# Rotokawa Upgrade Project: Midlife Geothermal Power Plant Development and Optimisation

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## ABSTRACT

Mercury operates the Rotokawa and Ngā Awa Pūrua geothermal power plants on the Rotokawa geothermal field located in the North Island of New Zealand. Over time, the geothermal fluid enthalpy has declined. The Rotokawa Upgrade project was initiated to mitigate the impact of this enthalpy decline on the generation output of the two power stations.

This midlife upgrade project sought to rebalance the steam and brine flows from the Rotokawa reservoir between the two power stations. The rebalancing was completed through the installation of two new separators and by increasing the brine processing capability of the Rotokawa Power Station. The project has extended the operational life of Ngā Awa Pūrua at design enthalpy and has resulted in a generation uplift at the Rotokawa power station.

The upgrade project was fully commissioned at the end of 2021. This paper presents the upgrade objectives, specific design aspects of the upgrade project, the performance of the generation equipment and ongoing optimisation efforts implemented over the two plus years since its completion.

## 1. INTRODUCTION

The Rotokawa geothermal field is in the Taupo Volcanic Zone 10km northeast of the Taupo township. The field has some of the highest temperature production fluids in New Zealand. The field has been developed for power generation in two stages. First, the Rotokawa (RGEN) power plant in 1998 and in 2010, the Ngā Awa Pūrua (NAP) plant was commissioned.

### 1.1 Rotokawa Power Plant

The Rotokawa Power Station (pictured in Figure 1 below) consists of a backpressure steam turbine and four binary cycle power units. Two-phase fluids from three production well pads are piped to a steam separator located at the station. Power is generated from the steam phase by a steam turbine generator (STG10). The steam turbine exhaust flows to two binary cycle power units (OEC11/12), where the steam is condensed and cooled for further power generation.

Brine from the station separator goes to a third binary plant (OEC01) for power generation. The cooled brine and steam condensate are combined for reinjection. In 2003 the station's generation capacity was increased to 34MW with the addition of another binary cycle unit, OEC21. This unit prior to the upgrade project used both steam and brine.

The separation plant pressure at Rotokawa (circa 25 bar g) is higher than typical for a geothermal plant reflecting high reservoir temperatures. The separation plant pressure was selected to optimise power generation from the high enthalpy fluid (Taylor, 1995).



**Figure 1: Rotokawa Power Station**

### 1.2 Ngā Awa Pūrua Power Plant

The 138 MW Ngā Awa Pūrua power plant (pictured in Figure 2 below) was commissioned in 2010. Located within two kilometres of RGEN the plant is a triple flash design with a single shaft steam turbine (Horie & Muto, 2010).

The NAP steam field consists of five production well pads and a central separation plant located at the power station. The operating pressure is slightly lower than the RGEN separator pressure at circa 24 bar g.



**Figure 2. An aerial photo of the Ngā Awa Pūrua power station. The three separators are pictured at the top left.**

### 1.3 Reservoir Enthalpy Decline

Since the original development of the Rotokawa Field in 1998 and as with all developed fields reservoir enthalpy has declined. Enthalpy decline is less than 1% per annum which is considered good by world standards. Enthalpy decline is


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expected and modelled to continue for a number of years before plateauing at a new natural state.

Field enthalpy is important in Geothermal Power Plant design as it determines plant technology selection and separation pressure.

The original design enthalpy of RGEN was circa 1550 kJ/kg however being a hybrid of back pressure steam turbine and binary technologies generation it is less susceptible to enthalpy decline than a flash plant such as NAP. Provided enough steam can be delivered to the steam turbine the plant to a degree can process higher brine flows with reinjection capacity being the primary constraining factor. Enthalpy decline, prior to the upgrade project had no impact on RGEN generation.

The design enthalpy of the NAP power plant was 1560 kJ/kg giving an output of 138 MWnet. The NAP flash plant design is more susceptible to enthalpy decline than a binary-hybrid plant. Figure 3 below shows the plant characteristic giving theoretical generation over a range of enthalpies. Relatively little generation decline is seen with enthalpy changes from 1560 to 1470 kJ/kg. However, after this generation decline becomes more severe.

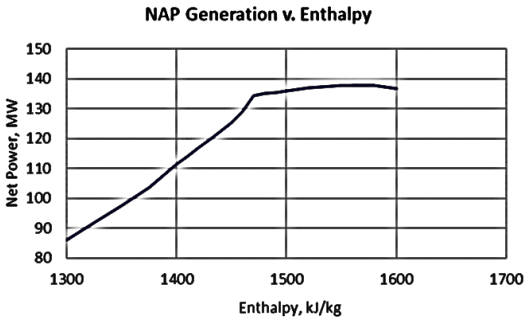



**Figure 3: Ngā Awa Pūrua Station Characteristic for generation at given enthalpy values.**

The mechanism responsible for this decline in generation is the total mass flow limit of the steam turbine. To maintain the same high pressure (HP) steam flow rate means increased brine flows must be accommodated by the plant. The HP brine is flashed to produce intermediate (IP) and the IP brine flashed to create low pressure (LP) steam.

