Optimising ORC use in Australian Geothermal Applications

Craig Morgan[1], David Paul[2]
[1] Pacific Heat and Power, Level 14, 500 Collins Street, Melbourne VIC 3000
[2] Pratt & Whitney Power Systems, 400 Main Street, East Hartford, Connecticut, USA
* Corresponding Author: craig.morgan@pacificheatandpower.com, +61 3 9013 4425

Introduction

Since Pratt & Whitney Power Systems acquired a majority stake in Turboden in 2009, many hot sedimentary aquifer geothermal power applications across the world have been assessed. A variety of power configurations have subsequently been developed and costed that have relevance for the future of the Australian geothermal industry.

This paper summarises the key considerations made in designing systems, as well as factors that affect overall performance.

Keywords: PureCycle®, Pratt & Whitney Power Systems, Turboden, Organic Rankine Cycle, Pacific Heat and Power

Input conditions

Input conditions for ORC use in geothermal applications across the world vary substantially:

- Geothermal brine input conditions vary such as 74C in shallow and small scale Alaskan wells, 98C in Birdsville, 130C from a hot sedimentary aquifer in the USA, 150C at the outlet of a high temperature separator in New Zealand, or as high as 240C+ in enhanced geothermal applications. These temperature conditions, including flow rate may also change over time.
- Air temperatures vary from -5 C to 50C+ during the day in desert regions of Australia.
- Water for cooling is sometimes available, but many times it is not.
- Energy prices vary between AUD 5c/kWh to 20 c/kWh, and is sometimes a market rate or government-regulated.
- Incentives include Renewable Energy Certificates equivalent to 2-4 c/kWh, or tax-incentive regimes.
- Well and steam field developments vary from free-flowing wells to 5km-deep wells.
- Noise restrictions vary from site to site depending on the location of the plant.
- Flammability and toxicity of ORC working fluids is subject to a variety of planning regulations.
- Atmospheric conditions can include H2S which aggressively corrodes copper in plant and equipment.
- Some project developers wish to contract for supply and commission of the ORC only, whilst others wish for a fully packaged Engineer-Procure-Construct (EPC) solution.

Amongst this, the ORC supplier must optimise each individual application according to a specific client's requirement, generally for highest economic return on their project and not necessarily lowest specific cost of the power plant ($/kW).

ORC design considerations

Apart from the input conditions, key considerations in the ORC system design include:

- Corrosion → special and costly materials for the heat exchangers influence the unit cost significantly increase lead time.
- Scaling → there may be limits to the minimum temperature of the geothermal brine due to deposition of silica or other products.
- Fouling → removable covers and straight cleanable tubes assist in cleaning and on-going efficiency.
- Cascade use and cogeneration (using the condensing heat for other purposes) can improve feasibility.
- Working fluid flammability can be an issue for urban areas / insurance cost.
- Vapour plume from cooling towers are unsightly and there is a need for makeup water in evaporative devices.
- There is a larger footprint required, and additional noise emissions from the fans in an air condenser or fin/fan cooler.

Water use is becoming a significant issue.

Evaporative cooling towers feature:

- Smaller footprint.
- Lower noise emissions.
- Fresh water consumption.
- Chemical water treatment requiring operation cost and environmental impacts.

Air condensers feature:

- Larger footprint.
- Higher noise emissions.
- No water needed.
- Virtually no environmental impact and low operating costs.

Other options include hybrid cooling systems that operate dry in winter and cooler ambient conditions, whilst using water in hotter conditions.

Critical issues we observe are:

- Investment costs need to take into consideration initial capital requirements, ongoing costs, and future water availability.
- The generated yearly power output is tightly linked to cooling conditions and parasitic loads, and is particularly significant for cooler resources.

The best solution is dependent on the application, but in the main we see Australian clients preferring dry or hybrid cooling systems of some sort.

