying.
The reservoir pressure is hydrostatic with usually negative static water level. The amount of solution gas is small, and the salt content also low (0.8 to 1 g/lit.). Outflow temperatures approach 100 °C locally. Discharges are usually big (1000 to 4000 lit/min).

2. The local small systems of thermal water reservoir include some levantian (pliocene) sediments, tortonian (miocene) reef limestones, and some fractured, fissured paleozoic formations. The reservoirs are of local importance. Reservoir pressures vary between hydrostatic to 100 % over-pressure. The outflow temperature reaches 130 °C (the wells Álmosd-13., Tótkomlós-14, and Nagyszénás-3 yielded wet steam). Salt content varies between 1 to 48 g/lit.

The summary of measured or estimated data in superdeep well Fábiánsebestyén-4 /1985/ (geothermal blow-out)

- Depth of reservoir	:	4239 m
- Type of reservoir	:	fissured and fructured dolomite
- Geothermal fluid	:	hot water + wet steam
- Production rate of geothermal fluid	:	180 - 300 m^3/h
- Cross section area of flow	:	casing 8 5/8" or well head equipment
- Well head temperature	:	140 - 160 °C

- Well head pressure	:	360 - 410 bar
- Salt content, g/l	:	25 NaCl
		0,82 $Ca/HCO_3/_2$
- Formation temperature	:	254 C
- Formation pressure	:	763 bar

Combining of 1.1, 1.2 and 2. type of reservoirs it becomes clear that geothermal energy is available all over the country.

In addition to the thermal energy of thermal waters, due to the heat flow well in excess of the world average, the Pannonian basin became during geological times a thermal reservoir suitable for thermal energy recovery.

3. The actual extent of geothermal energy utilization in Hungary.

It was mentioned before that the depletable geothermal energy reserves are 1380 times more than the recoverable hydrocarbon reserves.

At the end of 1986 some 1019 thermal water producing wells of more than 30 °C outflow temperature were listed, out of which 986 produced and 33 were shut off. The summarized geo-technical features for use of geothermal energy for electric power production by Organic Rankine Cycle (binary plants) in Hungary are shown in Table 1.

As well as you have been informed, Hungarian Hydrocarbon Institute to organise the field pilot test with use of a binary geothermal power unit at Zalakaros bath.

We would like to arrange the above mentioned pilot test with available power unit of your company, working by Organic Rankine Cycle (ORC).

Table 1. Summarized geo-techni cal data of geothermal energy utilization possibilities by binary plants in Hungary

Nº	- Number of geothermal wells - average depth of formations, m - lithology	type of fluids	type of flow	Production range m^3/h	Cross-section area for flow (diameter of choke), /"/	Temperatures, °C formation	Temperatures, °C at the well head (outflow temperature)	Well-head pressure bar	Salinity of fluids g/l
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
	I. Existing geothermal wells with low enthalpy fluids								
1.	Type 1. (upper pannonian)								
	- approx. 120 wells - 1800-2600 - terrigeniosus rocks	hot water	free flow (80%)	0-150 28 37 150	2 4 1/2 6	100-150	70-100	0-20	0-4 (NaCl)
2.	Type 2. (mesozoic)								
	- approx. 60 wells - 200-3000 - carbonate rocks	hot water	free flow (55%)	0-200	2 3/8 - 7	120-180	70-100	0-30	0-1 (NaCl)
3.	Type 3.								
	- approx. 35 wells - 2500-4300 - terrigeniosus and/ /or metamorphic rocks	hot water and wet steam	free flow (100%)	100-300 240	8 5/8	200-240	100-160	0-400	10-40 (NaCl) (Ca/HCO$_3$)
	Total amount of wells types 1-3: 215 wells								

Table 1. Summarized geo-techni cal data of geothermal energy utilization possibilities by lirary plants in Hungary

N^{o}	- Number of geothermal wells - average depth of formations, m - lithology	type of fluids	type of flow	Production range m^3/h	Cross-section area for flow (diameter of choke), /"/	Temperatures, ^{o}C formation	Temperatures, ^{o}C at the well head (outflow temperature)	Well-head pressure bar	Salinity of fluids g/l
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
		II. Abandoned CH wells (must be recompleted)							
4.	Type 4. - approx. 1000 wells - 1800-5200 - terrigeniosus and carbonate rocks	hot water and/or wet steam	free flow	0-300	2 3/8 - 7	80-260	70-160	0-55	mostly 0-10 (NaCl)
	Total amount of wells types 1-4: 1215 wells								

Total number of binary power units (Organic Rankine Cycle) are required for wells types 1-3:

Capacity of units:
- max. 250 kW : approx. 120 units
- max. 500 kW: approx. 60 units
- 1000 kW: and more approx. 35 units

The experimental system should be include:

- evaporator (vaporizer exchanger)
- turbine and control system
- generator (assynchronous)
- condenser
- surge tank, oil system, heaters and coolers, associated
- controls, etc.

Hungarian Hydrocarbon Institute would be required to:

- provide the geothermal well with suitable well-head
- equipment and pipe manifolding
- provide electrical switching mechanisms
- technical management for installation testing and period field evaluation test

Fundamental to Institute purchase of this geothermal power unit is that this will succesfully meet the operating parameters as specified by your company.

Successfull compliance of the operating test shall be mutually determined by regular inspections conducted by an appointed HHI engineer and your company's representative.

We hope that your company has a firm belief in the Hungarian market and the opportunities for recovering electrical power from geothermal energy which in conjunction with our company's strategic positions, presents an excellent economic opportunity for incremental power generation.

Please to evalueate our proposal. If we may be of further assitance in providing information, please feel free to contact us at your convenience.

Best regards

Dr. Árpási Miklós
advisor for president

HUNGARIAN HYDROCARBON INSTITUTE

Topic: Utilization of geothermic energy

Our subjets for the cooperative activities,

1. Modeling of vertical hydraulic fracture growth

2. A computer model for simulation of geothermic flow process
   (In connection with this topic there are two papers)

   The model consists of the following parts:

   - geometrical modul
   - fluid-rock modul
   - initial state modul
   - "time" modul
   - production modul

3. Research and development tasks relating to exploration and utilization of geothermal energy, and to the exploration of geothermal reservoirs and layer fluids

   - CH dead wells planned for the utilization of geothermal energy
   - Increase of producing thermal wells' yearly utilization factor, and increase of the energetical efficiency
   - Research of geothermal energy producing and utilizing systems

Research and development tasks in the SZKFI relating to exploration and utilization of geothermal energy, and to the exploration of geothermal reservoirs and layer fluids

1) Our tasks during putting into operation of CH dead wells planned for the utilization of geothermal energy, and/or at drilling of new geothermal wells.

- Evaluation of CH dead wells (technical condition, production capacity, etc.) from the point of view of utilisation possibilities.
  Searching of potential users.

- Design of well structures well treatment and production equipment being able for geothermal heat exploration in case of appearance of a real user.

- Elaboration of a proposal for the utili·ation of the produceable geothermal fluid, including reserve estimantion, exploration plan, application possibilities and/or their energetical and economical characterization, the possible alternative technical solutions, possibilities of the energy transformation, or transportation and their costs.

- Obtaining the necessary authority licences.

- Getting performed the instrumental examination of the well, furthermore other laboratory examinations relating to the composition and/or to other parameters of the produced fluid.

- Design of geothermal producing and/or utilizing systems, organization of their manufacturing.

- Elaboration of operational direction.

2) <u>Increase of producing thermal wells' yearly utilization factor, and increase of the energetical efficiency.</u>

- Elaboration of exploration plan, including the reliable reserve estimation.

- Elaboration of plans for well repairing, layer stimulation and other operations, and/or getting these operations performed.

- Elaboration, design and getting performed of simple, fastly realizable and cheap methods in order to solve the different technological problems relating to the production of geothermal fluid (the possible problems: water lifting, separation of contaminators, scale formation, corrosion, sand production, gas separation).

- Elaboration of plans for regular prevention treatment relating to the maintenance of operation of the equipment treating the energy production and thermal water, getting the regular prevention treatment performed.

- Organisation of service of equipment used during thermal water production (e.g. pumps, plunger pumps, heat exchangers, etc.).

- Performance of regular instrumental supervisions, water and dissolved gas examinations in laboratory.

- Elaboration of proposals and getting them performed for the utilization of heat of water flowing away, and for the improvement of their utilization efficiency.

- Elaboration of proposals for the location of return flow, and getting them realized.

- Technical and/or energetical supervision of the geothermal energy producing and utilizing system in order to improve the annual utilisation factor and that of energetical efficiency.

3) Research of geothermal energy producing and utilizing systems.

Development of geothermal reservoirs' heat exploration.

- Research of geothermal reservoirs' location by geological and geophysical methods.

- Simulation of geothermal reservoirs' thermal behaviour.

- Research of geothermal reservoirs' heat exploration methods.

- Layer fluid-exploration (simultaneous production of one or more layer(s) with ascending or auxiliary energy, and/or production with one well or well system, etc.).

- Recovery of the hot rocks' heat energy.

- Investigation for the supply of thermal reservoir's layer energy.

- Elaboration of the heat exploration's expectable figures for making economic plans.

- Investigation of corrosion phenomena being in connection with the production of geothermal reservoirs.

- Performance of examinations relating to the salt content of produced thermal water research of methods for the prevention of scale deposition demaging the user's facilities, and for its removal.

- Elaboration of methods for the cleaning of the produced thermal water (oil contamination, solid material-content, etc.), design of equipment.

- Investigation of the economical transportation of geothermal energy.

- Investigation of the effects of heat exploration being hazardous for the environment, elaboration of instructions for the protection of the environment.

Development of complex and multy-stage utilization systems of the thermal wells' layer fluids.

- Research of the layer fluids' seasonal, complex (according to layer fluid composition) and multy-stage (according to the temperature of thermal water) utilization on the fields of

  - industrial investments,
  - agricultural factories,
  - communal facilities and
  - balneological utilisation.

- Elaboration of the geothermal energy's user's price so that it could be fitted into the system of energy management by elaborating the geothermal energy's economical regulators.

- Providing information to the areal authorities being interested in the utilization of thermal water (sometimes preparation of informative materials with the aim of making it popular, for the competent institutions) and preparation of energetical proposals relating to the utilisation of thermal water.

- Handling of well documentation of wells that are able for the production of thermal water.

- Coordination of legal laws in order to make more simple the administration of thermal energy utilization, and elaboration of a rational administration system.

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EUROPEAN COOPERATIVE NETWORKS ON RURAL ENERGY

RÉSEAUX COOPÉRATIFS EUROPÉENS POUR LES ENERGIES RURALES

REDES COOPERATIVAS EUROPEAS SOBRE FUENTES DE ENERGIA RURAL

Rural Energy Country Review

JUNE 1989 NO:2

PRESENT STATUS OF GEOTHERMAL ENERGY: USE IN AGRICULTURE OF HUNGARY

Karai J., Kocsis K., Liebe P., Nagy A., Ottlik P. (Hungary)

Aquifers yielding thermal water above 50 C° in Hungary

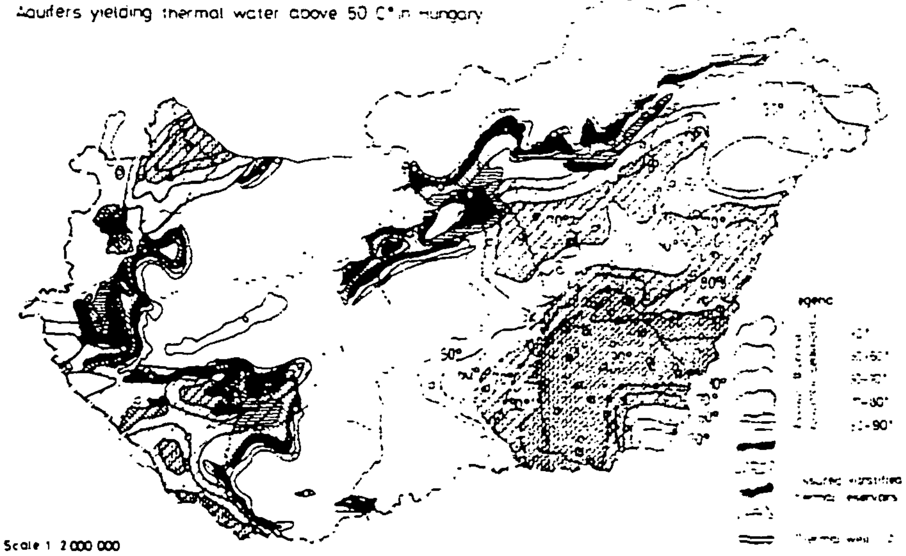

Fig. 1.: Aquifers yielding thermal water above 50 °C in Hungary

Research Institute for Water Resources Development
Budapest - Hungary

June 1989

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PRESENT STATUS OF GEOTHERMAL ENERGY: USE IN AGRICULTURE OF HUNGARY

Karai J.[1]

Kocsis K.[2]

Liebe P.[3]

Nagy A.[4]

Ottlik P.[5]

1. Karai J.: Professor and leader of the Mechanical Institute on the University of Horticulture, Budapest
2. Kocsis K.: Energy Network advisor, FAO Regional Office for Europe, Rome
3. Liebe P.: Department leader in the Research Institute for Water Resources Development, Budapest
4. Nagy A.: Hydrologist in the Research Institute for Water Resources Development, Budapest
5. Ottlik P.: Advisor in the Institute for Energetics, Budapest

1. INTRODUCTION

The FAO European Cooperative Networks on Rural Energy (CNRE) comprises seven Research Networks, viz., Energy Conservation in Agriculture, Production and Conversion of Biomass for Energy, Utilization of Solar Energy, Wind- and Hydropower in Rural Sectors, Integrated Farm Systems and Agricultural Use of Thermal Effluents, the latter including two working groups which deal with the

- Use of Geothermal Energy in Agriculture and
- Use of industrial Thermal Effluents in Agriculture.

In accordance with the general objectives of the CNRE R+D programme, both working groups have organized several technical consultations and workshops to promote the international exchange of technical-scientific information. The main subjects of these events were the presentation of, and discussions on, the results achieved at the pilot projects established and the operating experience gained at the producing plants using geothermal and waste heat in greenhouses. As a result of the cooperative research activities several reports and proceedings have already been published and disseminated, which contain the papers presented and the main conclusions arrived at during these events. The information made available by the participating countries served as the basis of the State-of-the-Art Study on the Geothermal Resources and their Use in Agriculture in Europe.

At the Third Joint Workshop on the Use of Solar and Geothermal Energy for Heating Greenhauses (11-14 April, 1988, Adana, Turkey) a group of Turkish experts presented the first of the CNRE Country Reviews on the "Present State and Prespectives of Geothermal Energy Use in Turkish Agriculture". The document was received with great interest by the members of the working group, as it presented a clear review of the current state of the geothermal resources in Turkey, their potential uses in agriculture and contained also recommendations concerning the wider practical introduction of the existing geothermal heating technologies. Encouraged by the positive experiences the Workshop recommended to extend the country reviews to other countries and subjects as well. The coordinators and cooperating experts of CNRE have expressed their appreciation to the Group of Hungarian Authors for their efforts at compiling the second Country Review.

This document offers a brief overview of the geology of the geothermal resources, further of the results achieved in Hungary in the agricultural uses of this important, renewable kind of energy. The primary aim of this document is to present general information to the scientists, development engineers and decision makers involved in national programmes, but it may be useful also to the professionals of other countries where large geothermal resources are available, but cannot be used in agriculture without addition technological know-how. This document, translated into the languages of several cooperating countries, is expected to find access to farming operations, just as to the institutions involved in agricultural and geothermal development, contributing thus to the spreading uses of geothermal energy for agricultural purposes in Europe.

2. The geothermal resurces of Hungary

Several papers have already been published in English on the results of the extensive studies performed thus far on the favourable geothermal conditions in Hungary. Without mentioning details, these have revealed that - as demonstrated by seismic measurements - the lithosphere under the Carpathian Basin is abnormally thin. Consequent therefrom the geothermal heat flux of 80-100 mW/m^2 is above the average for the continent and the geothermal gradient of 18-25 m/^{o}C is steeper than the normal 30-33 m/^{o}C value.

The fact that the subsiding area was covered by a closed freshwater lake during the late Tertiary Period contributes to the favourable situation in this respect. Subsidence and sedimentation occured at largely the same rate, as a result of which porous sand layers of large extension and containing syngenetic water are also present in the thick sediment formation thus developed. In the deepest parts of the basin such sandy layers have been found even at depths greater than 2000 m.

Owing to the lacustrine, littoral facies, as well as to the oscillating rate of subsidence the porosity and permeability of the layers vary in an irregular pattern both horizontally and vertically.

In these sandy aquifers, at the boundary of the Lower-Pannonian strata the water temperature rises consistently with depth. The highest aquifer temperature registered thus far was 140 ^{o}C.

Over 90 per cent of the thermal waters presently used are withdrawn from this reservoir at the highest surface temperature of 97 ^{o}C. Favourable conditions have encouraged the development of standard methods including water treatment processes and operative projects for the use of thermal waters.

Besides this hydrogeological-geothermal system consisting of the sandy reservoirs within the basin, large volumes of water are stored also in the Upper-Triassic limestone and dolomite rocks forming the basement of the basin. The water percolating downward from karstified outcrops and along tectonic zones is heated in accordance with the geothermal gradient, so that in the areas, where the basement is situated at depths greater than 1000-1500 m thermal waters can be withdrawn from these formations as well.

The elevated intake areas and the hot waters contained in the deep karstified rocks form an autoregulated hydrodynamic system, in that the heated water of reduced specific gravity tends to rise and emerges to the surface along faultlines at elevations lower than those of the intake.

Substantial differences exist between the two hydrological-geothermal systems:

a. In the porous, sandy reservoir the flow of water is unobstructed, attains velocities of 1 to 10 cm/year, whereas in the fissures of karstic rocks this may be higher by several orders. Depending on the degree of fracturing, the permeability of karstified rocks and sands ranges between the orders of 10^{-2} - 10^{-4} and 10^{-3} - 10^{-6} m/s, respectively.

b. Great depth and overlying impervious clay formations prevent virtually any surface precipitation water from reaching the deep sandy aquifers. Lateral inflow and compressible storage in the secondary rocks are thus the major sources of recharge.

