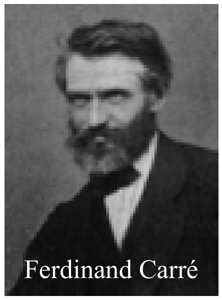
The Future of Absorption Technology in America

A Critical Look at the Impact of BCHP and Innovation

History of Absorption Technology

Edmond Carré developed the first absorption machine in 1850, using water and sulfuric acid. His brother, Ferdinand Carré, demonstrated an ammonia/water refrigeration machine in 1859, and in 1860 Ferdinand received the first U.S. patent for a commercial absorption unit.[1]



Servel was founded in 1902 as the Hercules Buggy Works, and became a manufacturer of electric refrigerators (the name is short for "Serve Electrically"). In 1925, Servel purchased US rights to a new AB Electrolux gas heat-driven absorption refrigerator invented by Swedish engineering students, Carl G. Munters and Baltzar von Platen. The new Electrolux-Servel absorption refrigerator entered the US market in 1926 and brought absorption refrigerators to millions of homes until production was stopped in the 1950s.

Figure 1. Natural Gas Utility Ad for Absorption Refrigerator

American companies manufactured 100% of $LiBr/H_2O$ absorption chillers worldwide, in the late 1960's, using the standard single-effect absorption cycle. Trane Company introduced the first mass-produced steam-fired double-effect $LiBr/H_2O$ absorption chiller in 1970. Several factors have influenced absorption chiller sales since then.

Natural gas prices, as well as, fuel availability concerns and governmental policies caused U.S. absorption chiller sales to decline in the mid-1970s and throughout the 1980s.

Since the early 1990s, absorption chiller sales have increased modestly in the USA. Absorption chiller use in countries like Japan Figure 2, China and Korea has grown exponentially since the mid-1970s. The general underlying reasons for the disparate growth phenomena in Asia are complex, but it is clear that the economics of delivered energy are being evaluated differently between historical America and modern Asia when it comes to commercial water chiller technology.

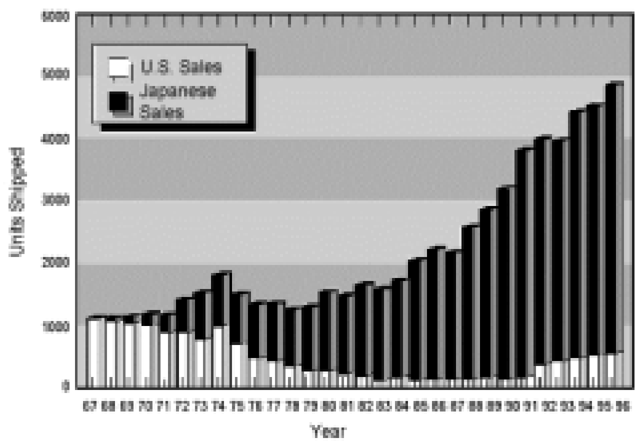


Figure 2. Japan versus USA Absorption Chiller Sales[2]

In many parts of Asia today, the siting of an electric water chiller, requires not only the usual economic capital of the chiller plant, piping, pumps and cooling tower, and boiler for heating, but also a portion of the electric transformer, wires and generating capacity needed to serve the chiller plant. Therefore, it is easy to see why

[1] Thévenot, R. 1979. *A History of Refrigeration Throughout the World.* Translated from French by J.C. Fidler. Paris, France: International Institute of Refrigeration (IIR).

[2] Courtesy of Oak Ridge National Laboratory

an absorption chiller/heater plant is frequently far more cost effective to install in Asia.

RE-POWERING OF AMERICA

Electric restructuring in America, as well as economic growth, will lead to a re-powering over the next 20 years. DOE/EIA projects that the US will need to build over 360 gigawatts of new electric capacity to meet growing demand and compensate for plant retirements. This shortage in electricity supply may be one of the primary contributors to sustaining, and possibly rising, electricity prices. Electric restructuring is also the principle cause behind the development of the combined heat and power (CHP) efforts in Europe over the past decade, and the buildings cooling, heating and power initiative (BCHP) in America today.

Impact of BCHP and Innovation on Absorption

Absorption technology has provided American business, industry and homes with refrigeration and air conditioning technology over the past 150 years. Absorption equipment was used to solve problems that could not otherwise be solved. In 1850 it was the only technology available. In 1926, the absorption refrigerator was the solution to an increasing number of consumer deaths caused by early vapor compression refrigerators (due to the toxicity of sulfur dioxide, methyl chloride, and ammonia gases used in earlier mechanical compressor home refrigerators since 1918). LiBr/H_2O water chillers were an efficient use of summertime steam from steam-loops and became very cost effect products to build.

