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PROTECTION OF CONTROL, INSTRUMENTATION AND ELECTRICAL EQUIPMENT AT OHAAKI POWER STATION

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ABSTRACT

This paper looks at the basic operating philosophies at Ohaaki Power Station and the consequent amount of control and instrumentation equipment utilised. A short description of the environmental hazards presented to the control instrumentation and electrical equipment is given, followed by details of how this equipment is protected from these hazards. It then briefly reviews the different control systems at Ohaaki noting the protective measures taken.

INTRODUCTION

Ohaaki Power Station is situated on a hill overlooking the Broadlands valley from where it gets its geothermal steam. Mixed steam and water from bores in the valley (the steamfield) is taken to five separation plants on the steamfield where it is separated, the steam being passed up the hill to the power station and the separated water being re-injected at the edge of the steamfield.

After extracting the energy from the steam it is condensed, and the combined condensate/circulating water is passed to the cooling tower to be cooled for re-use. Non condensible gases from the steamfield are also taken to the cooling tower where they are mixed with the plume of water vapour for dispersal.

Geothermal power plants in New Zealand are designed to be run as base load plants, ie. once on line they are only shut down for major maintenance and statutory inspection. With this consideration and with the advent of modern very reliable electronics and communications systems, it was decided that Ohaaki could run unattended (except at start-up and planned shut-down) with a consequent saving in operational costs. Oversight of the plant is carried out from a newly established Area Control centre at Wairakei, 26 km away. This centre is designed to cater for expansion to control Wairakei and future geothermal power stations.

This area control facility receives extensive information on the operation of the Ohaaki plant, including steam supplied, power generated, power used internally, plant status and all alarms, but has very limited control. This includes operation of the Extra High Voltage (EHV) switchgear on the system, turbine/generator tripping and control of real and reactive output from the station. All other operations are carried out locally at the station.

With the decision for remote supervision and limited remote control, automatic and safety systems controlling and protecting the rest of the plant are necessarily more extensive than would be the case for a manned station. In addition, in line with trends in process industries generally, more reliance is being placed on control and instrumentation to protect mechanical plant. These two factors have combined to produce a set of control systems far more extensive than at Wairakei.

Measurement of various parameters (eg. water level in a vessel) can be carried out using discrete, digital values (eg. high, low) or analogue values (eg. 0-100%). The measurement of the first of these has been traditionally carried out using electro mechanical switches and the second using electronic transmitters. Additionally, control of the parameter can be carried out by discrete actions (eg. starting or stopping a pump) or by modulating control (eg. by varying a valve position).

Over the last few years design philosophy has been standardised to use two separate sources of measurement where two or more of the functions of control, alarm or trip are needed. This frequently meant an analogue transmitter for the control and indication function and a discrete switch for the alarm or trip. In places where high integrity is required for control purposes duplicate transmitters are often used, the output of the transmitters being compared and an alarm raised in the case of a deviation between the two.

In the early stages of the Ohaaki design a study of the reliability of various devices was carried out, which showed that modern analogue devices were more reliable than discrete switches (especially in a hostile environment), mainly due to their lack of moving parts. It was consequently decided to use analogue transmitters rather than discrete switches for various measurements, any discrete levels required for control alarm or trip purposes being obtained by the use of electronic switching devices which monitor the analbgue value and switch on or off at a preset value. These devices are mounted in a clean air environment. As for conventional stations duplicate transmitters are used for integrity, especially where two or more of the above functions are required.

PROTECTION FROM THE ENVIRONMENT

Geothermal activity is associated with a variety of pollutants, including silica, heavy metals and sulphur predominantly in the form of sulphides (particularly hydrogen sulphide) but also as sulphates. The design of Ohaaki has been carried out to, as far as possible, eliminate the venting of geothermal steam to the atmosphere. Nevertheless, some operations, particularly during start-up and in the case of trips will cause venting. In addition, natural activity will cause geothermal steam to enter the environment.

