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LP Separator Level Control by Variable Speed and Multi Stage Brine Reinjection Pumps at Kawerau and Nga Awa Purua Geothermal Projects, New Zealand

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ABSTRACT

Kawerau and Nga Awa Purua Geothermal Power Plants have the largest capacity double flash and triple flash steam separation systems respectively, in the world.

This paper describes the system configuration selections, operations and commissioning experiences of low pressure (LP) brine reinjection systems utilizing two stage brine reinjection pumps to control LP separator brine level while achieving full brine reinjection under several operating scenarios.

1. INTRODUCTION

For Kawerau Project, after separation of the two-phase geothermal fluid in the high pressure (HP) separator, separated brine is flashed across the HP separator level control valves and directed to two LP separators. In the case of Nga Awa Purua Project an additional (IP) stage of flash is involved. LP brine separated in the LP separator(s) at a pressure of about 2 bar.a is disposed of by reinjecting it back into the ground. Both projects employ two stages of reinjection pumps.

A number of operating scenarios were considered for brine reinjection from the Kawerau and Nga Awa Purua Projects. The systems are required to discharge at modest pressures during normal operation, and this is achieved by use of the first stage brine reinjection pumps only. In the event of a loss of reinjection capacity (from any of the reinjection wells) substantially greater reinjection pressure is achieved by use of the second stage brine reinjection pumps. To achieve redundant capacity, three 50% brine reinjection pumps are provided for each stage.

2. KAWERAU BRINE REINJECTION SYSTEM

The brine reinjection system for Kawerau project was required to provide a maximum reinjection pressure of 15 bar.a at the interface between power station and steamfield using variable speed pumps. In addition, the reinjection system had to accommodate reinjection pressures down to about 2 bar.a (being the saturation pressure of the reinjection fluid). Furthermore, the performance guarantee point corresponds to an interface pressure, at the power plant, of 11 bar.a.

The interface reinjection pressure determines pump total head, and depends on the injectivity of reinjection wells, hydraulic losses in the reinjection pipelines, and the LP brine flow rate (squared); brine flow rate depends on the plant operating condition. As the plant was designed for a range of flow and enthalpy values, appreciable variation in brine flow had to be accommodated. (Normal flow to the plant was to be 45,000 t/d, with possible enthalpy values of 1,200, 1,300, and 1,400 kJ/kg. A high flow case of 55,000 t/d with enthalpy of 1,300 kJ/kg was also considered.)

As well, two injectivity cases were stipulated, being normal injectivity and reduced injectivity due to loss of an injection well, giving two system curves. Considering the various interface pressure requirements, and the differences between system curves, and the range of brine flows, single stage variable speed brine pumps would not provide sufficient turn-down to meet the wide range of brine reinjection system performance. Refer to the figure 1

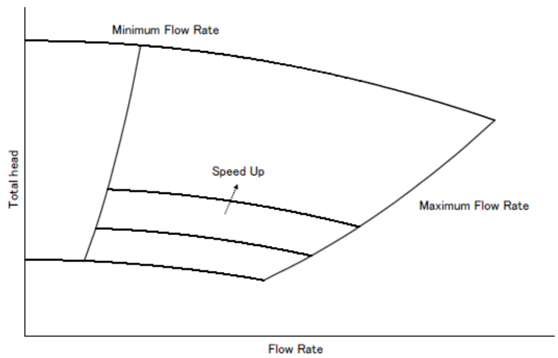


Figure 1: Conception of pump characteristic

Accordingly, the two stage brine reinjection pump system was selected in order to cover the required operating range.

2.1 Variable Speed Drive

Although mechanical means such as fluid coupling can be used for driving variable speed pumps, variable frequency (inverter) drive (VFD) is considered to be more favourable (less auxiliary equipment and utilities requirements).

2.2 Evaluation of System Configuration

The power plant contract was signed before the reinjection wells were drilled, which resulted in contract based on assumed pumping requirements. The Owner and Contractor worked together to accelerate the well drilling program and defer the pump procurement to enable the system to be optimised. Well testing and cold water stimulation showed the injectivity to be much better than originally assumed. Two reinjection pump schemes, original and alternative, were evaluated. Both schemes involved two stage of pumps, arranged per conceptual diagram below.

