One Hundred Ton Absorption Chiller/Heat Pump
Demonstrates the Real Cost of Saving Energy

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Abstract
A steam-fired demonstration of an absorption chiller/heat pump has now completed eight months of operation. This unit supplies 100-tons of chilling and 3.2 million BTU per hour of hot water simultaneously, from 2 million BTU/hour of 80 psig steam. It is installed at a poultry processing plant, where it pre-chills the cold water for the continuous chiller, and pre-heats the hot water for the continuous scalder. It operates on a 20/5 basis automatically and completely unattended. The savings in both natural gas and electricity add up to over $110K per year. The simple payback is approximately 1.5 years. Those savings are replicable in many applications, and represent only one of many overlooked opportunities in the energy efficiency field.

Introduction
A great deal of heating is done at low temperature, i.e. at a temperature only modestly above ambient temperature. Examples include hot water heating (120°F to 160°F); space heating (70-75°F); and drying (100-200°F). A surprising amount of energy is consumed for this purpose – nearly 20 quads per year in the United States alone.

Even more surprising is how inefficient the conventional low temperature heating processes are. Heater manufacturers claim efficiencies of 80 to 95% (fuel-fired) or 98+% (electric or steam powered). However those are "First Law" efficiencies. The true measure of thermodynamic efficiency is the Second Law efficiency. When fuel with a 2,800°F adiabatic flame temperature is used to heat water to 130°F, the Second Law efficiency is abysmally low – approximately 23%. With electric resistance heating, the Second Law efficiency drops to about 8%. In other words, an ideal reversible cycle using that same electrical energy would heat twelve times more hot water than the resistance heater.

One consequence of this extreme low efficiency exhibited by conventional low temperature (LT) heaters is that the door is thereby opened to a variety of other technologies, such as combined heat and power (CHP) or solar thermal. The low efficiency and resulting high fuel cost justifies use of much costlier technologies which consume less fuel.

Unfortunately, these currently available alternatives for more efficient LT heating (CHP and solar thermal) are so costly that they have made little inroad toward reducing the fuel wasted in this sector. The paybacks are at best in the four-year ballpark, and frequently much longer.

What is needed is a much more cost effective and less complicated method of improving the efficiency of low temperature heating. That is what the Heat Activated Heat Pump/Chiller (HAHP/C) accomplishes. Two field demonstrations of the HAHP/C have now been conducted, to support the claimed performance and economy. The first, now in operation for three and a half years, was at a small scale (10 tons) and limited operating hours (30 hours per week with lots of starts and stops) (references 1 and 5). The second, reported herein, is at 100-ton scale and operates 95 hours per week. The first demo showed long term operability, but didn't have enough operating hours to achieve good economics. The larger demonstration, reported here, has a 1.5-year payback even at the demonstration stage, without any subsidy, and points the way to many economic applications.

HAHP/C Characteristics

Being a heat pump, the heat entering the cold end of the HAHP/C, thus producing chilling, exits the warm end, thus producing warm water. In addition, the "heat-activated" property signifies that a much higher temperature heat input is supplied as the motive force, and that heat also exits as hot water.

Figure 1 illustrates these relationships. One BTU of high temperature heat is input to the HAHP/C, which is the motive force to produce 0.6 BTU of chilling. Both the 1 BTU and the 0.6 BTU exits the HAHP/C as warm water. Hence the net effect is 0.6 BTU's of chilling and 1.6 BTU's of water heating from a heat input of 1 BTU.

Figure 2 shows how an actual thermodynamic cycle (in this case an absorption cycle, plotted on pressure-temperature coordinates) would accomplish the above result. High temperature heat is input to the cycle at the generator; chilling is produced at the evaporator; and heat is rejected from the cycle both at the condenser and absorber, thus producing hot water. An absorption cycle which produces 0.6 BTU of chilling from 1 BTU of heat input is characterized by its Coefficient of Performance (COP) of 0.6.

Figure 3 translates the thermodynamic diagram into an actual flowsheet, showing components and interconnecting piping.

