ALTERNATE MATERIALS OF CONSTRUCTION FOR GEOTHERMAL APPLICATIONS

PROGRESS REPORT NO. 14
JULY - SEPTEMBER 1977

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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 \$4.50; Microfiche \$3.00

January 1978

610 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 four of these sites is continuing. Work accomplished during the period July 1 - September 30, 1977 is described in the current report.

Summary

Experiments to determine the effect of aggregate composition on the durability of PC to high temperature brine indicate that the presence of portland cement in the aggregate greatly enhances the durability. The evidence indicates that CaO reacts chemically with $-CH_2$ groups in the vinyl monomers. However, there is no evidence whether the reaction is caused by free CaO or the calcium ion.

Field testing of a 6-in.-diam section of lined pipe is in progress at Raft River and sections of pipe are being prepared for installation at East Mesa, Niland, and the U.S. Naval Weapons Center.

Laboratory testing of specimens in simulated geothermal environments was continued. Samples exposed to 25% brine solutions at 177°C (350°F) for 900 days have not deteriorated. Similar results have been obtained with pipe specimens exposed to a 400 ppm solution at 150°C (302°F) for 312 days.

Samples exposed to a pH 1 hydrochloric acid solution at 90°C (194°F) for 441 days have not deteriorated. Samples containing silica sand-portland cement aggregate have yielded similar results after 170 days in pH 1 hydrochloric acid at 200°C (392°F).

Field testing of specimens at Raft River and The Geysers is continuing. During the report period samples removed from The Geysers and East Mesa were evaluated. Good durability is indicated after exposure to 238°C (460°F) steam at The Geysers for 18 months. Similar observations were noted for samples exposed for 60 days to 160°C (320°F) flowing brine at East Mesa.

During the next report period two tests will commence at Niland. Additional tests will be started at The Geysers and East Mesa.

A study to determine the potential benefits of using PC as a material of construction in geothermal power plants has been completed. Conceptual designs for 50 MWe power plants at Heber and Niland were used as the basis for the study. The results indicate that savings can be accrued in the capital cost of both plants. These savings result in reductions in the cost of electric power of 2.7 mills per kilowatt hour. Additionally, the use of PC should markedly reduce corrosion problems in the plant. It was estimated that on-stream availability will increase by 4% and that electric power cost will be reduced by an additional 3.4 mills per kilowatt hour.

Alternate Materials of Construction for
Geothermal Applications

Progress Report No. 14
July-September 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 but the use of expensive materials such as Type 316 stainless steel and titanium base alloys 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 ~0.25in. 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 from field test exposures of up to 18 months are available. To date, good durability is indicated. Tests are currently in progress at two field sites and work at two others is scheduled to commence during the next report period. Work performed during the period July-September 1977 is described in the current report.

Summary of Previous Report²

Work to develop high temperature PC formulations was continuing. Preliminary results indicated 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 were made. Shear strengths varying from 360 to 425 psi were measured for liners applied to sandblasted surfaces. If sandblasting was not used, the value decreased to ~ 65 psi.

Field testing of a 6-in.-diam section of lined pipe was started at Raft River and a section of 3-in. pipe was 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 did not deteriorate. Similar results were 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 did not deteriorate. Samples containing silica sand-portland cement aggregate 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 showed no visible signs of deterioration.

Field testing of specimens at Raft River, The Geysers, and Niland was 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 was in progress. Samples exposed at East Mesa to flowing brine at 160°C (320°F) for 60 days were reported to be in good condition.

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 360°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).

To date two monomer formulations, 60 wt % styrene - 40 wt % trimethylolpropane trimethacrylate (TMPTMA) and 50 wt % styrene - 33 wt % acrylonitrile - 17 wt % TMPTMA, have been shown to be durable to geothermal fluids. Both systems can be polymerized using chemical initiators and heat or by chemical initiators and promoters. The latter monomer system appears suitable for temperatures up to ~ 240°C (464°F).

During the current report period work with styrene-acrylonitrile formulations containing acrylamide or methacrylamide and crosslinking agents was continued. Three variables: polymer content, and type and concentration of the crosslinking agent were investigated.