This increase in IP and LP steam flow eventually reaches the mechanical limit for the steam turbine. To stay under the maximum allowable flow the total flow to the station must be decreased which also decreases the flow of HP steam. This associated reduction in HP steam has a significant effect on generation.

## 2. PROJECT OBJECTIVES

Commissioned in 2021, the Rotokawa Upgrade project was initiated in response to reservoir enthalpy decline (increasing brine flow for the same steam production). The field enthalpy at the time of project initiation was circa 1500 kJ/kg. Objectives for the project were to,

- Maximise combined generation from Rotokawa (RGEN) and Ngā Awa Pūrua (NAP) stations by reallocating steam and brine flows to each,
- Operate within the resource consent basis with respect to reservoir take, avoiding a significant step change in total flow from the reservoir; and
- Include flexibility to reduce exposure to a change of the performance of any one well.

## 3. CONCEPT PHASE

### 3.1 Option Analysis and Selection

To achieve the project objectives more than 18 options were developed, assessed and screened to short list and select the final upgrade design concept. The high-level screening compared relative risk and Net Present Value (NPV) and the values for the options considered are plotted in Figure 4 below.

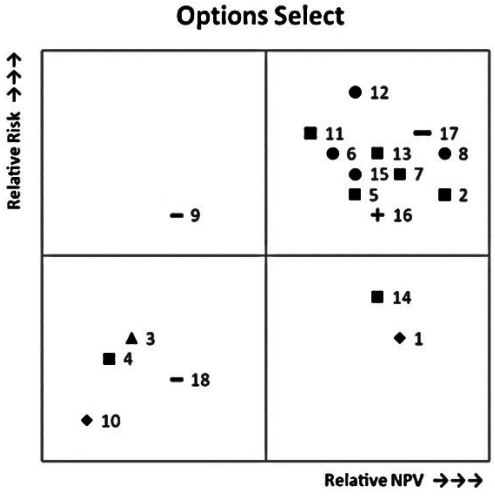



**Figure 4: Rotokawa Upgrade Option Select plot, comparing relative risk and Net Present Value.**

All options are presented in the plot in Figure 4 above. These included,

- A steam field separator to increase enthalpy to NAP and upgrade of brine processing (OEC units) at RGEN (Options 1, 2)
- Optimisation of existing wells (Options 3, 4)
- Increase hot brine to reinjection, low pressure venting (Options 7, 8)
- Replace the entire RGEN station with a new binary plant (Option 9)
- Do nothing (Option 10)
- Increase NAP low pressure steam or brine system capacity (Option 13, 17)
- Pump high-pressure brine from NAP to RGEN and upgrade brine processing (OEC units) at RGEN (Options 14, 15)

Two options were shortlisted for further analysis,

- Option 1. A steam field separator to increase enthalpy to NAP and upgrade of brine processing (OEC units) at RGEN; and


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- Option 14. Pumping of high-pressure brine from NAP to RGEN and upgrade of brine processing (OEC units) at RGEN.

On balance Option 14, the brine pumping system had a slightly lower NPV and although technically feasible, ongoing OPEX through electricity and maintenance costs and scaling risks made this option less attractive than the separator option, Option 1.

### 3.2 Selected Option

The selected option was to install steam field separation to remove some brine from the NAP H-Line production pipeline and transfer this brine to the RGEN steam separator. By removing a certain quantity of brine this artificially increases the enthalpy delivered to NAP, restoring it to its design value. This removes the generation constraint due to excess brine, provided an initial uplift and offsets future generation loss due to declining reservoir enthalpy.

At RGEN, a series of modifications convert it to a 'lower' (from 1550 to 1250 kJ/kg) enthalpy station ensuring higher brine flow can be processed and used for generation. Configuration changes to OEC21 allowed this unit to use brine only and provided a generation uplift from the unit.

No modifications were required at the NAP power station.

Figure 5 below shows process flow diagrams for the original design and the upgrade project. Figure 6 shows an aerial view of the project scope.

