The Chena Hot Springs 400kW Geothermal Power Plant: Experience Gained During the First Year of Operation

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ABSTRACT

In July 2006, Chena Hot Springs Resort installed the first of two 200kW Organic Rankine Cycle (ORC) power plant modules designed and built by United Technologies Corporation (UTC) at their Hartford, Connecticut research facility. The second unit was brought online the following December. The modules were designed based on the PureCycle 200 product released by UTC in 2004 and designed to operate off industrial waste heat applications. The PureCycle 200 uses components and hardware from the Carrier Refrigeration line, which is a division of UTC, in over 90% of the system. This greatly reduces the upfront cost of the equipment since air-conditioning equipment has a cost structure significantly lower than traditional power generation equipment. This is significant because Chena Hot Springs is a moderate temperature geothermal resource with a maximum produced water temperature of only 165ºF. For this reason, any ORC designed to generate power from the Chena resource is saddled with an inherently a low thermal efficiency. Low efficiency requires increased power plant equipment size (turbine, condenser, pump and boiler) that can ordinarily become cost prohibitive. One of the main goals for the Chena project was to reduce the equipment cost of these UTC designed PureCycle modules to $1300 per kW.

This paper describes the site preparation, installation and operation of the two PureCycle 200 units, and experience gained as the first anniversary of the installation approaches. This paper does not focus on the design of the system, which has already been covered in two previous papers presented at the 2005 (Joost, Biederman, Holdmann) and 2006 (Cogswell) GRC Annual Meeting.

Background

Despite being an oil exporting state, Alaska is home to some of the highest electric power costs in the United States, particularly in the numerous remote, isolated villages scattered throughout the state. For example, the cost of power at Manley Hot Springs, located northwest of Fairbanks, is currently 86¢ per kWhr. Residents in rural areas, where average income is below the national poverty level, typically spend 25% or more of their income on utilities, primarily electricity and heating (Davis, 2007). This is much higher than the national average of 6.8% as estimated by the Bureau of Labor Statistics.

Chena Hot Springs Resort, located 60 miles northeast of Fairbanks Alaska, is no exception to this rule. Prior to the installation of the geothermal power plant facility, power was generated from a 400kW diesel recip. The cost for generating power in 2006 was 30¢ per kWhr, which at an average load of 230kW represented a cost of $604,000 in 2005. The fuel cost represented approximately 60% of this expense, or $362,400.

Two well-known manufacturers of binary ORC systems for geothermal applications were approached in 2002 and

Figure 1. ORC 1(background) and ORC2 (foreground).

2003 about designing a system for Chena Hot Springs. One manufacturer declined the opportunity due to the low resource temperature, and the second manufacturer was more than willing to build a one of a kind system for Chena, however the cost per kW output would be very high.

In 2004, Chena Hot Springs was presented with a new opportunity of working with United Technologies Corporation (UTC) to demonstrate their existing PureCycle technology on the geothermal resource at Chena. UTC was awarded funding from the Department of Energy to complete design work on the system, and the power plant modules were designed, assembled, and tested at UTRC in Hartford, Connecticut beginning in late 2004. The first unit (ORC1) underwent 1000 hours of qualification testing before being disassembled and shipped to Chena Hot Springs. The second unit (ORC2) was partially assembled but not tested before being sent to Chena several months later.

Figure 2. Chena ORC1 turbine/generator assembly analogous to Carrier motor/compressor assembly.

Chena Power Plant Design

The PureCycle 200 platform that the Chena plant is based on was designed to produce 200kW of electric power from waste hot gas sources between 500 and 1000°F using mass-produced Carrier chiller components. The most critical components include a single-stage centrifugal compressor which runs in reverse as a radial inflow turbine to produce 200kW of power, and heat exchangers originally designed for large chiller applications. Additionally, local and remote monitoring and control was applied for both operation and data collection.