ORC performance & practical systems

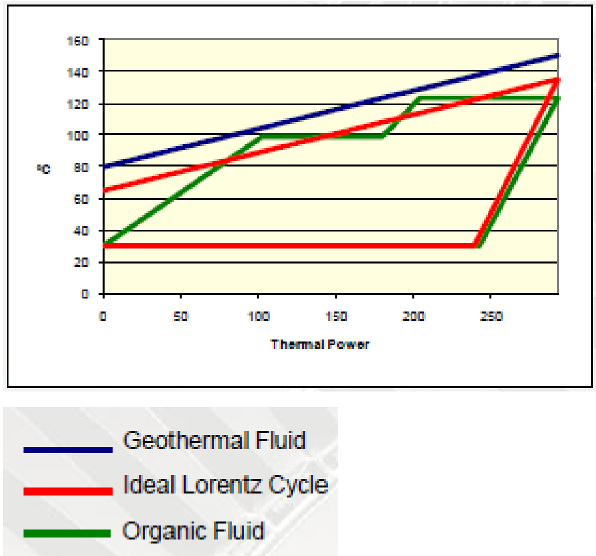
Availability of PWPS and Turboden ORC technologies in real world applications is at > 98%. Maintenance costs are very low relative to other power generation technologies such as engines, gas turbines or steam turbines.

The selection of working fluid is influenced by:

- Cost.
- Environmental impact.
- Pressure levels selected.
- Heat input curve.
- Enthalpy drop & flow rate.
- Flammability.
- Cooling system.

The optimal fluid, pressure levels, and turbine size varies from case to case.

In hot sedimentary aquifer applications the geothermal fluid normally stays in liquid phase. Currently the most proven and reliable ORC technology uses single-phase working fluids in 'normal' pressure cycles. These systems can be cascaded using multiple pressure levels to approach the ideal Lorentz cycle, minimising disadvantages whilst maximising the benefits of reliable systems.



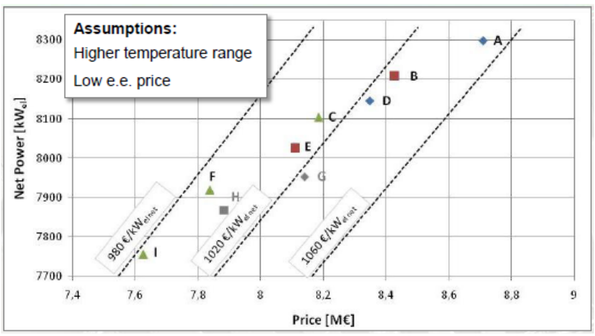
Technical innovations

The product development team continue to make system improvements that increase efficiency, broaden the variety of suitable applications, and provide the ability to operate in with zero water for cooling. Features available are:

- Air condenser for use in areas with limited access to water. The refrigerant is condensed directly in the air-condenser to maximise heat transfer.
- Coatings and equipment modifications such as those necessary for a high H2S environment in some international geothermal fields.
- High pressure evaporators may also be selected on a case by case basis for some applications.

Price vs Performance

A manufacturer is able to design for maximum efficiency, or minimum specific cost. It is critical that the client and equipment supplier work together to optimise the unit design for each specific application. The chart below illustrates this.



The table shows price/power ratios for different possible configurations of an air-cooled ORC unit (installed, BoP excluded) for the same Project.

Generally speaking the price/power ratio is influenced by the boundary conditions as follows:

- a colder(hotter) geothermal water will raise(decrease) the price/power ratio.
- a more aggressive and impure geothermal water will raise the price/power ratio.
- a higher(lower) average annual air temperature will raise(decrease) the price/power ratio.

But in the design phase the choice between a bigger or a smaller heat exchanger will influence performance and price, that means also the price/power ratio

The future and corporate update

PWPS and Turboden have recently been successful in winning orders for a 5 MW geothermal power plant in Germany (based on the Turboden technology), and a 500kW geothermal power plant in Taiwan (based on PureCycle®).

Conclusion

There is a wide variety of input conditions and design considerations that influence the final cost of an ORC power plant, and as such each project, whilst based on modular technology, will most likely be configured in a project-specific manner. It is therefore critical that you work closely with your equipment supplier to optimise the configuration to balance:

- Technical performance
- Efficiency
- Economic performance,
- Reliability and
- Operability