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MATERIALS SELECTION FOR GEOTHERMAL DEVELOPMENTS

THE NEED FOR A MATERIALS STANDARD

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ABSTRACT

Reliable materials performance in geothermal power stations is required in order to avoid the costs associated with unscheduled down time and premature plant replacement. In comparison with conventional power stations and also the oil and gas industry with which it has features in common, the geothermal materials technology base underpinning materials performance is not well developed. A substantial improvement would be gained by following the approach of the oil and gas industry and developing a standard defining acceptable materials for use in geothermal developments.

1 INTRODUCTION

Electric power generation from geothermal steam has developed world wide from the beginning in 1913 in Italy. In New Zealand, Wairakei Power Station has been generating electric power since 1958 achieving load factors of between 85 and 90% (Thain, 1980). As a technology, it has developed from the experimental stage to the point where, when a geothermal development is being considered, costings are based on load factors equal to those attained by conventional power plant. However the materials technology base for geothermal power stations lacks thorough documentation. The objective of this paper is to compare the published technology base underpinning materials performance in geothermal power developments with, firstly conventional power stations, because of the similarity in plant, and secondly with the oil and gas industry because of the similar materials performance problems encountered. The approach taken by these two industries, provides guidelines for the geothermal power generation industry to follow, in order to improve the materials technology base.

2 THE ECONOMIC CONSEQUENCE OF CORROSION

Reliable and predictable materials performance is important for one basic reason - economics.

i Down time can cost in the order of $0.5 x 10^6/week for a 100 MW station.

ii Premature plant replacement can upset predictions of project profitability.

These two facts, which are common to all industries are the motivation behind corrosion research and testing and the development of appropriate codes of practice for materials selection and operating procedures.

3 CORROSION RESEARCH FOR CONVENTIONAL POWER STATIONS

Corrosion problems in conventional power stations, although encountered from time to time, have to a large extent been solved and appropriate codes of practice for materials selection and operating procedures have been adopted. The development of codes of practice have been supported, however, by extensive fundamental research funded by power generation authorities in various countries, for example the Central Electricity Generating Board (CEGB) in the UK and the Electric Power Research Institute (EPRI) in the USA. A simplifying aspect of materials performance in conventional power stations is the potentially identical steam chemistry in all stations. An objective of operational procedures is to achieve high levels of steam purity with the only additives being oxygen scavengers and pH control agents. Consequently experience gained in any station is generally universally applicable. Examples of the type of research and testing studies funded for conventional and nuclear power stations are listed in Table 1. It can be reasonably assumed that the motivation for some of these investigations were corrosion failures which were common to a number of stations.

Table 1 Examples of EPRI Funded Research for Conventional and Nuclear Power Stations

EPRI Report Number	Title
NP 2560	Valve Stem Packing Improvement Study, August 1982.
FP 754	Survey of Feed Pump Outages, April 1978.
CS 1512	Recommended Design Guidelines for Feedwater Pumps in Large Power Generating Units, September 1980.
CS 1811	Corrosion Problems in Coal-Fired Boiler Superheater and Exfoliation - Review and Results of Laboratory Test, April 1981.
CS 2378	Failure Cause Analysis for Condensers and Associated Systems, Vol 1 and 2, June 1982.
NP 2400	High Temperature Thermodynamic Data for Species in Aqueous Solution, May 1982.

4 THE MATERIALS PERFORMANCE DATA-BASE FOR GEOTHERMAL POWER GENERATION

Geothermal stations are smaller than conventional central power plant, their size being restricted by the output of the geothermal

field. Even where a field of substantial capacity is utilised for power generation, development occurs in stages with generating units of from 5 to 100 MWe being installed; steam production is required to prove the capacity of field. Although the world-wide installed plant capacity had grown to approximately 5,000 MW (diPippo, 1985) as at 1985 this is insignificant compared with conventional (and nuclear) plant capacity. There is not therefore the revenue base from which a substantial research and development programme could be funded. Furthermore the existing geothermal plants are spread around the world with a number of controlling authorities, requiring cooperation and exchange of information if the technology base is to expand.

