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STANDARDIZATION IN CONSTRUCTION, CORROSION CONTROL AND INSPECTION OF GEOTHERMAL POWER PLANTS

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ABSTRACT

Geothermal Power Plants are made up of steam wells, well heads, steam pressure piping, process piping, pressure vessels, heat exchangers, turbines, pumps, compressors, condensers and storage tanks. The fluids being handles are steam, brines, gases, water and hydrocarbons in several combinations depending on the nature and characteristics of the geothermal resource and the optimum process chosen for the resource.

In view of the fact that the Geothermal Energy is a relatively new industry expanding rapidly since the late 1950s and early 1960s, although geothermal waters in small quantities have been used since the turn of the century[1], the design and construction was and is based on codes and standards developed in other industries such as the steam power, oil and gas, petroleum refining and chemical processing industries.

PURPOSE

The purpose of this paper is to discuss the place of existing standards and codes in the Geothermal Industry in the arena of generating plant equipment and corrosion control associated with the facilities.

To tie in with the standards review, this work will talk about construction codes, corrosion rate measurement, equipment inspection and evaluation, and corrosion prevention. It will be devoted to steels, alloys and other materials but will not deal with resource development, geology, gas abatement and control, and environmental issues.

EQUIPMENT AND CONSTRUCTION

Steam and Water Wells (Specifications)

The design of steam wells (casing, liners and well heads), valves, flanges, piping is covered by the American Petroleum Institute (API) publications and standards, NACE International Materials recommendations and American Society for Testing Materials (ASTM) Annual Books of Standards.

The fluids to be handled include steam, water (brine), gases and soluble and insoluble salts and compounds (minerals). These fluids most often bear corrosive agents including carbon dioxide, hydrogen sulfide (hydrogen chloride), chloride salts, and acids. They also contain ammonia, hydrogen, silica and carbonates, some of which result in scaling of flow surfaces.

A key standard to which essentially all geothermal equipment needs to meet is, NACE Material Recommendation, MR-0175-95 (or latest edition), sulfide stress cracking (SCC), resistant metallic materials. Almost an entire geothermal plant, from the steam production well on through generation facilities and then fluid disposal, is exposed to wet, low temperature hydrogen sulfide in substantial quantities, part or all of the time which results in SCC of hardened steels above a Rockwell C value of 22.

Codes and Standards (examples)

- NACE MR-0175-95 Sulfide Stress Cracking Resistant Metallic Materials.
- API Bull 5C3 Formulas and Calculations of Casing, Tubing and Drill Pipe.
- API Spec. 5D Spec. for Drill Pipe.
- API Spec. 5L Spec. for Line Pipe. Also ASTM A53 Std. Spec. for Pipe, Steel Welded and Seamless. ASTM A106 Std. Spec. for Seamless Carbon Steel Pipe for High Temp. Service[2].
- API Spec. 6A Spec. for Valves and Weldhead Equipment.
- API Spec 6D Spec. for Pipeline Valves.

Steam and Brine Separation and Generating Plant

Generating plants are steam dominated rankine cycles such as the geysers, Wairakei and Puna, or liquid dominated flash such as Imperial Valley or liquid dominated flashed binary with heat transfer to a light hydrocarbon motive fluid.

These various processes utilize steam pressure piping, hydrocarbon pressure piping, separators and scrubbers which are pressure vessels, condensers, barometric condensers, vaporizers, hydrocarbon superheaters, which are heat exchangers built to the Unfired Pressure Vessel Code, turbines, pumps, and compressors.

Codes and standards for this construction are:

- American Society of Mechanical Engineers (ASME) B31.1 Power Piping and B31.3 Chemical Plant and Petroleum Refinery Piping Codes.
- ASME Unified Pressel Vessel Code-Section VIII - Divn. I.
- ASME PTC 8-2 Centrifugal Pumps.
- ASME PTC 6 (R19941) Steam Turbines.
- ASME PTC IO (R1992) Compressors and Exhausters.
- API Std. 650 Welded Steel Tanks for Oil Storage.
- API Std. 2510 - Design and Construction of Liquified Petroleum Gas Installations.

1 Klamath Falls, OR; Larderello, IT; and Iceland
2 ASTM - American Society for Testing and Materials

THE INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

ISO is a worldwide federation of national standards bodies from some 100 countries, one from each country. It was started in the late 1940s but has really come into prominence since 1976. The author has not yet seen their standards although their catalog lists 9178 published international standards. It would seem to be something like a combination of ASTM and ASME. American and foreign manufacturers are having to qualify their plants to ISO 9000 to compete in Europe and abroad. Many American factories have passed the audit.

Industry can expect to hear more about ISO in the future and the needs to adapt to it.

The headquarters are in Geneva, Switzerland, 3 rue de Verambé, CH-1211 Geneve 20, Switzerland (Suisse).

