ANALYSIS OF THERMAL/MECHANICAL ENERGY-CONVERSION CONCEPTS

FINAL REPORT

MASTER

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U.S. Department of Energy
Division of Geothermal Energy

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Report prepared by R. DiPippo

June 1981

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A. Goal

To assist in achieving an acceleration of the market penetration of geothermal energy as a source of electric power in accordance with the National Plan for Energy Research, Development and Demonstration of the Energy Research and Development Administration (ERDA) as enunciated in 1976.

B. Objective

To cultivate special competence in the field of geothermal energy in several centers in the United States, and through these to create a manual for the use of geothermal energy for the production of electricity.

C. Tasks

1. Organize and monitor the technical progress of a number of centers for the analysis of thermal/mechanical energy conversion concepts (CATMECs).
2. Conduct periodic seminars or conferences of the CATMECs.
3. Analyze hybrid geothermal/fossil energy conversion systems.
4. Perform engineering and economic analyses of a range of geothermal expanders including both conventional and advanced (proposed) systems.
5. Develop thermodynamically consistent formulations for equilibrium and transport properties of relevant working fluids.
6. Review existing knowledge of two-phase flow.
7. Create a reliable predictive method of analysis of geothermal well flow.
8. Create a manual (sourcebook) on the utilization of geothermal energy for the production of electric power.

D. Task-Related Achievements

1. Teams were enlisted from the following organizations:

Battelle Northwest Laboratories, Richland, WA.

City of Burbank, CA, Public Service Department.

General Electric Company, Medium Steam Turbine Department,
Lynn, MA.

Idaho National Engineering Laboratory, Idaho Falls.

Jet Propulsion Laboratory, Pasadena, CA.

Lawrence Berkeley Laboratory, Berkeley, CA.

Lawrence Livermore Laboratory, Livermore, CA.

Oak Ridge National Laboratory, Oak Ridge, TN.

The University of Oklahoma, Norman, OK.

Pacific Sierra Research Corporation, Santa Monica, CA.

Radian Corporation, Austin, TX.

Rogers Engineering Company, San Francisco, CA.

Weidlinger Associates, New York.

U.S. Environmental Protection Agency, Cincinnati, OH.

U.S. Geological Survey, Reston, VA.

2. A total of ten (10) meetings of the CATMECs were organized and conducted by the Brown group, the last eight (8) of these being formal technical conferences of one-three (1-3) day duration, some with associated geothermal site visits. A summary of the meetings follows:

<u>Meeting</u>	<u>Dates</u>	<u>Meeting Place</u>	<u>Geothermal Site Visit</u>
CATMEC-1	May 1, 1976	Washington, DC	-
CATMEC-2	May 12, 1976	Washington, DC	-
CATMEC-3	November 4, 1976	Providence, RI	-
CATMEC-4	January 24-25, 1977	Berkeley, CA	-
CATMEC-5	April 12-14, 1977	Salt Lake City, UT	Roosevelt Hot Springs
CATMEC-6	July 27-28, 1977	Washington, DC	-
CATMEC-7	November 1-2, 1977	Providence, RI	-
CATMEC-8	February 21-24, 1978	San Diego, CA	Salton Sea, East Mesa, Cerro Prieto
CATMEC-9	August 30-31, 1978	Providence, RI	-
CATMEC-10	February 24-26, 1981	Salt Lake City, UT	Raft River

Detailed technical proceedings (called "Minutes") were written for CATMEC-3 through CATMEC-10, and were published as Brown University reports. These have been given a wide distribution.

3. Our analysis and synthesis of a variety of hybrid fossil-geothermal power plant concepts began with a cooperative effort between Brown and the City of Burbank. Later, Pacific Sierra Research Corporation and Ralph M. Parsons, Architect/Engineers became involved. A large number of reports and papers have been written, published and presented. A listing follows:

- (1) DiPippo, R., Kestin, J., and Khalifa, H.E., "Hybrid Fossil-Geothermal Power Plants", ASME Winter Annual Meeting, Paper 77-WA-Ener-2, Atlanta, 1977. (*)
- (2) Khalifa, H.E., DiPippo, R., and Kestin, J., "Hybrid Fossil-Geothermal Power Plants", Proc. 5th Energy Technology Conference and Exhibition, Washington, DC, 1978.

