Low Cost Exploration, Testing, and Development of the Chena Geothermal Resource

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ABSTRACT

The Chena Hot Springs geothermal field was intensively explored, tested, and developed without a wireline unit between October 2005 and August 2006. Due to the remote location of the project and its small size of 0.4 MW, it was necessary to perform the work without the geothermal industry infrastructure typically utilized in the 48 contiguous states. This could largely be done because some of the wells were capable of artesian flow at below boiling temperatures. The geology, consisting of solid granite below a few tens of feet of alluvium allows for rapid air hammer drilling and minimal casing or tubing requirements. Wells up to 1020 feet deep were logged with precision temperature and pressure instruments under static, flowing, and injecting conditions with hand cranked reels. Low cost well monitoring hardware consisting of used capillary tubing systems and programmable data loggers were obtained and installed by hand for interference testing and monitoring purposes.

Introduction

In August 2006 the Chena Hot Springs resort in Alaska began producing 0.2 megawatt of geothermal power with 163 °F water. A second 0.2 megawatt generator was brought online in December, 2006 for a total installed capacity of 0.4 megawatts. Chena Hot Springs is now the lowest-temperature geothermal resource in the world used for electrical power generation. Due to the small power output, only a modest investment could be dedicated to exploration and development of the resource. Given the remote location it was not feasible to utilize existing geothermal industry infrastructure available in the western US. Instead, geothermal logging and testing equipment was rented and/or purchased at quite low costs and utilized at Chena as required for development and monitoring purposes beginning in October 2005. If additional small scale or remote geothermal power plants are to be installed without large subsidies it will probably be necessary to use similar or improved equipment and tactics.

The Chena Hot Springs Resort is the premier hot springs recreational and resort facility in Alaska. Chena Hot Springs is located on the floor of Monument Creek Valley in the upper reaches of the Chena River approximately 60 miles east-northeast of Fairbanks, Alaska (Figure 1). It has been used extensively for recreational bathing since its discovery in 1905 by prospectors. The Chena Hot Springs community is semi-remote, served by a paved road from Fairbanks, but 33 miles distant from the electrical grid. At Chena, power was historically generated using diesel generators, at a cost of 30¢ per kW. In 2005 approximately \$1000 per day was spent on diesel fuel for electricity, at an average price of \$2.46 per gallon. The Chena district heating system includes 44 buildings, some as large as 20,000ft^2. Chena also uses its geothermal resource for absorption chilling, proving 15 tons of refrigeration to the Aurora Ice Museum. Chena operates two geothermally

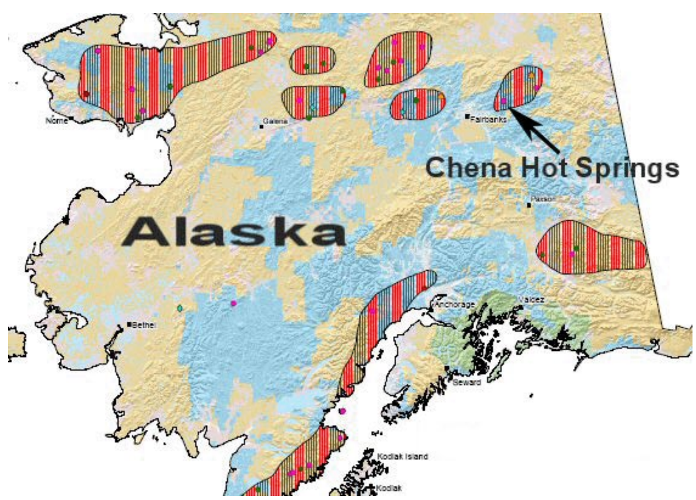

Figure 1. Regional Location Map.

heated greenhouses totaling approximately 6000ft^2 used to grow produce year-round for the restaurant. The centerpiece of the resort is a shallow rock bordered bathing/soaking pool of spring fed hot water referred to as Rock Lake. This existing infrastructure requires a continuous supply of hot water and imposed some constraints on exploration and testing that are normally not encountered in green fields projects. Nonetheless, these constraints have been offset by some substantial local infrastructure advantages.

