

## Gas Extraction System in Kawerau Geothermal Power Plant

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### ABSTRACT

Kawerau geothermal field has relatively high level of non condensable gas (NCG) content. The paper describes the experience of engineering, procuring and commissioning of 3 trains of the hybrid type NCG Extraction System by Fuji Electric Systems (FES). The hybrid Gas Extraction System (GES) at Kawerau Geothermal project, which consist of 2 stages of steam jet ejector and liquid ring vacuum pump, is one of the largest of its type in geothermal use in the world. This paper also reports the result of GES performance tests at both shop and site.

### 1. INTRODUCTION

In September 2006 Mighty River Power issued a request for proposal (RFP) for the Kawerau Geothermal Power Plant. The RFP included a performance based specification, a design geothermal fluid supply (tonnes/hr) and enthalpy (kJ/kg) along with commercial evaluation criteria (in terms of \$/kW). No specific plant output or type of gas extraction system was specified. This gave FES the opportunity to determine the maximum commercially justified plant output. Maintenance costs, as estimated by Mighty River Power, were also included in the evaluation.

To achieve the optimal power plant output, the main condenser pressure at the rated load was set at 0.08 bara. This relatively low condenser pressure and the relatively high gas content in the steam significantly influenced the selection of the GES. The successful selection and operation of GES was essential to achieve guaranteed plant overall efficiency.

In the process of the GES design, its performance (power and steam consumption rate), cost optimization, operability and reliability were considered.

### 2. TYPE OF GAS EXTRACTION SYSTEM

The three types of GES commonly used in geothermal power plants are described below.

#### 2.1 All Ejector Type

All ejector type consists of two or three stage ejectors and inter-/after- condensers. This type has been adopted since the early times. The advantage of all ejector type is easy operation, lower initial cost and minimal maintenance requirements. On the other hand, the steam consumption for all ejector type GES is relatively high and results in this type of GES being used where the NCG content is low.

#### 2.2 Hybrid Type

The hybrid type consists of ejector(s), condenser(s) and liquid ring vacuum pump (LRVP). LRVP is adopted for the

last stage instead of ejector and condenser at all ejector type. The efficiency of hybrid type is better than all ejector type, but more expensive and more complex.

#### 2.3 Turbo Compressor Type

The most efficiency type of GES is a turbo-compressor. This is typically a multi-stage axial machine with similar construction to the steam turbine. The wet NCG provides a corrosive environment, which requires the use of stainless steels. This represents the highest initial cost and most complex design when compared to other types. This type is appropriate for geothermal power plants where the amount of the NCG contained in the steam is large.

#### 2.4 Selection for Kawerau Geothermal Power Station

Considering the features of each GES type described above, three stage "hybrid type" GES was selected for Kawerau geothermal power station. The process conditions and the detailed specification of GES are described in the following section.

