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**ALTERNATE MATERIALS OF CONSTRUCTION
FOR GEOTHERMAL APPLICATIONS**

**PROGRESS REPORT NO. 16
APRIL-SEPTEMBER 1978**

**PROCESS SCIENCES DIVISION
DEPARTMENT OF ENERGY AND ENVIRONMENT**

**BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.**

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Table of Contents

	<u>Page</u>
Abstract	v
Summary	vii
Introduction	1
Summary of Previous Report	3
Selection of Lining Materials	4
Process Technology	13
Physical and Chemical Property Measurements	16
Field Tests	20
Technology Transfer and Economic Evaluation	33
Administrative	33
References	34

Summary

Polymer concrete (PC) containing organosiloxanes or cross-linked mixture of styrene, acrylonitrile and acrylamide appear to have excellent thermal and chemical resistance. Samples containing these materials have exhibited essentially no change in strength after exposure to brine at 238°C for 120 days. Earlier monomer systems have initial reductions followed by a leveling off in strength. The organosiloxane PC also has excellent high temperature strength. At 350°C, the compressive strength is $\sim 5,000$ psi.

A test to determine the feasibility of using a cavitating system to remove scale from PC surfaces has been performed. The results indicated that the threshold intensity of erosion for the PC was considerably lower than that of geothermal scale. This disadvantage can be overcome by the development of a nozzle with an immediate reduction in the effective range of intensity. This would allow removal of the scale without damage to the PC liner.

Field testing of small test samples and prototype sections of PC-lined pipe is in progress at Coso Hot Springs, Devils Kitchen, East Mesa, and the San Diego Gas and Electric Company facility at the Salton Sea. Visual inspections of the materials indicate good durability.

Test samples have been returned to BNL after testing in steam at The Geysers, high salinity brine at the Bureau of Mines facility at the Salton Sea and in low salinity brine at Raft River. Evaluation of the materials is in progress.

A test configuration has been installed at the Los Alamos Scientific Laboratory Fenton Hill site. Start-up of the test in October is anticipated.

Based upon the good durability and scale-free service exhibited by PC-lined pipe after an eight month test at East Mesa, a lined steam separator is being fabricated. This will be installed during the next report period.

Studies to determine the economic impact of the use of non-metallic materials in direct utilization processes are in progress. Two processes, barley malting and sugar beet refining, are currently being evaluated. It is planned to perform a similar analysis on a district heating application.

Alternate Materials of Construction for
Geothermal Applications

Progress Report No. 16
April-September 1978

Introduction

The cost and the reliability of geothermal electric power plants and direct utilization processes depend heavily on the availability of suitable construction materials. The chemically active nature of geothermal brine demands the use of materials with high erosion/corrosion resistance. The identification of materials with suitable properties will be a big step toward the development of a stable geothermal industry. If successfully implemented, this program could generate a reduction of 10 to 20% in the cost of geothermal power. Considerable cost benefits in direct utilization processes are also anticipated.

Work on the development of non-metallic construction materials for use in geothermal systems was initiated in April 1974. Since that time, 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, and economic studies started. Laboratory data for exposure time > 2 years are available. Results are also available from field exposure of up to 2 years in five geothermal environments. Good durability is indicated. Work at five test sites is in progress. These results have indicated the potential for the successful use of concrete polymer composites as lining materials for process piping and vessels in geothermal power systems and as durable low thermal conductivity piping for process-heat and district heating applications.

Economic studies performed concurrently with the research program have identified several cost-effective uses for the materials in geothermal processes. Large cost reductions as a substitute for stainless steel, titanium, and Hastelloy in acid-handling systems, condensate-piping systems, reinjection lines, and steam separators are indicated. Uses in cooling towers, district heating systems, and in the protection of concrete surfaces also appear cost-effective.

A study has indicated that the use of polymer concrete lining materials as a partial replacement for the corrosion allowance in carbon steel components for a 50 MWe geothermal plant will reduce the cost of power by ~ 6.2 mills per kwh.

During FY 1979 the scope of the program will be broadened to include investigations of other non-metallic materials such as ceramics and refractory cements. Investigations on the development of sealing materials for use in geothermal equipment will also be initiated. Brookhaven National Laboratory (BNL) will perform in-house research in each of the areas and in conjunction with industrial and university groups manage a series of contracted efforts aimed at evaluating and developing alternative materials of construction for power and direct utilization processes. Projects for determining: (1) engineering design requirements; (2) failure mode, and (3) properties of materials will be undertaken. Other efforts will include development of prototype equipment and the demonstration of the applications of the new materials. The work will be performed with potential geothermal plant owners in order to establish the groundwork for rapid implementation and to transfer the technology to industry.

Work performed in the program during the period April-September 1978 is described in the current report.