The most extreme geothermal environment (outside the process itself) is in the steamfield where there is a strong possibility of venting, and where fumaroles and other natural vents for geothermal fluids occur. The power station itself, being on a hill suffers less from the geothermal environment, but high levels of hydrogen sulphide can occur during venting operations at the station, or under certain adverse weather conditions or wind direction.

As a consequence of the pollutants in the geothermal steam there are two main areas to consider for protection of instrumentation. The first of these is the general atmosphere, the major geothermal fluids in the atmosphere being water vapour, carbon dioxide and hydrogen sulphide. For design purposes the maximum hourly average concentration of hydrogen sulphide in air at Ohaaki was taken as 50 parts per billion (ppb) but this can be exceeded at times. Hydrogen sulphide is extremely reactive attacking many metals, including the major metal used in electrical works - copper.

Instrumentation is used to measure various parameters in the process. By its very nature, therefore, it is in intimate contact with the highly chemically reactive geothermal fluids. Tables 1 and 2 give typical composition of two of these fluids. The so called "wetted parts" of the instruments therefore have to be chosen so that they are not prone to corrosive attack by the fluids.

Table 1 - Separated Water

Separated water is defined as the water to be pumped from the separation plants.

Typical composition of separated water is as follows:

Total SiO_2	550-900	mg/kg
Cl	1400-1700	mg/kg
Na	- 1000	mg/kg
K	- 200	mg/kg
Ca	1 to 2	mg/kg
Mg	- 0.005	mg/kg
'As	3 to 5	mg/kg
Sb	0.5	mg/kg
Total B	50	mg/kg
Total HCO_3 (CO_2 + HCO_3 + CO_3^{--})	50 to 200	mg/kg
Total H_2S (H_2S + HS^-)	4 to 6	mg/kg
SO_4	20 to 50	mg/kg
Total NH_3 (NH_3 + NH_4^+)	5	mg/kg
pH (measured at 100°C)	7 to 8	mg/kg
Plus other minor constituents		
Operating temperature range	155.5 to 167°C	

Note:

1. Mixing of air with separated water, for example by air leakage, causes a large increase in corrosivity of this fluid.

2. Silica may deposit out of the separated water if the water temperature is reduced. Leakage of process fluid to atmosphere will also lead to silica deposition.

Treated Air Environments

Measures need to be taken to protect instruments from the effects of the extremely corrosive hydrogen sulphide atmosphere around Ohaaki. There is a problem in obtaining proprietary equipment (especially if made in New Zealand) which has adequate protection against hydrogen sulphide (or other pollutants). Even if a special line of non-standard equipment is obtained, the fact that it is non-standard makes it difficult to maintain. The method of protection chosen therefore is to house susceptible equipment in an environment where the hydrogen sulphide has been removed. This has been done at Ohaaki with special annexes to the main and HP power houses (known as the "control annexes") and also the packaged substations (which house electrical and instrumentation equipment in the steamfield) having a treated air environment. This environment is generally provided by a fairly standard heating and ventilating system in each case to maintain a temperature of between 15 and 28°C and a humidity of less than 90%. However, all the make-up air and the recirculated air is taken via activated charcoal filters which remove the bulk of the hydrogen sulphide from the air bringing the average concentration down to 2 ppb. In addition to this, the rooms with treated air are held at a pressure slightly above atmosphere in order to prevent ingress of untreated air, and there are air locks between the treated air rooms and the outside world. Figure 1 shows the location of the treated air annexes at Ohaaki.

Table 2 - Condensate

Condensate is defined as the flow from the direct contact condensers, direct contact gas intercoolers, and station steam drains. The maximum temperature of condensate will be 56°C.