It should be clear from the foregoing and still emphasized separately that the geothermal energy which can be recovered from the thermal waters withdrawn in the Pannonian Basin is a virtually non-renewable source. This fact is demonstrated also by the regional depression developed in the SE part of country, where thermal waters are withdrawn at the highest rate. Measurements have shown the pressure in the layer to have dropped over the past 10 years at the annual rate of 0.1 - 0.2 bars (0.01 - 0.02 MP) so that the yield from originally free-flowing wells has decreased drastically and pumping had to be resorted to at most of them.

Mention must finally be made of the fact that some deep boreholes sunk to below 3500 m depth in recent years have demonstrated the presence of high-enthalphy resources in the Carpanthian Basin. In the absence of complete hydrodynamic studies, no more than the parameters registered at the well heads are available on these. Wet steam of temperatures between 200 and 300 °C and pressures over 100 MPa and with a very high salts content emerged from this reservoir to the surface. Additional measurements are needed to explore the conditions of, and to estimate the magnitude of the resources stored in these formations.

Of the three types of geothermal energy resources those stored in the sandy aquifers situated at the Lower-Upper Pannonian boundary and available for development over two-thirds of the country have been explored by boreholes sufficiently to permit reliable estimates of their volume and potential.

The data on these resources are indicated on the attached map, compiled at the Research Center for Water Resources Development, VITUKI - and in Tables 1. and 2. The geographic situation of the reservoir is clearly visible from the map, whereas the magnitude of the resources is shown in Table 2. in the form of fractions, the numerator of which represents the volume of thermal water developed and consumed already, the denominator that still available for development.

It should be noted here that in Hungary any water emerging to the surface with a temperature higher than 30 °C is termed officially as termal water. Owing to energy considerations only those warmer than 50 °C have been included as resources in the present report.

The volume estimation date back to 1982, so that the figures are no more fully accurate, but reflect well the geothermal potential in the country.

3. Distribution of the geothermal fields in Hungary

No geothermal fields complying truly with conventional geologic terminology can be distinguished in the Pannonian Basin. Fields are normally defined by the deposit of some useful mineral (petroleum, coal, etc.) with finite extension so that these can be confined by an accurately traced boundary or by negative boreholes. In the Pannonian Basin the principal thermal water reservoir situated under the largest area and yielding water of the highest temperature is - as mentioned before - the formation situated at the Lower-Upper Pannonian boundary, which contains relatively loose sands of high permeability. Besides representing a single large unit, this communicates also with the water horizons situated closer to the surface. The thermal water system extends thus practically from the surface down to the Lower Pannonian clay formations. The successive horizons thereof communicate with each other hydraulically through windows between the interstratified lenticular clay layers.

From the foregoing it will be perceived that virtually no sharp boundaries can be drawn between the thermal waters explored. The thermal water resources are situated over a large area in the main reservoir, differences being observable - at the same depth - in the yield capacity alone. The water temperature was found invariable to increase with depth.

The salt content of the waters stored in the Pannonian thermal aquifers increases normally with depth, but owing to the freshwater origin retains throughout its alkaline-hydrocarbonate character.

Owing to their seawater origin the very slight pre-Pannonian thermal water resources are characterized by a high chloride content.

These resources are, however, too small and contain salts in too high concentrations to be of practical significance.

As mentioned before, no thermal water fields or areas proper can be distunguished, so that it is deemed more correct to speak of thermal water occurrences, although these are not separated from each other by natural parameters, but rather by the influence radius of depression range of the wells developed.

The location of the areas termed thus as occurrences is defined primarily by the wells drilled in response to user demands and by the level of exploration. The demands for power and heating purposes can be met most expediently by using water of the highest temperature available. For this reason users have attained the highest level, where water of the highest temperature and the required volume could be developed. These areas are situated over the deepest parts of the basin in the SE regions of the country.

In the foregoing sense the Szentes geothermal area may be mentioned where 36 thermal wells are being exploited within the town region. Another similarly favourable area is the region of Szeged town, where over 14 wells are operated. The occurrence at Makó, Hódmezővásárhely, Szarvas, Mosonmagyaróvár and several minor geothermal sites are deemed also worthy of being mentioned.

The situation of the users of geothermal energy and geothermal areas is often fortuitous, since most thermal wells have been developed from unsuccessful hydrocarbon exploratory boreholes, the sites of which had been selected for their hydrocarbon potential, rather than by the considerations and needs of thermal water development. The initial encouraging results of users have prompted them to drill additional wells increasing thus the amount of energy to the desired level.

The fact that thermal waters are used primarily in agriculture for power development purposes is attributable in part to this reason. Domestic-communal district heating projects follow next, with wells drilled already close to the demand center (Table 3.). According to statistics, the majority of thermal springs and wells is used in balneology, for medicinal baths, but these yield normally waters in the 30-50 °C temperature range, which are not directly accessible to power development purposes.

The foregoing conclusions are reflected in Table 2. by presenting the values of the geothermal potential by geographic areas. Moreover, as clearly shown by the map attached, these areas communicate with each other and are delineated by the sedimentation (depth, porosity) and hydrologic (infiltration-upward flow) conditions in the basin.

Large volumes of karstic water are stored also in the karstified basement rock which again forms an integrated hydrologic system where no particular fields can be distinguished. Withdrawals from this reservoir by boreholes are confined to minor areas, so that its total volume is difficult to estimate. Examples of these areas are Szigetvár, Zalakaros and Komárom. The lower extent of exploration implies at the same time that the total volume of water used is substantially smaller than that of the flow withdrawn from the main reservoir, the Pannonian sands.

The thermal wells are grouped according to areas and purposes of development in Table 3. presenting the 1985 data, the variations over the last 10 years and capacity available in 1985 (data of the National Water Authority, OVH).

A grouping of the thermal wells according to well head temperature is presented in Table 4. (data of the National Water Authority, OVH).

4. USES OF GEOTHERMAL ENERGY IN HORTICULTURE AND AGRICULTURE

In Hungarian agriculture energy is consumed at the annual rate of 20 TWh (1,7914 . 10^6 t OE), of which. The share of horticulture is 3.5 TWh (313,495 . 10^3 t OE), including 2.5 TWh (223,925 . 10^3 t OE) for heating purposes, of which 1.8 TWh (161,226 . 10^3), or 72 per cent, are recovered from thermal waters. Of the total energy consumption thermal energy is thus responsible for 9 and 51.4 per cent in agriculture and horticulture, respectively. Thermal waters provide at the present over 80 per cent of the energy demand at the vegetable farms.

Besides greenhouse heating, thermal waters are used also at animal farms, for domestic heating and hotwater supply, but these amount to no more than 5 to 8 per cent of greenhouse heating. The percentage water resources actually used is 20 in terms of volume, or 23 if expressed in terms of thermal energy. This difference reflects the preferential use of waters of higher temperature. Warm waters are used for heating purposes at an efficiency of 50 per cent at farms only, where the heat is recovered in several stages or for several purposes, such as space and ground heating, in greenhouses irrigation water heating, hot-water supply for domestic purposes, etc.

Unsuccessful hydrocarbon boreholes developed into thermal wells are the main source of thermal waters in Hungary, though some wells are drilled to meet higher demands. Negative boreholes are available to farmers at a nominal, very low price, making the capital cost of development highly attractive. Although additional wells are very expensive to drill, these costs are reimbursed in 5 to 6 years thanks to the absence of fuel costs.

The commercial vegetable farms in Hungary are at least 10-12 hectares in size, while ornamentals are grown on areas of at least 6-8 ha to be profitable. The thermal energy needed for similarly large areas can be produced from groups of wells alone, each group comprising several wells, connected by a ring header. The pumps are operated according to a schedule depending on the actual energy demands.

New wells are normally free-flowing as long as the artesian head drops below the terrain level. Beyond this point pumping must be resorted to for obtaining the required flow.

A pumped thermal watersupply scheme is illustrated in Fig.2. Here water is withdrawn by deep-well pumps from three wells on the site which discharge through an atomizer to the de-gassing unit. The water flows therefrom by gravity to a collecting tank and is pumped then to the heaters in the greenhouses. The return flow from the greenhouses has still a temperature of 40 °C. Well water of 82 °C temperature is added to obtain water of 60 °C temperature which is then pumped to the heat exchangers of the foil tents. The 25 °C

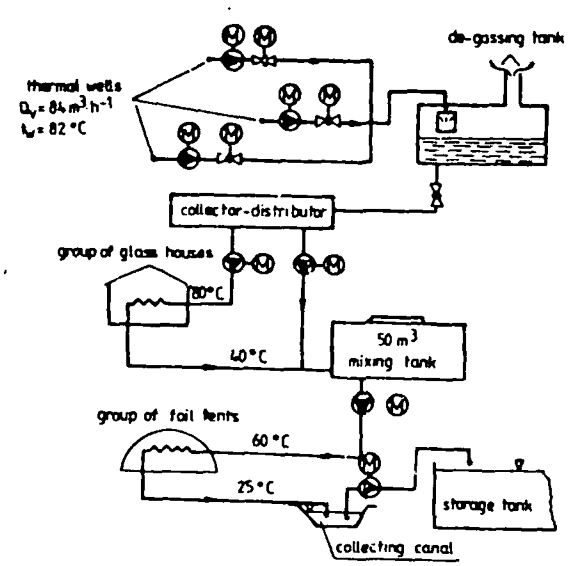


Fig.2.: Scheme of complex geothermal heating system consisting greenhouses and plastic tents with three wells

warm effluent from these latter is collected in a drain canal then lifted into a foil-sealed earth basin.

The water is released therefrom at regular intervals to a nearby recipient as specified.

Conventional radiators fed by forced circulation are used to heat greenhouses. Although the water is de-gassed at the wells, the air vents are usually more generously dimensioned than with conventional water heater systems. Ice and snow on the roof or in the down-pipes can also be melted. Some foil tents are heated using conventional radiators situated along the sides and also corrugated plastic piping placed horizontally on the ground (Fig.3). This is called the vegetative heating system and the water from the radiators is passed through it. These pipes have a total length of 100 m and consist of three sections, the diameter of which increases with the temperature drop. The diameters are 1/2", 3/4" and 1", respectively. The discharge from the heating system at 25°C is collected in an open drain and pumped into the basin.

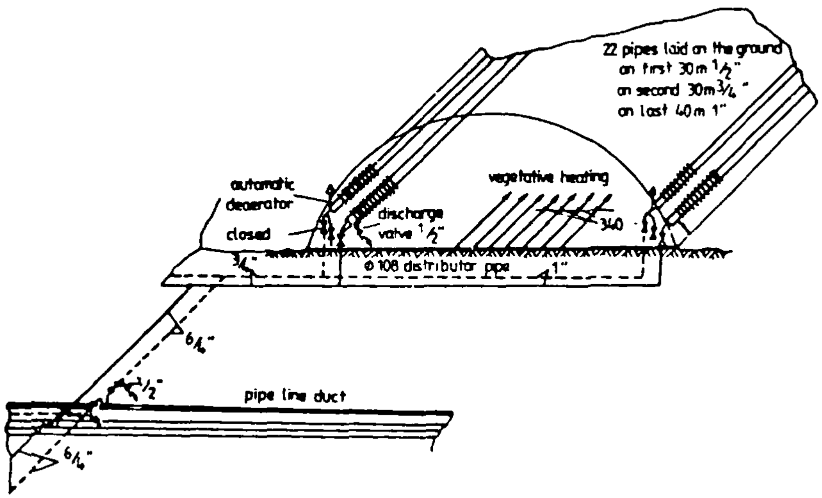


Fig.3.: Scheme of vegetation heating system

The heating system of foil houses used for growing seedlings is shown in Fig.4. Space and soil heating are installed in combination here. The dimensions of the soil heating arrangement are also indicated in the figure. The ends of the soil heating pipes are raised

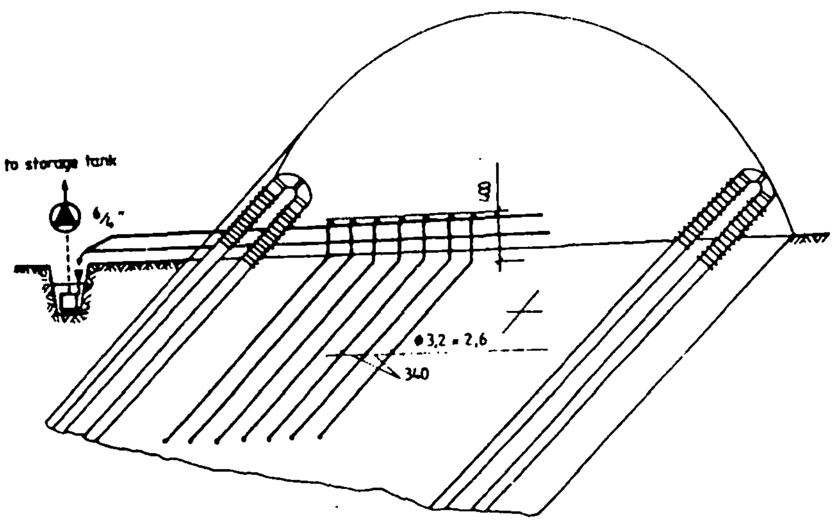


Fig.4.: Scheme of system with the combination of space and soil heating

slightly to ensure that the pipes are always completely filled with water.

The gravel-bed soil heating system is illustrated in Fig.5. These are installed experimentally in two foil tents of 100 m length each. The soil is excavated to 430 mm depth under the foil tent. Three layers of sealing foil are spread over the flat base and covered with a 100 mm thick gravel layer. This serves as the base of an 80 mm thick concrete course. The 250 mm thick topsoil is placed on the concrete course. Hot water is distributed in the gravel layer through 22 perforated plastic pipes of 32 mm diameter. The gravel bed is heated to water temperature and the heat is transferred across the concrete course to the soil. The heat flux to the soil attains 80 - 120 W/m^2 and additional space heating becomes necessary to meet higher demands. Thanks to the relatively high heat capacity of the concrete course and the soil, the resulting heat pattern is a uniform one and is thus eminently suited to growing crops which prefer a warm root zone.

One of the most several problems encountered in the use of thermal water wells is that the decreasing pressure in the vicinity of the surface tends to promote the formation of gas bubbles and the precipitation of salts. This in turn results scale deposits in the gate valves and in the well head, further in reduced flow and heat transfer. This phenomenon is frequently observable at wells yielding wa-

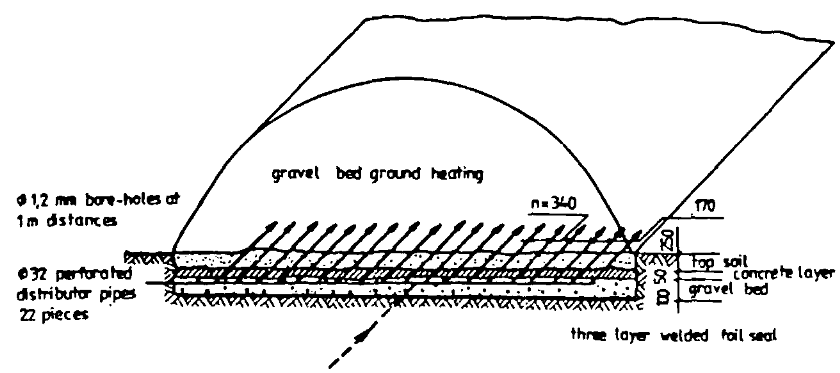


Fig.5.: Soil heating by pebble bed

ter above 50 °C temperature. The mineral salts were formerly allowed to precipitate in a cascade settling tank installed after the degassing unit and water was pumped from the last tank which yielded the cleanest effluent. High-rate wearing of the pump impeller and the stuffing boxes occurred where the settling tank was omitted.

This method of settling proved impracticable, where water was produced by means of submersible, or other types of pump mounted in the well, since the zone encrustation and gas separation extends down to the foot valve of the pump. This is the depth, where the head and, in turn, the partial pressure of the dissolved gases, as well as the solubility of the mineral salts decrease to a level conducive to separation and precipitation. A water softener is therefore added - and this is the solution most commonly adopted in Hungary - preferably ahead of the pump impeller.

The installation of a pump was observed repeatedly to decrease the rate of scale formation. The relatively cheap chemical sodium polyphosphate is widly used in Hungary for water softening. The technique thereof was developed and patented in Hungary at Szentes (Fig.6). The principle underlying this technique is that the softener, e.g. sodium tripolyphosphate, is fed through screens and a valve from a tank to a point situated below the foot valve of the pump. This has the advantage that no external energy is needed for feeding the chemical, since the gases escaping in the depression zone of the well are ducted to the top of the chemical mixing tank, creating thus a closed system, where the pressure in the chemical mixing tank is equal to that prevailing in the well. By balancing the pressures in this way, the softener flows by gravity into the well. The rate of chemical feed can be controlled by the valves with an accuracy adequate for practical purposes.

Fluctuating heat demands are met in several ways, depending on the heat source. A single free-flowwing thermal well with a well head pressure high enough to raise the water into the de-gassing unit can be controlled by throttling effected either manually or by motor-driven gate valves. Withdrawal from a pumped well is controlled by operating the pump intermittently, whereas the pumps in a well group are switched on successively again by manual, or au-

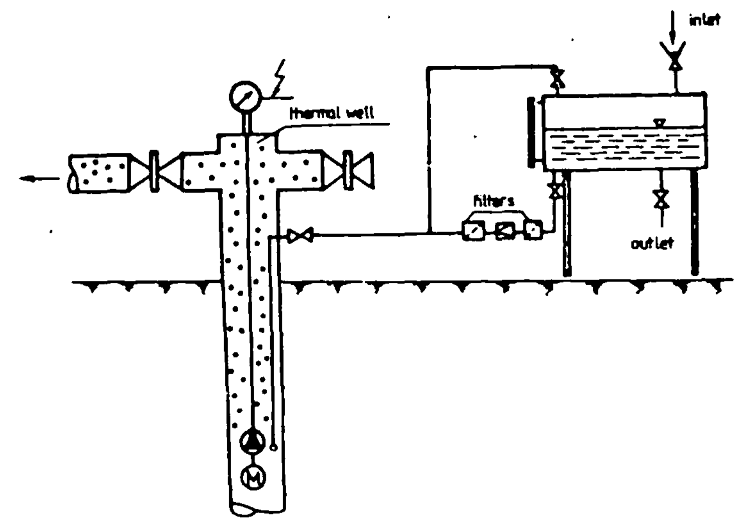


Fig.6.: Scheme of self regulated water treating system

tomatic control. Manual control has been found to consume more energy than required. The virtually free availability of thermal water is another factor conducive to overconsumption.

