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DESIGN OF OHAAKI POWER STATION SEPARATED WATER REINJECTION PUMPING SYSTEM

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ABSTRACT

Ohaaki Power Station is under construction on Broadlands Geothermal Field, 20km north of Wairakei.

Limited water rights for the discharge of geothermal waters into surface waters, namely the Waikato River, were sought and granted. These have necessitated the design of re-injection systems for separated water and condensate which are the major quantities of geothermal fluid requiring disposal.

The separated water reinjection system is the larger of the two systems and will be required to dispose 1500-1700 tonnes per hour of silica saturated water which has been separated from the production steam. The system consists of five similar pumping stations, each associated with a separation plant, seven reinjection wells and an inter-connecting network of pipelines.

In the paper, the design decisions taken in determining the required pumping station equipment based on problems associated with pumping silica saturated water, H_2S pollution of the environment and uncertainties in the fluid quantities and reinjection pressure are discussed. In addition, the proposed control of the reinjection system using electronic variable speed driven pumps is outlined.

INTRODUCTION

Reinjection is required at Ohaaki Power Station in order to minimise the discharge of toxic substances, particularly heavy metals, to the Waikato River. A second major concern is to minimise the heat input to the river.

Water rights granted for the operation of the power station recognise that, during times of maintenance and under abnormal situations, a discharge to the river will be necessary. The water right for emergency discharge under abnormal situation$ limits any such incident to a 12 hour duration. Hence, any fault in the reinjection system that results in a system outage of longer than 12 hours will require a power station shut down and loss of generation.

Reliability of the reinjection system and in particular the pumps, driver and control system is essential.

Silica Saturation

Problems associated with handling silica laden water played a major part in determining the power station operating parameters. In order to avoid silica deposition it is necessary to keep separated water above the silica saturation temperature. This requirement determines the minimum steam separation and hence turbine inlet pressures.

Separated' Water Separation System

At Wairakei, steam separation was carried out at the wellheads because it was believed that the two phase fluid discharged from the well could not be satisfactorily piped to a remote separation plant. This problem has since been overcome and at Ohaaki, the production wells will feed a two phase mixture to five separation plants located throughout the steamfield. Steam for power production will be separated from the mixture in a two stage flash process leaving hot water to be reinjected. Steam from the first stage flash will be used in two back pressure turbines which are being transferred from Wairakei. Rundown of the field will eventually make power production from these turbines uneconomic and the design of the separation plants allow for their conversion to single stage flash at that point.

Separated Water Reinjection System

Hot water leaving each separation plant will be discharged from a water vessel into the reinjection system.

There are initial uncertainties concerning both the total quantity of water to be disposed of and the probable enthalpy changes in the production fluid over the power station life. Reinjection requirements will also vary as a result of steamfield management as new production and reinjection wells are brought into service. Flexibility was therefore an important consideration in the design of the reinjection system.

A reinjection main linking the separation plants with all the allocated reinjection wells has been used as the basis for the system. This allows the distribution of the water to be reinjected over the greatest number of reinjection wells.

Reinjection Pressure

Reinjection pressure has a significant effect on the equipment that may be used for the reinjection system with particular reference to the pumping station. The reinjection pressure was therefore subjected to an optimisation study.

The method used, developed from Grant (1), compares the cost of a new well to the pumping costs. In order to make this comparison, it is necessary to express well costs and pumping costs as a function of P, the wellhead pressure at the reinjection well.

An assumption that piping network pressure losses would be equal to the suction pressure available at the pump (i.e. separation pressure) was made so that required pump generated head could be equated to the reinjection wellhead pressure.

A typical well cost was taken as NZ$0.75M. This cost was converted to the cost of a well requiring P bar to dispose of 1 tonne/hr of water by making use of a typical Ohaaki reinjection well injectivity Characteristic. A number of wells had been selected as possible reinjection wells (Bixley 1, 2, 3) and as a result of trials, had known abilities to accept reinjection fluid. These abilities were summed, averaged and a curve of best fit producted (typical well injectivity characteristic). This , curve related wellhead pressure to reinjection quantities and was generally of the form:-

$$R = AP + B$$

where R is the reinjection flow in tonnes/hour
P is wellhead pressure in bars
A and B are constants.

