Klamath Falls Geothermal District Heating System at 25 Years

Brian Brown P.E., Brian Brown Engineering, Klamath Falls, OR

Figure 1. Klamath Falls Geothermal District Heating system location map, 2005

ABSTRACT

In 1976 the OIT Geo-Heat Center began investigating the feasibility of developing a geothermal district heating system to serve the Klamath Falls downtown. The district heating system was installed in 1981. Startup and operational problems prevented reliable operation until 1991. In 1992, the city began marketing the district heating system to other buildings in the downtown area.

By 2006 the system approached the original design capacity, and more growth is planned. After 25 years, the system is beginning to realize the economic benefits envisioned by the original feasibility studies in 1977.

INTRODUCTION

The City of Klamath Falls, Oregon, is located in a Known Geothermal Resource Area (KGRA) that has been directly used to heat homes, businesses, schools, and institutions since the early 1900s. In 1976, Klamath Falls and Klamath County became interested in establishing a geothermal district heating system to extend the benefits of the geothermal resource to government buildings and businesses in downtown Klamath Falls. This led to construction of the district heating system in 1981. After a difficult start-up period, the system has provided reliable service since 1991. For more information on the system development, see Lienau, et al., (1989 and 1991).

The district heating system was originally designed for a thermal capacity of 20 million Btu/hr (5.9 MWt). At peak heating, the original ten buildings on the system utilized only about 20 to 25 percent of the system thermal capacity.

Total annual heating revenue from those buildings in 1991 was about $23,800, which was inadequate to sustain system operation. This led the city to begin a marketing effort in 1992 to add more customers to the system (Rafferty, 1993).

The Klamath Falls geothermal district heating system currently serves process heating at the Klamath Falls wastewater treatment plant (WWTP), 24 buildings totaling about 400,000 sq. ft., greenhouses totaling 150,000 sq. ft., and about 105,000 sq. ft. of sidewalk snowmelt systems. Figure 1 shows the existing district heating service area.

The year 2006 marked 25 years since completion of the district heating system construction. This paper is intended to provide a retrospective on system development and lessons learned. The author has provided geothermal engineering consulting to the city since 1992.

District Heating System Timeline

- 1977: Feasibility study. (Lienau, et al., 1977).
- 1981: Construction of downtown district heating system completed.
- 1982: Construction of Michigan Street district heating system to serve low income neighborhood of 120 homes, funded by HUD. Only about 10 homes connected.
- 1981-1984: Public opposition delayed operation of the system until an aquifer study was completed.
- Nov. 1984: System operation begins.
- Feb. 1986: System operation halted after multiple failures of the distribution piping.
- Jan. 1991: System operation restarted after reconstruction of distribution piping.
- 1992: Beginning of marketing effort to add customers (Rafferty, 1993).
- Sep. 1993: Earthquake damages four County buildings, about half of connected heating load shut down.
- Nov. 1993: Pipeline extension to the Ross Ragland Theater completed; allows connection of six new customers.
- 1995-1998: Development of the Klamath Falls Main Street streetscape project, with geothermally heated sidewalks and crosswalks (Brown, 1995).
- 1996: Engineering evaluation of system condition, load, and capacity (Brown, 1996).
- 1999: Rehabilitation of the upper production well, CW-1.
- 2000: Repair of the injection well piping due to a corrosion failure.
- 2000: Addition of new circulation pump, CP-2.
- 2000-2001: Extension of district heating system to serve the Klamath Falls wastewater treatment plant and 100,000 sq. ft. greenhouse facility.
- 2001: Michigan Street system abandoned.
- 2003: Evaluation of capacity and improvements needed to support an expansion of the greenhouses (now at 4.0 acres). Partially funded by NREL.
- 2003-2004: System improvements including new heat exchangers, new automatic controls, improved pipe tunnel and vault ventilation, replacement of pipeline expansion joints, rehabilitation of the lower production well, CW-2. Partially funded by NREL.
- 2006: Addition of circulation pump, CP-3, to match the pump added in 2000.
- 2006: Expansion of the district heating system mains and development of a new sidewalk snowmelt system to serve the Timbermill Shores development on a former mill site.

The Klamath Falls district heating system is beginning to be financially viable and self-sustaining after 25 years of operation. The path to that point has been long and difficult, but thanks to the long-term commitment of the people of Klamath Falls, a difficult beginning has been turned into a successful system.

LESSONS LEARNED

The geothermal district heating system design and materials selection was based on a preliminary design study in 1979 by LLC Geothermal Consultants, Klamath Falls, OR. (Lund, et al., 1979). The engineer of record, Balzheiser/Hubbard & Associates, implemented the preliminary design recommendations with minor modifications.