Summary of Previous Report¹

Test results indicated that polymer concrete (PC) containing cross-linked mixtures of styrene, acrylonitrile and acrylamide produce composites with the best high temperature and chemical resistance obtained to date. The results showed that the use of a 12 wt% concentration of a 55 wt% styrene-35 wt% acrylonitrile-5 wt% acrylamide-5 wt% TMPTMA monomer mixture in conjunction with 88 wt% of a 70 wt% silica sand-30 wt% portland cement aggregate produces a composite with a compressive strength at 20°C in the range 25,000 to 30,000 psi. The PC is thermally stable to ~ 240°C.

Work to determine the effect of calcium oxide compounds of anhydrous cement on the durability of PC was continued. The results indicated that the $3\text{CaO} \cdot \text{SiO}_2$ component of cement has the greatest effect on the thermal stability of vinyl-type polymers.

Work to determine the descaling characteristics of PC was started. Scale was used successfully as aggregate in PC. Specimens with compressive strengths up to 8,000 psi were produced. Durability tests were started. If successful, the technique may yield an environmentally and economically acceptable method for the disposal of scale.

Laboratory testing of specimens in simulated geothermal environments was continued. Samples tested after exposure to a 25% brine solution at 177°C for 960 days had strengths essentially the same as those measured after 63 days.

Field testing was being continued at The Geysers, Raft River, East Mesa, and Niland. Samples were shipped to the US Naval Weapons Center for installation at Coso Hot Springs and Devils Kitchen. Plans were made to install pipe specimens at the Los Alamos Scientific Laboratory Fenton Hill site and in the San Diego Gas and Electric Company Geothermal Loop Experimental Facility.

Work to determine the economic impact of the use of non-metallic materials of construction in direct utilization processes was started.

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. In a separate program,² research is being performed to determine if materials can be formulated for use as well cementing materials at temperatures up to 400°C.

During the current report period work was performed on PC systems containing organosiloxanes and crosslinked mixtures of styrene (St), acrylonitrile (ACN) and acrylamide (Aa). Recent results for the latter system are given in Task 3, Physical and Chemical Property Measurements.

Organosiloxanes are chemically resistant, being unattacked by dilute acids, alkalies, and by metals and metal salts. These properties are very important for geothermal applications. Another important property is the small change in viscosity with temperature.

The first phase of the BNL study involved the preparation of PC samples for use in determination of the thermal and hydrolytic stability and the compressive strength. The effects of various monomer additives and the curing conditions were also studied. This phase is essentially complete.

Results from thermal stability tests performed on PC containing a 75 wt% organosiloxane - 25 wt% styrene mixture at 260°C are shown in Figure 1. The results indicate initial weight losses followed by stabilization after ~ 250 hr. Compared to previously obtained data for PC containing organic systems, the organosiloxane PC exhibits considerable improvement.

Compressive strength data for PC containing organosiloxane and styrene in conjunction with various aggregate compositions are given in Table 1. Strengths before and after exposure for 30 days to brine at 240°C are given. These preliminary results support earlier work¹ which indicated that the addition of portland cement results in improved durability.

The effect of heating organosiloxane-styrene polymer in air at 260°C is illustrated in Figure 2. Decomposition is apparent after 16 hr.

The use of the same polymer system in conjunction with a 90% sand-10% portland cement aggregate improves the resistance to oxidation significantly. As shown in Figure 3, PC heated in air for 1500 hr at 260°C had an appearance similar to that of the control.

Some cracking was noted after exposure of the PC to steam at 275°C for 168 hr (see Figure 3). It is believed that this can be corrected by modification of the aggregate composition.

Since the hydrolytic stability of organosiloxanes is of primary importance in determining the potential for their use in geothermal processes, tests were run on two polymers after exposure in 25% brine at 250°C for 360 hr. The results indicated no appreciable weight loss or deterioration. IR spectra made before and after the brine exposure

Figure 1. Thermal stability at 260°C of PC containing organosiloxane.

Table 1

Compressive Strength of Organosiloxane PC as a Function of Aggregate Size and Composition

Monomer composition, wt%		Aggregate composition, %	Compressive strength, psi	
OS	St		Controls	After exposure for 30 days to brine at 240°C
75	25	100% No. 500 Sand	6,034	5,443
75	25	65% No. 500 Sand-35% Type II Cement	2,924	2,918
75	25	36% No. 16 Sand-17% No. 30 Sand-17% No. 100 Sand-30% No. 50 Sand	5,849	4,200
100	0	Same as Above	1,789	1,150
75	25	90% No. 500 Sand-10% Type III Cement	12,358 ¹	11,150
75	25	95% No. 500 Sand-5% Fe_2O_3	11,084 ²	9,200
75	25	100% No. 30 Sand	689	--
75	25	65% No. 30 Sand-35% Type III Cement	4,588	7,016
75	25	100% No. 100 Sand	370	--
75	25	65% No. 100 Sand-35% Type III Cement	3,160	3,200

OS, Organosiloxane

St, Styrene

1. Boiling water absorption %, 0.33

2. Boiling water absorption %, 0.31

Figure 2. Thermal oxidation degradation of siloxane-styrene copolymer in air at a temperature of 260°C.