The well cost attributable to reinjecting 1 tonne/hr is obtained by dividing the well cost by (AP+B).

Pump capital costs were obtained from suppliers. Costs were obtained for pumping station equipment capable of providing various generated pressures. These were used to produce an equation linking the pump generated head to capital cost. Pumping power costs were developed using traditional formulae to produce the power requirements combined with a capitalised cost of power based on the current unit cost, the projected station life (25 years), load factor (85%) and required discount rate. Pump efficiency plays a major part in determining pump power requirements and a mildly conservative figure of 60% was used.

Combining the equations for well cost, pumping station capital costs and operating costs and obtaining a minimum by differentiation, indicated that costs would be minimised if a wellhead pressure of 24 bars was adopted.

Predictions for the initial quantity of water to be disposed of varied depending on which production wells would be used. A figure of approximately 1700 tonne/hr was the average. The existing wells available for reinjection have a combined injectivity characteristic which allows this quantity to be disposed of at a little over 19 bar. In view of this it was decided to reduce the design pressure to 20 bar thereby easing the selection of pump type (single stage vs multistage), reducing pump operating speed and easing net positive suction head (NPSH) requirements.

Pumping Station Equipment

Pumping station equipment choices can be split into two main areas, choice of pump type and choice of pump drive or control method.

a) Pump Type:, Field trials used multistage 'canned' pumps, which are widely used in the power industry to limit excavation requirements where suction head is limited. However, this type of pump is prone to operational problems when called upon to handle silica laden water.

Overseas experience (Makban,Philippines) favours horizontal pumps, mounted below the water vessel, to overcome suction difficulties. There is a preference for single stage pumps or, at most, two stage pumps, to avoid silica deposition problems in inter-stage bushes, shaft supports etc. Horizontal, split case, pumps are also generally easier to maintain. The decision was therefore made to opt for horizontal single or two stage split case pumps.

Suitable mechanical seals are considered essential to avoid silica build-up from gland leakage and therefore they will be employed.Selection of seal type will require careful consideration.

b) Drive or control type: The initial uncertainty as to water quantity and the likelihood of variations during the life of the power station indicated that some form of flow control was required. A number of options were available. The following major options were considered:

i) Constant speed drive by direct coupled electric motor with throttle valve control:

Throttle control of pumps is a well proven, simple method for flow control. It is however, inefficient, particularly when throttling to low flows and the valve itself is liable to require a considerable degree of maintenance.

ii) Variable speed drive by direct coupled steam turbine:

This method has also been widely used.

Small, single wheel variable speed turbine drivers give reliable service, however, for this particular application they have a number of drawbacks. Firstly, the specific steam consumption of the turbine driver is higher than that of the large turbines used for power production at the power station, i.e. the turbine driver requires more steam per kW output. Therefore, a high opportunity cost for using the steam must be applied. Secondly, a steam turbine, even of the simplest type, is a reasonably complex machine requiring, particularly with reference to geothermal steam operation, considerable maintenance input. Thirdly, the turbine driver is, of necessity, a back pressure type with steam being discharged from an atmospheric exhaust. The noise and pollution from gas entrained with the steam become environmental nuisances. Finally, the reinjection system requires some degree' of standby operation or, at the very least, the ability to commission and start up extra pumpsets in the event of plant failure. A steam turbine driver cannot be left on standby for extensive periods when exposed to geothermal steam and gas due to the risk of corrosion and cannot be started quickly as it has to be pressurised and warmed through first.

iii) Variable speed drive using a fixed speed electric motor with hydraulic coupling:

The hydraulic coupling is commonly used €or speed control but is increasingly inefficient when the pump is operating at lower speeds.

iv) Variable speed motor drive.

A large number of variable speed motor drive types have been used in a wide variety of application. In general, they have a relatively high capital cost but maintain a high efficiency over a range of speeds.

Walker (1) considered a number of the drive types with specific reference to this application:

(a) Variable frequency AC drive making use of a standard induction motor fed with variable frequency from a static thyristor inverter.