- (3) DiPippo, R., "An Analysis of an Early Hybrid Fossil-Geothermal Power Plant Proposal", Geothermal Energy Magazine, Vol. 6, No. 3, pp. 31-36, 1978. (*)
- (4) Kestin, J., DiPippo, R., and Khalifa, H.E., "Hybrid Geothermal-Fossil Power Plants", Mechanical Engineering, Vol. 100, No. 12, pp. 28-35, 1978.
- (5) Khalifa, H.E., DiPippo, R., and Kestin, J., "Geothermal Preheating in Fossil-Fired Steam Power Plants", Proc. 13th Intersociety Energy Conversion Engineering Conf., Vol. 2, pp. 1068-1073, 1978. (*)
- (6) DiPippo, R., Khalifa, H.E., Correia, R.J., and Kestin, J., "Fossil Superheating in Geothermal Steam Plants", Proc. 13th Intersociety Energy Conversion Engineering Conf., Vol. 2, pp. 1095-1101, 1978. (*)
- (7) DiPippo, R., "Impact of Hybrid Combustion-Geothermal Power Plants on the Next Generation of Geothermal Power Systems", Proc. 3rd Annual EPRI Geothermal Conference and Workshop, 1979.
- (8) DiPippo, R. and Avelar, E.M., "Compound Hybrid Geothermal-Fossil Power Plants", GRC Transactions, Vol. 3, pp. 165-168, 1979.
- (9) DiPippo, R., Avelar, E.M., Kestin, J., and Khalifa, H.E., "Compound Hybrid Geothermal-Fossil Power Plants: Thermodynamic Analyses and Site-Specific Applications", ASME, Energy-Sources Technology Conference & Exhibition, Paper 80-Pet-83, 1980. (*)

NOTE: (*) denotes that a Brown report was also written.

4. Technical and economic analyses were conducted for the case of the single-flash geothermal plant at Ahuachapán, El Salvador, where a 60-MW system (30x2) had been in successful operation for a number of years. One of the Brown team, R. DiPippo, joined with three others

from various organizations and conducted a careful assessment of the Ahuachapán operation with the goal of transferring that information to a United States geothermal plant. The following report contains the findings of the team:

Bloomster, C.H., DiPippo, R., Kuwada, J.T., and Russell, B.F., "The Ahuachapán Geothermal Project: A Technical and Economic Assessment", Battelle, Pacific Northwest Laboratory, Rep. PNL-2926, UC-66i, April 1979.

The following article was prepared from a Japanese periodical: DiPippo, R. (editor), "The Economics of Geothermal Power", Brown Rep. COO/4051-43, Feb. 1979. Trans. from the Japanese by T. Sato, original article by N. Mori, ANRE, MITI, July 1975.

5. Attention was focussed on isobutane, a candidate working fluid for binary plants, in order to assess the existing literature on thermodynamic and transport property data, and the impact of imprecise property information on the design of plant components, particularly heat exchangers. The effort culminated in the publication of the following:

Kestin, J., Khalifa, H.E., and Kumar, B., "Thermodynamic and Transport Properties of Isobutane: A Survey of Available Literature", Brown Rep. COO/4051-35, CATMEC/27, November 1978.

Khalifa, H.E. and Kestin, J., "The Influence of Thermophysical Properties on the Design and Sizing of Geothermal Power Plant Components", ASME Winter Annual Meeting, Paper 79-WA/HT-18, 1979.

6. The Brown team performed an extensive and critical survey of the literature on two-phase flow. Those books and articles deemed to be of most value to problems in geothermal flow situations were assessed and briefly described in the following report:

Bilicki, Z., DiPippo, R., Michaelides, E.E., and Kestin, J., "Geothermal Two-Phase Flow: A Selective, Annotated Guide to the Literature", Brown Rep. DOE/ET/27225-11, June 1980.

7. We have begun the task of developing a reliable predictive method of analysis of geothermal well flow. This objective has been expanded and constitutes the main goal of our present contract. As a means of getting started in this effort, we organized a workshop/symposium at Brown for the research team. Several outside researchers with experience in the field participated including J. Bataille (Lyon), J. Butz (DRI), K. Hules (Sperry Research), R. Wood (General Electric). We published a summary of this week-long meeting:

DiPippo, R., "The Next Steps in Two-Phase Flow: Executive Summary", Brown Rep. DOE/ET/27225-12, September 1980.

8. The main objective of the contract was achieved with the publication of two volumes on the state of the art in geothermal power technology:

Kestin, J., Ed.-in-Chief, DiPippo, R., Khalifa, H.E., and Ryley, D.J., Eds., Sourcebook on the Production of Electricity from Geothermal Energy, U.S. Dept. of Energy, U.S. Government Printing Office, Washington, DC, 997 pages, 1980.

DiPippo, R., Geothermal Energy as a Source of Electricity: A World-wide Survey of the Design and Operation of Geothermal Power Plants, U.S. Dept. of Energy, U.S. Government Printing Office, Washington, DC, 370 pages, 1980.

