Steam Separator Selection for a Geothermal Power Station

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ABSTRACT

Mercury operates the Rotokawa and Nga Awa Purua geothermal power plants on the Rotokawa geothermal field located in the North Island of New Zealand. As part of the Rotokawa Upgrade project, Mercury installed two horizontal steam-brine separators in 2021. The horizontal separator design was a first for Mercury and two of only a few of those installed within the New Zealand Geothermal industry. This paper discusses the analysis and decision-making process undertaken to select the horizontal separator design over a more traditional vertical separator. The separators were commissioned in mid-2021, and the paper presents preliminary results on their performance.

1. INTRODUCTION

The Rotokawa geothermal field is located 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 Nga Awa Purua (NAP) plant was commissioned.

1.1 Rotokawa Power Plant

The 34 MW 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). Rather than a condenser, the steam turbine exhaust flows to two binary cycle power units (OEC11/12), where the steam is condensed and cooled for further power generation. The brine 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 uses both steam and brine.

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

Figure 1. An early photo of the Rotokawa Power Station, with Lake Rotokawa and Mount Tauhara in the background. OEC21 is located to the left of the plant site. The Production line running to the original vertical separator is from the right.

1.2 Nga Awa Purua Power Plant

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

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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.

When the NAP steam field was built, a simple piping cross over known as the 'Interconnect' was installed between the RGEN and NAP two-phase lines to allow sharing of production fluids. However, due to changing pipeline pressure, this installation was rarely used. Further to this, the piping configuration meant an uneven and uncontrollable split of steam and water flow between the two pipelines. Despite the limited use of the 'Interconnect', the idea of sharing or 'rebalancing' production fluids between the two power stations endured and eventually led to the Rotokawa Upgrade Project.

Figure 2. An aerial photo of the Nga Awa Purua power station. The three separators are pictured at the top left.

2. ROTOKAWA UPGRADE PROJECT

Commissioned in 2021, the Rotokawa Upgrade project was initiated in response to reservoir enthalpy decline (increasing brine flow for the same steam production). The upgrade project uses steam field separation to remove some brine from the NAP H-Line production pipeline and transfers this brine to the RGEN steam separator. This artificially increases the enthalpy delivered to NAP, restoring it to its design. This removes the generation constraint due to excess brine, provides an initial uplift and offsets future generation loss due to declining reservoir enthalpy.

At RGEN, a series of modifications convert it to a 'lower' (circa 1250 kJ/kg) enthalpy (high brine fraction) station ensuring the increased brine flow can be processed and used for generation. Configuration changes to OEC21 allowed this unit to use brine only and also provide a generation uplift from the unit. Two new steam separators were required to achieve the Upgrade project's aims,

1. H-Line Separator (Steam Field Separator) to transfer a portion of brine from the NAP H-Line production pipeline to RGEN; and
2. Rotokawa Separator (Station Separator) to separate the lower enthalpy fluid and feed STG10 and the brine binary units OEC01 and OEC21.

Figure 3 below shows the configuration of RGEN before and after the upgrade project. In 2018 the concept for the Rotokawa Upgrade project began to take shape. Initially, this first focused on the Steam Field Separator (H-Line Separator).