Polymer Content

The effect of polymer content on the strength and durability of PC containing a 55 wt % styrene - 35 wt % acrylonitrile - 5 wt % acrylamide - 5 wt %

trimethylolpropane trimethacrylate (TMPTMA) monomer mixture was studied. Polymer contents ranging between 12 and 20 wt % were used in conjunction with an aggregate consisting of 70 wt % silica sand - 30 wt % portland cement. Properties measured included compressive strength, water absorption, and thermal stability in air and hot brine at 238°C (460°F).

All of the specimens exhibited reductions in strength and increases in absorption after exposure to air and brine at 238°C (460°F) for 30 and 10 days, respectively. Increased polymer content resulted in a decrease in stability.

Crosslinking Agents

The incorporation of crosslinking agents into PC results in significant improvements in thermal stability and durability. During the report period two crosslinking agents, TMPTMA and divinyl benzene (DVB), were used with the styrene-acrylonitrile formulations containing acrylamide or methacrylamide. TMPTMA concentrations of 2.5 wt % and 5 wt % were studied. The DVB concentration was varied from 2.5 wt % to 10 wt %.

The results from these studies indicate that the use of DVB in PC produces composites with greater high temperature brine stability than samples containing TMPTMA. The best results were obtained with samples containing the styrene-acrylonitrile-acrylamide mixture in conjunction with DVB concentrations from 5 wt % to 10 wt %. These samples did not exhibit reductions in strength after exposure to hot brine at 238°C (460°F) for 10 days. Samples prepared without the inclusion of a cross-linking agent and with TMPTMA had strength losses of 50% and ~ 30% respectively, after similar exposures. The tests with DVB are being repeated to determine if the results are reproducible. Longer term tests have also been started.

Aggregate Composition

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 have been investigated. All of the materials can be used in composites which have good durability at temperatures $< 218^{\circ}\text{C}$ (425°F). Above this temperature, only PC materials containing mixtures of silica sand and portland cement have been durable to brine and steam.⁴

To determine the reason for this effect, infra-red (IR) 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) have been combined with silica sand and various vinyl-type monomers (MMA, TMPTMA, and styrene) to form PC. IR analyses are being performed on the samples before and after exposure to brine and air at 238°C (460°F) for 30 days. Preliminary results indicate chemical bonding between the CaO and $-\text{CH}_2$ groups in the vinyl monomers.

Evaluation of the control specimens has been completed and work with the specimens after exposure to brine and hot air is in progress. The observations from the control samples are as follows:

1. The absorption band of the $-\text{CH}_2$ groups, for the region $2900\text{--}3000\text{ cm}^{-1}$, of TMPTMA, polymethyl methacrylate (PMMA), and polystyrene in PC containing Type III portland cement and CaO was observed to be much smaller than that of the polymers alone.

2. The IR spectras of TMPTMA, PMMA, and polystyrene in PC's containing $\text{Ca}(\text{OH})_2$, Al_2O_3 , MgO , and SiO_2 were not similar to those when the polymers were used in PC containing Type III portland cement and CaO aggregate.

3. The IR spectras and absorbance ratios for the polymers in PC's containing 66 wt % Type III portland cement were observed to be very similar to those when the polymer was used in PC containing 56 wt % CaO. Calculation of the CaO content in the PC containing the portland cement indicated a CaO concentration of 56 wt %.

4. The absorption bands for -CH_2 groups at 2998 cm^{-1} for PC containing CaO become smaller as the CaO concentration is increased.

5. The evidence indicates that the CaO reacts chemically with the -CH_2 groups in the vinyl monomers. However, there is no evidence whether the reaction is caused by free CaO or the calcium ion.

IR and mechanical evaluation of PC after exposure to hot air and brine is in progress. Visual examination of the samples indicated cracking of most of the non-portland cement containing materials.

Work has been started to evaluate the use of PC containing polyimides as possible liner materials. A polyimide formed by reacting aromatic diamines with aromatic dianhydrides is currently being studied.