The thermal characteristics (Erkan, et al., 2007) and geology (Kolker, et al., 2007) of the Chena geothermal field have recently been published. Therefore, this paper focuses on the recent exploration and well testing activities that led to the configuration of the field layout, i.e. the relative locations of the production and injection wells. Due to the below boiling temperatures of the Chena resource it was possible to drill, complete, and test the wells in an exceptionally low cost manner.

1970s Exploration

Prior to the early 1980s a few shallow wells had been drilled to supply hot and cold water to the resort, but very limited data were obtained from these wells. The first evaluation of the potential of the Chena began in the mid 1970s with geologic mapping (Biggar, 1973). In 1979 a program of hydrological, geophysical, geochemical and additional geologic studies commenced by the University of Alaska with U. S. Department of Energy funding (Wescott and Turner, 1981). As part of this study the shallowest extent of the thermal anomaly was defined by snowmelt and eighty 0.5 m deep holes. These holes showed the thermal anomaly to be highly elongated in an east-southeast direction along the course of Spring Creek, which flows along the south side of Monument Creek Valley. The length of the defined thermally anomalous zone was about 1000 ft long and the maximum width was about 300 ft (Figure 2). This parallels a dominant set of shear zones, faults, and joints in the Chena pluton (Bigger and Forbes, 1981).

The structure controlling the hot upflow has been hypothesized to be a normal fault (Kolker et al., 2007) but no surficial evidence for this fault has yet been developed. Erkan et al. (2007) suggest that a fractured pluton border may be the controlling structure. Interpreted lineaments from U-2 photos parallel the Monument Creek Valley (Bigger and Forbes, 1981). Some of these features that have been interpreted as 2 m high fault scarps down dropped on the valley side, but none of these are in the immediate vicinity of the hot springs and the surface evidence of their existence is ambiguous.

A shallow electrical conductivity survey was performed in Sept. 1979 (Osterkamp et al., 1981) in the immediate vicinity of the thermal area. It suggested that the source of the thermal water was a narrow linear feature along the south side of the valley where the thermal springs crop out. Two Schlumberger depth profiles were run in 1979, one along the south side of the Chena Hot Springs Resort airstrip (shown on Figure 2) and one along the axis of the thermal anomaly (Wescott and Sydora, 1981). These inconclusive lines only showed lower resistivities at depths above 64 m in the vicinity of the thermal springs. In addition, three short inconclusive hammer generated seismic lines were run, but only penetrated to depths of a few tens of meters (Lockhart and Kienle, 1981).

A very limited helium and mercury sampling effort in the vicinity of the thermal springs showed anomalous amount of both elements (Wescott et. al., 1981) but too few samples were taken to outline the anomalies. By far the highest helium value obtained was at the far western end of the thermal anomaly at a weak thermal manifestation.