Field Demonstration Requirements

The sequence of preparing poultry for market is regulated by the U.S. Department of Agriculture, and includes a scalding step using 135°F hot water, followed in short order by chilling with 33°F chilled water. The plant which is hosting this demonstration processes 50,000 birds per hour for 16 hours each day. This requires a continuous flow of at least 208 gallons per minute (gpm) hot water and 208 gpm chilled water. The hot water is produced from 80-psig steam from natural gas-fired boilers, and the chilled water is produced from an ammonia vapor compression refrigeration plant powered by electricity. At current utility rates (90¢ gas and 9¢ electric), the plant spends $454K per year on natural gas to make the hot water and $100K per year on electricity for the refrigeration to make chilled water.

The HAHP/C produces both chilled water and heat pumped hot water from a single heat source. It is powered by the same steam which otherwise would make the hot water, but with two important differences. First, instead of the 98% efficiency of a steam hot water heater, the HAHP/C achieves 156% efficiency in converting steam to hot water, due to the heat pumping action. Second, the chilled water produced by the HAHP/C is energy-free.

Table 1 illustrates this demand for hot water and chilled water, and how the HAHP/C reduces the natural gas requirement from 97 therms per hour to 61, and reduces the electric demand from 242 kW to 12. Table 2 tabulates the corresponding savings: a reduction in the utility bill of

$276 per year, i.e. less than half the current cost. Based upon the typical installed cost for a 250 ton HAHP/C of $500K, the payback is 1.8 years. There is a corresponding large reduction in CO_2 emissions – 1,800 tons per year less.

Field Demonstration Results

In view of this promising economic projection, a demonstration was commenced at no cost to the host site. An available 100 ton HAHP/C was pressed into service, as a proof of principle. Connections were made to the 80 psig steam service, the condensate return system, city water supply, chill water supply, and hot water supply. The system was automated by installing level switches in the existing hot water storage tank and chill water storage tank. A full signal from either tank stops the HAHP/C, and both tanks must be below full for it to start. It was also found necessary to install a water booster pump on the city water supply since the supply pressure was highly variable. The water flow rates are the primary means of controlling chill water temperature and hot water temperature.

This demonstration HAHP/C operates during processing (about 16 hours per day, five days per week) and also during the first three to four hours of clean-in-place, when there is a high demand for hot water and the chill water storage tank is being re-filled. For the first several months it was manually started and stopped each day. Then that was automated with level switches on the storage tanks. The past four months of operation have been fully automatic.

As might be expected with any demonstration project, there have been a few glitches which required manual intervention. The most aggravating was caused by a leaking solenoid valve. Two shutdown solenoid valves are provided, which close upon shutdown to keep the cycle fluids in the proper locations to facilitate the subsequent startup. One valve had a slight internal leak, which allowed the pump receiver level to slowly decrease. This was not a problem during the daily shutdown, which only lasted about four hours. However during the forty hour weekend shutdown, the receiver level declined to where the pump lost suction and the HAHP/C would not start. This required that a bypass hose be manually connected to return the solution to the receiver. The immediate problem was fixed by replacing the solenoid valve. For the longer term fix, recognizing that solenoids do sometimes leak, we will make the HAHP/C more fault tolerant by installing a larger pump receiver and hard piping the bypass connection.

Table 4 provides snapshots of about a dozen discrete times where comprehensive data was recorded and the cycle performance was analyzed. Since this demonstration HAHP/C only supplies about 40% of the total demand of this plant, the chill water and hot water flow rates are maintained at high values. This increases the heat pumping capacity, to above 90 tons. Figure 5 illustrates that effect.

When both water flows were slowed to achieve higher temperature lift (e.g. 40°F chill water and 132°F hot water), the capacity declined to about 65 tons. Indeed, that is the rating we would supply to future versions of this unit which require a high lift.

The California Energy Commission provided financial assistance for data collection and analysis during three months of demonstration. Pacific Gas & Electric has indicated that their standard offer efficiency incentive will apply to this unit should the host site opt to purchase it.

Conclusions

This demonstration has shown that a steam-fired (or fuel-fired) HAHP/C can have exceptionally good economics with a reasonable utilization factor – about 62% in this case. Many applications exhibit these attributes.