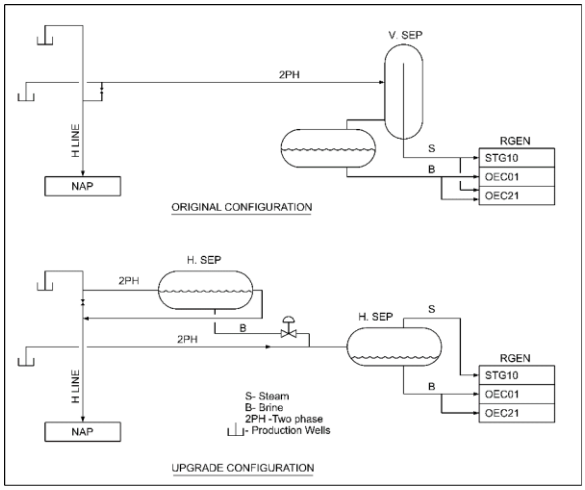



**Figure 5: The Rotokawa Power Station, RGEN before and after The Rotokawa Upgrade Project.**




**Figure 6: Scope of the Rotokawa Upgrade Project**

## 4. SPECIFIC DESIGN ASPECTS

### 4.1 Steam field Separation

The H-Line Separator (Steam Field Separator) (pictured in Figure 7 and Figure 8) was designed to transfer a portion of brine from the NAP H-Line production pipeline to RGEN.

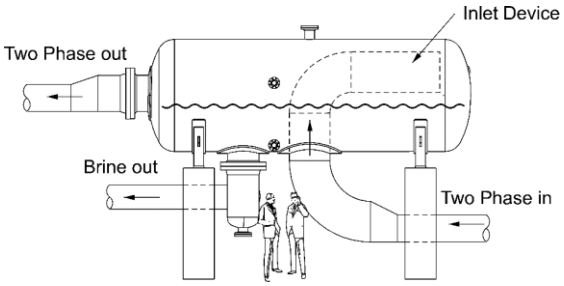



**Figure 7: Diagram of the H-Line Separator**

Details on the design for this are covered in a previous paper (McLellan, 2021) and include,

- The specification is unusual for a separator as only a portion of the total brine flow is required to be separated from H-Line, and steam quality is not a concern.
- Key design considerations for the H-Line separator centred around the stability of the system to ensure stable generation and safe operation of RGEN and NAP.
- A horizontal separator was selected as it was considered most likely to meet all the performance requirements, specifically the ability to control the brine offtake to RGEN and to minimise surges of flow to NAP



**Figure 8: Photo of the H-Line Separator (two-phase inlet from right)**

### 4.2 Station Separator

Throughout the course of the project high level design phase, it became apparent that by doubling the brine flow to RGEN, the existing station separator and accumulator were not adequate to accommodate increasing brine flow rates. This led to a new station separator (pictured in Figure 9 and Figure 10) being included in the project scope. Details on the design for this are covered in a previous paper (McLellan, 2021) and include,

- As the RGEN separator supplies steam to a steam turbine, separator performance (brine carry over) was a key design parameter for the separator.

- A horizontal separator design was selected for this service due to the combination of low enthalpy and high pressure (low steam fraction). These operating parameters were outside the range for traditional vertical separator sizing methods.

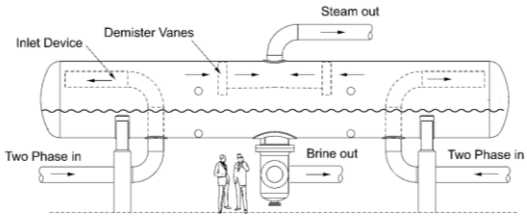



**Figure 9: Diagram of the Rotokawa Separator**



**Figure 10: Photo of the Rotokawa Separator, two-phase inlet from the front**

### 4.3 Brine Dump Facility

A new brine dump system was designed to replace the pre-existing RGEN dump facility which diverted brine through the brine bypass valve to the reinjection system and the RK11 reinjection pond.

The system was designed to provide improved separator high level protection and the ability to continue brine transfer from the H-Line separator for a few hours of operation (e.g. brine unit maintenance or a plant trip) without affecting enthalpy (and thereby generation) at NAP.

The design included two 100% capacity dump valves to divert brine directly from the RGEN Separator to the brine dump pond via a silencer. The dump valves open on separator high level according to the level control hierarchy.

The pond volume was designed for circa eight hours of brine flow from the plant. Brine disposal is through soakage.

### 4.4 Acid Dosing System

As the project changed the enthalpy to the RGEN Separator and hence the reinjection fluid ratio of condensate to brine. The condensate is recombined from two OEC bottoming units (OEC11/12) which condense low pressure steam from the steam turbine.

This lower ratio of condensate to brine significantly increases the pH and the silica concentration of the combined reinjection fluid. Both these factors increase the silica scaling potential of the reinjection fluid.

