# THERMALLY CONDUCTIVE COMPOSITES FOR HEAT EXCHANGER TUBING

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## KEYWORDS

bottoming cycles, corrosion protection, design studies, fouling coefficient, economics, heat transfer, mild steel, polymer cement composites, silicon carbide, thermal conductivity

## PROJECT BACKGROUND AND STATUS

The economic utilization of binary working fluids in geothermal energy conversion cycles operating in the 150° to 200°C temperature range would dramatically increase the size of the exploitable hydrothermal resource. Therefore, a key objective of the GD Conversion Technology Task is to reduce the cost of power from a binary plant by 8 to 20 percent through improvements in efficiency and in O&M cost components. A significant item of cost in a binary plant is the shell and tube heat exchangers, primarily due to the necessity of using high alloy steel tubing to prevent corrosion. Even then, excessive fouling prevents the economic use of binary processes with hypersaline brines. Both problems could possibly be solved with the development of a thin, scale resistant, thermally conductive polymer matrix composite which could be used as a liner on low cost mild steel tubing. Cost effective utilization of bottoming cycles in flash processes as a means of increasing energy conversion efficiency will also become possible.

The technical feasibility for the use of high temperature composite materials for corrosion protection was demonstrated by BNL in the early 1980s, and since then they have been used successfully by the geothermal industry. It was then shown that significant increases in the thermal conductivity of the polymer-matrix composites could be achieved by the incorporation of high conductivity materials as fillers. Conductivities approaching those of Type-410 stainless steel were obtained. It was later shown that the addition of high temperature antioxidants into the composite significantly reduced the rate of scale deposition and adhesion to the surface. Work to develop a low cost, low fouling replacement material for the high alloy steels used in geothermal heat exchange applications was then initiated.

In FY 1994, a 75 day field test of carbon steel tubing lined with a thermally conductive polymer composite (PCL) was conducted under conditions that simulated those in a bottoming cycle in a multi-stage flash geothermal process. The heat exchanger consisted of four 6-meter lengths of 2.54-cm o.d. x 1.24 mm wall tubing lined with a 0.76-mm layer of the PCL. The hypersaline brine inlet and outlet temperatures were 108° and 89°C, respectively. Concurrently, AL-6XN control tubes were evaluated under similar temperature, pressure, flow and brine composition conditions.

In FY 1995, analyses of the heat transfer, fouling and corrosion resistance performance of the PCL were completed. Preliminary design and cost studies for utilizing the composite in full scale shell-and-tube heat exchangers were also conducted. A second field test using PCL modified by the inclusion of antioxidants is planned for FY 1996.

## PROJECT OBJECTIVES

The objective of the research which is being performed as a cooperative effort with the National Renewable Energy Laboratory (NREL) and a cost-shared activity with the geothermal industry, is to develop, fabricate, and field test in a prototype single tube shell and tube heat exchanger, polymer cement lined tubing (PCL). If successful, low cost substitutes for high alloy tubing will be identified and reductions in the rate of scale deposition on heat transfer surfaces will be obtained.

***Technical Objectives***

Development of a material meeting the following criteria:

- Heat transfer and fluid-flow characteristics similar to those of AL-6XN tubing.
- Fouling coefficient <50% of AL-6XN when used in brines typical of the Salton Sea KGRA.
- Cost not more than twice that of mild steel.

***Expected Outcomes***

- Electric generation capacities in geothermal flash processes could be improved by 10% with the availability of cost-effective materials for use in bottoming cycle heat exchangers.
- Low temperature geothermal resources which are currently uneconomical will become more attractive for development, thereby greatly enhancing the exploitable geothermal reserves.
- Increased plant utilization factors due to reduced scale deposition and decreased quantities of waste sludge for disposal will result from the use of binary processes with hypersaline brines.

## APPROACH

The work is being performed as a collaborative effort between BNL, NREL and private industry. BNL performs the fundamental and applied research necessary to define the polymer cement formulations, determines protective coating thickness requirements, and develops methods for the placement of thin, uniform coatings on heat exchanger tubes. Post-field test evaluations are also performed at BNL.

Engineering analyses and heat transfer tests are conducted by NREL. The work includes measurements of heat transfer coefficients, cost estimates, and the management of field testing. NREL also coordinates technology transfer activities.

A geothermal company provides the field test site, operating personnel and ancillary equipment. Tests in an environment typical of that in a bottoming cycle application in a flash process are being performed. Design and economic studies are then conducted by a heat exchanger manufacturer.

## RESEARCH RESULTS

In FY 1995, BNL completed the post-test analysis of PCL and AL-6XN control tubing after completion of a 75 day field test exposure to flowing hypersaline brine under heat exchange conditions. In separate tasks, NREL evaluated the fouling and heat transfer characteristics and arranged for the performance of design studies and economic estimates. These NREL tasks are documented separately.

The BNL results from post-field test evaluations performed on four 3-meter sections of PCL tubes and on equal length sections of AL-6XN tubes that were cut from the 6-meter tubes are summarized below:

- After 75 days of exposure, the PCL and AL-6XN tubes were both found to contain a layer of scale ~3.2 mm in thickness. In general , the deposition of scale in the tubes was found to increase as the temperature of the brine stream decreased. Measurements also indicated that the deposition of scale on the PCL tubes was, on average, ~8.5 percent greater than that deposited on the AL-6XN tubes. The increased thickness of the scale in the tubes was probably due to the fact that the scale adhered more readily to the surface of the PC liner than to the AL-6XN.

- A visual examination of the PC liners indicated that the liners were still securely bonded to the tubing, and there was no evidence of any voids or delaminations between the liner and the tubing.

- Shear bond strength test results indicated that the bond of the liner to the carbon steel tubing had not deteriorated as a result of the exposure tests. After 75 days of exposure, the PCL had an average bond strength of 8 MPa, compared to an average control value of 7.9 MPa. A visual examination of the interior surface of the tubes after the liners had been pushed out indicated that there was no apparent evidence of corrosion at the interface of the liner and the tubing.

- Test results indicated that the bond of the scale to the surface of the liner was almost as high as the bond of the liner to the tubing. The average shear bond strength of the scale to the PC liner was 7.8 MPa.

- The average strength of the bond between the scale and the AL-6XN tubes was measured to be 1.2 MPa. A visual examination of the interior surface of the tubes after the scale had been pushed out indicated that there was no apparent evidence of corrosion at the interface between the scale and the AL-6XN tubing.

In conclusion, the results of the post-field test evaluation indicated that the PCL tubes were in good condition, and that they performed as well as the AL-6XN tubing.

## FUTURE PLANS

Laboratory R&D to evaluate the effectiveness of the use of antioxidants as a method for reducing scale accumulation on composite lined heat exchanger tubing will be completed. Based upon the laboratory results, four 6 meter lengths of tubing containing antioxidants will be prepared for use in a second field test. The conditions for this test will probably be similar to those for the FY 1994 test, and the results will quantify the benefits of antioxidant additions. Tubing samples will also be provided to heat exchanger manufacturers for use in work to define potential methods for the joining of tubes to tube sheets in shell and tube heat exchangers.

## INDUSTRIAL INTEREST AND TECHNOLOGY TRANSFER

| Organization(s) | Type and Extent of Interest |
|---|---|
| California Energy Co. | Possible CRADA participant. User of technology. |
| Hughes-Andersen Heat Exchangers, Inc.<br>Babcock & Wilcox | Heat exchanger manufacturer. |

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