(b) DC thyristor drive where the motor torque and speed are controlled by varying the , current and voltage respectively.

(c) Slip energy recovery using a slipring induction motor where speed is controlled by vsrying the effective rotor impedence with the resulting energy appearing in the rotor being restored to the supply by means of an inverter.

A comparison of these variable speed motor options concludes that DC motor based systems are unsuitable due to problems in protecting the motors from Hydrogen Sulphide corrosion and that the AC variable frequency system is preferable to the slip energy recovery system as the former uses standard induction motors which are more readily available. A disadvantage of the AC variable frequency drive inverter is that it generally has to be protected from Hydrogen Sulphide which means that the substation used to house control equipment in a low Hydrogen Sulphide atmosphere has to be enlarged to also house the inverter.

Pumping System Layout

The system layout was next considered. Flexibility and reliability were considered to be paramount and therefore, it was decided that a number of pumps should be installed at each pumping station. The size of pump was initially determined by assuming that two duty pumps would be installed at each pumping station. This produced a pump with a capacity of 170 tonne/hr.

As has already been mentioned, in order to use horizontal pumps they must be located below the water vessel so that their suction condition requirements can be met. This dictates that pumps must be installed close to the water vessel in a pit. Two basic system layouts can be developed from this point. Firstly, the pumps adjacent to the water vessels can be used as 'primary' pumps to feed the water to the suction of larger pressurising pumps at a centralised location(s) or secondly, they can be used to generate the entire pressure rise required in a single step. The single step system is less complex in physical and control terms.

System Adopted

Consideration of the various factors discussed above in conjunction with capital costs for equipment, maintenance costs and operating costs, led to the selection of the pumping station system outlined below.

The basic system consists of single step pumping using single stage horizontal split case pumps. Pump size has been standardised to allow pumps to be interchangeable and reduce spares holdings. Two or three duty pumps will be installed at each pumping station. Each pump will be driven by an induction motor supplied via a variable frequency AC inverter with the inverters installed in substations. The air supply to these substations is filtered to remove most of the Hydrogen Sulphide.

The design pumping pressure is a 20 bars increase above separation pressure which corresponds to a reinjection wellhead pressure of 20 bars. Additional flexibility was considered necessary and therefore the pumps will be capable of achieving the design flow rate at a differential head of 25 bars to take account of possible reductions in injectivity of Ohaaki reinjection wells. This is possible by increasing the pumps operational speed range while still remaining below the 200kW power rating of the drive.

Subsequent to these decisions being made, one of the allocated reinjection wells was found to be unsuitable for reinjection purposes and another was reallocated for condensate reinjection. Analysis of the remaining system at that stage indicated that it was more economic to adapt the basis system by adding two fixed speed booster pumps to increase the pressure of supply to two of the reinjection wells to provide the necessary system capacity, rather than drill a new well.

Control of the Separated Water Reinjection System

Control of the pumps at a given pumping station will be exercised from the water level in the water vessel feeding them. Basically, the pumps will operate to maintain the level in this vessel.

A number of reference levels are used. Firstly, a normal operating level near the midpoint of the vessel. A programmable controller is used to control the operation of the duty pumpsets by varying their speed in unison, increasing speed if the level rises and reducing it if the level falls. An upper level limit is set into the controller and if this is reached, the controller will start the next available pump. If, however, all available pumps are already operating, the controller will set all operating pumps to maximum speed and open a dump valve which will modulate the excess fluid in the vessel to waste. Conversely, there is a lower level limit set into the controller which runs off a pumpset provided more than one is operating. In the event that only one pumpset is operating a recirculation valve is opened between the pump discharge manifold and the water vessel thereby bypassing flow back to the water vessel and keeping the pump operating.

Outside these limits on the controller, level switches on the water vessel trip the pumpsets on high and low level.

In addition, the high level switch fully opens a second dump valve to prevent water carryover into the steam mains.

The control system is designed to at all times maximise the quantity of water being reinjected and minimise the quantity being dumped to the river. It achieves this by keeping as many pumps running as is possible and resorting to dumping only when absolutely necessary.

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