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FAILURE ANALYSIS REPORT

CIRCULATING PUMP IMPELLER
PRESBYTERIAN INTERCOMMUNITY HOSPITAL
KLAMATH FALLS, OREGON
GEOTHERMAL HEATING SYSTEM

Prepared by
David A. Mitchell, P.E.
Peter F. Ellis

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United States Department of Energy
Chicago Operations and Regional Office
Argonne, Illinois 60439

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1.0 Introduction

The Presbyterian Intercommunity Hospital located in Klamath Falls, Oregon, utilizes geothermal fluid pumped from its own well to provide space heat and domestic hot water. During an inspection of the heating system after a chemical cleaning of the heat exchangers, the circulating pump was dismantled to replace its seals which were found to be leaking. At that time, the impeller was found to contain many cracks. This report concerns the analysis of those cracks and a scale sample removed from the impeller.

This report is part of a continuing effort to gain insight into geothermal component materials used in the direct utilization of geothermal energy. The results of these analyses will provide materials data for use in the next issue of DOE's "Materials Selection Guidelines for Geothermal Energy Systems."¹

The geothermal heating system at the hospital consists of a single well producing 191°F (88°C) fluid with a submerged lineshaft centrifugal multi-stage pump. The pump capability is 500 gallons per minute. The fluid is delivered to a fluid holding tank which is vented to atmosphere. The useful heat of the geothermal fluid is extracted in a series of tube and shell heat exchangers. When the temperature of the recirculating fluid is

reduced below a specified value, the cooler fluid is disposed and additional hot fluid added to the system. The composition of typical Klamath Falls fluid is shown in Table I. The component studied in this investigation serves to circulate the geothermal fluid in a loop through the series of heat exchangers. The circulating pump has a capacity of 500 gpm at 65 foot head. It was in service for about 3½ years.

Due to fouling of the heat exchangers, a chemical cleaning of the system was performed using inhibited 10% hydrochloric acid. The process corroded the pump seals causing leakage. As a result, the pump was dismantled and impeller removed for evaluation when cracks were observed. This report concerns that evaluation and the cause of pump impeller cracking.

2.0 Visual Observations

When received, the impeller was observed to be cracked adjacent to the leading edge of each vane. Figure 1 illustrates the cracks observed on each vane. The location of the cracks is such that they occurred during service rather than during pump disassembly.

3.0 Examination Procedure

The pump impeller was sectioned to better reveal the conditions which led to its deterioration. Metallographic examination was performed to reveal the grain structure of the material. The material of construction of the impeller was determined. Elemental analysis of the deposit clinging to the impeller was determined by energy dispersive spectroscopy (EDS) in conjunction with scanning electron microscopy. The compounds present in the loosely adherent scale were determined using x-ray diffraction (XRD).

Overall view
showing number
and location of
cracks

Close-up of a
typical crack

Figure 1. Sectioned pump impeller. Arrows denote crack locations. Based on crack locations, impeller failed in service rather than when impeller was removed from pump case.

**TABLE I. TYPICAL COMPOSITION OF KLAMATH FALLS
 GEOTHERMAL FLUID**

Species	Concentration (ppm)
pH	8.39-8.65 (pH units; not ppm)
Total Dissolved Solids	643-798
Cl^-	36-49
CO_3^{2-}	0-3.9
SO_4^{2-}	260-395
CO_2	37-129
HCO_3^-	30-92
NO_3^-	4.9
HS^-	0.1-0.5
NH_4^+	0.2-3.0
Ca	26
F	1.5
Fe	0.3
K	4.3
Si	48
F^-	1.5
Na	205
O_2	0.0-.03

Resource Temperature - 192°F

Fluid tested at room temp.

4.0   Examination Results

Upon sectioning, the first indication of distress in the area of cracking was a change in the color of the metal in that area. The cracked areas had lost the normal "brass" color and appeared to have a red-like copper color. This effect is known as dezincification and is illustrated in Figure 2. The remaining strength of the dezincified areas was so low that the mere weight of the sectioned impeller caused fracture. Loss of zinc in the areas adjacent to the cracks is demonstrated in Figure 3. In this example, zinc concentration is plotted as a function of distance from the surface of the impeller on a cut section. The loss of zinc in the affected areas is demonstrated in Figure 3. In the most severe case, a weak, porous, spongy, copper-rich region remains. A comparison of sound and dezincified areas is shown in Figure 4. Multiple chemical analyses of the sound material indicates that the impeller is manufactured of silicon bronze (ASTM B584 Grade CA87500).

Table II presents the results of analysis of deposits removed from the pump impeller. These results indicate that the scale residue remaining after acid cleaning is composed of silica and various forms of cuprous sulfide.

Arrows denote location of most severely attacked areas. Note color change associated with dezincification.

Close-up (actual size) of area outlined above. Again, arrows denote most severely attacked areas.

