DEVELOPMENT OF A LOW TEMPERATURE GEOTHERMAL ORGANIC RANKINE CYCLE STANDARD

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ABSTRACT

Low temperature geothermal systems are an abundant energy resource in New Zealand with over 260 sites with a resource temperature of 150°C and lower. The Organic Rankine Cycle (ORC) is the standard process for low temperature energy conversion with commercial ORCs utilizing temperatures as low as 90°C, with one site at Chena, Alaska (discussed below) utilizing temperatures as low as 74°C. The ambient temperature of the plant determines the minimum utilization temperature. Resource prospecting, power plant design, and project development are normally carried out by established companies. New Zealand is lacking experience in the design and manufacture of low temperature geothermal ORC plants. One proposed method to develop this experience is to understand the design process of existing low temperature geothermal ORCs. A qualitative analysis of ORC projects around the world can highlight the common steps involved in their development. A thematic analysis is a qualitative research method that can identify themes and patterns in data, which could help identify the common processes involved in these projects.

This paper shows the outcome of our first investigation of a low temperature geothermal ORC project. The Chena ORC used for this case study is unique as it has a very low resource temperature which is only possible because it operates in Alaska, which has a very low average ambient temperature. The research material available from Chena was organized into the four key steps: prospecting, conceptual design and plant feasibility, detailed design, and construction. These steps were previously determined as important stages in ORC development. The outcome of this analysis will help to establish a guideline for developing ORCs. The number of case studies required to develop robust guidelines is unknown; however, once clear patterns and similar steps emerge from a number of case studies that should be sufficient to finalise the proposed guidelines. The final aim of this research is that industry will adopt these guidelines for their own ORC projects and eventually this will encourage development of the low temperature geothermal design standard for the Above Ground Geothermal Allied Technologies (AGGAT) research co-operative. A standard for ORCs could encourage industry in New Zealand to undertake more of their own ORC developments for utilization of both geothermal energy and waste heat and a standard should ensure that their product is on par with other ORCs produced elsewhere. The International Organization for Standardization (ISO) has a number of standards for thermal power plants that overlap with ORC components; however, there is no standard discussing the unique requirements of ORCs.

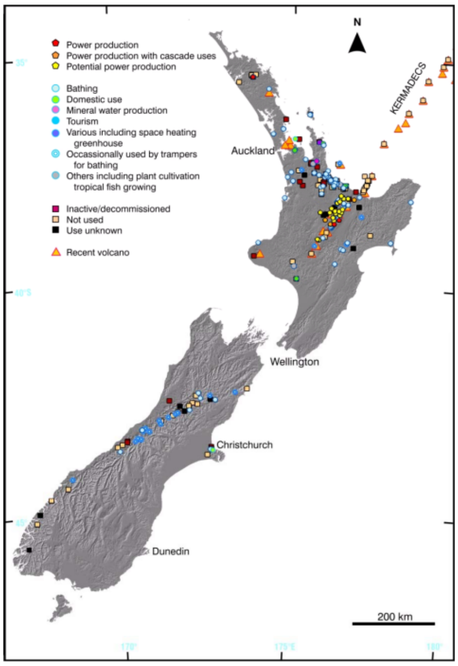

Figure 1. Low Temperature Geothermal sites across New Zealand, Image from GNS [1]

1. INTRODUCTION

1.1 Low Temperature Geothermal

Low temperature geothermal (LTG) heat is a common resource in New Zealand. GNS defines LTG or Low Enthalpy Geothermal to be a geothermal resource at temperatures between 150°C and 80°C [2]. LTG sources can be found at a number of sites around New Zealand but most of which are in the Taupo Volcanic Zone.

LTG heat can come from a number of sources and Figure 1 shows geothermal sites across New Zealand. LTG heat can be found in naturally occurring hot springs, abandoned hydrocarbon wells, and any unused brine that large geothermal power plants do not use because of the low temperature of the resource.