Experiments have been started to determine the feasibility of using refractory cements or combinations of polymeric binders in refractory cements to contain geothermal fluids. Cements cured at a temperature of 240°C (464°F) and then raised slowly in 100°C (180°F) increments to 600°C (1112°F) were found to be thermally stable after 10 days at 238°C (460°F) but had water absorptions of $\sim 22\text{ wt \%}$. Impregnation of the material with a high temperature polymer system or the formation of a PC using the refractory cement as the filler may produce high strength composites with good thermal and chemical resistance characteristics. Specimens are currently being prepared for testing in hot brine.

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 geo-thermal fluids. A prototype section of pipe is currently in test at Raft River. Additional sections will be installed at East Mesa, Niland, and China Lake.

Work is in progress to determine the hydrostatic capabilities of PC and polymer impregnated concrete pipe. In order to obtain design data for this effort, the compressive strength for various systems is being measured as a function of test temperature. Results obtained to date are given in Table 1. In this work only fine aggregate consisting of 70 wt % silica sand and 30 wt % Type III portland cement was used in order to approximate the material that will be used in thin-wall pipe or as a lining material. Higher strengths would be expected if larger size aggregate was included in the mix.

Four monomer systems were tested over the temperature range 21° to 238°C (70° to 460°F). Samples impregnated with 60 wt % styrene - 40 wt % TMPTMA exhibited the same strength at 238°C as at 21°C. The other materials had strength reductions from 18 to 35%.

Sections of 2-in. and 4-in.-diam polymer impregnated pipe have been produced for use in tests to determine the hydrostatic capabilities of the materials. 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, was found to be capable of operating at 200 psi and 120°C (~250°F). At a pressure of 250 psi, the operating temperature was reduced to 100°C (212°F).

Table 1

High Temperature Strengths of Polymer-Impregnated Mortar

<u>Monomer Formulation</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
<u>Compressive strength, psi,^a</u> <u>at test temperature, °C</u>				
21	13,889	11,782	10,069	9,487
66	14,154	10,948	10,334	7,838
150	12,154	10,222	8,427	8,102
175	13,619	13,898	8,282	8,180
204	9,475	9,786	10,453	6,600
238	11,207	9,632	10,308	6,197

A, 55 wt % styrene - 36 wt % acrylonitrile - 9 wt % TMPTMA

B, 50 wt % styrene - 33 wt % acrylonitrile - 17 wt % TMPTMA

C, 60 wt % styrene - 40 wt % TMPTMA

D, 70 wt % Derakane 470 - 30 wt % triallyl cyanurate

a, average of 2 samples at each temperature

A section of PC pipe capable of withstanding the pressure and temperature conditions in the "Raft River Mobile Corrosion, Deposition, and Component Test Laboratory" (~ 130 psi and 135° (275°F)) was fabricated. The PC consisted of a 13 wt % concentration of a 55 wt % styrene - 35 wt % acrylonitrile - 5 wt % acrylamide - 5 wt % TMPTMA formulation mixed with 87 wt % filler. The filler was 70 wt % sand and 30 wt % Type III portland cement. When cast to form a 2.1-in.-i.d. x 5.0-in.-o.d. pipe, the composite withstood a pressure of 150 psi at 150°C ($\sim 300^{\circ}\text{F}$). A subsequent increase in pressure to 175 psi resulted in the formation of cracks.

An 8-ft. long section of PC-lined 3-in. Sch 40 carbon steel pipe was shipped to East Mesa. Installation is scheduled for December. Other sections will be installed at Niland and at the US Naval Weapons Center. A test is in progress at Raft River. These efforts are discussed in Task 4.

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 ten 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. 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 900 days. A visual inspection made after 760 days indicated no cracking or other signs of deterioration. Strength measurements were last made after exposure for 417 days.⁵ 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 312 days to a 400 ppm brine solution at 150°C (302°F) (see Figure 1). The weight has remained constant. The test is being continued.

A section of PC-lined carbon steel pipe is currently being tested at Raft River. 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 last report period. To date, after 117 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 2.

Figure 1. PC pipe after exposure to 400 ppm brine at 150°C for 312 days. No deterioration is apparent.

Figure 2. PC pipe containing materials used for lined pipe in test at Raft River. After 117 days in 400 ppm brine at 204°C, no deterioration is apparent.