### 3. ENGINEERING

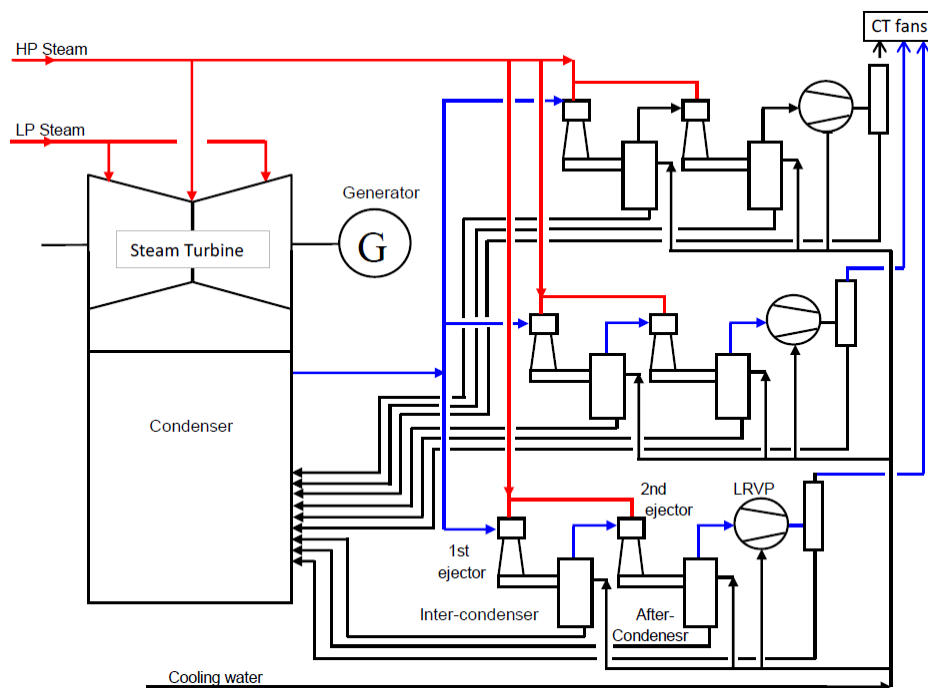
#### 3.1 Process Condition for Design Basis

The energy input at the power plant boundary was given by the two-phase geothermal fluid flow and enthalpy. Its composition data was defined as shown in table 1.

Table 1: Geothermal Fluid Composition Data

Element/ Compound	Expected Point	Normal Range	
		Low	High
pH (at reservoir temp)	6.25	5.8	7.0
Na	520	470	620
K	82	64	91
Ca	0.92	0.49	1.8
Cl	700	600	770
SO <sub>4</sub>	8.5	4.6	14.6
B	35	26	52
CO <sub>2</sub>	5600	3400	8600
H <sub>2</sub> S	200	100	250
NH <sub>3</sub>	4.9	3.4	6.2
H <sub>2</sub>	0.47	0.23	0.71
CH <sub>4</sub>	54	26	94
N <sub>2</sub>	43	27	69

GES consists of the three trains; each train is a three stage hybrid type and is sized as 40%, 60% and 80% capacity respectively. (Figure 1) The design point (100% capacity) of GES was defined as the NCG flow rate at the expected point. The 40%, 60% and 80% configuration provides flexibility to match the plant to variations in the NCG flow and the total 180% GES capacity is sufficient for the 'high case'.



**Figure 1: P&ID of gas extraction system**

At the design point, the suction pressure of the first stage ejector was determined as 0.068 bara according to the condenser internal pressure of 0.08 bara, and the suction piping pressure loss. The discharge pressure of vacuum pump was determined as 1.06 bara according to the atmospheric pressure of 1.00 bara and the discharge piping pressure loss. The turbine gland seal exhaust steam and air leakage were additional flow streams to be extracted by GES. The motive steam for ejectors was taken from HP steam supply line to turbine and its pressure was 11.0 bara. The cooling water for condensers and seal water for LRVs was supplied from auxiliary cooling water pumps

### 3.2 Design and Procurement Approach

The main condenser internal pressure was set at 0.08 bara. This low suction pressure required two stage steam jet ejectors, with a third stage LRVP.

After the NCG flow rate at the design point and the selection of GES type - 3 stage hybrid type were decided, the focus of design work was what is the most effective combination of ejector and vacuum pump. In other words, the combination was selected to minimize the steam and power consumption. Generally, the most effective combination would be smaller ejectors and larger LRVs to minimize ejector motive steam consumption rate. For evaluation purpose, 6.0 kg/hr of steam consumption for ejector was set as equal to 1.0 kW of power consumption for Kawaeru project.

Rather than outsourcing the whole gas extraction system to a single vendor, FES has designed the system and specified components in detail to minimize the steam and power consumption. Each component (i.e. ejector system and LRVP) was ordered individually from sub-suppliers to obtain the most efficient combination.

Though multi nozzle type ejector could reduce steam consumption when compared to a single nozzle design, single nozzle type was selected, in conjunction with Mighty River Power, since this would have less chance for nozzle scaling and was considered a more proven design. Direct contact spray type inter/after-condenser were chosen, in preference to tray type.