A variety of automatic control methods have been introduced recently, or are contemplated for this reason at several farms. Experience has shown that the capital costs thereof are reimbursed within a brief period of time thanks to the energy saved and the increment crop yield realized through more accurate temperature control. E.g. for a group of three wells the return period has been estimated at one year.

The block scheme of automated control is illustrated in Fig.7. The pumps mounted in the wells, or motor-drived gate valves are controlled of the water level in the gas separator. One, two or three wells are pumped, depending on the actual demand. A sand sensor is mounted invariably into the header connecting the wells, which acts first to throttle the pipe cross section then to stop the pump whenever the turbidity of the discharge surpasses a preset limit value. A flow meter may also be installed optionally into the header to check

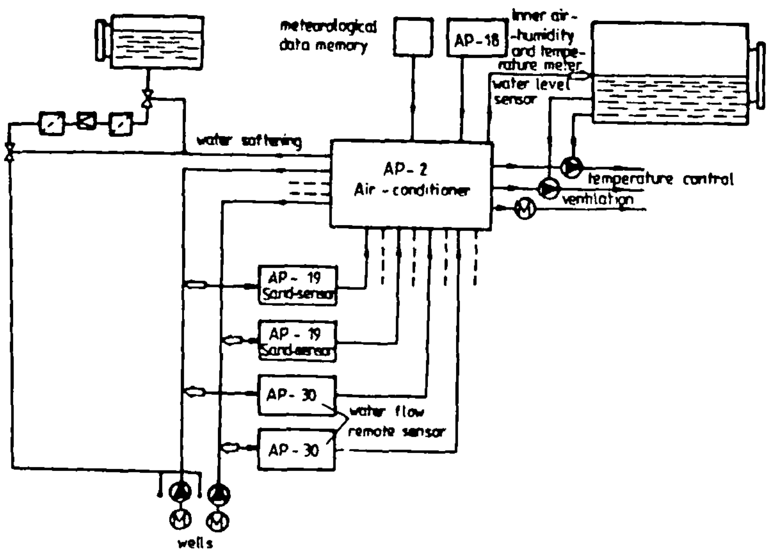


Fig.7.: Computer controlled geothermal heating system

consumption, though this is not essential, since owing to the constant pump discharge, the volume withdrawn can also be estimated from the time of operation.

The pumps connected to the header may be controlled sequentially in terms of external parameters, such as solar radiation, ambient temperature, wind speed or rainfall and the temperature within the greenhouse. The pumps drawing on the mixing tank, which deliver water according to the heat demand of the foil tents of the farm, are also controlled on the basis of the external parameters. A waterlevel control is used to actuate the lifting pumps in the return canal. Of these two should always be mounted, one serving as the stand-by unit, since any breakdown will involve the risk of the entire farm becoming flooded.

In automatically controlled pump operation water softening can also be automated in accordance with operation, since upon starting the pumps an opening signal is emitted to the magnetic valve installed into the feed pipe from the chemical mixing tank. The valve is kept open as long as water is delivered from the well(s). Otherwise the softener is operated continuously, or must be controlled manually.

The automated heating system can be supervised from a single control cabin and operates substantially without attendance.

Two parallel safety are incorporated into the automated control device, in case of any breakdown the sub-system affected is shut down, the stand-by unit is started and simultaneously a warning signal is emitted to the control centre indicating not only the breakdown, but also location and thereof. Thermal waterworks involving withdrawal pumps and pumped water softening have the additional advantage that heating can be dimensioned by techniques similar to those used in boiler heating. Encrustation and drop in well head pressure have been observed formerly to cause well flow losses of up to 150 - 200 $l.min^{-1}$ meaning that after five years a well yielded no more than one-half of the original energy supply.

5. Development potential of geothermal energy resources in Hungary

The development of geothermal energy in Hungary is controlled on the one hand by the availability of resources, on the other hand by the possibilities of improving the efficiency and technological level of the techniques, devices and equipment involved.

The thermal water resources in Hungary, i.e., the water stored in the pores of the thermal water reservoir formations from which water above 30 °C temperature can be withdrawn, are estimated at round 2500 km^3. The majority thereof is stored in the porous formations under the basin areas. Not included in the foregoing figure are the highly saline waters present in the layers older than Upper-Pannonian, whereas the round 50 km^3 stored in the fissured rocks are comprised.

In terms of the average temperature on the surface the thermal energy of the 2500 km^3 large thermal water resources is equivalent to 5.73 x 10-20 J (1,42 . 10^{10} TCE). Together with the heat stored in the skeleton this thermal resource is estimated at 2.6 times this value, and may be up to 10-fold when the amount of heat stored in the non-aquifer rocks is also added.

The present level of exploration and development is far below the potential. The 1067 wells (as of Jan. 1.1987) yielding water warmer than 30 °C represent an original capacity of 1337 thou. m^3/d, but the actual withdrawal should be 500 thou. m^3/d only. From the data of measurements on the wells the total volume of thermal water withdrawn thus far is estimated at 2.6 km^3, round one-half of which originates from storage, the other half from recharge contributed by cold or moderately warm groundwaters. The current yields and uses of the wells are shown by temperature ranges in Table 5.

As a consequence of abstractions the pressure drop in the majority of reservoirs has attained values between 0.1 and 0.5 MPa.In many areas free well flow has ceased and withdrawal by pumping had to be introduced. The highest pressure drop was observable in areas with a number of closely spaced wells, thus in the regions of Szentes towns in Csongrád Country, with values indicated in Fig.8.

The drop in layer pressure imposed an obstacle to the development of geothermal energy. The operational problems encountered thereupon have focussed attention on the importance of more detailed hydrogeological studies and geological explorations on the thermal water reservoirs, including the prediction of anticipated head losses caused by continued and increased rates of abstraction. Regional hydrogeological modelling was initiated on the basin areas in the interest of development. In these models the deep thermal water reservoir is subdivided into several horizons - which communicate with each other vertically - and the changes caused by future abstractions are simulated for each of these using numerical methods. The 10 by 10 km grid of the model presents a fair approximation of the ensuing pressure conditions, but the local effects must be fitted by a variety of techniques into the smoothed depression field produced by the model. The hydrogeological parameters of the model are obtained from the number of boreholes sunk in the basin areas. These parameters are currently being verified by simulating the pressure conditions pertaining to the present withdrawal rate and the verified model will be suited to studying the pressure conditions under different withdrawal strategies. The use of the model is expected to provided eventually an estimate on the magnitude of the thermal water resources available under different conditions. Completion and regular application of the model is scheduled for the next few years.

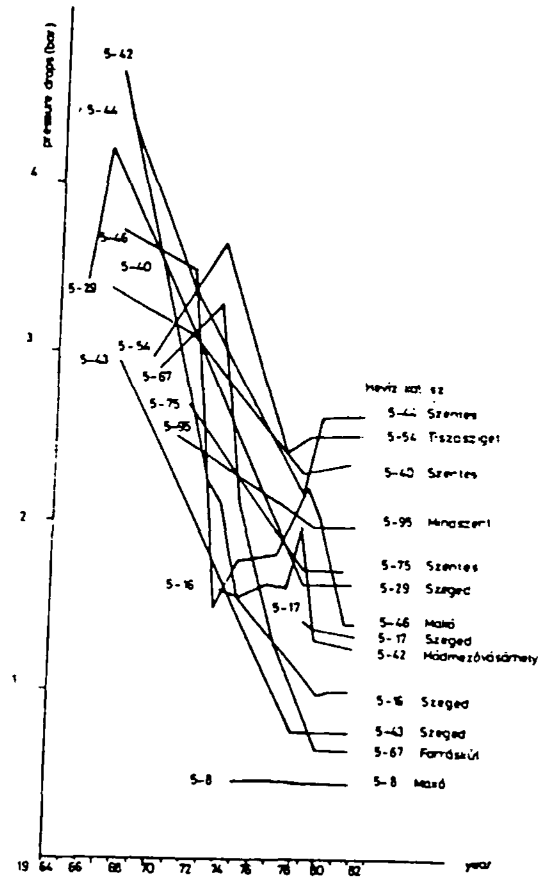


Fig.8.: Highest pressure drops in region of Csongrád county

As mentioned already the drop in free-flowing well yields due the reduction of the piezometric head has prompted a change-over to some kind of pumped withdrawal. Underwater pumps capable of handling waters of high temperature have become recently available, but limitations may be imposed on their use. The water resources available can be increased manifold over the original value by pumped withdrawal. At drawdowns of 100 to 200 m production could be increased five-fold, but this is limited by the load considered acceptable on the recipients, and in the case of replenishment from drinking-water supplies, by the allowable rate thereof. At the same time, inadequate designs of old wells, or their modification presents difficulties to the introduction of pumping.

The problems presented by the disposal of cooled effluents deprieved of their thermal energy are severe enough to prevent any substantial increase of withdrawal. Acceptable solutions to the disposal problem are absolute prerequisites of any further development. In areas, where there is no recipient stream or canal of the required flow rate available in the vicinity of the well, and where the thermal water carries a high salts content, this problem is virtually impossible to solve. The potential solutions for the disposal of minor effluent volumes include temporary storage and infiltration, although the latter may jeopardize groundwater resources. Reinjection into the aquifer appears to offer the solution for the disposal of thermal waters warmer than 40 °C, or having salts concentration higher than 2000 mg/l, which is regarded optimal from the viewpoints of environmental protection and water management alike. Recent reinjection trials in Hungary have revealed the technical feasibility of, but also the difficulties associated with, this method , although the increased costs render its economic feasibility questionable. For reinjection to be successful the effluent flow should arrive at a largely uniform rate and must contain virtually no suspended matter. The results of the same trials have shown thermal effluent reinjection to be uneconomical once the reinjection well head pressure is higher than 2 MPa.

The available water resources could be multiplied in volume by reinjection into the aquifer, though at appreciably higher capital and operating costs. One of the potential solutions in purely energy oriented development would consist of introducing the effluents of lower salts concentration level into coarser grained layers in the cover, enhancing thus the drinking water resources. This solution offers, evidently, no remedy to the head drop in the thermal water aquifers.

As a brief summary it seems safe to conclude that further thermal water development is limited by technicoeconomic, as well as water management considerations. However, reinjection of the effluents will answer these latter. Detailed geological-geothermal explorations are prerequisites to any major increase of the present withdrawal rates.

Another potential avenue of increasing the uses of geothermal energy involves the advancement of technology, with the aim of encouraging more rational uses of this non-renewable resource. As mentioned before, this presumes the introduction of techniques and equipment by which the withdrawal rate can be lowered exactly to the level at which the actual heat demand can be satisfied.

These include automatic valves and gates in the case of free-flowing wells and speed regulation for pumped wells. Any widespread introduction thereof depends substantially on the availability of financial resources. The creation of an economic environment in which the operator is interested in such savings may offer a solution to the problem.

Heat pumps have not been applied in Hungary thus far. Such devices would promote development in two directions, provided that they could be purchased at reasonable prices and could be operated economically.

In a geothermal heating system the heat pump would, on the one hand, improve efficiency by improving heat recovery from the liquid by Δt. On the other hand, the water of higher, 50 - 55 °C temperature could be used at higher ambient temperatures to substitute for thermal water, saving thus these resources. Another advantage of the heat pump would be the possibility of cooling, improving the uniformity and economics of well operation.

Higher complexity levels of use may also be mentioned among the development possibilities. These depend, however, on the opportunities and demands at a particular site.

Considerable advancement could be expected finally from the widespread application of radiation heating system, e.g. floor heating, which utilize a moderate-temperature energy carrying medium. This would make the energy of the 30 - 35 °C thermal water resources available for development.

6. Technico-economic and social aspects in the promotion of geothermal energy development and its uses in agroculture

The problems associated with the production and use of geothermal energy are general in nature and impossible to separate from those observable in the agricultural sector. It is deemed advisable to mention first those of most general, i.e., social character. The fundamental obstacle to the more widespread production and use of geothermal energy is that there is no state agency in Hungary that would be responsible for this kind of energy. Consequent therefrom no officially approved development policy or plans exist and no funds have been allocated for development from the state budget. Since water is the carrier of geothermal energy, the official regulations of the water authority apply to the thermal wells, but these contain no energy provisions, so that the energy uses thereof are not covered by any regulation. Under these conditions any development of this kind of energy is fortuitous, based on the initiative and decision of individuals. The economic appraisal of projects utilizing geothermal energy is likewise controlled by plant-level considerations alone, without regard to broader, national interests.

Geothermal energy is not included in the official listing of energy carriers and does not figure among the energy resources of the country.

Official projects and funds are available only for items related to the technical development of geothermal energy uses. Allocation from these funds can be obtained on the basis of grant applications. The technico-economic council organized under the project is responsible for appraising the applications received and for submitting its recommendations to a ministerial level committee on the acceptance of any application on the sum requested and on the approval thereof.

The uses of geothermal energy in Hungary look back upon a past of more than 20 years, so that the experiences gained this period, and especially in recent years have resulted in the evolution of the methods, techniques and equipment of production utilization and water treatment, so that any uncertainty in the realization of a thermal water based heating plant is confined largely to the amount of water obtainable from a drilled well. Once this information is available, the engineering desings for the heating plant can be completed without further difficulties.

Scaling has been observed in 30 per cent of the thermal wells drawing on the Upper-Pannonian aquifers, necessitating control measures from the very beginning of thermal water development. The simplest mechanical method, i.e., removing the scale by drilling, was used initially. This was superseeded by the slightly more advanced method of flushing the pipes with hydrochlocric acid (HCl). An even more sophisticated and currently still used methods involves chemical water stabilization, where the chemical (inhibitor) is introduced into the well below the depth of bubble separation, ensuring trouble-free operation for extended periods of time. Imported inhibitors were used initially, but such made in Hungary have become since available on the market, improving the economics of operation. Magnetic scale control has been introduced most recently with promising results. Equipment types have been developed, manufactured and patented in Hungary for such purposes. Some special desings are also available.

In the operation of heating systems based on thermal water - especially those realized earlier - the relatively low efficiency, the small temperature drop utilized and thus the rather high temperature of the effluent presents the main problem. A solution thereof is desirable not so much for theoretical, but rather for economic, operational and environmental considerations. The earlier plants have drawn mostly on free-flowing wells without any control facility installed into the system. The changeover to pumped withdrawal prompted by the drop in well yields was conductive to improved management of the resources and to the improvement of efficiency.

The gravest, still unsolved problem encountered is related invariably to the disposal of an effluent under a given set of natural parameters.

Up to the early eighties the water cooled within the heating system was discharged in the manner specified by the water authority, normally to a nearby recipient stream.

In response to the growing need of protecting the environment, the water authorities have refused to issue, or included increasingly stringent restrictions in the licenses for this manner of disposal.

Prompted by this refusal, or the growing costs of meeting the official criteria, several farms have started reinjecting such effluents on an experimental basis, some with encouraging results. Owing to the particular conditions in Hungary, successively higher pressures are needed for reinjection, affecting adversely the economics and increasing the risks attendant to thermal water projects.

Besides the risks involved, any more widespread use of effluent reinjection is hampered by the higher capital and operating costs. At some existing developments problems have been encountered also in finding adequate sites for the reinjection wells, viz. at the necessary distances from those producing.

In the general economic environment prevailing in Hungary, the development of geothermal energy is favoured by the fact that this kind of energy has no price. This results on the one hand in wasteful thermal water uses and, on the other, in low operating costs.

A discouraging economic factor is that all "mining" costs and risks of drilling must be borne by the investor. The construction costs of geothermal energy projects are normally higher than those of heating systems relying on a traditional fossile energy carrier, these latter involve no risk, so that those needing energy tend to decide in favour of an energy carrier which can be developed at lower risks, lower investment costs and operated with less problems. Such decisions are influenced, evidently, also by the actual price of oil and gas.

An agency of national scope would unquestionably contribute to the solution of the economic, risk and some development problems, just as to the improvement of coordination. A functioning agency of this would promote further the evolution of a more favourable economic environment.

7. The potential role of international organizations in furthering the agricultural uses of geothermal energy

Geothermal energy constitutes one of the recognized resources which is spread over areas, considered renewable in some areas and, depending on the thermodynamic and chemical properties of particular occurrences is suited to meeting primarily local, at the same time concentrated demands for heat and power. Although thermal springs have been used for public purposes over several thousand years, methodical exploration and development of geothermal energy has been confined largely to a few industrialized countries. Agricultural and general rural uses of geothermal energy is unquestionably of tremendous importance in the industrialized and developing countries alike. For this reason international organizations and institutions can, and are expected to assume important functions in gathering the relevant technico-scientific information, advanced technologies and practical experiences, as well as in transferring these to the interested, particularly the developing countries.

The various international organizations and institutions can offer support to the national development programmes under the main schemes outlined broadly as follows:

- Regular organization of technological and scientific information flow, including the organization of professional sessions, seminars, consultations and conferences, further by compiling, publishing and disseminating manuals, papers and guidelines on basic, intermediate and scientific levels.
- Initiating, organizing and supporting national and international cooperative exploration projects, mapping the geothermal energy resources, as well as studies aimed at the elaboration of the appropriate technologies of development.
- Initiating national demonstration and pilot projects, offering financial assistance to these in the interest of implementing the relevant technico-economic studies needed for any widespread practical application.

—Supporting the elaboration of international standard specifications, methods of study and technico-economic analysis in order to encourage the practical application of technologically sound techniques.

—Initiating and organizing professional training courses and other forms of education for professionals of the developing countries to import them the knowledge needed for designing, implementing and operating geothermal heating projects.

—Updating continuolsy the results of national and international R+D programmes and of practical applications in order to provide state-of-the-art information to the countries interested in the development of geothermal energy.

International organizations and institutions vary evidently in scope and objectives, and owing to technical and financial constraints they have different possibilities. UN organizations and agencies can be expected to become involved in a modest part only of the broad field of activities outlined in the foregoing. Regional international organizations and associations pursue particular objectives, thus e.g. the working groups of the Economic Commission for Europe are concerned mainly with the methodical exploration of the geothermal energy resources, viz. the compilation and publication of the geothermal maps of Europe. Other international organizations, such as the FAO, UNITAR or UNESCO are engaged in organizing the international flow of information, in formulating and perfecting continuously the forms of professional training with the basic aim of encouraging widespread development of various renewable sources of energy.

