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Low Pressure Flash-Steam Cycle at Hellisheidi – Selection Based on Comparison Study of Power Cycles, Utilizing Geothermal Brine

Gudmundur Kjartansson

Reykjavik Energy, Baearhalsi 1, 110 Reykjavik, Iceland

gudmundur.kjartansson@or.is

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ABSTRACT

This paper describes a selection of power generation cycles, utilizing separated brine, at the Hellisheidi geothermal field.

Reykjavik Energy made the decision to construct a combined heat and power plant (CHP-plant) at Hellisheidi in 2001. Initially electrical power was supposed to be generated by high-pressure (HP) separated steam, followed by heat generation for district heating in the Reykjavik area, using separated brine.

Exploration of the geothermal field for the planned CHP-plant indicated a wet-steam reservoir with excess amounts of separated brine for heat generation.

The utilization of excess separated brine was examined and compared using three different cycles: Organic Rankine cycle (ORC), Kalina cycle and low-pressure (LP) flash-steam cycle. In the end the LP flash-steam cycle was selected as the most viable option for the Hellisheidi plant.

This paper also describes the operation of the selected power generation cycle and its planned future development.

1. INTRODUCTION

Reykjavik Energy owns and operates the Hellisheidi geothermal plant. It is located in SW-Iceland only 20 km east of the capital of Reykjavik. The main pivotal points in its history are as follows.

2001: Permission to continue geological fieldwork and to start exploration drilling.

2003: Following the drilling and testing of numerous wells, various geothermal cycles were studies in relation to the results acquired at Hellisheidi. The results were to suggest and implement a single a conventional geothermal single-flash cycle generating 80 MW_e using separated HP steam, followed by heat extraction from separated brine for district heating in Reykjavik.

2004: Research suggested that the geothermal field would yield relatively more separated brine than first suspected and more than needed for the planned district heating system. It therefore became apparent the excess brine could be used for diverse purposes, i.e. electrical production. Following feasibility studies for the most economical and reliable power generation, three cycles were examined, i.e. Organic Rankine cycle (ORC), Kalina cycle and the LP flash-steam cycle.

2005: The LP flash-steam cycle chosen for the Hellisheidi plant.

2006: Two HP flash-steam cycle units are commenced, each consisting of a single 45 MW_e turbine generator condensing unit.

2007: A single LP flash-steam cycle unit is commenced. Consists of a 33.6 MW_e turbine generator condensing unit. Since the initiation of the LP flash-steam cycle unit in 2007, most wells drilled have proven to be high-enthalpy wells. Therefore, excess steam is available but there is a shortage of brine. To run the LP flash-steam cycle unit successfully, only part of the steam is supplied from flashed steam and part of it originates as pressure reduced HP flash-steam.

2008: Two more HP flash-steam cycle units are commenced, each consisting of a single 45 MW_e turbine generator condensing unit.

2009: The total current capacity at the Hellisheidi power plant is 213.6 MW_e.

Most of the planned expansion in the next year is connected with heat generation for district heating in Reykjavik. There will also be emphasis on providing enough brine for the LP flash-steam cycle.

Simplified flow diagram of the planned CHP power plant is shown in Figure 1.

NB: At Hellisheidi, pressure at 8-9 bar_a is defined as high pressure (HP), while pressure at 2 bar_a is defines as low pressure (LP).

2. THE SUGGESTED POWER GENERATION CYCLES

By the year 2004, the average well enthalpy averaged around 1200 kJ/kg steam. For 80 MW_e of steam generated electricity this meant that some 600 kg/s of brine at 175°C were available for space heating purposes. As this amount far exceeded the expected requirements for heat generation, the excess brine was considered for electrical power generation. Feasibility studies were therefore done to determine the most economical and reliable power generating cycle using excess brine. The three cycles were examined, i.e. Organic Rankine cycle (ORC), Kalina cycle and the LP flash-steam cycle.

The main brine parameters were as follows: Flow 600 kg/s, inlet temperatures 175°C, pressure 9 bar_a. The sub-cooling of the brine were optimized to 80°C when used in the ORC- and Kalina cycles, and 120°C when used in the LP flash-steam cycle. The brine at Hellisheidi is considered to qualify for heat extraction or sub-cooling. Despite some content of amorphous silica in the brine, no extensive scaling is expected.