Stainless steel (SS316) LRVs driven by electric motor via gear reducer were specified. A design margin was added to allow for tolerances permitted under the relevant codes for acceptance of performance test results.

The preliminary sizing of ejector/condenser and LRVP were done by FES and the specification was given to various vendors. Through tender process and evaluation, the manufacturers of each equipment were selected individually. Then, final optimization of the design was achieved by coordinating details with each selected manufacturer and FES.

The front and side views of the GES are shown in Figure 2 and 3 respectively. The layout of GES was decided taking consideration of several constraints; a) Accommodating the long ejectors within the limited space. The longest ejector dimension exceeded 13 m. b) The GES location had to be as close as possible to turbine building in order to minimize pressure drop across gas extraction piping from the main condenser. In addition, the size of gas extraction piping was determined with all three trains operating. c) Accessibility for maintenance of ejector steam nozzle and condenser water spray nozzle were also considered.

Performance testing of the ejector and LRVP were completed at the manufacturers' workshop and the combined system performance was verified at site. The test results are reported in the following section.



Figure 2: Photo of gas extraction system (front view)



Figure 3: Photo of gas extraction system (side view)

#### 4. SHOP PERFORMANCE TEST OF EJECTOR

##### 4.1 Test Fluid

NCG was not available at the manufacturer's workshop, hence clean steam was used as the suction fluid. Correction for the effect of molecular weight difference ("entrainment factor") was applied according to the Heat Exchanger Institute standard.

Clean steam was also used as the motive steam, since the effect of 2.3 wt% of NCG is negligibly small.

##### 4.2 Performance Test by Model Ejector

The performance of the actual ejectors was estimated based on the results of performance tests on a scale model ejector. This test method is considered reliable and widely used as the characteristics of ejectors closely follow geometric similarity rules. Although performance testing of the actual ejector was possible, considerable time and cost savings were achieved by testing a scale model.

Two models were prepared, one for the first stage ejector and the other for the second stage ejector. The reason being that the nozzle diameter of the first stage of each train was almost the same as that of the second stage, but the ratio between nozzle diameter and diffuser diameter was different. The scale of the models of the ejectors was approximately 1/2 to 1/5 of the actual size for the 40%, 60% and 80% of the ejectors (both stages).

##### 4.3 Result of Performance Test by Model Ejector

The result of the performance test by model ejector is shown on Figure 4.

The test results show that a higher than design flowrate was extracted at the rated suction and discharge pressures i.e., ejectors satisfy the required performance. According to the HEI standard, the allowable tolerance on performance at the design point capacity is minus 3 %.