The specific objective of the Chena project was to demonstrate the low cost of the power generation equipment ($1350/kWhr installed) and the feasibility of producing electricity at a cost of less than 5¢/kWh from a 165°F geothermal resource with 98% availability. The geothermal application for the PureCycle platform involved some additional innovation and opportunities for cost reduction beyond that of the original PureCycle 200 platform, including:

- Changing the working fluid used in the PureCycle ORC plant from R245fa to R134a. This fluid is a better match for low temperature geothermal applications and enables a significant cost reduction, both directly because R134a is a low cost fluid widely used in HVAC equipment and indirectly by allowing lower cost commercially available components to be used in the power plant.
- Developing low cost heat exchangers specific to geothermal applications based on designs and production capability in place for Carrier's large commercial and marine water-cooled chillers.
- Reducing the plant cost relative to the original PureCycle ORC plant by incorporating and qualifying more commercially available components made feasible by the lower operating temperature in geothermal applications.
- Develop control algorithms and methods for operation with tube and shell heat exchangers rather than the fin-tube technology applied in the original PureCycle plant.

The geothermal plant modules were designed and qualified at the United Technologies Research Center before installation at Chena Hot Springs. Cycle analysis showed that with 1060 gpm of 164 °F temperature geothermal liquid as the heat source and virtually unlimited 40-45 °F water (at least during the summer months) from a shallow infiltration well as heat sink, two geothermal power plants could be installed using HFC134a as the working fluid. The first unit (ORC1) was installed in August 2006, and the second unit (ORC2) a few months later in December. Both operate under the same design points with the exception that ORC2 is dual air and water cooled to take advantage of the cold ambient winter temperatures in interior Alaska. A picture of the two modules installed at Chena is show in Figure 2. Each power plant module has been operating at the following design conditions:

Water Design Points

Heat source:	Tin = 164°F	Tout = 135°F	Flow rate: 530 gpm
Heat sink:	Tin = 40°F	Tout = 49°F	Flow rate: 1614 gpm

Refrigerant Design Points

Mass flow rate:	26.8 lbm/s
Evaporator/turbine inlet pressure:	232 psia
Condenser/turbine exit pressure:	63.6 psia
Turbine gross power:	250 kW
Pump power:	40 kW
System output power (net):	210 kW
Thermal efficiency:	8.2 %

This efficiency was a challenge given the limited thermodynamic availability of the low temperature geothermal heat source. A completely reversible thermodynamic cycle working with the same heat source and heat sink temperature glides would have a thermal efficiency just under 18% (Figure 3). Fortunately, efficiency improvements are far less critical in power generation when the fuel is essentially free. Instead, the important factor is overall utilization of the geothermal fluid, and so minimizing flow rate of water through the evaporator is critical in system design.

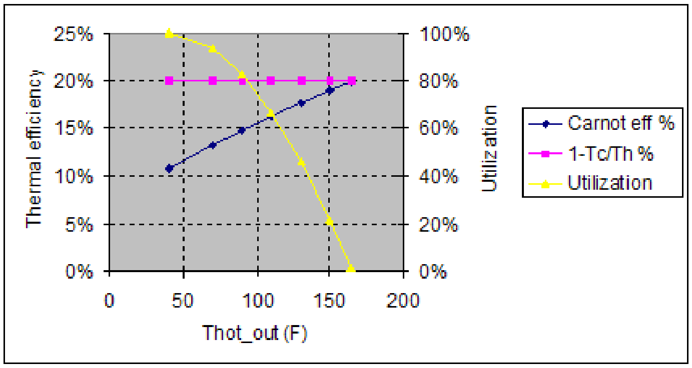

Figure 3. Carnot efficiency and utilization for limited hot resource. (T_{hot_int} = 165 °F, T_{cold} = 40 °F).