Photo 1: Drilling of CW-1 well (Geo-Heat Center)

Production Wells

Production well pumps are vertical line shaft pumps, oil lubricated, with variable-speed drives. The well pumps as originally designed were rated for 500 gpm each, and powered by 50 hp motors.

The well pump for CW-1 was removed and rehabilitated in 1999 and CW-2 was rehabilitated in 2004. Inspection of the pumps showed significant corrosion of the steel column pipe at and above the water level, but no corrosion significantly below the water level. The corroded column pipe was replaced and the rest of the column pipe was reused. The pump bowls, line shaft, bearings, and shaft tube were in good condition and were reused.

Photo 2: Well Pump (Brown)

The original 50 hp motors and Nelson fluid drive were removed and replaced with an adjustable frequency drive and a 75 hp motor. The adjustable frequency drive and larger motor give the capability to over-speed the pump by about 20% from the nominal design speed of 1750 rpm to 2100 rpm. The increased pump speed can provide about a 20% increase in pumping.

The original system used Nelson fluid drives for variable speed operation. City water which was used to cool the drive was discharged down the well. That cooling water kept the outside of the column pipe wet and introduced oxygen into the well, promoting corrosion. Replacement of the Nelson drives with adjustable frequency drives allowed elimination of the cooling water flow and the resulting corrosion.

Geothermal Transmission Pipeline

Geothermal flow from the production wells is conveyed to the heat exchanger building through an 8-inch steel pipeline, about 4400 feet long. The pipe is insulated with polyurethane foam insulation, protected by a fiber-wound FRP jacket. About one-third of the pipeline is direct-buried; the rest is enclosed in a concrete pipe tunnel.

Photo 3: Production Pipeline and Tunnel Construction (Babcock)

Pipe expansion in the direct-buried section is accommodated by expansion joints with stainless steel bellows, located in expansion joint vaults. Pipe expansion in the tunnel is accommodated by expansion joints and pipe roller-guides.

The interior of the pipe is in excellent condition with minimal corrosion. The exterior of the pipe has suffered varying degrees of corrosion damage, particularly at fittings, expansion joints, and pipe anchors where the steel has been exposed to moisture. The expansion joints and pipe tunnel were intended to protect the pipe by providing a dry environment. However, the atmosphere in the vaults and tunnel was extremely humid because of inadequate ventilation and infrequent maintenance of the vault drains. Moisture would condense on the vault and tunnel ceilings and then rain down on the pipe. There is evidence of past flooding, resulting in direct contact of water and sediment with the pipe.

The city installed two six-inch vent pipes to each expansion joint vault, with one pipe connected high in the vault and the other low. The vent pipes provide thermal and wind-driven ventilation of the vaults, which reduce the high humidity and condensation. Tunnel ventilation has been improved by installing a blower at the heat exchanger building to force air into the tunnel and a larger relief vent at the far end of the tunnel.

The city has had to repair two corrosion failures in the direct-buried portion of the pipeline. It appears that the FRP jacket is beginning to fail and allow soil moisture to contact the pipe. The City plans to replace the steel pipeline with pre-insulated ductile iron pipe as funds allow.

District Heating Distribution

The district heating distribution piping is a closed loop system with both supply and return pipelines. Almost half of the original system length was 10-inch, pre-insulated steel pipe. The rest of the piping, 8-inch and smaller, was key-lock fiberglass pipe.

The fiberglass pipe joints failed after the first heating season, possibly due to defective epoxy on the factory-glued joints, and were entirely replaced with pre-insulated ductile iron pipe. Where the ductile iron pipe has been inspected, it remains in good shape after 15 years of service.

The steel portion of the pipeline was protected by the insulation system and cathodic protection anodes, which have not been checked since construction. There have been recent corrosion failures in the steel pipelines; likely caused by failure of the FRP jacket coupled with diminished cathodic protection. The city plans to replace the pipe with pre-insulated ductile iron as funds allow.

Some customer service connections were installed using unprotected steel piping. Those connections have tended to fail after about ten years. Improved corrosion protection is being used on new and repaired connections.

District Heating System Controls

The control system was originally designed to maintain the district heating supply temperature at a constant 180˚F by controlling geothermal production and the flow through the heat exchanger. On decreasing temperature of the supply water, the system was intended to increase the geothermal production by increasing the well pump speed and automatically starting the second well pump if needed. On increasing temperature of the supply water, the system would reduce production, then modulate a three-way valve to bypass district heating water flow around the heat exchanger.