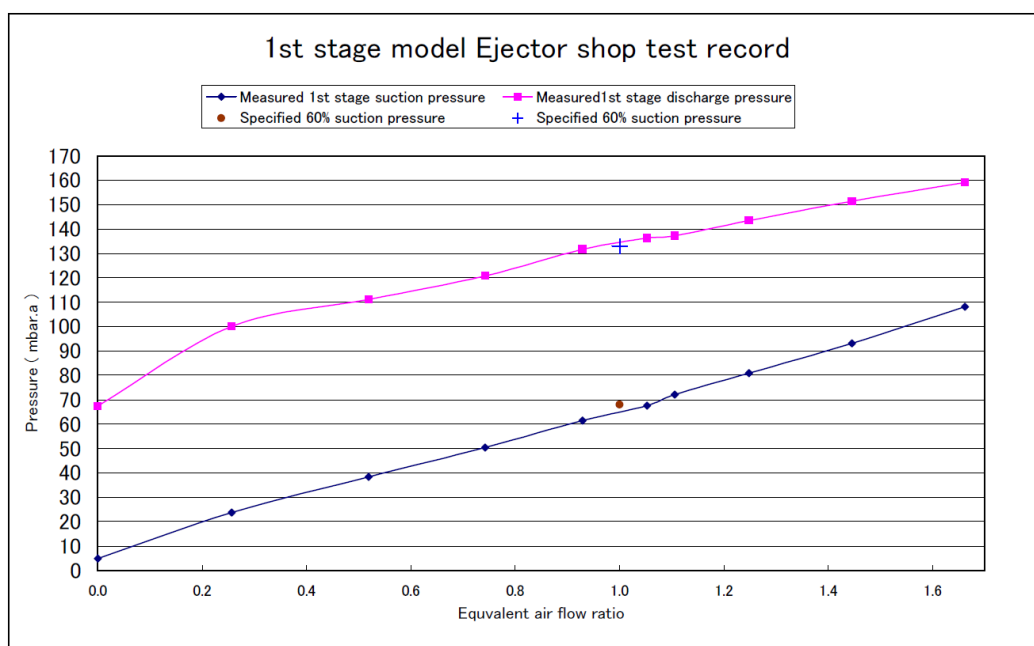


Figure 4: Shop test record of first stage ejector

## 5. SHOP PERFORMANCE TEST OF VACUUM PUMP

The performance of LRVP was tested at the manufacturer's workshop, using air as the test fluid. The test facility includes a motor equipped with torque meter. The rotation speed and seal water temperature deviations at shop test which affect the suction flow rate, were corrected according to the formula defined by HEI standard. Some differences between the HEI standard and test rig flow measurement were noted and accepted by Mighty River Power. The test results confirmed that the performance was satisfactory.

## 6. PERFORMANCE OF THE HYBRID SYSTEM AT SITE

The site performance test was carried out during the plant commissioning period. The actual operating fluid was used for the suction fluid and motive steam, i.e. the suction gas was NCG plus accompanying steam and the ejector motive steam was steam including 2.3 wt% NCG.

The ejector gas suction pressure, inter-condenser pressure and vacuum pump suction pressures were measured with temporally installed, high accuracy instruments (1/1000). The sensitivity is such that 0.01 bar variation in NCG suction pressure is equivalent to 17% variation in NCG flowrate at the ejector gas suction.

The test data was measured at turbine MCR condition, approximately 120% of the rated load, in other words high NCG flow rate condition. The motive steam sampled and analysed to measure the NCG content in steam. The NCG content was 1.5 times the rated. Namely, the NCG flow rate was approximately 1.8 times the design point of GES and all three trains were operated on the test day. This condition each train exceeded 105% of the design rating. The relationship between rated condition and MCR condition is shown on table 2.

Table 2: Rated condition & MCR condition

	Rated	MCR
Geothermal Fluid to Power Plant	45,000 ton/day	55,000 ton/day
Approx. Plant Net Output	90MW	106MW
Expected		
NCG % in HP steam	2.29wt%	2.41wt%
Required GES train	100%	100%
Actual at commissioning		
NCG % in HP steam	3.2 - 3.5 wt%	
Required GES train	180%	180%

Although the NCG flow rate at MCR is more than at the rated condition, 60%+40% GES trains have sufficient capacity since the condenser pressure is higher at MCR.

The characteristic curves and measured data of 80% train are plotted on Figure 5. This graph shows the performance data of both ejectors and the LRVP to confirm the entire hybrid GES performance in one graph.

The equivalent air flow rate of ejector suction at design point was defined as a capacity ratio of 1.0. The characteristic curve of the first stage shows the suction pressure run up when the flow rate exceeds the design point. This is because the suction pressure of first stage ejector is affected by pressure increase of the second stage and the third stage. This curve also shows that suction pressure of the first stage ejector was affected by the characteristic of LRVP. Suction pressure of ejectors over 100% capacity are

affected by suction condition of LRVP, so the curves of suction of ejectors are bent where the capacity ratio is 1.0. This means that GES can operate even if the suction flow rate exceed the design point, but the suction pressure of ejector run up and main condenser pressure will increase accordingly.

