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Organic Rankine Cycles in Geothermal Power Plants 25 Years of Ormat Experience

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1. Introduction

In the past 25 years Ormat has designed and supplied more than 900 MW of geothermal power plant, nearly all of which are still in operation.

Ormat has developed and manufactures organic vapor turbines from 200 W (non geothermal applications) to 15 MW. Initially focused on low temperature resources only (as low as 45°C! in Alaska), it has been expanded to a wide range of resource conditions (up to 225°C in Hawaii). Today, the Ormat Rankine Cycle (ORC) portfolio includes Organic Rankine Cycles, Steam Rankine Cycles and combinations of both.

The plants supplied demonstrate the economics of initial investments, as well as low operational costs. The principles of the Ormat power cycle design and examples of representative actual projects are given below.

2. The Ormat Approach to Power Cycle Design

2.1 Sadi Carnot Teachings

The Ormat approach to geothermal power cycle design is based on Sadi Carnot teachings, some of which were overlooked by generations of engineers until the last few decades. [Ref.1]

Sadi Carnot, in his famous treatise of 1824, in which he actually defined what we call “thermal efficiency” realized that this was by no means the most important consideration; his concluding paragraph is so relevant today that it deserves to be quoted: “the Economy of the Combustible (Carnot’s term for thermal efficiency) is only one of the considerations to be fulfilled in heat engines. In many cases, it is only secondary. It should often give precedence to safety, to strength, to the durability of the engine, to the small space which it must oc-

cupy, to small cost of installation, etc. to balance them properly against each other, in order to attain the best results by the simplest means”.

Carnot was mainly concerned with speculation as to the best possible performance of a heat engine using any working fluid in any possible cycle. He recognized early on several promising directions in the development of practical heat engines which, if given the attention they deserved when published, could have brought about the development much sooner of both vapor cycle engines using fluids other than steam, and of combined cycles.

2.2 Efficiency of the Heat Cycle

In most of the low temperature geothermal resources, where the heat source is single phase (sensible heat), the ideal cycle would have a varying source temperature, being a succession of infinitesimal Carnot cycles. A supercritical cycle provides such characteristics. In a sub-critical Rankine cycle the constant temperature of the evaporation leads to a loss of exergy. However, because of the lower latent heat of vaporization this drawback is smaller than in a steam cycle. (Figure. 1)

2.3 Efficiency and Work Ratio

The usual definition of thermal efficiency as the ratio between the net work done by the fluid and the total heat input to

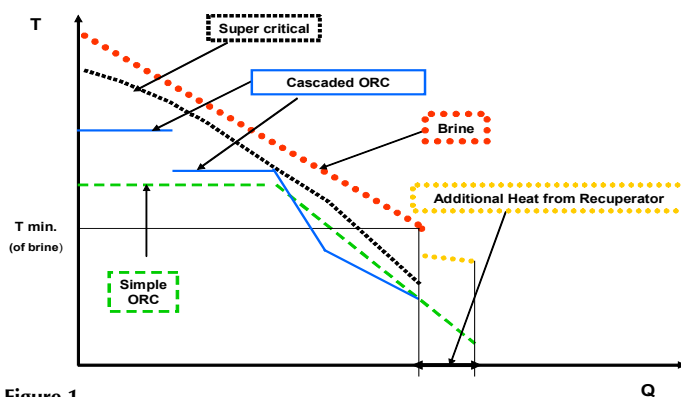


Figure 1.

the cycle can be misleading in assessing the suitability of a given cycle in a heat engine. A concept of paramount importance in evaluating the suitability of a particular cycle for use in a heat engine is that of *work ratio*, which may be defined as the ratio of the net work output of the cycle to the total positive (expansion) work of the cycle.

If there is very little negative work, as in a typical sub critical vapor cycle, where only liquid of small specific volume has to be pumped, at moderate pressure, back into the boiler, the work ratio will be high. By contrast, this ratio is lower in a super critical cycle where, because of the high pressure, a larger portion of the positive work of the turbine is used to drive the feed pump. [Ref. 2]

Taking into account all these practical implications of work ratio, it can be seen that in many ways the concept of work ratio can be regarded as almost more important than the concept of ideal cycle efficiency.

2.4. Matching and Optimization in the Design of Heat Engines

The process of design of a geothermal power plant can be considered as one of matching and optimization. We have a source and a sink of heat of certain characteristics and the problem is to match them with the working cycle, match the working cycle with the working fluid, and match the working fluid with the expander. But what matters most is the optimization of the whole system, involving the well-known process of trading-off a loss or gain. To get the overall efficiency of the system it is of course necessary to consider the output net of parasitics, such as cycle pumps, production pumps, injection pumps, cooling systems and non-condensable gas extraction power consumption. These considerations guided us in the choice of fluids away from supercritical cycles in spite of their higher cycle thermal efficiency.

In the matching processes, one has to consider the impacts not only on efficiency, but also on the environment, on the long-term pressure support and the geothermal resource availability. [Ref. 3]

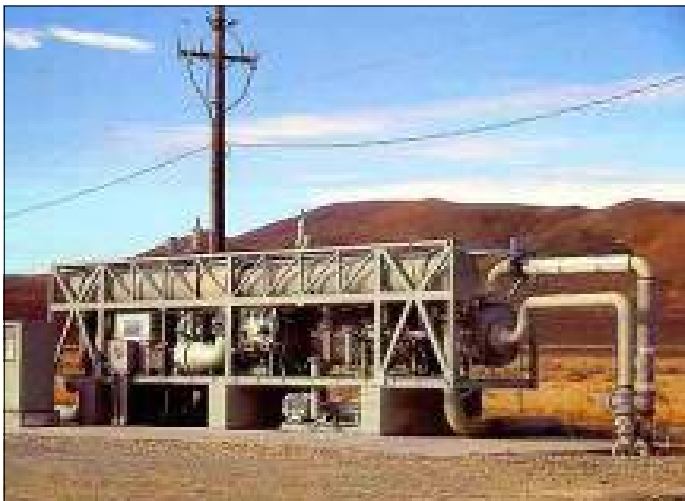


Figure 2.