The geothermal water temperature is above boiling temperature at the project elevation, so a backpressure valve and control was designed to maintain enough pressure on the geothermal production piping to prevent flashing to steam in the system.

The original pneumatic control system was not capable of meeting the design control objectives. The fully automatic temperature control operation resulted in serious oscillations of well pump speed and starting/stopping. The resolution was to operate the well pumps manually, and limit the automatic temperature control to the three-way valve. The backpressure control was also unstable, partially due to inappropriate valve selection.

The control system was upgraded in 2003 to modern digital controls, using Allen Bradley programmable logic controls (PLC). The telephone telemetry link to the production wells was replaced with spread-spectrum radio telemetry. The control system is fully integrated with the city control system for water and wastewater system operation.

The original temperature control and backpressure control concepts were retained with the new controls. The increased power and tuning capability of the modern controls have largely been able to tame the unstable control loops.

Back-pressure control is a difficult control service, with the valve required to operate over a wide flow range, controlling hot fluids that can flash to steam or cause cavitation on the downstream side of the valve. There remains some instability in the backpressure control even with the new control system and a new control valve. More stable operation can likely be achieved by reprogramming the controls to operate the valve for temperature control, and control the well pumps to maintain a pressure set-point. On decreasing temperature the controls would open the valve, resulting in increased flow and reduced pressure. The controls would then increase the pump speed to compensate.

CAPACITY AND LOAD

The capacity of a closed-loop district heating system is fundamentally different than the capacity of a potable water system. The purpose of a water system is to deliver water, which is consumed in some way and not returned to the water system. What the customer does with the water is not a major consideration; the water system is sized for the capacity to deliver given design flow.

A district heating system is designed to deliver heating energy. The water flow is merely a means to convey the energy. The capacity to deliver heat is limited both by the flow capacity of the system and what the customer does with the heating water before sending it back. The capacity of the system is thus very much constrained by the action of the customers. The amount of heat delivered by the water depends on both the flow rate and the temperature change of the water. This can be expressed by the equation:

$$ENERGY\ (BTU/HR) = FLOW\ (GPM) \times \Delta T\ (°F) \times 500$$

Flow is essentially fixed by the hardware selected in the design: the pumps, pipes, control valves, heat exchangers, production wells, and injection well. Any significant increase in the flow requires larger equipment and increased power to operate.

Temperature change of the heating water (delta-T) is equally important to the delivery of heat. The delta-T is affected by physical constraints such as the temperature of the heat source, the temperature requirements of the heat load, and the sizing of the heat transfer device. The main cause of low delta-T is failure to properly control heating water flow, with the consequence of reduced thermal capacity and higher than necessary pumping costs.

The Klamath Falls geothermal district heating system was designed with a thermal capacity of 20×10^6 Btu/hr (5.9 MWt), based on 1,000 gpm of loop flow, 1,000 gpm of geothermal flow, and a design delta-T of 40°F. The load on the district heating system is approaching the original design thermal capacity. According to the system data log, the peak load for the 2005-2006 heating season was about 14.9×10^6 Btu/hr, on December 1, 2005 at 7:58 AM, at an outside air temperature of 10°F. Geothermal flow was 764 gpm. Loop flow was 819 gpm.

In another sense, the system was operating at near capacity in 1993 when the loop flow was about 900 gpm at a maximum 10°F delta-T, or in 1996 at a loop flow of 850 gpm and 16°F system delta-T. The ability to add customers to the system and thus increase revenue has primarily been possible because of improved flow control at customer connections, increasing the delta-T and freeing up flow capacity.

Recent improvements were intended to increase the nominal system capacity to about 36×10^6 Btu/hr (8.5 MWt), based on 1,200 gpm pumping capacity and 60°F delta-T. Some of that increased capacity is due to new heat exchangers and increased circulation pump capacity. However, most of the capacity increase is dependant on improvement in system delta-T. Proposed measures to achieve improved delta-T include:

- Continued improvement of flow control at existing customer connections
- Cascading flow from higher temperature uses to lower temperature users. For example, operating snowmelt systems off the district heating loop return line rather than supply line.
- Designing new connections to the system for a higher delta-T of 60°F.

