ABSORPTION REFRIGERATION

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INTRODUCTION

The absorption cycle is a process by which refrigeration effect is produced through the use of two fluids and some quantity of heat input, rather than electrical input as in the more familiar vapor compression cycle. Both vapor compression and absorption refrigeration cycles accomplish the removal of heat through the evaporation of a refrigerant at a low pressure and the rejection of heat through the condensation of the refrigerant at a higher pressure. The method of creating the pressure difference and circulating the refrigerant is the primary difference between the two cycles. The vapor compression cycle employs a mechanical compressor to create the pressure differences necessary to circulate the refrigerant. In the absorption system, a secondary fluid or absorbent is used to circulate the refrigerant. Because the temperature requirements for the cycle fall into the low-to-moderate temperature range, and there is significant potential for electrical energy savings, absorption would seem to be a good prospect for geothermal application.

Absorption machines are commercially available today in two basic configurations. For applications above 32°F (primarily air conditioning), the cycle uses lithium bromide as the absorbent and water as the refrigerant. For applications below 32°F, an ammonia/water cycle is employed with ammonia as the refrigerant and water as the absorbent.

LITHIUM BROMIDE/WATER CYCLE MACHINES

Figure 1 shows a diagram of a typical lithium bromide/water machine (Li Br/H_2O). The process occurs in two vessels or shells. The upper shell contains the generator and condenser; the lower shell, the absorber and evaporator.

Heat supplied in the generator section is added to a solution of Li Br/H_2O. This heat causes the refrigerant, in this case water, to be boiled out of the solution in a distillation process. The water vapor that results passes into the condenser section where a cooling medium is used to condense the vapor back to a liquid state. The water then flows down to the evaporator section where it passes over tubes containing the fluid to be cooled. By maintaining a very low pressure in the absorber-evaporator shell, the water boils at a very low temperature. This boiling causes the water to absorb heat from the medium to be cooled, thus, lowering its temperature. Evaporated water then passes into the absorber section where it is mixed with a Li Br/H_2O solution that is very low in water content. This strong solution (strong in Li Br) tends to absorb the vapor from the evaporator section to form a weaker solution. This is the absorption process that gives the cycle its name. The weak solution is then pumped to the generator section to repeat the cycle.

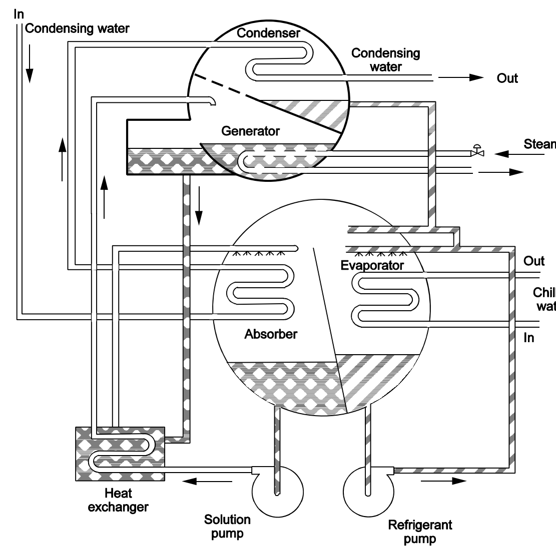

Figure 13.1 Diagram of two-shell lithium bromide cycle water chiller (ASHRAE, 1983).

As shown in Figure 1, there are three fluid circuits that have external connections: a) generator heat input, b) cooling water, and c) chilled water. Associated with each of these circuits is a specific temperature at which the machines are rated. For single-stage units, these tempera-tures are : 12 psi steam (or equivalent hot water) entering the generator, 85°F cooling water, and 44°F leaving chilled water (ASHRAE, 1983). Under these conditions, a coeffic-ient of performance (COP) of approximately 0.65 to 0.70 could be expected (ASHRAE, 1983). The COP can be thought of as a sort of index of the efficiency of the machine. It is calculated by dividing the cooling output by the required heat input. For example, a 500-ton absorption chiller operating at a COP of 0.70 would require: (500 x 12,000 Btu/h) divided by 0.70 = 8,571,429 Btu/h heat input. This heat input suggests a flow of 9,022 lbs/h of 12 psi steam, or 1,008 gpm of 240°F water with a 17°F ΔT.

