A TALE OF TWO HEAT PUMPS

By Kevin Rafferty
Geo Heat Center
Klamath Falls, OR 97601

Introduction

Over the past few years, the Geo-Heat Center has been involved in the evaluation of many groundwater source heat pump systems. Our experience has demonstrated that ground water systems can offer significant benefits to the building owner in the area of operational energy savings. In order for the owner to fully take advantage of the benefits, however, it is critical that the system be carefully designed, skillfully installed and operated according to the designers intent. Serious consequences can result when these precautions are not observed.

To illustrate this point, this paper describes the experiences of two systems. Each was installed in the last several years in newly constructed county jail facilities and shall henceforth be referred to as System #1 and System #2. System #1 is a 360 ton 2 machine installation which provides the heating and cooling needs of a 120,000 ft^2 county jail in Eastern Washington state. This system employs a 700 gpm (@72°F) Production well and injects all of the groundwater into a second well.

System #2 is a single machine 156 ton design using 56°F groundwater. This system serves a county courthouse and jail facility in Northern California. Two production wells, capable of a combined peak flow of 250 gpm, provide the heat source/sink. Effluent from this system is discharged to a nearby river.

System #1

System #1 is an excellent example of the need to carefully design the groundwater/mechanical system interface to minimize the extent to which the groundwater is exposed to the equipment.

Figure 1 provides a flow scheme fro the original system design. As indicated, the groundwater was pumped from the production well to a 6,000 gal. holding tank located in the mechanical room. Pump operation was on/off in response to a level control on the tank. From the tank, the 72°F well water was admitted directly to the heating and cooling loops to moderate temperature. Fluid flow into the loops was initiated when the chilled water loop fell below 46°F or when the heating loop rose above 108°F. A second set of valves discharged fluid from the loops as the groundwater was admitted.

The initial indications of problems with this system developed before construction was even completed. A serious corrosion condition became evident in the heating and cooling loop piping and the groundwater circuit. Large quantities of a pasty rust colored sediment were appearing in system strainers. The sediment was believed to be a result of a combination of sand produced in the well and products of corrosion.

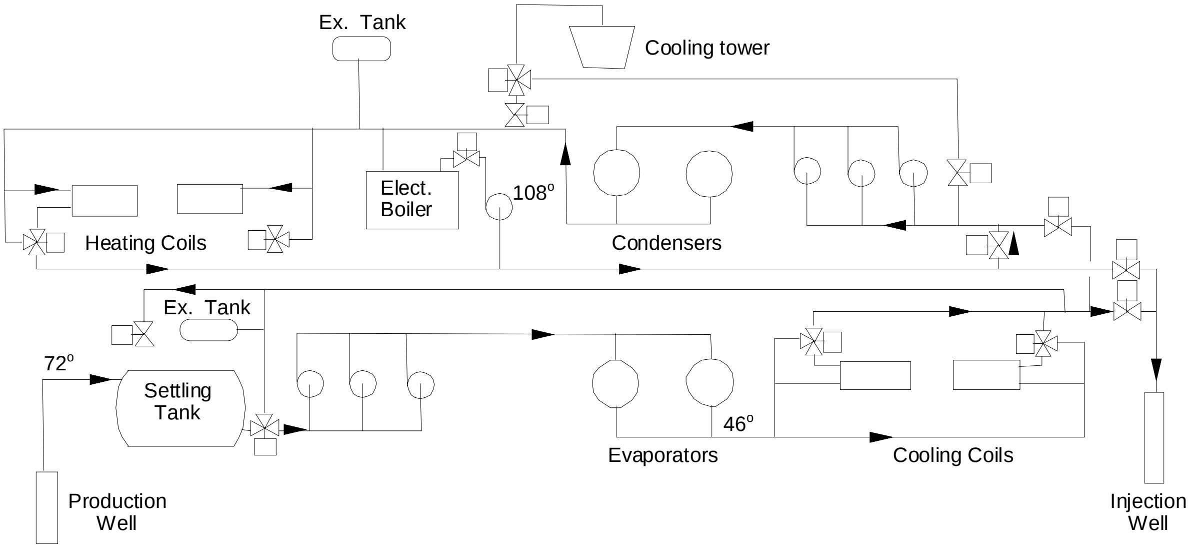

Figure 1. System #1 Original Design.