To mitigate the risk of silica scaling in the reservoir, brine is pH modified via sulphuric acid injection. By controlling acidity to a target pH of 5 the kinetics of the formation of silica scale are significantly reduced allowing the fluid to be dispersed within the reservoir before significant scaling can form. This strategy is employed at NAP and to date has proven to be successful for the reinjection system.

Acid is introduced upstream of the brine units to address silica scaling kinetics before oversaturation of the brine in the heat exchangers and therefore the risk of generating silica seeds. Silica seeding significantly increases the risk of nucleate colloid formation downstream, the reservoir being of primary concern.

The use of 80°C condensate for predilution decreases risk around the heat of dilution and flashing during pre-injection mixing. Increased dilution of the acid prior to injection further lowers the corrosion risk but also the temperature of the brine.

To ensure generation from the brine units is not affected by cooler brine only part of the condensate is directed for acid dilution. The cooling effect of adding condensate also serves to sub-cool the fluid and allows for some pressure drop without flashing along subsequent mixing processes such as the static mixers.

Mixing is required to further dilute the acid as soon as possible after injection to limit the requirement for corrosion resistant materials and better achieve pH modification. pH measurement is downstream of OEC01 and OEC21.

A photo of the Acid Dosing system area is in Figure 11 below. Equipment for the acid dosing system included,

- 24m³ stainless steel Acid Storage Tank
- 2 x 100% Acid Dosing Pumps
- Tantalum lined Pre-mixer (condensate and acid)
- 2 x 100% Condensate Booster Pumps (centrifugal)
- 500 NB Hastelloy static mixer in the main brine line from the separator (brine and pre-mixed acid)
- OEC01 and OEC21 heat exchanger tubes were specified as duplex



**Figure 11: Photo of the Rotokawa Acid Dosing System**

### 4.5 OEC21 Conversion and Uprate

Commissioned in 2003, OEC21 unit used both steam and brine and on average generated at 5.3 MW. The project

scope converted this unit to a brine only unit and uprated it to 8.3 MW net, an increase of 3 MW.

The scope of the Ormat unit conversion included replacement of the geothermal heat exchangers (Preheater and Vaporiser), new larger pentane feed pumps and additional cooling through an extra condenser bay. Figure 12 below shows an isometric view with the larger, additional cooling bay to the left.

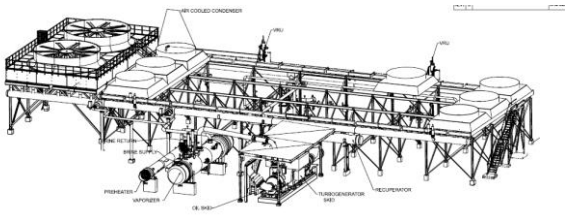


**Figure 12: Isometric view of the OEC21 unit.**

## 5. COMMISIONING

Commissioning for the project was completed over a few months commencing in April 2021. Commissioning phases for the project included,

- Commissioning of modified utility systems – air and water.
- Cold Commissioning activities including acid system first fill prior to geothermal wells flowing to the plant.
- Steam Blow to a temporary silencer carried out over several days to ensure modified steam separation plant and piping was free from debris (steam turbine protection).
- Separator brine dump capacity testing
- RGEN Generation – steam turbine, OEC11/12 and OEC01
- H-Line Separator Brine Transfer; and several months later
- OEC21 commissioning.

Prior to OEC21 completion and commissioning a serious steam hammer incident occurred at the site resulting in loss of containment. Lessons learned from this incident are presented in Lemmens (2024).

## 6. EARLY OPERATIONS

After commissioning had taken place and the plant handed back to Operations, several issues were encountered that impacted the availability of the RGEN plant. The main issues are discussed in the following sections.

### 6.1 RGEN Separator Emergency Dump Valves

The installed 8" separator dump valves (triple offset butterfly type) were found to be unreliable in operations as they frequently fail to open/close on demand. The issues were exacerbated by the hot brine bypass line being out of commission and the dump valves were required for modulating separator level.

The high temperature and high pressure drop service for these valves is challenging and as experienced at other Mercury assets getting an optimal solution continues to be problematic. Using the valves for level control causes a significant pressure drop leading to silica deposition on the valve seat and stem.

It was concluded that the issues experienced were a combination of valve and actuator design. To ensure more reliable operation, the valves were replaced (triple offset and a globe type) and actuators with larger torque were procured to improve reliability.

### 6.2 Brine Bypass

The paper Lessons Learned from the Rotokawa Condensation Induced Water Hammer Incident, Lemmens (2024) discusses issues around the brine bypass valve that contributed to the serious steam hammer event during commissioning.

