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MOBILE CORROSION TEST FACILITY
COMMISSIONING TRIALS, GEOTHERMAL STEAM, 2.5 wt% GAS

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ABSTRACT

DSIR has constructed a Mobile Corrosion Test Facility for short term corrosion monitoring trials at remote field sites. The facility was assembled to test the corrosivity of geothermal steam containing high levels of potentially corrosive gases, CO_2, H_2S and NH_3.

Commissioning experiments were conducted using geothermal steam derived from Broadlands well BR22 containing 2.5% by weight of gas in November/December 1984. Automated monitors were used to determine corrosion rates of carbon steel subjected to a range of simulated geothermal power station environments over short exposure periods. During the commissioning trials operational procedures were established for maintaining and monitoring the various test environments. The limitations of automated monitors were identified and the need for immediate, on-site assessment of corrosion results was also indicated. During these and subsequent trials a Slow Constant Extension Rate Machine was also proved capable of testing stainless steels for susceptibility to stress corrosion cracking. The commissioning results will allow a realistic comparison of the existing Broadlands database of materials results with those obtained from subsequent high gas trials.

INTRODUCTION

The concept of a Mobile Corrosion Test Facility was initially prompted by the need to rapidly assess the corrosivity of fluids derived from the gas-rich Ngawha geothermal field towards common construction materials (Wilson and Lichti, 1982). Although development of the Ngawha field has been postponed, the Mobile Corrosion Test Facility has proceeded because of the need to reduce the manpower required for running materials tests in geothermal fluids.

The range and complexity of fluids encountered in geothermal fields necessitates an evaluation of the corrosivity of the fluids towards engineering materials before it can be assumed that exploitation of new fields is economically feasible. This type of programme was carried out at Broadlands geothermal well BR22 for which an extensive database of materials performance. results is now available (see for example Lichti and Wilson, 1953). For other geothermal fields engineering data of a "go/no-go" nature can be rapidly generated, which together with available scientific data enables extrapolation of the existing database of results to closely related environment and materials combinations.

The instrumentation and hardware which make up the Mobile Corrosion Test Facility have been selected to address this type of problem, with an emphasis on the characterisation of new environments in terms of their corrosive effects on two or three common engineering materials. However, the test facility as built is sufficiently versatile so that more precise scientific information can be obtained if required in selected investigations.

DESIGN OF MOBILE CORROSION TEST RIG

The critical design aspects described previously by Driver et al, 1984 are summarised as follows.

Economics: The facility was designed to use automated corrosion monitors to minimise on site manpower and post experiment assessment time.

Mobility: The facility was trailer mounted for ease of transport with individually mounted test vessels.

Known Corrosion Results: Equipment was obtained to measure critical solution parameters and experiments were designed to be comparable to those of the existing Broadlands database.

INSTRUMENTATION

Table 1 describes the instrumentation which was selected to meet the guidelines listed above. The table gives an indication of the role of each instrument, the degree of automation, and the environments where these will be used. The rapid corrosion monitoring techniques of electrical resistance type probes and electrochemical probes have been previously characterised during the materials testing programme at Broadlands well BR22 (Lichti et 31, 1981; Lichti and Wilson, 1980). Both monitors were selected for specific applications: Corrosometers for use in steam, two phase fluids and high temperature water for long term corrosion rate prediction: electrochemical probes for use in liquid condensates for instantaneous corrosion rate measurements.

The Corrosometer 41/85 system allows automated data acquisition to be achieved for corrosion rate measurements in virtually any environment. The system is capable of continuously monitoring up to 15 probes, recording probe readings on magnetic tape for periods up to 30 days, and processing and outputting data as average corrosion rates, long term corrosion rates, metal loss and probe history. The automated polarisation resistance corrosion rate monitor, the Petrolite M1010, will continuously monitor up to 10 channels and record corrosion rate and electrode potential data in strip chart form. The principles upon which these instruments function have been well described in the corrosion literature, Hines, et al 1978, and with some important restrictions in their application and interpolation are generally accepted by the corrosion community.

