EROSION AND CORROSION PROBLEMS EXPERIENCED DURING THE OPERATION OF GEOTHERMAL TURBINES IN ITALY

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Key words: Erosion, corrosion, turbines

ABSTRACT

Corrosion problems on turbine blades in Italy are generally associated with the presence of chlorides in the steam.

In some cases the scrubbing of the steam with alkaline solutions before use is required.

To overcome this problem, new materials for turbine blades were tested.

Moreover, the presence of corrosion products (iron sulphides, etcc.) in the steam pipelines may cause some plugging in the turbine blading.

This phenomenon is worsened when solid particles are present in the steam.

PREFACE

Historical outline

Geothermal activity started in the 18th century with the extraction of some chemical substances from boric waters with natural steam manifestations in southem part of the Tuscany but it reached considerable importance with geothermoelectric production.

The first operating plant, at the beginning **of** the 20th century, consisted of two back-pressure turboalternator units with a 2x3,5 MW power, as well as the 1x0,2 MW small turbine.

Geothermoelectric production plants have been developing significantlyin the last sixty years.

The number of the plants has increased to the present 38 units of geothermoelectric production. The power initially installed at relatively few MW reached the present 630 MW with yearly production increasing from a few initial Mwh to the present 3.6 TWh.

Figures 1,2 and 3 respectively show historical trends of the installed power, electricity produced, and the yearly weight **of** geothermal steam used by turboaltemators.

Geothermoelectric plants started operating manned by personnel alternating in a 24 hour shift and each new plant which went into operation was manned by its own shift workers.

At present, all plants are remote controlled from only one manned centre.

Characteristics of fluids

The fluids consist mainly **of** superheated steam canying a small **per** cent of non-condensable gases.

The chemical and physical data **of** the fluids vary widely from area to area and, very often, from one well to the next within the same area.

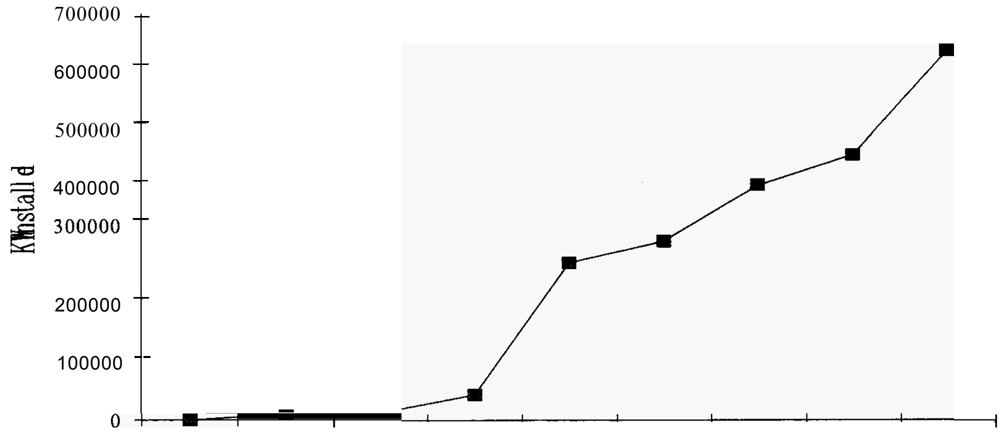

Figure 1. Historical trend **of** installed power

Figure 2. Historical trend of produced energy

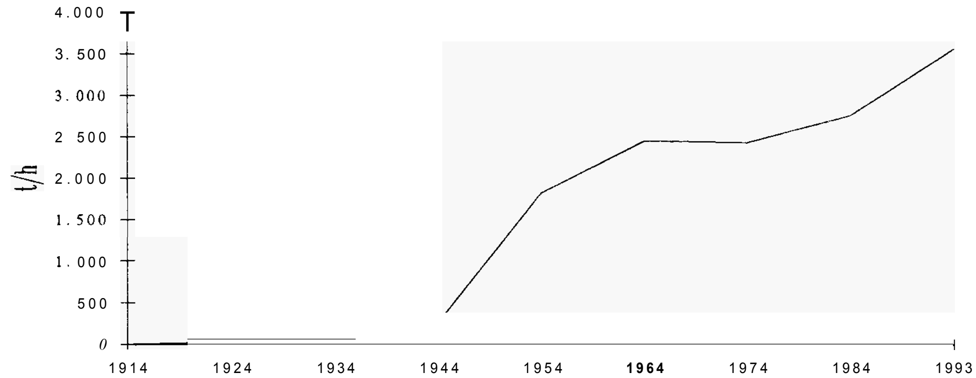

Figure 3. Historical trend of yearly steam flow rate

This situation creates some difficulty where production is concerned, and when selecting materials for equipment that comes into direct contact with the fluids (fig.4).

