Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Technical Successes and Financial Challenges of Micro-Geothermal

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Keywords: micro-geothermal, economics, global warming potential

ABSTRACT

Low temperature, micro-geothermal power generation offers significant power generation potential worldwide. In the past, low temperature geothermal and co-produced fluids were considered a nuisance and un-economical for power generation. However, technology is available to tap this prevalent resource to produce fuel-free, emission-free power and increase power output and site efficiency. But a lack of focus on sustainability in the industry has left this green energy opportunity on the side-lines, with hot water from micro-geothermal being overlooked almost completely. This presentation will discuss various case studies, beginning with a grant with the US Department of Energy to demonstrate waste heat to power generation for low temperature geothermal applications at a gold mine in Nevada. The mine utilizes geothermal water for its gold processing, and through the grant, Organic Rankine Cycle (ORC) technology was used to tap the previously wasted heat for electricity generation. The presentation will discuss the challenges and lessons learned, and how the site is easily repeatable at low temperature micro-geothermal sites worldwide. With a clearer picture of the reality of micro-geothermal, small scale waste heat to power technologies are more focused on economics and where units can be deployed with an acceptable payback. New technology using optimized equipment and new low global warming potential (GWP) refrigerants are driving additional acceptance across the industry. Another case study example will detail a geothermal unit in Romania. The unit was a commercial unit and ran successfully for several years. However, feed-in-tariff changes in the country have ultimately ceased operations. Finally, the presentation will focus on Japan with its geothermal feed-in-tariffs of ~30+ cents/kw. Small scale heat to power technology was recently commissioned on micro-geothermal in Japan and ORC companies continue to focus there today. This presentation will focus not only on the technical successes but economic challenges when making decisions on which projects move forward and which do not.

INTRODUCTION

To date, little electricity has been generated from so called "sub-commercial" shallow, and smaller low to moderate temperature geothermal fluid resources, which can be found in various locations throughout the globe. This is due to numerous factors, including: previous lack of commercial generation technology, failed micro geothermal projects, high equipment costs, and the location of some small geothermal resources in culturally or environmentally sensitive areas.

As such, small sources of hot brine go untapped for power production and may or may not be used for heating.

Yet the market pull for viable solutions is there. According to the Energy Information Agency (EIA), world net electricity consumption will continue to increase, doubling between 2003 and 2030. This increasing demand, coupled with the rising cost of fossil fuels and therefore electricity and concern over environmental issues, has led to significant interest in recovering power from low grade geothermal sources. The advent of smaller waste heat to power generators that focus on internal combustion engines, biomass, and many industrial processes are commercially available and can now be applied to micro geothermal sites.

Basically 99.9% of geothermal power production that occurs today is on the megawatt scale and larger. But there are literally thousands of existing bore holes (from oil and gas exploration, the search for large geothermal resources or just the existence of small heating districts) that could be tapped for sub MW scale powerplants.

CHALLENGES & SOLUTIONS TO COST-EFFECTIVE RECOVERY OF LOW GRADE HEAT

The ability to economically utilize low temperature geothermal resources for power generation depends on meeting both technology and economic challenges. Since the first commercial release of the Power+Generator in 2011 there have been many advances in technology which has resulted in a paradigm change in ORC design and application. ElectraTherm have been part of this technology revolution with the current Power+Generator incorporating

- Improved expander technology with integration of the BITZER twin screw expander which is a semi-hermetic design with built-in generator
- Latest technology control systems for improved performance optimisation and compliance with latest grid connection compliance codes.
- Increased output and improved efficiency through higher hot water input temperatures up to 150^{0}C.
- Improved flexibility with combined heat and power capability (CHP) and integration as part of diverse heat to power generation systems.

Economically the challenges have involved measures to reduce equipment costs through selection and design, generating savings in manufacturing by modulization and increased sales and optimization of balance of plant requirements and ease of installation.

Solving the low temperature challenge - employing a low boiling point working fluid

Replacing water with low boiling alternatives allows a modified version of the traditional Rankine cycle to successfully use heat, which is typically too low of a temperature to drive a steam engine in order to produce electricity. Such fluids include organic molecules, e.g. hydrocarbons like pentane, or hydrofluorocarbon refrigerants. Hence the moniker "*Organic Rankine Cycle*" (ORC).

Many ORC waste heat to power generators use a hydrofluorocarbon called R-245fa (1,1,1,3,3-pentafluoropropane), a nonflammable, nontoxic liquid with a boiling point slightly below room temperature, about 60°F/15C. The ORC process follows that of the steam engine, the principle difference being that the ORC works in completely sealed, closed loop. Consider the ORC a refrigerator running in reverse, i.e. heat flow across a difference in temperature generates power. And with the advent of newer more environmentally friendly refrigerants coming to the market now the access to lower temperature resources is increasing. See the basic cycle in Figure 1.