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2.1 Organic Rankine Cycle (ORC)

At present commercial ORC units have not been manufactured larger than 8 MW. In the case of Hellisheidi at least four such units would be needed to utilize the brine. Figure 2 shows how the ORC could utilize the brine at Hellisheidi.

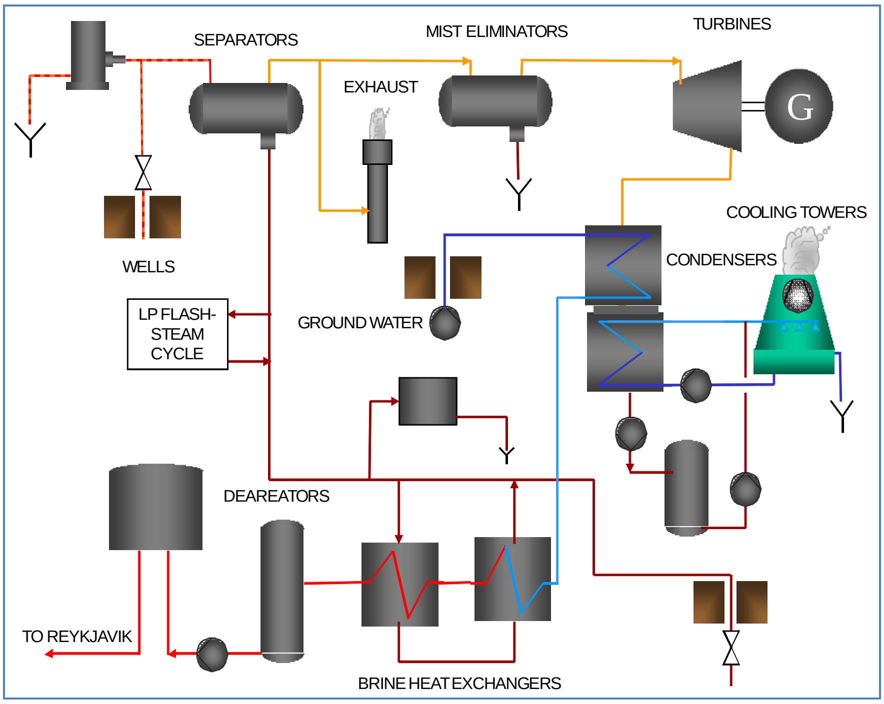

Figure 1: Simplified flow diagram of the planned CHP plant

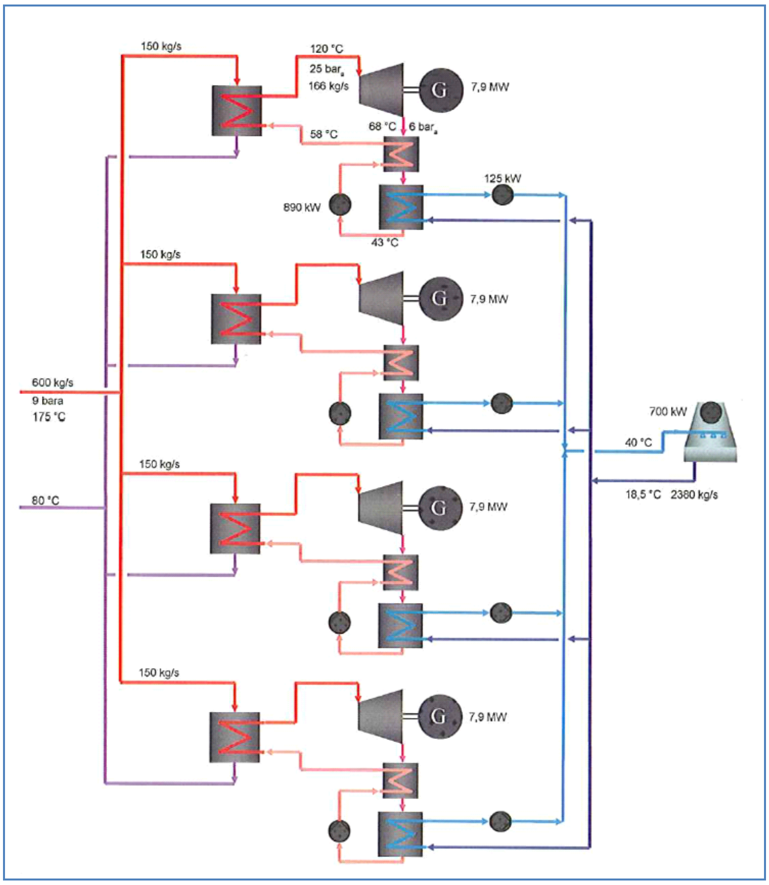

Figure 2: ORC-units utilizing the geothermal brine.

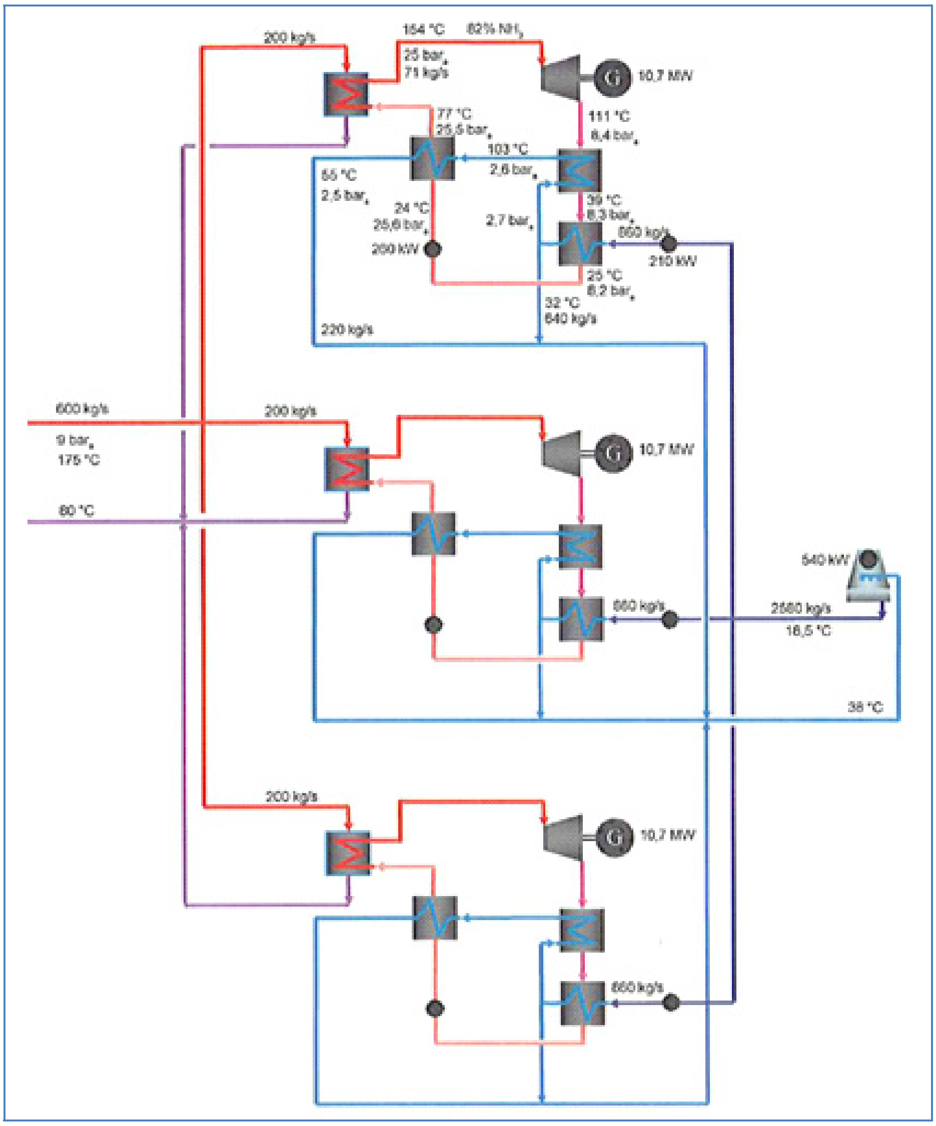

Figure 3: Kalina-units utilizing the geothermal brine.