Geothermal steam characteristically contains the corrosive gases carbon dioxide and hydrogen sulphide, and with water dominated fields, usually there is contamination with chlorides.

On the positive side there is often a significant ammonia content which has the beneficial effect of making the steam condensate more alkaline. This is a corrosion limiting factor which geothermal steam shares with conventional power station steam where ammonia is used for pH control in all volatile inhibitor treatments. Table 2 shows the composition of the geothermal steam from a number of geothermal fields, the installed capacity and length of generating experience. It is apparent that a major portion of the generating experience (MW x years) is from low gas geothermal fields (< 1% by weight) with significant amounts of ammonia present producing alkaline steam condensates. From results obtained at Broadlands and Wairakei, New Zealand (Borshevsky et al, 1982; Lichti and Wilson, 1983; Driver and Wilson, 1984) it is apparent that the ratio of CO_2/NH_3 and total H_2S content are significant parameters controlling the corrosivity of steam.

Although unpublished performance history is an important part of geothermal materials technology, more valuable contributions are from papers published in the open corrosion literature, detailing successful and unsuccessful use of materials and results of research and testing. In New Zealand materials testing has been carried out with funding from the Ministry of Works and Development, the Ministry of Energy and the DSIR. Some of these results have been published. Papers describing the problems experienced in the power stations at the Geysers, USA (Dodd et al, 1975; Burda et al, 1983) and Cerro Prieto, Mexico (Mercado, 1979) have also been published. Reviews of successful and unsuccessful materials performance world wide are also available (Ellis and Conover, 1981). From this published information the common modes of corrosion failure for various materials have been identified. In some cases the parameters of temperature, chloride levels, oxygen leaks, hydrogen sulphide content and metallurgical condition which determine the onset or rate of corrosion failure have been identified. In addition the empirical process of substituting a material of greater corrosion resistance when a corrosion failure has occurred, undoubtedly has produced in-house knowledge of the materials which perform successfully in different applications. In general however, the published information documenting experience at both the fundamental level or at the practical level is sparse with little attention being paid to steam chemistry, and does not compare with the range and depth of understanding of materials performance in conventional and nuclear power stations. Although there has not been any large costly plant failures, in the absence of thorough documentation of corrosion failures and an understanding of the failure mechanism, it would be premature to conclude that the composition of the geothermal steam does not influence long term materials performance throughout a geothermal power station.

5 CORROSION/MATERIALS INPUT DURING POWER STATION DESIGN

At present there are no published guidelines or codes of practice for selecting materials for use in geothermal steam and significantly there is an insufficient published data base from which such codes of practice would need to be drawn. An approach has been suggested to the problem of materials selection, which recognizes that geothermal steam has a corrosion impact across all aspects of power station design (Conover, 1983). It is proposed that the corrosion/materials engineering discipline be included as a separate function in the power station design team. The suggested arrangement of responsibilities is shown in Figure 1, where both options presented recognize that the corrosion/materials function should have an overview responsibility for all aspects of power station design.

6 DIRECTIONS FROM OIL AND GAS PRODUCTION INDUSTRY

The disparity in capacity of geothermal power plant compared with other forms of power generation and also the fragmented ownership, explains to some extent the unsophisticated state of materials technology. An approach which the geothermal industry could follow in order to improve the materials technology base is that adopted by the oil and gas industry through the National Association of Corrosion Engineers (NACE). The oil and gas production industry have a number of standards, designated "Recommended Practices" "Test Methods" or "Materials Requirements' , an illustrative selection of which are listed in Table 3. The Materials Requirement MR-01-75 : Sulphide Stress Cracking Resistant Metallic Materials for Oil Field Equipment is useful for geothermal applications. The scope of this document can be gauged from the titles of the various sections:

1 General
2 Definitions
3 Ferrous Metals
4 Non Ferrous Metals
5 Fabrication
6 Bolting
7 Platings and Coatings
8 Bearings, Springs, Pressure Measuring and Sensing Devices
9 Valves and Chokes
10 Wells, Flow Lines, Gathering Lines, Facilities and Field Processing Plants
11 Drilling and Well Servicing Equipment

The usefulness of the document can be gauged from a typical clause, eg. 3.6.1.