1.2 Technology

The most commonly used system for converting geothermal heat into electricity is an Organic Rankine Cycle (ORC). An ORC uses an organic fluid in a closed loop Rankine Cycle. The four main components of the ORC are the feed pump, vaporizer, expander, and condenser. New Zealand currently uses a number of ORCs for generating electricity from geothermal heat. The ORCs in New Zealand utilize moderate temperature geothermal fluids with temperatures of 150°C and above. The usual manufactures of ORCs do not focus on LTG heat because the plant output typically is much smaller than moderate to high temperature geothermal power plants. The Chena geothermal project is an example of a successful LTG electrical generation. Chena shows that it is possible to design an ORC for a low temperature resource without commissioning the usual large geothermal ORC design companies. The Chena geothermal power plant produces 400 kWe of electricity and can produce it at 5 cents per kWh [3]. The success of Chena is largely due to the very low ambient temperatures in Alaska which provide a sufficient temperature difference.

The leading provider of ORCs for the geothermal industry is Ormat [1]. The Ormat Energy Converter (OEC) is the ORC used at all of the binary plants in New Zealand. The ORC provided by Ormat is a flexible device that has been configured to operate from various geothermal sources. The Rotokawa plant uses three OECs which utilize both the exhaust steam of a 14MW back pressure turbine and the brine from the separator to produce another 15MW gross power [4], while the Wairakei binary plant only uses separated geothermal brine to generate an extra 14MW [5]. The OECs for these two plants are different because at Wairakei the heat source is all liquid while the Rotokawa OECs utilize both the steam and the liquid resource.

Recently, however, there has been growth in the industry with other international companies developing their own ORC technology [2]. One of these companies is Atlas Copco which has designed an ORC for a geothermal power plant in Turkey using their unique radial expander technology, with a capacity to generate 50MW of electricity [6]. The company that designed the ORC discussed in this report is United Technologies Center (UTC) who used the PureCycle waste-to-electricity device that was developed using air conditioning equipment from their sister company Carrier refrigeration [7].

1.3 Guidelines of the ORC Design Standard

The Above Ground Geothermal Allied Technologies (AGGAT) standard is being developed as an industry tool for ORC design. The final product is intended to be an accepted standard that can be easily used by industry. The current status of the standard is best described as a statement of guidelines as it is still in the very early stages of development. This paper looks at how closely a successful project matches the proposed guidelines. Figure 2 shows the proposed four main steps for the standard but this should not be interpreted as a standard in anyway at this point in the development.

Standards are available for a number of different types of power plants and they are designed to support the design engineer in decision making. There is currently no standard for the unique aspects of an ORC such as the working fluid selection and turbine options. A number of current standards can be used for certain aspects of the ORC design but a comprehensive standard could help minimize risks and encourage more development of LTG electricity generation. The eventual standard would also ensure the final product quality matches ORCs built elsewhere as the ISO states that 'Standards consistently provide requirements, specifications, and guidelines for product design and ensure the product is fit for purpose' [8]. The British Standards Institute defines a standard as: 'A standard is distilled wisdom of people with expertise in the subject matter' [9]. Once there is enough evidence that these guidelines best suit ORC development then experienced engineers can supply the finer technical aspects for the development of a standard

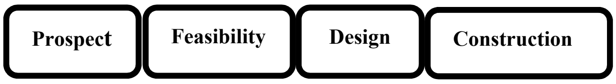

Figure 2. The main steps in the proposed standard

1.3.1 Thematic Analysis

The key steps suggested in Figure 2 were used to develop initial guidelines for ORC project design which eventually can be used to develop a standard. The first goal of this research is to develop robust guidelines that can be identified by studying a number of ORC projects. A qualitative analysis of a number of geothermal ORC project should uncover patterns that each project follows. A thematic analysis suits this type of investigation as it has been developed to identify themes and patterns in data and the sources of data available also suit a qualitative analysis. A thematic analysis codes the research material into recurring themes and identifies patterns in different material. The exact number of case studies required to confirm the themes identified is unknown; however, it should start to become obvious once each new case study starts to show the same patterns. Figure 3 shows the sources of possible data for the thematic analysis. It is likely that some of details required for a complete analysis may be confidential but a basic overview at this point may still help in setting up guidelines.