The Slow Constant Extension Rate Test (SCERT) was selected for testing material susceptibility to Stress Corrosion Cracking (SCC) and for identifying aspects of particular geothermal fluids which cause SCC. The technique was chosen because of its ability to provide a yes/no answer in a very short time - 4 to 7 days (Driver et al, 1984). For the commissioning trials the 4 channel machine was equipped with test vessels rated for use with hot condensate up to 100°C with a 2 m head of liquid. It was planned to assess whether hot (up to 90°C) aerated geothermal condensate would cause SCC of AISI 304 and 316 stainless steels; previous results had shown that aerated geothermal stem at 105°C would cause SCC of both of these alloys.

Testing for resistance to pitting corrosion is perhaps the most difficult to automate. For the commissioning trials historical assessments of the carbon steel monitors were used to assess this parameter.

Table 1: MCTF; November 1984; Description of Instruments and Monitors Used During Commissioning Trials; 2.5 wt% Gas

Monitor Description	Monitoring Details
Corrosometer 41/85 System (R) (Rohrback)	Surface Corrosion Monitor (Pitting) Electrical Resistance Probes Automatic, 15 Channels, Hourly All Environments, Limited Materials
Petrolite M1010 System (R) (Petrolite)	Surface Corrosion Monitor/Pitting Linear Polarisation Resistance Probes Automatic, 10 Channels, Hourly Liquid Environments, Moderate Conductivity
ASTM Weight Loss Coupons (Electrodes)	Surface Corrosion Monitor/Pitting Manual, Historic, Single Time Period All Environments, All Materials
Slow Constant Extension Rate Test (SCERT) (ASTM STP *665)*	Stress Corrosion Cracking Monitor Load vs Extension Tensile Test Machine Automatic, **4** Channels, Continuous Liquid Environments to 100°C (Steam With Appropriate Test Vessels)
HP3421A/HP85B Data Logger (R) (Hewlett Packard)	Corrosion Parameters, Chemistry Parameters, Physical Parameters With Appropriate Detectors Load Cells on SCERT Machine
Conductivity Meter CDM 80 (R) (Radiometer)	Solution Conductivity Manual (Automatic with HP3421A) Single Channel, Low Temperature
231 pH/T (R) (Orion)	Solution pH and Temperature Manual (Automatic with HP3421A) Single Channel, Low Temperature

Environment Monitoring

A 20 channel HP3421A data acquisition system was obtained to provide long term data storage and processing capability. During the commissioning trials **it** was used to monitor temperatures with Type T and Type K thermocouples and to monitor the load cells of the SCERT machine. Channels were available for logging other results such as solution pH and conductivity. An Orion 231 portable pH meter and Radiometer CDM80 conductivity meter were purchased for monitoring the chemistry of low temperature fluids.

Test Rig

Figure 1 shows a simplified flow diagram for the facility as used for the commissioning trials. Apart from the separated water and the two phase fluid test vessels, all other vessels are connected to a dry steam manifold, although each vessel can be isolated and removed from the system as required. Pressures, temperatures, and flow rates can be independently controlled for each vessel, and the condensers can be used to give fluids ranging from dry stem to condensate. An additional condenser (not show) was used to supply condensate for the SCERT machine.

Test Vessels

High pressure test vessels were approved by Marine Division, Ministry of Transport. Materials specifications were based on ASTM, API and BS standard specifications. Design and construction was based on the Rules for New Zealand Fusion Welded Pressure Vessels as issued by Marine Division in 1967, and the New Zealand Boiler Code, 1975. The steam test vessels were specified to 10 bar (150 psi) class 150. This pressure was selected to allow the planned geothermal tests as well as work on most steam raising boilers and heat exchangers encountered in industrial plants. Carbon steels and low cost austenitic stainless steels were selected for the majority of the components. Corrosion of these components in the planned geothermal tests was predicted as being sufficiently low within the time period of operation so as to avoid significant contamination of the test environment and failure in **a** catastrophic manner.