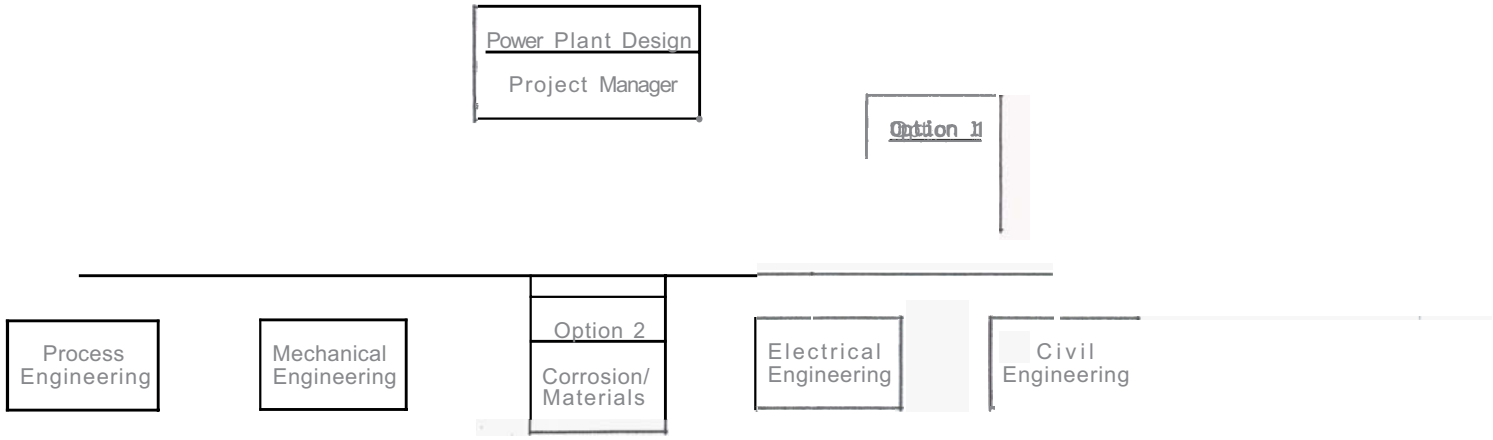
"Austenitic stainless steels with chemical composition specified in accordance with the standards listed in Table 2 either cast or wrought are acceptable at HRC 22 maximum in the annealed condition, provided they are free of cold work designed to enhance their mechanical properties."

Table 2: Composition of Geothermal Steam

Power Station	Gas Content % by weight Steam	Mole ratio CO_2/NH_3	H_2S in steam mmol kg^{-1}	Year of commissioning	Installed Capacity MWe	Footnotes
El Salvador						
Ahuachapan	0.2-0.4	1000-2000	~3	1975 1976 1980	30 30 35	(1, 2)
Indonesia						
Kamojang	1-2	>600	20-40	1982	30	(3)
Italy						
Lardarello 2	4.4	66-114	23	1938	69	(1, 2)
3	4.4			1952 - 1954	120	
Gabbro	4.4			1969	15	
Castelnuovo	4.4			1967	50	
Lago	3.0	84-133	35	1960	33.5	
Lagoni Rossi	3.0			1981 - 1969	65	
Monterotondo	3.0				12.5	
Sasso	3.5	59-107	42	*	17.2	
Serrazzano	3.5	59-107	42		47	
Bagnore	20.0	79-97	47	1954 - 1960		
Piancastagnaio	20.0	79-97	47	1969	15	
Travale	9	115-123	37	1973	18	
Japan						
Matsukawa	0.2-0.6(Vol %)	*	*	1966	20	(2)
Otake	0.05-0.5	*	*	1967	10	
Hatchubaru				1977	50	
Mexico						
Cerro Prieto	1	49	44	1973 1979 1982	75 75 30	(4)
New Zealand						
Wairakei	0.1	80	1.5	1960	190	(5)
Broadlands BR 22 (Ohaaki)	2.1	200	13	(1988)	100	
Philippines						
Tiwi	*	*	*	1979 -	330	(1, 6)
Tongonan	0.6-0.7	200-300	5-7	1980 -	112.5	
Palinpinon	0.6-0.7	200-300	3-5	1983	112.5	
Makiling				1979 -	330	
USA						
Geysers	0.4	6.5	5.3	1960 1961 - 1970 1971 - 1980 1980 - 1985	11 67 830 770	(1, 2)

