ALTERNATE MATERIALS OF CONSTRUCTION FOR GEOTHERMAL APPLICATIONS

PROGRESS REPORT NO. 13
APRIL - JUNE 1977

Contributors:

L.E. Kukacka	T. Sugama
J. Fontana	W. Horn
J. Amaro	

Work performed for the
DIVISION OF GEOTHERMAL ENERGY
UNITED STATES ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
WASHINGTON, D.C. 20545

M. STEINBERG - Head
L.E. KUKACKA - Project Leader

PROCESS TECHNOLOGY DIVISION

DEPARTMENT OF APPLIED SCIENCE

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America

Available from

National Technical Information Service

U.S. Department of Commerce

5285 Port Royal Road

Springfield, VA 22161

Price: Printed Copy \$4.00; Microfiche \$3.00

September 1977

800 copies

Abstract

A program to determine if non-metallic materials such as polymers, concrete polymer composites, and refractory cements can be utilized as materials of construction in geothermal processes is in progress. To date, several high temperature polymer concrete systems have been formulated, laboratory and field tests performed in brine, flashing brine, and steam at temperatures up to 260°C (500°F), and economic studies started. Laboratory data for exposure times > 2 years are available. Results are also available from field exposures of up to 18 months in four geothermal environments. Good durability is indicated. Work at two of these sites is continuing. A test has recently been completed in the Imperial Valley and another test is in progress. Work accomplished during the period April 1-June 30, 1977 is described in the current report.

Summary

Preliminary results indicate that the significant improvements obtained in the durability of polymer concrete materials to hot brine and steam when aggregate containing portland cement is used, may be due to chemical bonding between the vinyl groups in the monomer and CaO.

Measurements of the bond strength of polymer concrete liners on steel pipe have been made. Shear strengths varying from 360 to 425 psi have been measured for liners applied to sandblasted surfaces. If sandblasting is not used, the value decreases to ~ 65 psi.

Field testing of a 6-in.-diam section of lined pipe has been started at Raft River and sections of 2 and 3-in. pipe are being prepared for testing at East Mesa.

Laboratory testing of specimens in simulated geothermal environments was continued. Samples exposed to 25% brine solutions at 177°C (350°F) for 760 days have not deteriorated. Similar results have been obtained with pipe specimens exposed to a 400 ppm solution at 150°C (302°F) for 252 days.

Samples exposed to a pH 1 hydrochloric acid solution at 90°C (194°F) for 322 days have not deteriorated. Samples containing silica sand-portland cement aggregate have yielded similar results after 94 days in pH 1 hydrochloric acid at 200°C (392°F).

Polymer concrete pipe sections exposed for 18 months to high sulfate containing soils show no visible signs of deterioration.

Field testing of specimens at Raft River, The Geysers, and Niland is continuing. During the report period samples were removed from The

Geysers and East Mesa. Visual examination of the former after 18 months exposure to dry steam at 238°C (460°F) indicated no apparent deterioration. Evaluation is in progress. Samples exposed at East Mesa to flowing brine at 160°C (320°F) for 60 days are reportedly in good condition. These samples have not yet been returned to BNL.

Alternate Materials of Construction for Geothermal Applications

Progress Report No. 13
April-June 1977

Introduction

A serious problem in the development of geothermal energy is the availability of durable and economic materials of construction for handling hot brine and steam. Hot brine and other aerated geothermal fluids are highly corrosive materials and they chemically attack most conventional materials of construction. Corrosion and scale incrustations have been encountered in all geothermal plants, and to various degrees, adversely affected plant lifetimes and power output. To date carbon steel has been the primary material of construction used in these facilities but the use of expensive materials such as titanium base alloys and Hastalloy C may be required to insure long-term operation.

The purpose of the current Brookhaven National Laboratory (BNL) program is to identify areas in geothermal processes where non-metallic materials such as concrete polymer composites, plastics, and refractory cements may be utilized in a cost-effective manner and to develop and test these materials under laboratory and field conditions.