Redesign of the brine bypass valve system to mitigate the risk of a similar event took place. This resulted in a smaller sized valve in conjunction with additional instrumented protective functions have resulted in a significant reduction in dumping of brine to the pond (see Section 6.1).

### 6.3 OEC21 Feed Pump Double Mechanical Seal Leakages

OEC21 pentane feed pumps are fitted with double mechanical seals; however, it was found that the mechanical seal of the left hand side feed pump was prone to leak after a short period in service, requiring regular replacement. The seal life before leakage in service from December 2021 to December 2023 varied from two days to 47 days (longest).

As there are no standby pumps for this unit, each time a seal replacement is required generation output is de-rated. A cross-collaboration effort between the Operations and Engineering teams (process, mechanical, control systems) with some assistance from Ormat, was undertaken to address the issues that contributed to the increased leakage. This included pump/shaft alignment, startup and logic changes, introduction of collector level limits to ensure sufficient pentane levels. The learning from this unit is applied to other OEC units operated by Mercury.

### 6.4 Other Issues

OEC21 stability was also challenged by the sizing of the heat source valve where it was significantly oversized causing fluctuations in pressure and power generation. These stability issues had a cascading effect on the acid dosing system as pressure and flow swings caused frequent trips leading to pH excursions within the station.

To address these issues, logic changes were implemented to improve pH control and reduce the frequency of the trips. The long term solution involved resizing the valve. The newly installed, smaller valve resulted in better control, leading to a higher average output from the unit.

The upgrade also introduces additional operational complexity at both plants due to the connection between RGEN and NAP, particularly during station trips.

## 7. CURRENT OPERATIONS AND OPTIMISATION EFFORTS

Since commissioning, significant efforts have been made to enhance the availability of both stations to maximise efficiency. In the financial year ending June 2024, NAP achieved its record annual generation while RGEN recorded its best availability in four years.

The upgrade project which involved sending higher enthalpy fuel to NAP was successful, resulting in a significant uplift in plant enthalpy back to design levels and subsequently leading to a higher net generation at NAP (più sottoFigure 13).

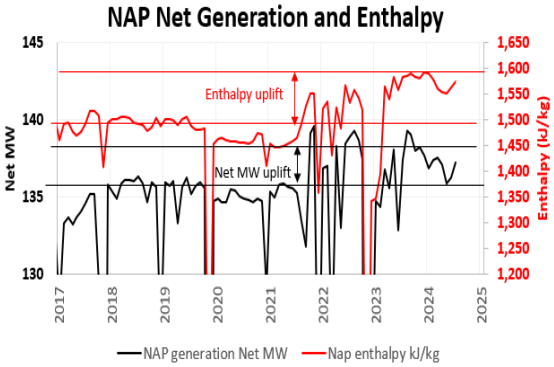



**Figure 13: Plot showing NAP enthalpy and generation uplift after commissioning of the Rotokawa Upgrade.**

The conversion of OEC21 to brine was also successful in uplifting the total generation of the unit as shown in Figure 14 below.

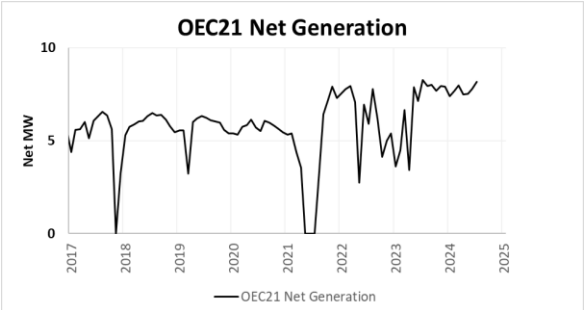



**Figure 14: OEC21 net generation history from 2017 to current showing the uplift**

At the time of writing, the focus is on automating and tuning the brine system in Rotokawa to minimise the need for Operator interventions, ensuring stable operations and to maximise the output from both stations. These efforts are part of a broader strategy to leverage advanced process controls and a data driven approach, positioning both stations for sustained high performance and availability.

## 8. CONCLUSION

The Rotokawa Upgrade project was a midlife upgrade project to reduce the effect of declining reservoir enthalpy on generation at NAP. The project had many interesting aspects similar to many geothermal developments including acid injection, horizontal separation and enthalpy management.

Challenges in commissioning and early operation affected generation and reliability and have taken a number of months to systematically work through and resolve. The culmination of these efforts has resulted in the project aims being realised (generation uplift) and furthermore record generation and availability performance for both NAP and RGEN stations.

## ACKNOWLEDGEMENTS

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