After reviewing the system, construction documents and water chemistry data, it was evident that the problems were traceable to both water chemistry and system design. Specifically, the problems included the following:

1. Water chemistry. As indicated in Table 1, the basic water chemistry suggested a tendency toward corrosion based on the Ryznar and Langlier indices. Although these indices do not agree in terms of the magnitude of aggressiveness, both indicate a corrosion potential for the water.

2. Oxygen. The aggressive tendency of the water was compounded by a system design which offered two potential avenues for oxygen intrusion. The first of these involved the production well pump operated in an on/off mode in response to settling tank level. A pump column check valve was not employed. As a result, at each off cycle, the pump column and a portion of the wellhead piping was drained of fluid (down to the static water level) and air entered the piping through an air/vac valve. This operation not only permitted the water in the pump column to become aerated, but continuously exposed the piping in the vicinity to a wet aerated environment.

   In addition the settling tank itself was vented to atmosphere. This allowed additional oxygen to enter the system.

3. Open type system design. The conceptual design of this system was very similar to the early groundwater heat pump systems designed by J. Donald Krocher in the late 1940s to early 1950s. In his systems, the groundwater used to provide temperature control of the heating and cooling loops are admitted directly into the loops. The original Krocher designs, on which numerous papers and articles were published, eventually were modified in the mid-to-late 1950s. The modifications included, in most cases, the installation of heat exchangers to isolate most of the mechanical system from the groundwater. Installation of the heat exchangers was motivated by

the cost and only marginal success of chemical treatment used to attempt corrosion control. The Commonwealth building in Portland, Oregon, is a classic example of Krocher early design and subsequent modification.

Table 1. SYSTEM #1 - WATER ANALYSIS.

	Test Number											
	1	2	3	4	5	6	7	8	9	10	11	12
Total hardness	34	26	34	26	34	28	29.3	29	30	33	30.96	
pH	8.6	8.6	8.7	8.3	8.4	8.4	8.4	8.5	8.5	8.5	8.3	8.2
M Alk.	80	80	40	80	70	70	54.2	80	75	80	59.0	61
P Alk.				5	30	30	3.6	20	25	25	0	
Cl	6	8	6	4	3	4		5	6	6		<1
S_1O_2	14	6		24	26	12		22		32	35.8	
Fe	0.3	7	2.9	1.0	4.2	16	1.31	.75	2.2	1.5	1.21	0
Ca Hardness	24			21			23.9	21	24	32	26.4	24
TDS							76				152	87
Conductivity	200	210	140	180	140			170	175	185		
Langlier	-0.2			-.20			-.5	-.37	-.32	-.14	-.35	-1.2
Ryznar	9.0			9.0			9.4	9.24	9.14	8.78	9.0	10.66
Date	3/2/84	3/2/84	3/2/84	4/23/84	4/23/84	4/23/84	5/8/84	6/19/84	6/19/84	6/19/84	6/19/84	6/19/84
Sample Location	Well Inlet Holding Tank	Condenser Water	Boiler Water	Well Inlet & Holding Tank	Condenser Water	Boiler Water	Well Inlet & Sewage Tank	Well Head 10 AM	10:25 AM Well Head 940 gpm	145 PM Well Head	10:40 AM Well Head 650 gpm	Well Head 700 gpm

The System #1 building owners had solicited bids from a number of chemical companies to address the apparent corrosion problem. Calculations indicated that such treatment for this system could cost nearly $4,000 annually (1984 dollars). Based on a 20-year life, this amounted to nearly $47,000 present value, a significant sum. In addition, chemical treatment was complicated by the fact that the effluent from the system was to be injected for disposal.

Environmental regulations required that the injected fluid be “unchanged except for temperature.” This would have required removal of the treatment chemicals prior to disposal – such removal was not economically feasible.