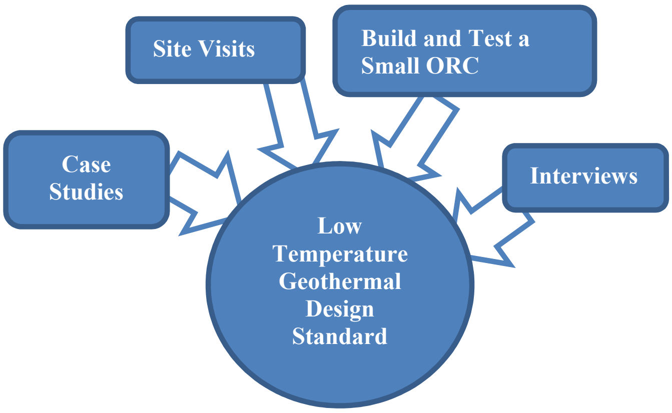

Figure 3. Sources of possible information for the thematic analysis to develop a Low Temperature Geothermal design standard.

2. POSSIBLE STANDARD

The following sections describe possible key steps that could be included in a standard. The steps discussed here should not be treated as a finished standard but instead they provide guidelines for the key aspects involved in a LTG ORC project.

2.1 Prospecting

There have been four key steps identified in the development of an ORC. The first step is the prospecting stage, the point of which is to assess the available heat resource and to decide whether or not an ORC is the best option. Figure 4 shows the key steps of the prospecting stage with a decision gate to decide early on if there is a likely chance of success for the project. In the case of a LTG resource the prospecting stage assumes that the resource is already understood and further test drilling is not required. The main goal of this step is to check whether the geothermal resource is suitable for an ORC and to determine a rough estimate of the maximum electricity output. The owner's conference will also identify if electrical generation is the best option and whether the plant should be connected to the grid, used directly by nearby industry or used as a remote power generator. In some cases direct use of the geothermal heat may be the better option.

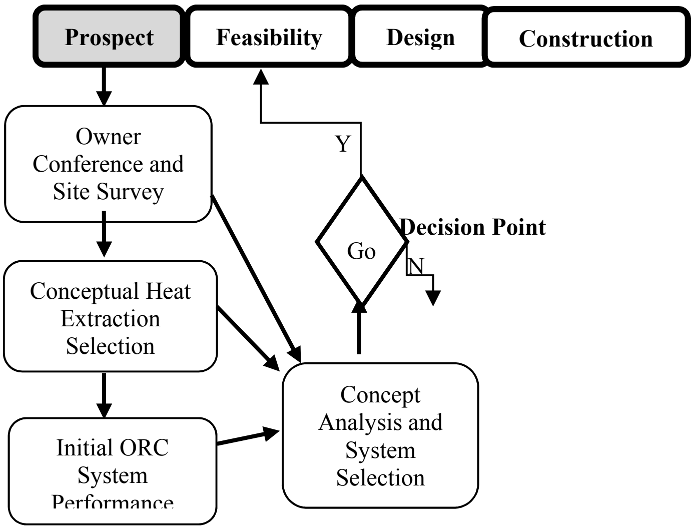

Figure 4. The prospecting stage steps in the current version of the ORC standard

The next step is a conceptual heat extraction design which will be used for a rough estimate of the size of the ORC. The properties of the geothermal fluid and any constraints on minimum temperature of the geothermal fluid will determine what type of heat exchanger should be selected and the amount of heat available. The operating conditions of the working fluid are given consideration however the geothermal fluid constraints will be the deciding factor. A rough estimate of land use should also be made in case there are space limitations. A rough estimate for the size of an ORC is 1415m^2/MW [10].

The final step at the prospecting stage is estimating the proposed ORC performance, such as the power output and efficiency. Initial cost estimates and calculation of the payback period can be made after this step and they will significantly influence the decision on whether or not to progress with the project. At this point in the project the risk of failure is still high because a comprehensive analysis still needs to be done, and therefore the investment in the prospecting stage should be minimal to avoid significant financial loss if the project is abandoned.

2.2 Feasibility

The purpose of the feasibility stage is to further develop the initial approximate model from the prospect stage to determine if the project is economically and technically feasible. The feasibility study should also provide the best possible solution for the client. The feasibility stage should only be carried out once it is clear there is a chance of utilizing the geothermal fluid because a comprehensive feasibility study requires resources and time. The final outcome of a comprehensive feasibility study can be used as the front-end engineering design (FEED) and can also be used for an in-depth economic analysis.

The goals of each step in Figure 5 of the guidelines are described in the following sections. This stage of the design process involves a number of iterations and revisions to optimize the model.