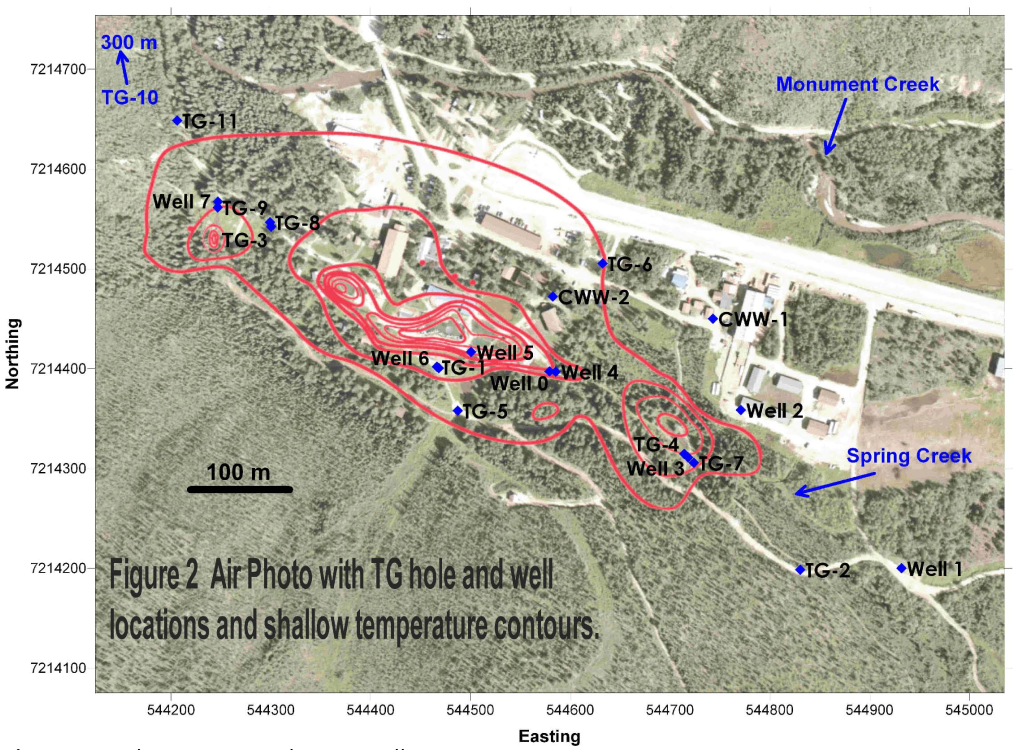

Figure 2. Local Location Map showing Well Locations.

2005 and 2006 Exploration and Testing

Prior to 2005, 6 wells with depths less than 280 ft were drilled with the purpose of tapping the shallow thermal reservoir for resort use with mixed success. Some were too cool to use for heating purposes, and one was not properly cased and eventually caved in at a shallow depth and was later abandoned. At the time, the available equipment and personnel were unable to drill deeper than about 300 feet. Only Well 5 was continually in service during the recent exploration work, pumping about 200 gpm of hot water for resort use. The resort also has two shallow cold water wells (Figure 2), one which is pumped to provide drinking water for use throughout the site.

As part of the Geothermal Resources Exploration and Definition Program III, the U. S. Department of Energy provided funding for a geological, hydrological, geochemical and geophysical evaluation of the Chena resource in 2005 and 2006 (Benoit, et. al., 2006). The centerpiece of the exploration effort, at least in terms of getting the power plant on line, was the drilling of 11 temperature gradient (TG) holes and production Well #7 (Figure 2). The only difference between the "TG holes" and the "wells" at Chena is that the TG holes were drilled with GRED funding while the wells were funded by Chena Hot Springs Resort for beneficial use, including the geothermal power plant. Otherwise, all these holes were drilled with similar diameters to similar depths. While the other aspects of the GRED program provided interesting information about the geothermal system (Benoit et al., 2006), they are not further discussed here as they were not directly relevant to getting the power plant into operation.

October 2005 Temperature Logging

The first temperature logs of acceptable quality in the Chena wells were obtained in mid October 2005 with a lightweight and portable hand-operated system provided by Southern Methodist University. These initial temperature measurements in holes ranging from 62 ft to 284 ft deep showed maximum temperatures ranging from 44 to 165 °F. All of these holes were more or less along an east-southeast trending line, resulting in data basically confined to two dimensions. The October 2005 temperature logs showed nearly the complete range of character seen in geothermal systems with linear, isothermal, and overturned profiles (Erkan et al., 2007). The hottest temperatures were in TG-1 and Well 6, holes located just south of the Rock Lake and now described as being in the central part of the geothermal field. Wells in the central and western part of the geothermal area, at slightly lower elevations than the eastern wells, are all capable of artesian flow. Wells in the eastern part of the area generally were not capable of artesian flow. The temperature-depth profile from TG-5 indicates that the structure controlling the upwelling hot water is either vertical or dips to the north (Erkan et al., 2007).

Based on the Oct. 2005 temperature profiles, and the fact that a capable water well drilling contractor with good equipment was now available, decisions were quickly made to deepen and/or redrill holes in the eastern and western parts of the field that had promising temperature profiles. The first necessity was to develop an improved understanding of the flow directions within the shallow part of the geothermal system and to determine the highest accessible temperatures at relatively shallow depths. It was obvious that the geothermal field would have a limited areal extent at shallow depths and that developing a strategy for maximizing the horizontal separation between production and injection wells would be an important consideration in the overall future field layout.