Figure 3. PC containing siloxane and styrene after exposure to hot air and steam.

indicated a small amount of hydrolysis. It is believed that this can be overcome when the polymer is used in PC. If cement is used in the aggregate, the presence of MgCO_3 and CaCO_3 should act as buffers and reduce hydrolysis to essentially zero.

The second phase of the program on organosiloxanes which includes the optimization of the monomer and aggregate systems has recently been started. As part of this work, samples have been prepared for testing at the Los Alamos Fenton Hill site and at the San Diego Gas and Electric Company site at the Salton Sea.

In the previous report¹ studies to determine the effects of CaO containing compounds of anhydrous cement on the thermal and chemical stability of PC containing methyl methacrylate (MMA) were described. The preliminary results from this work indicated that the $3\text{CaO}\cdot\text{SiO}_2$ component of cement has the greatest effect on the durability (see Figures 4 and 5). An interaction between the $-\text{CH}_2-$ group of the vinyl-type polymer and the CaO of $\text{CaO}\cdot\text{SiO}_2$ systems was indicated.

During the current report period these studies were extended to include styrene (St), another vinyl-type polymer. Work in which a high temperature polymer system, 55 wt% St-36 wt% ACN-9 wt% TMPTMA, was used in conjunction with CaO-SiO_2 and $\text{CaO-Al}_2\text{O}_3$ aggregate systems was also performed. Studies to determine the effect of residual free lime in the CaO-SiO_2 system on the dimensional stability of PC specimens upon exposure to hot brine were also performed. These results are discussed below.

Figure 6 shows the results from DSC studies on PSt and PSt combined with various aggregates. The results for PSt (curve a) indicate

Figure 4. Methyl methacrylate (left) and PC containing methyl methacrylate and $3\text{CaO}\cdot\text{SiO}_2$ (right) at a temperature of 240°C .

Figure 5. PC containing methyl methacrylate and various amounts CaO in the aggregate after exposure for 30 days to brine.

Figure 6. Differential scanning calorimeter thermograms of polystyrene (PSt) samples. a, bulk PSt; b, 34 wt% PSt - 66 wt% 3CaO·SiO₂; c, 34 wt% PSt - 66 wt% 2CaO·SiO₂; d, 50 wt% PSt - 50 wt% SiO₂; e, 34 wt% - 66 wt% Al₂O₃. Heating rate = 20°C/min.

the first endothermic peak at $\sim 332^{\circ}\text{C}$ and a second endothermic peak at $\sim 425^{\circ}\text{C}$. The first peak is attributed to the thermal decomposition of $-\text{CH}_2-$ groups in the main PSt chain while the second is due to the thermal decomposition of single $-\text{CH}_2-$ linkages within the aromatic ring.

Curves for PC samples containing $2\text{CaO}\cdot\text{SiO}_2$ and $3\text{CaO}\cdot\text{SiO}_2$ (curves c and b, respectively) do not have the endothermic peak at $\sim 332^{\circ}\text{C}$. Therefore, it appears that the thermal decomposition between the $-\text{CH}_2-$ main chains in PSt is prevented by the presence of C_2S and C_3S .*

The results from compressive strength tests performed on PC containing PSt and various aggregates are summarized in Table 2. Each sample with the exception of the control (PC-0) contained 13 wt% polymer, 70 wt% silica sand and 17 wt% of the $\text{CaO}\cdot\text{SiO}_2$ or $\text{CaO}\cdot\text{Al}_2\text{O}_3$ -containing materials. The results after exposure of the specimens for 30 days to air at 238°C indicate that the samples containing C_2S and C_3S maintain high strength. All of the other materials exhibited considerable reductions in strength.

After exposure to brine at 238°C for 30 days, specimens containing C_3S with a free lime concentration of 8.7% could not be tested due to a large expansion due to the chemical reaction between the lime and the brine. However, a sample containing 2% free lime in the C_3S had a strength of 16,150 psi after the brine exposure.

Good durability was also indicated for PC samples containing C_2S (free lime content $\sim 2.7\%$). This material exhibited a 2.59% increase in diameter and had a compressive strength of 15,270 psi.

* $\text{C} = \text{CaO}$, $\text{S} = \text{SiO}_2$.