As far as the role of the FAO Cooperative Network in the programme on Agricultural Uses of Geothermal Energy is concerned, firm support should be accorded - regardless of the limited funds available for this purpose - to transferring the knowledge and experiences accumulated in Hungary over the past thirthy years to other European and developing countries. Under this broad programme it is recommended to organize an international professional consultation in Hungary, the aim of which would be the demonstration of greenhouses heated with geothermal energy and to discuss the experiences gained over the decades. A similar event would offer excellent opportunities for initiating international research programmes on the subject and for evaluating the results of such cooperative programmes. Moreover, since the greenhouse area heated with geothermal energy in Hungary is among the largest not only in Europe but also on a global scale, the organization of an international training course of longer duration in Hungary would be of mutual interest.

Table 1. MW/day may be gained from producable thermal water when it is cooled till 25 °C

		Temperature of the outflowing water, °C					
		50-60	60-70	70-80	80-90	90	Total
1 Already exploited quantity of thermal water 1000 m³/day		48.0	59.0	33.0	38.0	46.0	224.0
2. Thermal water quantity to be yet produced 1000 m³/day (till 200 m depression)		432.0	343.0	195.0	97.0	77.0	1144.0
Capacity to be gained by cooling till 25 °C MW/day	Transdanube	2510.0	2419.0	1394.0	349.0	.0	6672.0
	Great Plain	12558.0	13535.0	9943.0	6420.0	5819.0	48275.0
	Total	15068.0	15954.0	11337.0	6769.0	5819.0	54947.0
Oil equivalent of the capacity tons/day	Transdanube	216.0	208.0	120.0	30.0	.0	574.0
	Great Plain	1080.0	1164.0	855.0	552.0	500.5	4151.5
	Total	1296.0	1372.0	975.0	582.0	500.5	4725.5

Table 2. Thermal water resources of pliocene sediments
Exploited / Exploitable water quantity by pumping. (1000 m³/day)

		Water temperature °C					
		50-60	60-70	70-80	80-90	90	Total
1	Kisalföld	0/38	10/36	3/19	0/5	0/0	13/98
2	Lenti bas.	0/5	0/2	0/0	0/0	0/0	0/7
3	Zala-Somogy	1/17	0/6	0/2	0/0	0/0	1/25
4	Drávavölgy	1/12	1/8	0/3	0/0	0/0	2/23
	Transdanube	2/72	11/52	3/24	0/5	0/0	16/153
5	Szeged terr.	12/28	8/24	6/12	12/15	7/12	45/991
6	Déltisza bas.	2/92	7/70	11/52	19/40	26/30	85/284
7	Délalföld	1/27	3/26	9/30	7/20	12/26	32/129
8	Békés bas.	2/53	11/52	1/27	0/17	1/9	15/158
9	Jászság	22/88	12/73	0/24	0/0	0/0	34/185
10	Középtisza bas., Nyírség	9/72	7/46	3/26	0/0	0/0	19/144
	Greatplain	46/360	48/291	30/171	38/92	46/77	208/991
	ΣΣ	48/432	59/343	33/195	38/97	46/77	224/1144

Table 3. **Distribution of the number of thermal water wells according to their utilization**

Utilization	Number of wells				Production capacity m^3/min.
National Water Authority data	1975	1980	1984	1985	1985
Public baths, balneology	221	240	262	277	271.13
Drinking water supply	351	416	366	236	196.14
Heating in agriculture	81	97	160	258	255.23
Flat heating, warm water supply	20	20	19	14	21.19
Industrial purposes	15	21	64	70	61.94
Other purposes	21	46	94	128	68.25
Closed	84	58	44	33	19.21
Summarized	793	898	1009	1016	893.09

The summarized quantity of produced thermal water in 1970 was 259 million m^3/year but in 1985 it was already 420 million m^3/years.

Table 4. **Number of thermal water wells according to the outflowing water temperature**

Temperature of yielded water °C	Number of wells			Production capacity m^3/min.
	1975	1980	1985	1985
below 35	257	297	325	240.05
35-44	223	243	273	195.15
45-59	159	168	196	175.27
60-69	57	75	87	98.34
above 80	57	65	82	121.16
Summarized	793	898	1016	893.05

National Water Authority data

Table 5. Thermal wells in Hungary 1987. 01. 01.

Temp. 20 °C	Number of wells	Flow rate m³/min	Utilization						
			Drink.	Balneo.	Agricult.	Komm.	Industry	Other	Closed
30-39.9	516	348.00	211	74	109	1	36	73	12
40-49.9	209	190.11	28	98	25	2	12	39	5
50-59.9	105	96.99	5	44	20	2	12	15	7
60-69.9	92	100.67	1	43	25	3	6	11	3
70-79.9	59	67.39	0	24	23	4	2	3	3
80-89.9	46	62.33	0	5	35	1	1	1	3
90-	40	63.27	0	5	27	4	2	1	1
Total:	1067	928.76	245	293	264	17	71	143	34

MAGYAR SZÉNHIDROGÉNIPARI KUTATÓ-FEJLESZTŐ INTÉZET

SZKFI

THE POSSIBILITIES OF GEOTHERMAL ENERGY UTILIZATION IN HUNGARY

Hungarian Hydrocarbon Institute

- 1987 -

THE POSSIBILITIES OF GEOTHERMAL ENERGY UTILIZATION IN HUNGARY

SZKFI

The possibilities of geothermal energy utilization in Hungary.

(SZKFI)[+]

During the last twenty years increasing attention was focused on the utilization of geothermal resources in Hungary due to the specific geothermic conditions of the country, to raising energy prices, to increased energy demand and to environmental protection. In consequence, geothermal energy is a factor of increasing importance to be reconned with in the energy policy of the country, because it represents an additional and replacing energy source and in several cases it is more advantageous than some other energy sources.

Naturally economy is also a condition of the rational utilization of geothermal energy, but also the fact is an important point of view, that it makes the utilizer independent of energy import and to a certain extent, of increasing energy prices, being a locally available energy source.

The prospecting, concluded sofar, clarified the geothermal conditions of the country already. With respect to international comparison, the exploitable geothermal energy resources of the country can be considered as a potentially big.
The thermal water resources of higher than 35 °C temperature existing down to 3000 m depth as thermal energy carriers and the depletable thermal energy is very big, having in addition, the advantage that it can be found all over the territory of the country and it can be exploited over a long time period by a well drilled on location.

The temperature degree interval of most of the geothermal energy, which can be obtained from the Hungarian thermal water fields and rocks corresponds the requirements of heating and warm water supply making up 40 per cent of the total energy consumption.

+ for: Hungarian Petroleum Research Institute.

In addition to utilize geothermal energy for heating and in thermal power stations there are also numerous other possibilities, such as e.g.: in the industry and agriculture, refrigeration, utility warm water, thermal baths, winter sport facilities, etc.

The further investigation of geothermal energy resources in Hungary, the development of their theoretical and practical utilization is some complex task. It shall be solved by the researchers in geology, hydrology, drilling, energy utilization, machine manufacturing, etc.

Some significant results were obtained, first at all in the field of thermal baths and vegetable production, with respect to both, technical solutions and economy as well. Despite the results thus achieved we shall not forget, that the possibilities of thermal energy utilization are manifold more than exploited sofar. The crucial problem of further development is actually the organization. The requirements, the technical possibilities shall be interpreted, the money necessary for the expansion of utilization shall be provided for, and the research to increase efficiency shall be organized in a way as not to contradict each other, to serve the expansion of geothermal energy utilization, and increased economic efficiency harmonically coordinated.

The aim of present paper is to add some new ideas to the existing, complex and multiple stage system of thermal energy utilization. We want to focus some attention on the possibility of organizational actions, on their necessity, on the engagement of research, further on upon the possibilities given by the application of well completions as applied in petroleum production taking into consideration that all these will serve more efficient economical rentability.

Geothermal energy reserves and occurances in Hungary.

A typical characteristic of the area of Hungary is the strong geothermal overheating. The measurements have shown that the heat flow density makes some 100 mW/m^2 and the geothermic gradient 0.05 K/m in contrast to the world average of 63 mW/m^2, and 0.03 K/m, respectively. Beneath the surface of Hungary the earth's crust is thinning out and the elevated position of the mantle explains the higher heat content of the sediments, filling up the basin.

The geothermic energy reserves are composed partly of the heat content of the subsurface rocks, and partly of the heat content of the thermal waters filling the porous rocks.

The geothermal energy reserves contained in the subsurface waters makes some 53.10^{18} kJ in the depth interval from 0 to 3000 m. This is equivalent to $1.26x10^{12}$ tons-oil-equivalent (toe). If the interval between 3000 and 10 000 m is also considered, then the thermal energy reserves in place make some 500.10^{18} kJ corresponding 12.10^{12} toe (2). Naturally the total thermal energy in place can not be exploited fully. If 15 % depletion ratio is taken into account then the recoverable thermal energy from the depth interval 0 to 3000 m makes 8.10^{18} kJ, i.e.: $0.189x10^{12}$ toe. Compared to the recoverable hydrocarbon reserves, estimated in 1976 for the same depth interval, it becomes that the thermal energy reserves are 1380 times more. This represents such a potential possibility the exploitation of which deserves much more efforts.

Geothermal energy is actually depleted from two reservoir systems: regional big systems and local small systems (3).

The two types of big systems, known in Hungary are as follows:

- The upper pannonian sand and sandstone series of multiple horizons and reservoirs extending all over (!) the Great Plain.

In the lower and middle section of the upper pannonian formations porosity may reach 20 to 30 %, and in the upper section it may exceed even 30 %. The horizontal permeability of sandstones below 2000 m depth is 0.05 to 0.2 μm^2, though in the thermal water reservoirs it is alternating between 0.2 to 0.5 μm^2. The reservoir pressure of the upper pannonian reservoirs is hydrostatic. The solution gas content of the thermal waters in the reservoir (hydrocarbon and CO_2 gases) is one of the most important driving factors. E.g. at Orosháza the GWR (gas water ratio) makes some 1.1 to 1.5 m^3/m^3, at Debrecen 1.2 to 1.96 m^3/m^3. The outflow temperature of the thermal waters goes up to 373 K (especially in the southern, and sout-eastern part of the Great Plain). At 1600 to 2000 litre/min discharge outflow temperatures of 369 to 371 K have been often observed. The salt content in solution makes max. 2 to 4 g/lit. (mostly sodium hydrocarbonates) (fig. 1.).

- Triassic fractured, fissured limestones and dolomites, sometimes partly karstic, showing vertical flow patterns. Thickness may reach 4000 to 5000 m. The fissure-fracture system is locally and vertically very variable, it can not be characterized geometrically. The formation has secondary porosity and permeability, areally varying.
  The reservoir pressure is hydrostatic with usually negative static water level. The amount of solution gas is small, and the salt content also low (0.8 to 1 g/lit.). Outflow temperatures may approach 373 K locally. Discharges are usually big (1000 to 3000 lit/min) (fig. 2.).

The local small systems of thermal water reservoir include some levantian (pliocene) sediments, tortonian (miocene) reef limestones, and some fractured, fissured paleozoic formations. The reservoirs are of local importance. Reservoir pressures vary between hydrostatic to 100 % over-pressure. The outflow temperature reaches 303 K (the wells Álmosd-13., Tótkomlós-14. and Nagyszénás-3 yielded steam). Salt content varies between 1 to 48 g/lit.

Combining fig. 1. with fig. 2. (irrespected the local geothermal systems) it becomes clear that geothermal energy is available all over the country.

In addition to the thermal energy of thermal waters, due to the heat flow well in excess of the world average, the Pannonian basin became during geological times a thermal reservoir suitable for thermal energy recovery.

Depletion methods of reservoir fluids for thermal energy recovery.

Depletion of geothermal energy means the exploitation of the heat content accumulated during geological times in the rocks, and in the fluids stored in porous formations. The reservoir fluids, depletable for thermal energy recovery, include the thermal waters, and their solution gas content as well: the non combustible mixed gases composed of hydrocarbon gases, CO_2 and N_2, further on CO_2 gases, occuring usually in the Pannonian basin beneath the upper pannonian regional thermal water reservoirs, which are depletable together with the geothermal energy and may play some important role in the komplex utilization of thermal wells.

Exploitation of thermal energy from the fluidum of a geothermal reservoir.

Conventionally geothermal energy is obtained from the fluidum of the geothermal reservoir. Thermal water can be depleted from wells of positive water level by free flow, or from wells of negative water level.

In case of free flow wells, the flow is promoted by the reservoir energy and/or by the solution gas content of the water, reducing density. Depletion of the reservoir energy can be slowed down by reinjection of the cooled down water, the heat content of which has been utilized already, and if available, also by the reinjection of the produced gas, as it is well known (4). The reinjection of the waste water promotes in some cases also environmental protection (5). Fig. 3. shows the thermal energy in fuel oil equivalent, obtainable from free flow wells. The depleted thermal energy is naturally not equal with the utilized energy, due to the efficiency of the heat utilizing equipment. In addition to the conventional completion of free flow wells, in case of simultaneous exploitation of reservoirs containing thermal water and inert gases, the well structure as shown by fig. 4. can be employed. The down hole valve built into the tubing of 2 7/8 in dia (1) can be regulated by choke (2) (back pressure regulation) and according to this regulation valve (1) transmits gas into the upward flowing thermal water. The valves would begin operation in case the reservoir energy of the thermal water reservoir would drop below the critical value, i.e. the well would turn negative. Fig. 4. shows a well completion scheme used to open up the upper pannonian regional big system. In this case the reservoir, containing inert gases, must be below the water reservoir. In case an older thermal water reservoir is opened up below the inert gas reservoir, the well structure must be changed accordingly due to the change of the reservoir position. The thermal water will flow through the tubing of bigger diameter, while valves (1) and (2) shall be placed to the "gas side".

Fig. 5. shows some well structure for the case, when saltwater of density ρ_2 is depleted causing salt precipitation in the well head. Some freshwater of volume V_1 is injected into the well fluid changing the density to ρ_3 preventing salt precipitation at the temperature of the waste (utilized) water and also no salt is precipitated at the well head at p_2 and t_3.

This production system has also the advantage, that in case of sufficiently long h of the mixing water of volume V_1 it contacts the warm, or hot rocks on a large surface and due to the good heat conductivity of the casing it becomes also warm, thus increasing the heat productivity of the well.

Well completion schemes of free flow wells are shown on figs. 6. and 7. These structures make possible the simultaneous production of freely flowing thermal water and with inert gases mixed gas and provide possibility also for mix-water injection (similarly to fig. 5.). If the well turns negative (free flow ceased) the well structure makes possible the application of the system shown by fig. 4.

In case of wells of negative water level the reservoir energy is insufficient to cause free flow. To produce the thermal water some additional energy is requested, such as submersible pump, mammoth pump or plunger pump especially in case of practically unlimited amount of flow, as e.g. production from the Triassic big system. The utilization of the mentioned pumps and the related operational experience is well known (6., 7.) yet the application of the system, shown by fig. 4., is recommended, utilizing mixed gas as lift gas, instead of additional energy investment, to bring the thermal water to surface.

<u>Thermal energy production from the geothermal reservoir.</u>

The exploitation of thermal energy from the geothermal reservoir is not applied in Hungary. Two such methods can be recommended to this end. Injection of water from the surface into the properly completed well to get it heated up and then to exploit its heat content, or to circulate water between injection and production wells where the geothermic reservoir is also a part of the circulation system.

The circulation of cold water injected from the surface into the well may render some possibility for thermal energy recovery /8/. According to the principle the well structure is heat-insulated sufficiently on the production side and the closed circulation system is well suited for thermal energy recovery, yet this still shall be proved by experiments.

There are several examples abroad for thermal energy recovery by the system of injecting and producing wells. An example is given by fig.8. /8/. This method can be employed economically there, where layers of good water intake capacity are present. In Hungary geothermal energy recovery is planned by such well paires at Szeged /9/. An improved variety of this system is the drilling of several deviated holes from the same drilling location to supply bigger consumers (district heating agricultural combines). In this case the surface equipment can be simplified and the length of heat-insulated surface piping can be reduced.

In New Mexico (USA), under nearly similar geothermal conditions than in Hungary, a steam turbine driven electric generator, utilizing the thermal energy of one well pair, produces 10 to 20 MW electric energy /20/. Depth of the injection well is at 2932 m (bottom hole temperature 470 K) and that of the producing well is at 2708 m (bottom hole tempe-rautre 428 K). The communication between the two wells was made possible through several parallel vertical fractures created by fluid formation fracturing in the precambrian granite.

The actual extent of geothermal energy utilization in Hungary.

It was mentioned before that the depletable geothermal energy reserves are 1380 times more than the recoverable hydrocarbon reserves. This ratio is much more warse if the actual yearly production of the two energy carriers are compared.

In 1978 the number of thermal wells producing thermal water of more than 333 K outflow temperature was 147 and they represented 637 k toe energy. The yearly hydrocarbon production made some 9 M toe, indicating that thermal energy made 7 % of the hydrocarbon production only. The distribution of the thermal energy depleted from the 147 thermal wells, according to utilizing sectors, is given by table 1. /18/.

According to the data of the Central Statistic Office for 1980, the picture is only somewhat more favorable. At the end of 1980 some 842 thermal water producing wells of more than 303 K outflow temperature were listed, out of which 586 produced (69.6 %) and 256 (30.4 %) were shut off. Their distribution according to sonsuming sectors is shown in table 2.

Out of the grand total of 185 Mm^3 per year thermal water produced, actually some 167 Mm^3 per year is utilized representing 30.4 PJ/year geothermic energy (cooled down to 288 K), i.e. 740 k toe which is only 8.2 per cent of the actual hydrocarbon production.

The geothermal energy produced is utilized at fairly big losses. The more significant sources of losses are as follows:

- produced but wasted thermal water, without any utilization,
- temperature reduction in the pipeline between the thermal well and the consumer,
- utilization of high temperature water for lower temperature purposes after cooling,
- the energy content of water discharged from the location of utilization is above 288 K.

The energy thus lost is estimated as 284 k toe (38.4 %!).

One of the restricting factors of thermal energy utilization, mentioned usually on the first place, is the fact, that the thermal energy producing location and the consumer is bound to the same place.