Recommended System #1 Modifications

Beginning at the production well, the major modifications suggested included:

1. Modifications of the production well pump operation for on/off to variable speed control. Under this approach, the pump would operate continuously eliminating the start/stop of the original design. This modification provided several benefits. Mostly importantly it eliminated one of the two major sources of oxygen entering to the system. Second, the constant surging of the well would be eliminated, possibly reducing sand production from the aquifer. Finally, the constant, variable speed operation should provide for longer pump and motor life compared to on/off operation.

2. Elimination of the settling tank. This proposal eliminated the second major avenue for oxygen intrusion into the system. With the installation of a variable speed drive for the production well pump, the tank would be unnecessary for groundwater flow control. If sand continued to be a problem, the use of a centrifugal sand separator was recommend in lieu of the settling tank

3. Installation of heat exchangers to isolate the groundwater from the balance of the mechanical system. This was the most important recommendation. Even without implementation of the previous two items, the use of heat exchangers would significantly reduce the extent of groundwater induced damage. In this particular case, the heat exchangers would have no direct impact upon the performance of the heat pump itself. This was due to the system design. Groundwater used for temperature control primarily below 46°F (cooling loop) and above 108°F (heating loop). Therefore, transfer of heat from the 72°F well water did not require any adjustment of the basic system design temperatures. Assuming a 5° approach temperature (in the heat exchanger), only 15 – 20% increase in groundwater flow rates was necessary. Figure 2 presents a flow scheme of the system after modifications.

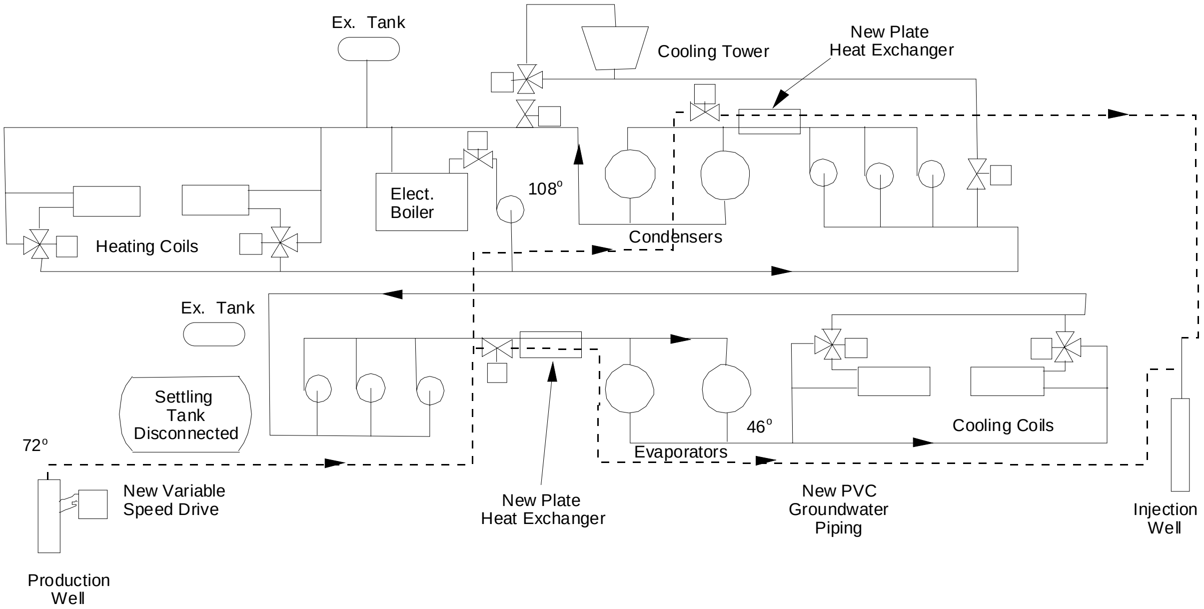

Figure 2. System #1 Modified Design.

Results

Plate heat exchangers and a production pump variable speed control were installed in 1984. At this time, the large settling tank was also disconnected from the system. These measures eliminated the corrosion problems from the building mechanical system and no additional problems have been reported.