It is anticipated that after a period of running the condensate will have the following analysis:

pH	5.8-7.0	
free CO_2	60-15	mg/kg
HCO_3	30-100	mg/kg
H_2S (including HS^-)	11-1	mg/kg
SO_4^{--}	290-140	mg/kg
NH_4^+	125-70	mg/kg
NH_3	0.15-0.5	mg/kg
Cl^-	2-10	mg/kg

In creating annexes in the power station with treated air environments it was realised that the activated charcoal filters would need to be refreshed regularly in order to maintain them in a condition where they would continue to remove hydrogen sulphide. However, since the quantity of atmospheric hydrogen sulphide var'ies in time and space, the time for any quantity of charcoal to lose its capacity for removing hydrogen sulphide would also vary considerably. A search was therefore made for some equipment which would detect very low concentrations of hydrogen sulphide in air, in order to detect incipient breakdown of the activated charcoal filters. Such a device was found and, after extensive site tests, was adjudged suitable. A design was developed to enable samples of air to be drawn off from the plenum between two banks of filters so that the condition of the upstream filters could be assessed.

Protection from the Air

A great deal of copper is used at Ohaaki, both in the standard electrical circuits and in instrumentation. In modern instruments it is used as fine wire, and tracks on printed circuit boards. Tests have shown that hydrogen sulphide can migrate through polyethylene and PVC insulation on cables and attack the copper underneath. Fortunately tin, which bonds very well to copper, does not corrode in the presence of hydrogen sulphide. Consequently, all wiring and cables were specified to use tinned copper conductors. Switches and relays were also specified to be resistant to hydrogen sulphide attack. Because these precautions are relatively cheap, they were specified even for panels housed in the controlled atmosphere environments. To assist local equipment manufacturers who would have had difficulty in obtaining small amounts of tinned wire, a stock was bought for issue to these Contractors.

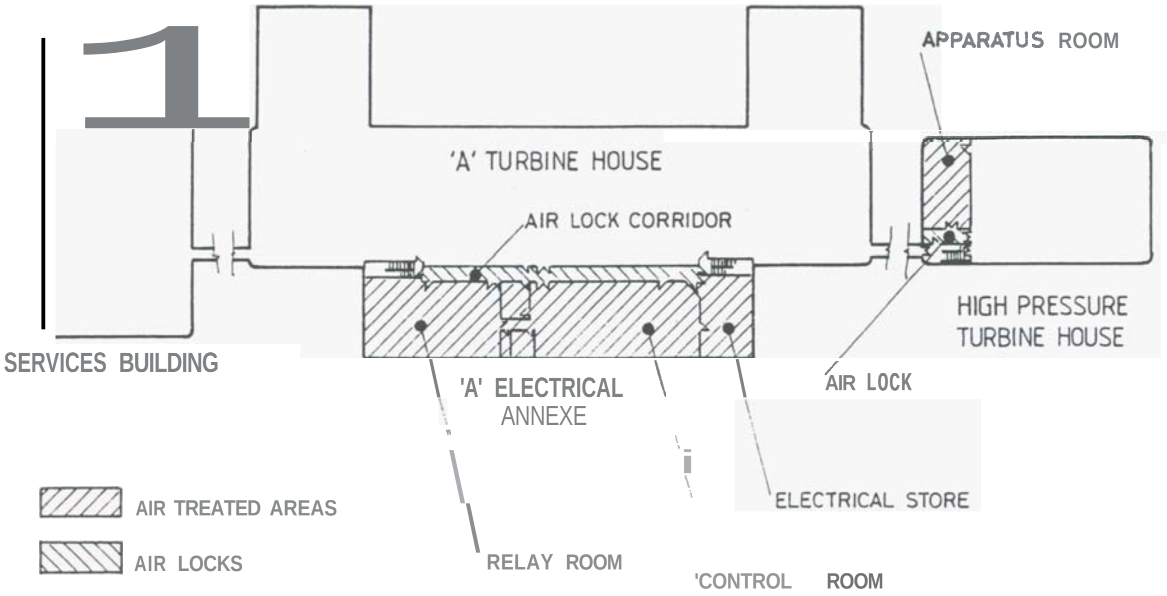

Figure 1 Layout of Ohaaki Turbine Houses

Although manufacturers of proprietary equipment will not modify that equipment (eg. programmable controllers) to be resistant to hydrogen sulphide, much of this equipment does come with standard features which are useful for this environmental protection. Gold or silver contacts on sliding surfaces are used extensively to ensure good contact. As silver corrodes in the present of hydrogen sulphide, gold contacts were used as standard. Printed circuit boards usually use tinned copper for the circuits to enable components to be easily soldered, and once the components are mounted varnish is frequently used to protect the boards, particularly against condensation. One coat of varnish was accepted as a minimum with a higher degree of protection preferred.