CORROSION, CORROSION MONITORING AND CORROSION CONTROL

The geothermal resources are in most projects contaminated steam and water. These motive fluids, which have valuable natural heat energy, coming from the earth contain corrosive agents in the form of carbon dioxide, hydrogen sulfide, hydrogen chloride, chloride salts and acids. The penalty for natural heat is corrosion. In this regard then, the steam handling equipment is exposed to corrosion not found in a fossil fuel fired or power plant nuclear generating facilities. Most geothermal plants are dealing with contaminated steam and foul water.

However, most components of a geothermal plant, the steam turbine, of which is a good example, are fabricated from conventional steam plant alloys. The discs and blades are fabricated from 410 or 403 martensitic air hardenable stainless steels. Most of the steam piping and pressure vessels are fabricated from carbon steels.

It is not surprising then that corrosion problems occur and operational problems occur from corrosion debris. Corrosion in various forms becomes more prevalent than in a conventional power generation plant.

FORMS OF CORROSION IN GEOTHERMAL

Uniform Attack - Figure 1

Uniform attack is the most common form of corrosion. It is characterized by a chemical or electrochemical reaction which proceeds uniformly over the entire surface area. The metal becomes thinner and eventually fails. The attack may be fast or slow, and may leave the metal clean or coated with corrosion products. Uniform attack is easy to evaluate. Weight loss measurements or loss in thickness suffice. They are made over a period of time and expressed in inches per year (ipy) or mils per year (mpy).

Uniform attack is expected to occur to carbon steel in the steam, brine, condensate, and NCG. The condensate from steam laden with CO_2 (carbonic acid) may cause smooth uniform attack in long grooves at the bottom of steel lines and equipment. This is a form of acid attack which most frequently uniform in nature in the broad grooves.

Figure 1. An example of uniform corrosion. This is a brass tube washed with heavy concentrations of ammonia. The area to the left was protected by a steel support baffle.

Pitting and Crevice Corrosion - Figure 2

Pitting is corrosion in localized areas. Where such areas are small as compared to the whole surface they are called pits. A pit is generally distinguishable by relatively sharp or well-defined change of orientation of an otherwise level surface.

Pitting occurs in carbon steel along with uniform corrosion. Pitting of steel is usually broad with respect to the size of the opening or area and not sharp. Pitting, unless it is strong acid attack, occurs under deposits of iron oxide, iron sulfide, inorganic minerals or organic sludge. This attack is also known as "deposit" attack, "under deposit"corrosion or "crevice" corrosion (with stainless steels). Pitting of this form is usually irregular and not necessarily deep. Crevice corrosion occurs to stainless steels under metal to metal, plastic to metal, or deposit to metal crevices. With SS, it can be very sharp and deep. Chlorides and thiosulfate cause pitting of 304 and 316SS. In addition, chlorides cause deep pitting of chromium martensitic stainless steels such as 410, 416 and 420.

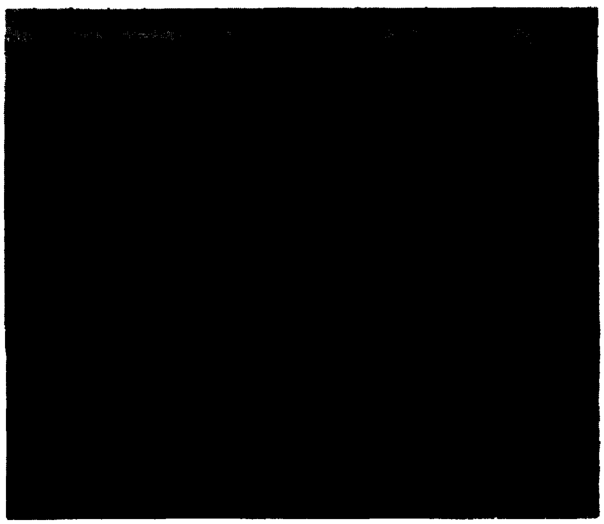

Figure 2. An example of pitting. A carbon steel re-injection line with a mixture of brine and CO_2. The pitting if from wet turbulent flow with free CO_2.

Cavitation Erosion and Impingement - Figure 3

Cavitation erosion or cavitation damage is caused by the formation of vapor bubbles (steam) in a liquid near a metal surface and collapse of the bubbles causing unusually high local implosive forces. The forces are in excess of the yield strength of the metal locally and repeated pounding causes small fatigue cracks. Eventually, pieces of metal pop out. The surface appears very spongy. Cavitation occurs in all metals but stainless steels and nickel and cobalt base alloys are much more resistant than carbon steel. Cavitation is basically mechanical damage and the penetration rates quite often are very high.

Impingement by water droplets in high velocity steam is similar in its effect on metals and is found on turbine blades, steam valves and airplane propellers.

