FUTURE SUCCESS LOW TEMPERATURE MICRO GEOTHERMAL POWER GENERATION

Robert Emrich

4080 Enterprise Way, Flowery Branch, Georgia 30542 USA

remrich@electratherm.com

Keywords: *Geothermal, Organic Rankine Cycle, Power Generation, Energy Efficiency*

ABSTRACT

Low temperature, micro geothermal generation offers significant renewable energy opportunities worldwide. In the past low temperature geothermal and co-produced fluids were considered a nuisance and uneconomical for power generation. Today advances in technology are available to tap this prevalent resource to generate fuel-free, emission-free power, but unfortunately due to a lack of knowledge on technologies available for sustainability, the industries opportunity to utilize low temperature resources is often overlooked.

We are working diligently to overcome this knowledge gap, communicating with the Industry that a solution exists for the development of these resources and coupled with the growth in electricity usage and environmental concerns of the use of fossil fuels for power generation, they should no longer be overlooked.

Currently, the majority of geothermal power production that occurs is on the multi megawatt scale that require investment in resource development and infrastructure. There are however thousands of existing bore holes available from exploration for oil and gas, exhausted production wells, exploration for large geothermal resources and natural hot water springs that can be tapped for sub MW scale powerplants with minimal infrastructure and impact on local environments.

This presentation will discuss the advances in technology enabling the economic use of low temperature geothermal resources for power generation and application as bottoming plants to improve efficiency of existing geothermal infrastructure. It will cover the development and application of Organic Rankine Cycle technology incorporated in compact heat to power generation equipment, the lessons learnt, case studies of installed systems and future developments including the optimization of equipment for use of low global warming potential refrigerants.

This presentation will also include incorporation of power generation as part of direct use systems, containerized systems and potential for efficiency gains in existing high capacity geothermal plants.

1 INTRODUCTION

Modern society relies on reliable sources of electricity to efficiently function and world energy usage in the form of electricity continues to grow. Electricity demand has increased from 13 TWh in 2000 to a projected 24 TWh for 2020 (45% increase) and is expected to continue to grow to a forecasted 37 TWh by 2040. Installed Geothermal generation capacity as of 2020 is 15.9 GWe with forecasted electricity generation of 95 GWh which equates to just 0.004% of world electricity demand. The majority of this generation capacity is from large scale geothermal power plants.

Geothermal, unlike other renewable energy sources such as wind and solar, is a base load renewable energy solution that uses earth's heat for emission free power generation. The scope for increased geothermal power generation to contribute to meeting the worlds energy demand remains high but issues such as resource development, environmental issues, capital costs and low economic return continue to restrict the development of new generating capacity.

To date, very little electricity has been generated from so called "sub commercial" shallow and smaller low to moderate temperature geothermal resources despite these resources being found in various locations throughout the world. The lack of development of these resources can be attributed to numerous factors including limited commercial development of available technologies, previous failed micro geothermal projects, high equipment and infrastructure development costs and the location of a percentage of these resources in culturally and environmentally sensitive areas.

Yet as indicated the market pull for commercially viable solutions for geothermal generation, and in particular now with the drive to decarbonize the power generation sector, the interest in the development of these low-grade geothermal resources for power generation is increasing.

With the advent of the smaller commercially proven waste heat to power generators, that initially focused on recovering waste heat from internal combustions engines and using biomass sources for power generation, the opportunity now exists to utilize this equipment for low grade geothermal resources.

ElectraTherm has been in the forefront of the development of small compact heat to power generators having released to the market in 2011 the commercially proven Power+Generator.

2 OPPORTUNITIES

There are many and varied opportunities for ORC based heat to power generation systems to contribute to the de-carbonization of the electricity networks. These opportunities include the use of low temperature geothermal resources where the economics and electricity demand supports the installation of the equipment.

Resources include the thousand's of exploration wells drilled by oil and gas companies that have either tapped geothermal brines or can be used to heat water though water injection/ recovery. In addition as oil and gas reservoirs are depleted the output from the well will often include co-produced fluids which can be separated from the oil and gas

ISSN 2703-4275

components and then used for power generation. In the past these co-produced fluids, including those present in the mining process, have been considered as both a nuisance and waste product but are in-fact a valuable resource that can be utilized

Apart from existing wells there are many shallow low temperature resources/ hot springs that can be utilized for power generation depending on the temperatures and flow rates available. In many geothermal zones, including in New Zealand, there are geothermal resources available that can not support the development of large energy intensive power generation infrastructure that can now be utilized by small compact ORC systems. These systems can generate electricity and provide for subsequent direct use of the heat for food production (heating of greenhouses and animal enclosures) and district heating systems.

