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Combined Heat and Power Technology Fact Sheet Series

CHP Technologies: Absorption Chillers

Chillers are used in commercial buildings and industrial plants to provide air conditioning, refrigeration, and process fluid cooling. Two common chiller types are vapor compression and absorption. Vapor compression chillers use reciprocating, screw, or centrifugal compressors to power the cycle. The compressors are most often driven by electric motors, although they can also be powered by natural gas engines or steam turbines. Absorption chillers are driven with thermal energy produced from a direct-fired burner integrated with the chiller or with thermal energy supplied indirectly to the chiller. Indirect thermal sources include hot water, steam, or combustion exhaust.[1] Absorption chillers can convert thermal energy from CHP and industrial heating operations into useful onsite cooling, reducing power requirements and associated carbon emissions.

A 300-ton absorption chiller located at a data and research center at Syracuse University, New York. The chiller uses exhaust from twelve 65-kW microturbines and can cool water to 45°F. Photo courtesy of New York-New Jersey Onsite Energy Technical Assistance Partnership (TAP).

Absorption Chillers for CHP

Combined heat and power (CHP) systems can deliver both heating and cooling to a facility by using thermal energy recovered from a prime mover (e.g., reciprocating engine, gas turbine, or microturbine) to drive the absorption chiller cycle. Table 1 provides an overview of key absorption chiller attributes for CHP applications.

Applications

Absorption chillers use a binary solution of a refrigerant and an absorbent. The solution is selected based on specific site cooling requirements. For space conditioning and other requirements that require chilling fluid temperatures of 40°F or higher, water/lithium bromide (refrigerant/absorbent) is the most common solution. For lower temperatures, ammonia/water (refrigerant/absorbent) is typically used. Absorption chillers are most cost effective at sites that have significant space conditioning requirements or year-round cooling loads. Applications with significant space conditioning loads include hospitals, hotels, large commercial office buildings, and college campuses. Sites that may require year-round cooling include manufacturing plants with process cooling needs, cold storage warehouses, and district energy plants. The image on the next page shows an absorption chiller integrated with a CHP system at the University of Central Florida.

Table 1. Summary of Absorption Chiller Attributes for CHP Applications

Attribute	Description
Size Range	5 to 3,000 refrigeration tons.
Input Heat	Hot water, steam, or prime mover exhaust.
Configuration	Available in single and double effect designs (also referred to as single or two stage, respectively). Single effect machines can be driven with hot water (190°–240°F) or low pressure (15 psig) steam and are often used with reciprocating engine CHP installations. Compared to single effect chillers, double effect machines require higher temperature hot water (e.g., 350°F) or higher pressure steam (e.g., 100 psig) and are often used with combustion turbine CHP installations. In addition to hot water and steam, absorption chillers can also be exhaust fired (required exhaust temperatures typically above 750°F).
Refrigerant/ Absorbent	For 40°F and higher chilling fluid temperatures (e.g., building air conditioning), a common mixture is water (refrigerant) and lithium bromide (absorbent). For chilling fluid temperatures below 40°F (e.g., cold storage), a common mixture is ammonia (refrigerant) and water (absorbent). Lithium bromide water or ammonia water mixtures have negligible global warming potential compared to traditional refrigerants.

1 Exhaust fired chillers require steady state loads due to the difficulty with controlling high temperature exhaust with minimal back pressure allowances.

A 992-ton absorption chiller (left) integrated with a reciprocating engine at the University of Central Florida. The chiller is used to supplement the district chilled water system and uses waste heat and exhaust from the engine (right). Photo courtesy of the Southcentral Onsite Energy Technical Assistance Partnership (TAP).

Technology Description

The absorption cycle is similar to the vapor compression cycle except the prime mover (typically an electric motor) and compressor are replaced by a thermal compressor system consisting of an absorber, solution pump, and generator (see Figure 1). Like a mechanical compressor in a vapor compression chiller, the thermal compressor takes low pressure/low temperature refrigerant vapor from the evaporator and delivers high pressure/high temperature refrigerant vapor to the refrigerant condenser. Instead of directly compressing the refrigerant vapor using mechanical energy (typically electricity), a thermal compressor uses an absorbent fluid to chemically bond with the refrigerant vapor (essentially compressing it by changing phase from a gas to a liquid). This dilute solution of absorbent/refrigerant is pumped to a generator where the refrigerant is boiled using thermal energy, and the refrigerant vapor then migrates to a condenser where it is changed back into a liquid refrigerant to begin the process over again. The absorbent is returned from the generator to the absorber to bond again with refrigerant vapor. The absorption process is exothermic (i.e., it generates heat), and heat must be rejected from the absorber through the condenser water loop to a cooling tower. Because the absorption process is exothermic, absorption chillers require a larger cooling tower compared to a mechanical chiller with the same capacity.