Two-stage machines with significantly higher COPs are available (ASHRAE, 1983). However, temperature requirements for these are well into the power generation temperature range (350°F). As a result, two-stage machines would probably not be applied to geothermal applications.

PERFORMANCE

Based on equations that have been developed (Christen, 1977) to describe the performance of a single-stage absorption machine, Figure 2 shows the effect on COP and capacity (cooling output) versus input hot-water temperature. Entering hot water temperatures of less than 220°F result in substantial reduction in equipment capacity. The reason for the steep drop off in capacity with temperature is related to the nature of the heat input to the absorption cycle. In the generator, heat input causes boiling to occur in the absorbent/refrigerant mixture. Because the pressure is fairly constant in the generator, this fixes the boiling temperature. As a result, a reduction in the en-tering hot water temperature causes a reduction in the temperature difference between the hot fluid and the boiling mixture. Because heat transfer varies directly with temper-ature difference, there is a nearly linear drop off in absorp-tion refrigeration capacity with entering hot water tempera-ture. In the past few years, one manufacturer (Yazaki, undated) has modified small capacity units (2 to 10 ton) for increased performance at lower inlet temperature. How-ever, low-temperature modified machines are not yet avail-able in large outputs, which would be applicable to institutional- and industrial-type projects. Although COP and capacity are also affected by other variables such as condenser and chilled water temperatures and flow rates, generator heat input conditions have the largest impact on performance. This is a particularly important consideration with regard to geothermal applications.

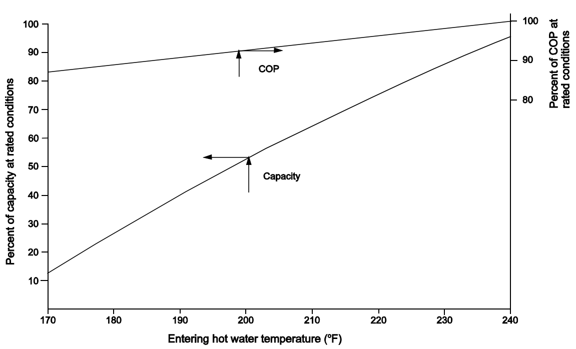

Figure 2. Capacity of a lithium bromide absorption chiller (Christen, 1977).

Because many geothermal resources in the 240°F and above temperature range are being investigated for power generation using organic Rankine cycle (ORC) schemes, it is likely that space conditioning applications would see temperatures below this value. As a result, chillers operating in the 180 to 230°F range would (according to Figure 2) have to be (depending on resource temperature) between 400 and 20% oversized respectively for a particular application. This would tend to increase capital cost and decrease payback when compared to a conventional system.

An additional increase in capital cost would arise from the larger cooling tower costs that result from the low COP of absorption equipment. The COP of singe effect equipment is approximately 0.7. The COP of a vapor compression machine under the same conditions may be 3.0 or higher. As a result, for each unit of refrigeration, a vapor compression system would have to reject 1.33 units of heat at the cooling tower. For an absorption system, at a COP of 0.7, 2.43 units of heat must be rejected at the cooling tower. This results in a significant cost penalty for the absorption system with regard to the cooling tower and accessories.

In order to maintain good heat transfer in the generator section, only small ΔTs can be tolerated in the hot water flow stream. This is a result of the fact that the machines were originally designed for steam input to the generator. Heat transfer from the condensing steam is a constant temperature process. As a result, in order to have equal performance, the entering hot water temperature would have to be above the saturated temperature corresponding to the inlet steam pressure at rated conditions. This is to allow for some ΔT in the hot water flow circuit. In boiler coupled operation, this is of little consequence to operating cost. However, because ΔT directly affects flow rate, and thus pumping energy, this is a major consideration in geothermal applications.

For example, assuming a COP of 0.54 and 15°F ΔT on the geothermal fluid, 250 ft pump head and 65% wire-to-water efficiency at the well pump, approximately 0.20 kW/t pumping power would be required. This compares to approximately 0.50 - 0.60 kW/t for a large centrifugal machine (compressor consumption only).

The small ΔT and high flow rates also point out another consideration with regard to absorption chiller use in space conditioning applications. Assume a geothermal system is to be designed for heating and cooling a new building. Because the heating system can be designed for rather large ΔTs in comparison to the chiller, the incremental cost of the absorption approach would have to include the higher well and/or pump costs to accommodate its requirements. A second approach would be to design the well for space heating requirements and use a smaller absorption machine for base load duty. In this approach, a second electric chiller would be used for peaking. In either case, capital cost would be increased.