The feasibility of using concrete polymer composites as materials of construction for handling hot brine and steam was demonstrated in 1972.¹ As part of this work the concrete liner on a vertical tube evaporator at the Office of Saline Water Desalting Facility in Freeport, Texas was partially impregnated to a depth of ~ 0.25 in. The results from these tests indicated that the composites have long-term stability in

seawater at 177°C (350°F) and in acid solutions. Based upon these results, a research program to develop the composites for use in geothermal systems was started in April 1974. To date, high temperature polymer concrete (PC) systems have been formulated, and laboratory and field tests performed in brine, flashing brine, and steam at temperatures up to 260°C (500°F). Results are available from field exposures of up to 18 months in four geothermal environments.² Tests at two other sites have recently been started. To date, good durability is indicated. Work performed during the period April-June 1977 is described in the current report.

Summary of Previous Report

Work to develop high temperature PC formulations was continuing. Two new monomer formulations were identified which may extend the operating limit for PC in brine to > 260°C (500°F). The onset of decomposition of a polymer containing 50 wt % styrene - 32.8 wt % acrylonitrile - 9 wt % TMPTMA - 8.2 wt % polyphenylene oxide is 262°C (503°F). The use of 30 wt % styrene in conjunction with 60 wt % triallyl cyanurate and 10 wt % polyphenylene oxide produces a polymer which starts to decompose at 286°C (547°F).

A technique for producing PC-lined carbon steel pipe was developed. A 6-in.-diam section of lined pipe was sent to Raft River for testing and sections of 2 and 3-in. pipe were being prepared for testing at East Mesa.

Laboratory testing of specimens in simulated geothermal environments was continuing. Samples that were exposed to 25% brine at 238°C (460°F) for up to 234 days had not deteriorated. Similar observations were made after exposure at 177°F (350°F) for 631 days.

Samples exposed to a pH 1 hydrochloric acid solution at 90°C (194°F) for 236 days had not deteriorated. After 25 days in a similar solution at 200°C (392°F), PC containing a silica sand-portland cement aggregate was unaffected. Samples containing limestone aggregate cracked.

Evaluation of samples exposed at Klamath Falls for one year was completed. The results from compressive strength measurements indicated no significant reductions in strength.

Testing of specimens at Raft River and The Geysers was continuing. Field tests utilizing the Battelle Northwest Laboratory equipment at East Mesa were started during April 1977. The test consisted of the exposure of 48 specimens of PC to 160°C (320°F) brine flowing from Well 6-1. It was planned to examine the samples after exposure for 70 days.

Samples were installed at six locations in the Bureau of Mines test facility at Niland in the Imperial Valley. The test was scheduled to start during April.

The applicability of PC as an electrical insulator was demonstrated in EPRI-sponsored research. This work will have application in the transmission of power from geothermal plants. The mechanical strength of PC is equivalent to that of porcelain but it has twice the dielectric strength. It can also be used for configurations too complex for porcelain materials. The estimated cost of a PC insulator is less than half of the cost of porcelain.

Economic studies to identify other potential applications for concrete polymer materials in geothermal systems were started. Applications in condensate piping systems, acid handling systems, reinjection lines, cooling towers, district heating systems, and to repair and protect concrete surfaces

appeared cost effective.

During the third quarter of FY 1977 work has been continued in each of the program tasks. This work is described in the current report.

Task 1. Selection of Lining Materials

Work is being performed to develop polymer formulations and PC composites which can be used as materials of construction at temperatures up to 260°C (500°F). In a separate program,³ research is being performed to determine if materials can be formulated for use as well cementing materials at temperatures up to 400°C (750°F).

In the previous progress report⁴ several promising high temperature polymer formulations were listed. Two systems, 50 wt % styrene - 32.8 wt % acrylonitrile - 9 wt % trimethylolpropane trimethacrylate (TMPTMA) - 8.2 wt % polyphenylene oxide and 30 wt % styrene - 60 wt % triallyl cyanurate - 10 wt % polyphenylene oxide, had onset of decomposition temperatures in a nitrogen environment of 262°C (504°F) and 286°C (547°F), respectively.

Work with these systems was continued during the current report period. PC specimens containing the two formulations were exposed to air at a temperature of 238°C (460°F) and to brine at 238°C (460°F) and 260°C (500°F). The styrene-acrylonitrile-TMPTMA-polyphenylene oxide system showed excessive degradation. After 60 days in brine at 238°C (460°F), the compressive strength decreased from a value of 10,500 psi to 2200 psi.