The success of BCHP technology will focus on two key elements:

- ⇒ Optimizing the recovery of thermal energy from onsite power generation
- ⇒ Cost effective integration of thermal recovery/use systems

The first element has focused the manufacturing community on all aspects of efficiently coupling existing technologies, and then further integrating these technologies through innovative engineering. This process has led to the following development focus:

- ⇒ Examination of existing power generation sites that can benefit from integration with absorption chillers
  - ⇒ Gas turbine inlet cooling
- ⇒ Focusing attention on advanced direct-fired chiller/heater plants.
- ⇒ Planning new onsite installations with existing absorption chillers
  - ⇒ IC engines
  - ⇒ Gas Turbines
  - ⇒ Micro-turbines
  - ⇒ Fuel Cells
- ⇒ Developing new absorption technologies as a result of new BCHP requirements
  - ⇒ Development of Next Generation Single-Effect Absorption Systems
  - ⇒ Development of Co-Fired Micro-turbine/Absorption Systems
  - ⇒ Developing Air-Cooled LiBr/H_2O water chiller designs
  - ⇒ Developing combined NH_3/H_2O / desiccant residential system

GAS TURBINE INLET COOLING

Combustion turbines are mass-flow engines. Power output increases within limits, in inverse proportion to the temperature of the inlet air. Cooler air is denser and consequently provides more mass flow. Output will typically increase by 10% to 18% for every 20°F of reduction in inlet air temperature.

Historically, evaporative cooling was used where the air temperature is reduced as a percentage of the difference between dry bulb and wet bulb temperatures. This means that, in relatively humid areas, this method is not effective. However, even in hot and relatively dry climates, the temperature drop may be as little as 25°F. This is far higher than the standard ISO rating condition of 59° F.

For example, cooling the inlet air to the gas turbine system to 50º F from 110º F increases the turbine output power up to 60%, depending on the turbine performance.

Refrigeration Inlet Cooling: Refrigeration Inlet cooling is used to provide power enhancement for base load operation. Since the cooling is to be provided on a continuous basis, a chiller (Absorption or Mechanical) or direct refrigeration system is used.

An on-line chiller circulates a secondary refrigerant (glycol, water) to the cooling coils in front of the turbine. This system uses an absorption chiller or vapor compression chiller, water-cooled condensers, cooling tower and cooling coils. Absorption chillers typically cool the inlet air to about 50ºF. This temperature is usually low enough to maximize potential gains in gas turbine power output. If additional turbine capacity is required, today's advanced absorption chillers can cool inlet air to as low as 42ºF. Cooling the air to below 42ºF is not generally recommended because it could lead to ice formation, unless the air has been dehumidified appropriately.

A direct refrigeration system uses compressors, condensers, a low-pressure recirculation system, a high-pressure receiver, and cooling coils. The refrigerant is directly circulated to the cooling coils in front of the turbine.

Refrigeration inlet cooling provides constant power output, regardless of weather, and constant moisture content of inlet air to facilitate NO_x control.

Direct Water Injection: Inlet air evaporative cooling with direct water spray offers a relatively simple, low cost method to increase power output from existing gas turbine installations. The concept is simple; a high-pressure pump system pressurizes water (*typically deionized water for gas turbine applications*). Normal operating pressures are from 1000 to 3000 psi. The high-pressure water flows through a network of stainless steel tubes to special nozzles. The nozzles atomize water into micro-fine fog droplets that evaporate quickly.

Evaporative Media Water Cooling: Evaporative pads have also been used to increase the production and efficiency of gas turbines. The evaporative process also adds moisture to the air, which reduces the inlet air temperature and reduces the NOx in the exhaust, thus reducing pollution. An additional benefit derived from the water distribution mechanism of the pads is that some dust in the air will be removed, thus reducing dust loading on the turbine inlet filters.

Economic Benefits Of Turbine Inlet Cooling
Gas turbine power plants are ideal for providing certain midrange and peaking electric power to the grid for onsite power generation, as they provide a clean source of energy. Gas turbines are responsive to load and are very cost effective, however, they have one drawback. Gas turbine power performance falls off rapidly with ambient air temperature. Economically reducing inlet air is highly beneficial.

Table 1. Installed Cost of Inlet Cooling Equipment[3]

System	Installed Cost
Single-Effect Steam	$800/RT
Double-Effect Steam	$970/RT
Double-Effect Direct-Fired	$1,030/RT
Electric Centrifugal	$800/RT
Evaporative Cooling	$4/kW

Using the installed cost estimates from Table 1, Figure 3 can be constructed showing the relative costs of various inlet-cooling schemes. Providing no inlet cooling clearly shows up as the most expensive, and the three types of absorption chillers show up as the least expensive options.