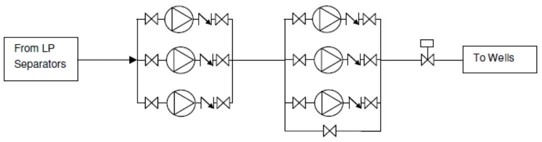


Figure 2: Conceptual diagram of reinjection systems

2.2.1 Original Scheme

Three 50% duty first stage pumps cover all operating conditions up to the guaranteed reinjection interface pressure (11 bar.a). The first stage pumps are fixed speed, operating in conjunction with a level control valve. Three 50% duty second stage pumps would normally be by-passed but would operate when needed to boost pressure up to the maximum reinjection interface pressure (15 bar.a). The first stage pumps sizing was based on the maximum flow plus a 10% design margin, which corresponded to the low enthalpy – e.g. 1,421 t/hr at an interface pressure of 11 bar.a. Having sized the first stage pumps, the second stage pumps were then sized to achieve the extra head needed to deliver 15 bar.a interface pressure at the same flow rate. Two second stage pumps run via VFD and the third is fixed speed. The governing condition for pump head requirements is 2 x 50% pumping at 45,000 ton/day plant operation rather than 3 x 33% operation at 55,000 ton/day.

2.2.2 Alternate Scheme

Three 50% duty first stage pumps cover the operating range based on the expected reinjection systems characteristics. 2 pumps would run via VFDs, with the third being fixed speed. 3 x 50% second stage pumps to provide boost pressure up to the maximum reinjection interface pressure. The first stage pumps were sized to achieve the normal reinjection interface pressure at both 45,000 ton/day and 55,000 ton/day plant operation. The first stage pumps sizing condition is the low enthalpy case reinjection flow rate, plus a 10% design margin – i.e. 1,421 t/hr. The corresponding reinjection pressure is 3.02 bar.a based on the reinjection well test data. Having sized the first stage pumps, the second stage pumps were then sized to achieve the extra pressure needed to deliver 15 bar.a interface pressure at the same flaw rate. All second stage pumps are fixed speed, and operate in conjunction with a level control valve. The governing condition for pump head requirements is 2 x 50% pumping at 45,000 ton/day plant operation rather than 3 x 33% operation at 55,000 ton/day.

2.2.3 Results of Analysis

The key aspects of pump performance analysis are summarized below.

- **Table 1: Pump Details**

Item	Unit	Contract Basis Scheme	Alternate Scheme
First Stage Pumps			
Rated Flow	m^3/hr	755	755
Rated Head	m	108	40
Nominal Motor Size	kW	315	110
Second Stage Pumps			
Rated Flow	m^3/hr	755	755
Rated Head	m	51	119
Nominal Motor Size	kW	132	355

- **Table 2: Contract Basis Scheme Operation**

Operating Case	1st Stage Pumps Running 3 x 50% fixed speed	2nd Stage Pumps Running 3 x 50% (VFD x 2)	Approx. Power Demand (kW)
(1) Low Flow	2	0	478
(2) Base Case	2	0	492
(3) 55,000 ton/day	3*	0	691
(4) N-1 loss PK4a	2	0	492
(5) Guarantee Point	2	0	492
(6) Max. Operation	2	2	632
(7) Overload Operation	3	3	814

* Could potentially be achieved with 2 pumps depending upon actual performance curve.

- **Table 3: Alternate Scheme Operation**

Operating Case	1st Stage Pumps Running 3 x 50% (VFD x 2)	2nd Stage Pumps Running 3 x 50% fixed speed	Approx. Power Demand (kW)
(1) Low Flow	2	0	91
(2) Base Case	2	0	120
(3) 55,000 ton/day	3	0	187
(4) N-1 loss PK4a	2	2	720
(5) Guarantee Point	2	2	720 (610 **)
(6) Max. Operation	2	2	720
(7) Overload Operation	3	3	972

** Separator level is controlled via LCV and all pumps are operating at fixed speed. If operating speed of 1st stage pumps is manually reduced via VFD's to a minimum practical level, then this is the indicative power consumption (subject to actual pump curves).

- **Table 4: Comparative Power Demand**

Operating Case	Power Demand Difference (kW) (Alternate – Contract Basis)
(1) Low Flow	-387
(2) Base Case	-372
(3) 55,000 ton/day	-504
(4) N-1 loss PK4a	228
(5) Guarantee Point	228 (118**)
(6) Max. Operation	88
(7) Overload Operation	158

** Separator level is controlled via LCV and all pumps are operating at fixed speed. If operating speed of 1st stage pumps is manually reduced via VFD's to a minimum practical level, then this is the indicative power consumption (subject to actual pump curves).