Table 2

Stability of PC Containing $\text{CaO} \cdot \text{SiO}_2$ and $\text{CaO} \cdot \text{Al}_2\text{O}_3$ Systems After 30 Days
Exposure at 238°C to Hot Air and 25% Brine

Specimens No.	Composition ^a	Before Exposure	After Exposure to Hot Air		After Exposure to Brine	
		Compressive strength, psi	Compressive strength, psi	Weight loss, %	Compressive strength, psi	Diameter changes, %
PC-0	11% P-89% S	8,850	860	5.20	981	+ 0.26
PC-1	13% P-70% S-17% Cement	10,500	4,100	2.25	4,403	+ 1.88
PC-2	13% P-70% S-17% CaCO_3	10,633	881	3.06	952	- 0.95
PC-3	13% P-70% S-17% SiO_2	3,922	548	7.21	768	- 1.25
PC-4	13% P-70% S-17% Al_2O_3	7,765	684	4.36	1,090	- 0.15
PC-5	13% P-70% S-17% $2\text{CaO} \cdot \text{SiO}_2$	17,436	16,487	0.47	15,270	+ 2.59
PC-6	13% P-70% S-17% $3\text{CaO} \cdot \text{SiO}_2$	18,231	16,276	0.46	16,150	--
PC-7	13% P-70% S-17% $4\text{CaO} \cdot \text{SiO}_2$	17,900	15,826	0.43	-- ^b	--
PC-8	13% P-70% S-17% $5\text{CaO} \cdot 3\text{Al}_2\text{O}_3$	13,368	3,217	1.39	3,117	+ 4.08
PC-9	13% P-70% S-17% $3\text{CaO} \cdot \text{Al}_2\text{O}_3$	13,957	6,417	1.16	933	+11.67
PC-10	13% P-70% S-17% $4\text{CaO} \cdot \text{Al}_2\text{O}_3$	14,855	7,061	0.64	-- ^b	--

a, P = 55 wt% styrene - 36 wt% acrylonitrile - 9 wt% TMPTMA; S = 50 wt% #16 sand (size, 1.19 mm) - 25 wt% #30 sand (size, 0.595 mm) - 25 wt% #100 sand (size, 0.149 mm).

b, Failed (large expansion and removed from test).

The effect of free lime content in the $\text{CaO} \cdot \text{SiO}_2$ compounds on the expansion of the PC after exposure to hot brine is shown in Figure 7. The data indicate that the expansion can be maintained below 1% if the free lime concentration in the $2\text{CaO} \cdot \text{SiO}_2$ or $3\text{CaO} \cdot \text{SiO}_2$ is $< 2\%$.

Currently work is in progress to determine the effect of the aggregate composition on the thermal stability of epoxy, phenol-formaldehyde and furan resins. Evaluation of the bonding structure between PMMA and C_2S by use of scanning electron microscopy is also being made.

Task 2. Process Technology

Work to develop the technology to produce PC and PC-lined pipe and vessels for use in containing geothermal fluids is continuing. Field testing of pipe and lined pipe is in progress and a PC-lined vessel is being fabricated. This work is described in Task 4.

A study to determine the descaling characteristics of PC surfaces was completed by Daedalean Associates, Inc. (DAI) as a subcontract to BNL. Under an earlier DOE/DGE contract, DAI developed a cavitating descaling system for removal of geothermal scale in pipe sections. In their work it was found that the threshold intensity of erosion for steel pipe utilized in geothermal applications is several orders of magnitude greater than the intensity required for scale removal.

For use in tests to measure the threshold intensity of erosion for PC, BNL supplied DAI with PC samples containing two monomer formulations: 55 wt% St-36 wt% ACN-9 wt% TMPTMA and 60 wt% St-40 wt% TMPTMA. The test results indicated that the threshold intensity of PC was less than that required for scale removal. Conclusions and specific

Figure 7. Dimensional stability of PC after exposure to hot brine as a function of free lime concentration in C_3S -containing aggregate.

recommendations from the study are listed below.

1. The threshold intensity of erosion for the PC ranged from 2.46 w/m^2 to 4.8 w/m^2 . The threshold intensity of erosion for geothermal scale encountered in the field is in the range of 85 w/m^2 . Therefore, in order to descale a pipe lined with PC under present conditions, a nominal layer of scale would have to remain to ensure a margin of safety in preventing damage to the pipe walls. The pipe design for that particular application should be oversized to accommodate the protective layer of scale and still maintain the desired inside pipe diameter.

2. Reformulation of the PC may result in a composition rendering a threshold intensity of erosion greater than that of the geothermal scale. Problems associated with removing the scale without damage to the pipe lining would then be eliminated.

3. It was recommended that further engineering studies be performed to develop a nozzle with an immediate reduction in intensity beyond its effective range. Introduction of a swirl inducer into the nozzle assembly produces an immediate reduction in the effective range of intensity. By minimizing the distance between the effective intensity for descaling and the threshold intensity for PC, the scale would be removed without damage to the PC liner. This would minimize the thickness of the remaining scale.

4. An engineering investigation should be conducted to determine the intensity required to remove the scale from the PC surface. Should the intensity required to break the bond between the scale and the PC be less than the threshold intensity of the PC, removal would be

facilitated with no harmful effects to the pipe lining. This investigation will require the build-up of geothermal scale on PC samples.

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. Several autoclaves operated at conditions simulating geothermal environments in which field tests are in progress or being planned are being utilized in the test program.