Considerably better results were obtained with the formulation containing styrene-triallyl cyanurate-polyphenylene oxide. Compared to the control compressive strength of 6372 psi, essentially no change in strength was detected after 30 days in an oven at 238°C (460°F). After 60 days in brine at the same temperature, the compressive strength was reduced to 4200 psi. Additional work with both of these systems is planned.

Good results were obtained when a PC formulation consisting of 17 wt % of a 80 wt % styrene - 8 wt % TMPTMA - 12 wt % polyphenylene oxide mixture was exposed to hot brine at 238°C (460°F). After 30 days in test, a strength of 11,074 psi was measured. The control value was 10,965 psi.

Work with styrene-acrylonitrile formulations containing acrylamide or methacrylamide was continued. Cross-linking agents (TMPTMA or divinyl benzene) are added to the monomers. Tests are being performed at temperatures up to 300°C (572°F). These formulations produce high quality composites with compressive strengths generally ranging between 20,000 and 25,000 psi and with water absorptions < 0.5%. Good thermal stability and durability to hot brine has been observed. Preliminary indications are that the use of the formulations in conjunction with an aggregate containing from 20 to 30 wt % portland cement gives the maximum durability.

Based upon results discussed below which indicate possible bonding between vinyl groups and CaO, the effect of the use of CaO and mixtures of CaO and Al_2O_3 on the durability will be investigated.

The durability of PC to geothermal fluids has been found to be highly dependent upon the composition of the aggregate. Materials such as quartz, silica, fly ash, and portland cement are being investigated. All of the materials can be used in composites which have good durability at temperatures < 218°C (425°F). Above this temperature, only PC materials containing mixtures of silica sand and portland cement have been durable to brine and steam.

To determine the reason for this effect, infra-red and Differential Thermal Analysis (DTA) studies are being performed. In these tests, each of the chemical constituents of Type III portland cement (SiO_2 , Al_2O_3 , Fe_2O_3 , CaO, and MgO) are being combined with silica sand and various

vinyl-type monomers (MMA, TMPTMA, and styrene) to form PC.

Evidence of chemical bonding between the CaO and $-CH_2$ groups in the vinyl monomers has been detected using infra-red spectroscopy. This is indicated by the transmittance ratio of $-CH_2$ groups to C=O groups which is reduced by half when the ratio of monomer to CaO is doubled. This effect is not noted when SiO_2 , Fe_2O_3 and Al_2O_3 are used as the aggregate. Similar tests are currently being performed with samples that have been exposed in an autoclave to brine at 238°C (460°F). Preliminary data indicate that under this condition mixtures of CaO and Al_2O_3 yield the most durable composites.

Task 2. Process Technology

Work is in progress to develop the technology required to produce PC and PC-lined carbon steel pipe and vessels for use in containing geothermal fluids. A prototype section of pipe is currently in test at Raft River, and it is planned to initiate a test at East Mesa and possibly at Boise.

Development of the techniques required to make PC-lined pipe continued with the performance of tests to determine the effect of surface roughness on the bond strength of PC to carbon steel. In these tests sections of 2 and 3-in.-diam Sch. 40 pipe were lined with PC containing a 55 wt % styrene-36 wt % acrylonitrile - 9 wt % TMPTMA monomer mixture and an aggregate consisting of 80 wt % silica sand - 20 wt % calcium aluminate cement. Liners were placed on surfaces that were cleaned and others that were cleaned and sandblasted. The effect of sandblasting was large. Bond strengths varying from 50 to 80 psi were measured for liners placed against non-sandblasted pipe. For sandblasted surfaces, the bond strengths increased to values

between 360 and 425 psi. Based upon the results from these and earlier tests, sections of lined pipe are being fabricated for testing at East Mesa.

Work is in progress to determine the hydrostatic capabilities of PC and polymer impregnated concrete pipe. To date, PC pipe capable of operating at 200 psi and 120°C (~ 250°F) has been produced. A section of PC pipe being tested at room temperature is shown in Figure 1. Non-reinforced concrete pipe, 6-in.-o.d. x 4-in.-i.d., that was impregnated with 55 wt % styrene - 36 wt % acrylonitrile - 9 wt % TMPTMA also met these test conditions. Compressive strength data for the materials as a function of temperature are currently being obtained. When available, these data will be used to design sections with higher pressure and temperature capabilities.

