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PROTECTIVE COATINGS TO REDUCE CORROSION PROBLEMS OF TURBINE ROTORS

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ABSTRACT

Corrosion reduces service life of geothermal turbine components by reducing efficiency and increasing downtime. Any component in the turbine may be susceptible to corrosion. Failure of the rotating parts can cause a forced outage. These components are subjected to severe corrosive conditions by their exposure to corrosive chemicals in steam. These chemicals include hydrogen sulfide, carbon dioxide, and ammonia, as both condensate and noncondensable gases, resulting in several types of corrosion damage, including pitting corrosion, stress corrosion cracking, erosion, and corrosion fatigue.

This paper describes a research program to identify, test, and evaluate commercially available coatings for reducing the susceptibility of the rotors and rotor components to corrosion-related problems and extending the useful life of the rotors.

INTRODUCTION

Nineteen operating geothermal units are located at The Geysers, in Sonoma and Lake Counties, California. Superheated dry steam from geothermal wells run directly into plant turbines at approximately 300 to 350 degrees F and 100 psi supplying a total capacity of 1361 megawatts of power. The first operating unit was put on-line in 1960. Corrosion and reduced service life of geothermal turbine components is of large concern. Specifically, the rotors are designed for 30 years service (in a clean environment). The Geysers have experienced extensive corrosion and erosion related damage to many rotors. There are 33 rotors and new rotors cost approximately $2M each. It is hoped that this study will result in reducing the corrosion problems and extending the useful life of the rotors.

One potential method of corrosion control is the use of protective coatings. Coatings could increase component life and service of the unit without costly replacements. Often sacrificial, coatings allow protection and refurbishment of the existing components. In addition to this, the rotors are large, expensive, and difficult to purchase with a long lead time making coatings a very attractive alternative.

Properly conceived laboratory and field corrosion tests can duplicate many of the factors involved in service and serve as a guide for material and process selection. Several types of tests are required for the different service conditions as well as for the various component types. For example, the turbine blade root geometry contributes to a crevice corrosion condition. However, corrosion-resistant coatings suitable for the blade fit area of the rotor may not be successful for turbine blade problems. Erosion-corrosion problems of the blade are very different than crevice corrosion problems of the root and the coating requires different characteristics.

By considering all the factors involved in a particular process, it is possible to make reliable predictions of the behavior and relative ranking of coatings performance based on laboratory and field data. Because of the corrosion problems experienced at The Geysers, a research program was formed to evaluate coatings for reducing the corrosion susceptibility in several areas of the rotor and components.

BACKGROUND

While coatings have been used to protect steam turbine and gas turbine components for several years, there is limited technical information about the use of coatings in geothermal environments. In general, the only methods that have been used for correcting aqueous corrosion problems associated with steam turbines was to remove the corrodents from the steam or to replace the substrate with a more corrosion-resistant material. The former case is not easily applicable to geothermal steam. Although this has been considered, the quality of the steam chemistry is difficult to modify. Substituting materials, if possible, requires long lead times for development and would affect overall turbine design.

PROBLEM AREAS

There are primarily four problem areas where failures occur. The problem areas and their primary corrosion mechanism are listed in Table 1.

Table 1. Problem Areas and their Primary Corrosion Mechanism.

Problem	Corrosion Mechanism
rotor	stress corrosion cracking, erosion, corrosion
blade fit	stress corrosion cracking, crevice corrosion
nozzles	erosion
blades	corrosion, corrosion fatigue, erosion

COATING PROCESSES

As an alternative to changing the steam chemistry or the rotor materials, coatings, applied to protect the metal substrate and minimize corrosion on the rotor and components may be a possible solution to The Geysers corrosion problems. There are many commercially available coatings available to the industry.

EPRI published reports on the results of their work on "Corrosion Resistant Coatings for Low-Pressure Steam Turbines" research project 1408-1. These reports, EPRI Report CS-3139 and CS-5013, identify coatings to protect low-pressure, steam-turbines from corrosion which will lead to early component failure. The candidate coatings were evaluated relative to their ability to shield the metal substrates from corrodents in the steam either by forming a surface barrier or by cathodic protection. These are the two primary methods of protection, barrier and sacrificial. However, the EPRI study was performed with particular reference to fossil fuel plants and can not be directly applied to geothermal steam turbines.

Using the information from the EPRI reports, as well as further developments in coating technology, various coating systems were selected for evaluation. The coating processes considered for PG&E's program fall into four categories:

1) electroplating
2) thermal spray
3) chemical vapor deposition
4) nonmetallic

Electroplating

The component to be plated is the cathode in an electrolytic cell and the metal to be deposited is the anode or in the electrolyte. The plating acts as a protection from corrosion. Similar in concept to electroplating, electroless nickel plating is used to deposit a nickel coating by immersion without the use of an electric current.

Thermal Spray

Thermal spray coatings are generally systems where a properly prepared substrate is coated with a variety of materials. The coating materials have been heated to a molten or semimolten state and propelled with sufficient velocity to produce a bond.

Chemical Vapor Deposition

Chemical vapor deposition is a process where a reactant atmosphere gas is fed into a chamber. The gas decomposes on the workpiece and the coating adheres to the substrate.

Nonmetallic

Nonmetallic coatings are typically organic coatings that are sprayed and cured.

MATERIALS

A summary of all the coating systems under consideration for The Geysers rotor coating project is given in Table 2. Although a large number of commercial coatings are available, a total of only twenty-two coating systems were chosen for the initial study.