The net result of the precautions is that the equipment mounted in the controlled atmospheric environments is designed to withstand most of the contamination of the outside air, and hence is suitable for the low concentrations of hydrogen sulphide in the treated air, even for occasions when the air plant is not fully operational.

Plant outdoors was subject to more rigorous quality control with respect to protection from hydrogen sulphide. The design of the control systems had already been arranged to reduce the number of components in the field by use of transmitters in the field with electronic signal level detection in the control room, and by locating most relays and similar devices in panels in the control room. The transmitters have few or no moving parts and very little heat dissipation, hence the electronics can be encapsulated in an inert compound. In addition, the whole electronic equipment of the transmitter is put into a separate, hermetically sealed compartment, so that removal of the main cover uncovers only the terminations for the outgoing cables. This compartment also contains adjustments for the transmitter calibration, the potentiometer spindles for these passing through "O" rings to maintain the hermetic seal. The same precautions were taken, as far as possible with valve actuators. Many actuators which would otherwise have been suitable were not acceptable because of lack of protection from the geothermal atmosphere. Any relays or switches which are required in the field were also subject to these protective treatments.

Protection of Wetted Parts

Prior to the final decision to proceed with the design of Ohaaki, DSIR had undertaken tests exposing different materials to various geothermal fluids (including geothermal steam, separated water, condensate). From these tests a list of suitable materials for instruments in contact with the various geothermal fluids was developed. Table 3 gives a list of suitable materials for one of these fluids. Lists for each type of fluid were different, but, in general there was some overlap. As far as possible the "active" parts (ie. diaphragms, etc. sensing fluid pressures) were chosen to be Ni/Cr/Mo Hastelloy C276, this being an acceptable material for active parts for all tested fluids, and fairly standard diaphragm material provided by instrument manufacturers.

The choice of material for instrument (impulse) pipework was slightly more difficult. According to the DSIR list stainless steel AISI 316 was acceptable for circulating water; but not for separated water, whereas stainless steel AISI 410 was acceptable for separated water, but not for circulating water. Instrument pipe runs are normally made up on site of small bore (6-15 mm) pipe and are not, therefore, supplied preformed and identified like process piping. If different materials for different fluids were used it would be necessary to segregate the material types at site to prevent them being used wrongly. However, DSIR advised that, although 316 stainless would not be recommended for separated water process pipe, it would be suitable for pipe not subject to continuous flow such as instrument pipe. Stainless steel AISI 316 was therefore chosen for all instrument pipe and instrument valves at Ohaaki.

In choosing the physical position of transmitters a compromise is made between having the transmitter as close as possible to its tapping point to reduce instrument pipe costs and possible signal delays, and grouping of transmitters at a distance for accessibility and ease of technician maintenance. Generally, as long as the transmitters are accessible to operators and technicians, short instrument piping runs were preferred at Ohaaki, with no significant grouping of transmitters. The fluid in instrument pipes is basically static - in the case of Ohaaki, therefore, this fluid could be prone to freezing. One advantage of short pipe runs is to reduce this possibility, In a number of cases, capillary tubes filled with an anti-freeze fluid have been used, with the diaphragm close to the tapping point.

This cuts down the possibility of freezing and also enables the instrument pipework to be free from the potentially corrosive geothermal fluid.

Table 3 · Metals in Contact with Separated Water

A range of materials have been exposed in a variety of geothermal fluids, including separated water, at Broadlands well BR 22. From the results obtained, the following acceptable and non-acceptable materials for use with separated water have been identified.