Nov. and Dec. 2005 Drilling, Injection Testing, and Logging Preparation Activities

In the eastern part of the field, Well 2 was deepened from 250 ft to 813 ft in November and TG-7 was drilled to a depth of 702 ft in December, 2005. Temperatures in Well 2 measured after the deepening have never reached the highest values measured before deepening; indicating that down flow of cooler water was induced by the deepening (Erkan et al., 2007).

During the drilling of TG-7, major hot water zones were encountered during drilling using an air hammer. Below a depth of 20-40 ft of alluvium, firm granite is easily drilled with a hammer tool with borehole stability problems. Therefore, casing programs in the TG holes and wells are generally minimal with only a few tens of feet of uncemented casing. It was not necessary to run tubing in any of the holes at Chena for temperature logging. TG-7 was found to have a static fluid level exactly at the ground surface, and it was determined that this was the easternmost well capable of hot artesian flow. After it was also noted that cold water could be easily poured into the well with a bucket, an initial injection test of TG-7 was performed in Dec. 2005 by pumping about 30 gpm (the maximum a small portable gasoline pump could pump) from nearby Spring Creek into the hole through a 2 inch hose. This 30 gpm did not overflow the top of the casing.

An overnight injection test was performed on Well 2 by running two ½" garden hoses from nearby residential units, each flowing about 10 gpm. Temperature logs confirmed the fluid outlet in Well 2 to be near the bottom. These initial injection tests (TG-7 and Well 2) were performed before the production area was identified.

In the western part of the field, TG-8 was drilled adjacent to TG-3 in late December to a depth of 604 ft. TG-8 was capable of an artesian flow of 158 gpm, by far the largest artesian flow then measured at Chena. This artesian flow was easily controlled with cold water during drilling, as the fluid temperatures were substantially below boiling and did not present a drilling hazard. TG-8 was the first well at Chena that was so strongly artesian that a valve had to be installed on the top of the casing. The shutin TG-8 wellhead pressures prior to producing the field were as high as 18 psi. In fact, TG-8 had the first real "wellhead" installed at Chena. At all of the other artesian wells at Chena a few additional feet of casing were simply welded on top of the casing to form a stand pipe that prevented the wells from flowing.

During Dec. 2005 a hand cranked reel was obtained, customized, and outfitted with low cost 1/8 inch stainless steel aircraft cable to allow the running of Kuster K 10 "Strain" Electronic temperature and pressure memory tools. The reel was customized so that the Southern Methodist University rope counter could be utilized for depth control. The Kuster K 10 tools are not heat shielded, but they are rated to withstand temperatures up to 302 °F, they weight about 10 pounds and record temperature and pressure data as frequently as every second. The software is user friendly and these tools can be run by one person to depths as great as 500 ft. At greater depths it is useful or even necessary to have a second person assist in pulling the tool out of the well.

Capillary tubing systems were also assembled during Dec. 2005 for pressure monitoring in the Chena wells at depths of a few hundred feet. The pressure chambers consisted of 1 in galvanized nipples two feet long with a few holes drilled the side. Short lengths of used capillary tubing were obtained from a project in Nevada and three-way valves were purchased for purging the systems with locally available nitrogen. However, temperatures between -20 and -40 °F did not allow these systems to be installed until April 2006. Madgetech pressure data loggers were obtained for recording the pressures. These robust data loggers are basically enclosed in a pipe and operated at temperatures as low as -40 °F.

January 2006 Temperature and Pressure Logging

During mid January 2006 the Kuster K 10 logging tools were run in all the existing wells to develop a pressure map of the resource. This required some work with a propane heater to melt ice plugs formed from vapor condensation or liquid inside of the casings above ground level. None of the wells near the geothermal area are impacted by permafrost or ice below ground level. A lubricator, fabricated from 1 ½ in galvanized pipe nipples from the local hardware store, was constructed so that static conditions could be documented in the strongly artesian TG-8 well.

The Kuster temperature profiles showed temperatures consistently 2 to 3 °F hotter than the SMU equipment, which is obviously a simple calibration difference. The 172.5 °F temperature measured at 604 ft in TG-8 was 10 °F hotter than any previous temperature measured at Chena Hot Springs (with the Kuster tools). This was good evidence that the hottest part of the Chena geothermal system at relatively shallow depths is near the western end of the thermal anomaly.