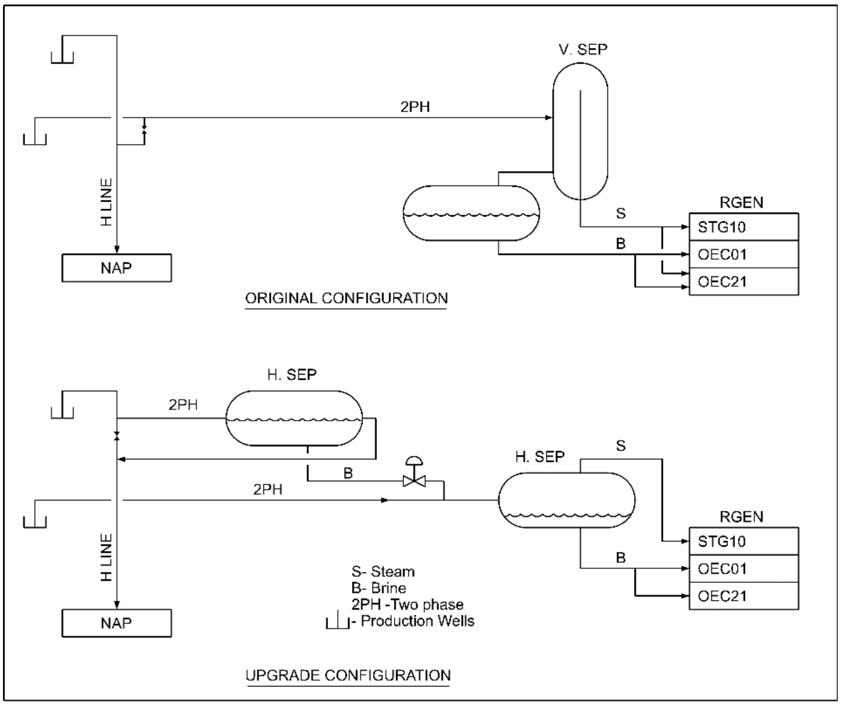

Figure 3. The Rotokawa Power Station, RGEN before and after The Rotokawa Upgrade Project.

3. SEPARATOR DESIGN

3.1 H-Line Separator Specification

The H-Line Separator was specified to separate a portion of brine and transfer it to RGEN. The remaining, higher enthalpy fluid continues to NAP, increasing its enthalpy and thereby achieving a generation uplift. The specification given in Table 1 below 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. Entrainment of steam in the brine flow to RGEN needed to be minimised, and smooth, consistent flow of the higher enthalpy fluid was required to feed NAP. Both these aspects were considered important to ensure stable generation and safe operation of RGEN and NAP.

Unconventional separator designs were investigated. This included consideration of a vertical pass through separator, an 'inline' separator with a simple pipeline bottom take-off (Koorey, 2008) and a horizontal separator. The 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

Table 1. Design Specification for the H-Line Separator

Variable	Units	Design
Inlet Pressure	bar g	29.5
Inlet Temperature	°C	235
Inlet Flow	t/hr	1500
Inlet Enthalpy	kJ/kg	1465
Brine Flow to RGEN[1]	t/hr	480
[1]Brine flow to RGEN, the remaining brine is recombined with the steam and delivered to NAP (via H-Line)		

2.2 Rotokawa Station Separator Specification

In parallel to the H-Line Separator design process, it became apparent that by doubling the brine flow to RGEN, the existing station separator and accumulator were not adequate to accommodate the increased brine flow rates. This led to a new station separator being included in the project scope.

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

Table 2 below gives design parameters specified for the RGEN Separator.

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Table 2. Design Specification for the Rotokawa Separator

Variable	Units	Design
Inlet Pressure	bar g	25.8
Inlet Temperature	°C	228
Inlet Flow	tph	1000
Inlet Enthalpy	kJ/kg	1245
NCG Content in Steam	%wt	1.3

3. VERTICAL STEAM SEPARATOR DESIGN

3.1 Vertical Separator Design

Vertical separators have long been used in New Zealand Geothermal developments. Vertical cyclone bottom outlet separators were developed in New Zealand for the Wairakei project (Bangma, 1961). Later, sizing calculations for vertical separator design were published (Lazalde-Crabetree, 1984).

The design parameters for the RGEN Separator (refer to

Table 2 above) are unusual for a geothermal separator design. The pressure is high (high steam density), and the steam fraction is relatively low. This is due to brine transfer from H-Line lowering the enthalpy. A geothermal field producing an enthalpy of circa 1250 kJ/kg would typically result in an optimal separation pressure in the order of 12 bar g.