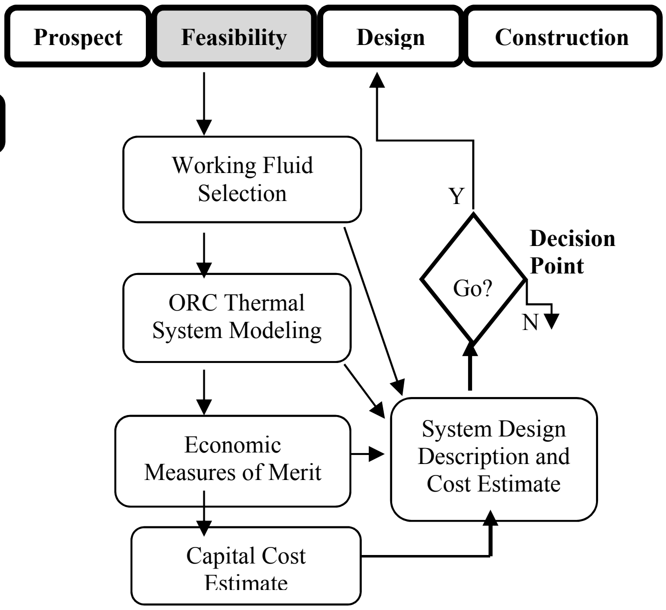

Figure 5. Flow diagram outlining the feasibility stage of the current version of the ORC standard

The selection of the working fluid is the first step in a more comprehensive analysis. The working fluid must be able to operate between the system constraints set by the geothermal fluid and the ambient environment. Other important considerations for the selection of working fluid include the availability of the working fluid, the toxicity, and compatibility with component materials. Typically large geothermal operations use hydrocarbons as the working fluid, such as pentane in the Rotokawa OECs [4] or butane in the planned Pamukuren Atlas Copco ORC [6], because they are relatively cheap and readily available. ORCs that utilize lower temperature geothermal fluids tend to use refrigerants, such as the UTC PureCycle at Chena that uses R134a as the working fluid [11].

The thermal model from the prospecting stage is reviewed and the components of the ORC are modeled in more detail using the parameters for the selected working fluid. The modeling process involved here should also investigate the possibility of a preheater or a regenerator. A regenerator is commonly used when there is a low temperature limit required on the geothermal fluid to avoid scaling. The thermal model will also determine required flow rates of working fluid, geothermal fluid, and cooling fluid for the optimum design. ORC outputs from this analysis also include theoretical parasitic losses on the system and the pressure drop through the heat exchangers.

The detailed thermal model can be used to better understand the economics of the system and to determine a proposed initial capital cost. There are some models available such as the GT-Small model [12], which provide approximate estimates of the capital cost of small geothermal projects. An economic analysis of the system can determine the unit savings of energy over the proposed lifetime of the ORC. The economic analysis also determines the payback period and the net present value of the entire system. The economic analysis of the system should be presented to the client before the next decision is made: i.e. if the project should progress to the design stage, as this requires a large investment of time and money. As mentioned in the discussion of the prospecting stage the decision gate provides the opportunity to abort the project before a significant financial investment is made. The feasibility study should aim to minimize the present and future risks in the project so that it has the highest chance for financial success.

2.3 Design

This stage is used to produce a detailed design of the proposed ORC. The detailed design will produce specifications for fabrication or selection of appropriate components and this stage can also be referred to as the Engineer Procure Construct (EPC) stage. For large geothermal projects the EPC contract is usually awarded to a company that specializes in the required technology. Ormat is an example of a specialist company that has carried out the EPC stage for geothermal ORCs. The design steps outlined in Figure 6 are possible guidelines that a smaller company could follow in order to design their own ORC for a geothermal energy source.