2.2 Kalina Cycle

The Kalina cycle is a new concept in heat recovery and power generation, which uses a mixture of ammonia-water as the working fluid with the potential of significant efficiency gains over the conventional Rankine cycle. The Kalina cycle is not as common as the ORC-cycle and so far only a few Kalina power plants are operating worldwide.

Detailed examinations of the Kalina expanders have revealed that units larger than 11 MW_e are not recommended. Therefore three Kalina units would be needed to utilize the brine at Hellisheidi. Figure 3 shows how the Kalina units could utilize the brine at Hellisheidi.

2.3 LP Flash-Steam Cycle.

The LP steam is generated by flashing separated brine. At Hellisheidi this flashing lowers the pressure from 9 bar_a to 2 bar_a. Presently, numerous geothermal LP-turbines are in operation worldwide, generating 20 - 30 MW_e, at 1 - 3 bar_a inlet pressure, each unit. The LP cycle has a major advantage over the ORC- and Kalina cycles, being able to utilize all of the flashed brine in one unit, instead of three or four units. Figure 4 shows how the LP units could utilize the brine at Hellisheidi.

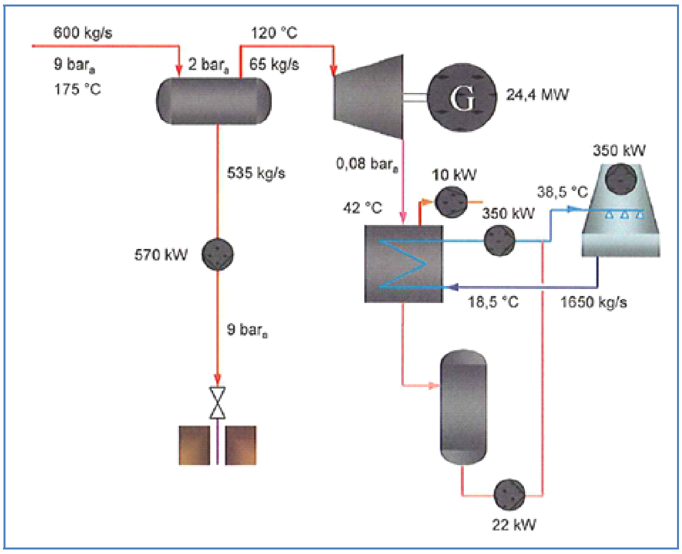

Figure 4: LP flash-steam cycle.

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3. HOW DO THESE THREE POWER GENERATION CYCLES COMPARE?

3.1 Comparison

A financial/efficiency comparison was done on the three power generation cycles. The results are shown in Table 1.

Table 1 Cost estimation and comparison of the examined power cycles.

	LP-steam	Kalina	ORC	
$Power_{gen.}$	24.2	3x10.7	4x7.9	MW_e
$Power_{system}$	1.3	1.9	4.7	MW_e
$Power_{net}$	23.1	30.2	26.9	MW_e
Investment cost	30	42	45	$EUR*10^6$
Unit invest. cost	1.29	1.37	1.67	EUR/W

NB: The cost estimates should not be taken as exact, due to a volatile global market.

According to Table 1 the Kalina cycle has the best power generation capabilities and the LP-turbine has the lowest unit investment cost. The investment cost of the LP flash-steam units and the ORC units are based on similar sized units in operation worldwide. The investment cost for the Kalina cycle, on the other hand, is based on smaller units, as only a handful of small units (2 - 4 MW_e) are in operation worldwide.

The reasons for the lowest investment cost of the LP flash-steam cycle are as follows:

- Capability of the cycle to utilize the brine flow in a single unit, when the comparable cycles need three or four units to accomplish the same task.
- Less costly components like separators can be used instead of more expensive heat exchangers.

The capability of the cycles to generate hot water for district heating using the return brine was also compared. The LP flash-steam cycle proved superior as the return brine had the highest temperature, therefore being most efficient to generate hot water for district heating.

4. THE LP FLASH-STEAM CYCLE AT HELLISHEIDI

In early 2005 the LP flash-steam cycle project was initiated at Hellisheidi and commercial proposals of various turbine manufactures were received and evaluated. Eventually a single 33.6 MW_e turbine generator from Toshiba was selected.