Figure 3. Cavitation damage of a 316L, 6 inch, hot brine pipeline into which a colder steam condensate was introduced. It was loaded with CO_2 and H_2S Gas.

Erosion Corrosion - Figure 4

Corrosion can combine with erosion to produce severe attack of steel, cast iron, copper, copper alloys and aluminum. The attack most often is local in nature. Many metals and alloys owe their corrosion resistance to protective films of oxide, sulfides or other corrosion products. Removal of these protective films by erosion exposes fresh metal to attack. As a result, the metal corrodes much faster than in the absence of erosion.

Stress Corrosion Cracking (SCC) - Figure 5

SCC is the fracture of a metal or alloy in a corrosive environment, under a tensile stress, either residual or applied. The fracture is frequently in a ductile material such as steel, brass, stainless steel or even gold. The fracture, where it occurs, makes the metal act like it is brittle and renders the component structurally useless. Cracking can be either transgranular or intergranular, depending on the alloy, the heat treatment and the corrosive environment. Often the metallic part shows little or no surface corrosion.

- Chloride Induces SCC of Austenitic SS (316, 316L, 304, 304L).

The 300 series, austenitic stainless steels, display SCC at temperatures above 140°F in the presence of wet concentrated chloride salts when stressed in tension and when oxygen (air) is present in amounts greater than 50 ppb.

Residual stress from welding is high and the most common source of residual stress. Residual hoop stress, introduced into pipe at the steel mill when it is being straightened, is another common source of tensile stress. In view of the salt in the atmosphere at sea coastal locations along with rain, splashing and dripping from hoses, the 316L and 304L piping is often externally coated with a high temperature silicone rubber to keep the stainless isolated from a corrosive environment to avoid SCC from external conditions.

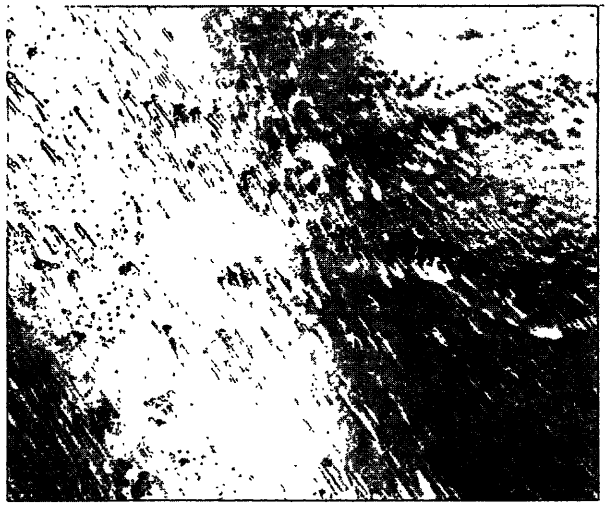

Figure 4. Erosion - corrosion of a cast 410 stainless pump impeller after 20 years of intermittent service. It is unusual to observe erosion of stainless but time takes its toll. The metal loss was minor.

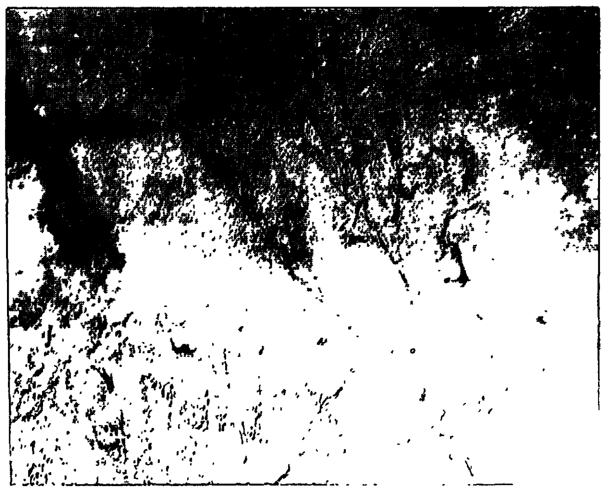

Figure 5. Stress corrosion cracking (SCC) of a 316L austenitic stainless steel internal shell in a brine concentrator. Notice the web like pattern with chips falling out. Stresses were from rolling; temperature 215°F, and salt content about 20,000 ppm

Sulfide Induces SCC of Martensitic SS and Carbon Steels - Figure 6

Wet hydrogen sulfide causes intergranular and sometimes transgranular SCC of the martensitic stainless steels such as 403, 410, 416 and 420 at temperatures below 400°F. The hardness generally has to be greater than Rc 28. The same problem occurs with the PH stainless steels such as 17-4PH above Rc30. The component has to be under a form of tensile stress. It does not occur with compressive stress.

The same problem occurs in carbon steels and low alloy steels if the hardness exceeds Rc 22. Sulfide SCC occurs frequently at welds due to localized hardening in the heat affected zone of a weld.