Construction

The details of the trailer have been described by Driver et al, 1984. The vessel and piping construction work required for the facility was undertaken by IPD DSIR workshop staff. The test vessels were mounted vertically with steam and two phase fluid entry at the top of the vessels and discharge from the bottom. For the separated water test vessel this situation was reversed. *The* trailer and frame assembly allows rapid mounting and demounting of the test vessels. The layout of vessels provides ready access to all probe and instrument ports and to all control valves from the side of the trailer, and the frame provides handholds for access to the top vessel flanges for removal and insertion of coupon racks. Space is also available on the trailer for transport of the SCERT machine, condensing heat exchanger tanks and for additional piping. Once on-site, the trailer can be fully supported by four jacks attached to the corners of the trailer, so that the weight can be removed from the wheels. This also enables levelling of the trailer.

The facility will normally be operated under a permanent cover such as in a garage. For example, for the commissioning trials and for the high gas experiments which will simulate the Ngawha steam chemistry, a "kitset-type" double garage was installed on the Broadlands well BR22 site. It should be noted that the use of the facility in such a confined space requires considerable caution to be exercised as regards disposal of fluids and toxic gases with, in particular, appropriate gas detectors and alarms. In addition to the garage to house the trailer assembly, the facility requires the use of an appropriately designed instrument room or caravan. At Broadlands, **a** hut with air conditioning and air filtration facilities was available. The air filtration unit circulates air within the hut through a pair of activated charcoal filters to remove any H_2S which may enter the building.

COMMISSIONING TRIALS

Objectives

The objectives of the commissioning trials were as follows:

- To confirm the mobility of the facility by taking **it** to a remote site
- To determine the time period within which the facility could be connected to the fluid supplies and drains, and the instrumentation made operational.
- To establish the monitoring and manning requirements for the facility.
- To determine the medium to long term reliability of the automated instrumentation at a remote site.

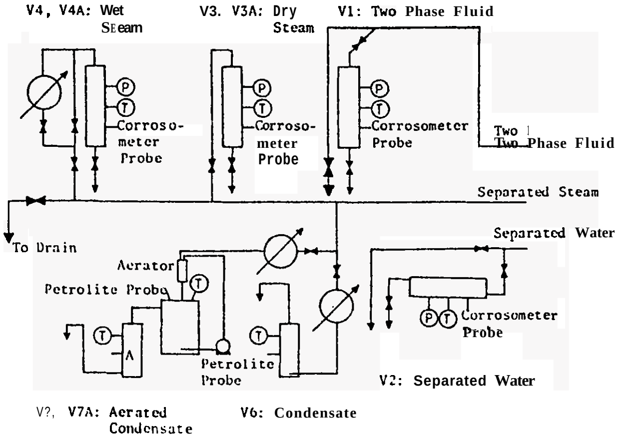

Figure 1: MCTF; November 1984; Schematic representation of test vessels **used** during commissioning trials.

- To field test flow control valves, orifice plates, condensers and pressure relief valves and to ensure that specified fluid flows, temperatures, and wetness factors could be obtained and maintained in the test vessels.
- To test the ability of the facility to duplicate selected results of the previously used immobile corrosion test rig at Broadlands well BR22 within a test period of one month.
- To prove the ability of SCERT machine to monitor SCC in geothermal fluids.

Test Facility Performance

Mobility:

The trailer mounted facility was towed to Broadlands from Wellington using a short wheel base. 4 wheel drive vehicle, Future towing operations would benefit from use of a vehicle of about 3 tonnes (the maximum for a "light" vehicle) and/or a long wheel base. A reduced load on the trailer would also result in improved road handling.

Installation:

Major time commitments during the initial rig installation were in connection of piping for inlet process fluids, vessel discharges to drains and cooling water and in installation of automated monitors and cables. The total time taken to completely prepare the facility, to obtain local Marine Division approval and to conduct a short steam cleaning prior to installation of the Corrosometer probes was 11 days.

Manning During Commissioning:

Three scientists and three science technicians shared the workload involved in setting up the facility at well BR22 for the commissioning trials. Following the start of the corrosion monitoring the facility was run primarily by one science technician, and was unmanned for two weekends. The time required for set-up prior to steam-on could have been reduced with more staff however the final costs in terms of manpower would not have changed - the work still needed to be done. Future work involving a larger number of tests would require one scientist and one science technician on-site every day with at least two scientists and two science technicians available for the first week of set-up. More staff than four would likely result in confusion and disorganisation on the site.