These books have been distributed worldwide among engineers, scientists, educators, law makers, policy makers, plant managers, engineering and science students, and interested members of the public. The main distribution center has been and continues to be Brown University. Initial mailings were done by the GPO according to a list compiled at Brown from replies to a number of announcements that were printed and disseminated among the geothermal community. Of the original 3000 copies (2000 hardback, 1000 paperback) of the Sourcebook, fewer than 1000 remain at Brown; of the same number of Surveys, fewer than 750 remain at Brown. The GPO has sold out its first printing of the Survey and is in the process of reprinting this volume for sale through government bookstores.

We have attempted to compile a distribution list of those people who have been sent books from Brown, but it cannot be called "complete" owing to secondary distribution by other agencies, such as Lawrence Berkeley Laboratory, Oak Ridge National Laboratory, etc. The list is kept up to date as books continue to be mailed out.

Both books have received high praise from those in the industry. A sampling of unedited, complete reviews and a letter of testimony are included, the latter coming from the president of the Geothermal Resources Council is particularly noteworthy.

GEO THERMAL REPORT

Vol. IX, No. 15 August 1, 1980

NEW WORLD SURVEY OF OPERATING GEOTHERMAL PLANTS IS HOT OFF PRESSES and DOE geothermal div., its sponsor is providing broad distribution to rally greater engineering-earth science expertise to banners of geothermal electricity.

HIGHLY READABLE. Ronald DiPippo, prof. of mechanical engineering at Southeastern Massachusetts Univ. and adjunct prof. of engineering at Brown Univ., authored new book. Over last 3 yrs. he has amassed vast set of documents and references, talked with equipment vendors and utility operators and visited many geothermal sites. From these comes thoroughly digested and organized, highly readable, fact-filled volume. Overview of his world findings were presented to N.Y. section of GRC this Spring (GR,15May,2). Survey was brain-child of DOE's Clifton B. McFarland, who asked DiPippo to prepare tome as running-mate to separate sourcebook on production of geothermal electricity being prepared by Joseph Kestin, also prof. at Brown. Kestin's work is to be issued this September.

DiPippo's book, "Geothermal Energy as a Source of Electricity," provides comprehensive view of national geothermal programs, country-by-country, with snapshots, plant diagrams, equipment specifications for almost every operating installation. Table in opening chapter puts worldwide electric geothermal capacity at 1759 MW through July 1979, U.S. still leading at 663 MW. DiPippo provides one of first looks at China's geothermal effort, receiving attention under People's Republic emphasis of education, science and technology, with but one presently operating plant. But geothermal seems certain to be developed rapidly in Himalayan Mountains both for electricity and other applications.

YANG-PA-CHING. China's single plant is high in Tibetan Himalayas, at 4300 m. altitude, in plateau of Yang-pa-ching Basin west of city of Lhasa, at installed capacity of 1 MW. Plant site is just one of better than 400 in Himalayan geothermal belt, basin extending more than 1250 mi. to east and into Western Yunnan Province. Yang-pa-ching plant built in 3 mos. by Chinese and Tibetan technicians and workers as single-flash facility won medal for technical achievement from Tibet Communist Party.

Started-up in 1978 and producing kilowatts for nearby residents, plant apparently has suffered no bad effects from its high 14,000 ft. altitude. Large scale geothermal plant is supposed to be under present construction, and plans are for construction of separated steam/hot water flash (double-flash) plants, according to reports from Univ. of Peking geothermal group.

Sourcebook also reviews plants, geology and future plans of older and well-established programs of Italy (421 MW), Japan (165), Mexico (150) and New Zealand (203).

BALANCED SOVIET PROGRAM. Russia's geothermal potential though huge, estimated at 48,000 MW for direct thermal applications and "several hundreds of megawatts" for electric power, DiPippo's tables only showed two small operating plants, at Pautetka and Paratunka on Kamchatka Peninsula, of which latter as first binary cycle plant has been shut down reportedly due to freon-12 leaks (GR,15Dec'78,3). DiPippo acknowledged difficulty of gaining info on Soviet Union plans, and of confirming it once obtained (so what else is new?). But he felt Soviets mean to balance their future development of relatively low temperature hydrothermal fluids between space heating, agricultural soil heating and electrical generation.

DiPippo's volume as companion to Kestin's broader geothermal electricity source book is being distributed by Oak Ridge National Lab and freebie copy is going to names on ORNL's geothermal distribution list. DOE also passed out forms at last September's GRC annual meeting for all wanting complimentary copy. Printing costs are estimated at \$6-7 per copy and 3000 copies have been printed. Total cost of both volumes haven't yet been added-up, but McFarland is figuring about \$100,000.

McFarland says aim of Kestin-DiPippo books is to attract many in engineering and manufacturing fields able to make contribution to geothermal development, but not yet aware of or conversant with geothermal technology, which still includes many in oil and gas industry. "We see publication of these volumes as a start in opening eyes to geothermal possibilities, but it's only tip of the iceberg," says McFarland.