Cooling Supply for Condensers (Water and Air)

To maximize system performance and take advantage of the excellent cold water resources available locally, the first ORC module was designed to be water cooled at 40-45 °F. In order to maximize net power production, a water supply system was designed which would require no pumping load. This was accomplished by employing a low tech siphon to 'pull' water out of a shallow, large diameter well located 2700 ft to the east of the power plant. The elevation difference of +33 ft between the cold water well and the power plant allows 1500 gpm to flow through each condenser at 5 psi without a pump. To minimize pressure loss due to friction in the pipeline, the pipeline was oversized with 2400 ft of 18 in and 300 ft of 16 in steel pipe. All pipe installed as part of this project (including the hot water supply and return lines) were recycled or reused from other projects around the state.

The cold water gains 9-10 °F in the condenser before being discharged to Monument Creek, which runs along the northern boundary of the Chena Hot Springs property via an existing drainage ditch. An automated shutdown procedure is in place to avoid the potential for refrigerant discharge into Monument Creek if a leak in the condenser is detected.

The second ORC unit was designed to be either air or water cooled by installing a separate air cooled condenser adjacent to the power plant building. The air condenser fans draw an additional load of 24kW, however they allow for an increase in net generating capacity at sub zero temperatures, which are common at Chena during the winter months. During the summer, the unit is reconfigured by turning two manual valves to use a water cooled condenser identical to the one installed in ORC1. In fact, the air cooled system has worked so effectively, a second air cooled condenser has been ordered and will be installed on the first ORC unit for use next winter. Maximum net power generated during winter operation was 220 kW, at an ambient temperature of -43 °F.

Hot Water Supply and Reinjection System

All available geothermal waters in the vicinity of Chena Hot Springs have been sampled and analyzed for their basic brine chemistry, stable isotopes, total organic carbon and dissolved inorganic carbon as part of the Department of Energy funded GRED III project (Holdmann, Benoit, and Blackwell, 2007). Quartz and Na-K-Ca geothermometers predict temperatures as high as 278 and 263 °F respectively as the base temperature of a deeper resource at Chena. These temperatures are expected to be accessed at depths of 1500 to 2500 ft, according to the model developed through the Chena GRED III project.

The Chena thermal spring waters are quite dilute for thermal waters, having a total dissolved content of only 300 to 388 mg/l, with a pH near 9. This has made selecting materials for the power plant heat exchangers somewhat easier than usual for a geothermal fluid, however there are still concerns about the sulfur content and reactions with the copper alloy (90/10 Cu-Ni) as well as potential oxidation in the evaporator units. This causes some minor pitting and scaling which has been observed in the evaporator tubes, and ultimately it may be necessary to inject a corrosion inhibitor into the hot water supply, as is common in many other geothermal installations. This issue is still being researched.

Development as part of the current power generation project has focused on the shallow geothermal system, and extensive testing of the resource has determined the upflow zones lies approximately 1500 ft to the west of the natural hot springs area. Test wells with the highest artesian pressures and temperatures were drilled in this area during 2006. Prior to 2006, drilling had focused on the area immediately surrounding the hot springs and extending toward the east. It has now been established from clear rollovers in the temperature depth curves that this area is part of the outflow plume, and not the source of the upflow.

The main geothermal production well was drilled to a depth of 713 ft in May and June, 2006 based on data from the test wells. Three productivity values for the well were calculated during separate flow tests, and the overall productivity of the well is approximately 15.6 gpm/psi. From this value, we were able to estimate a drawdown of 148 ft in the well at the production rate of 1060 gpm, which is required for power plant operation. This allowed us to select a pump and determine at what depth the pump should be set (220 ft) to prevent cavitation. A 100 hp submersible Centrilift pump was selected, with a VSD controller. A backup pump, capable of supplying 500 gpm, will be installed in 2007 in a nearby well in case of primary pump failure.