System #2

System #2 is an example of a well designed system which developed problems as a result of its operation under conditions quite different from those specified by the designer. In addition, the system was not installed with the type of controls envisioned by the designer.

Figure 3 present a flow scheme for the system as originally designed. Two production wells capable of a combined flow of 250 gpm of 56°F water deliver groundwater to the two plate heat exchangers. Water flows first thru the heat exchanger located in the chilled water loop and then onto the second in the heat rejection loop. The chiller is a "double bundle" unit with both heat recovery and heat rejection condensers.

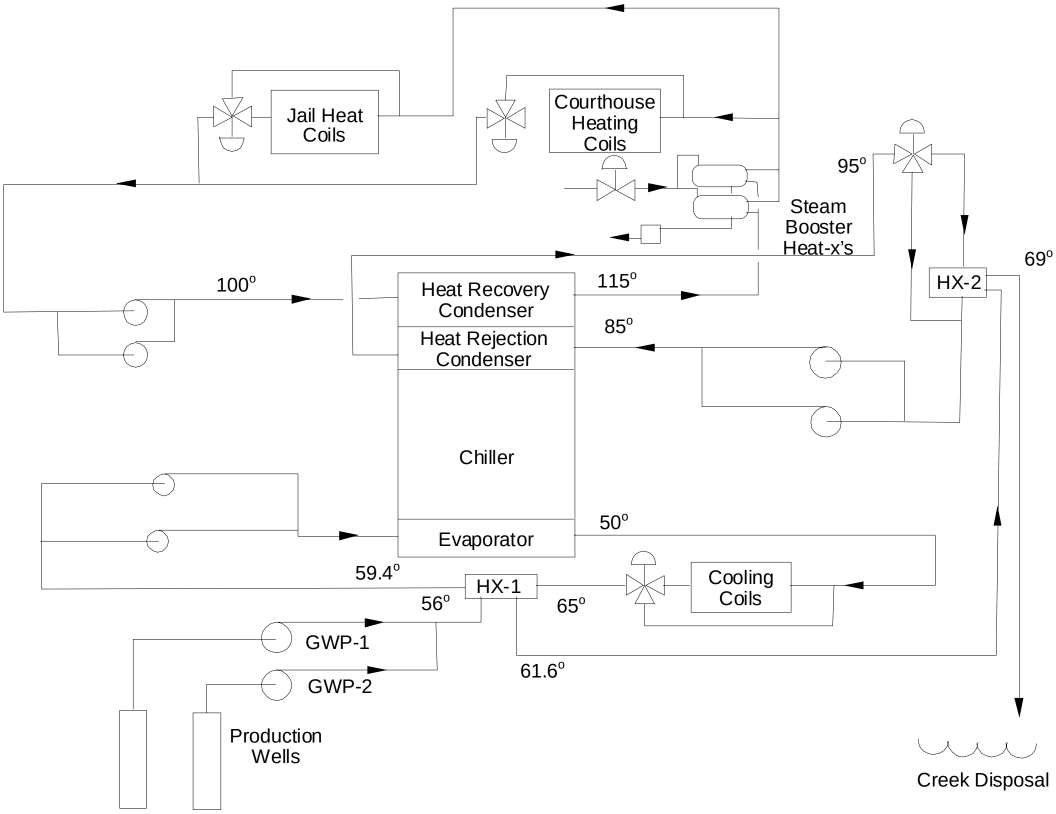

Figure 3. System #2.

The original designed called for a chill water supply temperature of 50°F. Based on this temperature and a 15° rise through the coils, a return water temperature of 65°F resulted. By the placement of the chilled water heat exchanger and the use of 56°F well water, a portion of the cooling load, at peak conditions would be handled by the well water.

The heat recovery condenser of the chiller is connected to the building space heating loop. Steam heat exchangers are provided for use in the event that the chiller cannot meet 100% of the heating requirement. Design hot water supply temperature (out of the recovery condenser) was 115^{o}F. The heat rejection condenser was connected to the second groundwater heat exchanger. As noted earlier, this heat exchanger operates on the effluent from the chilled water heat exchanger.