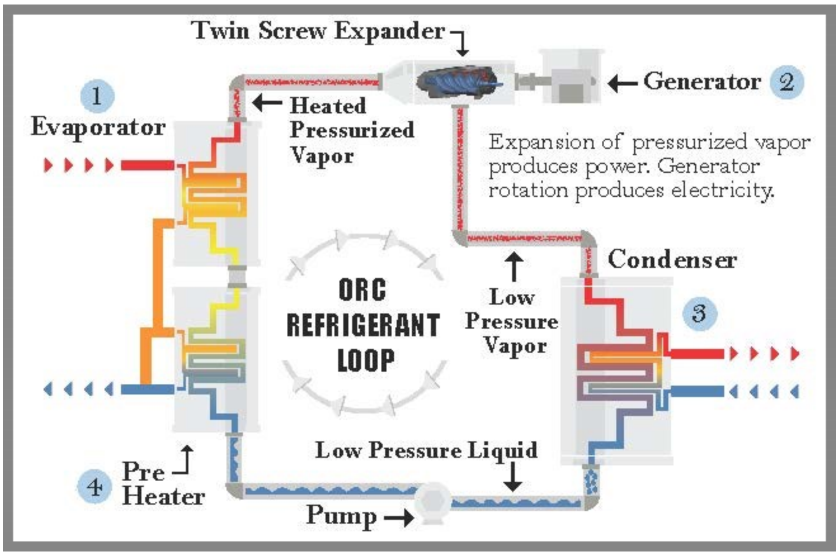

Figure 1. The organic Rankine cycle (ORC) has much in common with both the steam engine and a refrigerator. It is a thermodynamic device (an engine) to interconvert thermal and mechanical energy.

Steps in the process include:

1. Surplus heat is used to boil a working fluid in an evaporator.
2. Under pressure, the vapor is forced through a twin screw expander, turning it to spin an electric generator.
3. The vapor is cooled and condensed back into a liquid in the condenser.
4. The working fluid liquid refrigerant is pumped to higher pressure and returned to the evaporator to repeat the process.

DISTRIBUTED GENERATION SOLUTION - SHRINKING ORC FOOTPRINT BY USING A TWIN SCREW EXPANDER

Twin screw expander technology results from years of internal development, and proven results. The twin screw expander offers a number of benefits over the conventional turbine:

- Runs at about 1/20th the rotational speed of turbine/turbo expanders.
- Operates in the range of 3000-3600 RPM without the high-speed turbine's expensive gear boxes and/or frequency conversion electronics.
- Ability to operate safely under "wet" conditions when the working fluid is not fully vaporized.
- Has an extended operating envelope with 10 to 1 turndown.
- Has special rotors machined to engage in only rolling contact, making for a very low wear device.
- Robust and cost-effective design with in-process lubrication, provides excellent lubrication for the bearings and screws of the low-speed expander, without requiring an oil pump and with no oil changes.
- The use of semi-hermetic designs with no shaft seal between expander and generator offer increased robustness

FEEDING POWER TO THE GRID - INDUCTION GENERATOR & AUTOMATED CONTROLS

Advances in process logic controllers (PLCs) combined with the simplicity of the induction generator have made for fully automated operation of small-scale ORC technology. Software controls the start-up and shut down, and provides for remote operation and monitoring. Simple and robust is a great fit and requirement for micro geothermal sites.

Induction generators deliver significant advantages over other devices for small automated power plants. Electromechanically analogous to an induction motor, they are inexpensive, robust and proven, employing a) no brushes, b) no commutator, c) no slip rings d) no exciters, no regulators, no synchronizers or other complex parts. Because induction generators are not self-excited and have no magnetization or terminal voltage prior to coming on-grid, synchronization is not required. This is much simpler than the case of the synchronous generator or alternator which has stand-alone terminal voltage when it rotates, and requires synchronization before being placed on-grid. For more stringent grid requirements that require an inverter based solution there are commercial electronics available that allow for induction to inverter to grid interconnections.

Automated control system: After installation and startup, the onboard feed pump sends working fluid (R-245fa) to the evaporator, which builds system pressure. The twin-screw expander turns, which accelerates the generator. When the unit approaches synchronous speed, a contactor (switch) closes and connects the un-excited induction generator to the line. Inrush current magnetizes the unit (just as it would when starting an induction motor conventionally) but since it is already up to speed, no large or prolonged acceleration current is required. As working fluid flow increases, the motor transitions to generator and power output gently ramps up. Power output increases to the limit of available heat or the unit achieves rated output. The PLC continuously monitors a variety of internal transducers while also providing safety interlocks, log files, a graphical user interface and parameter display, power maximization and remote control.

Putting the technology to work for an attractive return on investment

The following factors help identify situations with short payback for micro geothermal applications.