Task 3. Physical and Chemical Property Measurements

In support of the experimental work being performed in Tasks 1, 2, and 4, the mechanical and chemical resistance properties of concrete polymer materials are being determined. The tests are being performed in autoclaves at conditions simulating environments in which field tests are in progress or being planned. The facility consists of 10 autoclaves which are designed for continuous operation with brine and steam at a temperature of 220°C (428°F) and two other pressure vessels rated at 280°C (536°F). Two additional autoclaves are currently on order.

Preliminary testing of PC specimens in an autoclave containing a 25% concentration of synthetic Imperial Valley geothermal brine at a temperature of 177°C (350°F) was continued during the report period.

Figure 1. Hydrostatic test being performed on PC pipe.

Two PC formulations, 60 wt % styrene - 40 wt % TMPTMA and 50 wt % styrene - 33 wt % acrylonitrile - 17 wt % TMPTMA are being evaluated. The formulations consist of 12 wt % of the monomer mixture and 88 wt % of a 90 wt % silica sand - 10 wt % portland cement aggregate.

The test has been in progress for 760 days. A visual inspection made at that time indicated no cracking or other signs of deterioration. Strength measurements were last made after exposure for 417 days.⁴ At that time the strengths were the same as those measured after exposure for 63 days. This test is continuing.

The testing of a 3.5-in.-i.d. x 1-in.-wall PC pipe which is a prototype of sections to be installed at Raft River was continued. The PC consists of a 60 wt % styrene - 40 wt % TMPTMA mixture and an aggregate containing 90 wt % silica sand - 10 wt % portland cement. With the exception of slight discoloration, no evidence of deterioration is apparent after exposure for 252 days to a 400 ppm brine solution at 150°C (302°F). The pipe section is shown in Figure 2. The test is being continued.

During the previous report period⁴ a section of PC-lined carbon steel pipe was sent to Raft River for testing. The PC formulation consists of a 70 wt % Derakane - 30 wt % triallyl cyanurate monomer mixture and an aggregate containing 80 wt % silica sand - 20 wt % calcium aluminate cement.

Laboratory evaluation of PC pipe composed of the same materials was started during the current report period. After 57 days exposure to a 400 ppm brine at 204°C (400°F), no change in weight or appearance has been observed. This section is shown in Figure 3.

Figure 2. PC pipe after exposure to 400 ppm brine at 150°C for 252 days.
No deterioration is apparent.

Figure 3. PC pipe containing materials used for lined pipe in test at Raft River. After 57 days in 400 ppm brine at 204°C, no deterioration is apparent.

Tests are in progress to determine the durability of PC pipe to acid soil conditions. As part of this work, samples of concrete, PC, and steel pipe have been exposed since February 1976 to soil containing a 10% (2N) H_2SO_4 solution.⁵ The pH of the soil is 2.9. During the current report period the samples were removed for evaluation. To date, after 16 months in test, the concrete and PC specimens show no visible signs of deterioration or weight loss. Slight corrosion of the steel pipe is evident. This test is continuing.

Work to determine the feasibility of using concrete polymer materials in high temperature - low pH environments is also continuing. Two tests are currently in progress.

In one test 3 PC samples are being exposed to a pH 1 HCl solution at 90°C (194°F). To date the samples have been in test for 322 days. No evidence of corrosion of the PC as determined by pH and weight change measurements has been detected. These samples are shown in Figure 4.

A test in pH 1 HCl at 200°C (392°F) is also in progress. During the previous quarter⁴ three specimens were examined after 24 days in test. Two samples containing limestone aggregate were found to be cracked. A sample containing 55 wt % styrene - 36 wt % acrylonitrile - 9 wt % TMPTMA with a 90 wt % silica sand - 10 wt % portland cement aggregate was not attacked. Testing of this sample has continued for a total of 94 days. No deterioration is apparent.

Two additional specimens containing the sand-cement aggregate have been placed into test. Two monomer formulations, 60 wt % styrene - 40 wt % TMPTMA and 50 wt % styrene - 33 wt % acrylonitrile - 17 wt % TMPTMA were used in these samples. To date after exposure for 70 days, the samples are in good condition.