Acceptable Materials (or equivalents)

Stainless Steel AISI 410
Stainless Steel FV520B
Stainless Steel Sandvik 2RK65
Ni/Fe/Cr Alloy Carpenter 20Cb3
Ni/Fe/Cr Alloy Incoloy 825
Ni/Cr Alloy Inconel 600
Ni/Mo Alloy Hastelloy B
Co Alloy Stellite 6B
Titanium Commercial Purity
Ti-4Al-4Mo-2Sn-0.5Si IMI 550

Acceptable Materials for Active Parts

Avesta 254 SMO
Inconel 625
Titanium IMI 155
Ni/Cr/Mo Alloy Hastelloy C276
Ti-6Al-4V IMI 318

Unacceptable Materials (or equivalents)

Carbon Steel AISI 1018
Low Alloy Steel AISI 4140
Ni Resist Type 1 Cast Iron
Aluminium Brass
Lead
Nickel
Monel
K-Monel
Copper
Zinc
Aluminium
Aluminium Alloys
Stainless Steel AISI 300 Series

Other Precautions

Because most modern instrumentation is now electronic, with extensive use of microprocessors, the power output is insufficient to drive the final process controlling element (control valve, variable speed pump). This output power has to be amplified by some means, the most common actuating and amplifying medium for control valves in process industries being compressed air. Since compressed air actuators have standard diaphragms or pistons (ie. made of standard materials), either non-standard diaphragms would have to have been used to avoid corrosion from the hydrogen sulphide laden atmosphere, or special treatment of the air would have to have been made. The same problem applies to the compressors which would have non-standard parts and to the compressed air system which would require to be of stainless steel. The difficulty of obtaining non-standard parts and the cost of maintaining such non-standard equipment were factors considered in making the decision not to use compressed air for valve actuators at Ohaaki. An alternative of using already treated air from the control annexes would have increased the capacity of that plant at great expense and was not considered further.

The alternatives are hydraulic and electric actuators and these were chosen for Ohaaki. For the bigger valves with high torques required, hydraulic actuators are generally used. Small control valves are actuated by electric actuators. These have to be chosen with care as control valves inherently move frequently requiring a great deal of starting and stopping, which is not the ideal treatment for the electric motors driving the actuators. However, special electric actuators for control valve duty are available, and most are designed for contaminated environments with sealed electrical compartments and access to cable terminals in separate enclosures, similar to those described for transmitters above.

OPERATIONAL DESCRIPTION

Steam/Water Separation

Cyclone separators separate steam from two phase well fluid and from the two phase mixture resulting from flashing HP separated water. The water separated is collected in water vessels which maintain a seal between each system, the levels in each vessel being controlled automatically by a flash valve and variable speed pumps respectively.

Each water vessel has duplicate level transmitters, There are also a large number of the peripheral items in the open associated with the hydraulic system for actuators. Being in the heart of the steamfield means that there is a very high environmental contamination by geothermal gases. but the bulk of the control equipment is housed in the packaged substations with a treated air environment. This equipment includes the variable speed drives (for the separated water reinjection pumps), parts of which have a high heat output. These parts, therefore use untreated air for cooling and are specially protected. The electronic parts are "tropicalised" (ie. extra coats of varnish are applied) and the busbars painted.

Main Steam Supply

HP and IP steam are collected from the separation plants and transmitted to the station. HP steam pressure and flow are measured and the steam is passed through the HP turbines to exhaust at IP pressure. The HP steam pressure is controlled by the HP bypass valves which pass any excess steam directly to the IP main.

IP steam pressure and flow are also measured and the IP steam pressure is controlled by four vent valves. These vent valves also act as safety valves and for security reasons the electronic equipment for the safety function is located close to the valves in the geothermal atmosphere.

Both sets of pressure control have redundant transmitters for reliability and these and some other peripheral equipment are exposed to the geothermal environment. However, most of the control equipment (with the exception of the safety circuits) is located in the controlled atmosphere of the main control room. The pressure switches and other equipment associated with the safety circuits are hermetically sealed.