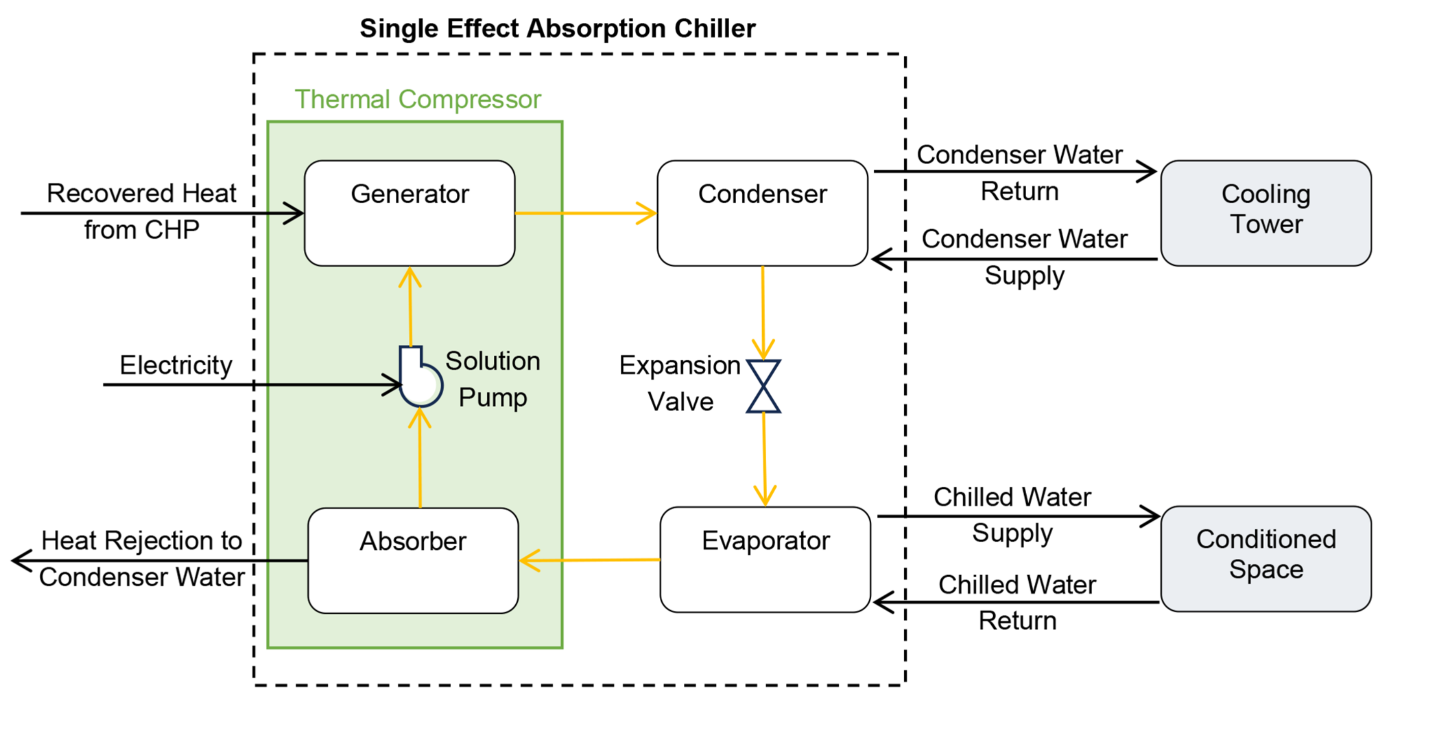

Figure 1. Single Effect Absorption Cycle. Graphic Credit Exergy Partners

Absorption chillers are available in single and double effect designs (single effect shown in Figure 1). Double effect chillers operate at higher temperatures and pressures compared to single effect units and have higher efficiencies. For CHP applications, single effect machines are often used with reciprocating engines, while double effect machines are often used with combustion turbines. In recent decades, improvements to absorption chiller design and preventative maintenance strategies have resulted in dependable equipment with reliable operation comparable to other types of chillers.

Performance Characteristics

Absorption chillers can use hot water, steam, or exhaust gas as a heat source. When exhaust is used, it is referred to as a direct-fired chiller. When configured with prime movers that produce high-temperature exhaust, such as gas turbines or microturbines, direct-fired absorption chillers can offer efficiency benefits; however, hot water and steam are more commonly used as heat sources in CHP chiller configurations. Roughly half of available heat from reciprocating engines is in the form of hot water, making hot water the most common heat source for chillers paired with engines. High-temperature steam is most often produced from gas turbines with heat recovery steam generators, so steam is often used as a heat source for chillers paired with gas turbines.

The efficiency of an absorption chiller is measured by the coefficient of performance (COP), which is defined as useful thermal energy output (i.e., chiller load) divided by heat input. COP is a unitless number and does not include energy consumed by pumps, fans, or other ancillary components. COP values for single effect chillers are typically less than one, and COP values for double effect systems are typically greater than one (i.e., chilled energy delivered exceeds heat required to drive the system).