The key conclusions drawn from the comparative analysis are summarized as follows.

The alternate scheme provided considerably lower electrical demand at the anticipated usual operating conditions. However, the electrical demand at the guarantee point would have been 200kW higher for the alternate scheme, (compared to the original design based on Contact interface conditions).

2.3 Final System Configuration

According to the results of analysis, the final system configuration for Kawerau project was decided according to the alternate scheme.

The first stage pumps cover the operating range based on the expected reinjection system's characteristics; for all cases of 45,000 t/d flow only 2 x 50% pumps are required; the third 50% pump is required for 55,000 t/d. For operating flexibility, all three first stage pumps run via VFD's.

The second stage pumps increase the discharge pressure up to the maximum reinjection interface pressure. The system control logic is configured so that the same number of first and second stage pumps will run. The second stage is shut down and bypassed when interface pressure is low enough to permit operation with first stage pumps only.

The final system configuration is shown figure 3.

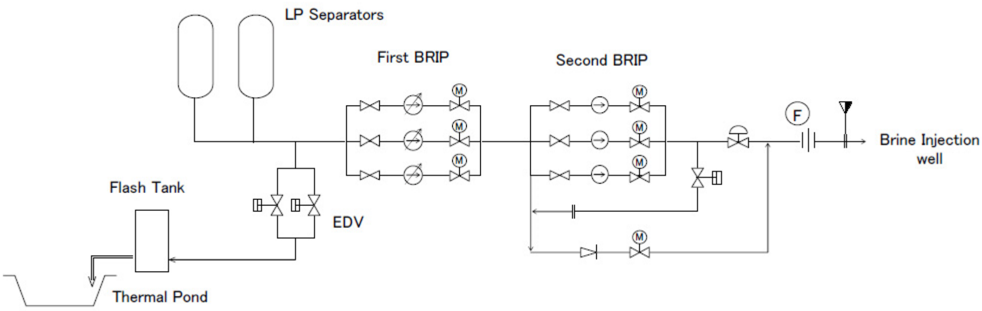


Figure 3: The finalized system

At start up and during transient conditions (e.g. when Brine pH is out of acceptable range) brine is not pumped to the reinjection wells. An emergency dump line takes brine from first stage Brine Reinjection Pump (BRIP) suction piping and discharges to a thermal pond via an atmospheric flash tank. A level control valve (LCV) is installed on the second stage BRIP discharge pipe and the system is completed with the provision of the second stage BRIP bypass and recirculation lines.

The detailed pump specifications are shown table 5.

Table 5: Rating of BRIP for Kawerau

			1st stage	2nd stage
Pump Rating Point				
	Quantity		3 sets x 50% capacity	
	Control		VFD	Const.
	Type		Horizontal, Centrifugal type	
	Flow rate	t/h	555 (672)	672
	Total head	m	45.3 (36.1)	116
	Temperature	deg. C	128	121
	Specific gravity	kg/lit	0.937	0.942
	Efficiency		72	72.2
Driving motor				
	Type		Totally Enclosed Fan Cooled type	
	Output	kW	110	340
	Voltage	V	AC415	AC3300

Both driving motor and VFD controller (inverter) was manufactured by FES in order to ensure compatibility and high reliability.

The first stage BRIPs were installed in a pit to maintain the required suction head because the topography of the Kawerau site is flat.

Figure 4: Photo of BRIP area

Figure 5: Photo of 2nd stage BRIP and LP separators

3. NGA AWA PURUA BRINE REINJECTION SYSTEM

The system configuration for Nga Awa Purua project was determined from a similar analysis to that for Kawerau.

As the fluid enthalpy is higher for Nga Awa Purua, and the field production pressures are higher, a triple flash steam separation system was selected. These factors result in lower brine flow rates for reinjection than in the Kawerau project, even though the two-phase fluid extraction rates are similar..

In addition, Nga Awa Purua project has a more significant static head component than Kawerau (where the terrain is essentially flat). This means that the reinjection pump head required is appreciable, even at low to moderate flows.

The particular factors existing at Nga Awa Purua have resulted in selection of the pump specifications shown below. As the table shows, the maximum delivered head is the same for both stages, whereas for Kawerau the first stage pumps provide approximately a quarter of the maximum delivered head.