The wells in the exploited area are generally 3000-4000 mt. deep with temperature reaching 400°C and above.

Increases in the average temperature encountered by the wells and also in the salinity of some of the fluids recovered, have given rise to corrosion problems.

PARAMETER	UNITS	RANGE
Temperature	°C	160 - 250
Pressure	MPa	0.2 - 1.2
NCG Content	%	1.5 -7.0
Condensate pH	-	5 - 8
H_3BO_3	ppm	150 - 500
NH_4^+	ppm	30 - 800
Cl^-	ppm	0 - 40
SiO_2	ppm	traces
Na^+	ppm	traces

Figure 4. Typical characteristics of the steam in Larderello

Chloride was seldom detected in the steam before 1960; however, its concentration increased up to 80 ppm_W in the central area of the field and up to 10 ppm_W in other areas by the year 1970.

Chloride concentrations peaked during 1975 to 1980 and then decreased sharply in 1985 in response to reinjection of condensate, which started in 1978-1979 (Truesdell et al, 1989).

The chloride decrease related to reinjection is undoubtedly due to scrubbing of soluble steam components in the reservoir as superheated steam mixed is with injected water (or saturated steam is produced from it).

The zones where the produced steam contains chloride are quite well defined, as shown by Figure **5.** An interpolation of the concentration data was attempted which, although having only a qualitative value, clearly shows a belt in the southwest and an area near Larderello where the chloride content is highest.

The greatest corrosive effects have in fact been registered in the power plants fed with steam from the wells located in these zones.

1. TECHNICAL DESCRIPTION OF THE PLANTS

After the fist direct steam and turbines discharging-to-atmosphere at back-pressure came the so-called "indirect" cycle with