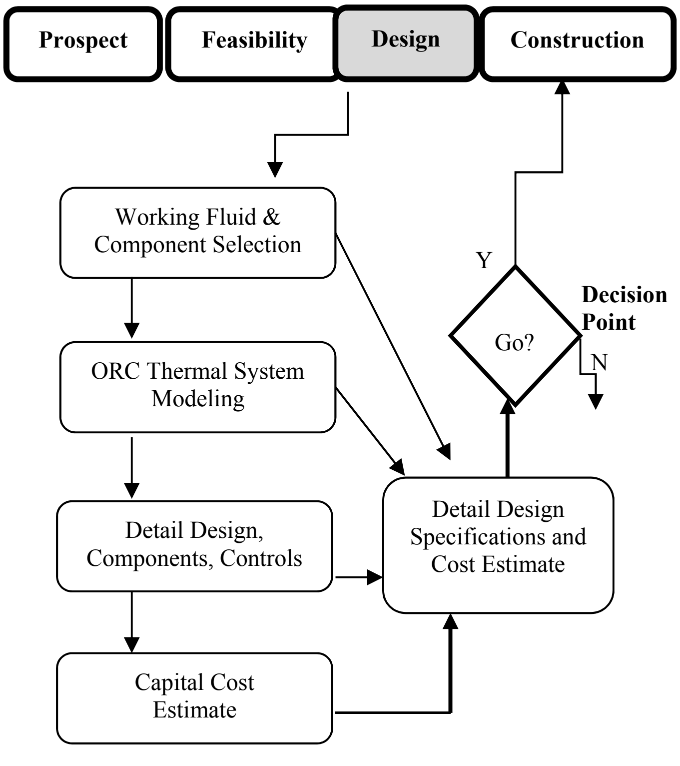

Figure 6 Design process stage in the current version of the design standard

The working fluid selection should be finalized before the design of the other components because certain components such as the turbine are sensitive to the properties of the working fluid. Throughout the design stage the thermal model should be updated to maintain a comprehensive economic evaluation.

The design process will also determine whether the components need to be manufactured or can be purchased from a local or international company. Once again these decisions can significantly change the economic outlook of the project.

Current ORC developers such as Ormat typically design and manufacture the key components for their ORCs. The OEC uses original Ormat designs for the turbine, pump, and heat exchangers [13]. The success of Ormat in the binary geothermal power plant sector could be related to the reliance on their own designs rather than sourcing outside components. Other companies mentioned above that are also developing their own ORCs are also using in-house designs for critical components. For example Atlas Copco have designed a unique radial turbine that can be used with organic fluids[6]. ORCs developed by Barber-Nichols in the past have also used their own designs for key components [12].

It is possible to design small ORCs using alternative expanders rather than relying on turbines. A scroll expander is an alternative expander for an ORC [14] and screw expanders have also been used. The ElectraTherm Green Machine uses a screw expander and can produce up 65kW from low temperature heat sources [15].

The success of the larger companies in completing their own design is an indication that specific design is a key factor in the optimum planning of an ORC project because each heat source evaluated is unique. Once the design of the ORC is complete the capital cost estimate for the construction and commissioning of the project will be much more accurate and then the client or financial backer can make the final investment decision (FID) before construction starts.

This section in a standard would reference a number of current standards as there are a significant number of components in ORCs that have standards elsewhere, such as heat exchangers. Once the design is completely signed off the project can move on to the construction stage which can be contracted out to construction companies or if the design company has the resources then they can complete the project themselves.

3. CHENA ALASKA

The Chena resort is a remote geothermal site in the middle of Alaska that uses the geothermal heat for electricity generation and heating for the resort.

3.1 Motivation

Originally the Chena resort used a diesel generator for electrical generation. The average cost to run the diesel generator for the 180-380kW load at Chena was $1000/day in 2004 and close to $500,000 per year. Electricity at Chena was costing 30¢/kW. The vision of the Chena Springs community was to become self-sustaining in terms of energy, food, heating and fuel.

In 2004 Chena began their energy independence plan to increase the use of locally available resources, which included geothermal. Geothermal heat was used to heat 44 buildings and was also used for an absorption chilling to cool the Aurora Ice Museum. The owners of Chena were also interested in the possibility of using the geothermal resource for power generation. It was thought that electricity production from geothermal heat could reduce the cost of electricity in Chena to 5¢/kW.

3.3 Resources

The geothermal potential in the area was explored in the late 70's and early 80's; however, the results of the survey discounted the site for power generation with the technology of the time. For the Chena geothermal project it was decided to take a two-tiered approach for electrical generation. Two separate projects were developed simultaneously at Chena: the first project was to install a small geothermal plant designed for the existing proven resource. The second project was a more extensive exploration of the deeper geothermal resource and its potential for long term sustainable power generation.