Tests in an environment simulating the anticipated well-head conditions at the San Diego Gas and Electric Co. facility (25% brine, 238°C (460°F)) are continuing. During the report period two samples were removed from test after exposure for 325 days and another one was removed after 349 days. One sample consisting of 55 wt % styrene - 36 wt % acrylonitrile - 9 wt % TMPTMA in conjunction with a 90 wt % sand - 10 wt % portland cement aggregate had slight erosion at the corners. The erosion was progressively worse for samples containing 52 wt % styrene - 35 wt % acrylonitrile - 13 wt % TMPTMA and 50 wt % styrene - 33 wt % acrylonitrile - 17 wt % TMPTMA. The compressive strengths of these samples will be determined for comparison with earlier data.

Testing of more recently developed systems: 55 wt % styrene - 33 wt % acrylonitrile - 3 wt % polyphenylene oxide - 9 wt % TMPTMA, 50 wt % styrene - 33 wt % acrylonitrile - 8 wt % polyphenylene oxide - 9 wt % TMPTMA, and 30 wt % styrene - 60 wt % triallyl cyanurate - 10 wt % polyphenylene oxide is being continued. To date, after 108 days in test, no visual indication of deterioration is apparent and the weights have remained constant.

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 three 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 441 days. No evidence of corrosion of the PC as determined by pH and weight change measurements has been detected.

A test in pH 1 HCl at 200°C (392°F) is also in progress. Earlier, 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 170 days. No deterioration is apparent (see Figure 3).

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 146 days, the samples are in good condition. These are also shown in Figure 3.

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 and Raft River. Work at East Mesa, Niland, and at the U.S. Naval Weapons Center near China Lake is 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.

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

Figure 3. PC samples after exposure to pH 1 hydrochloric acid at 200°C.

method are other variables in the test series.

Samples have been evaluated after exposure for 90, 180, 365, and 540 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 one set 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. Two other sets of samples had compressive strengths of 2300 and 2440 psi after exposure for 180 days.

During the previous report period four specimens consisting of 50 wt % styrene - 33 wt % acrylonitrile - 17 wt % TMPTMA and a 90 wt % sand - 10 wt % portland cement aggregate were removed from test after exposure for 18 months. Visual examination of the samples indicated them to be in good condition.² Compressive strength and water absorption measurements made on the samples during the current period indicate average values of 2600 psi and 9.5%, respectively. Unfortunately, due to an error at the field site, the identification of the specimens was lost. This will be determined during the next report period when the remaining samples in the series are removed after exposure for two years and sent to BNL. At the current time it appears that the strengths should be compared with the samples that had strengths of 2300 or 2440 psi after exposure for 180 days. The water absorption of these samples was 8.5 and 8.9%, respectively.

Plans have been made to initiate a third test series at The Geysers upon the completion of the current series in November. Based upon recent results obtained in Task 1 and Task 3 of the program, 4 PC systems have

been selected for field evaluation. These systems are listed below.

<u>Monomer</u>	<u>Aggregate</u>
80 wt % styrene - 12 wt % polyphenylene oxide - 8 wt % TMPTMA	80 wt % sand - 20 wt % Type III cement
30 wt % styrene - 60 wt % triallyl cyanurate - 10% polyphenylene oxide	80 wt % sand - 20 wt % calcium aluminate cement
55 wt % styrene - 35 wt % acrylonitrile - 5 wt % acrylamide - 5 wt % TMPTMA	70 wt % sand - 30 wt % Type III cement
50 wt % styrene - 40 wt % acrylonitrile - 5 wt % methacrylamide - 5 wt % TMPTMA	70 wt % sand - 30 wt % Type III cement

Twelve samples of each of the above systems have been sent to the Union Oil Company. It is expected that testing will commence at The Geysers during November.

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 days 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°F 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 $\sim 150^{\circ}\text{C}$ (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. The current exposure time is ~ 6 months.