Figure 4. PC after exposure to pH 1 hydrochloric acid at 90°C for 322 days. Concrete control failed after 21 days.

Task 4. Field Tests

To date, test series have been completed at The Geysers, Baca Wells, Klamath Falls, Raft River, and East Mesa. Tests are currently in progress at The Geysers, Raft River, and Niland. Another test at East Mesa is being planned. The status of each of these programs is summarized below.

The Geysers

Tests are in progress to determine the durability of PC when exposed in a well-head chamber to dry steam at 238°C (460°F). A preliminary test series was completed in September 1975 which indicated that the materials had high strength and low permeability after exposure for 90 days.⁶

Based upon these data, a second series of samples was placed in test during November 1975. Two monomer systems, 50 wt % styrene - 33 wt % acrylonitrile - 17 wt % TMPTMA and 55 wt % styrene - 36 wt % acrylonitrile - 9 wt % TMPTMA, are being tested. Aggregate composition and polymerization method are other variables in the test series.

Samples have been evaluated after exposure for 90, 180, and 365 days. All samples containing an aggregate consisting of 90 wt % silica sand - 10 wt % portland cement have shown good durability. Composites containing other aggregates failed. The average compressive strength of specimens exposed to the test conditions for 1 year was 4200 psi, ~ 50% of the control but in fair agreement with a value of 4900 psi that was measured after a 90 day exposure.

During the current report period specimens were removed from test after exposure for 18 months. All appear to be in good condition (see Figure 5). Evaluation of the samples is in progress. The last specimens

Figure 5. Test specimens after exposure at The Geysers to dry steam at 238°C for 18 months.

in the series will be removed after exposure for 24 months.

Baca Wells

A test to determine the durability of PC to flashing brine at a temperature of $\sim 160^{\circ}\text{C}$ (320°F) was performed at Baca Wells, New Mexico. The total exposure time was 180 days.

The test series consisted of two monomer mixtures, 60 wt % styrene - 40 wt % TMPTMA and 50 wt % styrene - 33 wt % acrylonitrile - 17 wt % TMPTMA, mixed with an aggregate consisting of 90 wt % silica sand and 10 wt % portland cement. Three different polymerization methods were utilized.

The specimens were found to be in good condition after the 180 day test. Two samples which contained the 60 wt % styrene - 40 wt % TMPTMA mixture polymerized using benzoyl peroxide and dimethyl aniline, were slightly cracked. All of the other materials were crack-free.

Tests performed on the samples included dimensional stability, weight change, water absorption, and compressive strength. Little if any changes in the dimensions and weight were detected. Compared to the controls, all of the samples containing styrene-TMPTMA had strengths which were essentially unaffected by the exposure. The samples containing styrene-acrylonitrile-TMPTMA polymerized by promoters and initiators were also unaffected. The other samples exhibited slight strength reductions and increases in absorption. These strengths were in the same order as those obtained after 180 day exposure at The Geysers (~ 4500 psi).

Klamath Falls

Samples of concrete polymer materials have been exposed to low temperature geothermal fluids at Klamath Falls, Oregon.

Field testing was started in November 1975. Forty-eight cylindrical specimens of PC, PIC, and glass polymer composite (GPC) were placed into wells at temperatures ranging between 27°C and 99°C (81° and 210°F). Samples were removed for evaluation after exposure for 90, 180, and 360 days.

All of the specimens were found to be crack-free. The results from compressive strength and water absorption tests indicate that both properties are independent of the exposure temperature. The water absorptions remained constant throughout the test. Reductions in compressive strength ranging between 14 to 18% were noted for samples exposed for 180 days. Beyond that time, the strengths remained essentially constant.

Raft River

A preliminary test has been completed and two others are in progress.

In the first experiment, twenty 2-in.-diam x 0.25-in.-thick cement discs, impregnated with 60 wt % styrene - 40 wt % TMPTMA, were subjected to the ~ 150°C (302°F) fluid in an attempt to measure the resistance of PIC to abrasion. After 70 days in test, no deterioration of the PIC was apparent. Severe attack was noted on several metallic samples.