Figure 3.



Figure 4.

3. Examples of Ormat Low Temperature Plants

The first Ormat ORC supplied in 1980 for a geothermal application was a small hermetically sealed unit of about 4 kW, designed for operation with a hot spring at 45°C and cooling water at 4°C.

The first commercial unit was supplied in 1984 and is still in operation at Wabuska, Nevada. It supplies 700 kW to the grid from a 104°C resource (Figure 2).

Other representative small units are: a 300 kW in Fang (Thailand), a 200 kW at the Rogner Hotel in Bad Blumau (Austria), supplied respectively in 1984 and 2001, still in operation from a resource at about 100°C.

A similar unit was supplied for a solar pond application where it operated from 1986 to 2002 at temperatures as low as 65°C in El Paso, Texas, USA.

Larger units to use spent geothermal brine from single or double flash existing power plants.

- o Hatchobaru, Japan providing 2 MW from a 143°C brine (Figure 5)



Figure 5.



Figure 6.



Figure 7.

- Miravalles V, Costa Rica, providing 18 MW from a 166°C brine (Figure 6) [Ref. 4]
- Brady, Hot Springs, USA, providing 6.5 MW from a 110°C brine (Figure 7)

4. Examples of ORC For Moderate and High Temperature Applications

4.1 Cascaded ORC

A 30 MW water-cooled Ormesa I geothermal power plant in East Mesa, California, USA is shown in Figure 8. It is comprised of 26 1.2 MW units arranged in three cascading levels, with a resource temperature of about 150°C. [Ref. 5]

4.2 Recuperated Cycle

In most of the actual cases, the perfect match as above is not feasible, mainly because of limitation in the cooling temperature of the brine to avoid scaling. A method for overcoming partially the cooling temperature limit is to add a recuperator which provides some of the preheating heat from the vapor exiting the turbine, this typically increases the efficiency by 10 to 15% (Figure 1). [Ref. 6]

The recuperated process is used by Ormat in many geothermal projects all over the world, such as the 20 MW Zunil in Guatemala (Figure 9), 1.8 MW Oserian and 13 MW Olkaria III in Kenya.



Figure 8.



Figure 9.



Figure 10.



Figure 11.

4.3 Two-Phase Geothermal Power Plant

In the majority of geothermal the resource, the geothermal fluid comes in two phases which are separated in an above-ground separator into a stream of steam and a stream of brine. In a low to moderate enthalpy resource the steam quality is 10 to 30% as a function of fluid enthalpy and separation pressure. The two streams can very efficiently be utilized in a “Two-Phase ORC Unit”. Separated steam (usually with some percentage of Non-Condensable Gases or NCGs) is introduced in the vaporizer to vaporize the organic fluid. The geothermal condensate is mixed with the separated brine to provide the preheating medium of the organic fluid. Since 1994 this process is utilized in the 14 MW plant in San Miguel, Azores (Figure 10), with a resource enthalpy of 1,108.5 kJ/kg.

4.4 Geothermal Combined Cycle

For high enthalpy fluids with very high steam content a solution is the geothermal combined cycle configuration where the steam flows through the back pressure turbine to the vaporizer, while the separated brine is used for preheating or in a separated ORC. This configuration is used in the 30 MW Puna plant in Hawaii (Figure 11) as well as in the 125 MW Upper Mahiao in the Philippines, the 100 MW Mokai and the 27 MW Rotokawa (Figure 12) both in New Zealand. This last plant is probably the most efficient geothermal plant in the world, using per MWh only 5.2 ton of 24 bar steam. [Ref. 7]

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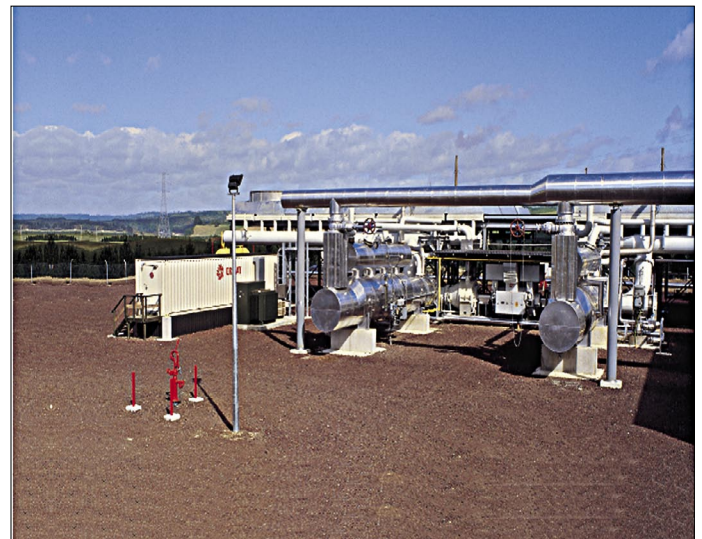


Figure 12.

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