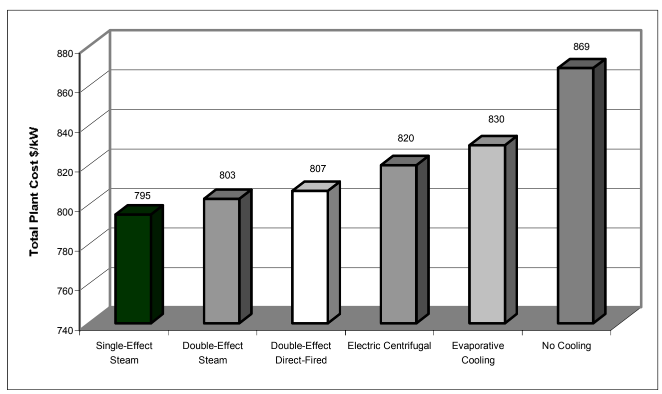


Figure 3. Plant Cost of Inlet Cooling Options[3]

SELECT THE RIGHT INLET COOLING SYSTEM

The right inlet cooling systems depend upon the specific power plant economic requirements. For example, an 83.5 MW gas turbine distributed generation plant located in Houston, Texas[3]; Figure 4 shows that a gas turbine using an absorption chiller air inlet cooling system can produce over 4,000 MWh per year more than

[3] Example form GRI Absorption Chiller Application Brief

the electric chiller air inlet cooling system. More detailed analysis must account for factors such plant capacity and configuration, cost of gas, price of electricity, water availability, and plant operating schedule.

Table 2. Houston Texas Inlet Cooling Example[3]

Industrial Turbine	**83.5 MW**
Ambient	95ºF
Inlet Air	50 ºF
Evaporative Cooler Power Increase	3.7 MW
Electric Centrifugal Power Increase	8.9 MW
Absorption Chiller Power Increase	11.4 to 11.6 MW

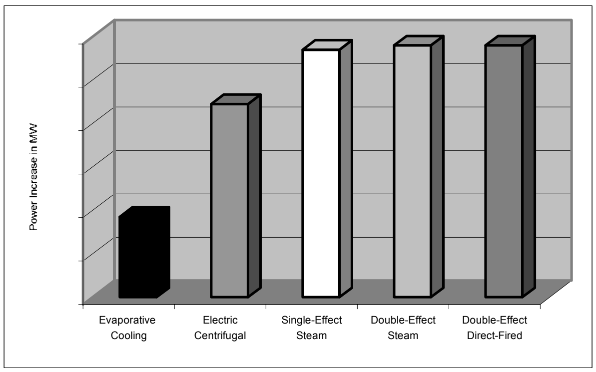


Figure 4 – Power Increase Capability of Turbine Inlet Cooling

Absorption Gas Turbine Inlet Cooling in Action

The federal government's focus on Distributed Energy Resources (BCHP and ICHP) will highlight the need for all gas turbines, expected to perform optimally at high ambient temperatures, to examine the economics of absorption chiller inlet cooling. This will include existing evaporative cooling installations that can benefit from reduced temperatures. This will in turn stimulate interest in performance of existing installations. GRI has recently published an Absorption Chiller Application Brief, which identifies the following installation:

- ⇒ 48 MW gas-turbine simple-cycle power plant with co-generation of steam, owned by Dynegy Corporation, in Lathorp, California. The plant uses a 1,400 refrigeration ton single-stage absorption chiller to generate 36 percent more electric power than its capacity without inlet air-cooling.
- ⇒ Two cogeneration power plants (48 MW each) at a chemical manufacturing facility of Huntsman Chemicals in Houston, TX using 1,400 ton steam-heated single-effect chiller.
- ⇒ One combined-cycle power plant (57 MW) at Trigen's Energy Park in Nassau, NY using a 1,200 ton hot-water-heated single-effect chiller.
- ⇒ 200 MW combined-cycle plant (five turbines of 40-MW each) of Fort Lupton Cogeneration Corp, in Fort Lupton, CO using two 1,100 ton gas-fired double-effect chillers.
- ⇒ 315 MW cogeneration power plant (three turbines of 105 MW each) of Calpine Corporation in Clear Lake, TX using five 1,600-ton hot water heated absorption chillers, one 1,200-ton electric centrifugal chiller, and a chilled water storage system.

DIRECT-FIRED CHILLER/HEATER PLANTS

Increasing interest in BCHP and ICHP systems has already caused a reexamination of direct-fired absorption chiller/heater plants for the same economic, GRID reliability and environmental reasons.

Design For Purpose

Conventional absorption design philosophy was to create a system that provides chilled water, and, because it was thermally activated, also use it to provide hot water or steam. This led to a design that was chiller centric and limited the heating capacity and temperature availability based on the chiller design.

Several international companies recognized this design philosophy would severely limit chiller/heater plant applications. Advanced chiller/heater designs are able to meet the required cooling tons and also meet the heating loads through and independently design philosophy for each system. This permits these advanced systems to eliminate the need for auxiliary boilers and provide a capital cost advantage of a single system filling all the building heating, domestic hot water and cooling needs.

Direct-fired double effect chiller performance has increased to 1.2 COP at full load and 1.35 COP under IPLV[4] operating parameters providing significant cost savings over electric chiller / boiler combinations operating in much of the

[4] In accordance with ARI Standard 560

Northeast, upper-Midwest and several Western states.