1. An existing bore hole or natural hot spring with flows and temperatures that match commercially available (off the shelf) equipment.
2. **The pump parasitics are already paid for (i.e. an existing district heating system)/the well is artesian or shallow - excessive pump power required to move the water to the surface and back down can weight down an otherwise good project.**
3. Difficulty of installation with new modular designs and packaging providing the opportunity to access difficult sites that would not normally be considered.
4. **The higher the cost of power** the shorter the payback window. Power over 10 US cents/ kWh, plus incentives, can often reach required payback periods. Local facility electricity demand should exceed the power production potential so the power is consumed by the site, or a favorable rate from the utility for power sold back must be verified.
5. **Strong Delta T,** or difference in temperature between hot-in and cold-in, allows ORC equipment to output greater electrical energy (kWe) and reduce the payback period.
6. **8,760 hours of operation per year – typical micro geothermal sites are not limited to factory or process operating hours and the goal would be to target sites that can run 24/7/365.**

CASE STUDY 1

The first example of a successfully commissioned ORC on micro geothermal is at the Florida Canyon Mine in Imlay, Nevada. This project was commissioned in partnership with the U.S. Department of Energy (DOE) and a gold mining operation. The machine was manufactured with a cleanable heat exchanger, an increased power output of up to 75kWe gross and a fully-containerized solution for ease of transportation and installation through a grant from the DOE. The DOE supported the development of the micro geothermal ORC with the target of co-produced fluids from the oil and gas industry in the US with flows and temps that could add renewable energy to the oil and gas production from 1,000's of existing wells.

The site used ORC technology to generate electricity from low temperatures unattainable by other technologies. First, hot water entered the ORC to boil a working fluid into a vapor. The high pressure vapor expanded through the twin screw power block, spinning an electric generator. After turning the twin screw expander, the vapor was then condensed back into a liquid through the use of an external air-cooled condenser. Following condensing, the working fluid flows back to the evaporator as a liquid to repeat the process.

The result of the project was a successful demonstration and a unit that was sized for smaller resources, could be operated and monitored remotely and was easy to maintain. The commercial lesson learned from the project was the realization that the oil and gas industry is not in the business of producing electricity and market acceptance did not materialize.

Figure 2. The ORC at Florida Canyon Mine in Nevada.

CASE STUDY 2

The second example of a micro geothermal ORC was at a geothermal well in Romania. The machine produced 50kW (gross) of electricity from a geothermal resource (216°F/102°C) without any fuel or emissions. To further increase the application's efficiency, once geothermal water has passed through the heat exchangers to pressurize the working fluid, it continued on to heat nearby residential buildings in the winter.

This site operated for several years and was supported by government feed-in-tariffs (FITs) that supported geothermal power production – when the FIT ceased so did the economic viability of the project and the unit has not operated since due to the loss in the additional FIT revenue for the 24/7 renewable energy.

Figure 3. The organic Rankine cycle (ORC) in Oradea, Romania.

CASE STUDY 3

A low temperature ORC generator was installed in Japan, located in the city of Beppu. The machine utilizes geothermal heat to generate fuel-free, emission-free electricity at the site. It was a conversion from a four-home district heating system to a power plant also – taking advantage of a system that already existed and adding the power generation component.

The ORC runs off low temperature geothermal steam from a small district heating system. As the ORC generates power, it also provides cooling with zero environmental impact or imposition on the onsen's primary function as a community resource. The power generated is sold to the local utility at an attractive feed-in-tariff rate for renewables.

Figure 4. ORC machine in Beppu, Japan.

At this site, the onsen provides varying flows of geothermal steam at approximately 110°C. Unlike other renewable sources, geothermal heat is baseload, providing a continuous hot water flow with power generation capabilities 24/7. Hot geothermal water is the fuel used to create a high-pressure vapor that expands through the twin screw power block, spinning an electric generator to produce clean electricity while simultaneously cooling the water up to 20°C.

Japan has several advantages that other locales do not 1) thousands of existing bore holes for district heating and a great FIT for 24/7 renewable energy that approximates ~30+ cents/kw. These incentives increase the return on investment for ORC technology significantly, offering the potential for payback in 3–5 years.

CASE STUDY 4

A second commercial geothermal site is also operating in Japan and new grid connect requirements are being met with product enhancements to allow for ease of grid interconnect with Japanese utilities. This installation site was particularly difficult with innovative installation techniques required to place the ElectraTherm equipment in place.

Figure 5. ORC Installation Central Japan.

CONCLUSION

Employing well proven, robust technologies, small Organic Rankine Cycle waste heat to power generating systems can tap what has been, until now, untapped. The convergence of technologies with the quest for clean energy production - through renewable sources including energy efficiency - has enabled small organic Rankine cycle systems to become, in their aggregate, a major green energy solution. Waste heat to power applications are creating markets for these smaller (kW scale units) and this is enabling the focus on micro geothermal sites.

New technology using optimized equipment and new low global warming potential (GWP) refrigerants are driving additional acceptance across the industry. It's also reducing the costs per kilowatt to be more competitive with other energy efficiency technology. As awareness for ORC technology grows, the opportunity to capture low temperature heat from micro geothermal, in addition to various waste heat applications, will prove vast with a simple solution that comes with millions of hours of proven run time proven fleet experience, and robust equipment already available, ORC micro geothermal technology will play an increasing role in future energy generation.