Reliability of Automated Instrumentation:

The performance of electronic equipment at remote sites is directly dependent on the reliability of the power supply, the environmental protection system and the security system. Electrical supply was from a recently installed substation at the Ohaaki Power Station construction site. Voltage surge protectors were also obtained to protect the electronic equipment. Security at the Broadlands site was good. The air conditioned instrument hut was of painted galvanised iron, was lined and insulated, and had a double door entrance with the external door opening out. Both doors could be locked and the hut had no windows. Regular visits were made to the site throughout night times and on weekends by the Ohaaki Power Station construction site/Broadlands field security guards. Work at less secure sites may require constant surveillance.

The Corrosometer 41/85 system software was written for industrial users, and as such has limited data storage and retrieval capabilities. System start and interrogation procedures have been simplified to allow operation by personnel with limited computer experience. However, minor errors in resetting parts of the program can result in loss of stored data. The system can be set to give paper print-outs at a rate of one per hour and this allows a manual check for all results. During the commissioning trials the program tape malfunctioned and data storage was erratic, although complete failure of the system never occurred. A replacement tape was obtained but this also malfunctioned with 3 days of the commissioning trial remaining, although the last day's readings were recovered when the system was shut down.

Previous experiments using the Petrolite M1010 linear polarisation resistance monitor had identified a need to reduce the measurement frequency of this instrument, Wells and Driver, 1984. A modification utilising time switches on the instrument's power supply was used during the commissioning trials to give one measurement of each probe per hour.

The main drive motor speed of the SCERT machine was found to be erratic during commissioning. A square wave frequency generator was found necessary to accurately run the synchronous motor controller. Rigid fluid inlet and outlet fittings on the test vessels tended to twist the tensile test specimens and alter the direction of applied strain. Flexible couplings were required to minimise this effect.

Few problems were experienced with the HP3421A data acquisition system operation although during commissioning, the program consistently read Type K thermocouples as much as 10°C lower than was measured manually. This was traced to errors in selection of thermocouple connecting wire and to the types of connectors being used.

Flow Control/Test Conditions:

Considerable difficulty was experienced in obtaining representative two phase fluid in test vessel 1. Several piping changes were tried after the commissioning trials, with the final selection being a system which allows ponding of some water to ensure water is provided to the vessel and the mixing of water and steam to achieve desired wetness. The wetness of this vessel during the commissioning trials was not readily identifiable.

Minor problems were encountered in regulating low flows of steam through test vessels 3 and 4 and it was found necessary to replace the 1" discharge ball valves with ½" ball valves in order to extend the range of control.

The separated water test vessel 2 failed to fully fill with water when located in a vertical aspect. This occurred because the vessel discharge valve was located higher than the water level in the separator. Raising the water level in the separator resulted in unstable separator operation and frequent high water conditions requiring balancing of flows through various bypass lines. For this reason the vessel was placed horizontal at a height which was below the level of the separator sight glass. The vessel was subsequently kept full of water and seldom required adjusting for flow, pressure or temperature control.

Considerable difficulty was encountered in controlling the temperatures and the amount of deliberate contaminant concentration in the SCERT test vessels. These problems were attributed to low and variable fluid flow rates and to high heat losses resulting from the once through fluid supply system chosen. These problems were not fully resolved during the commissioning experiments.

Commissioning Experiment Details and Results:

During the steam cleaning period the physical conditions for the commissioning trials were established (Table 2) and carbon steel corrosion monitors were prepared for all test vessels. Electrical resistance Corrosometer probes were exposed in the steam, two phase and separated water environments whilst electrochemical probes with removable weight loss electrodes were used to monitor the corrosivity of the steam condensates. The exposures were conducted for a period of 30 days.

Four environments were selected for a comparison of corrosion chemistry of the Mobile Corrosion Test Facility with that obtained previously in test vessels operated under similar physical conditions at BR22 (see Table 3). Chemical samples were collected on day 10 of the trials. The sampling of fluids from V1: Two Phase Fluid proved difficult. Water could not be obtained from side ports on the vessel and the total discharge was then passed through a Webre sampling separator placed on the vessel discharge line. The chemical analysis results shown in Table 3 for V1: Two Phase Fluid, MCTF are for fluids collected from this separator operated at 770 kPa(a). This pressure was made higher than the selected operating pressure in an attempt to increase the water content of the vessel - ie by moving the vessel pressure closer to the bypass line pressure. After day 14 the vessel operating pressure was increased to 800 kPa(a) for this same reason.