As it will be shown later by an example of the Árpád agricultural association at Szentes, even the connection of thermal wells within a circle of 5 to 6 km radius and the transportation of the energy carrier to a central place is also economic. Naturally it is mroe favorable if the thermal well and the consumer are on the same location, thus eliminating the cost of transport. Since, as it was shown above, geothermal energy can be produced all over Hungary, therefore at the location of any consumer can thermal wells be drilled.

It is not necessary to locate the consumer at the source of energy since the energy supplying well can be located at the place of consumption.

An other counter-argument is that the drilling and installation of the thermal well demands high investment. It is naturally true, but it is valid also for hydrocarbon production and coal mining. It can also not be neglected that a base of thermal energy utilization can be constructed within 3 to 5 years, and thermal energy is relatively cheap. In the USA the specific cost of electric energy produced in a nuclear power station makes 1.55 ¢ per kWh, that produced in a coal base thermal station is 1.45 ¢, while produced by geothermal energy it is 0.74 ¢ only.

In Hungary some calculations were made with respect to economy in the agricultural combine "Árpád" at Szentes. There a greenhouse plant of 136 000 m^2 is heated by thermalwater obtained from 7 wells, discharging some 1177 km^3 per year thermal water of 353 - 358 K temperature (under "year" the heating season of approximately 6 months is understood). During the heating season 240 TJ thermal energy is utilized (the water becomes cooled down to 308 K). The expenses of the equipment delivering thermal energy makes 9 925 000 Ft, including also the depretiation of the wells and heat insulated pipes (it is 10 % = 7 174 000 Ft per year). Further on it includes also the cost of chemicals preventing salt precipitation (25 000 Ft), the cost of electric energy for pumping (1 609 000 Ft) and other expenses (wages, etc. totally 1 117 000 Ft) as well. An index number, typical for the price of thermal energy, is the ratio of the cost of equipment and the utilized thermal energy. This was found to be 41.35 Ft/GJ. The same index would be for fuel oil 277.92 Ft/GJ, for natural gas 117.83 Ft/GJ and for coal 106.81 Ft/GJ.

(With respect to the alternative energy sources only the cost of fuel was considered, without the depreciation of the installations and without some other expenses).

Komplex and multistage utilization of thermal wells.

Fields of application.

The utilization and the technology applied for heat transfer is decisively influenced by the quality of the thermal water (temperature, pressure, salt content, gas content, etc.)

The quality and quantity of thermal waters in Hungary secures the komplex and multistage utilization of thermal wells. Komplex utilization means utilization in series or parallel in the different sectors (e.g. utilization for communal purposes and parallel to it, or following it: industrial utilization). Multistage utilization means serial utilization according to temperature stages (e.g. in an agricultural combine the water is first utilized for greenhouse heating, and following, the cooled-down water is utilized in an intensive fish hatching plant).

In Hungary thermal waters are mainly utilized in the field of agriculture and within this in horticulture. In addition to heat the air in greenhouses (363-318 K water) and to heat the soil (318-308 K water), the thermal water of 308 to 288 K temperature, considered usually as waste water, can still be utilized for many purposes. It can be well utilized in double sheeted plastic tent blocks /10/. Even in case of 248 K outside temperature by the utilization of 308 K water, adequate temperature can be maintained inside the house. The same water is suitable, in addition, to regulate the temperature of the water in the intensive fish hatching plant (naturally applying mechanical filtration, biological nitrification and ion exchange), further on to warm up irrigation water (in the pipe system the irrigation water is warmed up by the thermal water). Thermal water is utilized, in addition to horticulture also in animal husbandry (brooders, henneries, calf-breeding sheds, hog-farms), further on as utility warm water.

In addition to agricultural utilization also industrial utilization would be important. Thermal water can be utilized in addition to heating, and utility water supply also in some manufacturing technologies. Even some salts can be obtained in industrial quantities in certain special cases (NaCl, Br, J, etc.). Abroad, first at all, electric energy is obtained by the utilization of steam from steam producing wells. (There are also in Hungary some wells producing steam). In California an experimental power station of 45 MW capacity is operated by a two cycle geothermal energy utilization system (the thermal water is utilized to heat a secondary liquid of low boiling point (e.g. iso-butane, iso-pentane) and the steam of this liquid drives the turbines) /1/.

The geothermic generator, utilizing the Seebeck principle is well known. In the USA and in the Sovietunion numerous thermoelectric generators are operated. Development in this field is very fast. In 1960 8 to 10 % energy utilization efficiency was obtained and the discharge/weight ratio of the equipment appoached that of the conventional dynamos. Nowdays bigger thermoelectric generators of several hundred, even several thousand MW capacity are produced, as compared to the previous years /16/.

Fig. 9. shows the basic circuit scheme of such a generator. In boiler (1) the ammonium, circulating in the energy producing system, is vaporized by thermal water. (Instead of ammonium also freon can be employed). The steam engine, obtaining 358 K temperature ammonium gas of 46 bar pressure from the boiler drives the electric generator. The ammonium gas, coming from the steam engine, is expanded in condenser (3) and it is pumped back by pump (4) through heat exchanger (5) into the boiler /21/.

A conventional utilization of thermal waters is the communal supply for the population, to provide heating and utility warm water for baths, swimming pools, sanitary institutions, housings communal institutions, etc. The thermal energy of thermal waters can be utilized in many fields also for cooling, a possibility not much exploited sofar. In those fields, where thermal water is utilized for heating purposes during the cold season, it is at hand to utilize it for cooling during the warm season (e.g. in air conditioning, in cold-storage plants etc.)

Several physical principles and equipment are known to utilize the thermal energy of thermal waters for cooling. The change of phases (physical state) are connected with heat generation or heat extraction. For evaporation heat shall be fed into the system. This can be geothermal energy as well. In case of condensation the phase change is connected with heat extraction, which is already some cooling process. This is the principle of the thermotube /11/. The thermotube is a corrugated pipe filled up with some cooling agent, e.g. freon. One end of the pipe is an evaporator, the other end a condenser. It is operated by independent cooling circulation. In case of vertical arrangement the warmer medium (thermal water) shall be introduced at the lower end thus the lower end of the tube is an evaporator, the upper end a condenser. The vapor of the cooling agent (e.g. freon) becomes condensed in the upper part of the tube extracting heat from the environment (from the circulating air or water) then it flows back by gravity into the lower part of the tube in continuous circulation.

The above principle is utilized in the various absorption type refrigerators employed also in the industry /12/. As shown by fig.10. the cooling agent is absorbed (dissolved) in the absorber. Following, the solution goes into a space where through warming up the gas-in-solution can be removed. (Compared to the conventional compressor type refrigerator, the compressing work of the compressor is replaced in this process by the introduction of heat into the solvent). In the later stage of the technological process the gas becomes condensated in the condenser (by cooling water) and the liquid gas is forwarded to the evaporator. The evaporation extracts heat from the space to be cooled. The circulation can be maintained exclusively by the utilization of the thermal energy, practically without any mechanical work. According to the technical literature the absorption type refrigerator is there significant, where waste heat can be utilized and cheap cooling water is available in unrestricted amounts. In the multistage thermal water utilizing system both conditions are fulfilled. During summer, when no heating is requested, the hot thermal water is utilized in boiler (1) for warming. The water leaving the boiler through (3) satisfies the requirements of some other utilizers and returns through (15) to cool absorber (9), condenser (5) and deflegmator (4). The cooling water, leaving the system through (16) can be further utilized, e.g. reinjected into the reservoir to maintain reservoir pressure. In case the thermal water well produces also some inert contaminated gas, instead of conventional cooling agents (ammonium) also CO_2 gas can be used.

The utiliz ation of natural gases obtained from thermal wells is also possible in the Maiuri type diffusion refrigerator. The absorption refrigerator, operating with pressure equalizing gas is employed in high capacity industrial installations. (The same principle is utilized in Hungary in the "Electrolux" household refrigerator). The refrigerator is operating in multiple stages. The cooling agent is diffunded into a neutral agent at varying intensity to establish evaporation of varying degree, and in the evaporator varying temperatures at given points. Mairuri utilized ammonium-water agent pair as cooling agent and hydrogene, or nitrogene as neutral gas to create more moderate temperatures. For very low temperatures a mixture of different hydrocarbons was recommended.

The Carrier Co. (U.S.A.) manufactures an absorption refrigerator of 1200 MJ/h capacity, operating with water-lithiumbromide cooling agent pair, for climatizing purposes. In the boiler steam or warm water! is utilized for heating /17/.

It seems to be reasonable to develop the above described coolers for thermal water utilization. In additon, it seems also to be worthwile to develop a thermal water variety of steam jet refrigerators. As shown in fig. 11. /12/ steam is blown into the ejector of the equipment provoking vacuum in the atomizer. The vacuum sucks away the water steam from the atomizer. The steam pressed into the ejector becomes condensed in the condenser, and some part of it will be pumped into the boiler, and the other part of it goes into the evaporator. The water is sprayed into the evaporator and here some part of the water, thus transformed into mist by the strong vacuum (created by the ejector), evaporates, cools the rest of the liquid and the chilled water can be pumped into the space to be cooled. The steam-jet type cooler is utilized abroad first at all in air conditioners. It is simple and safe, yet its considerable water and steam consumption is considered as some disadvantage.

In Hungary several steam wells are available and most probably still more could be drilled. The steam could be utilized immediately, without a boiler, and that part of the warm water which is pumped to the boiler according to figure 9., could be pumped to the condenser, following multistage utilization, to cool the steam. In areas, where only thermal water is available without steam but with mixed gases, from which hydrocarbon gases could be separated, there steam could be generated by additional heating, utilizing the separated hydrocarbon gas.

<u>Utilization of the gases produced with the thermal water.</u>
As mentioned above already, some thermal water wells also produce some gases therefore their possible utilization shall be considered as well.

Fig. 12. shows the known occurances of natural gases with inert gas content (NGI) /13/. These occurances became known through hydrocarbon exploration therefore the discovery of some more can be expected for, if gas exploration will be aimed also at the utilization of NGI combined with thermal water exploitation.

Table 3. shows some typical characteristics of NGI.

Fig. 13. shows the occurances of CO_2 gases in Hungary. These occurances became known also by hydrocarbon exploration. The areal distribution indicates that Hungary is rich in CO_2 gas occurances /19/. The program aimed at the discovery of more CO_2 gas could begin with the reinterpretation of some well logs of hydrocarbon exploration drillings to reevaluate the pools containing CO_2 gas. It is probable that by this process numerous pools, containing CO_2 gas in solution, can be found

and utilized in a complex system with thermal waters.

The hydrocarbon gases dissolved in thermal waters migrated by dispersion partly from hydrocarbon pools, due to poor cap rocks into the thermal water pools, but some part of them might be autochtonous /14/. Most probably this is the reason why in some areas the solution gas content of some thermal waters is very significant. Some examples are given in table 4.

Both: the inert gases and the hydrocarbon gases in solution in thermal waters play some significant role in the multistage, komplex utilization of thermal waters. The areas of utilization are the followings:

- They supply additional energy in the production of thermal waters. As described above they can be utilized as lift gas to extend the period of free flow production. As it is well known, the quantity of gas in solution influences favorable the production mechanism of thermal waters.
- The gas, produced with the thermal water, can be separated and its components can be utilized in the multistage, complex process. The hydrocarbon gases represent additional fuel the flue gas of which, free of CO, can be used as a fertilizer for plants.

The N_2 gas may reduce the corrosion of the wells and equipment up to 90 %. The CO_2 gas can be utilized in greenhouses as a fertilizer, dissolved in water for irrigation (also some kind of fertilizer), in cold storage plants, as cooling medium, or as protecting medium for big masses of vegetables and fruits (CO_2 gas is slowing down biological processes).

It shall be mentioned, that the separation of the gases produced with the thermal water is not some problem of principles but much more that of economy. Especially in case NGI is produced with the thermal water. The mixture of CO_2 + Hydrocarbongases + N_2 can become enriched in hydrocarbon gases by the removal of $CO_2 + N_2$, but further separation of all the other components is very expensive. While planning an actual utilization process the above aspects shall be seriously considered with respect to economy.

As a summary of what is described above, fig. 14. shows the ideal principles of a multistage, komplex utilization process.

Some of the more significant expenses of thermal water production.

The most costly item of thermal water production is the drilling of the well. For planning purposes the most essential are the expenses of drilling, or the transformation of an existing, unsuccessful hydrocarbon exploration well into a thermal water producing well, and the expenses of water injection. Prices are given by the Lowlands Petroleum Exploration Company for 1982.

Drilling a new well	million Ft
1. to 1200 m depth, with filter	4.5 to 5.5
2. to 1500 m depth, with filter	5.6 to 6.5
3. to 2100 m depth, with filter	7.8 to 8.8
4. to 2100 m depth, perforated: the drilling rig is removed having cemented the production casing string, perforation and formation test will be done by a well-completion rig	
expenses of the drilling rig:	6.2 to 7.0
expenses of the well-completion rig:	0.8
total expenses:	7.3 to 8.1

Expenses to transform an existing duster into a thermal water well (naturally only if thermal water pays are present). Expenses are not much related to the depth of the pay to be opened up.

1. Simple completion: no technical difficulties, opening up by perforation, starting production, measurements related to quantity, quality, etc.:	0.6 to 0.8

2. Moderately complicated well completion requesting drilling of cement plugs, squeeze cementation if there is no cement behind the casing at the level of the planned perforation, if the casing is damaged at one or more levels, if the hanger of liner is not water proof, if the well discharges sand after perforation requesting the placing of a filter, etc.: 1.0 to 1.7 MFt
3. Severely complicated completion, if the above mentioned difficulties appear combined, or formation stimulation is necessary by formation fracturing, or acidizing, eventually repeatedly: 1.5 to 3.5 MFt

Expenses of water injection.

If the utilized (from its thermal energy deprived) cool water can not be disposed off but by reinjection into the pay, or because it must be reinjected for pressure maintenance, in addition to the drilling or completion of a reinjection well, also some other expenses shall be considered as well. The Lowlands Petroleum and Natural Gas Producing Company reinjected in 1982 altogether 4 331 000 m^3 water. The specific cost made 10 to 11 Ft/m^3.

Some problems associated with geothermal energy production and their possible solutions.

The geothermal energy exploitation has its own peculiar problems, as any other energy production. These problems are solved step by step depending upon the production history of energy resources, the accumulation of production experience, upon the technical development level of the energy production in question and upon the organization (coordination between production plants, technical research and development, and central controlling) of the energy producing branche. The science dealing with these problems is the geotermia. The development of the applied geotermia began only a few decades ago. In consequence the unsolved problems are still numerous reducing the spirit of enterprise. Yet the energy demand and supply of Hungary requests imperatively to replace import energy by the locally availabel thermal energy as much as possible to reduce the cost of energy. Some of the problems of thermal water production in Hungary:

- problemes of exploitation,
- problems related to utilization,
- economic problems.

Problems of thermal water exploitation.

1. Decrease of reservoir energy. Depletion over a long time period will reduce the reservoir energy. From the Hajduszoboszló thermal water pool some 58 million cu.m. thermal water was depleted between 1926 and 1980. Calculation shows that reservoir pressure decreased by 0.14 bar per 1 million cu.m. The initially free-flow production had to be replaced by gas-lift. Static level of the water is actually at -45 m in the wells.

   The thermal water pool at Debrecen discharged 31.5 million cu.m. water between 1932 and 1980. Reservoir pressure decreased by 0.16 bar per 1 million cu.m. water produced. The initially free flow wells, producing also a relatively high amount of associated gas, turned to negativ static level.

   The thermal water pools at Szolnok produced 42 million cu.m. water between 1929 and 1980. Reservoir pressure decreased by 1.85 bar per million cu.m. in the wells producing at higher GWR, but it corresponded the country wide average of 0.1 to 0.2 bar per million cu.m. water produced, in the wells producing at low GWR (0.5 m^3 per m^3).

   The thermal water pool at Szentes delivered 120 million cu.m. water between 1959 and 1980 from about 32 wells. The discharge of the individual wells decreased by some 10 to 20 %, yet they produce still at free-flow.

Solution of the problem.

- To reduce or to eliminate reservoir pressure decline widespread water reinjeciton shall be applied with attention to the hydrodynamic conditions of the reservoir, and to the connections between thermal water and hydrocarbon pays respectively.
- Pressure maintenance by the injection of natural gas produced with the thermal water, or obtained from hydrocarbon wells (if available). Only such gases shall be injected which correspond the reservoir rocks and can not be utilized in the complex thermal water utilization process (hydrocarbon gaes, CO_2, N_2, etc.), or their removal is important due to environmental protection.

2. Random depletion, ruthless exploitation. Usually abandonned petroleum exploration wells, or wells drilled by local, individual iniciatives are exploited in this way unsystematically, thus the production life time of the reservoir, the proper depletion factor (at the given geothermic system), the proper utilization of the reservoir energy to maintain free-flow over a long period is not secured. In consequence the consumers show some mistrust with respect to long operative life time of the wells.

Solution of the problem.

Planned location of the wells and drilling numerous deviated wells from the same location. The life time of the reservoir and the depletion ratio depends to a considerable extent from the location scheme of the producing wells. The drilling of deviated holes from the same location has the advantage of concentrated installation eliminating long insulated, very expensive, pipe systems.

3. The wells of the agricultural combine "Árpád" at Szentes are "twins", i.e. from the same location two wells were drilled each of them exploiting one individual reservoir.

Solution of the problem.

The application of dual, or multiple completion to deplete two or more reservoirs through the same well. If gas pays are present, free--flow production can be maintanined. By this type completion the expenses can be reduced considerably.

4. Improper selection of pays. A typical example is the well Táska-1. in the area of the Buzsák agricultural combine. Out of four wells (T-1, T-2, T-3. and T-4.) only T-1 is producing, because the water is the hotest in this well (355 K outflow temperature), although the water of this well is at the same time of highest salt content (6.7 g per lit.). Therefore the surface installations must be acid treated in every two weeks. Production is obtained from lower pannonian, fractured marl and volcanic tufits, therefore the water is heavily contaminated with solids. Picture 2. shows a strongly scaled valve of the well, and picture 3. the big heap of sandy shale and tuffit produced with the water.

Solution of the problem.

More reliable well log interpretation and more exact knowledge of the geological conditions with respect to the thermal water reservoir. The data base and experiences of hydrocarbon exploration wells can be adapted to this end.

5. By advancing depletion both: the reservoir energy and the discharge of the well decrease. The well turns negative. Production of the desired amount of water can be obtained only by the application of submersible or plunger pumps. This involves usually some well structure modifications increasing the expenses and the energy requirements.