The Chena hot springs are one of around 30 low to moderate temperature geothermal sites in Alaska. The proven resource is geothermal brine with a temperature of around 74°C, which makes this the lowest temperature geothermal resource used for electricity generation in the world. Another important resource consideration is the geothermal brine chemistry as this affects the heat exchanger design if the fluid is highly acidic or has a high silica concentration. At Chena the geothermal brine was quite dilute with a dissolved content of only 300 to 388 mg/L and a pH near 9. The geothermal water is classified as drinkable which makes it a unique resource [3].

One production well is used to supply the geothermal fluid for the Chena power plant. The well is 217 meters deep and a submersible pump was installed in the well to achieve the desired flow rates for the power station.

A unique aspect of the Chena geothermal site is the unconstrained supply of cold water at 4.4°C. The cold water can be used as a heat sink in the ORC to achieve a greater temperature difference in the cycle and subsequently produce more work. This low temperature water is why the ORC at can operate all year round with the cool geothermal resource of 74°C. The average ambient temperature over the winter months is negative which contributes to the ORC performance.

3.4 The Chena ORC

3.4.1 Companies

It was difficult to find geothermal manufactures willing to work on a small generation project with such a low temperature resource. Ormat and Barber-Nichols both provided initial project quotes. Barber-Nichols was initially selected to provide a 400 kW power plant for Chena. UTC approached Chena and offered to install a PureCycle 200® which is an ORC designed to operate on waste gas; however, they were exploring further applications for the PureCycle and were willing to modify it to work with a geothermal fluid. UTC was eventually chosen as the manufacturer as it could help further develop the geothermal field and also Barber-Nichols had not manufactured a geothermal plant since the 80's.

3.4.1 PureCycle 200® Design Changes

The main aspect that made the PureCycle affordable was using the single-stage centrifugal compressor from Carrier chillers, which is a mass produced refrigeration system. The compressor was reversed and used as a single stage radial expander. There were a number of changes made to the original ORC that was designed for utilization of waste heat. Originally R245fa was the designed working fluid for the PureCycle. However, at Chena the working fluid was changed to R134a because it was a better match for the LTG application. R134a also reduced the cost of the project because it is a cheaper fluid and there is more HVAC equipment compatible with R134a. The working conditions of the ORC are shown below and Figure 7 is the T-S diagram of the designed system [16]. The documentation for PureCycle advertises that is can use any heat source with a minimum temperature difference between the heating fluid and the cooling fluid of 38°C [17]. The Chena geothermal project was a good match.

Water Design Points

Heat source: Tin = 73 °C Tout = 57 °C Flow rate: 33.4 L/s
Heat sink: Tin = 4.4 °C Tout = 9.4 °C Flow rate: 101.8 L/s

Refrigerant Design Points

Mass flow rate: 12.18kg/s
Evaporator/turbine inlet pressure: 16 Bar
Condenser/turbine exit pressure: 4.4 Bar
Turbine gross power: 250 kW
Pump power: 40 kW
System output power (net): 210 kW
Thermal efficiency: 8.2 %

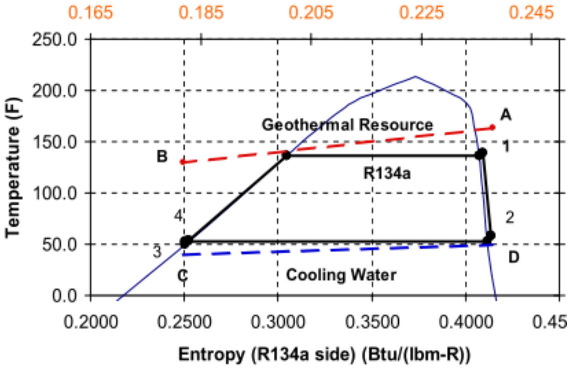

Figure 7. T-S diagram of the Chena geothermal project, Image from Chena Power [3]

The main components that changed in the ORC were the heat exchangers. Originally they were designed for gas to liquid heat transfer not liquid to liquid. The original PureCycle ORC used a fin and tube evaporator for waste heat applications to facilitate the heat transfer between waste exhaust gas and the working fluid and the condenser was a fin and tube fan bank.