Corrosion results in the form of cumulative material loss were obtained for Corrosometer probes as illustrated in Figures 2 and 3. The tape malfunction which occurred during the initial 10 days resulted in low readings being obtained for part of each day. By using only the highest values recorded normal Material Loss vs Exposure Time plots could still be constructed. The reason for the malfunction at the end of the exposure period is not known, however, the final recovered data readings were sufficient to realistically extrapolate the obtained results.

Table 4 summarises the Corrosometer probe results as corrosion rates at day 1 and at day 30 and material loss at day 30. For the condensate environments corrosion rate results (Table 4) were obtained from removable weight loss electrodes, assuming that corrosion was linear throughout the commissioning trials. The table also lists: the adhesive properties of the scales and corrosion products; the pitting - characteristics of the corroded surfaces; X-ray diffraction results for collected corrosion products (taken from DSIR, Chemistry Division reports by M Ryan); and corrosion results of comparable tests conducted in similar environments in the old BR22 corrosion rig.

The electrochemical monitors exposed in condensate both gave occasional erroneous (very low) instantaneous linear polarisation resistance results. These results were assumed due to conductive corrosion products bridging the measurement electrodes which were 8 mm apart. Examination of the probes after the 30 day exposure revealed thick flaking corrosion products were indeed present on the electrodes exposed in V7: Aerated Condensate. Bridging of electrodes exposed in V6: Condensate however could only have occurred along a path at the base of the electrodes across telfon insulating washers as the products remaining on the electrodes were relatively thin. The measured instantaneous linear polarisation resistance corrosion rate results were corrected for probe solution resistance factors which are known to vary as a function of solution conductivity, Lichti and Wilson, 1980. This correction yielded positive values for V6: Condensate but for V7: Aerated Condensate negative corrosion rate values were obtained after day 5 of the exposure.

SCERT tests were conducted on AISI 304 and 316 stainless steel in condensate, aerated condensate and chloride contaminated condensates. Many of the early results were of little value because of the problems with control of motor speed, temperature and chloride content. Figure 4 illustrates typical results for AISI 304 and 316 in aerated condensate containing 600 mgkg^{-1} of added chloride ions. Temperatures achieved were less than desired - the system is currently being modified to overcome this problem.

Discussion of Commissioning Results:

The surface corrosion results obtained were generally in accord with those obtained previously using the old BR22 corrosion rig. Long term predictions of corrosion resistance were possible from the results of the 30 day trials.

Previous attempts at testing in "bore fluid" using a horizontal vessel resulted in phase separation and most corrosion monitors were exposed to the stem phase only (Lichti et al, 1981). The vertical aspect of the new vessel promoted stratified flow and silica scaling with some corrosion was observed, although the corrosion chemistry was altered by preferential draw off of stem from the two phase sampling point.

Table 2: MCTF; November 1984; Physical Conditions for Commissioning Trials; 2.5 wt% Gas

Test Vessel Designation	Pressure kPa (a)	Temperature °C	Mass Flow Rate kgh^{-1}	Fluid Velocity mms^{-1} (nominal)	Fluid Wetness wt%
V1 : Two Phase Fluid	650 ± 50 800 ± 50	162 ± 2 170 ± 3	55	Unknown	Unknown
V2 : Separated Water	630 ± 40	158 ± 2	200 ± 50	(7)	Liquid
V3 : Dry Steam High Pressure	650 ± 40	162 ± 2	20 ± 5	(220)	<<1
V3A : Dry Steam Low Pressure	130 ± 5	107 ± 2	20 ± 5	(940)	<<1
V4 : Wet Steam High Pressure	650 ± 50	160 ± 2	20 ± 5	(≈184)	15 ± 5
V4A : Wet Steam Low Pressure	130 ± 5	107 ± 2	10 ± 5	(≈850)	15 ± 5
V6 : Condensate	2 m head of liquid	30 ± 3	12 ± 2	(0.42)	Liquid
V7 : Aerated Condensate	Atm	30 ± 4	200 ± 50 Recirculating	(0.55)	Liquid
V7A : Aerated Condensate	Atm	28	12 ± 2	(0.42)	Liquid

Notes: Conditions in V1, V3A and V4 were not previously tested.