Figure 6. Sulfide Stress Corrosion Cracking of hardened steel. A 5% chrome-1/2 moly elbow was inadvertently welded to carbon steel. Five chrome-1/2 moly is an air hardenable alloy of steel.

Corrosion Fatigue - Figure 7

Fatigue is the fracture of a mechanical part over a relatively lengthy period of time by repeated cycles of stress with the stress being below the yield strength of the material. In air, for instance, the mechanical part, depending on the alloy, has a limiting cyclical stress below which it does not fail with an infinite number of cycles. This is called the Endurance Limit.

In a corrosive environment, such as fresh water, sea water and geothermal steam corrosion enters the picture and the material no longer has an Endurance Limit. A material can be tested in a particular environment for 10^7, 10^8 or 10^9 cycles. The dividing line now is called the Corrosion Fatigue Strength (CFS). The more corrosion resistant the material, the higher the CFS. The CFS for Inconel 625 for instance, is much better than that for carbon steel or 316L S.S. in a given environmental circumstance.

Corrosion Fatigue has been experience in 410SS steam turbine blading at the Geysers and Wairakei. The problems were solved by improved mechnical designs.

Figure 7. Corrosion Fatigue of a 316 bolt in fresh water. 15 to 20 years of service clamping a nose cone to a large pump impeller in the California water system.

STANDARDS AND PRACTICES IN CORROSION TESTING, CORROSION RATE DETERMINATION AND EQUIPMENT INSPECTION

NACE Int'l.

TM (Test Method) 0169-76 Laboratory Testing of Materials for Process Industries

TMO 177-90 Laboratory Testing of Materials Resistance to Sulfide Stress Cracking in H_2S Environments.

ASTM

Annual Book of Standards Wear and Erosion; Metal Corrosion, Section 3, Volume 3.02.

G-1 Preparing, cleaning and evaluating corrosion test specimens.

G-4 Conducting corrosion coupon tests in plant equipment.

G-28 Detecting susceptibility to intergranular corrosion in wrought, nickel rich, chromium bearing alloys.

G-30 Making and using U-bend stress corrosion test specimens.

G-46 Examination and evaluation of pitting corrosion.

G-48 Pitting and crevice corrosion resistance of stainless and related alloys by use of ferric chloride solution.

G-58 Preparation of stress corrosion test specimens for weldments.

G-71 Conducting and evaluation galvanic corrosion tests in electrolytes.

G-78 Crevice corrosion testing (multiple crevice assembly).

G-96 On-line monitoring of corrosion in plant (electrical resistance and polarization resistance).

G-102 Calculation of corrosion rates from electro chemical measurements.

ASTM - Equipment Inspection

Annual Book of Standards, Section 3, Volume 3.03

E-690 In Situ EC Examination of Nonmagnetic Heat Exchange Tubes

E-1003 Hydrostatic Leak Testing

E-1002 Ultrasonic Leak Testing

E-427 Halogen Leak Testing

E-165 Liquid Penetrate Examination

E-709 Magnetic Particle Examination

E-114 Ultrasonic Pulse - Echo, Straight Beam Examination

E-797 Ultrasonic Pulse - Echo, Measurement of Thickness by Manual Contact.

E-1032 Radiographic Examination of Weldments.

ASME - Equipment Inspection

Boiler and Pressure Vessel Code, Section V - Nondestructive Examination

B31.G Remaining Strength of Corroded Piplines.

API - Equipment Inspection

510 Pressure Vessel Inspection Code

570 Piping Inspection Code

653 Welded Steel Storage Tanks

API RP 572 - Inspection of Pressure Vessels

API RP 574 - Inspection of Piping, Tubing, Valves and Fitting

API RP 576 - Inspection of Pressure Relieving Devices.

DISCUSSION

From the foregoing information outlined in this article, there are in place engineering societies, trade associations, testing associations, national and international organizations devoted to Standards and Codes. These associations are ASME, API, ASTM, ANSI, ISO and NACE International. The geothermal industry in the United States and probably in foreign countries is making use of the existing codes, standards and recommended practices of these associations in exploration, resource development, erecting plants and in plant operation. In the disciplines of corrosion monitoring, corrosion control and equipment inspection for safety, the applicable documents have been cited in the body of this text.

It should be mentioned that within NACE Int'l Group Committee T-2 for Energy Technology, there is a unit committee T-2E for control of degradation of materials in geothermal systems. The author has cited the primary locations for standards, but within these associations, there are additional helpful and useful standards and publications.

For management and personnel in operating geothermal facilities who have a desire and dedication to be sure that standards are satisfactory for this Industry and their Plants, some individuals may find it important to join and participate in Committee work.

All of the Societies and Associations cited in this paper are open to membership.