ECONOMICS

Original Projections

The geothermal district heating system was designed to initially serve 14 government buildings with planned expansion to serve additional buildings on 11 commercial blocks along the route, then the entire 54-block downtown commercial district. The anticipated system heating loads for the planned construction phases were: (Lienau, 1981)

Phase	Description	Peak heat load Btu/hr
I	14 Government Buildings	21×10^6
II	11 Commercial Blocks	34.8×10^6
III	54 Commercial Blocks	143×10^6

The system feasibility study was conducted during the late 1970s energy crisis, when there was sharp run-up in the cost of natural gas and other energy. Figure 2 shows a 20-year life-cycle cost comparison of the proposed project on a unit energy basis. (Lienau, 1981) Key assumptions included:

- System peak load: 34.8×10^6 Btu/hr (Phase II)
- Annual energy use: 60×10^9 Btu
- Capital cost: $3,753,259 at 8%
- O&M 6.2% of capital; inflated at 7%/year
- Natural gas inflation: 14.6% to 17.6% /year

The analysis calculated that the cost of the geothermal energy would match natural gas at about year five, at a cost of about $7.00 per 10^6 Btu, and simple payback would occur at ten years.

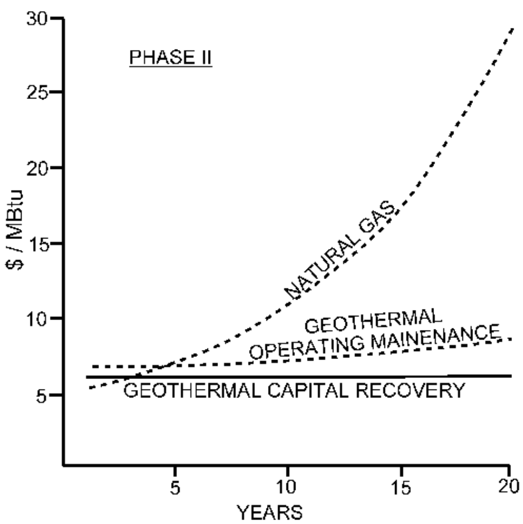

Figure 2. Phase II Unit Energy Cost Comparison (Lineau, 1981)

Initial Operation

Phase I was funded and constructed as a demonstration project, with most of the cost covered by grants. On that basis, the expectation was that the economics would be better than the Phase II analysis. Unfortunately, the system did not meet those expectations.

The first hurdle was concerns by home owners about the impact of operation of the geothermal system on their private wells. Klamath Falls has hundreds of private homes heated by private geothermal wells. The concern was that the city system would lower the water level and/or reduce geothermal temperatures, negatively affecting the private wells. The home owners initiated a city ordinance that effectively prohibited operation of the newly constructed district heating system. That problem was resolved by extensive aquifer testing, including full operational testing that showed no negative impact. However, start-up of the district heating system was delayed by three years to November 1984.

The next hurtle was failure of the fiberglass distribution system piping after only one heating season. The city was faced with the question: do they rebuild, or shut the system down. The decision was to borrow the needed funds and rebuild the distribution system. The system was restarted in January 1991.

Meanwhile, the cost of natural gas dropped from a high of $0.627/therm ($10^5$ Btu) in October 1982, to a low of $0.378/therm in December 1991. See Figure 3. That compares to a projected cost of about $1.10/therm at year ten in the original economic analysis. The total heating revenue for 1991 was about $23,800, which was well below the cost of system operation.

The city was again faced with a choice: shut the system down, or subsidize operation while attempting to grow the connected load and revenue. The city began a marketing push in 1992, and over the following 13 years the system load has been increased to near the original Phase I design capacity. The cost of conventional energy has also increased, making the renewable geothermal energy more valuable.

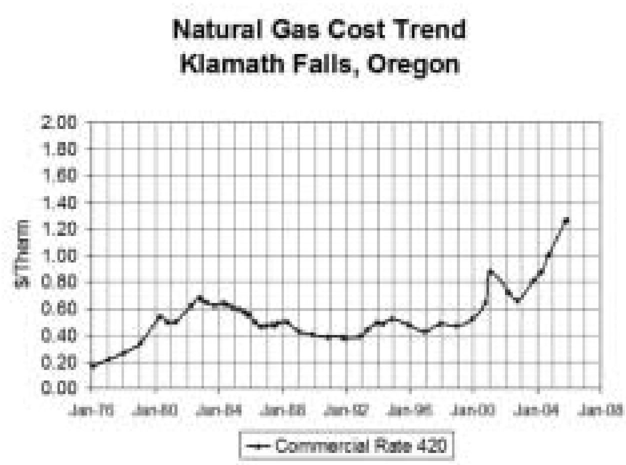

Figure 3. Local Natural Gas Cost Trend.