The pumping system design provided the opportunity to select identical pumps for the first and second stages. To enable flexibility to be able to adapt the pumps to possible changes in reservoir conditions, the pump was sized so that the impeller diameter can be increased without changing casing size.

Table 6: Rating of BRIP for Nga Awa Purua

			1st stage	2nd stage
Pump Rating Point				
	Quantity		3 sets x 50% capacity	
	Pump speed control		VFD	Const.
	Type		Horizontal, Centrifugal type	
	Flow rate	t/h	570	570
	Total head	m	94	94
	Temperature	deg. C	128	128
	Specific gravity	kg/lit	0.937	0.937
	Efficiency		79	79
Driving motor				
	Type		Totally Enclosed Fan Cooled type	
	Output	kW	260	260
	Voltage	V	AC415	AC415

The topography at Nga Awa Purua provides an elevated platform suitable for the location of the LP separator. The elevation difference to the BRIP of 11 meters is sufficient to provide sufficient suction head to allow the pumps to be installed on ground level.

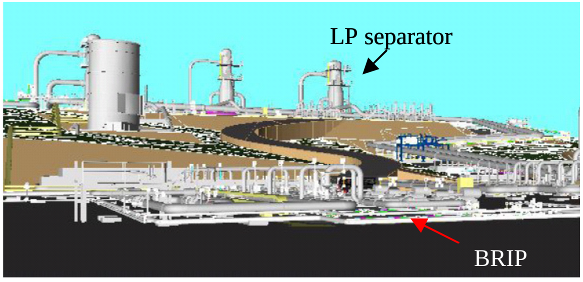


Figure 6: Installation level of LP separator and BRIP

4. BRIP OPERATION

LP separator water level is controlled in two modes. One mode is that the level is controlled by modulating the speed of the first brine reinjection pump. This mode is called “Mode 1”. Another mode is that the level controlled by modulating the level control valve. This mode is called “Mode 2”. Control mode is changed manually according to the interface pressure.

Automatic pump start-up and shutdown is provided: When total flow rate falls below the minimum operational flow rate per pump, one operating pump is stopped. Conversely, when total flow rate become higher than maximum operational flow rate per pump, one standby pump is started.

When the required interface pressure exceeds the pump delivery pressure, the operation mode is changed from Mode 1 to mode 2. Following graphs showed the BRIP operation mode at Kawerau project.

In the event of a system upset or transient, where the LP separator level rises to a predetermined level, emergency dump valve (EDV) is opened and brine is discharged to the thermal pond. The thermal pond capacity is approximately three hours. Then, plant auto-shutdown logic will start if the operator acknowledges. BRIP suction pipe and EDV piping were sized to prevent the brine from flashing when EDV is opened.

External flushing water is provided for the mechanical seals because the brine includes silica, which is saturated. Raw water was planned as the source of the seal water at early stage of engineering. But, hotwell pump discharge water, which is geothermal steam condensate was used for the mechanical seal water. This change reduces the amount of oxygen ingress, which represents a corrosion risk.

5. COMMISSIONING EXPERIENCE

At Kawerau project, the LP separator level control functioned well for all system configurations. Most of the time, only the first stage brine pumps were used during commissioning. The 2nd stage brine pumps were used to match the discharge pressure to that required when the combined well injectivity was low.

During commissioning of the Kawerau project two minor technical issues arose, as outlined below. The solutions implemented for these issues were successful and have been incorporated in the design for the Nga Awa Purua project.

5.1 Low Suction Pressure

One of the first stage reinjection pumps experienced low suction pressure and the suction head almost fell as low as the minimum required Net Positive Suction Head (NPSH), which would have initiated an automatic shut-down of the pump. The cause of this issue was determined to be trapped non-condensable gas or unvented air that accumulated at the pump common suction header. This may have resulted in open channel brine flow and flow restriction, giving rise to reduced suction pressure. This was rectified by adding suction vent lines and venting a small continuous stream of gas.