New applications are being investigated for the use of earth's heat including a closed circuit underground loop system and the use of heated water reserves found in exhausted and abandoned underground mines.

3 CHALLENGES & SOLUTIONS - RECOVERY OF LOW GRADE HEAT

As indicated 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.

3.1 Solving the low temperature challenge

Solving the low temperature challenge is achieved through the replacement of the traditional Rankine Cycle water/steam circuit with a low boiling refrigerant circuit. The use of the low boiling refrigerant enables low temperature heat sources such as small geothermal resources to be used to generate electricity. Due to the fact that these refrigerants include organic molecules such as hydrocarbons like pentane or hydrofluorocarbons this modification is known as the Organic Rankine Cycle or ORC.

Many modern ORC waste to heat power generation systems use a hydrocarbon called R-245fa (1,1,1,3,3 – pentafluoropropane), a non-flammable, non-toxic refrigerant with a boiling point of 15^{0}C. The ORC process follows that of the steam engine, with the principal difference being that the ORC operates in a completely sealed, closed loop. Consider the ORC as a refrigerator running in reverse with the heat or energy flow across a difference in temperature being used to generate electricity.

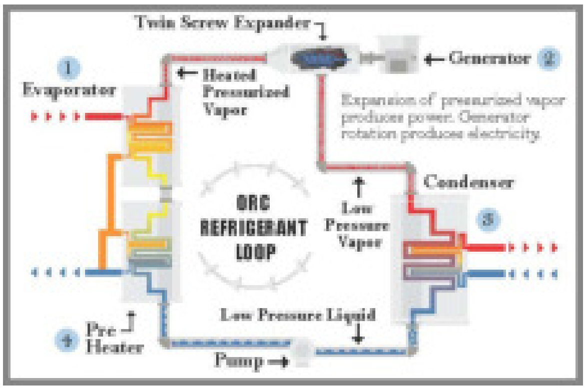

Figure 1: The Organic Rankine Cycle (ORC) has much in common with both the steam engine and a refrigerator. It is a thermodynamic device (an engine) that converts thermal (heat) into mechanical energy.

Steps in the process include:

1. 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 a higher pressure and returned to the evaporator to repeat the process in a closed circuit.

The difference in temperature between the heat input and the condensing water creates the pressure differential that determines the amount of power generated. So just like a tropical storm/ cyclone the greater the difference between the low pressure core and the surrounding atmosphere the more power generated.

3.2 Shrinking the ORC Footprint

To achieve greater space efficiency through the development of a more compact ORC, ElectraTherm have incorporated a twin-screw expander for the transfer of energy from heat to mechanical. Current twin-screw technology is based on years of extensive development that has resulted in the manufacture of highly efficient screws with proven reliability. Twin-screw technology is used in both compression and expansion.

Apart from a compact design the twin screw expander offers a number of benefits over a conventional turbine. These benefits include:

- Rotates at about 1/20th the rotational speed of a turbine/ turbo expander
- Ability to operate safely under "wet" conditions when the working fluid is not fully vaporised.

- Has an extended operating envelope with 10 to 1 turndown.
- Is a robust and cost effective design with in-process lubrication eliminating the requirement for an oil pump and reservoir.
- Screws manufactured to only engage in rolling contact making for a very low wear device

The Power+Generator ORC uses the BITZER expander which is a semi-hermitic design incorporating a built in induction generator adding an additional operational advantage of no shaft seals required between the expander and the generator.

3.3 Packaged Solution

A key for the development of small low-grade geothermal resources is to minimize onsite infrastructure. Many ORC supplier's offer standard compact modular designs that require minimal additional equipment.

The Power+Generator has been designed with that requirement from conception and the design continues to be refined to further advance modulization and ease of installation at remote and environmental sensitive sites.

Typically the components required for a micro geothermal installation are a source of geothermal brine, an interface geothermal brine/ clean water heat exchanger, the Power+Generator, Cooler or source of condensing water, interconnecting pipework and connection to an energized grid.

4 FEEDING POWER TO THE GRID – INDUCTION GENERATOR & AUTOMATED CONTROLS

Advances in process logic controllers (PLC's) 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 design and operation is a great fit and requirement for micro geothermal sites.

4.1 Induction Generators

Induction generators deliver significant advantages over other generating 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
e) No regulators
f) No synchronisers

or other complex parts. As 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 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 connections.

ElectraTherm have recently incorporated upgraded electronics for specific markets to meet new grid connections regulations in United Kingdom and Germany.

4.2 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 onboard 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.

5 PUTTING THE TECHNOLOGY TO WORK

The economics that determine the development of a low grade geothermal resources depend on various factors.