References

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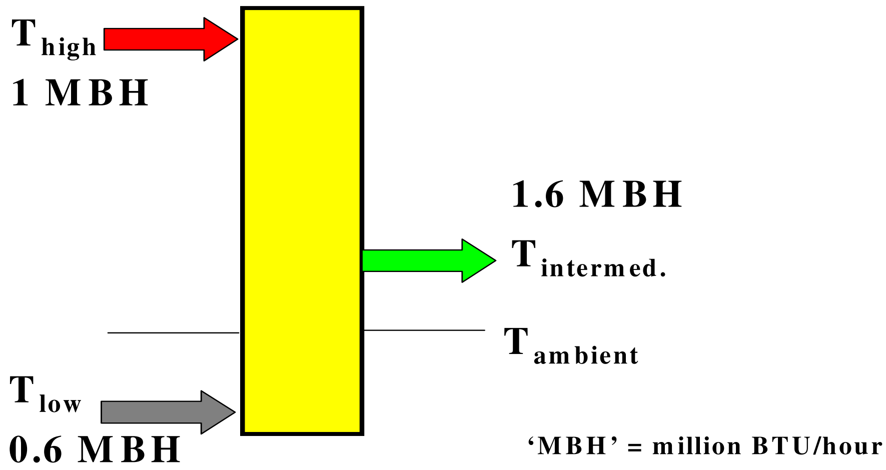