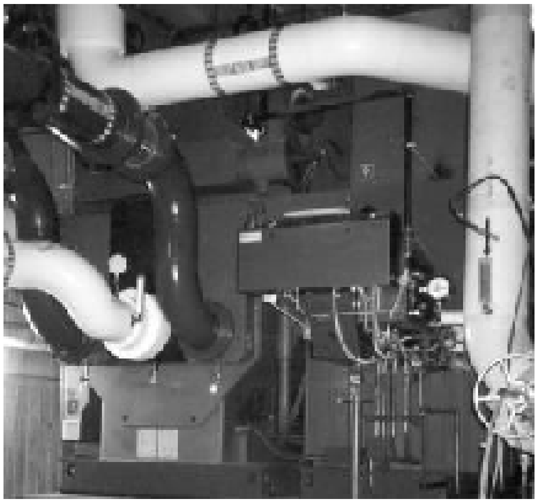


Figure 5.Direct-Fired Double-Effect Chiller/Heater Plant (523 Tons Chilled Water @44°F, 12 MMbtuh Hot Water @ 200 °F)

PLANNING NEW ONSITE INSTALLATIONS WITH EXISTING ABSORPTION CHILLERS

Thermally driven technologies like absorption systems depend on heat and temperature for operation. Therefore, when examining onsite power technologies for BCHP combination with absorption technologies, one must first look toward the quality of available recoverable thermal energy streams.

Figure 6 shows optimal matching of recoverable energy streams with absorption technologies. Care must be taken when examining this chart to realize there are design considerations in trying to achieve close approach temperatures between the recoverable energy temperature and the absorption activation temperatures.

Examining Table 4, one can conclude potential development projects matching the following:

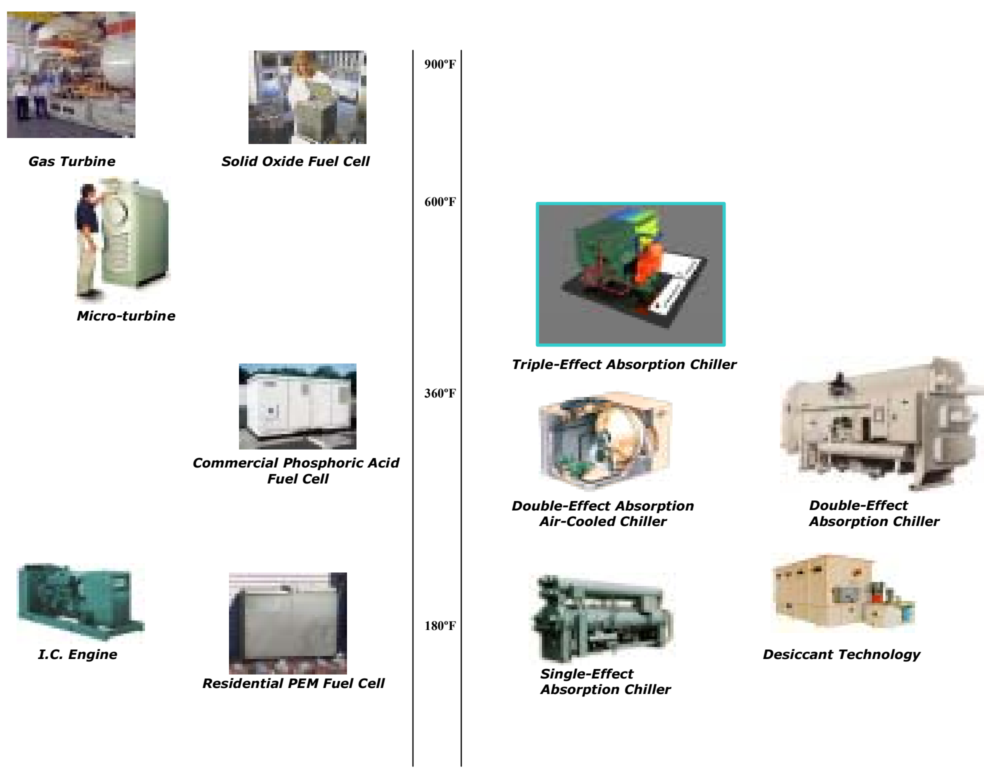


Figure 6. Recoverable Energy Quality (Temperature) and Absorption Technology Match

Power Source	Temp	Matching Technology
Gas Turbine	>1,000 F	Triple-Effect, Double-Effect or Single-Effect
Solid Oxide Fuel Cell	~ 900 F	Triple-Effect, Double-Effect or Single-Effect
Micro-turbine	~ 600 F	Triple-Effect, Double-Effect or Single-Effect
Phosphoric Acid Fuel Cell	~ 250 F	Double-Effect or Single-Effect
IC Engine	~180 F	Single-Effect
PEM Fuel Cell	~ 140 F	Single-Effect

Table 4. BCHP Matching Power Generation and Absorption

DEVELOPING NEW ABSORPTION TECHNOLOGIES AS A RESULT OF NEW BCHP REQUIREMENTS

Development of Next Generation Single-Effect Absorption Systems

The BCHP and ICHP in Europe for the past decade, as well as, the emerging initiatives in the USA have already spurred two major manufacturers of absorption chillers to rethink single-effect chiller product lines.