Two substrate materials are being used for the coated coupons. Coupons of turbine blade alloy material, ASTM A276, Type 403 (12 Cr stainless steel) were selected as well as coupons fabricated from material removed from a rotor, ASTM A470, Class 8 (CrMoV).

Table 2. Coating Systems Under Consideration for Testing.

	Materials	Vendors
1.	SermeTel SPE-8515-HT & Cr_3C_2	Sermatech Int. Limmerick, PA (215) 948-5100
2.	ENPLATE Ni-422 Electroless nickel	ENTHONE, Inc. New Haven, CT (203) 934-8611
3.	ENPLATE Ni-426 Electroless nickel	ENTHONE, Inc. New Haven, CT (203) 934-8611
4.	Low pressure plasma spray Ni Al	Electro Plasma Irvine, CA (714) 863-1834
5.	Electroless Ni (particle enhanced) NiCarb, EN + SiC	ElectroCoatings Houston, TX (713) 923-5935

	Materials	Vendors
6.	ESA (Electro Spark Alloying) WC + TiC + TaC + Ni	Advanced Surfaces Forrest Grove, OR (503) 357-2389
7.	ESA (Electro Spark Alloying) WC + TiC + TaC + Co	Advanced Surfaces Forrest Grove, OR (503) 357-2389
8.	ESA (Electro Spark Alloying) Cr_3C_2 + Ni	Advanced Surfaces Forrest Grove, OR (503) 357-2389
9.	IVD Aluminum Class 1, type II	AAA Plating Compton, CA (213) 979-8930
10.	High Vel. thermal spray Cr_3C_2	Turbine Metal Tech. Tujunga, CA (818) 352-8721
11.	Sulfamate nickel electroplate	Metal Surfaces, Inc. Bell Gardens, CA (213) 927-1331
12.	Nickel/Cadmium electroplate	Metal Surfaces, Inc. Bell Gardens, CA (213) 927-1331
13.	Nickel aluminide diffusion	Turbine Metal Tech. Tujunga, CA (818) 352-8721
14.	SermaTel 2200	Sermatech Int. Limmerick, PA (215) 948-5100
15.	SermaTel 5380	Sermatech Int. Limmerick, PA (215) 948-5100
16.	ESA (Electro Spark Alloying) Kanthal AlM	Advanced Surfaces Forrest Grove, OR (503) 357-2389
17.	Apexior No. 1 organic coating	Dampney Co. Everett, MA (617) 389-2805
18.	CM-X copolymer organic coating	Allied Engineering Plastics, Ausimont Morristown, NJ (201) 455-4225
19.	Ryton organic coating	Phillips Petro. Bartlesville, OK (918) 661-1984
20.	PVD TiN	Liburdi Eng. Ltd. Canada
21.	CVD TiN	Liburdi Eng. Ltd. Canada (416) 689-0734
22.	Purethane	Steel Svcs. & Parts Portland, OR (503) 789-1321

TEST PROGRAM

The test program for geothermal turbines is in the early stages. Coupons are being coated and the test fixtures are being assembled. Actual testing should begin in the second quarter of 1989.

Modified Salt Spray Test

The objective of the salt spray test is to obtain a relative ranking by performance of the coating/substrate systems in geothermal condensate. The modified salt spray test is similar to ASTM B117 but at ambient temperature and using condensate from the geothermal steam. The test fixture is set up using a bypass of the condensate line running from the direct contact condenser to the cooling tower. Flat coupons, as well as stressed coupons to evaluate stress corrosion cracking tendencies, will be used.

Erosion Test

The objective of the erosion test is to obtain a relative ranking of the coatings under controlled erosion conditions. The test will use one particle type, two particle velocities, and two particle impingement angles. The particles chosen are sediment removed from the condensate, consisting primarily of iron oxide. The particles were filtered to obtain the 90 mesh fraction.

In Situ Tests

The objective of the in situ test is to obtain a relative ranking of the coatings previously tested under modified, but near actual, conditions. There are two parts to the in situ tests. Coupons will be attached to the raincatcher section of the turbine shell. The conditions will serve to expose the coupons to the temperatures seen in service but with less erosion than the blades and nozzles experience.

In addition to the coupons in the raincatcher, diaphragm nozzles are being coated with selected candidate materials for evaluation. This will give actual service experience for certain coatings in a combination erosion-corrosion environment, a better evaluation for coatings that would be suitable for blades and nozzles.

DISCUSSION

In addition to recognizing that there are four problem areas where failures occur (with various corrosion mechanisms), one must recognize that one coating will not satisfy all the requirements. A number of factors need to be considered in selecting the best coating. These include component size, availability of process (distance parts would need to travel to be coated) as well as availability of parts to be coated, applicability of a given process to a given component, cost, compatibility with substrate, delivery time, ability to repair coated parts, durability, and so forth. For instance, one coating may work well for a specific application such as the blade, but is not capable of being applied to a large item such as a rotor because the size of the machine for coating is smaller than the rotor.

Using data from EPRI and turbine coating research, candidate materials were selected. In this way, the specific application of the geothermal corrosion problems were kept in mind as materials were screened. This survey resulted in about five materials for each problem area being chosen as suitable for testing.

CONCLUSION

An attempt has been made to show how laboratory data, coupled with field tests, are making it possible to make reliable predictions as to the behavior of coatings on turbine rotors to reduce the corrosion problems in geothermal steam. Coatings are being used for increasing the service life of steam turbine blades in fossil power plants. This program explores using protective coatings to reduce corrosion problems of turbine rotors.