For use as base-line data and as a guide for potential users of the materials, typical properties of PC and polymer impregnated concrete at 20°C have been compiled. These data are summarized in Tables 3 and 4, respectively.^{3,4}

During the current report period the compressive strengths of two high temperature PCs, 75 wt% organosiloxane-25 wt% St and 55 wt% St-35 wt% ACN-5 wt% Aa-5 wt% TMPTMA, at elevated temperatures were measured. These data and the polymer weight loss at the test temperature are given in Figure 8. In contrast to the PC containing the organic polymer which showed a marked decrease in strength with temperature, the strength of the organosiloxane-St PC decreased at a much slower rate. At 350°C, the strength was ~ 5000 psi.

Autoclave testing of PC samples containing St-ACN-Aa-divinyl benzene (DVB) mixtures is continuing. Data for exposure times up to 120 days in 25% brine at 238°C are available. Compression strength measurements are being made at ambient temperature and at 150°C. These data are summarized in Table 5. All of the samples had initial strengths at room temperature > 25,000 psi. A sample containing 50 wt% St-35 wt%

Table 3

Polymer Concrete

Summary of Properties for Ambient Temperature Applications
Monomer System, 90 wt% Methyl Methacrylate-5 wt% Polymethyl
Methacrylate-5 wt% Trimethylolpropane Trimethacrylate

Property

Compressive strength, psi	10,000
Tensile splitting strength, psi	900
Flexural strength, psi	2,800
Shear strength, psi	3,200
Bond strength, psi	700
Fatigue strength, ^a	$> 2.5 \times 10^7$ cycles
Water absorption, %	0.6
Specific gravity	2.4
Modulus of elasticity, 10^6	5.3
Poisson's ratio	0.23

a, measured at ~ 50% of ultimate flexural strength.

Table 4

Polymer-Impregnated Concrete

Summary of Properties for Ambient Temperature Applications
Monomer System, Methyl Methacrylate

Property	Concrete Control	PIC	Difference, % ^a
Compressive strength, psi	5,270	23,800	352
Modulus of elasticity, 10^6 psi	3.5	6.4	83
Tensile strength, psi	420	1,700	305
Modulus of rupture, psi	740	2,100	184
Flexural elasticity modulus, 10^6 psi	4.3	7.6	77
Creep, $\mu\text{in./in.}$	200	28	--
Hardness, "L" type impact hammer	32	54	69
Abrasion loss, in.	0.0497	0.025	50
Loss in weight, g	14	2	86
Cavitation, in., 2-hr exposure	0.320	0.016	95
Water absorption, %	6.4	0.06	99
Water permeability, 10^4 ft/yr	5.3	0	100
Thermal conductivity, 23°C , BTU/ft-hr- $^\circ\text{C}$	2.398	2.279	5
Diffusivity at 23°C , ft^2/hr	0.0697	0.0754	8
Coefficient of expansion, $\mu\text{in./in.-}^\circ\text{C}$	7.24	8.8	22
Specific heat, 23°C , BTU/lb- $^\circ\text{C}$	0.434	0.369	15
Specific gravity	2.171	2.261	4

a, control-PIC/control $\times 100$

Figure 8. Polymer weight loss and PC compressive strength at various temperatures.

Table 5

Compressive Strength of PC After Exposure to
25% Brine at 238°C

Monomer composition, wt%				Compressive strength, psi, after				
St	ACN	Aa	DVB	preparation	30 days in brine		120 days in brine	
52.5	40	5	2.5	27,788 ^a	30,726 ^a	18,590 ^b	23,334 ^a	18,547 ^b
62.5	30	5	2.5	29,358	32,927	20,577	25,364	19,786
50	40	5	5	27,478	28,440	21,891	21,368	19,722
50	37.5	5	7.5	25,619	34,381	24,103	25,790	21,808
50	35	5	10	26,217	34,466	23,483	33,632	21,463

Monomer concentration, 13 wt%
Polymerization initiator, 0.5 wt% AIBN
a, tested at room temperature
b, tested at 150°C
St, styrene
ACN, acrylonitrile
Aa, acrylamide
DVB, divinyl benzene

ACN-5 wt% Aa-10 wt% DVB exhibited essentially no change in strength after exposure to 25% brine at 238°C for 120 days. Samples tested at a temperature of 150°C after exposure to that environment for 120 days had a compressive strength of 21,463 psi.

Task 4. Field Tests

In earlier reports, the results from tests performed at The Geysers,^{1,5} Baca Wells,⁶ Klamath Falls,⁷ Raft River,⁸ and East Mesa⁹ were given. Data from a third test recently performed at The Geysers and one completed at the Bureau of Mines Testing Facility at the Salton Sea are described in this report. Additional tests are currently in progress at Raft River, East Mesa, Coso Hot Springs, Devils Kitchen and the San Diego Gas and Electric Company site at the Salton Sea. Pipe sections have been supplied to the Los Alamos Scientific Laboratory but the test has not yet been started. A test of a prototype PC-lined steam separator and ancillary piping is scheduled for East Mesa. Each of these current projects are reviewed below.