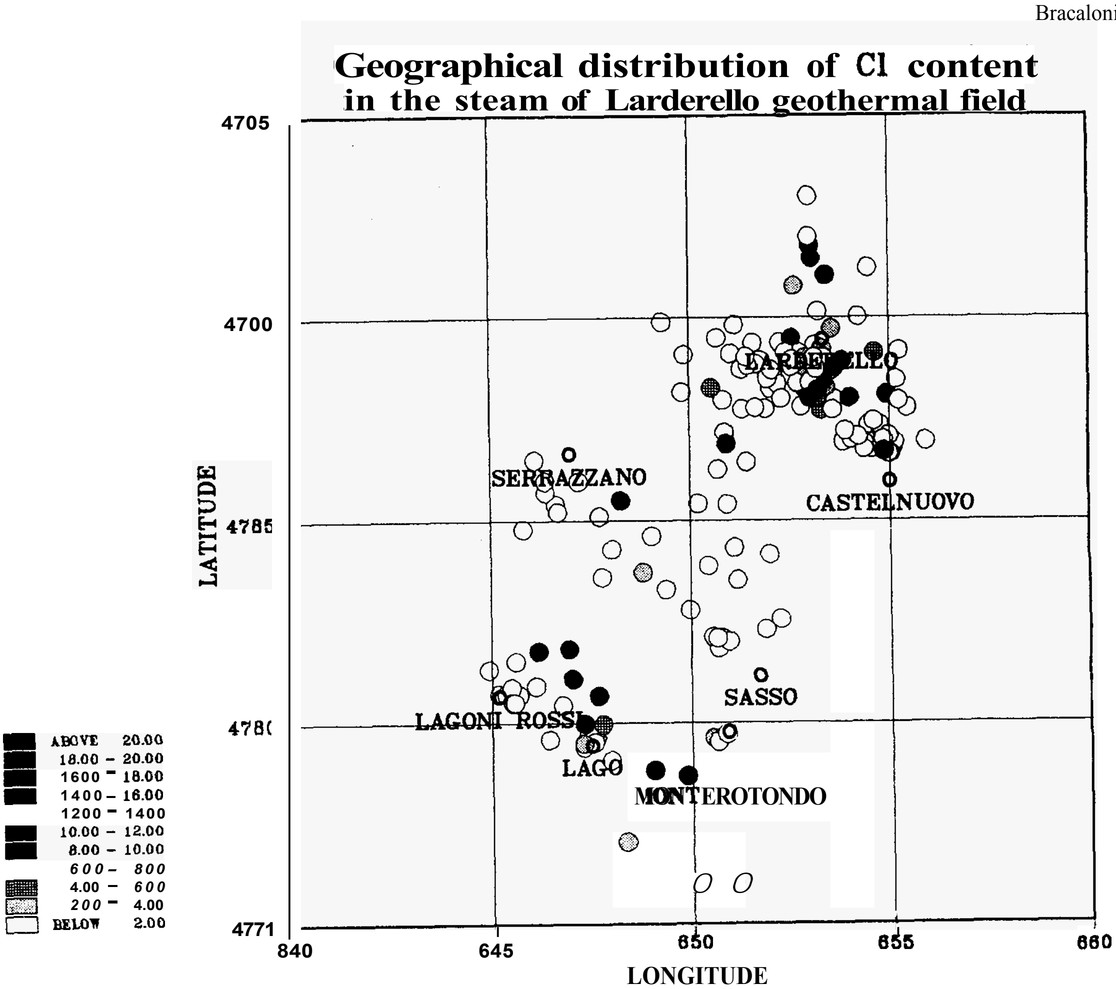

Figure 5.

turbines discharging at non-condensable condensation and extraction (made up mainly of air) by means of an alternate electrocompressor.

Geothermal steam coming from production plants was allowed to circulate in a surface exchanger which generated "clean" steam from fresh water conveniently decalcified. In this case the steam coming into contact with the turbine blading was neither chemically aggressive nor mechanically abrasive.

Therefore, material choice was not difficult and turbine operation went on with no significant setbacks.

However the output was affected by the exchanger being there.

This went on at Larderello 2 and Castelnuovo V.C. plants until the end of the fifties.

During the same period, from the end of the forties, the "direct" cycle was experimented for some plants, where geothermal steam came into contact with the blading. Steam quality, which was then coming from surface beds, was qualitatively similar to the "pure" steam generated in the exchangers of the "indirect" cycle.

Brass blades were used at first. Evolution of geothermal production plants went on side by side with the progress of drilling techniques for geothermal steam availability and, with the deepening of productive beds, steam aggressiveness increased when in contact with the blading.

During the past years various kinds of materials were used for blading, while rotors were carbon steel.

2. CONSTRUCTIVE CHARACTERISTICS OF TURBINES

Three kinds of bladings are present at the moment in geothermal turbines:
a) -reaction multistage blading;

b) -multistage blading (first and second active stage and other reaction stages);

c) -action multistage blading.

Methods of mechanical assembly of bladings are as follows:

1) free blades;

2) blades tied with brazed wire onto the blade;

3) blades tied with a coulked binding onto the blade edge;

4) blades tied with tooth brazed;

5) blades with wire winding through holes. The wire is intermediate at the blade and left free (Rateau system).

At present materials used for blades are UNI X12 CrMo13 and for rotor CrNiMo126 (fig. 6).

3. THERMODYNAMIC CHARACTERISTICS AND TURBINE PERFORMANCE

Geothermal turbines have at present a pressure operating field ranging from **2** Bar to 20 Bar in saturation temperature conditions.

Specific consumptions range from a value of 10-12 kg/kWh to a minimum value of about **6** kg/kWh for higher pressure machinery.

ALLOY TYPE (UNI/ISO)	NOMINAL COMPOSITION (%)	MICROSTRUCTURE	YS 0.2% (MPa)	TS (MPa)	Elong. (%)	Hardness (HB)	CVN impact test (J)
X15CrNiMo13 (blade steel)	0.15C 13Cr 3Ni 2Mo	Tempered martensite ASTM grain size 4-5	766	1217	18.2	372	127
X3CrMnNiMoN2564 (blade steel)	0.03c 25Cr 6Mn 4ni 2Mo	Duplex: austenite in a ferric matrix	692	853	34.0	265	25
Ti6Al4V (blade alloy)	6Al 4V	a-phase matrix with intergranular b-phase	904	996 779	12.2 22.6	299	46
X12CrMo13 (blade steel)	0.12C 13Cr 0.5Mo	Tempered martensite	617	893	21.0	223	136
X5CrNiMo126 (rotor steel)	0.05c 12Cr 6Ni 1.5Mo	Tempered martensite ASTM grain size 1- 4	163		21.0	289	206

Figure 6. Nominal composition and mechanical properties of the tested alloys

4. TURBINE COMPONENT FAILURES

The presence of acid volatile chlorides in geothermal steam is one of the main causes of severe corrosion phenomena on the turbine blades.