Turbines and Generators

The HP turbine generators are re-furbished units from Wairakei. Although environmental precautions were taken at Wairakei, much less was known at the design stage of that power station of the effects of geothermal atmosphere than is known now. Nevertheless, with some minor exceptions particularly in the area of instrumentation, the units were in good condition.

A number of changes were made to the turbine peripherals to take the increased knowledge into account. Firstly, the old turbine gauge boards were replaced by new control panels located in a controlled air environment, thus moving most of the "at risk" equipment out of the geothermal atmosphere. In addition, the generator cooling circuits were modified to prevent carbon dust laden air from the brushgear being passed through the generator, This involves using air from the power house in a once through system over the exciter and brushgear, with activated carbon filters to remove the hydrogen sulphide prior to passing it through the exciter. The generator cooling is by a closed air circuit with make-up via activated carbon filters.

The IP turbines are manufactured by Mitsubishi who have had extensive experience of geothermal technology. In line with their experience and the general Ohaaki philosophy, most of the controls are placed within the controlled air atmosphere of the control room, with only transmitters subject to the geothermal atmosphere. The generators are cooled with once through air, which is passed through activated carbon filters prior to entering the generator air circuit.

Gas Exhausters

With the large volumes of non-condensible gases entrained with the steam, gas exhausters are necessary to maintain vacuum in the condensers. The exhausters are of the high speed centrifugal type, motor driven via speed increasing gear and are supplied by Franco Tosi. This company has also had extensive experience of geothermal stations and their instrument protection strategies are very similar to those of the turbines described above. The motors supplied by GEC, are totally enclosed (with an air to water cooler) to keep hydrogen sulphide atmosphere from contact with the electrical components. Also, the varnish used for the insulation of the motor conductors was specially chosen for extra durability and tinned joints are used where the cables are connected.

CW System

The overall design of the CW System (Brown and Hall 1989) involved a complex control system requiring multiple measurement of hotwell levels and system pressures, temperatures and flows. Many of these are discrete measurements, particularly of hotwell level, to stop pumps or close valves in order to prevent pump damage or hotwell overflow respectively, and, in low ambient temperature conditions, to prevent the freeze-up of the cooling tower. This is a case where the philosophy of using transmitters in the field and obtaining the required discrete values electronically in the treated air environment minimised the number of components which would have been mounted in the geothermal environment. With the complexity of the control system there are, nevertheless still large numbers of components exposed to the geothermal environment, not only transmitters, but also switches and relays controlling the CW pump suction and discharge valves,

The prime controls in the CW system are flow controllers controlling the flow of water into the condensers. This water is used to condense the steam passing through the turbine, but also influences the solution of geothermal gases in the condensate. It is important to maintain the correct distribution of water in different sections of the condenser - too much increases the solution of gas causing excessive acidity, too little will result in a poor vacuum and hence low efficiency. Other controls control the hotwell level, and reinjection of condensate, of which there is a net gain to the system. The CW pump motors are cooled by closed circuit air cooling to avoid contact with hydrogen sulphide laden air with the heated air passed through an air to water cooler in the circuit.

Auxiliary Cooling

River water is pumped from the Waikato River to a river water header tank. This tank supplies some water for cooling, (mainly the transformers and HP turbine auxiliaries) and also the initfal fill of the CW system and any make-up. An intake has been formed on the river with three pumps controlled from a packaged substation. The pumps are controlled automatically - levels in the header tank at the station signal via a telemetry system to start and stop the pumps as required. Local interlocks prevent damage to the pumps due to conditions such as low suction level. By siting a packaged substation at the River Water intake most of the controls have been kept out of the geothermal environment.

Other auxiliary cooling uses CW. As the systems are close to the power house, only the sensors on the plant are subject to the geothermal environment.