4.1 The Turbine Generator Unit

The turbine is a single casing, single flow exhaust, condensing steam unit. The turbine stages are four and the last blades are 31.2 inches. The rotor is a so-called super-rotor, where gland packing areas and nozzle packing areas are hard coated to prevent either corrosion or erosion. The nozzle diaphragms have a feature peculiar to the impulse type design. Figure 5 shows the turbine and generator and Figure 6 the condenser.

The main turbine design parameters are as follows:

- Rated output: 33.6 MW_e
- Steam consumption: 83.5 kg/sec
- Non condensable gasses: 0.1 %
- Rated speed: 3000 rpm
- Initial pressure: 2.0 bar_a
- Initial temperature: 120°C
- Exhaust pressure: 0.07 bar_a

Figure 5: Turbine and generator

Figure 6: Condenser

4.2 Operation of the LP Flash-Steam Cycle.

No major operational problems have been encountered running the LP flash-steam cycle since it's commencement in 2007, although presently only part of the steam is supplied from flashed steam and part of it originates as pressure reduced HP flash steam. This is due to the fact that the average enthalpy of the wells in the geothermal field has risen from 1200 KJ/kg in 2005 to 1600 KJ/kg in 2007/2008. The wells drilled in the last few years have proven to be high-enthalpy wells, providing ample HP steam for HP turbines but less brine than expected for the LP flash-steam cycle. At present the enthalpy of the geothermal field is estimated at 1700 KJ/kg. Figure 7 shows the present flow diagram of the cycle.

5. SUMMARY

The most efficient use of geothermal steam is direct flow into the turbines. Any pressure change on route involves loss of power and is therefore undesirable. The future for the Hellisheidi plant involves the possibility of installing more HP steam turbines. That would involve the availability of additional brine for the LP flash-steam cycle and reduce or eliminate the need for pressure reduced steam.

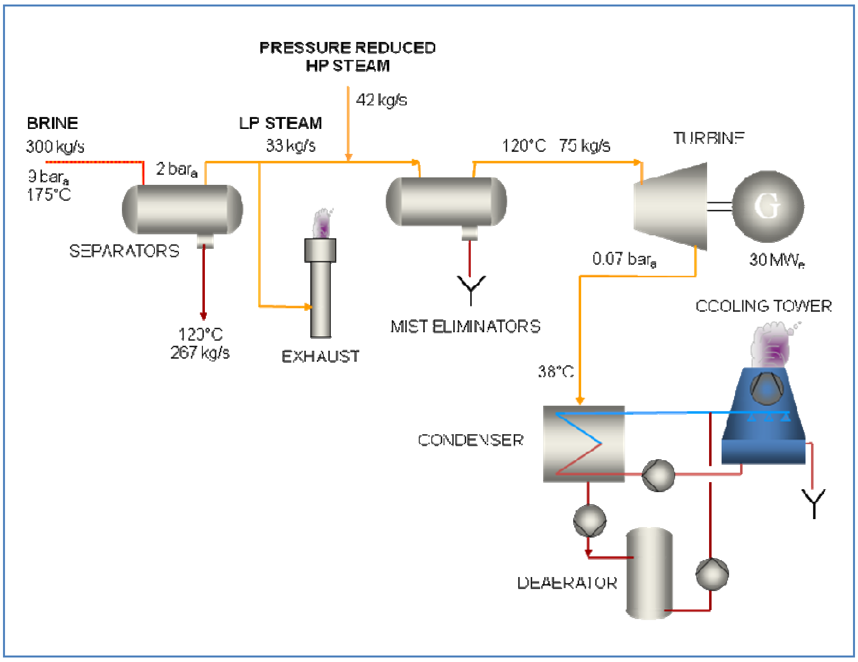

Figure 7: Present flow diaphragm of the LP flash-steam cycle

Alternatively, until that time comes, the LP flash-steam cycle unit will continue to be used on a mixed supply of brine and steam. The LP unit would therefore supplement the power generation while excess steam is available and/or come into play when the HP steam turbines suffer malfunctions or go through periodic maintenance stops.

The LP flash-steam cycle proved most efficient in comparison with other cycles in generating hot water for district heating.

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