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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 would dramatically increase the size of the exploitable hydrothermal resource. 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 that 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 PC.. The hyersaline 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. The post-test examination indicated that the base metal was fully protected by the lining. In addition, the heat transfer performance and fouling rate of the PCL tubes were similar to those of the high alloy controls. In FY 1996, preliminary design, manufacturing and cost studies for utilizing the composite in full scale shell-and-tube heat exchangers were conducted. These results established that contingent upon the development of a cost-effective method for joining PCL tubing to tube sheets, significant reductions (17 to 65%) in the cost of a heat exchanger could be realized. A second field test using PCL modified by the inclusion of antioxidants is planned for FY 1997.

PROJECT OBJECTIVES

The objective of the research is to reduce the levelized cost of heat exchangers in geothermal binary power plants by 30%.

Technical Objectives

The objectives of the project will be met by the 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 that 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, the National Renewable Energy Laboratory (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, manufacture method and economic studies are then conducted by a heat exchanger manufacturer.

RESEARCH RESULTS

Plans for a second large-scale field test of a PCL heat exchanger were formulated, and contractual negotiations are nearing completion.

BNL continued work to identify methods for improving the surface texture and scale-bonding characteristics of PCLs applied to carbon steel tubing. As part of this effort, fundamental work to elucidate the interactions that take place at PCL- or polymer-/scale interfaces was performed. The results from these studies indicate that polymers containing esters, ketone, or ether groups should not be used in PCL formulations. These groups were found to react with divalent cations such as Ba and Co that are present in geothermal brines. The reactions promote hydrolysis of these groups to form carboxylic acid which subsequently reacts with Ba and Ca hydroxides through general acid-base reaction routes. These form Ba- and Ca- complexed carboxylate salt derivatives such as -COO · · · M · · · OOC-, where M is Ba or Ca. The formation of these interfacial reaction products results in chemical bonding which causes the high shear bond strength (>7 MPa) of scale on PCL surfaces. The use of polyaryl-type polymers such as polyphenylene sulfide (PPS) should significantly reduce the magnitude of the bonding, and thereby make the use of hydroblasting practical for descaling PCL surfaces. This issue will be addressed in Field Test No. 2 that will be performed in FY 1997.

FUTURE PLANS

Laboratory R&D to evaluate the effectiveness of the use of antioxidants and oxidative resistant polymers as methods for reducing scale accumulation on composite lined heat exchanger tubing will be completed. Based upon the laboratory results, three 6 meter lengths of tubing containing antioxidants will be prepared for use in a second field test. Three others that do not contain the antioxidant will be tested as controls. In addition, tubes lined with PPS and PPS-SiC will also be tested. The conditions for this test will be similar to those for the earlier field 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	Type of Extent of Interest
California Energy Co.	Possible CRADA participant. User of technology
Hughes-Andersen Heat Exchangers, Inc.	Heat exchanger manufacturer.

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