During the previous report period a 4-ft section of PC-lined pipe was installed in the test facility. The section consists of a 6-in.-diam Sch 40 pipe. A 1-in.-thick PC liner consisting of a monomer mixture of 70 wt % Derakane - 30 wt % triallyl cyanurate and 80 wt % silica sand - 20 wt % calcium aluminate cement aggregate was applied to the wall of the 6-in. pipe. This monomer system was selected based upon the decomposition temperature of 193°C (379°F) and the relatively high viscosity which is advantageous in producing thin liners. To date, the unit has been in test for approximately 10 weeks. A date for the first visual examination has not yet been established.

East Mesa

With the cooperation of the Battelle Northwest Laboratory (BNWL), a test was started in April 1977 in the Imperial Valley at East Mesa. 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 inspection of the specimens indicated no apparent deterioration. A thin layer of scale was apparent on the carbon steel containment basket and in the space between the basket and the samples (see Figure 4). The scale was firmly bonded to the steel but could be easily brushed from the PC. The inner surface of the hollow cylinders was free of scale.

Crushing strength measurements were made on eight of the samples. No deterioration was evident. Compared to the controls, the average strengths for the monomer systems containing 1/1 and 4/1 ratios of sand and portland cement increased from 35 to 97%. The data exhibited considerable scatter, probably due to the small-sized samples. The remaining samples will be used in compressive strength, water absorption, and hydrostatic tests.

Arrangements have been completed for the installation of an 8-ft flanged section of PC-lined 3-in. Sch 40 carbon steel pipe at East Mesa. The PC liner is 0.5-in. thick and is composed of a 60 wt % styrene - 40 wt % TMPTMA monomer mixture. The aggregate contains 70 wt % sand and 30 wt % Type III portland cement. The unit will be installed during December in a line connecting Well 8-1 with the collection pond. The section is expected to see brine at a temperature and flow rate of $\sim 160^{\circ}\text{C}$ (320°F) and 60-80 gal/min, respectively.

Niland

Twenty-four PC specimens were installed in the Bureau of Mines (USBM) test facility at Niland during April 1977 but to date they have not been

Figure 4. PC samples in containment baskets after exposure to flowing brine at 160°C for 60 days.

exposed to brine. Start-up of the system by January 1978 is now anticipated.

The test will consist of the exposure of 1 monomer mixture, 55 wt % styrene - 36 wt % acrylonitrile - 9 wt % TMPTMA, and two sand-portland cement aggregate mixtures, 9/1 and 4/1, 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.

Plans have been made to install a 6-ft section of PC-lined pipe in the line connecting the well to the USBM test equipment. It is anticipated that the pipe will be exposed to a 25% brine solution at a maximum temperature of 260°C (500°F) and a pressure of 350 psi. It is planned to fabricate and install the section prior to January.

US Naval Weapons Center

An invitation to test sections of PC and PC-lined pipe in geothermal fluids at the US Naval Weapons Center near China Lake, California was received. Preliminary plans have been formulated and they are currently being reviewed. It is planned to fabricate and install several 4 to 6-ft. sections during January.

Task 5. Technology Transfer and Economic Evaluation

Studies are being performed 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 power plant designs.

During this report period, the Burns and Roe Industrial Services Corporation, under contract to BNL, reviewed conceptual designs for 50 MWe power plants at Heber and Niland, California⁶ to determine the potential savings in capital and operating costs resulting from the use of polymer concrete in applicable portions of the plants. The results indicate that savings can be accrued in the capital cost of both plants. These savings result in reductions in the cost of electric power of 2.7 mills per kilowatt hour. Additionally, the use of PC should markedly reduce corrosion problems in the plants. It was estimated that on-stream availability will increase by 4% and that electric power cost will be reduced by an additional 3.4 mills per kilowatt hour. The report on this study will be issued during the next report period.⁷

Task 6. Administrative

During the current report period, three "Monthly Administrative Letters" were submitted to DGE and Quarterly Progress Report No. 13² was issued. A paper entitled "Polymer Concrete Materials for Geothermal Applications" is being prepared for presentation at the 85th National Meeting of the American Institute of Chemical Engineers. The paper will be presented at a session titled "High Temperature Polymeric Materials for Hot Oil, Gas, and Geothermal Well Applications".

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6. Conceptual Design of Commercial 50 MWe (net) Geothermal Power Plants at Heber and Niland, California, Energy Research and Development Administration, SAN-1124-1, Oct. 1976.
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