Table 3: MCTF; November 1984; Comparison of Measured Corrosion Chemistry versus old BR22 Corrosion Rig

(a) Gas Phase Chemistry in Steam. mg kg^{-1}

	CO_2	H_2S	NH_3	N_2	CH_4	H_2
V1 : Two Phase Fluid (Stem Only)						
Old Rig (2.5 wt% Gas 650 kPa(a))	24440	387	37	97	113	1.1
WCTF (4.8 wt% Gas 770 kPa(a))	47007	691	72	196	231	54
V3 : Dry Steam, HP						
Old Rig (2.1 wt% Gas)	20750	357	39	123	93	1
NCIF (2.1 wt% Gas)	20558	333	51	122	94	0.9

(b) Water and Condensate chemistry at 23°C and Atmospheric Pressure. mg kg^{-1}

	pH	κ (Sm^{-1})	HCO_3^- (Tot)	H_2S (Tot)	NH_3 (Tot)	Fe (Tot)	SO_4^{2-}	SiO_2	Cl^-
V1 : Two Phase Fluid (Water Only)									
Old Rig (650 kPa(a))	7.8	0.48	192	7	5.5	0.3	10	706	1410
MCTF (770 kPa(a))	6.0	0.45	201	11	na	<0.1	37	502	1034
V2 : Separated Water (Water)									
Old Rig	7.9	~0.5	196	9	5.4	na	7	727	1536
MCTF	7.6	0.60	219	13	na	<0.1	27	720	1436
V3 : Dry Steam, HP (Condensate)									
Old Rig	5.5	0.042	1401	54	52	1.6	<1	2	na
MCTF	5.6	0.041	1001	45	na	<0.1	13	<1	<1
V4A : Wet Stem. LP (Condensate)									
Old Rig (V4)	5.2	0.021	1277	57	40	na	<1	<1	na
MCTF	5.6	0.061	1291	49	na	<0.1	113	<1	1

Notes:
1. Results taken from Chemistry Division Reports by Glover (1982) and Middendorf (1985) on analysis of samples collected by Klein.
2. na = not analysed.

Table 4: MCTF; November 1983; Comparison of Measured Corrosion Results versus Old BR22 Corrosion Rig

Test Environment Designation	Corrosion Rates Day 1 μmy^{-1}	Corrosion Rates Day-30 μmy^{-1}	Material Loss Day 30 μm	Corrosion Products by X-Ray Major + Minor	Corrosion Products Integrity	Pitting Characteristics Density ASTM G46-76	Pitting Characteristics Pit Depths μm mean(max)
V1: Two Phase Fluid							
MCTF	120	<0.5	<0.5	(Silica)+Pyrr+T	A	A2 to A3	17(44)
V?: Separated Water							
Old Rig	3	<0.5	<0.5	(Silica)	A	<A1	-(<5)
MCTF	370	<1.0	<1.0	(Silica)	A	A3	22(32)
V3: Dry Steam, HP							
Old Rig	146	5.0	2.8	T+Mac+Pyrr+U	A	>A5	24(46)
MCTF	490	6.4	3.5	T+Pyrr+Mac+U	A	A5	5(12)
V3A: Dry Steam, LP							
MCTF	≈ 50	53	4.3	T+U+Mac+Pyrr	F	Non-Uniform Corrosion	-(22)
VJ: Wet Steam, HP							
MCTF	146	5.0	2.8	T+Pyrr	A/F	Large A1 Small A5	21(26) 8(12)
V4A: Wet Stem, LP							
Old Rig (V4)	?	≈2.0	3.2	Mac+U	A	A3	7(20)
MCTF	190	30	7.0	T+Mac+U+Pyrr	F	Large A1 Small A2	26(31) 7(11)
V6: Condensate							
Old Rig	180 to 670	180 to 670	15 to 55	Mac	F	(Rough Surface)	-(-)
MCTF	280	280 (Linear)	23	Mac+T+Gr+ Pyrr+Mar	F	A2 to A3 (Rough Surface)	25(82)
V7: Aerated Condensate							
Old Rig	4400	1200	320	Mgn+Cem+Sid	F	(Rough Surface)	-(-)
MCTF	1100	1100 (Linear)	90	Mac+S+Lep+ Gr+Go+Mar	F	A2 to A3 (Rough Surface)	34(74)