The evaporator and condenser designed for Chena were once again based on equipment from Carrier refrigeration. Shell and tube heat exchangers were designed for the evaporator and condenser, which are commonly used heat exchangers in geothermal power plants. The evaporator designed for Chena was an integrated preheater and evaporator to reduce components, complexity, and cost. A partition was designed to separate the preheater and evaporator and a distributor nozzle guided the working fluid into the evaporator from the baffled preheater to produce the most effective heat transfer. The chemistry of the brine did not constrain the material selection process which allowed UTC to use copper which is generally not used for geothermal applications. The final evaporator design specs are listed below [3].

- 2-pass on geothermal resource side,
    - including 1-pass in boiler region, 260 tubes
    - 1 pass in preheater region, 90 tubes
    - ¾" OD, 0.035" tube thickness, Cupro-Nickel 90-10 TurboChill
- 32" OD shell, 10" flanges

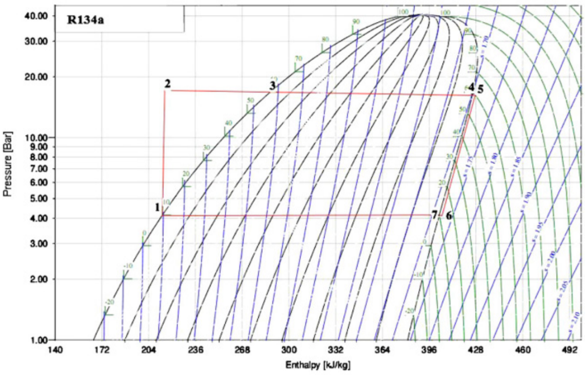

Figure 8. P-H Diagram of the ORC installed at Chena, Image from Performance of Chena Binary Geothermal plant [16]

The turbine and generator for this system was a single hermetically sealed unit. A sealed system reduced maintenance and also shaft leakage which is a common problem with most turbines. The turbine was only slightly modified from its original purpose as a vapor compressor and so could be manufactured to the same quality as the compressors for commercial chillers. UTC tested the design at their research center for more than 1000 hours before sending it to Chena for LTG electricity generation.

Two 200 kWe ORCs were installed at Chena. The first ORC used the designed water cooled system. The second ORC installed was designed to use either cooling water or an air cooled condenser. The fan bank required 24kW to run opposed to the cooling water which was siphoned out of the nearby well. However, the air cooled condenser allowed for a larger temperature difference in the winter months due to the ambient air temperature being below -40°C, which produced a maximum net power output of 220 kW [18].

The geothermal generators required a stable grid input during startup. The solution was a 3MW UPS system with a AC/DC inverter to provide the stable input for the generator, which allows the Chena power plant to work independently from the grid [18].

The PureCycle plant had a control system installed for its original purpose and this was modified for remote control and monitoring for the Chena installation. A data collection and monitoring system using Labview was installed in the system once it was setup so that UTC engineers and Chena power could monitor the power plant either onsite or remotely.

The owners of Chena recognized the importance of reinjection for the success of any large geothermal project [3]. Two reinjection wells were drilled to reinject 100% of the geothermal fluid. The primary reinjection well is 213m deep and situated far enough away from the main production well so that it does not affect the hot reservoir.

3.6 Results

The first ORC was installed in August 2006 and the second ORC came on stream in December. The second ORC was designed to also run with an air cooled condenser to capitalize on the low ambient air temperature in Alaska and this ORC ran continuously once installed. The first ORC, which was designed for water cooling, encountered problems with the cold water supply in late winter and early spring, which caused it to shut down. A second air cooled condenser was installed so that both ORCs can either use the cooling water or the air cooled condenser. The plant currently uses the water coolers in summer and the air coolers in winter. The current Chena power project now uses three ORCs to produce a total gross power output of 730kW with a net output of 500kW [19].

The project was completed on schedule and with a total cost of $2,007,770 ($5000/kWe) which was only over 5% of the original budget. The projected was partly funded through a grant from the Alaska Energy Authority and a project loan through the Alaska Industrial Development and Export Authority. However, 55% of the project funding came directly from Chena Hot Springs.

A report for the Geothermal Resource Council in 2007 stated that the Chena power plant had been operating with 95% reliability and had generated 400MWh [20]. The cost of power was successfully reduced to 5¢/kWh and in 2007 the ORC plant saved an estimated $500,000 on diesel fuel, and therefore the project had a four year payback period on the savings from diesel fuel [21].