One company is revamping and upgrading their existing single-effect chiller line to incorporate all the latest design features. (Figure 7)

A second major manufacturer, that previously made only double-effect machines, has introduced an entirely new single-effect, indirect-fired product line specifically for BCHP and ICHP applications. (Figure 8)

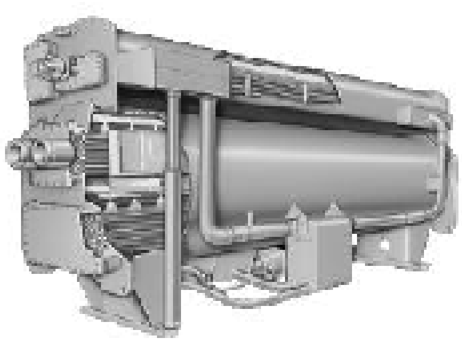


Figure 7. Redesigned Single-Effect Indirect-Fired Chiller

Figure 8. Introduction of New Single-Effect Indirect-Fired Chiller

Development of Co-Fired Micro-turbine/Absorption Systems

Single-effect absorption chillers can easily operate in conjunction with micro-turbines, using conventional heat recovery systems now being offered by the micro-turbine manufacturers. However, this combination of equipment and low chiller performance may have difficulty finding a home in the marketplace. Directly coupling the ~ 600°F micro-turbine exhaust to the air supply for a direct-fired double-effect chiller appears to have an economic advantage.

Micro-turbines, like their larger counterpart, will experience reductions in capacity with ambient temperatures rising above rated capacity (ISO conditions are 59°F and Sea Level). Maintaining air inlet conditions near ISO conditions will allow maintenance of power while extending maintenance intervals.

A very effective BCHP integration that is being developed is combining gas turbines (or micro-turbines) with direct-fired double-effect absorption chillers. Applying a co-fired DFDE absorption chiller/heater plant to a building has the following implications:

1. Reducing the building's electrical requirements by using a co-fired chiller versus and electric chiller. Electric load savings can be up to 1/3 of a conventional building's electric load requirement.

2. Increasing turbine capacity at high ambient temperatures (20% to 36% capacity increase at 95°F)

3. Providing the building with power, and all the cooling, heating and domestic hot water it requires.

Figure 9. 75 kW Micro-turbine

Co-firing may require modulation of the air delivered from the micro-turbine to the high stage generator, as the electric load may not follow the cooling load.

A second consideration for coupling an absorption chiller/heater plant with a micro-turbine is proper matching of micro-turbine exhaust airflow with required combustion air requirements of the high stage generator.

Figure 10. Direct-Fired Double-Effect Chiller/Heater being designed for Micro-turbine Co-Firing

A preliminary design coupling a skid mounted 75 kW micro-turbine, 50-ton DFDE chiller/heater plant and cooling tower is underway for demonstration at a government test site. Approximately 10 tons will be available for inlet air cooling and 40-tons will provide complete cooling for the building's zone serviced by the micro-turbine (see Figure 11).

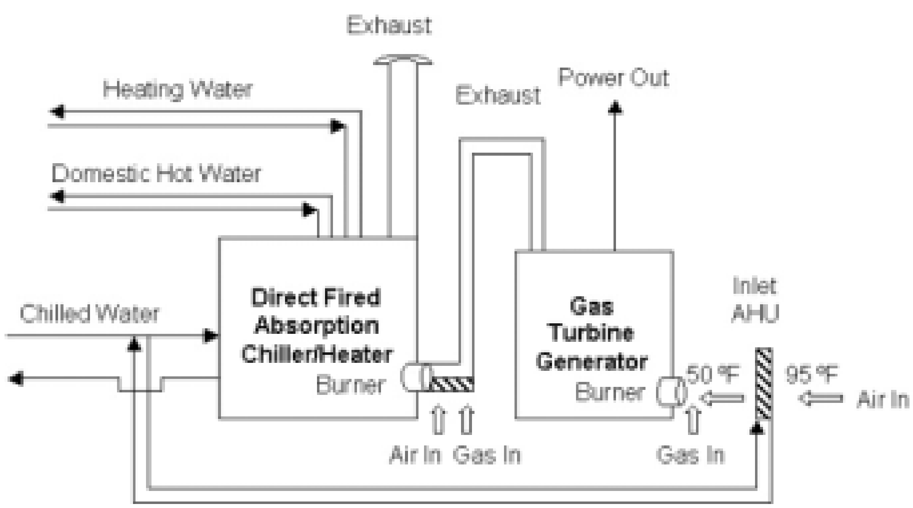


Figure 11. Micro-turbine / Co-Fired Absorption BCHP System Schematic

Development of Next Generation Air-Cooled Absorption Systems

The preceding development concept can be improved upon, with innovation. Cooling towers are well understood and have their place in larger commercial applications; however, cooling towers are not well suited for smaller size applications because of cooling tower maintenance requirements.