S = Sulphur : S
P = Pyrite : FeS_2
Mar = Marcasite : FeS_2
Gr = Greigite : Fe_3S_4
Pyrr = Pyrrhotite : $Fe_{(1-x)}S$
T = Troilite : FeS
Mac = Mackinawite : $Fe_{(1+x)}S$

(Silica) = Amorphous : SiO_2
U = Unknown
Cem = Cementite : Fe_3C
Sid = Siderite : $FeCO_3$
Mgn = Magnetite : Fe_3O_4
Go = Goethite : α-FeO(OH)
Lep = Lepidocrocite: γ-FeO(OH)

A = Adherent Products or Scales
F = Flaking Products or Scales
A/F = Non-Uniform Adhesion

Pit depths obtained from an average of >40 readings/monitor. Pits showing the greatest depth were selected for measurement.

Improved sampling was subsequently achieved however as a result of this difficulty several probe access ports were installed in a vertical section of the high pressure two phase fluid supply line for future work.

Separated stem and separated water chemical analysis results indicated sufficient steam quality was achieved (low Cl^- and low SiO_2) but that some steam entrainment in the separated water may have occurred. The separated water results for the Mobile Corrosion Test Facility show slightly lower pH and a small increase in total HCO_3^- and total H_2S over that observed previously with the "old rig". This mode of separator operation was preferred over the alternative option of allowing excess carryover of water to the steam vessels.

The carbon steel Corrosometer probe exposed to V3A: Dry Steam at low pressure failed to passivate or scale in the 30 day exposure period. All other steam and high pressure water tests gave low corrosion rates after only 10 to 20 days (compare Figures 2 and 3 and see Table 4). The non-uniform corrosion observed on the V3A probe and poor adhesion of corrosion products suggested a continuous presence of oxygen in the test vessel. The point of air ingress was thought to be the inlet control valve where steam was expanded from 650 kPa(a) to 150 kPa(a), the leakage being past the valve stem packing to a region where valve design promoted formation of a venturi and sub-atmospheric pressure condition. Installation of a second valve and pressure gauge allowed a double expansion from 650 kPa(a) to 300 kPa(a) to 130 kPa(a) for future tests. This result highlighted the need for immediate analysis of corrosion results and chemical analysis of fluids present in all test vessels.

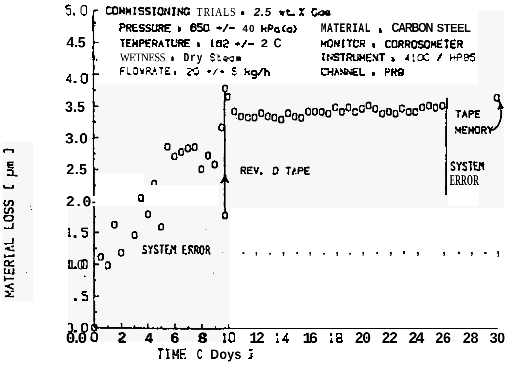

FIGURE 2 : MCTF; Nov 84; DRY HP STEAM; CARBON STEEL; VESSEL 3.

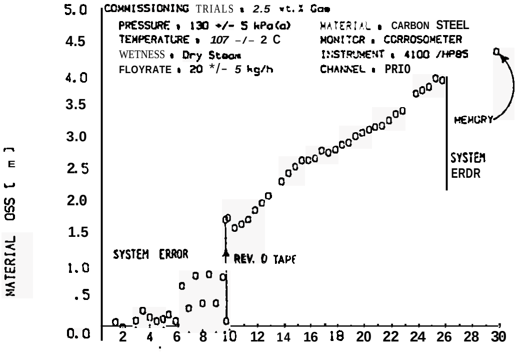

FIGURE 3 : MCTF; Nov 84; DRY LP STEAM; CARBON STEEL, VESSEL 3A.