Absorption chiller capacity is a function of thermal energy input quantity and quality, as well as chiller design (single or double effect), and it is therefore important to match CHP prime mover characteristics with desired absorption chiller performance. While a double effect absorption chiller has a higher COP compared to a single effect chiller, it requires a higher temperature heat source (the generator temperature of a double effect chiller is about 150°F higher than a single effect unit). Where high temperature heat sources are available, either design can be used. A double effect absorption chiller can produce more chilled water from a high temperature heat source compared to a single effect chiller, but it is more complex and can be more expensive for a given chiller size.

Table 2 shows representative performance characteristics for single and double effect water/lithium bromide absorption chillers ranging in capacity from 50 to 2,000 tons. Four capacities are included for single effect chillers, and three capacities are included for double effect units. The four single effect examples are based on using hot water to drive the absorption chiller, and the three double effect examples are based on using steam as the heat source. All seven systems deliver 44°F chilled water based on an inlet water temperature of 54°F. The four single effect absorption chillers have a COP of 0.70, and the representative double effect units, which are more efficient, have a COP of 1.35.[2] For the single effect absorption chillers, operation is based on using hot water at 195°F with a 20°F delta (outlet temperature of 175°F). The double effect chiller operation is based on saturated steam at 100 psig.[3]

Table 2. Absorption Chiller Performance Characteristics *(typical values for water/lithium bromide chillers)*

Description	Nominal Cooling Capacity (tons)						
	50	250	500	1,000	500	1,000	2,000
Design	Single Effect				Double Effect		
Heat Source	Hot Water				Steam		
Thermal Energy Input							
Hot Water Inlet Temp (°F)	195	195	195	195	n/a	n/a	n/a
Hot Water Outlet Temp (°F)	175	175	175	175	n/a	n/a	n/a
Steam Pressure (psig)	n/a	n/a	n/a	n/a	100	100	100
Heat Required (MMBtu/hr)	0.86	4.30	8.60	17.10	4.40	8.90	17.80
Chiller Water Output							
Inlet Temp (°F)	54	54	54	54	54	54	54
Outlet Temp (°F)	44	44	44	44	44	44	44
Cooling COP (full load)	0.70	0.70	0.70	0.70	1.35	1.35	1.35

Notes: Performance characteristics are based on multiple sources, including vendor data and discussions with industry experts. The characteristics are intended to illustrate typical absorption chillers and are not intended to represent performance of specific products.

2 Assumptions for COP calculations are: 1) single effect chillers have identical mechanical designs, 2) double effect chillers have identical mechanical designs, 3) all chillers use water/lithium bromide, and 4) all chillers have same chilled water conditions. With these assumptions, the single effect chillers have the same COP and the double effect chillers have the same COP.

3 For the hot water and steam examples, the boiler efficiency is not considered in the calculations.

Capital and O&M Costs

Table 3 shows estimated capital and maintenance costs for the same seven systems described in Table 2. In Table 3, the equipment cost is for the chiller only. The cost of a cooling tower is included in the construction and installation category. For estimating purposes, the cooling tower accounts for approximately 30% of the total construction and installation cost for a typical single effect absorption chiller and approximately 25% of the total construction and installation cost for a typical double effect absorption chiller.

As shown in Table 3, installed costs range from $1,600 to $4,500 per ton for the four single effect systems and from $1,300 to $2,200 per ton for the three double effect absorption chillers. Capital cost per ton of cooling capacity declines as chiller size increases for both single and double effect units. Maintenance costs range from 0.4 to 1.0 ¢/ton-hr for all but the smallest (50-ton) chiller in Table 3. Maintenance costs do not include energy costs required for operation but do include all maintenance requirements for an absorption chiller system, including periodic tube cleaning, inspecting and maintaining a cooling tower, and monitoring and treating chilled water.

Table 3. Absorption Chiller Capital and Maintenance Costs *(typical values for water/lithium bromide chillers)*

Description	Nominal Cooling Capacity (tons)						
	50	250	500	1,000	500	1,000	2,000
Design	Single Effect				Double Effect		
Heat Source	Hot Water				Steam		
Equipment ($/ton)	$2,373	$1,129	$860	$697	$1,086	$787	$649
Construction and Installation ($/ton)	$2,135	$1,189	$1,003	$893	$1,076	$884	$665
Installed Cost ($/ton)	$4,508	$2,318	$1,863	$1,590	$2,162	$1,671	$1,314
Maintenance Cost (¢/ton-hr)	3.75	1.00	0.75	0.50	0.90	0.65	0.40

Notes: Costs are based on multiple sources, including vendor data and discussions with industry experts. The values shown are composite results and are not intended to represent costs for a specific product. Site-specific conditions can have a large impact on installed costs, particularly for smaller systems.

Emissions

Absorption chiller emissions depend on the application. If the chiller is integrated with a CHP system and driven by thermal energy from the CHP system, there are no incremental emissions from the absorption chiller. If the absorption chiller is a stand-alone unit that is direct-fired, emissions will depend on the fuel used to produce thermal energy to drive the system and the specific combustion technology used for direct firing. For direct firing, absorption chillers can use low NO_x burner technologies and other emission control measures to comply with local air quality requirements as needed.

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