The January 2006 Kuster pressure logs represented the first pressure profiles obtained at Chena Hot springs. The pressure logs showed linear profiles with the exception of the abnormally low pressure gradient in the shallow TG-2 hole, which must be highly deviated. When all of the pressure profiles are contoured at a constant elevation on a map there is an abnormally complex pattern in the western half of the geothermal area. The pattern can be clarified by plotting the deepest holes i.e. those greater than 300 ft deep, separately from holes completed above a depth of 300 ft. The shallower holes show an expected pattern of pressures decreased toward lower elevations in the west (Figure 3). In contrast, the deeper holes show a pattern of pressures decreasing toward the east (Figure 4). These deeper holes show the highest pressures in the geothermal system to be in the far western part of the system, which is in agreement with the highest temperatures occurring in this area.

The pressures measured in TG-8 in January were about 18 psi greater than in the TG-3 hole which is only 20 ft away. The TG-3 hole is 197 ft deep while TG-8 was 604 ft deep at that time. This strong pressure increase with depth suggests that there are subhorizontal flow barriers at Chena, not the type of pressure response expected from a simple steeply dipping normal fault.

Based on these January 2006 logs, it was decided to deepen TG-8 and drill TG-9 further to the west to determine if perhaps even higher temperatures could be located and to extend the documented length of the shallow geothermal system, if possible.

February 2006 Flow and Interference Test of Well 6

On Feb. 26 and 27 the 135 ft deep Well 6 in the central part of the field was pumped at a rate of approximately 1000 gpm with Kuster tools monitoring the temperature and pressure responses in TG-1 and TG-8. Perhaps the primary result of this test was the realization that large scale pumping in the immediate vicinity of the natural hot springs could have a serious impact on the future existence of the Rock Lake pool. This realization was supported by an earlier Aug. 2005 12 hour air assisted flow test of Well 5 which showed TG-1 cooling by almost 30 °F. Cold water can easily penetrate into the shallower Chena wells, even with relatively modest pressure declines of less than 10 psi.

April 2006 TG-8 and TG-9 Logging and Flow Testing

By early April 2006, TG-9 had been drilled 400 feet west of TG-8 to a depth of 455 ft and TG-8, at a temporary total depth of 604 ft, was flow tested under natural artesian conditions at 158 gpm. The fluid-entry temperature in TG-8 was 172.65 °F. TG-9 was flow tested at a temporary total depth of 457 ft at natural artesian rates of 99 – 142 gpm, but had a fluid-entry temperature of about 162 °F, about 10 °F cooler than TG-8. In mid April TG-9 was deepened to 790 ft. At that depth, the

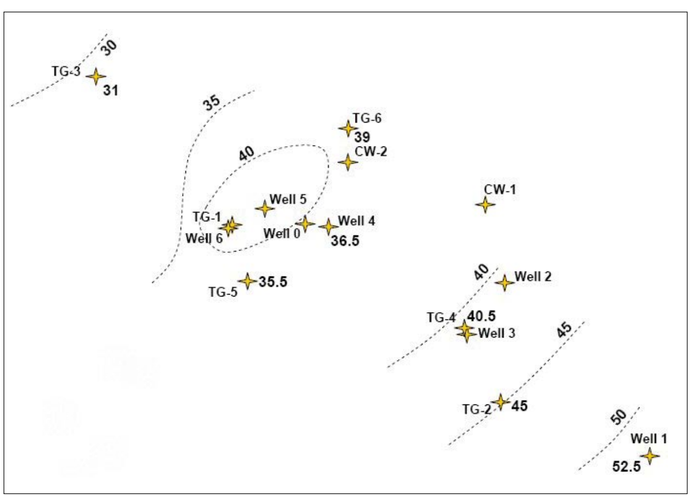

Figure 3. Shallow Pressure Map.

