H. 1563

CONF-7805211-

COO-3904-1

COO-3904-1--2

GEOTHERMAL SYSTEMS MATERIALS: A WORKSHOP/SYMPOSIUM

Proceedings, May 23-25, 1978

Work Performed Under Contract No. EG-77-C-04-3904

Radian Corporation Austin, Texas



U. S. DEPARTMENT OF ENERGY Geothermal Energy

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GEOTHERMAL MATERIALS SYMPOSIUM, PROCEEDINGS, MAY 1978

Materials Selection

for

Geothermal Steam Turbines

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Materials Selection for Geothermal Steam Turbines

Selection of materials for steam turbines using geothermal steam is fundamentally similar to the selection of materials for turbines operating on steam from fossil fuel fired boilers with some modification in importance attached to certain properties and characteristics of these materials. For example, geothermal steam turbines do not operate in the range where long time high temperature properties of materials need to be considered. Conversely, resistance to sulfide stress cracking and stress corrosion cracking may be more important in the case of geothermal steam than with more conventional boiler generated steam.

In the evaluation and selection of materials for geothermal steam turbines it is necessary to consider the following properties and characteristics:

- 1. Tensile properties
- 2. Modulus of elasticity
- 3. Corrosion resistance
- 4. Erosion resistance
- 5. Fátigue strength
- 6. Coefficient of thermal expansion
- 7. Susceptibility to brittle fracture (toughness)
- 8. Material damping
- 9. Specific heat
- 10. Thermal Conductivity
- 11. Hardenability
- 12. Weldability

Each of the above items will be discussed separately using the same identifying numbers as above:

- 1. Tensile properties, especially the yield strength, must be known to select materials having adequate strength to withstand the stresses that will be imposed in service. Generally the operating stress is higher for rotating parts than for stationary components.
- 2. The modulus of elasticity must be known in order to compute operating stresses and to determine the deflection that will be encountered when a given stress is applied.

Materials Selection for Geothermal Steam Turbines

Page 2

- 3. Corrosion resistance, including resistance to sulfide stress cracking and stress corrosion cracking, is very important in the case of geothermal steam turbines. These problems are considered carefully in conventional steam turbines, but need to be even further emphasized in the case of geothermal steam. While geothermal steams do not often contain caustic soda, they can be high in hydrogen sulfide, chloride, and other corrosive agents which might give rise to premature and unexpected failures. These same contaminants can cause corrosion in the wet regions of a turbine or during the time the turbine is on stanby operation if it is not blocked in such a way that steam cannot enter.
- 4. Erosion resistance is a factor in the selection of materials and protection systems in the wet regions of steam turbines. Since virtually the entire turbine is wet in geothermal steam turbines, it is important to use materials of adequate resistance to erosion. Erosion of turbine parts may also be accelerated in geothermal steam due to the presence of contaminants which make the moisture more aggressive.
- 5. Fatigue problems due to resonance are less likely in turbines driving constant speed generators than in mechanical drive turbines which may be called upon to operate over a wide range of speed. Nevertheless, in geothermal steam where pitting corrosion is more likely to be encountered than in steam from fossil fuel fired boilers, fatigue is quite important.
- 6. The coefficient of expansion determines the dimensional change which will take place in a turbine as the temperature increases from ambient to operating. The changes are less for geothermal steam turbines than for other turbines operating at higher temperatures, but this effect must still be taken into account.
- 7. Susceptibility to brittle failure, (toughness) does not usually present a problem in geothermal steam turbines. It should, however, be examined, especially for new materials to avoid possible problems.
- 8. Damping is considered in stress calculations, particularly with regard to vibration which may take place in turbine buckets. Conventional turbine bucket materials are good in this respect.

Materials Selection for Geothermal Steam Turbines Page 3

Specific heat and thermal conductivity like the coefficient of
thermal expansion are used in the computation of dimensional changes and thermal stresses.

- 11. Hardenability is important to the turbine manufacturer in selecting materials that will respond to heat treatment in the section thicknesses involved. This property is not ordinarily of interest to the turbine user.
- 12. Weldability is considered in selecting materials for parts which may be fabricated by welding or where repair welding may be performed as a field operation.

