FIELD TESTING OF THERMALLY-CONDUCTIVE, CORROSION-RESISTANT LINERS

Edward Hoo and Vahab Hassani
National Renewable Energy Laboratory (NREL)

KEY WORDS

materials testing, materials development, polymer concrete lining, heat exchangers, industrial coatings

PROJECT BACKGROUND AND STATUS

A major concern in the utilization of geothermal resources, for producing low cost electricity, is the scaling and fouling of the heat exchanger surfaces used in binary geothermal power cycles. The formation of scale can help to accelerate the rate of corrosion at the heat exchanger surface and can drastically reduce the effectiveness of this heat transfer surface. Brookhaven National Laboratory (BNL) has developed a low cost Polymer Concrete (PC) material that when applied to an inexpensive base metal (e.g. carbon steel) can protect it from corrosion. In addition, it is believed that this PC lining may be able to reduce the level of scale buildup, thus reducing the rate of fouling of the heat transfer surface.

A collaborative effort between NREL and an industry partner, which began in 1993, sought to quantify the heat transfer, anti-corrosion, and anti-scaling properties of a set of Polymer Concrete Lined (PCL) heat exchanger tubes provided by BNL. These field tests were concluded in November 1994 after a total of 75 days in brine service. The data gathered during the test were analyzed to determine the heat transfer and pressure drop performance of the PCL tubes. Both the PCL tubes and the high alloy stainless steel (AL-6XN) tubes were removed from the heat exchanger and examined to determine the anti-corrosion and anti-scaling performance of each. In addition, an economic analysis was conducted to ascertain the cost savings potential of PC lined heat exchangers.

PROJECT OBJECTIVES

The goal of this activity is to reduce the cost of electricity generation from moderate temperature geothermal resources by improving the performance and economic viability of binary geothermal power cycles. The objective of this task is to conduct a series of field experiments for quantifying the heat transfer, anti-corrosion, and anti-scaling properties of tube liner materials, polymer concrete (PC) to date, in geothermal brine service. This task is important to the geothermal industry because it provides an alternative to the high cost of heat exchanger tubes made from corrosion resistant materials, such as titanium and high alloy stainless steel. In addition, it has the potential to reduce operational and maintenance costs of general process piping in brine service.

Technical Objectives

- Characterize the heat transfer, anti-corrosion, and anti-scaling properties of industrial polymer coatings, such as the polymer concrete lining developed at BNL, in relation to the currently available corrosion resistant metal alternatives.
- Identify potential difficulties arising from normal operations with a lined heat exchanger instead of a more conventional heat exchanger, employing corrosion resistant materials.
- Identify the significant manufacturing issues raised in the commercial production of lined heat exchangers, using the polymer coatings under consideration, and propose possible remedies and solutions.
- Assess the economic advantages of lined heat exchangers over heat exchangers employing corrosion resistant materials like titanium and high alloy stainless steels.

Expected Outcomes

- Thermal and mechanical data for use in designing full-scale heat exchangers used in binary geothermal cycles.
- General cost data, which can be used to gauge the overall costs associated with the fabrication of lined heat exchanger.
- Manufacturing techniques and processes for use in constructing lined heat exchangers in a commercial production environment.
- New heat exchanger lining materials that will lower the cost of electricity generation and extend the life of the primary heat exchangers.
- Similar coatings that could significantly reduce the operational and maintenance costs associated with general brine service piping and well casings.
- An additional outcome of this project could be the development of appropriate coatings that could be used to extend the life of the plant's rotating equipment that must be periodically repaired as a result of corrosion and erosion damage.

APPROACH

The approach taken in this task is to work closely with industry partners and BNL to develop, field test, and analyze polymer liner systems that provide viable alternatives to expensive corrosion resistant metals for geothermal heat exchanger tubing and service piping. Previous tests of a polymer concrete liner material developed by BNL were conducted under a Cooperative Research and Development Agreement (CRADA) between NREL and one of its industry partners. This CRADA enabled field testing of the PCL material in the presence of an aggressive geothermal brine, which was provided by the industry partner at one of their geothermal power plants. Plans are currently underway to establish a new research agreement between NREL, BNL, the current industry partner, and a new industry partner to develop, test, and manufacture new polymer liner formulations. The steps taken by NREL for achieving the objectives of this task include:

- A detailed analysis of the thermal and mechanical data obtained over the course of the long-term field tests concluded in November 1994.
- Post field test examinations of the PCL and AL-6XN tubes to gauge the impact of the geothermal brine on fouling and corrosion in the tubes.
- Hydroblasting tests of the scaled PCL tubes to determine the cleaning potential of PC lined tubes.
- An economic study that quantifies the potential cost savings associated with heat exchangers constructed using PC linings in lieu of exotic corrosion resistant materials.
- An assessment of the manufacturability of full-sized lined heat exchangers. NREL is working closely with U.S. firms knowledgeable in the areas of advanced materials and industrial coating technology, and heat exchanger construction to assess and evaluate manufacturing issues related to lined heat exchangers.
- Development of research plans and industry partnerships to develop and test new and existing types of organic polymer linings that exhibit some or all of the properties cited previously.

RESEARCH RESULTS

Early testing of the PC lining, by BNL researchers, indicated that the lining was capable of protecting pipes exposed to an aggressive brine environment. In addition, the relatively high measured thermal conductivity of the material (k_{pcl} = 3.7 Btu/hr-F-ft) pointed towards its use in protecting heat transfer surfaces exposed to aggressive brines. Estimates indicated that if this PC material was used as a liner on carbon steel (k_{cs} = 26 Btu/hr-F-ft) and this liner was made suitably thin (approximately 30 mils) then the overall thermal conductivity of the composite heat transfer surface was comparable to that of high cost corrosion resistant metals like titanium and high-alloy stainless steels (k_{AL} = 8.2 Btu/hr-F-ft), having the same wall thickness.