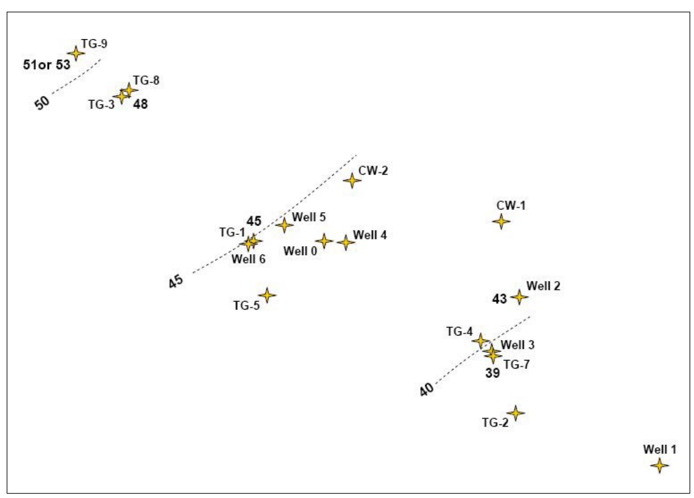

Figure 4. Deeper Pressure Map.

artesian flow rate tripled to 450 gpm but the overall flowing temperature increased by less than 1 °F. Although TG-9 was about 10 °F cooler than TG-8 the much greater artesian flow rates more than compensated for the lower temperatures. The productivity of TG-9, after deepening, is 26 gpm/psi of drawdown, the highest value measured at Chena.

Several temperature and pressure logs were made in TG-8 and 9 under static, flowing and injecting conditions to characterize the productivity of the wells and identify the producing zone depths (see details in Erkan et al, 2007). Flow measurements for these tests were made by simply pushing a drainable open top metal tank beneath the flow and measuring the time to fill the tank.

TG-8 and TG-9 were repeatedly flowed under natural artesian conditions for periods of 6 to 18 hours in April, 2006. Other wells throughout the field were monitored with both Kuster tools and downhole pressure bombs with Madgetech data loggers for pressure interference. A wide variety of pressure responses were obtained from the monitoring wells, perhaps the most important being a small amount of probable interference with Well 1, the most easterly of all the wells. Also, considerable pressure build-up and fall-off data were obtained to determine the productivity of the wells.

As a result of these April flow tests it was decided to drill a larger diameter production well for the power plant (which was mostly fabricated at this time). Well 7 was drilled adjacent to TG-9 to take advantage of the relatively high permeability in this area as well as the increased distance west of the Rock Lake pool. In this configuration, possible injection at the east end of the field near the power plant site would be as widely separated as possible from the production well and Rock Lake.

May TG-8 Deepening

In early May TG-8 was deepened from 604 to 1020 feet, making it the deepest hole at Chena. The deepening resulted in a 1 °F increase in temperature and no significant increase in flow rate. The productivity of TG-8 is 9.3 gpm/psi.

June and July Well 7 and TG-11 Drilling

In early July 2006 Well 7 was completed at a total depth of 713 ft. It was flow tested for 8 hours on July 8 at natural artesian rates as high as 240 gpm. Flow measurements for these tests utilized an inline flow meter supplied by the drilling contractor. The productivity of the well under artesian flow was 15.6 gpm/psi, which is between that of TG-8 and TG-9. This indicated that a pump setting depth of 100 ft would allow 1000 gpm to be pumped. During this flow test clear pressure responses were seen in 4 monitoring wells in the central and eastern parts of the field. In detail, these pressure responses show the usual complexity seen in tests from most other geothermal fields. A plastic camera with a temperature limit of 100 °F supplied by the drilling contractor was run under injecting conditions to a depth of 630 feet to photograph one of the permeable fractures feeding the well.

After Well 7 was completed, TG-11 was drilled a few hundred feet further northwest. TG-11 confirmed that the shallow temperatures rapidly diminish to the west of Well 7, and that shallow permeability is probably also greatly reduced in this direction. Therefore, Well 7 is viewed as being close to the western margin of the shallow portion of the Chena geothermal field. Deeper drilling is required to test if deeper permeability might be present west of Well 7 and is planned during the second phase of the Chena GRED program.

Injection Testing

The first small scale injection testing at Chena occurred in December 2005 when 20 to 30 gpm was injected into Well 2 and TG-7. During these tests only temperature logs were run to determine the depths of permeable intervals. Due to very low ambient winter temperatures no meaningful injection tests could be performed until the following summer, after the production Well 7 had been completed. Therefore, the intent of the 2006 injection testing was to identify the existing easternmost well or combination of wells furthest from the production well that would accept 500 gpm of injectate at the lowest possible wellhead pressures.