These factors include:

a) Availability of the resource from an existing bore hole or natural hot spring with temperatures and flow rates that match the operating parameters of available (off the shelf) equipment.
b) Availability of grid close to resource and demand for electricity generated.
c) Opportunity to use the geothermal resource more than once. ie. Power generation and direct use/ district heating system.
d) Minimum pumping requirements and/or pumping costs already covered by alternative use.
e) Ability to achieve a strong Delta T, or difference in temperature between the heat in and cold water for the condensing circuit. Condensing water can be provided by an integrated cooler or alternative cold water source.
f) 8,760 operating hours per annum. Typically micro geothermal sites are not limited in hours of operation and the general goal is to target sites that can operate 24/7/365.
g) Capital costs for equipment and balance of plant.
h) Difficulty of installation. The modular nature of the Power+Generator provides opportunities for the development of difficult sites that would normally not be considered,
i) Value of power that meets investment requirements. The high the value for the power generated the shorter the capital payback window and better long term return on investment.

To assist in the initial evaluation of a potential application, ElectraTherm have developed internally a suite of tools that are used to initially determine the viability of a heat source to support the installation of an ORC system. The factors that are used in the initial evaluation include:

- Available heat from the resource (temperature, flow rate and thermal energy)
- Sources and temperature of cooling water (radiator or alternative water source)
- Estimated Outputs based on the above
- Estimated Project Capital Costs
- Hours of Operation, and
- Value of electricity generated

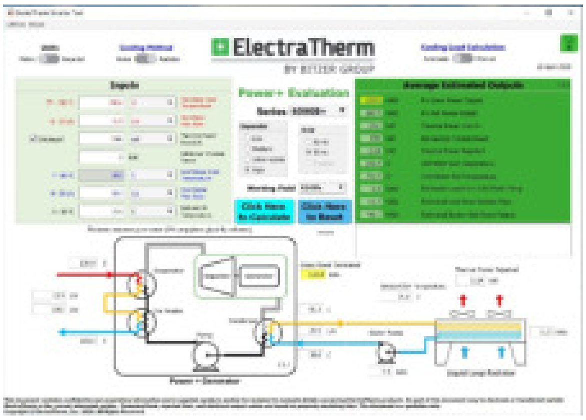

Figure 2: ElectraTherm Output Estimating Tool

The output assessment tools provides for the selection of the cooling method, entering details of the heat input, entering details of the cooling water – either ambient temperature or cold water temperature and the selection of Power+Generator specification. The tool provides indication of electrical outputs, thermal requirements and water return temperatures

The second component of evaluation is an economic payback estimate based on estimated capital costs, calculated output from the output estimating tool, hours of operation and value of electricity generated.

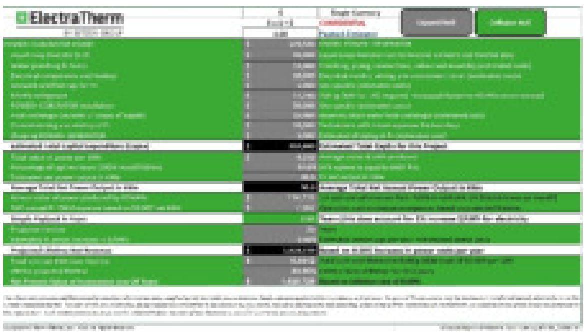

Figure 3: ElectraTherm Payback Estimating Tool

Using these tools ElectraTherm are able to provide an initial indication to a client if a heat source will support a viable project before a commitment is made to develop a full proposal. In many instances the results from these assessments have surprised clients who were unaware of the potential economic return of a resource they considered to be a nuisance or waste with no economic value.

When the economics support the development of the geothermal resource then a commercially proven ORC System will provide a long-term solution for power generation and provide an ongoing source of income for the developer or asset owner.

As indicated this technology is also suitable for use as a bottoming plant for existing or new large capacity geothermal power plants. The technology allows the use of low temperature brine exiting the primary power plant to generate additional electricity providing an improvement to the energy efficiency of the overall generating asset.

The factors that determine the economics for a bottoming plant are similar to any low temperature geothermal project namely

a) A resource that meets the operating parameter of the available equipment
b) Source of condensing water that enables the provision of a strong Delta T
c) Installation in close proximity to source of heat source
d) Minimal balance of plant requirements

6 ELECTRATHERM CASE STUDIES

ElectraTherm have developed their expertise in small geothermal applications since the inception of the company. ElectraTherm was original recognized for their work in this area at the 2007 Geothermal Association annual meeting where we were awarded the Best in Show for our paper on pertinent applications of ORC's.