Chiller capacity was controlled based on chilled water return temperature.

The first difficulty with the system arose out of a simple misadjustment of controls. The chilled water temperature was set to 40oF. This had the affect of substantially increasing the system energy use. The lower setting caused the chiller to run fully loaded 100% of the time regardless of the actual building cooling load. This was the result of the placement of the groundwater heat exchanger in the chilled water loop. At a 40^{o} chilled water supply temperature and low coil loads, the temperature of the chilled water arriving at the heat exchanger was much lower than the well water temperature. Therefore it was able to absorb considerable heat from the well water, thus maintaining a load on the machine even under conditions of <u>no</u> building load. No controls were installed on the well water side of the loop.

A second problem was related to the required hot water supply temperature. A small zone in the jail facility experienced difficulty in maintaining space temperature during the heating season. To compensate for this, the operator raised the temperature set point on the steam heat exchangers. This increased temperature (approximately 130-135^{o}) virtually eliminated the ability of the heat pump to contribute to the heating load via the recovery exchanger.

The inability of the chiller to deliver heat during the heating season was further reduced by the control sequence. The only control on the 3-way valve (located at heat exchanger #2) instructed that it modulate to maintain a temperature of 85^{o}F returning to the heat rejection condenser. As a result, virtually all the condenser heat passed out of the loop at the heat rejection condenser.

The system contained no allowance for modulating the heat output of the chiller according to heating load during the heating season. It was equipped with a capacity controller which was capable of operating in either heating or cooling modes, nit not both. Since the controller was connected for cooling operation, it was not capable of modulating capacity according to heating needs during the winter.

The design engineer had specified that the machine be equipped with both heating and cooling capacity controls. It was his intent that the controls be capable of both functions; however, in practice, the controller could only be connected for one function at a time.

In summary then, the situation was that the machine was running at nearly fill capacity 24 hours per day, even during low cooling loads, delivering little if any heat to the hot water loop and discharging most of the heat absorbed from the well water (at heat exchanger #1) back to the well water (at heat exchanger #2).

System #2 Recommended Modifications

The recommendations for this system consisted of:

1. Reset the chilled water back to the originally specified 50°.
2. Reset the hot water temperature back to the originally specified 115°.
3. Addition of supplemental heat to the one zone in the jail which required hotter water.
4. Installation of appropriate controls for the modulation of chiller capacity according to heating needs during the heating season.

These controls would have to address two areas: Chiller capacity control and the control of the 3-way valve at heat exchanger #2. To fully take advantage of the groundwater as a heat source, it is necessary to install capacity modulation controls which, during the heating season, modulate the capacity of the machine according to the hot water load.

In a conventional (non-groundwater augmented) double bundle chiller installation, the chiller capacity is controlled only by the load on the chilled water circuit. A 3-way valve at the cooling tower modulates toward the bypass position to drive heat out of the heat recovery condenser (rather than the heat rejection condenser) when a heating load exists. No controls to modulate the capacity of the chiller according to hot water load are included. This is because heat is only a byproduct of the cooling process. Heat is only available when there is a chilled water load.

In a groundwater system, heat (from the groundwater) is always available. As a result, controls on the 3-way valve at the heat rejection condenser, as described above, must be augmented by chiller capacity controls for the heating mode in order to fully take advantage of the heating source provided by the groundwater.

The county is in the process of implementing the above recommendations as of this writing.

Conclusions

Two general conclusions can be drawn from the experience of these systems:

1. When implementing an unusual design, it is important to fully research the operating history of similar systems and incorporate modifications made subsequent to the original design. These modifications typically receive much less publicity than did the initial design. Most of the problems with System #1 could have been eliminated had a thorough review of similar systems been accomplished prior to design.

2. A rigorous commissioning procedure is important for all systems. It is critical to non-conventional systems such as this. The controls problems with System #2 would have been identified quickly during a careful commissioning program. In addition, the important of control set points could be passed along to the operator during this process.