More substantive injection tests were performed between June and August 2006 by simply pumping cold water into the top of the casings when a greater supply of liquid water was available from Spring Creek. During June and July injection tests were performed in Well 1, Well 2, TG-2, and TG-7. All of these wells accepted modest amounts of fluid, but TG-7 was by far the best injector, accepting between 60 and 100 gpm with no wellhead pressure. However, during the TG-7 injection testing there was 4-½ in liner pipe hanging in the 5-½ in hole to almost the total depth. Previous temperature logs and drilling records indicated that the main injection zone was above the bottom of the 4-½ in pipe so this completion greatly reduced the overall injectivity by requiring injectate to flow back up the small (½ in) annulus between the pipe and the wellbore.

Due to scheduling problems with the drilling rig, the 4-½ in pipe was not removed from the well until a couple of days before the power plant commenced operating so there was considerable uncertainty as to whether TG-7 would perform as the sole injector for the power plant. Fortunately, TG-7 accepted 500 gpm at a wellhead pressure of 30 psi and to date has been the only injector while 200 kW has been generated. An injection strategy at higher rates has yet to be tested.

Field and Power Plant Performance

The Chena geothermal power plant commenced operations in early August 2006 with a production temperature of 163 °F, a pump rate of 500 gpm, and an injection wellhead pressure of 31 psig. Since then, the plant has been operating at 95% availability and generated 400 megawatt hours in 2006. Because the overall site load is greater than 200kW a diesel generator was still required to supplement the geothermal plant. Nonetheless, the resort saved $179,418 in diesel fuel between August and December 2006 when compared to 2005.

A second 200kW unit was installed in late December 2006. This unit was designed to be air or water cooled, to take advantage of the cold ambient winter conditions. This has allowed for 10-20% additional power generation over the rated 200 kW capacity of the unit.

During the summer months, both units are water cooled from a shallow large diameter well located 2700 ft and at 33 ft higher elevation than the power plant. Water is siphoned from the shallow well and supplied to the power plant condenser at 1500 gpm and 5 psi using only gravity feed. In the winter months, switching to an air condenser had the additional benefit of avoiding reduced output caused by a lower regional water table during the winter months and consequently a reduction in flow available to cool the plant.

As of April 2007, the two power plant units have not been run in tandem. This is because a larger production pump will need to be installed and an additional injection well will need to be brought online to handle the increase in produced fluid. Once both 200kW units are online simultaneously (expected in May, 2007), the diesel generator will be relegated to backup status and potential savings should approach $365,000 per year. At this rate, payback of upfront costs to install the system is expected in 6 years.

There has been no measurable change in temperature in the water produced from Well 7 between August 2006 and March 2007. The production of 500 gpm has reduced the pressures near Well 7 to the point that TG-8 is no longer artesian, a drop of about 20 psi as measured by Kuster logs.

Conclusions

The characterization of the Chena geothermal field was completed within a period of about six months following the collection of the first high quality temperature logs. This was done without accessing the on site services of companies normally utilized for similar projects in the contiguous United States. An ideal combination of good access, shallow drilling depths, competent rocks, below boiling temperatures, and artesian pressures allowed the wells to be drilled, completed, and tested at minimal cost. Another important factor was the ability to utilize the existing Chena Hot Springs Resort infrastructure of roads, vehicles, tools, equipment, housing, maintenance personnel, office space, junkyard, etc.

The field was primarily characterized by using digital Kuster temperature and pressure memory logging tools run on a hand cranked reel. By simply utilizing artesian flow and artesian wellhead pressures, the production area was characterized with interference testing using a combination of Kuster tools, wellhead pressure gauges, and pressure bombs run into the well by hand. These tests showed that all of the monitored wells in the field communicate with the production well. This gave confidence that the injection well would be effective in maintaining the resource pressure so that hot water would continue to support the Rock Lake, which is after all the primary attraction of the Chena Hot Springs Resort.

Acknowledgements

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