In FY 1990, Idaho National Engineering Laboratory (INEL) and BNL in conjunction with a geothermal industry partner conducted a series of field tests involving a counterflow heat exchanger lined with the PC material and exposed to an aggressive geothermal brine. These field tests experienced numerous difficulties and were terminated after only 30 hours of operation, due to plugging of the heat exchanger tubes. An examination of the tubes following the termination of the field tests found that a non-uniform application of the PC liner was the primary cause of the poor performance and rapid plugging. A technical report (1) containing the complete results of these field tests was provided to all the involved parties by INEL, in FY 1993.

NREL resumed the field testing of PCL heat exchanger tubes in FY 1993, along with BNL and the original geothermal industry partner. By the time these field tests resumed, BNL had devised a method of fabricating PCL tubes with a uniform liner thickness of 30 mils. In these tests the performance of the PCL tubes were compared to a control case using AL-6XN tubes. These tests utilized the original test skid that was built by INEL for their field tests back in 1990. The test skid contained two parallel counterflow heat exchanger loops, each 80 ft. in length. The field tests began in the summer of 1993 and were not concluded until November 1994. This time period is considerably longer than the 100 days of testing that had been envisioned as a result of several technical difficulties and delays that surfaced in both the test skid and the brine delivery system from the geothermal power plant. A total of 75 days of process data was obtained over this entire period.

Analysis of the thermal and mechanical data over the 75 test days (2) found comparable heat transfer and pressure drop performance for the PCL and AL-6XN tubes. The test results demonstrated that under similar operating conditions the overall heat transfer coefficient for the PCL tube was about 9% lower than for the AL-6XN tube. Pressure drop data found a similar rate of increase for both types of tubes, indicating a similar rate of fouling and scale buildup for both sets of tubes.

Following the conclusion of testing in November 1994, the PCL and AL-6XN tubes were removed from the heat exchanger test skid for further analysis. Approximately half of the PCL tubes and all of the AL-6XN tubes were sent to BNL for a detailed analysis of the PCL performance. The other half of the PCL tubes were sent to a commercial hydroblasting outfit to determine the cleaning potential of a PC lined heat exchanger surface.

Post field test examinations by BNL (3) found that the PC liner successfully protected the carbon steel tube from corrosion. Measurements of the scale-liner bond strength in the PCL tube found that it was more than six times the strength of scale-tube bond in the AL-6XN tube. Furthermore, measurements of the scale buildup found that the scale layer in the PCL tube was approximately 8.5% thicker than the one in the AL-6XN tube. This would seem to indicate that the scale bonded more readily to the surface of the PC liner, contrary to what was originally anticipated. Measurements of the bond strength between the PC liner and the carbon steel tube found it to be essentially the same as the bond strength between the scale and the PC liner. It is believed that a new formulation of the PC liner that was recently developed at BNL will drastically reduce the bond strength of the scale to the PC liner.

Hydroblasting tests indicated that geothermal scale deposited on the current formulation of PC lined tubes could not be consistently cleaned without destroying the liner in the process. A predictable pattern of pressure and flow rate that would result in a consistent removal of the scale only, leaving the underlying PC liner intact, could not be identified. Based upon the results, it was concluded that the unpredictable nature of the scale removal was a result of a scale-liner bond strength similar in magnitude to the liner-tube bond. This conclusion was supported by the measurements made by BNL.

An economic study was commissioned with a geothermal heat exchanger manufacturer to determine the potential cost savings of a PC lined heat exchanger over one constructed using corrosion resistant metals (4). The corrosion resistant material selected for this study was titanium, which at the time of the study had the lowest material cost of the four compatible materials identified by the geothermal industry partner. The study was meant to identify cost targets for a PC lined heat exchanger. The analysis of the PCL heat exchanger included PC material costs and all standard heat exchanger fabrication costs, but did not include the costs associated with applying the PC material. It was, therefore, meant to be used to determine the maximum allowable cost of applying the PC liner that would still result in an attractive cost reduction. The study found that the titanium heat exchanger was close to three times as costly to manufacture as a PCL heat exchanger minus the PCL application costs, which we will call the base cost of the PCL heat exchanger. If we assume a 50% price target for the PCL heat exchanger to be selected over the titanium alternative, the total costs associated with the application of the PC liner must be less than half the base cost of the PCL heat exchanger.

The information gathered from this field testing will help to establish the engineering design data for full-scale heat exchanger design for use in binary cycles in conjunction with electric power generation.

FUTURE PLANS

Preparations for a new set of field tests are underway to evaluate the new formulation of PCL that has been developed at BNL. This new set of tests may also include testing of two additional liner materials in their current commercial formulations or a slightly modified formulations.

A new research agreement is currently being negotiated between NREL, BNL, and the previous geothermal industry partner. Negotiations are also underway with a US-owned industrial coatings firm to develop and test new and existing organic polymer coating for use in geothermal brine applications. With the help of this new industry partner, manufacturing issues relating to the application of such protective coatings in a production environment will be resolved, resulting in more accurate cost estimates for a lined heat exchanger. This would eventually lead to the fabrication of a pilot scale lined geothermal heat exchanger and ultimately to production units.

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CONTACTS

DOE Program Manager:

Raymond LaSala
U. S. Department of Energy
Geothermal Division, EE-122
1000 Independence Ave., SW
Washington, D. C. 20585
Tel: (202) 586-4198
Fax: (202) 586-8185

Principal Investigators:

Edward Hoo Tel: (303) 384-7447
Fax: (303) 384-7540
Vahab Hassani Tel: (303) 384-7464
Fax: (303) 384-7495
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401