The success of the Chena power plant indicates that LTG is a competitive power generation option for remote power sites that use diesel generators to meet their electricity demands. The Chena project also investigated the deeper geothermal resource with hopes that it could one day operate a 10MW power plant that would justify a transmission line to the closest town.

4. CHENA AND STANDARD COMPARISON

The Chena LTG ORC is the first reviewed for this study of existing ORC projects and the categorizing of the available data with the proposed guidelines discussed. The Chena development is also an example of competent engineering and good project management and following a similar process should help with the success of other ORC projects. However, more projects will need to be reviewed so the details of each step can be expanded, which will help generate robust guidelines that new ORC projects can follow.

4.1 Prospect

The first step in the Chena project was a prospecting stage. The resource for Chena was already understood from previous government led investigations. There was minimal discussion on the site and no owners conference because the site owners undertook the investigation themselves to discover the feasibility of using the geothermal resource to increase their renewable energy production. The characteristics of the geothermal fluid were understood and there was evidence from the earlier exploration of the area that the geothermal resource had the potential to produce electricity. However, at the time of the initial investigation in the 70s the technology of the time and cost of diesel did not merit investment in a small geothermal power plant. The importance of a prospecting stage is clearly shown in the Chena project because it provided clear resource data.

4.2 Feasibility

Once a design company has been selected to design the ORC there are steps that can be connected to guidelines for the feasibility of a project. A feasibility study in a project is carried out prior to the large portion of the design. The Chena project approached two companies before being offered an ORC design from UTC. Therefore, there would have been some feasibility study prior to approaching these companies. The selection of working fluid to best match the geothermal resource is something highlighted in the guidelines. The original PureCycle used R245fa, but with the low temperature nature of the cycle R134a was chosen because it would yield better results at the lower temperatures. Even though the PureCycle operates well at other sites with R245fa, updating the design with R134a would deliver better results. The thermo system was changed with a new working fluid selected and Figures 7 and 8 show the temperature enthalpy and pressure enthalpy diagrams respectively. UTC focused on reaching their goal of a low cost ORC for LTG fluid to expand their product range. They focused on utilizing mass produced refrigeration equipment to reduce the capital cost and cost per kilowatt. It was clear early in the project that geothermal power at Chena would have a quick payback period because of the high diesel costs, which can be seen as an economic consideration in the feasibility guidelines.

4.3 Design

The design process in the Chena project closely resembles the guidelines for approaching an ORC design. R134a was selected as the working fluid in the ORC and the main components had to be designed and selected for the final product. The selection of R134a also helped the selection of components for the ORC because there was more refrigeration equipment compatible with R134a. The expander was the first choice because it was already used in the current setup of the PureCycle. The expander was developed by UTC to operate as close as possible to the design condition. UTC was in a unique position as they already had an expander that worked and so this section did not require much design. The heat exchangers, however, had to be modified to work with the geothermal fluid. The original heat exchangers were not designed for liquid to liquid heat transfer and so UTC developed two new heat exchangers that used a shell and tube design, commonly used for geothermal applications, to utilize the liquid resources. The first ORC installed used cold water from a well as the heat sink in the condenser, but it developed issues in the first year of use. The second ORC used water cooling in the summer and air cooling in the winter. Once it was clear that the increased power output from the air cooled fan bank was greater than the parasitic losses of the fans a second fan bank was installed for the first ORC. It did show that an air cooled condenser in the winter month would yield more net electricity generation.

The PureCycle was constructed at UTC and tested there prior to installation at Chena. The first ORC was installed and connected by both UTC and Chena employees. The Chena employees constructed the pipe line from the geothermal well to the power plant and also the cooling water supply. The UTC staff installed the PureCycle with help from Chena. The second ORC was almost completely installed by the staff at Chena with UTC only needed for setting up the control systems.

5. CONCLUSION

The first case study shows that prospecting, feasibility, and design are important steps in an ORC project. There was only a small discussion on the construction of the Chena plant because the PureCycle delivered to Chena was a complete unit and only had to be connected to the geothermal fluid at Chena. It is clear that more case studies still need to be analysed before these guidelines can be considered robust. Interviews with engineers on LTG ORC design projects may also help to develop the more detailed aspects of the guidelines that reports of past projects do not generally discuss. Regular communication with industry is an important aspect for the development of the final standard because experienced members of the industry with expertise in ORC projects will understand the important aspects of design and how to incorporate them in an eventual standard.

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