The hot water is delivered to the power plant via a 3000 ft length of 8 in insulated HDPE. The line was laid in a shallow ditch along 90% of the route, and will eventually be buried. The pipeline follows an existing unimproved road along the south boundary of the Chena Hot Springs Resort property. A maximum of 1.8 °F is lost in the pipeline between the production well and the power plant during the winter months.

Developing a successful injection strategy is integral to the success of any large scale geothermal project. Chena has been working on characterizing its wells for nearly 2-1/2 years, largely in anticipation of minimizing the stresses placed on the reservoir due to increased production necessitated by the power generation project. Initial injection well candidates were chosen primarily due to their distance from the proposed production area and the natural hot springs. However, additional testing showed that while these wells are unequivocally linked to the geothermal system/reservoir, they have low injectivity indexes which make them poor candidates for injection of any substantial volume of fluid under the low wellhead pressures planned.

Currently, Chena is using a single injection well located near the power plant building. This well has a total depth of 702ft, and injection testing conducted in December 2005 indicated a very high injectivity index which has subsequently been verified through actual injection of spent fluid. The well was cemented in July, 2006 and has been used successfully for injection ever since the first unit began operating. The geothermal field is still being monitored, and changes to the injection strategy over the long term is expected in order to minimize cooling of the resource. No cooling has been observed to date in produced fluid, and temperature increases of up to 8 ºF have been observed in holes near the production well. Unfortunately, the injection well is located only 500 ft upstream of the shallow district heating supply well, and temperature declines have been observed in this hole. As a result, the district heating well will be abandoned in 2007 and the heating system subsequently supplied directly by the discharged fluid from the power plant in combination with low volumes of hotter waters from the main hot water supply line for the power plant.

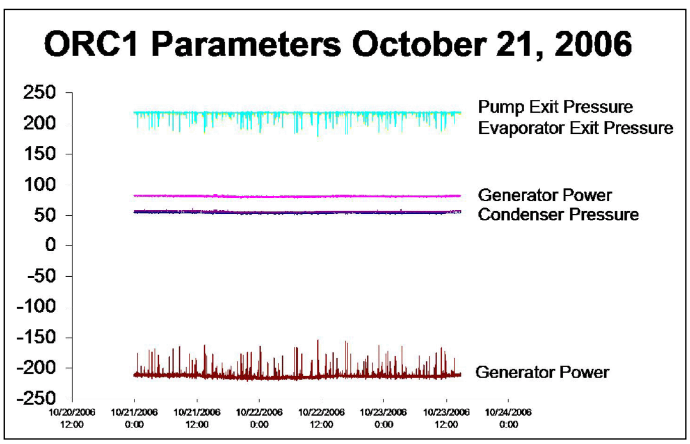

Figure 4. Sample of data collection and tracking of limited number of parameters from ORC1 from October, 2006.

Installation of Units

The first power plant module was delivered to Chena Hot Springs on July 8th, 2006, and officially began operation on August 20th when the official ribbon cutting ceremony was conducted. 1400 people were on hand to celebrate the grand opening.

The second ORC power plant module was delivered in mid-November, 2006 as scheduled. It was brought online December 16th, 2006. The installation of the second unit was completed almost entirely by the crew of Chena Power, with UTRC and UTC Power representatives onsite for only a few days to complete final hookup of control wiring, systems check, and initial startup. The second unit is essentially identical to the first one, with the exception of some alterations to the turbine exhaust pipe and bypass tubing for the refrigeration system.

As discussed previously, the second ORC unit is a dual air and water cooled system. This allows maximization of system performance by taking advantage of the cold ambient air in winter, and the cool groundwater in the summer months. The second unit has been operating consistently since installation. Due to problems with the cold water supply during the late winter and early spring months (a lower water table and temperatures dropping to -50 ºF hampered operations), ORC #1 was temporarily shut down. This issue will be eliminated with the installation of a second air cooled condenser and possible construction of a cooling pond during intermittent seasons. Both units are expected to be running in tandem by August 2007.