* Signifies data not available

(1) diPippo, 1985
(2) Ellis and Conover, 1981
(3) Healy and Mahon, 1982
(4) Mercado, 1979
(5) Lichti and Wilson, 1983
(6) Dobbie, 1986



: Geothermal Power Plant Design Team with proposed Corrosion/Materials Engineering Overview Function (Conover, 1983).

Table 3 Standards Issued by the National Association of Corrosion Engineers (NACE) for Oil and Gas Production

Recommended Practices	
RP-01-70 (1985 Rev.)	Protection of Austenitic Stainless Steel From Polythionic Acid Stress Corrosion Cracking During Shutdown of Refinery Equipment.
RP-01-75	Control of Internal Corrosion in Steel Pipelines and Piping Stystems
RP-04-75	Selection of Metallic Materials to be Used in All Phases of Water Handling for Injection into Oil Bearing Formations
RP-06-75	Corrosion Control of Offshore Steel Pipelines
RP-07-75	Preparation and Installation of Corrosion Coupons and Interpretation of Test Data in Oil Production Practice
RP-01-76 (1983 Rev)	Control of Corrosion on Steel, Fixed Offshore Platforms Associated with Production
Test Methods	
TM-01-77	Testing of Metals for Resistance to Sulphide Stress Cracking at Ambient Temperatures
TM-02-84	Test Method for Evaluation of Pipeline Steels for Resistance to Stepwise Cracking
Materiel Requirements	
MR-01-75 (1984 Ed. Rev.)	Sulphide Stress Cracking Resistant Metallic Materials for Oil Field Equipment
MR-01-76	Metallic Materials for Sucker Rod Pumps for Hydrogen Sulphide Environments

These standards are underpinned by a substantial depth of knowledge of materials performance generally available in the corrosion literature as published papers. A collection of literature that has developed since the early 1950's concerning sour oil and gas is available (Tuttle and Kane, 1981), a companion volume describing CO_2 corrosion in oil and gas production is also available (Newton and Hausler, 1982). The standards are being updated as new materials become available and are proven firstly by laboratory testing under standard conditions and then by in field experience. An example is the nickel containing martensitic stainless steel, Grade CA6NM (for castings) or F6NM (for forgings), which gained approval in the 1984 Edition of MR-01-75 subject to appropriate heat treatment. Laboratory testing of this material has been carried out, (Kane et al, 1977) demonstrating the advantage of this material over Grade CA15 (13%Cr) and the need for the appropriate heat treatment. This example demonstrates the continuing committment by the industry to the concept of peer review of research and testing of materials, which in effect, acts as a quality assurance procedure.

Cooperation between companies within the industry has produced this comprehensive standard (MR-01-75) for materials selection for H_2S containing fluids which provides a high level of assurance that corrosion failure will not occur. The development of a similar standard for materials selection for geothermal fluids would be a major step forward for the geothermal industry.