Figure 1. Trithermal Heat Activated Heat Pump/Chiller

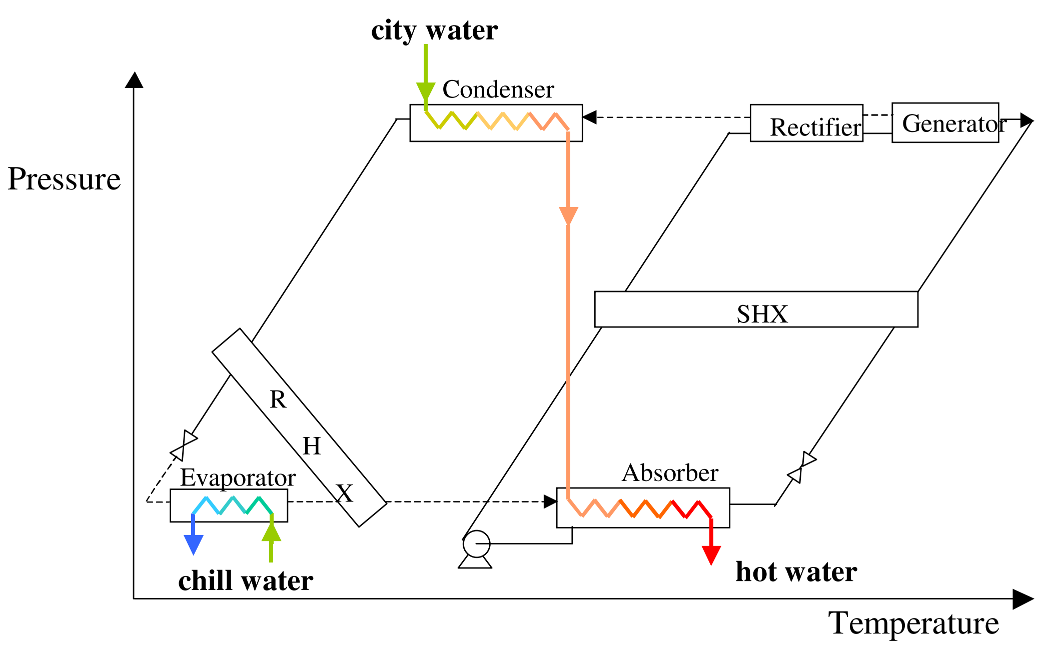

Figure2. Thermodynamic Diagram of Ammonia Absorption HAHP/C

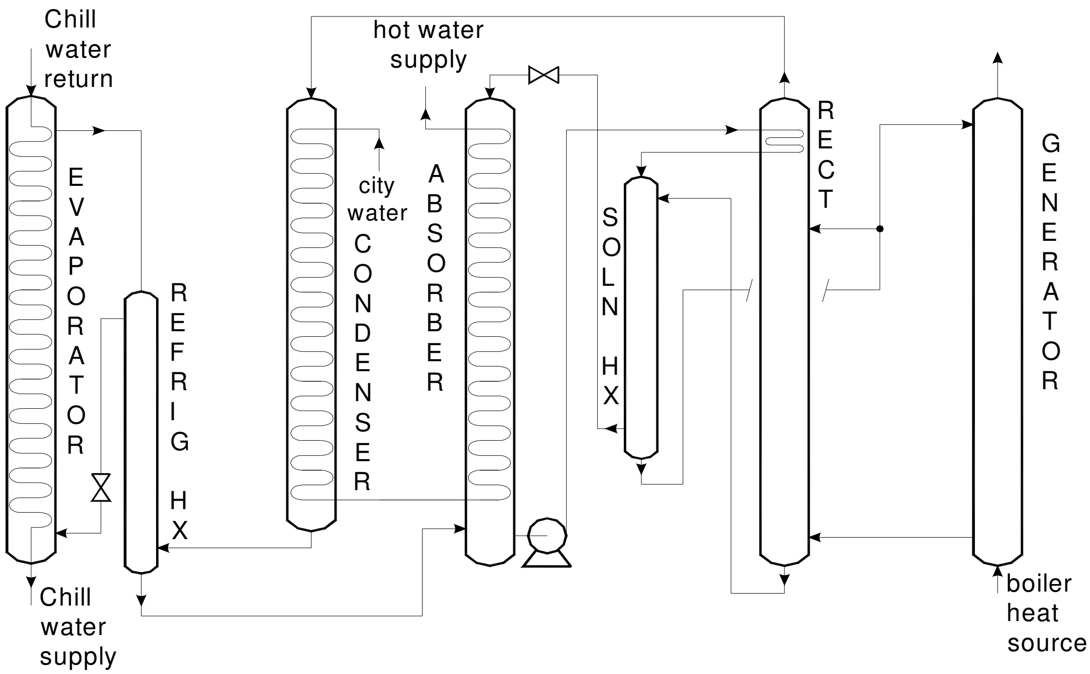

Figure 3. HAHP/C Flowsheet

- Delivers up to 100 tons chilling and 3.2 MBH heat pumped hot water from 2MBH steam.
- Saves 30% of water heating and 90% of chilling energy.
- 40ºF chill water and 136ºF hot water.
- Automated, unattended operation, 20/5

Figure 4. HAHP/C FOR LARGE POULTRY PROCESSOR

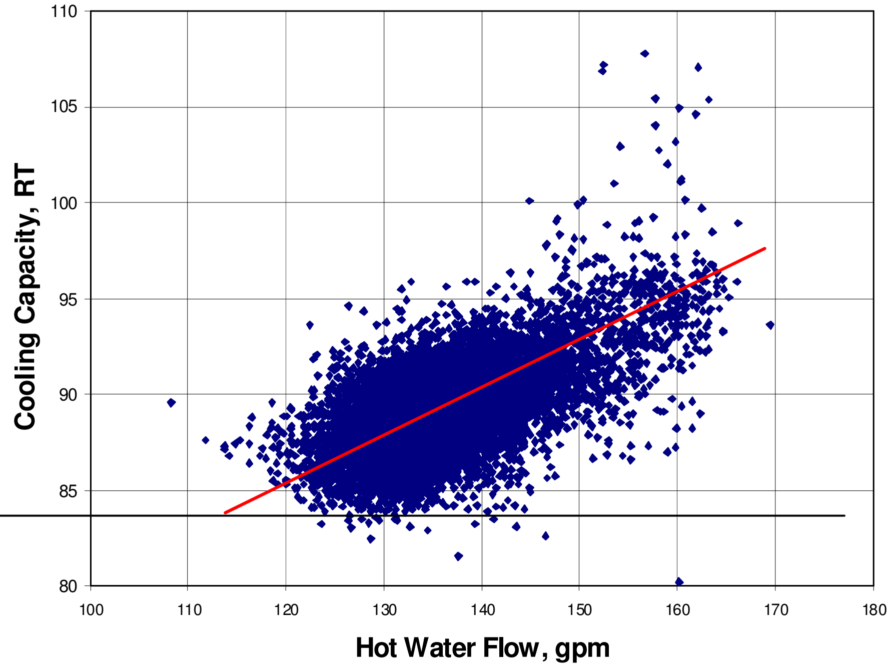

Figure 5. Water Flow Effect on HAHP/C Capacity

- Continuous scalder and chiller: 50,000 birds/hour and 1/4 gallon/bird = 208 gallons/minute
- Hot water heating requirement: 208 gpm from 61°F to 135°F = 7.78 MBH (97 therms/hour)
- Chill water refrigeration requirement: 208 gpm from 61°F to 33°F = 242 tons (242 kW)
- THERMOSORBER:

61 therms/hr → TS 250 → 7.8 MBH hot water

12 kW → TS 250 → 242 tons chill water

Table 1. POULTRY PROCESSING EXAMPLE

- HOURLY SAVINGS
  - 36 therms @ $0.90/therm $32.40
  - 230 kWh @ $0.09/kWh 20.70

  $53.10/hour
- ANNUAL SAVINGS (for 20/5 operation)
  - 5200 HOURS @ $53.10 $276,120/year
- INSTALLED COST $500,000
- PAYBACK 1.8 Years
- AVOIDED CO2 EMISSIONS 1800 tons/year

Table 2. ECONOMICS OF POULTRY PROCESSING APPLICATION

Date		040706	040806a	040806b	040806c	040806d	053106	060106	060607	061306	061406	080106	080206
Temp [F]	Steam	309.4	310.4	318.0	315.5	317.1	313.0	315.0	317.0	318.0	315.0	318.8	317.0
	Condensate	303.4	309.2	314.3	312.8	314.6	311.0	310.0	311.0	317.0	298.0	316.8	315.0
	City water	70.0	69.1	69.8	69.7	68.9	69.0	69.0	70.0	69.0	69.0	70.0	70.1
	Chill water	51.4	50.1	50.1	51.7	51.0	52.0	52.0	52.0	51.0	52.0	51.8	52.7
	Hot water	118.5	118.9	122.6	121.4	122.3	121.0	120.0	119.0	121.0	118.0	115.2	115.9
Flow Rate [gpm]	Sol-Pump	17.3	16.4	16.7	15.8	15.5	16.2	16.6	16.3	16.4	16.8	17.6	17.6
	Chill Water	117.5	117.5	117.5	117.5	117.5	119.0	119.0	121.0	118.0	123.0	124.0	124.0
	Hot Water	122.3	123.7	120.0	114.6	109.0	110.0	112.4	125.3	115.7	120.7	137.5	131.8
	Condensate	4.5	4.7	4.9	4.6	4.5	4.4	4.5	4.8	4.7	4.5	4.8	4.7
Pressure [psig]	HP	210	211	213	212	217	201	201	202	201	201	217	215
	LP	53	50	51	51	53	56	57	57	54	56	54	55
Performance	RT	90.6	92.6	96.0	87.7	87.2	84.1	84.1	90.5	88.3	86.9	93.8	89.7
	COP	0.586	0.570	0.576	0.557	0.567	0.551	0.548	0.553	0.548	0.550	0.574	0.560
Heat Duty [kW]	COND	358.6	382.0	394.5	372.6	365.3	360.3	358.4	389.7	382.6	370.5	379.4	365.0
	RHX	30.7	35.0	35.6	33.8	35.9	29.7	29.6	31.6	30.7	26.1	28.5	30.8
	EVAP	318.7	325.5	337.6	308.5	306.8	295.7	295.7	318.3	310.5	305.6	329.8	315.3
	HT-ABS	324.8	327.4	329.1	305.0	294.3	321.5	341.8	379.2	363.5	357.7	340.9	366.6
	LT-ABS	181.2	189.1	201.4	186.4	189.8	153.5	136.5	127.1	132.3	134.7	186.6	149.5
	SHX	105.8	114.5	115.7	107.9	104.0	118.3	121.6	120.9	125.5	123.4	130.7	128.8
	GHX	76.0	77.6	88.7	73.5	75.9	53.5	56.4	69.4	59.0	59.7	52.2	60.6
	GEN	544.2	571.5	585.9	554.1	541.2	536.8	539.2	575.9	566.1	555.5	575.0	563.5

Table 3. HAHP/C Demonstration Unit Results