Turbines for use on geothermal steam which have been built to date have been made from the same materials as would be used in turbines using steam from fossil fuel fired boilers. The compositions of the materials referred to in the following paragraphs are listed in Table 1:

- 1. Rotating buckets have been made from 12% chromium steel, AISI Type 403 or 410. The standard analysis is frequently modified slightly to minimize the occurrence of ferrite in the microstructure. The buckets of stages operating where there are substantial amounts of moisture are sometimes fitted with Stellite strips on the back side of the leading edge to minimize erosion by the moisture.
- 2. Diafram blades have been made from a 12% chromium steel, AISI Type 405. Usually this non-hardening grade of 12% chromium steel is used to improve weldability of fabricated diaframs or castability where the diafram centers and outer rings are made from cast iron.
- 3. Turbine rotors and disks have been made from carbon steel and low alloy steel such as AISI 4340, ASTM A517 Type B or F, and ASTM A470 Class 4, 6, or 8.
- 4. Sleeves on the shaft between disks have been made from either a medium carbon steel or a medium carbon alloy steel such as AISI 4140 or 4340.

Materials Selection for Geothermal Steam Turbines

Page 4

- 5. Shafts seals have been made in at least two ways. One method involves the use of thin strips (0.012" thick) of 12% chromium steel (AISI Type 410). The other method utilizes austenitic nickel alloy cast iron (D2C Ni Resist) seals.
- 6. Casings operate at low temperatures and low pressures. Cast or fabricated carbon steel has been used. In some cases AISI Type 304 stainless steel liner strips have been used in the casing to protect from erosion due to moisture being thrown off the rotating buckets.

Even in the case of fossil fuel fired boilers there may be a considerable difference in the quality of steam from one plant to another. Steam quality varies with such things as composition of the raw water, feed water treatment employed, percentage of makeup required, mode of operation, etc. In the case of geothermal steam, the variations are much greater. Variations in geothermal wells occur with time and from one location to another. To illustrate the substantial differences, Table 2 shows the range of impurity concentrations in domestic goethermal waters. The acidity of these geothermal waters can be very high, the pH can be as low as 1.8.

Variations in separated geothermal steam are much less extreme than those in geothermal waters because the solids in solutions in the water which cause the greatest variations should not be present in the steam. Efficiency of separation has a substantial influence on steam quality. Non-condensible gases may raise or lower the pH. The greatest variations will occur in the first condensate to form where the concentrations of dissolved gases will be greater than when more of the steam has condensed.

As pointed out previously, corrosion and erosion resistance are important properties of steam turbine bucket materials. It is usual in conventional turbines to provide erosion shields on turbine buckets operating over about 1000 feet per second and with moisture contents above 6-8%. It may be necessary in aggressive geothermal service to adopt more conservative criteria and use moisture catchers. It has also been suggested that erosion may be reduced by limiting the tip speed. This is a solution which, while effective, could limit performance and increase the cost of turbines.

Materials Selection for Geothermal Steam Turbines

Page 5

Because of the aggressive nature of the steam and water, general or pitting corrosion may occur on turbine buckets under conditions of temperature and pressure where these problems would not ordinarily be encountered.

A phenomenon usually called stand-by corrosion occurs in turbines when steam is allowed to leak into a machine which is not in service. The steam then condenses and pitting corrosion results. This problem will undoubtedly be more acute with geothermal turbines because of the contaminants which will make the condensate more aggressive than is generally the case with steam from conventional fossil fuel fired boilers. These contaminants, for example hydrogen sulfide, are even more aggressive in the presence of oxygen. Geothermal steams usually do not contain oxygen. It is possible, however, that air containing oxygen may leak into a turbine during periods of standby. If there is condensate from a hydrogen sulfide bearing geothermal steam in a turbine and this leakage of air occurs corrosion will be accelerated. This problem may be avoided by arranging the piping (Figure 1) to prevent the leakage of steam into the turbine when it is not in operation and by purging the turbine when it is shut down with a non-reactive gas such as nitrogen.