The RGEN separator design point has a low steam fraction of 14% (by weight), and the inlet line flow is well into a slug flow regime (Spedding & Nguyen, 1980), more so than any other separation plant in New Zealand. In

KEY		
◆	RGEN 1	Original Rotokawa Separator
◆	RGEN 2	Original Rotokawa Separator for Rotokawa Upgrade parameters
◆	RGEN 2*	New vertical separator Rotokawa Upgrade parameters and sized for Lazalde-Crabtree range
●/■	MBC	MB Century Measured Operating Data close or over 1% carry over

Figure 4 below, separator operating points of the RGEN separators are plotted with inlet superficial steam velocity on the X-axis and total mass flux on the Y-axis. High Y values correspond to a high liquid fraction (low steam fraction).

MB Century has field measurements that indicate steam-water separation breaks down (defined as more than 1% carryover) at specific operating points. This is represented as the diagonal line to the right of the graph.

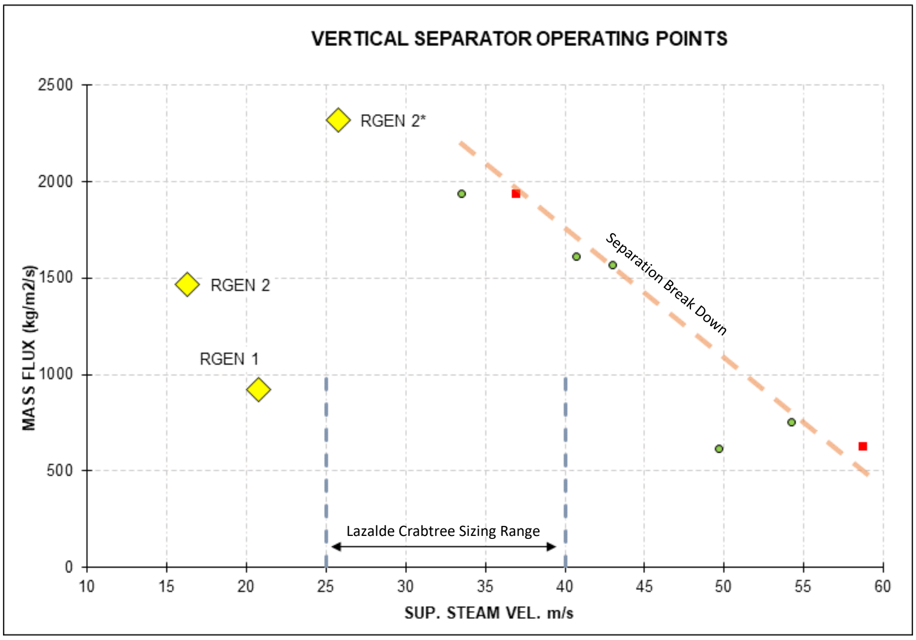

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Figure 4. Vertical Separator Operating Point, with Mass Flux plotted against Superficial Steam Velocity

The Lazalde-Crabtree sizing steam velocity range is shown in Figure 4 above. This method of sizing separators does not consider high liquid fraction feeds. The new RGEN (Point RGEN 2*) design parameter plotted in Figure 4 is approaching the planned line (dashed) for separation breakdown.

Using the original RGEN vertical separator (point RGEN 2) for the new Rotokawa Upgrade design would have kept the operating point the same distance from the breakdown line as the pre-upgrade operating point (RGEN 1), but the lower velocity would have made the vertical separator susceptible to unstable flow and vibration and likely contribute to poor separator performance.

In comparison, the separator design points from other Mercury power stations were analysed and found to be within or close to the suggested Lazalde-Crabtree validity range. From this analysis, it became apparent that designing a traditional vertical separator was not necessarily a low-risk option for the project.

4. HORIZONTAL STEAM SEPARATOR DESIGN

Horizontal separators are used in many other industries and in geothermal applications in Iceland, America and other geothermal regions in the world for separating steam and brine.