Solution of the problem.

In case some gas pays were also opened up by the well, the gas shall be utilized to secure free-flow production. This will request some proper equipment and regulating system. The gas produced with the water can be further utilized in the complex system.

Some problems related to the water.

1. The salt content is higher than the amount soluble in the water. The surplus precipitates as scale. Several methods are known to prevent, and to eliminate scale formation. The precipitation of salt can be prevented by thermal water production at critical or higher pressure, by the establishment of electromagnetic field around the well head /15/, by the application of inhibitors (e.g. "Árpád" agricultural combine at Szentes) or by the reduction of salt content (mixing fresh water to the thermal water).

Solution of the problem.

Depending upon the chemical composition of the water the salt concentration can be regulated by mixing fresh water at the level of the pay horizon to the thermal water in such a way as to eliminate scale precipitation in the producing and utilizing equipment. An additional advantage of this method is the fact, that the mixing water absorbs heat from the neighbouring rocks increasing its heat content.

At the thermal wells of the bath Zalakaros the scale formation was prevented by mixing fresh water to the thermal water to reduce the salt content and now some experiment is continued to mix the water at 500-600 m depth to prevent scale formation also in the tubing.

Salt precipitation can be removed mechanically (e.g. by drilling out the scale from the pipes), by replacing the involved tubing and equipment or by dissolving the scale with hydrochloric acid.

2. The produced thermal water is contaminated with oil.

Solution.

The oil can be separated fairly well in steel tanks as e.g. at Csiszta--bath, near Buzsák. The water flows into a tank provided with steel plates to change several times the direction of flow, thus promoting the separation of the oil. The light oil swims upon the surface of the water and is discharged by an overflow pipe on the top of the tank. The clean warm water is discharged from the bottom of the tank into the bath. Picture 4. shows the well and the tank, walled by concrete. Some emulson treating methods probably could be also successfully adapted to remove oil contamination from thermal waters.

3. The well is producing with the water also high amount of debris and heaving shales fill up the bottom of the well (see picture 3.).

Solution.

Avoiding quick opening and closing of the well. Producing at optimum ratio. Application of methods to solidify heaving formations. Cleaning the well. Running in filters.

4. The produced thermal water causes corrosion in the casing and in the surface equipment.

Solution.

Application of inhibitors or installation of corrosion proof equipment. Both methods are very expensive. If N_2 can be also produced from the well it cann be injected into the thermal water in a regulated way and may reduce corrosion by some 80 to 90 per cent.

Problems of economy.

1. Drilling the wells needs high investments. The high cost of geothermal energy utilization shall be reduced.

Solution.

- The expenses of drilling and completion of the well can be reduced by proper well structure, well equipment and drilling technology. The drilling of deviated holes from the same location can also reduce expenses if the reservoir can be depleted by this way.

- The expenses can be reduced also by the location of the wells close to the place of utilization. This is possible in Hungary nearly everywhere by one of the two methods: thermal water production, or circulation, thus thermal energy can replace conventional energy for consumers already operating. The expenses to install long insulated pipe systems can be also saved up.

  The utilization of the thermal energy all over the year, or over the best part of the year, can result also considerable savings. (To utilize thermal energy during the cold season for heating and during the warm season for cooling, air conditioning, refrigeration, in additon to other possible applications as described already above.) The utilization of associated gases is an other possibility for further savings.

- An other possibility to reduce expenses is the multistage utilization of thermal energy according to temperature stages. Where steam is available (as in Hungary at many places) it shall be utilized as a first step for power generation, but also the method shown by fig. 9. can be applied as well.

- To reduce expenses careful planning and design shall be requested from the competent planning and research institutions with respect to power generation and mass refrigeration in industrial scale (equipment and technology).

- An other possibility for savings is the application of water and CO_2 gas for irrigation and fertilizing, firtst at all in horticulture (vegetable growing in greenhouses).
  In this respect some promising experiments are conducted also in Hungary.

Summary.

The study is somewhat extraordinary. Instead of giving technical details it suggest such solutions which are available already in the field of water and hydrocarbon production and which can be still further developed promoting the utilization of this, for the future much promising,energy source.

The recognition that thermal energy is available nearly all over the area of Hungary is extremely important, thus the energy can be located at the installation in which it has to be used.

The gases associated with thermal waters (hydrocarbons, CO_2, N_2) can be also utilized to promote free-flow and to expand the field of utilization. The well structures and technology, necessary to this end, are availabe.

To prevent salt precipitation and to increase the yield of geothermal energy, some water circulated from the surface, can be used. There are further possibilities to reduce the expenses, the already very favorable unit cost, as compared with other energy sources, by two new ways:

- Expanding the time of utilization by the elimination of only seazonal consumption (winter heating, summer cooling) and by the expansion of associated gas utilization.

- Extension of multistage utilization, where it is given by nature, as e.g. power generation by steam or gas tubines, by thermal elements.

The application of deviated drilling and multiple well completion is a factor of cost reduction, sofar poorly applied. To solve the related problems the competent research institutions are to be involved. The tasks, as elucidated in the study, request coordination. The increased and improved utilization of thermal energy is one of the most important tasks for the future, especially if we consider that the energy content of an average thermal well (1500 lit. per min., 353 K temperature) is equal to an oil well, producing 10 to 12 ton per day oil.

To make further expansion and increased efficiency possible, the necessary planning organization shall be established and the design and manufacturing of the equipment requested to this end shall begin with as soon as possible. To expand the application of thermal energy and associated resources further scientific research is also needed.

The study, in addition to some technical suggestions, shows a complex, multistage, theoretical scheme the realization of which is the common interest of the consumers and the country.

Literature.

Ábra-feliratok.

Fig. 1. Thermal wells producing from the upper pannonian thermal water reservoir system (the outflow temperature of the water is higher than 333 K) /3/.
1: thermal water well, 2: group of thermal water wells,
3: contour lines on the base of the upper pannonian showing depth below sea level

Fig. 2. Thermal wells producing from the carbonate thermal water reservoir system (outflow temperature of the water is higher than 308 K) /3/.
1: thermal water well, 2: group of thermal water wells,
3: Triassic carbonate rocks

Fig. 3. Thermal energy which can be obtained from thermal water, expressed in fuel oil equivalent
1: energy obtainable in 1 month (temperature of waste water 303 K)
2: toe/month
3: energy obtainable in one year (temperature of waste water 303 K)
4: toe/year
5: Δt = difference between the temperature of the outflowing thermal water and that of the waste water

Fig. 4. Scheme of the production system in case of mixed well fluid.
a: to the separator to separate the NGI from the thermal water
b: to the heat utilizer or to the separator
c: thermal water pay
d: NGI pay

Fig. 5. Well structure for the prevention of salt precipitation. Mixing water: intake pressure = p_1, quantity = V_1, temperature = t_1, density = ϱ_1, in-flowing thermal water:

pressure = p_2, quantity = V_2, temperature = t_2, density = ϱ_2, h = depth of mixing V_1 with V_2; p_3 = well head pressure on the tubing; outflowing water: quantity = V_3 (= V_1+V_2), temperature = t_3, density = ϱ_3

Fig. 6. and Fig. 7. Schemes of well structure, suitable for mixed fluid production
a: to the separator to separate NGI from water,
b: thermal water, c: cold water, d: tubing,
e: casing, f: gas pay containing NGI,
g: thermal water pay.

Fig. 8. Heating 2000 apartments with thermal water. (Melun, France).
1: rèservoir (pay), 2: heat exchanger, 3: peak boilers, 4: heating, 8: utility warm water supply, 6: sewage, 7: supplementing cold water

Fig. 9. Flow diagram for steam engine.
1: thermal water, 2: further utilization.

Fig. 10. Operation of an absorption type refrigerator with thermal energy.
1: boiler (distiller), 2: heating steam inlet, 3: condensed water outlet, 4: choke valve, 7: evaporator, 8: cooled space, 9: solvent (absorber), 10: solution pump, 11: heat exchanger, 12: intake of enriched solution, 13: regulator valve, 14: intake of lean solution, 15: intake of cooling water, 16: outlet for cooling water

Fig. 11. Operation of steam-jet type refrigerator with thermal energy
1: warmed-up water, 2: steam, 3: atomizer, 4: ejector, 5: boiler, 6: regulator valve, 7: into the space to be cooled, 8: water, condensor, 9: pump, 10: cold water, 11: feeding pump

Fig. 12. NGI occurances in Hungary /13/.
1: symbols, 2: fields containing N_2, 3: inert content, 4: producing fields

Fig. 13. Areal distribution of natural gases contaminated with CO_2 /19/
É = N, D = S, NY = W, K = E, ÉNY = NW, ÉK = NE
1: Key to fig. 13., 2: symbols, 3: anomalies

Fig. 14. Complex utilization of reservoir fluids.
1: summer utilization, 2: winter-summer utilization, 3: water reinjection, 4: well, 5: water, or steam, nat.gas, 6: winter utilization, 7: cooling water, 8: geothermic power generation, 9: cooling water, 10: absorption type cold-storage plant, air conditioners, 11: degasser (gas separator), 12: water, 13: heating of animal husbandry installations, 14: heating of apartments, houses, offices, workshops, 15: additional heating energy, 16: flue-gas fertilizing, 17: utility warm water supply for baths, sanitary institutions, houses, plants, 18: crop driers, 19: soil heating of greenhouses, 20: horticulture, 21: canning house, 22: sewage, 23: irigation water warming, 24: double sheated plastic tent block heating, 25: regulating the water temperature in fish hatchers, 26: outflowing water.

A képek feliratai.

Picture 1.: Producing wells in the thermal water field at Szentes.

Picture 2.: A valve of the well Táska-1. filled by scale, precipitated from the thermal water.

Picture 3.: Sandy shale and tuffite produced by thermal well Táska-1.

Picture 4.: Oil skimming tank at the bath of Csisztapuszta.

Feliratok a táblázatokhoz.

Table 1.

1: utilization, 2: number of wells, 3: water discharge, m^3/min, 4: exploited thermal energy, PJ/year, 5: exploited thermal capacity, 6: 10^3 toe, 7: agriculture, 8: building heating, 9: industry, 10: baths, 11: water works, 12: water reinjection, 13: temporarily shut-in, 14: total

Table 2.

1: field of utilization, 2: number of wells, 3: producing, 4: non--producing, 5: total, 6: industrial branches, 7: agriculture, 8: transport, 9: water economy, 10: others, 11: total

Distribution of not exploited wells:	item
the produced water flows unitilized	16
temporarily shut-in	138
observation well to control water level	50
abandoned	52

Distribution of producing wells according to temperature:

item	temperature of out-flowing water, K	total discharge km^3 per year
286	303 to 313	81 468
179	314 to 333	48 223
121	334 to 373	55 276

Table 3.

Some characteristics of mixed natural gases contaminated with inert gases

1: Name of occurance, 2: initial in place reserves, 10^9 m^3, depletion factor, %

4: gas composition:

hydrocarbons N_2 CO_2

5: heating value, kJ/m^3

6: I. Occurances exploited

7: II. Occurances utilized for the Tisza thermal power station

8: III. Occurances not exploited

9: Prognostic occurances

10: IV. Occurances containing high amount of N_2

11: + N_2 and CO_2 together

Table 4.

Some examples of thermal water wells, showing high gas/water ratio (GWR).

1: location of thermal water wells, and their designation, 2: depth of thermal water pay, m, 3: initial discharge m^3/d, 4: initial GWR m^3/m^3, 5: outflow temperature, K

6: bath, 7: municipal horticulture, 8: horticulture, 9: castle gardens, 10: hospital, 11: agricultural combine, 12: agricultural cooperative, 13: wagon washer, 14: swimming pool, 15: sports ground, 16: sugar factory.

بسم الله الرحمن الرحيم

34986/M/10 الرقم :

التاريخ : ٩ / ١١ / ١٤١٠هـ

Date: June 2, 1990 الموافق

rec'd by DOE 6/6

Rec 7/17/90 @ 10:08am
CWURI by HPR.

HPR

مدينة الملك عبدالعزيز
للعلوم والتقنية
مكتب الرئيس

Dr. Robert L. San Martin
Deputy Assistant Secretary
for Renewable Energy
Conservation and Renewable Energy
Department of Energy
Washington DC 20585
U.S.A.

Dear Dr. San Martin:

I was pleased to receive your letter dated April 24, 1990 along with the draft Annex of Solar Energy in Remote Application Project. We have reviewed the annex and found out that it will fulfil KACST's objectives in the areas of developing, designing, and evaluating solar applications in remote areas. We feel that the stated activities can start as soon as the annex is finalized. Other annexes such as the two proposed herein, can be discussed and prepared concurrently.

I would like to propose two additional annexes at this time, both related to renewable energy resources assessment in Saudi Arabia. The first project (Annex No.2) is for satellite solar data extrapolations and Saudi solar atlas development. This project was started at the conclusion of the SOLERAS agreement, but was not completed due to budget and time constraints. At that time, the project was awarded to Dr. Carl Justus of Georgia Institute of Technology, Department of Geophysical Sciences. I would like DOE to consider the inclusion of the project under the current agreement in the field of renewable energy research and development.

Access to USGS field camp @ Jidda; mess hall, BOQ, pool, etc.
For $150K all we can do is: - remote sensing
- visit on site, scope geophys surveys
- test SP, near surface resistivity
- geochem;

soil moisture
depth of water table

34986/M/10

Dated: June 2, 1990
Dhual qada 9, 1410H

The second project is for studying the feasibility of geothermal resource utilization in Saudi Arabia. Our proposed annex for this project, which is attached, is based on the presentation of Mr. Joel L. Renner, Senior Program Specialist of Idaho National Engineering Laboratory. Mr. Renner showed the extensive experience the U.S. have in this field and indicated the possible availability of geothermal in Saudi Arabia.

I look forward to KACST and DOE finalizing Annex 1 and selecting the applications to be implemented under the project.

Thank you and best regards.

Sincerely,

Dr. Saleh Al-Athel
President
KACST

المملكة العربية السعودية

مدينة الملك عبدالعزيز للعلوم والتقنية

90JN281

D./ Hajjah 1, 1410 H
June 23, 1990

Dr. Robert San Martin
Deputy Assistant Secretary for
Renewable Energy
Conservation and Renewable Energy
Department of Energy
Washington DC 20585
U.S.A.

Dear Dr. San Martin:

Please find attached a draft Management and Financial Plan for the Renewable Energy Research and Development Project. The document is prepared according JECOR instructions and guidelines promptly since six months of the current fiscal year have already passed.

The document includes only a plan for Saudi portion of the budget and view of the management plan. To complete the document your expenditure according to your allocated budget this year, and your questions, concerns and comments on our draft plan are to be included therein. I would appreciate your submitting them to us so that they can be incorporated in the final document.

Looking forward to hear from you.

Thank you and best regards.

Sincerely,

Dr. Saleh Al-Athel
President
KACST

Attachment:
as stated.

SAUDI ARABIAN - UNITED STATES
JOINT COMMISSION ON ECONOMIC COOPERATION

KING ABDULAZIZ CITY FOR SCIENCE AND TECHNOLOGY
AND
DEPARTMENT OF ENERGY

MANAGEMENT AND FINANCIAL PLAN BUDGET
FISCAL YEAR
1990

The signatures below hereby submit for review the proposed Management and Financial Plan Budget for the Renewable Energy Research and Development Project.

Submitted by:

Department of Energy	King Abdulaziz City for Science and Technology
Date	Date
U.S. Coordinator	Saudi Coordinator
Date	Date

U.S. - SAUDI ARABIAN JOINT ECONOMIC COMMISSION
RENEWABLE ENERGY RESEARCH AND DEVELOPMENT
FY 1990 - FINANCIAL PLAN
PROPOSED ANNEX - 3

PURCHASE OF SERVICES - BUDGET CATEGORY 1900

OTHER SERVICES

RESEARCH CONTRACTUAL SERVICES	2510	$ 53,112

TABLE - 8

U.S. - SAUDI ARABIAN PROJECT FOR COOPERATION IN THE FIELD OF RENEWABLE ENERGY RESEARCH AND DEVELOPMENT

DRAFT: ANNEX - 3

FEASIBILITY STUDY ON THE POSSIBILITY OF GEOTHERMAL UTILIZATION IN SAUDI ARABIA

1. Objective: Study the possibility of geothermal availability in the Kingdom of Saudi Arabia.

2. Scope of work: The project will review available studies on geothermal potential in Saudi Arabia from documentation available at KACST or elsewhere internationally, will perform pre-exploration investigations at two promising locations and along the coast of the Red Sea, and will carry out a structure study of the southern region of the Kingdom for geothermal availability.