LARGE TONNAGE EQUIPMENT COSTS

Figure 3 presents some more general cost information on large tonnage (>100 tons) cooling equipment for space conditioning applications. The plot shows the installed costs for both absorption chillers (Abs. chlr.), centrifugal chillers (Elec. chlr.), and auxilliary condenser equipment (cooling tower, cooling water pumps and cooling water piping) for both absorption chillers (Abs. twr.) And centrifugal chillers (Elec. twr.). As shown, both the chiller itself and its auxilliary condenser equipment costs are much higher for the absorption design than for electric-driven chillers. These are the primary capital cost differences that a geothermal operation would have to compensate for in savings.

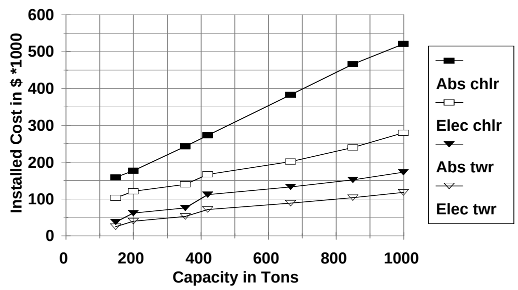

Figure 13.3 Chiller and auxiliary equipment costs - electric and absorption (Means, 1996).

SMALL TONNAGE EQUIPMENT

To our knowledge, there is only one company (Yazaki, undated) currently manufacturing small tonnage (<20 tons) lithium bromide refrigeration equipment. This firm, located in Japan, produces equipment primarily for solar applications. Currently, units are available in 1.3, 2, 3, 5, 7.5, and 10 ton capacities. These units can be manifolded together to provide capacities of up to 50 tons.

Because the units are water cooled chillers, they require considerably more mechanical equipment for a given capacity than the conventional electric vapor compression equipment usually applied in this size range. In addition to the absorption chiller itself, a cooling tower is required. The cooling tower, which is installed outside, requires interconnecting piping and a circulation pump. Because the absorption machine produces chilled water, a cooling coil and fan are required to deliver the cooling capacity to the space. Insulated piping is required to connect the machine to the cooling coil. Another circulating pump is required for the chilled water circuit. Finally, hot water must be supplied to the absorption machine. This requires a third piping loop.

In order to evaluate the economic merit of small absorption equipment compared to conventional electric cooling, Figure 4 was developed. This plot compares the savings achieved through the use of the absorption equipment to its incremental capital costs over a conventional cooling system. Specifically, the figure plots cost of electricity against simple payback in years for the five different size units. In each case, the annual electric cost savings of the absorption system (at 2,000 full load hours per year) is compared to the incremental capital cost of the system to arrive at a simple payback value. The conventional system to which absorption is compared in this case is a rooftop package unit. This is the least expensive conventional system available. A comparison of the absorption approach to more sophisticated cooling systems (VAV, 4-pipe chilled water, etc.) would yield much more attractive payback periods.

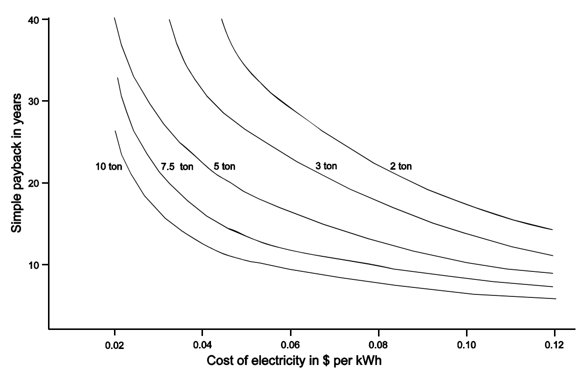

Figure 4. Simple payback on small absorption equipment compared to conventional rooftop equipment.

The plot is based on the availability of geothermal fluid of sufficient temperature to allow operation at rated capacity (190°F or above). In addition, other than piping, no costs for geothermal well or pumping are incorporated. Only cooling equipment related costs are considered. As a result, the payback values in Figure 4 are valid only for a situation in which a geothermal resource has already been developed for some other purpose (space heating and aquaculture), and the only decision at hand is that of choosing between electric and absorption cooling options.