A key driver for the use of horizontal separators in Iceland is the separators need to be housed in a snow/weatherproof building. Therefore, a shorter/lower design is preferable over a tall vertical design. Horizontal separators are commonly used in many other industries, including thermal power plants and oil and gas plants. The gravity separation mechanism and its design are well defined.

Mercury engaged Verkis Consulting Engineers based in Iceland to carry out the process design for the Rotokawa Upgrade separators. Verkis were selected for their experience in horizontal geothermal separator design. The separators were mechanically designed and fabricated in New Zealand by ACME Engineering Ltd in Petone.

4.1 H-Line Separator

The H-Line separator is shown in Figure 5 and Figure 6 **Error! Reference source not found.**. As high steam quality was not required, a knockout drum with an overflow outlet was designed.

Two-phase fluid enters the separator through a bottom entry nozzle. A vane inlet device first reduces fluid momentum and directs liquid droplets towards the walls to aid with separation. As the two-phase fluid progresses along the length of the separator, gravity separates water droplets from the steam phase. Brine is transferred from the bottom boot of the vessel to RGEN.

A level control valve on the RGEN brine line prevents the vessel from draining and steam passing to RGEN. The same valve also modulates to meet the brine flow required by OEC01 and OEC21. The balance of the brine exits with the steam flow and 'overflows' from the separator back to the H-Line.

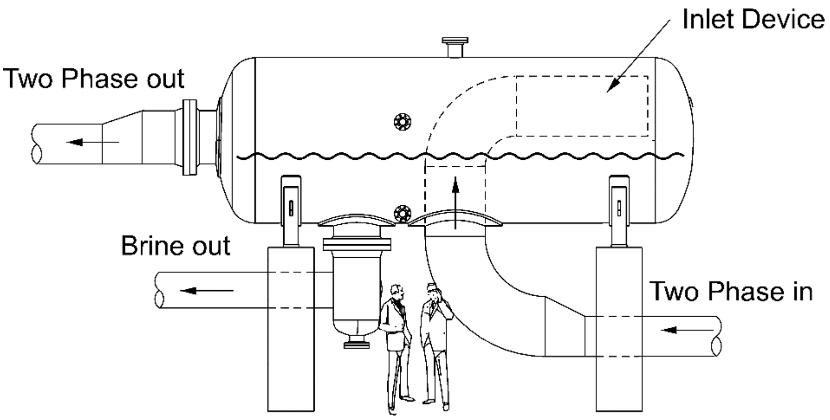

Figure 5. Diagram of the H-Line Separator

Figure 6. Photo of the newly completed H-Line Separator (two-phase inlet from right)

4.2 Rotokawa Separator

The Rotokawa Separator has two two-phase bottom entry inlet nozzles (through vane inlet devices), a single brine outlet and a top steam outlet nozzle (Figure 7 and Figure 8). While the separator could have been designed with a single inlet nozzle, this would require a larger diameter to maintain steam velocities. A longer vessel with a smaller diameter and wall thickness is more cost-effective. Demister baffles installed in the steam chamber remove water droplets from the steam. The droplets drain to the bottom of the vessel.