Studies carried out on turbine component failures in the last years have given considerable information on failure causes.

Besides the currently known phenomenon of blade failure from fatigue in some cases was caused by breakages in the binding wire (fig.7, 8), often because the more or less extended pit corrosion; a series of breaks connected with stress corrosion cracking phenomena was also detected.

This last phenomenon occurs with blade materials such as UNI X15 CN19, while it has never been detected with materials such as UNI X12 CrMo13 (fig.9, 10).

5. TURBINE CORROSION MITIGATION

5.1 Alternative Materials for Turbine Blades and Rotors

Turbine blades failures, mainly experienced in Larderello from the late nineteen seventies to the mid-eighties, caused extensive research to be started, focusing on the evaluation of alternative materials for geothermal turbines.

The experimental activities were aimed at testing materials with improved resistance to corrosion in order to increase power plant reliability and the time span between planned maintenances. Four alternative alloys available on the market or still under development and suitable for the proposed use, were selected for the tests, together with the blade steel currently employed (X12 CrMo13 martensitic s.s) as a term of reference.

The materials (four blade alloys and one rotor steel: a high-durability matensitic and a duplex stainless steel, a titanium alloy, modified AISI 410 and a martensitic forged stainless steel) are tested in laboratory and on the field (pilot plant feed with superheated steam)

The work carried out with the main Italian turbine manufacturers showed that none of the tested alloys can safely substitute the currently employed blade material (uni X12 CrMo13).

Already in the 1950's, it was apparent that the practice of steam scrubbing was also extremely useful in order to avoid solid deposition in the turbines and, above all, to protect steam pipelines and turbines from the corrosion phenomena experienced in areas where the produced steam contained chloride, as most of the steam contaminants passed into the liquid phase.

On the other hand, a considerable corrosion problem was observed, in this latter case, on the steam pipeline downstream from the recycled solution inlet point and on the first separator.

This led to the practice of alkali (NaOH) addition to the injected solution, thus marking the beginning of chloride scrubbing as it is widely known today.

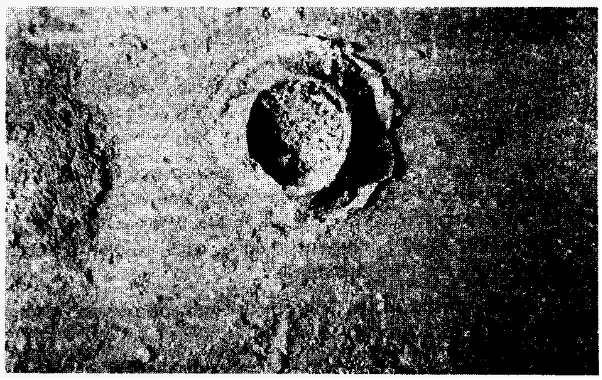

Figure 7. Twenty MW turbine; Blade of the tenth row Fatigue breakage of the wire; magnification 6x

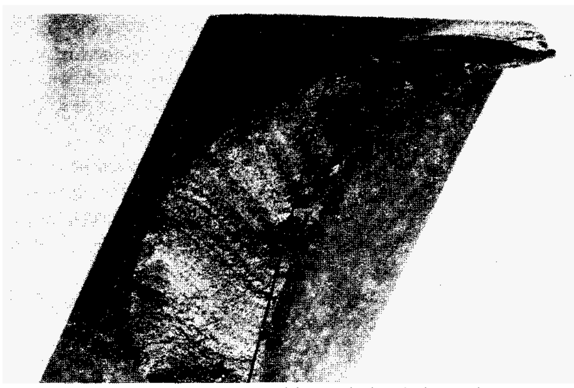

Figure 8. Twenty MW turbine, Blade of eleventh row Fatigue breakage material UNI X12CrMo13 magnification 5x

Figure 9. Turbine 12.5 MW;
overview of secondth row blade
Crack start with SCC
Material UNI X 15Cn19,magnification 5x