Figure 4 also shows that the economics of small tonnage absorption cooling are attractive only in cases of 5 to 10 ton capacity requirements and more than $0.10 kW/h electrical costs. Figure 4 is based on an annual cooling requirement of 2,000 full load hours per year. This is on the upper end of requirements for most geographical areas. To adjust for other annual cooling requirements, simply multiply the simple payback from Figure 4 by actual full load hours and divide by 2,000.

The performance of the absorption cooling machine was based on nominal conditions in order to develop Figure 4. It should be noted that, as with the larger machines, performance is heavily dependent upon entering hot water temperature and entering cooling water temperature. Ratings are based on 190°F entering hot water, 85 °F entering cooling water and 48°F leaving chilled water. Flow rates for all three loops are based upon a 9°F ΔT.

Figure 4 illustrates the effect of entering hot water temperature and entering cooling water temperature on small machine performance. At entering hot water temperatures of less than 180°F, substantial derating is necessary. For preliminary evaluation, the 85°F cooling water curve should be employed.

COMMERCIAL REFRIGERATION

Most commercial and industrial refrigeration applications involve process temperatures of less than 32°F and many are 0°F. As a result, the lithium bromide/water cycle is no longer able to meet the requirements, because water is used for the refrigerant. As a result, a fluid which is not subject to freezing at these temperatures is required. The most common type of absorption cycle employed for these applications is the water/ammonia cycle. In this case, water is the absorbent and ammonia is the refrigerant.

Use of water/ammonia equipment in conjunction with geothermal resources for commercial refrigeration applications is influenced by some of the same considerations as space cooling applications. Figure 13.5 illustrates the most important of these. As refrigeration temperature is reduced, the required hot water input temperature is increased. Because most commercial and industrial refrigeration applications occur at temperatures below 32ºF, required heat input temperatures must be at least 230ºF. It should also be remembered that the required evaporation temperature is 10 to 15ºF below the process temperature. For example, for a +20ºF cold storage application, a 5ºF evaporation temperature would be required.

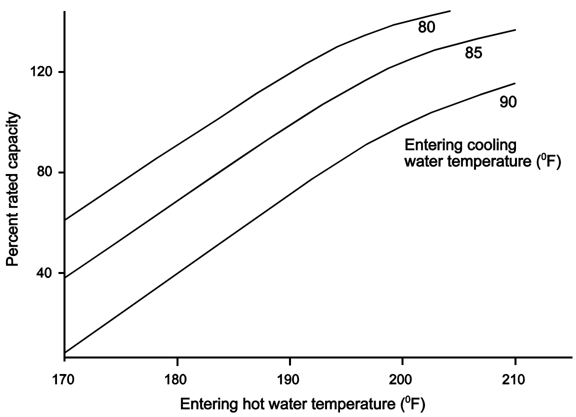

Figure 5. Small tonnage absorption equipment performance.

Research suggests a minimum hot water temperature of 275ºF would be required. There is not a large number of geothermal resources in this temperature range. For geothermal resources that produce temperatures in this range, it is likely that small scale power generation would be competing consideration unless cascaded uses are employed.

Another consideration for refrigeration applications. That is the COP for most applications is likely to be less than 0.55. As a result, hot water flow requirements are substantial. In addition, the cooling tower requirements, as discussed above, are much larger than for equivalently sized vapor compression equipment.

CONCLUSION

In conclusion, it is necessary to evaluate the following factors when considering a geothermal/absorption cooling application for space conditioning.

Resource temperature

Substantial derating factors must be applied to equipment at temperatures less than 220ºF. Very high resource temperatures or two-stage are required for low-temperature refrigeration.

Absorption machine hot water requirements compared to space heating flow requirements

Incremental well and pumping costs should be applied to the absorption machine.

Refrigeration capacity required

Larger machines have lower incremental capital costs on a $/ton basis. Coupled with the larger displaced energy, this result in a more positive economic picture.

Annual cooling load for space conditioning, in full load hours or for process cooling, in terms of load factor

Obviously higher utilization of the equipment results in more rapid payout.

Pumping power for resources with unusually low static water levels or drawdowns

Pumping power may approach 50% of high efficiency electric chiller consumption.

Utility rates

As with any conservation project, high utility rates for both consumption and demand result in better system economics.

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