Initial developments included the installation of a prototype system at the SMU Geothermal Laboratory in 2008 and a field trial at a Mississippi Oilfield in 2011 using co-produced fluids.

6.1 Case Study Florida Canyon Mine Nevada

The first example of a successfully commissioned ORC on a micro geothermal was an installation at the Florida Canyon Mine in Imlay, Nevada. This project was commissioned in partnership with the US Department of Energy (DOE) and a gold mining operation.

Figure 4: The ORC at Florida Canyon Mine in Nevada

The ORC was manufactured with a cleanable heat exchanger, an increased power output of up to 75 kWe 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 temperatures 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 expander spinning an electric induction generator. After turning the twin screw expander, the vapor was then condensed back into a liquid though 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 at that time was not in the business of producing electricity and market acceptance did not materialize.

However, with the latest advances in technology, improved efficiencies and lower capital costs due to volume production industry is again re-assessing the viability of these resources to generate renewable energy particularly as governments around the World are continuing with efforts to de-carbonize electricity generation.

6.2 Case Study Oradea Romania

The second example of a micro geothermal ORC was at a well in Romania. The Power+Generator produces 50 kE (gross) of electricity from a geothermal resource (102^{0}C) without any fuel or emissions. To further increase the applications efficiency, once the geothermal water passes through the heat exchangers to pressurize the working fluid, it continued on to heat nearby residential buildings in the winter.

Figure 5: The ORC in Oradea Romania

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

This clearly demonstrates the effect that government policies/ incentives have on the development of these small scale geothermal resources.

6.3 Case Study Beppu Japan

A low temperature ORC Generator was installed in Japan, located in the city of Beppu to utilize the available heat from a geothermal system to generate renewable energy. This installation was an addition to a four home district heating system to include power generation, taking advantage of a geothermal resource that was already being exploited.

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 6: ORC Installation at Beppu Japan

At this site, the onsen provides varying flows of geothermal steam at approximately 110^{0}C. Unlike other renewable sources the geothermal heat is baseload, providing a continuous hot water flow with power generation capabilities 24/7. The hot geothermal water is used to heat the ORC working fluid into a high pressure vapor that expands through the twin screw expander spinning the induction generator to produce clean electricity while simultaneously cooling the water by up to 20^{0}C

This installation demonstrates the importance of both dual use of the heat (power generation and district heating) and the dual operation of the ORC (generating electricity and cooling of resource)

6.4 Case Study Second Install Japan

A second Power+Generator has been installed in Japan using low temperature geothermal steam for the generation of renewable energy. The power generated is sold to the local utility at an attractive feed-in tariff for renewables.

The installation site for this unit was particularly difficult with innovative installation techniques required to place the Power+Generator in the required location.

This demonstrated the need for compact modular designs to enable installation in difficult and environmentally sensitive sites. The design of the Power+Generator is such that it has a small footprint and is unobtrusive, allowing it to blend into the environment making is suitable for installation in residential areas.

Figure 7: ORC Installation Central Jappan

Japan has several advantages in the use of small geothermal resources that other countries do not, including thousands of existing bore holes for district heating systems and an advantageous feed-in-tariff for 24/7 renewable energy. These incentives increase the return of investment for ORC technology significantly offering opportunities for capital payback in the range of 3 to 5 years.

7 THE FUTURE

The future for low temperature ORC heat to power generation systems will continue to be driven by economics and improvements in design and efficiency. Government policies, in particular with regards to carbon neutral power generation, will also have an influence in the uptake of renewable power generation including baseload geothermal.

At ElectraTherm we are continuing to be at the forefront of development of ORC technology with further development of the Power+Generator and other products utilizing our ORC technology. This development process includes;

- Improved design and modulization to drive costs down and reduce equipment footprint
- Increased performance through larger capacity heat transfer and expander that will result in reduced costs per kWh
- Continued optimisation of control systems, and
- Development of new working fluids with improved low temperature performance and low GWP

Apart from technology improvements, the development of new and innovative applications such as the use of closed circuit underground systems and greater direct use of the heat in combination with power generation (CHP) will also influence the uptake of ORC heat to power generation systems.

8 CONCLUSION

The challenges for the future success of low temperature geothermal resources for power generation are many and varied as presented, but with the continued development of low temperature ORC technology and improvements in economics through a combination of lower equipment costs and increases in electricity value, low temperature geothermal resources will play an increasing role in future energy generation.

9 REFERENCES

IEA International Energy Agency, *World Energy Outlook 2019*

Huttrer, G.W.: Geothermal Power Generation in the World 2015-2020 Update Report *Proc. World Geothermal Congress 2020, Reykjavik Iceland, 2020*