The suction pressure, measured at each stage of the GES train is below the suction characteristic curves. This means that the 80% train has performed better than designed. Similarly, the test records of the other trains showed the performance to be better than designed.

Inter and after condenser performance was evaluated by reviewing the suction pressure of the first stage ejectors. The suction pressure at the first stage of each GES train was lower than designed, it is assumed that all of inter and after condensers performed satisfactorily even with higher than design NCG levels.

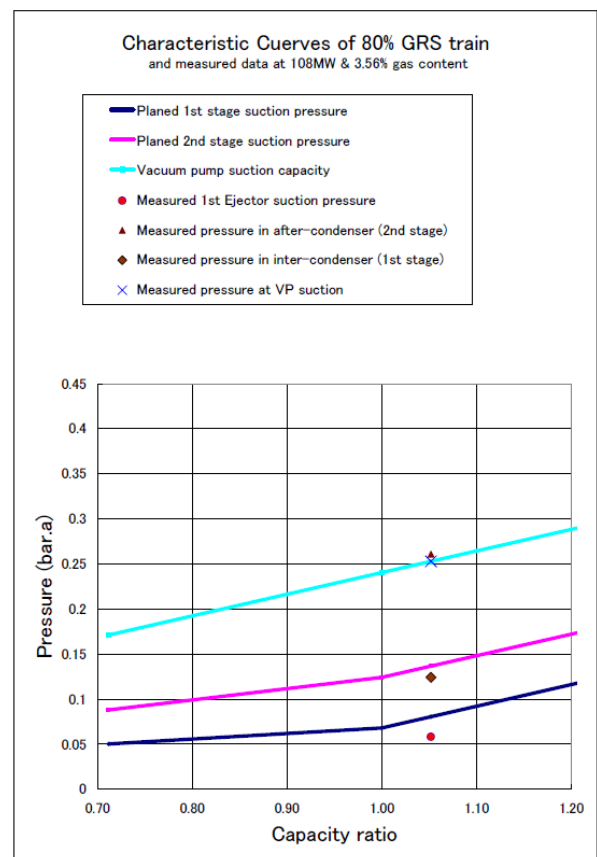


Figure 5: Site test record of 80% GES train

## 7. COMMISSIONING EXPERIENCE

The 90MW Kawerau Geothermal Power Station owned by Mighty River Power Limited (MRP), New Zealand was put into commercial operation in August 2008.

### 7.1 Number of Operation Trains

The NCG flow rate during commissioning exceeded 150% of the design point and all three trains were operated. After approximately eight months of commercial operation, NCG content was decreased and GES has been operating with 40% and 80% trains only. The 40-60-80% train configuration has been shown to provide flexibility to adjust to the changing reservoir conditions.

## 7.2 Sound Insulation

The ejectors generate, by nature of their operation, high noise levels. Noises emitted by an ejector during operation are comprised of air borne sound radiation and the discharge noise occurring at the discharge diffuser's end point. In addition, the condenser effectively works like a drum. Expected total sound pressure level of one ejector exceeded 100 dB(A).

The noise level exceeded the allowable limit at the power plant boundary point when GES was not covered with sound insulation. The insulation material specification was determined after the noise level was measured with no sound insulation. The insulation material was 50mm thick supatel fiberglass blanket. The sound barrier was 8 kg/m<sup>3</sup> barium loaded sheet. These were covered by 0.9mm aluminum cladding. The boundary noise limit was satisfied after sound insulation was installed. Table 3 shows the effect of noise insulation.

Table 3 : Noise Monitoring Data

Point	Before	After	Noise limits
Boundary (450m from power station)	68.4	44.0	Daytime : 55 Nighttime : 45
Near GES	approx. 113	approx. 90	–

## CONCLUSION

The performance of GES designed by FES was confirmed at both shop and site. This GES contributes to the entire plant performance. Also, the 40-60-80% train configuration has been shown to provide flexibility to adjust to the changing reservoir conditions.

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