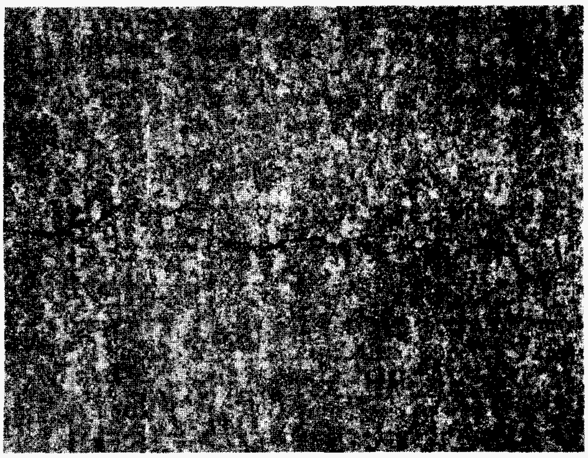

Figure 10. Stress corrosion cracking
Cracks; material UNI X15Cn19
magnification 200x

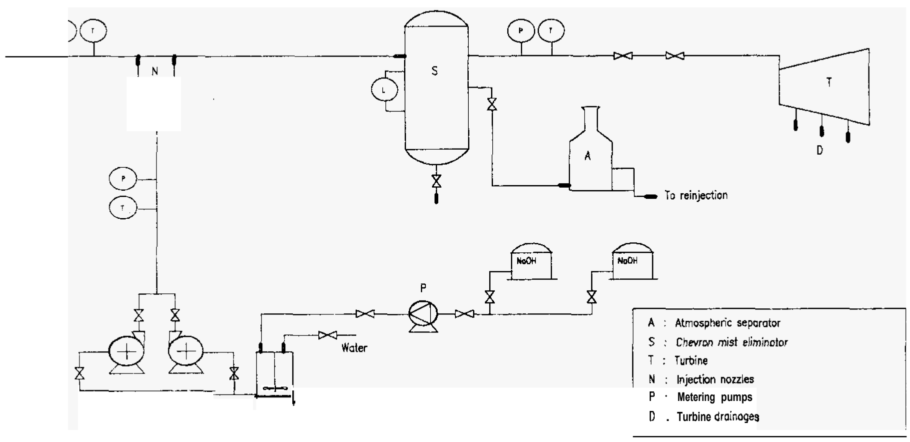

Figure 11. Chloride scrubbing system for a 20 MW power plant (mid - 80s)

5.2 Steam scrubbing (Chloride abatement)

The practice of steam scrubbing goes far back in time : since the fist discharging-to-atmosphere turbines were installed in Larderello, it has been used on the exhaust steam for boric acid recovery, due to the effectiveness of this product.

With the introduction of the direct-steam condensing cycle, steam scrubbing upstream from the power plant was thus installed to overcome this inconvenience, beginning with Serrazzano in 1957.

Although in some cases they were also used to protect pipelines delivering steam from wells with high chloride contents, generally the steam scrubbing system was installed upstream from the power plants,

in order to avoid corrosion damages to the turbine blades when the chloride content of the steam exceeded 5 to 10 ppm. In fact, the steam of Larderello field is almost always superheated enough to prevent condensation, and consequently corrosion, in the steam gathering system.

The main problem was the limited efficiency of the separators, typically in the 80-85% range, which might give rise to scaling problems in the turbine due to the high salinity of the entrained droplets.

A standard chloride scrubbing system, as built in the first half of the 1980s for a modular 20 MW unit, is shown in Figure 11. Injection nozzles are located about 50 m upstream from the separator, having an axial inlet with a baffle providing a rough cenmfugal separator and a horizontal flow chevron mist eleminator before. the steam outlet.

PARAMETER	UNITS	RANGE
Pressure	Kpa	300 - 2.000
Temperature	°C	20 - 25
Air flow rate	m^3/h	10 - 200
HCl Content	mg/m^3	5 - 30
NaOH Solution Flow rate	l/h	15 - 300
NaOH concentration	%	0 - 2

Figure 12. Working conditions of the HCl scrubbing pilot plant

The typical operating conditions for such plants were adjusted **by** varying the injection rate of the alkali (NaOH) solution and its concentration, so as to obtain a separated liquid flow rate of 2.5-3.5 t/h with a pH ranging between 8 and 9 (fig. 12).

CONCLUSIONS

The presence of acid volatile chlorides in geothermal steam is one of the main causes **of** severe corrosion phenomena on the turbine blades none of the tested alloys can safely substitute the currently employed blade material (uni x12 CrM013).

Actually the steam scrubbing remains the only system to remove chloride from steam and to avoid corrosion in the turbines and pipelines.