The Geysers

Testing of PC materials in flowing dry steam at 238°C has been in progress since May 1975. Tests of 3, 24, and 9 mo duration have been performed. Results for the first two series were published^{1,5} and the third series of samples was removed from the well-head chamber on August 12, 1978.

The third test series consisted of 48 cylinders. Four monomer systems; 80 wt% St-12 wt% polyphenylene oxide-8 wt% TMPTMA, 30 wt% St-60 wt% triallyl cyanurate-10 wt% polyphenylene oxide, 55 wt% St-35 wt% ACN-5 wt% Aa-5 wt% TMPTMA and 50 wt% St-40 wt% ACN-5 wt% MAa-5 wt% TMPTMA,

in conjunction with sand-cement aggregate were tested. The samples were returned to BNL for evaluation. Visual inspection indicated cracks in some of the specimens while other samples containing the same formulation appeared sound. A detailed evaluation of the samples is in progress.

Raft River

Tests are being performed utilizing the "Raft River Mobile Corrosion, Deposition and Component Test Laboratory".

During the current report period, 2-in. cube PC samples and a 4-ft section of PC-lined pipe were removed from test but they have not yet been returned to BNL for examination. The samples were exposed to ~ 200 gpm of low salinity brine at a temperature of 135°C. The cubes were exposed for ~ 700 days and consisted of two monomer formulations: 55 wt% St-33 wt% ACN-17 wt% TMPTMA and 60 wt% St-40 wt% TMPTMA with a sand-flyash aggregate. Compressive strengths measured after exposure for 90 days⁸ indicated strength reductions of ~ 33% compared with those of the controls.

The PC-lined pipe was fabricated using a 70 wt% Derakane-30 wt% triallyl cyanurate monomer mixture and a 80 wt% sand-20 wt% calcium aluminate cement aggregate. At the time of removal from the test facility, the section had been exposed to flowing brine for ~ 480 days.

East Mesa

Two 8-ft sections of PC-lined 3-in. Sch 40 carbon steel pipe are being tested at the East Mesa Geothermal Site. The PC liners are 0.5-in. thick and are composed of a 60 wt% styrene-40 wt% TMPTMA monomer mixture used in conjunction with a 70 wt% sand-30 wt% Type III portland

cement. One section has been exposed to 60 to 80 gal/min of $\sim 26,000$ ppm brine at a temperature of $\sim 160^{\circ}\text{C}$ for 8 mo. A visual inspection of the section was made after exposure for 4,410 hr. No deterioration or scale accumulation was apparent. An ~ 2 -in. layer of scale was reported to have accumulated in ~ 2000 hr on carbon steel pipe downstream of the PC test section.

Based upon the above results, the second pipe section was installed in May downstream of the first section. A $5/8$ -in.-diam orifice between the sections insures that the second pipe is exposed to flashing brine. After 1710 hr in test, a visual inspection showed no scale accumulation or deterioration of the liner. Plans are being made to induce additional flashing in both sections by the installation of a valve upstream of the two pipes.

A prototype PC-lined carbon steel steam separator (2-ft diam x 6-ft long) and 3-in. Sch 40 inlet and discharge piping are currently being fabricated. Start-up of the unit during the next quarter is anticipated.

Niland

Two series of experiments were completed at the Bureau of Mines Materials Testing Facility located on the Salton Sea geothermal field. The experiments were removed from test during April when operation of the facility was terminated.

In one test a 4-ft section of 4-in. Sch 40 pipe lined with a 0.5-in.-thick PC was exposed to flowing brine at the well-head condition. The salt concentration was $\sim 280,000$ ppm and the temperature 235°C . The PC liner consisted of a monomer mixture of 55 wt% St-36 wt% ACN-9 wt% TMPTMA

used in conjunction with a 70 wt% silica sand-30 wt% Type III portland cement aggregate.

Visual inspection of the section after exposure for 90 days indicated a 1/8- to 1/4-in. thick layer of uniformly deposited scale. No deterioration of the PC or loss of bond to the steel was apparent. A cut section of the pipe is shown in Figure 9.

The strength of the bond between the PC and the steel will be determined by measuring the force required to push the PC liner out of the pipe. A similar test will be performed on another piece at 200°C. Tests to determine the depth of salt penetration into the liner are also planned.

The second test completed during the report period consisted of the evaluation of twenty-four 1-in.-diam x 2-in.-long PC cylinders after exposure for 60 days to several environments in the facility. The environments consisted of flowing well-head brine (~ 280,000 ppm salt), steam from the first steam separator (~ 1500 ppm salt), brine from the second steam separator (> 300,000 ppm salt), steam from brine flashed at atmospheric pressure, in sludge, and intermittently in brine in the holding tank prior to reinjection.

The PC cylinders contained a 55 wt% St-36 wt% ACN-9 wt% TMPTMA monomer mixture used in conjunction with 9:1 and 4:1 sand-cement aggregate mixtures. The results from compressive strength and water absorption measurements are summarized in Tables 6 and 7.