Electrical Switchgear and Controls

With the exception of the EHV switchyards the electrical switchgear has been kept in the treated air environments of the main control annexes and the packaged substations. The operators' controls are also maintained in these environments and remote control is provided to the steamfield by telemetry. Protection circuits are carried on a catenary cable along with the telemetry and communication circuits.

A convenient way of isolating the EHV equipment from the corrosive environment would have been to use gas insulated switchgear in which the busbars, disconnecting switches, earth switches and circuit breakers are totally contained in large metal tubes and insulated with sulphur hexafluoride gas. However, the high cost of this, especially as considerable expansion of the switchyard had to be allowed for, could not be justified.

Outdoor circuit breakers using hexafluoride gas as an insulating/arc quenching medium were used. Considerable care was taken in the selection of components in mechanism boxes fox circuit breakers and disconnectors. The door seals on these and the cabling junction boxes were carefully designed and activated carbon is placed in them to remove hydrogen sulphide from the air.

The other main items in the switchyard are the towers and conductors both of which are aluminium. The aluminium structures are built to the same design as standard steel towers, with nuts and bolts of 316 stainless steel. There are still some items of galvanised mild steel, and where these are in contact with aluminium a bituminous/aluminium paint has been applied to the laps.

A further potential problem is that, under certain wind conditions spray from the cooling tower can be blown into the switchyard. Drift eliminators are placed at the base of the cooling tower to reduce this.

Hydrogen Sulphide Measurement

A requirement of the licence to operate Ohaaki under the Clean Air Act was that measurement of hydrogen sulphide in the atmosphere be taken before operation of the plant to establish "normal" levels, and that these would continue after commissioning the plant to determine whether environmental limits were being exceeded. The detail of this hydrogen sulphide monitoring is included in another paper. However, it is noted here that, at the time, it was difficult to obtain equipment which could automatically and accurately monitor levels in the atmosphere down to 5 ppb, especially when they reach to greater than 50 ppb. Until the Ecotech equipment purchased to meet the Clean Air Act requirements was supplied most hydrogen sulphide detection was carried out using impregnated paper and visual inspection.

In addition, the measurement equipment itself which included proprietary equipment such as data loggers not designed for a hostile environment had to be protected. The equipment is housed in standard electronic equipment racks which in turn are placed in concrete tanks external to the power station. Active air conditioning had to be added to these enclosures to prevent the build up of high temperatures during summer, because they are not ventilated. However, the fan circulating air through the electronic equipment draws its air across activated charcoal filters to remove hydrogen sulphide.

PROBLEMS ENCOUNTERED

Operational Problems

In the design of the station electrical and instrumentation equipment, environmental protection was taken very seriously. A great amount of effort was put into ensuring that where a clean hydrogen sulphide free environment was provided, it would be reliable and that appropriate provision was made for cable entry and personnel and equipment entry and egress. Unfortunately the message did not get across strongly enough to the workforce and to a large extent such methods as wedging doors open for access during construction have degraded the precautions. With the decline of the construction forces on site and a changeover to operational staff, this problem is reducing, but nevertheless it has been extremely difficult to persuade staff of the need for care. One difficulty is that no problems are immediately obvious - hydrogen sulphide corrosion is cumulative, so that an incipient problem may be being set up. No failures are attributable so far to hydrogen sulphide attack.

Environmental Problems

Evidence from Wairakei indicates that non protected equipment used continuously in a geothermal atmosphere can fail within six months. Some electrical and instrumentation items have now been on site for up to four years, with no failures due to hydrogen sulphide corrosion so far. Although not conclusive proof of the efficiency of the precautions taken, this at least indicates that those precautions have been of the right type.

The only problem noted on instruments "wetted parts" concerns the level transmitters on the separated water vessels, which on occasions have "stuck" at an intermediate level. This was discovered to be due to silica deposition on the diaphragm. Such deposition implies that the water in contact with the diaphragm must be significantly cooler than in the main vessel. The vessels themselves are lagged, but not the instrument tappings. Lagging of these is now in hand.

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