Air-cooled absorption chillers are not new. They are on the market today but are ammonia/water based and less than 10 tons in capacity. During the 1980s and 1990s, there have been a number of significant attempts to design and manufacture Li/BR water chillers with air-cooled condensers to eliminate the need for cooling towers.

The principal technical obstacle to manufacturing air-cooled LiBr/H_2O absorption chillers is the crystallization limit for LiBr/H_2O. The crystallization line for LiBr/H_2O is very close to the working concentrations needed for practical LiBr/H2O absorption chillers. A second critical consideration is that conventional LiBr/H_2O absorption chillers use a very effective heat and mass transfer additive (2-Ethyl Hexanol). It is generally accepted that large LiBr/H_2O absorption chillers would not have been commercially practical had it not been for the accidental discovery of the heat and mass transfer additive decades ago at Carrier. Numerous additive studies throughout the world since then have failed to find and demonstrate a practical heat and mass transfer additive that is significantly better than the conventionally used 2-Ethyl Hexanol.

For decades, researchers have tried to develop air-cooled LiBr/H_2O absorption chillers. Two principal technical approaches have been used in trying to develop air-cooled LiBr/H_2O absorption chillers. These two basic approaches are: (1) mechanical design changes (such as very highly efficient heat exchangers) to squeeze the air cooled operation within the existing LiBr/H_2O crystallization limits and (2) adding chemicals to shift the crystallization line to higher temperatures to allow air-cooled operation with commercially practical margins of safety from crystallization using conventional heat exchangers. Each of these two approaches will be briefly discussed. It is also possible to combine both approaches in the same machine.

Conventional mechanical approaches: Several Asian manufacturers have developed and offer for sale air-cooled LiBr/H_2O chillers using mechanical approaches with conventional LiBr/H_2O chemistry. These products, which use very high efficiency heat exchangers and (in some cases) multiple heat exchanger configurations, are suitable for use at moderate summertime temperatures. However, these systems are still limited by the LiBr/H_2O crystallization limits and are at best marginally adequate (or completely inadequate) for high temperature operation in the hotter climates in the United States. Additionally, the high efficiency heat exchangers and the extra heat exchange steps involved in some designs are significantly more expensive per ton of capacity than conventional water cooled LiBr/H_2O absorption chillers. For these reasons the conventional mechanical approaches to developing and manufacturing air-cooled LiBr/H_2O absorption chillers using standard LiBr/H_2O chemistry are not presently considered suitable for use in many U.S. BCHP applications (relatively high price and inadequate safety margins from crystallization in hotter climates - where such BCHP combinations are most needed). Hence, this illustrates the need for development of the next-generation of air-cooled absorption systems for BCHP applications.

Chemical approach: Many studies have been made in an attempt to modify the crystallization characteristics of the basic LiBr/H_2O system by the addition of other chemicals. Numerous attempts to find suitable organic and in-organic chemical combinations have been well documented in the literature. A number of chemicals have been demonstrated in the laboratory to adequately shift crystallization for air-cooled operation. Unfortunately all of the suitable chemicals have negative characteristics that effectively limit their practical application. All the chemicals found to date (in the open literature) have higher viscosity along with the associated reduction in absorber heat and mass transfer performance (usually described as an undesirable increase in absorber sub-cooling from about 1ºC to about 15ºC, even for the best performing chemical combinations). This reduced absorber performance essentially negates the improved crystallization characteristics of the chemical mixtures, while also requiring much larger (more expensive) absorbers. Just as an effective heat and mass transfer additive is considered critical to the commercial feasibility of conventional $LiBr/H_2O$ absorption chillers, an equally effective heat and mass transfer additive could theoretically solve the poor absorber performance for the chemical mixtures, while maintaining the improvement in crystallization characteristics. Such additive absorption mixture combinations would theoretically make relatively inexpensive air cooled absorption chillers possible. Unfortunately the conventional heat and mass transfer additive (2-ethyl hexanol) is not effective with any of the chemical mixtures that have otherwise displayed crystallization improvement for $LiBr/H_2O$.