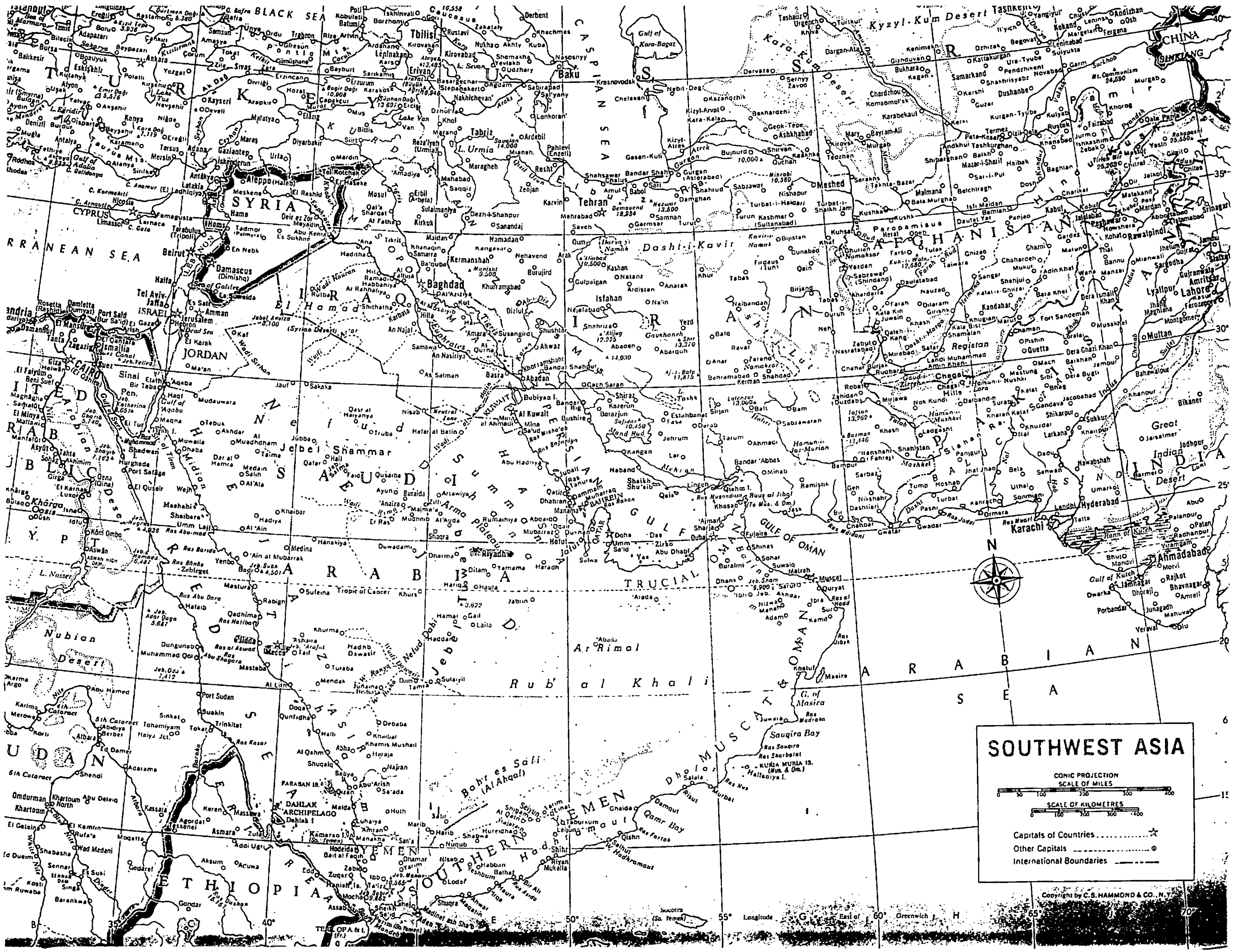
3. Plan of work and schedule:

	Months
A. Preparatory review of existing studies and reports; development of a list of potential locations where pre-exploration investigation can be performed.	1-2
B. Experts meeting in Saudi Arabia (KACST and DOE laboratory personnel); initial presentations on U.S. and Saudi Arabia's experiences in this field; visit to selected potential geothermal locations; development of detailed plan including measurements.	3
C. Pre-exploration investigations of selected locations.	4-8
D. Data analysis.	9-10
E. Draft report, on the results of the project findings and recommendations for further action such as exploration potential and its cost and economics.	11
F. Submission and publishing of final report.	12

4. Cost: KACST will budget $150,000 for the project.

5. The Annex will be under the articles and terms and conditions of the Project Agreement for Cooperation in the Field of Renewable Energy Research and Development, February 4, 1987.

6. Products: The products of the Annex will be the final report.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SOUTHERN YEMEN
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EXPLOR.GPY

UURI OUTLOOK ARTICLE

EXPLORATION GEOPHYSICS

Exploration geophysics is probably considered to be a rather narrow, specialized field to most people not working in the earth sciences, and even to many within these sciences. In truth it is a field which includes many different specialties and is best applied by those with a broad science background and substantial field experience. Sheriff (1984) defines exploration as "the search for commercial deposits of useful minerals, including hydrocarbons, geothermal resources, etc", and exploration geophysics as "the application of geophysics to exploration and also to engineering and archaeology" - in short, applied geophysics.

Earthquake Seismology and Reflection Seismology

Perhaps the best known areas of geophysics are earthquake seismology and reflection seismology. Reflection seismology comprises roughly 90 percent of the dollar volume of geophysical surveys completed throughout the world, almost entirely in the exploration for petroleum and natural gas, but also for coal resources and engineering applications. UURI geophysicists have several years of experience in reflection seismic exploration for petroleum, and some experience in its application to geothermal and mineral resources. Because of the highly specialized field equipment, experience, and interpretation algorithms required for state-of-the-art work in the field, UURI defers to the University of Utah Department of Geology and Geophysics (UUGG), and to major seismic contractors for expertise in this specialty.

While earthquake seismology is not generally regarded as a branch of exploration geophysics, passive seismic techniques have application to regional geology and geothermal exploration through the mapping of the earth's veocity structure. Low magnitude (M<3) seismic activity has been noted at several major geothermal areas, and several passive seismic methods have evolved which address the exploration for and development of geothermal reservoirs. Most important of these is the microearthquake method, in which several portable microearthquake recorders and seismometers are deployed in an area of a few km2 to perhaps 100 km2. Microearthquakes are observed for a period of time varying from a few weeks to a few years to evaluate the nature of seismicity, and how this may relate to open fractures, permeability, and the possible movement of geothermal fluids. UURI has completed microearthquake surveys in diverse places such as Adak, (AK), Ascension Island, Raft River (ID), and Roosevelt Hot Springs (UT). These surveys have demonstrated the potential for open fractures at depth on Ascension Island, and the probable importance of the Negro Mag fault as a major fluid conduit at Roosevelt Hot Springs, UT.

Exploration Geophysics at UURI

UURI geophysicists and geologists have used most of the non-seismic geophysical methods, and UURI geophysicists are recognized for their expertise in the electrical and potential field methods. Table 1 presents a classification of these methods and identifies the more common areas of application. Other classifications and applications are possible.

A glance at Table 1 indicates the variety of methods and applications available. It is clear that space does not permit an in-depth discussion of methods and applications in this article. Instead, we present a brief description directed at the non-geophysicist, and indicate some of our areas of experience. A more complete description of most methods can be found in Telford et al (1976) and Wright et al. (1985).

Potential Field Methods

The potential field methods measure natural earth fields, which in the strict sense are described by Laplace's equation. The gravity method measures the local acceleration of gravity, typically to an accuracy of 0.1 milligal, or one part in 10 million of the earth's average gravity field. Small variations in the gravity field result from different densities of rocks and sediments in the subsurface. The range of bulk rock densities rarely varies beyond 1.6 to 2.9 g/cm3. The method is often used to estimate the thickness of less dense materials (volcanic rocks, alluvium) over consolidated sediments or igneous rocks, and to map faults which place rocks of different densities in contact. UURI has conducted and interpreted gravity surveys for geothermal and mineral exploration in Utah, Nevada, Colorado, Ecuador, and Guatemala.

Magnetic surveys map the total magnetic intensity of the earth's field, which varies primarily as a function of the distribution of magnetite, Fe_3O_4. Magnetic susceptibility of earth materials often varies over a wide range, perhaps 0 to 6,000 micro cgs, so the method is often effective in mapping igneous and volcanic rock types, and for locating concentrations of magnetite or other iron ores. As in the case for gravity, the method is useful for mapping faults which place bodies with different magnetizations in contact. Metal trash such as barrels, and rebar, in waste dumps facilitates mapping due to their strong magnetic expression. Old well heads or casing may also be mapped from the air or surface. UURI has completed contract aeromagnetic interpretations for geothermal and petroleum exploration, and for base, energy, precious metals, and industrial minerals applications. We have completed detailed ground surveys for environmental and engineering projects. In 1988 UURI completed both regional and detailed airborne surveys of the Los Azufres geothermal area in Mexico, using a portable aeromagnetic digital recording system which was installed in a fixed wing aircraft and a helicopter. Areas of geothermal or mineral alteration are sometimes indicated as areas of reduced magnetization.

The self-potential (SP) or spontaneous-polarization method can be classified either as a potential field or electrical method. The method measures small voltage differences at the surface of the earth which result from subsurface electrical currents. The currents themselves may be caused by diffferential oxidation of sulfide mineral deposits, by earth temperature differences (the thermoelectric effect), or most commonly, by the movement of ionic species in moving groundwaters (the electrokinetic effect; Corwin and Hoover, 1979; Sill, 1983). The method is not used in the general sense of geologic mapping, as are several geophysical methods, but rather for specific purposes. The earliest uses, dating back to the early 1900's, resulted in the discovery of a number of buried mineral deposits.

While the method is still used to a limited extent in mineral exploration, it has been used extensively in geothermal exploration. Surveys recently completed at Newcastle, Utah (Ross et al, 1990) appear to have delineated the primary upflow zone for a large geothermal plune which is being mined for greenhouse and other space heating. SP anomalies can be positive or negative, simple or multi-polar, and can vary from a few mV to as much as 2,000 mV in amplitude. In recent years precise SP surveys have been used to map subsurface coal burns, hazardous waste dumps, and the subsurface flow of waters through earthen dams, dikes, etc.

Electrical Methods

Table 1 only hints at the variety of electrical techniques, and their broad range of applications. We will only attempt a brief description and further classification of the methods here, and indicate a recent example of one method. The basic rock property of measurement, the electrical resistivity, spans more than five orders of magnitude for common earth materials. Surveys in a one sq km area at Hill Air Force Base yielded appparent resistivity values from 2 to 1200 ohm-m (Ross et al, 1989). For most rocks and sediments, the resistivity depends on the porosity and the resistivity of the contained pore fluids, as approximated by Archie's Law.

The electrical methods themselves can be classified in several categories, depending on whether the electrical field is natural or introduced, the frequency range of measurement, and other factors relating to measurement technique.

Natural Field Methods

The natural field methods utilize the measurement of time-varying electrical and magnetic fields present in the earth as a result of ionospheric-solid earth interaction, and worldwide thunderstorm activity. In the telluric method, only electric field variations are measured to interpret subsurface resistivity differences. The magnetotelluric (MT) method utilizes measurements of various field components for both the electrical and magnetic field through a broad range of frequencies (.0001 to 10E4 Hz) to infer the earth's resistivity structure to great depths (to 100 km for the lowest frequencies). Audiomagnetotellurics (AMT) refers to measurements, often scalar, in the range 1 Hz to 1000 Hz, the frequency range dependent on worldwide thunderstorm activity. An earlier OUTLOOK article (v. 1, no.3, 1989) described the magnetotelluric methods in some detail. UURI operates a state-of-the-art research oriented MT system for crustal structure and geothermal studies, and offers quantitative MT interpretation services for the geothermal and petroleum industries.

Active Field Methods

In the active electrical methods, electrical currents are caused to flow in the upper portions of the earth's crust through current introduction at electrodes or by magnetic field induction about a loop source. In the oldest method, galvanic resistivity, low frequency (0.01 to 10 Hz) current is introduced through grounded electrodes arranged in a great variety of configurations to map the earth's resistivity structure from the surface to depths of a few km. Some arrays are designed only for lateral profiling or areal mapping (i. e. the gradient array), some for depth profiling (Schlumberger soundings or VES), and some for both purposes (pole-dipole or dipole-dipole arrays). UURI has completed numerous resistivity interpretations for geothermal resource areas throughout the world, and conducted contract surveys for geothermal, mineral, engineering and environmental applications. Galvanic resistivity remains one of the most commonly used geophysical survey methods. Figure 1 illustrates the mapping of a thermal fluid upflow zone and outflow plume at Newcastle, Utah, using the dipole-dipole array and 152 m (500 ft) dipoles.

In the Induced Polarization (IP) method, chargeability or phase lags at mineral or clay boundaries are determined for different reading delay times or different frequencies while simultaneously completing the resistivity measurement. The primary application of the method is for mineral exploration, but there is also application for petroleum and geothermal exploration, and for engineering and environmental problems. UURI personnel have extensive experience with the IP method.

The electromagnetic methods include several ground based and airborne methods which induce time varying currents in the earth to determine electrical resistivity variations. These would include time-domain electromagnetics (TDEM), controlled source audiomagnetotellurics (CSAMT), and a host of specialized arrays and methods. UURI has developed a variety of computer programs for EM interpretation and has recently acquired a versitile ground based EM system. The electromagnetic methods will be the subject of a future OUTLOOK article.

Ground Penetrating Radar (GPR) or Subsurface Imaging Radar (SIR) is a relatively new electromagnetic surveying method in which a mobile antenna transmits energy into the earth at frequencies in the 1-100 MHz range and records the reflected energy in a format similar to reflection seismic methods. Depth penetration is limited by conductivity losses in the near surface, so the primary applications have been in the groundwater, engineering, environmental, and archaeological areas. UURI has not made use of the GPR methods.

Other Geophysical Methods

UURI has made extensive use of the thermal methods in geothermal energy exploration. Temperature gradients are determined in shallow (10-50m), intermediate (100-200 m), and deep (300-1000 m) holes and in deeper wells, to evaluate heat flow, fluid entries, and proximity to the thermal system. Shallow temperature measurements are completed in holes of 1-3 m depth in some reconnaissance geothermal programs, and in coal burn studies and groundwater or environmental studies, as indicated in Table 1. UURI has a temperature logging capability for depths to 700 m.

Radiometric methods, principally gamma ray spectroscopy, have been extensively used in the search for uranium, and most of the United States was surveyed by air in the NURE program. Airborne gamma-ray spectroscopy (GRS) also has substantial value as a mapping tool, particularly in the Potassium 40 (K40) channel, due to the widespread and variable content of K40 in igneous, volcanic, and sedimentary rock types. UURI has completed interpretaions of airborne magnetic and GRS data for mining clients, and used surface GRS surveys in geothermal and mapping applications. UURI scientists are currently evaluating Radon health hazards in Utah using NURE airborne data, and surface GRS surveys. UURI has a Geometrics Model GR-310 four channel spectrometer for mapping and survey work.

Well-logging is employed in a wide variety of applications, with the most complete log suites generally reserved for the high cost petroleum and geothermal wells. A large number of different tools are available to measure seismic (sonic), resistivity (1/conductivity), density, magnetic, radiometric, temperature, IP, thermal, and other properties. UURI has broad experience in integrated well log interpretation for geothermal areas, and is well known for the interpretation of borehole breakouts and dipmeter logs. UURI does not maintain a well log survey capability, with the exception of the 700 m temperature system, but is active in log interpretation as part of integrated exploration and development projects.

UURI Survey Capabilities and Interests

UURI geophysicists have extensive experience in both ground and airborne surveys for most of the major methods, and extensive software for quantitative data interpretation. UURI does not maintain standing survey crews that would be cost competitive with, and compete with, geophysical contractors. We do offer survey design, supervision, evaluation and interpretation services. UURI scientists do assemble field crews for long term or in-depth integrated exploration, engineering or environmental projects, and rents appropriate survey equipment when in house equipment is not available to, or optimum for, a specific study.

For further information about our geophysical capabilities, contact Howard Ross at (801) 524-3444 or Mike Wright at (801) 524-3439.

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Terrestrial Heat and Geothermal Resources in Hungary *

T. BOLDIZSÁR

The Hungarian basin is a part of the Alpine geosyncline system. The basin is surrounded by the Carpathians and the Dinarics. The territory of the present basin in the Mezozoic was characterized by thin sediments, and the sequence of rocks is incomplete, but in some places, especially in the mid-Hungarian Mountains, the thickness of the Mezozoic deposits is considerable. At this time the Carpathians and the Dinarics Alps, owing to intensive subsidence, were zones of thick deposition. In the Tertiary period the Hungarian basin began to subside intensively and was filled up especially by Pliocene sediments. The zones of the Carpathians and Dinarics were uplifted simultaneously with the subsidence of the Hungarian basin. In the Neogene period, in connection with the mountain risings, great volcanic activity took place. While the Alpine mountain ranges are folded and fractured, within the Hungarian basin owing to small scale tectonic movements no folded structrures are to be found.

Geologic Structure of the Hungarian Basin

Intensive exploration for oil deposits in the Tertiary sediments of the Hungarian plain has revealed the subterranean surface of the Paleozoic-Mezozoic bedrocks and supplied reliable figures on virgin rock temperature. The Hungarian plain is in the center of the Carpathians. The Paleozoic-Mezozoic bedrocks are elevated along a SW-NE fracture line forming the mid-Hungarian Mountains rising up to 1000 m above sea level. These elevated, mostly Mezozoic strata divide the Hungarian plain into two basins, a smaller in a NW- and a greater

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in a SE-direction. The depression are filled with Tertiary porous sediments; about half of their thickness consists of Lower Pliocene (Pannonian) strata. The maximum depth of the depressions is about 5000 m below sea level; the average depth of the Tertiary basins is about 2000 m. The porous and permeable sandstone strata contain immense quantities of water and up to now oil and gas deposits of commercial value have been located in about 50 traps.

Discovery of Heat Flow Anomaly

A surprisingly high heat flow was measured in 1956 (Boldizsár, 1956). A figure of 3.035 $\mu cal/cm^2sec$ was found, and there was some doubt among the experts in accepting a value so much higher than the average (1.2 $\mu cal/cm^2sec$). Other investigators in England (Bullard and Niblett, 1951), Canada (Misener, 1955), Japan (Uyeda and Horai, 1960) and Australia (Newstead and Beck, 1953) have also found considerably higher values than the average, but it may be doubted whether all these high values, including the Hungarian, represent the regional heat flow of greater areas.

The high heat flow published in 1956 was measured in the SW part of Hungary in the Liassic coal mine district of Komló. The mine district is in the Mecsek Mountains consisting chiefly of Permian, Triassic and Liassic sediments. The measurement refers to the heat flow in vertical direction of two large shafts of 7 m diameter, 90 m distant from each other. Further sinking of the twin shafts allowed measurements to be extended to a depth of over 600 m. The result has confirmed the earlier high heat flow and the new value is more exact, containing more virgin rock temperature and conductivity data. The average heat flow in Komló in the twin shafts is 3.34 ± 0.04 $\mu cal/cm^2sec$ (Boldizsár, 1964/a).

Similar measurements were made in Hosszuhetény a distance of 5 km from Komló. The Hosszuhetény coal mines being opened up, two shafts with the same dimensions and the same distance from each other as in Komló were sunk to a depth of 530 m. In the same Middle Liassic strata as in Komló, the average heat flow was 2.49 ± 0.02 $\mu cal/cm^2sec$ (Boldizsár and Gózon, 1963). Rock conductivity is about the same as in Komló, the decreased heat flow is the consequence of the smaller temperature gradient. The gradient of temperature in Komló is 47 deg/km, whereas in Hosszuhetény it is 36 deg/km, both values are quite high compared with areas outside the Carpathians. Taking the average value from the two measurements mentioned above, it gives a heat flow in the NE region of the Mecsek Mountains of about 2.9 μcal/cm²sec.