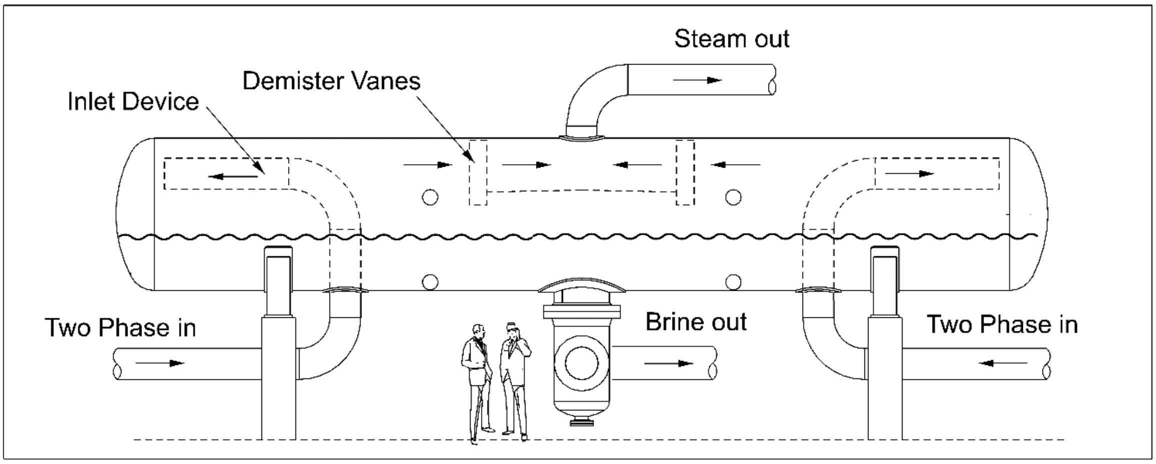

Figure 7. Diagram of the Rotokawa Separator

Figure 8. Photo of the near-complete Rotokawa Separator (insulation is partly complete), Two-phase inlet from the left

5. SEPARATOR OPERATION

5.1 H-Line Separator

Early operating experience, the H-Line separator has been good. Stable flow to NAP of high enthalpy fluid and continuous flow of brine to RGEN has been achieved.

5.2 Rotokawa Separator

Early experience from operating the RGEN Separator compared to the previous separator has also been encouraging. After commissioning, improved steam pressure control (e.g. in response to process upsets) was observed. The risk of high-pressure events and rupturing of burst discs has been significantly reduced. Likewise, level control and slug/surge capacity has enabled improved operation.

Two key aspects of the new design are credited with this improvement in operation.

1. The overall vessel and piping design have increased the steam field (production wells to turbine) working steam volume by 20%. The higher volume decreases the rate of pressure rise during upsets. There is also a larger area of exposed water surface within the separator.
2. The geometry of the system has been simplified with improved hydraulics. This is through shorter vertical inlet piping to the separator and removal of a loop seal and balance pipe (between the old separator and accumulator).

6. SEPARATOR PERFORMANCE

Separator performance is defined as the amount of brine carryover or lack of it in the steam phase at the outlet of the separator. High separator performance is essential to prevent damage from mineral scaling (e.g. silica, sodium) of downstream equipment, i.e. the steam turbine.

Typical separator design performance is very high, greater than 99.997% steam. However, actual values or practical verification of this is difficult due to limitations in sampling and analysis methods. (Rivera-Diaz & Koorey, 2021)

Without the tangential separation mechanism from a vertical separator, the separator performance is highly reliant on demister performance. Demister equipment suppliers quote performance in terms of 99% removal of droplets over a certain size (in the example of RGEN this was 14 microns). With the distribution of droplet sizes unknown, it is inherently difficult to translate to a separator performance.

At the time of writing separator, performance tests were incomplete. However, results look promising, and steam purity (silica concentration) at the steam turbine as measured by an online analyser has been reduced. This improvement cannot solely be attributed to separator performance as the increase in steam piping lengths, and the existing steam purifier will also play a part in this improved steam quality.

7. CONCLUSION

Two horizontal separators were selected for the Rotokawa Upgrade project. The H-Line Separator is a knockout pot design with an overflow outlet. The RGEN Separator is a more traditional horizontal design and supplies the RGEN station with steam and brine.

The new RGEN Separator process conditions were well away from other Mercury separator installations (all vertical), which led to the selection of a horizontal separator. This was primarily due to the combination of low enthalpy and high pressure. This low steam fraction is outside the range for traditional vertical sizing methods (Lazalde-Crabetree, 1984)

The H-Line and Rotokawa Separators were commissioned in mid-2021. Early operating experience of both these separators has been encouraging with improved control and stability.

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