7 MATERIALS FOR USE IN GEOTHERMAL FLUIDS - A MATERIALS REQUIREMENT STANDARD

The standards discussed above have been developed by a Technical Group Committe T-1 of NACE. There is also a similar NACE Technical Committee T2-E : Corrosion in Geothermal Systems. It would be the appropriate vehicle to use for developing a standard primarily because of the support NACE gives to these activities. In addition the NACE stamp on the standard would give it international acceptability it would otherwise not receive.

The structure of such a standard would be built around the various fluid types and components encountered in geothermal developments: for example:

1 Bore Fluid

- 1.1 Casing
- 1.2 Well Head Equipment

2 Separated Water

- 2.1 Pipe lines
- 2.2 Valves
- 2.3 Pumps
- 2.4 Expansion Compensators

3 Steam

- 3.1 Steam Pipe
- 3.2 Valves
- 3.3 Expansion Compensators

4 Aerated Steam

- 4.1 Valve stems
- 4.2 Safety Relief Valves

5 Aerated Condensate

- 5.1 Condenser
- 5.2 Auxiliary Heat Exchanger

6 Atmospheric applications

- 6.1 Electrical Equipment
- 6.2 Walkways
- 6.3 Building and Pipeline cladding

It should also include sections on operating procedures, similar to the recommended practice RP-01-70 (see Table 3)

To take the standard further requires support and input from the majority of the participants in the geothermal industry especially in the form of published papers describing either results of research and testing in simulated fluids or plant experience.

8 AREAS WHERE ADDITIONAL TESTING IS REQUIRED

A systematic approach to materials selection covering all aspects of the use of geothermal fluids leads to the identification of those areas where information is sketchy or non-existant. A mobile corrosion rig has been described (Lichti et al, 1985) which demonstrates that with modern corrosion test equipment it is possible to assess the corrosivity of geothermal steam rapidly and to identify appropriate materials for different geothermal fluids. Filling in the gaps in our knowledge should not be an insurmountable or over expensive task. Since 1985 the corrosion rig has been used to assess the corrosivity of geothermal steam containing up to 20 wt.% non-condensible gas. These results remain confidential, but when combined with the results from Wairakei and Broadlands they give a more complete picture of the corrosivity of non-aerated geothermal steam and condensate as a function of non-condensible gas content (Lichti and Wilson, 19861.

Aspects identified as requiring further investigation include:

i Corrosion in aerated geothermal fluids as a function of temperature and chloride content in order to identify lowest cost materials for components where air leakage is likely and where chloride and sulphide are present at high temperature, 'eg separated water re-injection systems, two phase piping systems

ii Development of monitoring probes which would provide early warning of air leakage into separated water reinjection systems

iii Corrosion in aerated condensate typically encountered in cooling systems, to identify lowest cost materials as a function of temperature, chloride concentration and sulphur chemistry.

iv Monitoring and prediction of performance of non-metallic materials in low temperature geothermal fluids.

9 CONCLUSIONS

1 The small capacity of geothermal power generation and hence the small revenue base prevents any large scale corrosion research and testing programme comparable with that for conventional or nuclear power plant. As a result the level of understanding of corrosion processes in geothermal plant is substantially lower.

2 A major portion of successful generating experience using geothermal steam is from low gas (< 1%) geothermal steam with significant amounts of ammonia and which is typically of low corrosivity.

3 Although the common modes of corrosion failure have been identified there is only a qualitative understanding of the relationship between steam environment parameters and rates of corrosion failure. Information describing in-plant experience with materials is infrequently published and then generally with little attention to steam chemistry.

4 The design team for a geothermal power station should include a corrosion/materials specialist with an overview function.

5 The cooperative approach taken by the oil and gas industry in formulating industry standards for materials selection is an appropriate model for the geothermal industry. The formulation of similar standards for the geothermal industry would be a major step forward.

6 Where gaps in information and understanding of materials performance exists, modern corrosion instrumentation and techniques are able to rapidly provide the test results.

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