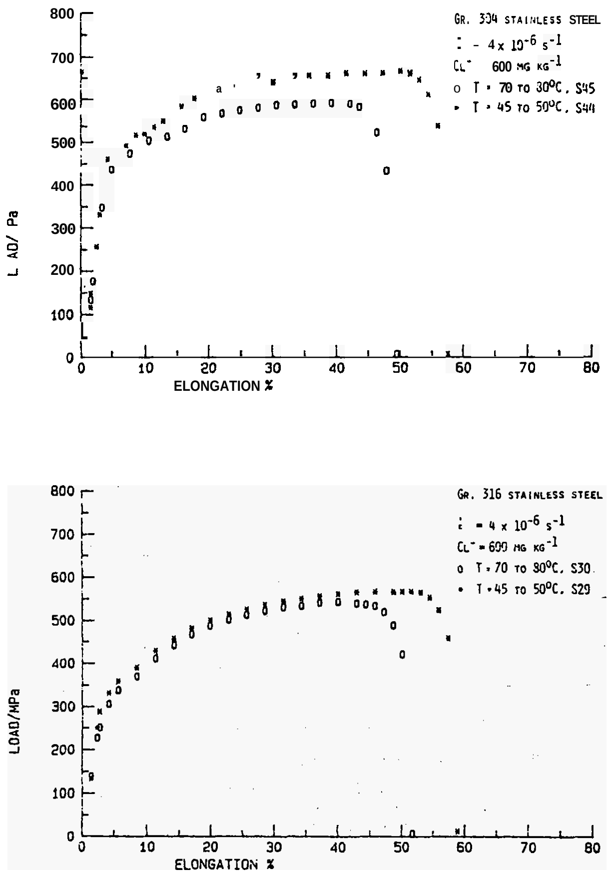

Figure 4: MCTF; November 1984; SCERT Results **for** Stainless Steels in Aerated Geothermal Condensate with Added Chloride Ions

The electrochemical linear polarisation resistance technique for determining corrosion rates of carbon steel in condensate **was** not suitable for corrosion rate prediction. The main source of error was due to formation of corrosion product films which not only affect the electrochemical theory on which the system is based but occasionally bridged the test electrodes. The effective probe solution resistance factors appeared to change from those previously obtained to such an extent that negative corrosion rate values were obtained. Although the technique still has value in situations where excessive mounts of corrosion product **are** not formed and where pitting corrosion may be the dominant form of corrosion both Corrosometer probes and coupons will be used in future tests to ensure reliable results are obtained. Probes having lower solution resistance factors were also obtained. On-site assessment of corrosion results would again have allowed early detection of errors arising from failure of the measurement technique.

The SCERT results shown in Figure 4 demonstrate the ability of the machine to test for susceptibility to SCC in geothermal condensate. Both AISI 304 and 316 show a reduction in ductility at 70 to 80°C over that observed at 45 to 50°C which indicates that these materials have only marginal resistance to SCC in this solution at the higher temperature. However further tests are required to confirm this behaviour in particular a test at 90°C where an even greater reduction in ductility would be expected. Tests are **also** required to develop load vs elongation results for a chemically inert fluid at a similar temperature and strain rate.

CONCLUSIONS

The objectives of the commissioning trials of the Mobile Corrosion Test Facility have been achieved. The facility has appropriate mobility for transport to remote sites and with practice the set-up time could be reduced below that needed for this first use of the facility. The manpower requirements for running the facility have been established together with operational procedures for obtaining specified fluid characteristics. Similarly operational procedures necessary for obtaining reliable results have been identified and these include the need for immediate on-site evaluation of corrosion results. The corrosion results obtained with the Mobile Corrosion Test Facility were comparable to those of previous tests conducted with the old well BR22 rig. The Slow Constant Extension Rate Testing machine **was** proven capable of determining the susceptibility of stainless steels to stress corrosion cracking in geothermal condensate.

The' success of these commissioning trials shows that the cost of corrosion testing and the duration of the tests can be reduced significantly without affecting the reliability of the results.

ACKNOWLEDGEMENTS

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