Heat-flow measurements in the Nagylengyel oilfield near the Austrian border revealed 1.9 to 2.0 μcal/cm²sec (BOLDIZSÁR, 1959). While the dense rocks in Komló and Hosszuhetény made it possible to ascertain rock conductivity with precision, in Nagylengyel the Tertiary rocks of high porosity presented difficulties. The samples were saturated with water before the conductivity was measured.

Recent Investigations

My further measurements of heat flow indicated in the Pliocene sediments of the Hungarian plain at Hajduszoboszló a heat flow amounting to 2.4 to 2.6 μcal/cm²sec. At the edge of the mid-Hungarian Mountains near Szentendre in Oligocene sandstone 2.0 μcal/cm²sec has been found, further in the southern part of the Mecsek Mountains in Permian sandstone near Hetvehely and Bakonya the heat flow amounted to about 2.4 μcal/cm²sec. The papers relating to these heat flows are being prepared for publication.

In the Czechoslovakian part of the Hungarian basin at Selmecbánya (Banska Stiavnica) in Tertiary andesite and dacite rocks 2.66 μcal/cm²sec heat flow was observed (BOLDIZSÁR, 1965). All heat flow values are shown in Figure 1. The distribution of high heat flow values over the whole Hungarian basin without any exception suggest that this tectonic structure is somehow connected with this geophysical phenomenon.

More than 400 carefully controlled temperature measurements were made in boreholes to ascertain virgin rock temperature of the rocks of th Tertiary basin and the bottom rock. Points of measurement are well distributed over the whole country and iso-temperature-gradient lines were constructed as shown in Figure 1. The average value of the temperature gradient is 54.2 deg/km, but over big territories (about 3500 km²) the temperature gradient is over 70 deg/km. The highest measured temperature gradient at Lakitelek is 165 deg/km in Pliocene sediments with no indication of volcanic activity. This territory of about 50 sq.km suggests an extremely hot water or steam deposit suitable for electrical power generation (Fig. 2).

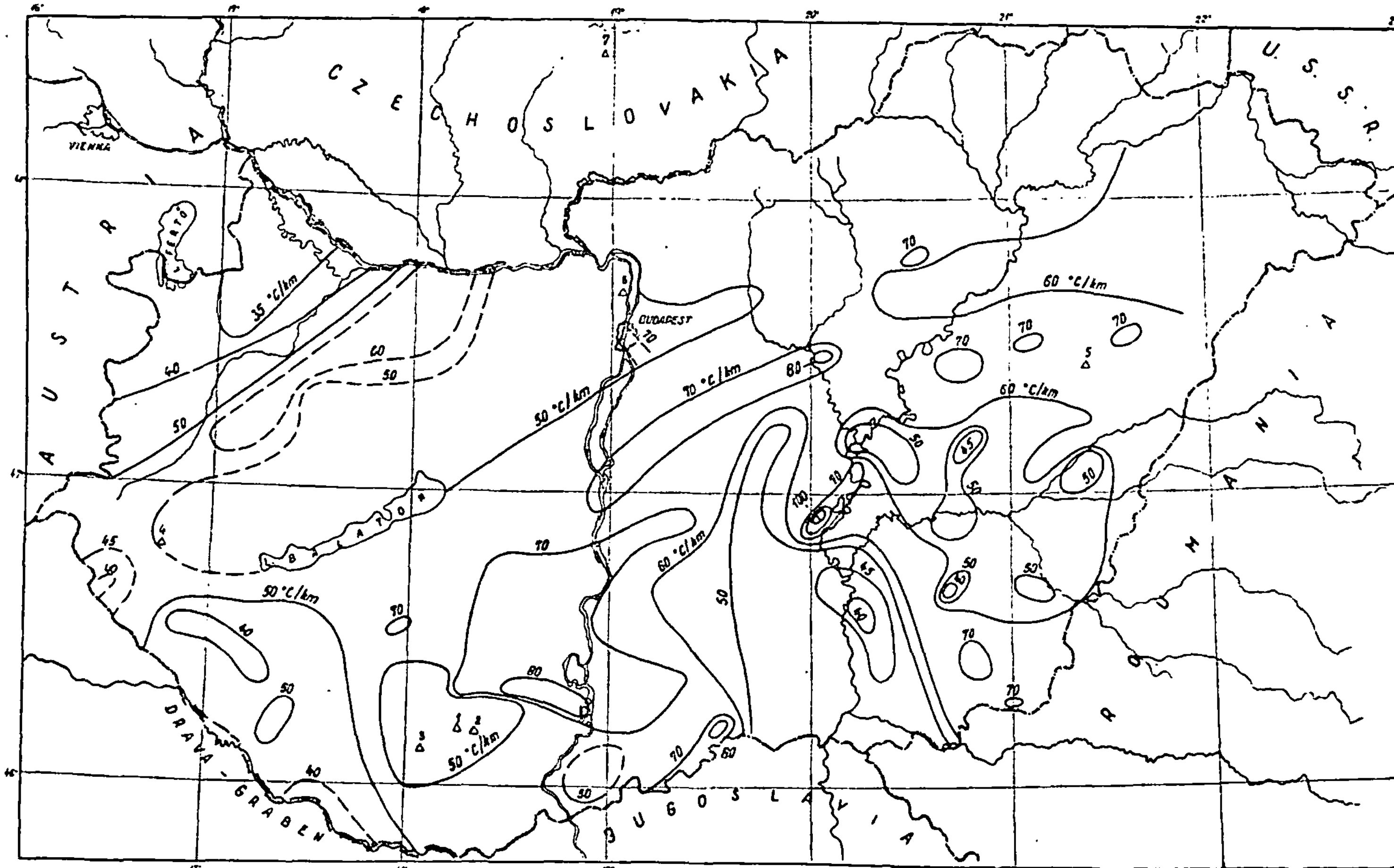

FIG. 1 - Temperature gradients and measured heat flow values in Hungary.

▲ Places of heat flow measurement — 3 Bakonya 2,4 — 6 Szentendre 2,0

1 Zobak 3,3 — 4 Nagylengyel 1,9 - 2,0 — 7 [illegible] 2,6

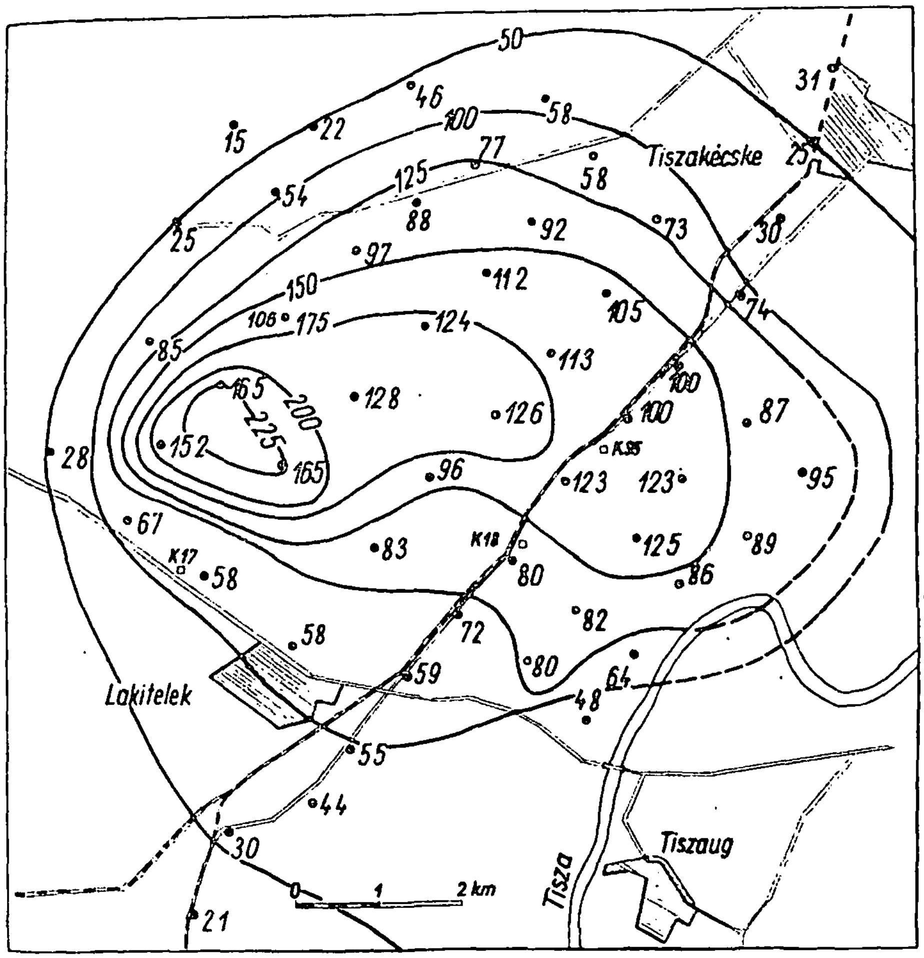

FIG. 2 - The geothermal anomaly of Lakitelek. (Number at the black dots indicate measured surface temperature gradients in deg/km. Numbers on the iso-gradient lines indicate temperature gradients relating to the conductivity of of the deep formation. Surface gradients were measured between 20 and 50 m depth.

Economic Value of the Hot Water Deposits

The volume of Tertiary and younger rocks is about 160,000 km³. The volume of porous rocks with porosity over 10 % is about 20,000 km³. Over 4,000 km³ hot water of 60° to 200°C temperature, is stored in the pores of the rocks below 1000 m deep; most of it can be mobilized by making boreholes everywhere to create hot water wells with capacities of 1 to 3 m^3/min. This immense quantity of stored heat dropping the temperature down to 40°C amounts to 2.3×10^{19} cal, which is about 50 % of the calorific value of the known petroleum deposits in the entire world at the end of 1963.

According to my proposition, the hot water is now being exploited in a great scale for heating and industrial purposes since the geothermal heating is more economic than any other alternative. Wells 1000 to 2000 m deep can produce 1 to 3 m^3/min hot water of 60° to 100°C for decades. The newly discovered Lakitelek steamfield may possibly be used for power generation. Preliminary estimates show 10^{11}kWh recoverable energy reserve.

Heat Flow and Tectonics

I believe that the ultimate cause of the tectonic processes are thermal phenomena in the subcrustal regions of the earth. The terrestrial heat may be primary or radioactive or both; the direction of the heat flow may be upward, downward, or a combination of them, but there is no thermal equilibrium and that is why heat flows within the mass of the earth causing displacement, plastic flow of the subcrustal rocks and therefore the oscillatory movement of the crust. The heat flow within the earth is a non-stationary phenomenon, which tends in time to get nearer to the stationary state and in some parts of the earth the thermal state may already be quasi-stationary. If this is so, a reasonable explanation is offered of the observation that the amplitude of the tectonic activities are decreasing with time and also that great parts of the earth, the « nuclei » of the continents, are tectonically inactive, while great tectonic activities take place in the active belts, in the geosynclines.

The uniform high heat flow in the Hungarian basin can be explained by the fact that the Hungarian basin is a part of the Alpine orogenic system. The orogenic cycle was induced by radioactive heat production which caused the dilatation of the crust. The decreased remains of the high heat flow which have caused this orogenic cycle, can now be measured along the Alpine system. Few heat flow measurements are available, but high temperature gradients in the Pyrenees (Lacq gas-field), in the Appenines, in the Alps and measured high heat flow in the Carpathian basin support this view. On the contrary, north and northeast of the Alps and Carpathians measured temperature gradients are between 30-10°C/km. In the Ukrainian Precambrian shield heat flow measurements show values between 0.62-0.74 μcal/cm²sec (LUBIMOVA, 1964). These low heat flow and geologic evidence show that the Russian platform was inactive during the Alpine period.

At Lakitelek, where heat flow increases to 9.1 μcal/cm²sec, the maximum temperature gradient is about 225°C/km. The bottom of the Tertiary basin is assumed at about 1500-2500 m. Recent investigations show that the Alpine flysch, which covers the Mesozoic bottom rocks is present under Tertiary sediments. The situation is somewhat similar to that of Larderello except that at Larderello the flysch is not buried under thick cover rocks. According to my measurements at Larderello (BOLDIZSÁR, 1963) the maximum heat flow value is 13.7 μcal/cm²sec compared to 9.1 μcal/cm²sec at Lakitelek. The cause of the exceptional high heat flow in both case may be an unknown intrusive body in the depth. This intrusion has heated up the fractured Mesozoic rocks; in connection with the hydraulic system, hot water up to perhans 374°C at Lakitelek and superheated steam at Larderello have been found. It is also possible that at Lakitelek a superheated steam deposit exists.

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The Self-sealing Geothermal Field *

G. FACCA

Worldwide Geothermal Exploration Co., 10889 Wilshire Blvd. S 1460,
Los Angeles, California; and 11, Vicolo Clementi (Portuense), Rome 8, Italy.

F. TONANI

Istituto di Mineralogia, University of Florence, Italy.

Abstract

A geothermal field producing dry steam or high temperature water is a trap for convection currents generated in an aquifer of high permeability and of sufficient thickness by a deep heat source. A basic implication of this concept is that a geothermal field requires a cap-rock of more or less impermeable rocks above the producing aquifer.

In Larderello, Monte Amiata, and Salton Sea geothermal fields, a clearly reconnaissable tight formation overlies the producing zone and limits the upward movements of the convection currents.

In other fields, *i.e.* The Geysers (California), Wairakei and Waiotapu (New Zealand) we do not know a geologically well defined cap-rock formation, presenting a large difference in permeability in comparison with the reservoir formation.

The hot water circulating in a hydrothermal system without a cap-rock can produce deposits and rock alteration in proper places along the flow paths. The fracture and pore filling and any other permeability reducing factors increase resistance to the water circulation; those processes can originate an effective cap-rock. By such processes a hydrothermal system can become a self-sealed geothermal field.

The silica deposition is probably the main self-sealing process. In fact, 1) silica is very common, 2) it is available with almost no limitation, 3) its deposition is strictly related to temperature changes, and 4) it is likely to produce very effective patterns of deposition.

Where an unlimited CO_2 supply is available at depth, the calcium carbonate deposition appears to be a noticeable sealing process, which is controlled by

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pressure, at relatively shallow depth. In other cases $CaCO_3$ precipitation should not be an important factor in the self-sealing of geothermal fields.

Argillization appears to be an important shallow process. It is especially effective in the acid environment of many thermal shows, thus determining their migration and/or extinction.

According to our analysis and to present evidence those three self-sealing processes are the most important ones.

In The Geysers Field, the wells penetrated the same formation, the Franciscan graywackes, from top to bottom. The Franciscan Formation has a very low primary permeability; secondary or fissure permeability is at the contrary very high. It is evident that there is no recognizable cap-rock in the accepted sense of petroleum geology.

The wells produce superheated steam; the producing zone begins at 300 m depth or so; the quantity of steam increases with the thickness of the producing zone penetrated by the holes.

Beginning in 1964, the wells have been drilled with air as circulating medium. No steam or water has been observed in the top few hundreds meters drilled: we can safely conclude that the graywackes are impervious in the upper section of the holes.

Cores and cuttings show frequent fissures filled with silica in different mineral forms and hydrothermally altered rocks are common.

In the Geysers area, hot springs, steam vents, carbon dioxide and hydrogen sulphide fumaroles are numerous, and wide zones of rocks, altered by past hydrothermal activity, are prominent features. As usual in many hyperthermal areas, also in The Geysers the manifestations of surface heat change frequently in place, in size, and in fluids discharge. The filling of rock fissures by mineral deposition seems the simplest and most natural explanation of the place changes of the individual springs.

The active faults continually generate new fissures, limit the sealing action, and account for the persistent surface thermal activity of the area.

The composition of the waters from the hot springs at The Geysers has been re-considered, in comparison with both surface waters and natural steam. The hot springs mainly originate by natural steam condensation, as Allen and Day stated in 1927. This conclusion is now strenghtened and extended: the perched water table producing hot springs at The Geysers is purely condensed steam. Practically all its characteristics can be explained by this condition alone. Separation from other shallow water bodies is extremely sharp.

Let us sumarize: the impermeability of the upper section of the holes is demonstrated by the lack of fluids in the Sulphur Bank area, whereas the geochemistry of the hot springs compared with shallow waters indicates that similar conditions occur in the Geysers and Little Geysers areas. Furthermore, silica and other fissure-filling processes occur all over the region, as well as argillization of graywackes.

We conclude that:

a) a cap-rock exists in The Geysers Field; this fact readily explains the production of dry steam;

b) the relative impermeability of the cap-rock is due to the hydrothermal activity, which fills by mineral deposition the fissures of the graywackes and in places argillifies the original sandstone;

c) the active fault movements provide temporary openings for the hot ascending fluids; this process explains the surface thermal activity.

The numerous excellent papers on the Wairakei and Waiotapu fields suggest a similar explanation for some New Zealand geothermal fields. Steiner's observations on the rocks penetrated by drillholes in Waiotapu reveal many pertinent details of the self-sealing process. Grindley's paper on the structure of Waiotapu seems to anticipate some of our conclusions, notwithstanding the noticeable differences in general principles.

Furthemore, in some Iceland thermal areas the self-sealing process seems active and we suggest that further studies on this subject may provide a new outlook in geothermal exploration in that country.

A self-sealing geothermal field is defined as a geothermal field, in which hydrothermal activity has generated a cap-rock, by transforming originally permeable rocks into low permeability rocks in such a manner and with such a geometry, to constitute an efficient trap for convection currents. The Geysers Field is a typical example of a self-sealing geothermal field.

Thermal manifestations related to vaporization-condensation processes through channels in an impervious capping formation can be named « leak manifestations ». Their interest for geothermal exploration cannot be overlooked, all the more that they are recognizable by geochemical investigations.

The sealing process of « leak manifestations » and the incrustation process of steam wells are expected to be similar. However, argillization is a frequent and important sealing process of natural channels.

Calcite deposition is likely to be important both in natural shows and in wells, where steam-water separation goes on poorly. Plugs in wells can be produced also by soluble salts. Alkali and ammonium borates, boric acid, sodium sulfate and other compounds have been observed at Larderello; ammonium acid carbonate with some boron has been observed at the Ceysers.

According to our thinking the study of the incrustation process is important for the reservoir engineering.

The new concept broadens the geothermal exploration possibilities: many areas with recent thermal rock alterations and mineral deposition deserve proper consideration as possible areas for self-sealed geothermal fields. The new theoretical tool can be also usefully applied in rationalizing the geothermal exploitation and evaluation.