Testing of PC samples in the "Raft River Mobile Corrosion, Deposition, and Component Test Laboratory" was started in September 1976. The test conditions are as follows: temperature 135°C (275°F), flow 200 gpm, and pressure 130 psi. To date only the results from samples exposed for 90 days are available. These data indicate trends similar to those obtained in the other field tests; slight reductions in strength, dimensional stability, and constant water absorption. This test is continuing.

During the current report period a section of PC-lined pipe was placed into test. A description of the test section is given in Ref. 4.

East Mesa

With the cooperation of the Battelle Northwest Laboratory (BNWL), a test was performed in the Imperial Valley at East Mesa. The test was started during April. In this work, 48 hollow cylinders of PC (7/8-in.-o.d. x 3/16-in. wall x 2 3/8-in.-long) were exposed to flowing brine at $\sim 160^{\circ}\text{C}$ (320°F). Formulations containing two monomer mixtures, 50 wt % styrene - 33 wt % acrylonitrile - 17 wt % TMPTMA and 55 wt % styrene - 36 wt % acrylonitrile - 9 wt % TMPTMA, in conjunction with 4/1 and 1/1 ratios of sand and portland cement aggregate, were exposed to the fluid.

The samples were removed after 60 days in test. Visual examination made at the site indicated no apparent deterioration. The specimens are being returned to BNL for analysis.

Niland

A total of 24 PC specimens are being tested in the Bureau of Mines facility at Niland. The test was originally scheduled to start during April but was delayed until June. One monomer mixture, 55 wt % styrene - 36 wt % acrylonitrile - 9 wt % TMPTMA, and two sand-portland cement aggregate mixtures, 9/1 and 4/1, are being exposed to six environments. These are in the 220°C (428°F) brine at the inlet to the first steam separator, the brine and steam effluents from the first steam separator, the brine and steam effluents from the second steam separator, and at the steam/brine interface in the second separator. A date for removal of the specimens has not yet been established.

Task 5. Technology Transfer and Economic Evaluation

Plans have been made to initiate detailed studies to identify areas in geothermal processes where the use of non-metallic materials such as plastics, concrete polymer composites, and refractory cements can favorably affect the economics of the processes. The first stage of the effort is to evaluate existing conceptual geothermal power plant designs with respect to the specified materials of construction. Studies to determine the potential savings in capital and operating costs resulting from the use of non-metallic materials in applicable portions of the processes will then be made. This work will commence during the next report period.

Task 6. Administrative

During the current report period, three "Monthly Administrative Letters" were submitted to DGE and Quarterly Progress Report No. 12⁴ was issued. A paper entitled "The Applicability of Concrete Polymer Materials for Use in Geothermal Environments" was presented at the 1977 Society of Petroleum Engineers of AIME Symposium on Oilfield and Geothermal Chemistry.

References

1. DePuy, G. W. and Kukacka, L. E., Editors, Concrete Polymer Materials, Fifth Topical Report, BNL 50390 and REC-ERC-73-12, Dec. 1973.
2. Kukacka, L. E., The Applicability of Concrete Polymer Materials for Use in Geothermal Environments, SPE 6611, Presented at 1977 SPE-AIME International Symposium on Oilfield and Geothermal Chemistry, La Jolla, Cal., June 27-28, 1977.
3. Cementing of Geothermal Wells, Progress Report No. 4, January-March 1977, BNL 50647.
4. Alternate Materials of Construction for Geothermal Applications, Progress Report No. 12, January-March 1977, BNL 50665.
5. Concrete Polymer Materials for Geothermal Applications, Progress Report No. 8, January-March 1976, BNL 21244.
6. Concrete Polymer Materials for Geothermal Applications, Progress Report No. 7, October-December 1975, BNL 20865.

Distribution

Energy Research and Development Administration
Division of Geothermal Energy

Robert Reeber
John Walker
Ronald Toms
James C. Bresee
Louis B. Werner

Brookhaven National Laboratory

Joseph M. Hendrie
Warren E. Winsche
Bernard Manowitz
Meyer Steinberg
Lawrence Kukacka
Peter Colombo
Jack Fontana
David Schweller (ERDA)
William Horn
Arkady Zeldin