GEOTHERMAL ENERGY AS A SOURCE OF ELECTRICITY

A Worldwide Survey of the Design and Operation of Geothermal Power Plants by Ronald Di Pippo, Professor of Mechanical Engineering, Southeastern Massachusetts University, North Dartmouth, Massachusetts 02747 and Adjunct Professor of Engineering (Research) Brown University, Providence, Rhode Island 02912. Published January 1980 and prepared under the sponsorship of the U.S. Department of Energy, Assistant Secretary for Resource Applications, Division of Geothermal Energy, Washington, D.C. 20585. DOE/RA/28320-1. Paperback copies available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20404 for \$6.00.

This work by Ron Di Pippo is concise, thorough, and should be read by energy planners all over the world. The book makes realistic arguments, based on numerous excellent references, for the unrealized potential of geothermal energy. Carefully covering all the existing geothermal installations, the book provides a firm basis for the current success of geothermal electrical systems and for future successes should the U.S. undertake more vigorous development. There are overviews in each segment which aids in establishing a proper perspective on the development in each country which now avails itself of the geothermal resource, and their histories as well as geologic discussions of each area. Covering all aspects of geothermal developments including geopressured resources and offering informative maps, charts and diagrams, this work is really an important adjunct to any geothermal library, and should be read by those wishing to increase their knowledge of the state-of-the-art in geothermal exploitation electrically.

GEO THERMAL REPORT

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IN INDUSTRY

"SOURCEBOOK ON THE PRODUCTION OF ELECTRICITY FROM GEOTHERMAL ENERGY" EDITED BY Joseph Kestin of Brown University is hot off press and, as running mate to world survey of operating geothermal plants by Ron Di Pippo, also sponsored by DOE and published recently (GR, 1 Aug'80,2), should help power engineers and utilities, design and prepare economic evaluations of future plants. DOE has printed 3000 copies and as "outreach" service to emerging geothermal industry is passing them out gratis. GEOTHERMAL REPORT readers may request 1000-page sourcebook from Di-Pippo, Brown Univ., P.O. Box D, Providence, RI 02912.

Some 40 authors contributed to text and its ten chapters and subdivisions covering such principal topics as resource characteristic, available work in geothermal energy, power systems, waste heat rejection, materials selection, economic consideration, design optimization and environmental considerations. Due to no. of pens writing sourcebook, both Kestin and DOE project mgr. Cliff MacFarland agree it's more an encyclopedia or handbook, rather than text book or treatise. And though tilted to power engineer, both think sourcebook should be valuable to geologist prospecting for geothermal, mgrs. of geothermal reservoirs, mathematicians working out codes for reservoir behavior, mechanical-chemical engineers designing plants and components, physicists working on thermodynamic properties, metallurgists, economists, environmentalists, govt. planners, etc.

GEOHERMAL RESOURCES COUNCIL

(916) 758-2360 • P.O. Box 98 • Davis, California 95616

DAVID N. ANDERSON
Executive Director

BEVERLY A. HALL
Assistant Director

February 19, 1981

Dr. Jack Salisbury
Division of Geothermal Energy
Department of Energy
20 Massachusetts Avenue, N.W.
Washington, D.C. 20585

Dear Dr. Salisbury:

On behalf of the Geothermal Resources Council, I would like to commend you and the staff of the Division of Geothermal Energy of the U.S. Department of Energy for a job well done in the development of the two volumes: "Geothermal Energy as a Source of Electricity" and the "Source Book on the Production of Electricity from Geothermal Energy." These two outstanding reference documents, which were prepared under the direction of Dr. Ronald D. DiPippo and Dr. Joseph Kestin of Brown University, have made a tremendous impact and filled a void in the field of geothermal power plant design within utility and private architectural and engineering organizations.

It is this type of project and the commitment to excellence by those who were involved that the Council would like to see the Division of Geothermal Energy pursue in the future. I am sure the effort spent by you and your co-workers on this project will not go unrewarded.

Yours truly,

C. W. Berge
President

CWB:jm

cc: Hon. James Edwards
Ron DiPippo
Joseph Kestin
Cliff McFarland

C. W. Berge
President

W. Leo Parchman, Jr.
Vice President

Jim Combs
Vice President

James T. Kuwada
Vice President

John Woods
Secretary-Treasurer

E. Personnel

The following individuals participated in the project over the course of its lifetime:

Dr. Joseph Kestin, Principal Investigator, Editor-in-Chief
Dr. P. F. Maeder, Co-Principal Investigator
Dr. R. DiPippo, Visiting Professor (Research), Editor
Dr. H. Ezzat Khalifa, Adjunct Assistant Professor (Research)
Dr. D. John Ryley, Visiting Professor (Research), Editor
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