Modification to Existing Electric Infrastructure and Hookup to UPS System

One of the major project challenges has been upgrading an aging diesel generator plant and marginal power distribution infrastructure to permit installation of the geothermal power plant modules. Modifications to the existing electric infrastructure began almost a year prior to the installation of the first ORC module.

One specific challenge was how to allow the geothermal modules, which generate power via induction generators and thus requires grid support to provide a stable input voltage and frequency for startup to operate as stand alone generation. This was accomplished through the installation of a 3MW UPS system. The 480VAC/DC inverter which is part of the UPS system can provide voltage and frequency to the induction generator as it extracts current. This type of system, with batteries for startup and load balancing, allows for the grid-independent operation required by Chena Power.

An additional benefit of the UPS system was that it allows seamless power production from multiple sources (primarily the ORC units and the paralleled diesel generators) to smoothly and continually provide power to the site, via the inverters.

Project Economics

The project has been completed on schedule and close to the original budget of $1,899,065. At the end of 2006, project expenses totaled $2,007,770, or 5% above the original estimate. The project was funded in part through a $246,288 grant from the Alaska Energy Authority. An additional loan was obtained through the AIDEA Power Project Loan Fund in the amount of $650,000. The rest of the project included cash and in-kind contributions from Chena Power and its sister corporations Chena Hot Springs Resort and K&K Recycling.

The Chena geothermal power plant was completed on schedule and very close to the initial budget projection. The power plant logged over 3000 hours with 95% availability in 2006, generating 578,550kWhrs and displacing 44,500 gallons in diesel fuel. In 2007, the project is expected to generate 3 million kWhrs of clean geothermal power and displace 224,000 gallons of diesel for an estimated savings of $550,000.

Chena Fire

On May 10th, 2007, a fire broke out in the building the houses the power plant modules. The fire was started by welding sparks that fell inside the building when supports for an overhead door were being mounted to the exterior of the building. Because there was no one inside the building when the fire broke out, it was not noticed immediately. The fire was put out quickly using the power plant water supply and the building received moderate damage which has since been repaired. Unfortunately, burning insulation fell on top of the power plant modules and melted much of the control and electric wiring as well as the control panel. The control room itself was largely undamaged.

The fire was a very unfortunate setback, however the Chena crew was able to get ORC2 restarted one month after the fire and it is operating at full capacity. As of the writing of this paper, ORC1 is now being repaired and is expected to be back online in early July. None of the primary system components was damaged during the fire (turbine, generator, heat exchangers, pump). Cold water ran through the units during the entire event, which helped to keep the temperatures down and prevent thermal breakdown of the oil or refrigerant. Fortunately, the refrigerant used in the system (r134a) is non-flammable and therefore did not cause a concern in terms of an accidental release causing the fire to spread.

Conclusion

Overall, the Chena project has been highly successful for both UTC and Chena Hot Springs. Chena was able to dramatically reduce costs of onsite power generation, and UTC released the product for sale in early 2007 in a slightly reconfigured package.

The power plant has received international recognition, and was awarded the Project of the Year Award by Power Engineering Magazine in the renewable energy category. Chena Hot Springs Resort also received a Green Power Leadership Award from EPA and DOE, and more recently was selected for a very prestigious R&D 100 Award from the Department of Energy.

It is hoped that the Chena geothermal plant will encourage other sites to develop moderate temperature geothermal resources in Alaska, throughout the US, and around the world. The project has demonstrated the cost of power production, even in semi-remote locations such as Chena, can be reduced to below 5¢ per kWhr. This makes geothermal power generation highly competitive with existing diesel generation in rural Alaska, particularly since fuel costs are virtually eliminated once the plant is installed. Even in locations with no geothermal resources, the same ORC power generation technology can operate off other industrial waste heat sources to reduce power generation costs.

Abbreviations

ORC	Organic Rankine Cycle
UTC	United Technologies Corporation
UTRC	United Technologies Research Center

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