Fatigue failures of rotating buckets in geothermal steam turbines have occurred due to fatigue cracks propagating from corrosion pits. Pits on one such bucket are shown in Figure 2. With the exception of standby attack, pitting corrosion rarely occurs in conventional turbines. This problem, like that of moisture erosion, could be alleviated by limiting the tip speed, but it would be preferable to find other solutions.

Fouling due to deposition of solids can occur in nozzles with loss of performance. Fouling, which causes an accumulation of solids under the shroud of steam turbine buckets, can also cause unbalance. This problem may be reduced by the use of lashing wires rather than shrouds. Where it is possible to design around the use of these damping devices their elimination will further reduce the foulding problem.

It has been reported that there have been failures in geothermal steam turbine buckets protected with Stellite strips due to the poor resistance to corrosion of the silver brazing alloy used

Materials Selection for Geothermal Steam Turbines

Page 6

to attach the strip. This material would have poor resistance to corrosion in geothermal steam in bulk, but the access of the brazing alloy to the steam is very limited, and there may be an alternate explanation.

Attaching the Stellite strip by brazing requires heating the material locally to about 1400°F. This is enough to cause some degree of hardening in the material immediately underlying the strip. Many thousands of buckets have been protected in this manner without difficulty when operating on conventional steam. In the case of many geothermal steams, however, the steam is contaminated with hydrogen sulfide, and conditions at the location of the attachment of the Stellite strip to the turbine bucket may favor sulfide stress cracking. This problem may be avoided by using a post brazing heat treatment at 1100-1150°F to reduce the hardness of the heat affected zone.

In order to avoid sulfide stress cracking due to hydrogen sulfide it is frequently recommended that materials be used having a maximum yield strength of 90,000 psi and/or a maximum hardness of Rockwell C22. Both buckets and disks, especially the latter, have been used successfully in geothermal steam turbines with yield strengths well above this figure. The yield strength of some of the disks has been about 120,000 psi. It is apparent that the conditions of operation in these turbines have been less severe than in applications such as casings in sour crude oil wells where the more restrictive limits may be needed.

Materials Selection for Geothermal Steam Turbines

Grade	<u> </u>	Mn	<u>Ní</u>	Cr	Mo	<u> </u>	Others
Type 403/410	0.10	0.6	0.2	12.0	0.1		Contraction
Туре 405	0.06	0.6	0.2	12.0	0.1	un di co in	0.2 Al
AISI 4140	0.40	0.8	••••••	1.0	0.2	والترقيق والمركبين	<u>emitte des tra</u>
AISI 4340	0.40	0.8	1.8	0.8	0.25		
ASTM A470 C1. 4	0.24	0.4	2.8	0.6	0.3	0.04	
ASTM A470 C1. 6	0.24	0.4	3.5	1.5	0.4	0.08	
ASTM A470 C1. 8	0.30	0.8	0.5	1.2	1.3	0.25	
ASTM A517 Type B	0.18	0.8	ميل الخرختيريون	0.5	0.2	0.05	0.02 Ti, 0.002B
ASTM A517 Type F	0.15	0.8	0.8	0.5	0.5	0.05	0.3 Cu, 0.002B
D2C NiResist	2.6	1.8	22.5				
Туре 304	0.05	1.2	9.0	19.0	-		
Carbon Steel	0.25	0.7					

Table 1

Chemical Analysis of Materials Used in Turbines

Materials Selection for Geothermal Steam Turbines

Variations in U.S.	Domestic Geothermal Waters
Contaminant	Range of Concentration (ppm)
Silica (SiO ₂)	16-96
Sodium (Na)	9-6500
Ammonia (NH3)	1-1400
Calcium	2-9200
Chloride (Cl)	1-124000
Sulfate (SO4)	3-5700

Table 2

Materials Selection for Geothermal Steam Turbines



Figure 1

Example of piping arrangement used to avoid standby corrosion in steam turbines.

Materials Selection for Geothermal Steam Turbines



Figure 2

Corrosion pits in bucket from turbine operating on geothermal steam. In service 2-3 years. Also shows mechanical damage on leading edge (on left).

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