The compressive strength results exhibit a great deal of scatter and no trends are apparent. In general, samples containing the 90% sand-10% cement aggregate mix had better durability than the PC containing

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Figure 9. Cut section of PC-lined pipe after exposure to flowing 280,000 ppm brine at 235°C for 90 days.

Table 6

US Bureau of Mines Test Facility at Salton Sea
Summary of Results for 60 Day Exposure

Sample No.	Aggregate system	Geothermal environment temp, °C	fluid	Compressive strength, psi	Average, psi	Change, %	Boiling water absorption, %	Average, %	Change, %
1039	a	control	--	11966			0.22		
1040	a	control	--	14316	13141	--	0.23	0.23	--
1055	b	control	--	17222			0.15		
1056	b	control	--	17974	17598	--	0.16	0.16	--
1031	a	< 100	c	11658			0.67		
1032	a	< 100	c	11786	11722	-10.8	0.60	0.64	+178
1049	b	< 100	c	15479			0.37		
1050	b	< 100	c	15974	15727	-10.6	0.37	0.37	+131
1027	a	100	d	12821			0.29		
1038	a	100	d	12393	12607	- 4.1	1.13	0.71	+209
1045	b	100	d	17855			0.53		
1046	b	100	d	17573	17714	+ 0.6	0.52	0.53	+231
1025	a	235	e	21068			1.58		
1026	a	235	e	20021	20545	+56.3	1.93	1.76	+665
1043	b	235	e	12393			3.20		
1044	b	235	e	10684	11539	-34.4	3.88	3.54	+2113
1033	a	< 100	f	16761			0.35		
1034	a	< 100	f	16265	16513	+25.7	0.29	0.32	+39
1051	b	< 100	f	12718			0.36		
1052	b	< 100	f	10633	11676	-33.7	0.57	0.47	+194
1023	a	170	g	17821			1.05		
1024	a	170	g	14889	16355	+24.5	2.28	1.67	+626
1041	b	170	g	7111			4.58		
1042	b	170	g	9675	8393	-52.3	3.91	4.25	+2556
1029	a	200	h	20769			0.54		
1030	a	200	h	21111	20940	+59.3	0.47	0.51	+122
1047	b	200	h	12598			1.63		
1048	b	200	h	13581	13090	-25.6	1.21	1.42	+788

Monomer system, 55 wt% St-36 wt% ACN-9 wt% TMPTMA.

Specimen size, 1-in.-diam x 2-in.-long

a, Aggregate 90 wt% sand-10 wt% cement

b, Aggregate 80 wt% sand-20 wt% cement

c, Baker Tank bottom sludge

d, Steam from brine flashed at 100°C

e, Well head brine, 280,000 ppm salt at 235°C

f, Baker Tank brine, intermittent contact

g, Brine from second steam separator, > 300,000 ppm salt

h, Steam from first steam separator, 15,000 ppm salt

Table 7
Average Test Results from Samples Exposed
at US Bureau of Mines Facility

Aggregate system,		90% sand-10% cement		80% sand-20% cement	
Test temperature, °C	Environment	Compressive strength, psi	difference, ^a %	Compressive strength, psi	difference, ^a %
20	control	13,141	--	17,598	--
< 100	sludge	11,722	-10.8	15,727	-10.6
< 100	brine	16,513	+25.7	11,676	-33.7
100	steam	12,607	-4.1	17,714	+ 0.6
170	brine	16,355	+24.5	8,393	-52.3
200	steam	20,940	+59.3	13,090	-25.6
235	brine	20,545	+56.3	11,539	-34.4

a, compared to controls
each value represents average of two samples.

the 80% sand-20% cement aggregate mix. Compared to the controls, the former exhibited changes in strength ranging from a decrease of 10.8% to a 59.3% increase (see Table 7). A trend towards higher strength with increased exposure temperature is evident. A possible explanation for this is the presence of unreacted monomer which is subsequently polymerized during the exposure to the environmental conditions.

All of the samples containing the 80% sand-20% cement, with the exception of those exposed to steam at $\sim 100^{\circ}\text{C}$, exhibited considerable reductions in strength and increases in water absorption. Based upon work described in Task 1 which indicates improved durability with increasing cement or C_3S concentrations, these results were unexpected. Laboratory tests to determine the cause of these results are in progress but data are not yet available.

U.S. Naval Weapons Center

Sections of PC and PC-lined pipe are presently in test at two locations, Devils Kitchen and Coso Hot Springs. Both test sites are shallow steam pockets delivering ~ 300 lb/hr and 700 lb/hr, respectively of steam at $\sim 105^{\circ}\text{C}$.