Figure 2. Cross-section of bronze pump impeller illustrating areas of dezincification. Loss of zinc from bronze (yellow metal) leaves copper-rich (red) areas shown.

Figure 3. Scanning electron micrograph of both sound and dezincified material. Zinc concentration along scan line is superimposed on photograph. Zinc concentration is higher in sound material (on right side of photograph.)

Sound Material

Etchant: Potassium
Dichromate

Magnification: 100X

Microstructure shown is
indicative of the dendritic
solidification pattern.

Dezincified Material

Etchant: None

Magnification: 100X

Matrix is "spongy" copper.

Figure 4. Microstructure of pump impeller material.
Dark areas of lower photo are voids created
by dezincification.

TABLE II. ANALYSIS OF LOOSELY ADHERENT
IMPELLER DEPOSIT

Elements Present (by EDS)	Relative Concentration
Silicon	Major
Copper	Major
Sulfur	Minor
Chlorine	Trace
Potassium	Trace
Zinc	Trace
Iron	Trace

Compound Identification (by XRD)

Copper Sulfide (various forms including
 $\text{Cu}_{1.97}\text{S}$, $\text{Cu}_{1.765}\text{S}$,
 $\text{Cu}_{1.93}\text{S}$)

5.0 Discussion

The pump impeller is manufactured of cast silicon bronze alloy. The composition of that material is shown below:

COMPOSITION OF SILICON BRONZE IMPELLER ALLOY		
<u>Element</u>	<u>wt. % Concentration</u>	
	<u>Sample</u>	<u>B584 Grade CA87500</u>
Cu	82.06	<u>79.0 min.</u>
Zn	13.29	12-16
Si	4.49	<u>3-5</u>
Sn	<0.01	---
Pb	0.07	<0.05
Fe	0.06	---
Mn	<0.01	---
P	0.005	<0.05
As	<0.01	---
Sb	<0.01	---

NOTE: Spec. Requirements are underlined.

A material of this composition is susceptible to dezincification. The process whereby zinc is selectively removed from a material is a special case of a process referred to as "dealloying." It has been thoroughly documented in the literature.^{2,3,4} Specifically, alloys of copper containing about 15% or more zinc by weight are candidates for dezincification. The geothermal fluid of the Klamath Falls area contains sufficient dissolved carbon dioxide and, in this case, oxygen from inleakage

to produce dezincification. Low flow or stagnant conditions have been known to enhance the process. While this condition is not met in the pump, the pattern of the dezincification indicates that fluid impingement on the material leads to increased dezincification. Although the alloy is on the borderline of susceptibility, the Klamath Falls fluid is sufficiently aggressive to lead to attack.

The deposit removed from the impeller was found to be copper sulfide. This corrosion product has been observed to coat other copper-based components used in Klamath Falls, Oregon.^{5,6} This general corrosion mechanism can eventually lead to failure. Hydrogen sulfide in the geothermal fluid is the constituent responsible for this attack.

6.0 Conclusions and Recommendations

- The pump impeller failed due to dealloying (dezincification). Operational stresses were sufficient to crack the weak, spongy, dezincified material. The failure by dezincification of an alloy (ASTM B584 Grade CA87500) only marginally susceptible to this mode of attack indicates that zinc-bearing copper alloys should be avoided for high velocity service. Experience at other heating systems at Klamath Falls indicates that copper-zinc alloys have performed successfully in applications such as valve bodies.

- Based on other geothermal experience^{1,7}, a nickel-free, nine percent aluminum-bronze should have satisfactory resistance to dealloying as well as acceptable resistance to uniform corrosion, pitting, and crevice corrosion. These alloys are not known to be susceptible to stress corrosion cracking under conditions existing at Klamath Falls. Aluminum-bronze is a common pump impeller material. In this case, an appropriate purchase specification is ASTM B148 Grade C95200.

Copper-nickel alloys (such as 70-30 cupronickel, 90-10 cupronickel, Monel 400, and aluminum-nickel-bronzes) should be avoided. Experience in other geothermal fluids shows that the presence of nickel in copper alloys causes rapid attack by hydrogen sulfide.

- Given the system operating temperature, fluid chemistry, and the apparent contamination by oxygen, use of cast stainless steel impellers is questionable. ACI grades equivalent to AISI 400 series alloys may not have sufficient resistance to localized attack. Cast grades equivalent to most AISI 300 series alloys have sufficient resistance to localized attack but may be susceptible to chloride stress corrosion cracking. It has been shown that AISI 300 series stainless steels containing more than 3.75 percent molybdenum are resistant

to chloride stress corrosion cracking in much more severe conditions than those encountered at Klamath Falls.¹ Should the aluminum-bronze recommendation above pose a procurement problem, a stainless steel impeller purchased to ASTM A296-77 Grade CG-8M should be suitable.

7.0

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