However there has been a breakthrough in the identification and application of a practical heat and mass transfer additive for single effect air-cooled operation. In the late 1970's and early 1980's, Carrier Corp. identified a chemical additive that allows the effective use of a $LiBr/H_2O$ and ethylene glycol mixture (named Carrol). The new chemical heat and mass transfer additive has essentially the same effect with Carrol (for air-cooling) as 2-ethyl hexanol has with conventional $LiBr/H_2O$. The heat and mass transfer in the absorber is improved so that the subcooling is effectively reduced from about 15 ºC to about 1ºC, essentially achieving the same absorber performance as with conventional $LiBr/H_2O$ absorption chillers. This innovation with the new additive allows essentially all of the gain in crystallization obtained with the ethylene glycol to be used to achieve air-cooled operation with robustly adequate margins of safety from crystallization, even at high outdoor temperatures. This is accomplished with relatively conventional inexpensive heat exchangers; thereby avoiding the high costs associated with the Asian air-cooled $LiBr/H_2O$ absorption chillers. Based on this innovative chemistry in the early 1980's Carrier build and demonstrated air-cooled absorption chillers for solar applications (with the support of Department of Energy Solar Program funding). These prototypes were designed for low-temperature solar hot water input, hence would be easily adaptable to BCHP application. Figure 12 shows the 35 kW air-cooled solar absorption chiller prototype package. Fundamentally, a single effect air-cooled absorption chiller using Carrol should cost less to manufacture and require far less maintenance by eliminating the cooling tower for smaller BCHP applications (10 RT to 150 RT sizes where cooling towers are not commonly used).

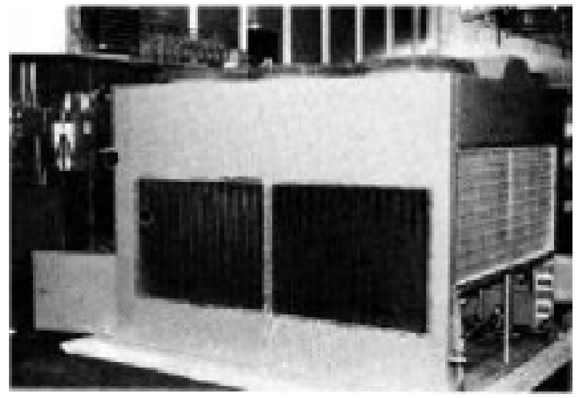


Figure 12. Prototype 35 kW (10 ton) air-cooled solar absorption chiller.

Because of the relatively high-cost to of the complete air cooled solar chiller package (due to the expensive solar collectors available in the late 1970's – early 1980's) the single-effect air-cooled technology was not further commercialized at that time. Also at that time, interest in absorption chillers was focused on developing practical direct-fired double effect cycles for higher efficiency. Fortunately, for BCHP applications, an air-cooled single effect $LiBr/H_2O$ absorption chiller should be an ideal match for smaller size BCHP applications where cooling towers or evaporative condensers are undesirable.

Perhaps the time has come to "dust off" the old solar air-cooled $LiBr/H_2O$ chemical technology by developing and demonstrating modern lower-cost single-effect air-cooled $LiBr/H_2O$ absorption chillers specifically engineered for BCHP applications.

Unfortunately the Carrol mixture used in the solar machines does not have adequate thermal stability for operation at double effect temperatures. Also, some manufacturers are very resistant to the potential use of organic chemicals in $LiBr/H_2O$ machines even though the specific chemistry appeared to be robustly adequate when demonstrated by Carrier in the solar absorption chillers. Fortunately, recent proprietary research has identified inorganic chemical combinations that laboratory level experiments indicate should be adequate for single effect and double effect air-cooled absorption chillers. This provides additional justification for conducting R&D necessary for developing and demonstrating the technology for low-cost single effect and double effect air-cooled absorption chillers based on $LiBr/H_2O$.

TRIPLE-EFFECT ABSORPTION CHILLERS FOR LARGE COMMERCIAL APPLICATIONS

The goal of DOE's Large Commercial Absorption Chiller Program is to build U.S. developed triple-effect chillers that improve cooling efficiency by 30 to 50 percent, compared to equivalent double-effect absorption chillers currently on the market.

Figure 13 shows relative energy usage for single, double, and triple-effect large commercial absorption chillers.

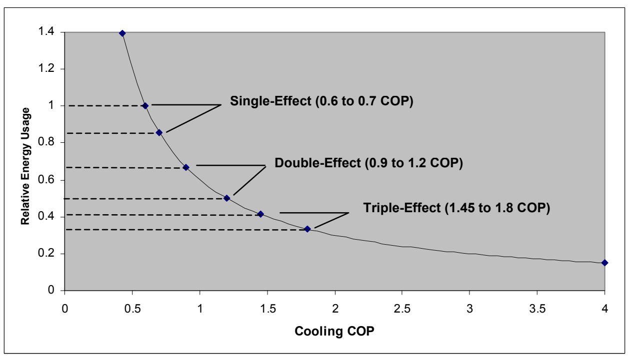


Figure 13: Relative Energy Usage for Large Commercial Chillers

Currently, there are no triple-effect absorption chillers sold commercially. Previous work has shown that there are theoretically a large number of cycles that fall into the category of "triple-efficiency".