Four-ft lengths of PC and PC-lined pipe are being tested. The PC-lined pipe is 3-in.-Sch 40 lined with a 0.5-in. thick PC. The PC pipe is 3.5-in.-o.d. x 0.75-in.-wall. Three monomer formulations: 55 wt% St-36 wt% ACN-9 wt% TMPTMA, 55 wt% St-35 wt% ACN-5 wt% Aa-5 wt% TMPTMA and 80 wt% St-12 wt% polyphenylene oxide (PPO)-8 wt% TMPTMA were used in conjunction with a 70 wt% sand-30 wt% Type III portland cement aggregate. The pipes were installed in May 1978 and have been

in test in aerated and non-aerated fluids since that time. A test configuration is shown in Figure 10.

A crack in one PC pipe became apparent immediately upon installation at Coso Hot Springs. It is believed that a fine crack was formed during fabrication of the sample and the subsequent heating to 105°C resulted in the crack opening to visual proportions. This section will be returned to BNL for evaluation. Visual inspections during August of all of the other sections indicated no apparent deterioration.

Los Alamos Scientific Laboratory (LASL)

Plans were made during the previous report period¹ to initiate tests on PC-lined pipe and fittings at the LASL Fenton Hill hot rock geothermal site. The flow conditions for the test are estimated to be 150 gpm at 250 psi and 185°C.

During the current report period four 4-ft long sections of PC-lined 3-in. Sch 40 pipe and 4 PC-lined elbows were fabricated and shipped to LASL for installation. Two sections of 6-in. Sch pipe containing PC cylinders for use in compression and water absorption tests were also fabricated. All of these components are shown in Figure 11. Two monomer systems: 55 wt% St-36 wt% ACN-9 wt% TMPTMA and 80 wt% St-15 wt% PPO-5 wt% TMPTMA were used in the PC formulations.

The test sections have been installed (see Figure 12) and operation is scheduled to commence in early October.

San Diego Gas and Electric Company (SDG&E)

Sections of PC-lined pipe and small cylindrical specimens were fabricated and are currently in test at the SDG&E Geothermal Loop Experiment Facility at the Salton Sea. Two 6-ft-long pieces of 10-in.-diam

Figure 10. PC and PC-lined pipe in test at Coso Hot Springs.

Figure 11. PC-lined components prior to installation at Los Alamos Fenton Hill site.

Figure 12. PC-lined components (left) installed at Fenton Hill geothermal site.

pipe and a 4-ft section of 8-in.-diam pipe were fabricated. These are shown in Figure 13. A monomer system consisting of 55 wt% St-36 wt% ACN-9 wt% TMPTMA used in conjunction with a 70 wt% sand 30 wt% Type III portland cement aggregate was used for all of the specimens.

The two 10-in.-diam pipes were installed during August 1978 in the brine reinjection line where the flow rate is typically 50 gpm and the temperature is $\sim 93^{\circ}\text{C}$. The injection line is kept free of scale by forcing a "pig" through the pipe every 24 hr. The "pig" is forced through the line by water pressure to dislodge accumulated scale. To evaluate the compatibility of PC with pigging, the injection line was modified so that one PC pipe will be cleaned with the pig while the other is isolated from the fluid stream during the pigging operation.

The first inspection of the pipe was made after 1374 hr. The results are as follows:

1. The PC-lined pipe through which the pig is being forced was scale-free and no signs of abrasion or erosion of the PC were apparent. The pipe was reinstalled in the line for continued exposure.

2. The PC-lined pipe that was not subjected to the descaling procedure had accumulated an ~ 1.5 -in. layer of a soft fluffy scale. This amount of scale was equal to that deposited on carbon steel pipe during similar exposure. A sample of the scale has been sent to BNL for analysis and use as an aggregate in PC.

Testing of the cylindrical PC samples has also been in progress since August. These samples are immersed in brine in the second steam separator. A visual inspection has not yet been made.

Figure 13. PC-lined pipe prior to installation at San Diego Gas and Electric Co. Geothermal Loop Experimental Facility.

During the next scheduled shutdown of the facility (October 1978), the 8-in.-diam pipe section will be installed between the first and second stage steam separators. The pipe is expected to carry ~ 150 gpm of brine at 182°C and 150 psig.

Task 5. Technology Transfer and Economic Evaluation

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 are continuing.

Work to evaluate direct utilization processes is being performed as a subcontract with the Burns and Roe Industrial Services Corporation. Two processes, barley malting and sugar beet refining, are being evaluated. Reports previously prepared by Coury and Associates under DOE Contract No. EG-77-C-07-1626 are being used as the basis for the studies. A report summarizing this work will be issued during the next report period.

Task 6. Administrative

During the current report period, six "Monthly Administrative Letters" were submitted to DGE and Progress Report No. 15¹ was issued. A paper entitled "Polymer Systems in Geothermal Applications" has been accepted for publication in the "Journal of Applied Polymer Science". Another paper entitled, "The Effect of Dicalcium Silicate and Tricalcium Silicate on the Thermal Stability of Vinyl-Type Polymer Concrete" has been submitted for publication in "Cement and Concrete Research, An International Journal".

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