Figure 7: Mode-1 Operation (per One Pump)

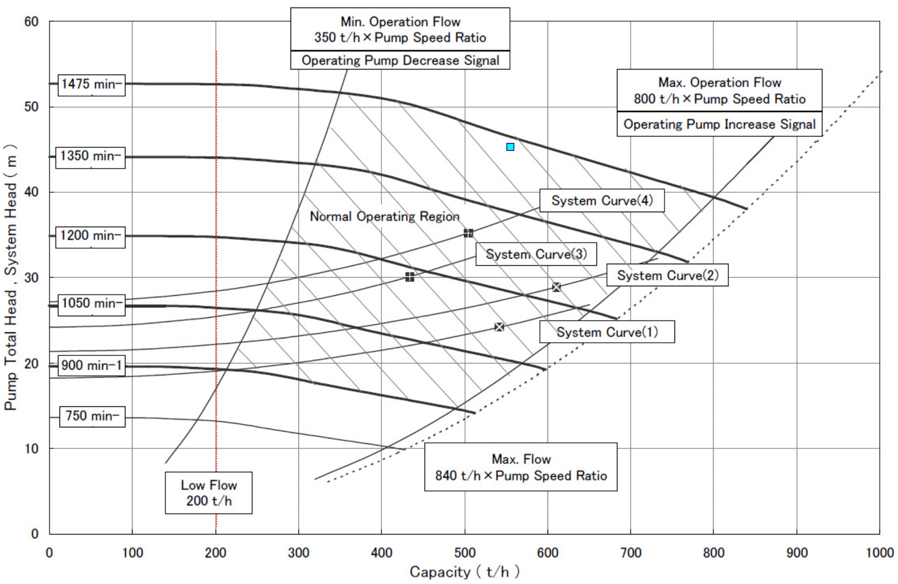
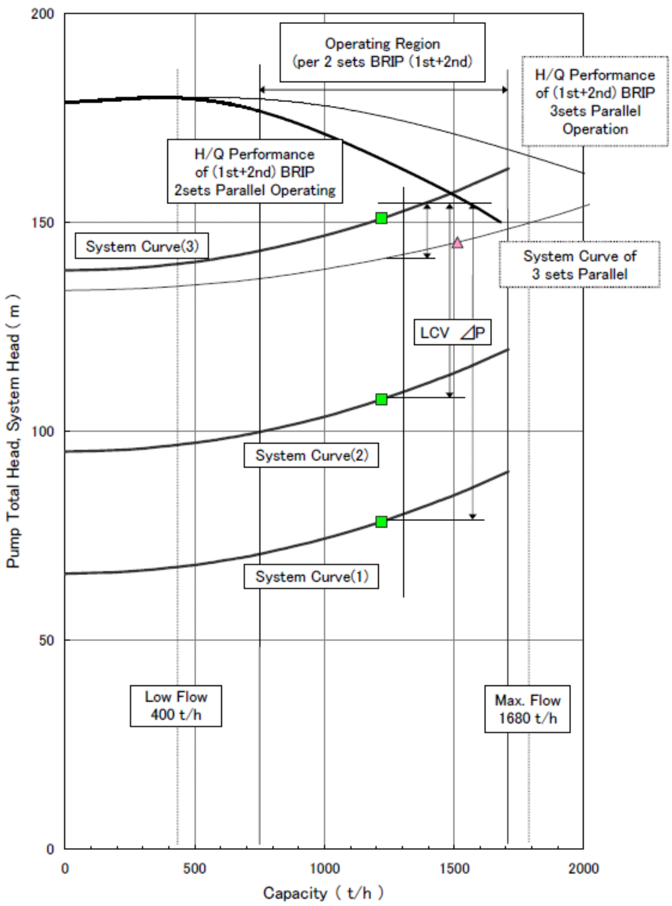


Figure 8: Mode-2 Operation (2 sets Parallel Operating)



5.2 Low Flow Switch

Flow switches were installed on the discharge piping of each brine pump to detect low-low flow condition, but they failed to work reliably. Instead of the flow switches, the orifice flow meter on the common brine reinjection line, , was used together with the calculation of measured total flow per running pump in distributed control system (DCS).

6. CONCLUSION

At Kawerau project, the LP separator level control functioned well in response to changes in injectivity as the system configuration was changed. The automatic start up of stand-by pumps and the change over from first stage variable speed pumps to second stage fixed speed pump control provided an effective response to the variation in injectivity.

At Kawerau project, the contractual design was based on assumed data as the well injectivety was unknown. The ability to obtain test data before the pump system design was finalized enabled an optimized system design, which saved 110kW power consumption.

Success of Kawerau project suggests the system configuration may be applicable to the other similar plants. However, the changes made for Nga Awa Purua, project show that each plant will have its own specific requirements