Current Status

The geothermal district heating system provides a significant financial impact on the local community. For 2005, the metered geothermal energy sales was about 26.1×10^9 Btu, and un-metered building energy use was about 5.3×10^9 Btu, for a total of 31.4×10^9 Btu. Currently, the commercial natural gas rate is $1.26353 per therm, or assuming a seasonal conversion efficiency of 67%, about $18.8/10^6 Btu. The direct economic value of using geothermal energy from the district heating system rather than fossil fuels was about $589,000.

Economic value is also realized indirectly by the contribution of the geothermal system to economic growth and downtown revitalization. The availability of geothermal energy was a major factor in the decision of the IFA Nurseries greenhouses to locate in Klamath Falls. The geothermal energy allows IFA to control their energy costs. In return they contribute jobs to the community and tree seedlings for local reforestation efforts. Geothermally heated sidewalk snowmelt systems are a very visible and popular feature of the downtown redevelopment project, which has helped turn around a formerly declining downtown area.

Photo 4: Geothermally Heated Sidewalk Snowmelt (Geo-Heat Center)

The economic value of the geothermal district heating system to the community is clearly significant. The other question is whether the revenue to the system operator is adequate to cover costs. The city cannot charge the full value of conventional energy, or there would be no incentive for customers to connect.

The city metered geothermal rate is set at 80% of the current commercial natural gas rate, with rate increases limited to no more than 10% per year. The current standard rate is $8.828 /10^6 Btu. A significant portion of the load is still billed at long-term flat rates negotiated several years ago, of $5.40/10^6 Btu or $5.60/10^6 Btu. The 2004-2005 heating season average for metered accounts was $6.15/10^6 Btu. There are still several unmetered buildings that will be metered within the next couple years.

Total system revenue for the 2004-2005 heating season was $170,012. Direct operating expenses for the same period were $47,403. Additional deferred maintenance costs that should be included in the annual costs include about $15,000 annually for heat exchanger plate cleaning and regasketing, and about $70,000 annual financing costs for about $800,000 in needed pipeline repair and upsizing. The city should also be funding a maintenance reserve and greater staff time for managing system operation, system growth, and customer connection delta-T control.

After 25 years the system operation is at or near operational break-even. The revenue should continue to increase over the next few years as more customers are added and existing unmetered customers are switched to metered service. The increased revenue should help with funding of other operational needs.

In retrospect, the original economic analysis was not too bad; there was just a 20-year pause in the growth of energy costs, and a 15 year delay in geothermal system expansion. The people of Klamath Falls are to be commended for their perseverance through the lean times.

ACKNOWLEDGMENTS

This paper was partially based on work funded by the National Renewable Energy Lab, Golden Colorado, and the City of Klamath Falls. Opinions expressed in this paper are those of the author. Thanks to John Lund, the OIT Geo-Heat Center, and Brent Babcock (Balzheiser/Hubbard project manager), for their perspective on the original system design and construction.

REFERENCES

Brown, B., 1995. “Klamath Falls Downtown Redevelopment Geothermal Sidewalk Snowmelt”, Geo-Heat Center Quarterly Bulletin, Vol. 16, No. 4., p. 23- 26.

Brown, B., 1996. “Klamath Falls Downtown Geothermal District Heating System Evaluation ”, Geo-Heat Center Quarterly Bulletin, Vol. 17, No. 3., p.16-23.

Lienau, P.; G. Culver and J. Lund, 1977. “Klamath County Geo-Heating District Feasibility Study” prepared for Klamath County Commissioners, Geo-Heat Center, Klamath Falls, OR.

Lienau, P., 1981, “Design of the Klamath Falls Geothermal District Heating Network”, ASHRAE Transactions, Vol. 87, p. 2, Atlanta, GA

Lienau, P.; G. Culver and J. Lund, 1989. “Klamath Falls Geothermal Field, Oregon, Case History of Assessment, Development and Utilization”, Presented at Geothermal Resources Council 1989 Annual Meeting, Santa Rosa, CA.

Lienau, P. and K. Rafferty, 1991. “Geothermal District Heating System: City of Klamath Falls”, Geo-Heat Center Quarterly Bulletin, Vol. 13, No. 4., p. 8-20.

Lund, J. W.; P. J. Lienau; G. Culver and C. V. Higbee, 1979. “Klamath Falls Geothermal Heating District” Report to City of Klamath Falls, LLC Geothermal Consultants, Klamath Falls, OR.

Rafferty, K., 1993. “Marketing the Klamath Falls Geothermal District Heating System”, Geo-Heat Center Quarterly Bulletin, Vol. 15, No. 1., p. 4-6.