A "dual-loop" triple-effect cycle was patented by ORNL under the DOE Thermally Activated Heat Pump Program in 1988. The Trane Company licensed this triple-effect technology in 1989. With support from the Gas Research Institute, Trane built an operational triple-effect prototype, of greater than 100-ton capacity in the early 1990's. Trane's triple-effect product goal is a 50 percent improvement in COP with no more than a 25 percent cost premium over the current equivalent double-effect chillers on the market.

Recently (April, 2000) Trane announced that they have had a 375 – ton production prototype triple-effect in operation for several years. Their triple-effect is based on currently manufactured "off-the-shelf" double-effect components. Trane has achieved a thermodynamic COP exceeding 1.6 (compared to 1.0 to 1.2 for equivalent technology double-effects), demonstrating more than a 30% increased COP. The Trane triple-effect has a 450ºF generator solution temperature, making such a triple-effect potentially a good match to a variety of power-generating turbine and fuel cell technologies for BCHP applications.

In the early 1990's, while the Trane/GRI dual-loop, triple-effect program was underway; DOE and ORNL conducted additional scoping studies to identify promising alternative triple-effect technologies. A parallel program for development of an alternative technology would improve the U.S. potential for getting a triple-effect chiller to market. Alternate technologies were extensively reviewed, including 3, 4, 5, 6 and 7 effect cycles.

One particular triple-effect cycle, using a double-condenser coupling (DCC) concept, emerged as the best alternative and was patented by ORNL in 1993. This triple-effect cycle was predicted to be more than 30% higher efficiency than equivalent double-effect machines. York, In a cost-shared program with DOE, has fabricated and extensively tested a 450 ton indirect-fired triple-effect chiller based on the DCC cycle (Figure 14).

Figure 14: York Prototype Indirect-fired Triple-Effect Chiller

Because it is an indirect-fired chiller, it is already suitable for using recovered heat from a turbine or fuel-cell power generating machine in BCHP applications.

The design of York's triple-effect chiller is based on an existing double effect absorption chiller.

The indirect-fired triple-effect chiller was operated for a total of about 2000 hours with no unusual accumulation of non-condensibles in continuous operation at different loads. The COP was close to original predictions.

Based on the results of the indirect-fired triple-effect chiller testing, York and DOE are co-sponsoring a full-scale field demonstration of a 450 – ton direct-fired triple-effect absorption chiller. Figure 15 shows a model of the direct-fired triple-effect chiller that is now under construction.

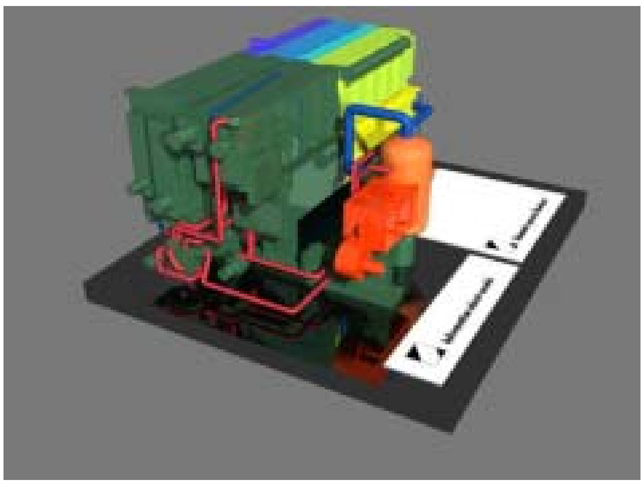


Figure 15: Model of York's Field Demonstration Triple-Effect Chiller

The triple-effect chiller is scheduled for installation at the Clark County (Las Vegas), Nevada Government center later this year for the field demonstration.

RESIDENTIAL SYSTEM GAX HEAT PUMP INTEGRATION

The BCHP approach frees the designer to optimize the system versus having to optimize one particular component. The next generation of residential and light commercial ammonia/water absorption chillers and heat pumps are called Generator Absorber heat eXchange (GAX) systems. GAX chillers have just entered the market (1999), and are AGA rated as 30% more efficient than the previous generation single-effect ammonia/water absorption chillers. Currently, 3 RT and 5 RT GAX chiller versions are available, with 10, 15, 20, and 25 RT integrated units also available.

Heating and cooling heat pump versions of the GAX chiller are under development and a family of GAX heat pump products is expected to enter the marketplace in the next few years. In heating, the initial GAX heat pump prototypes have already demonstrated efficiencies that are 33% higher than the best available gas furnaces. GAX systems have the potential to be 50% more efficient than the best gas furnaces.

GAX chillers and heat pumps are expected to be a potentially excellent match to Fuel Cells or micro-turbines for residential and light commercial applications. GAX heat pumps operate at about 380° F to 425° F (varying with ambient conditions); and can be fired using higher temperature waste heat from a micro-turbine.

Additionally, as shown in Figure 16, it is also possible to fire the GAX system using lower temperature waste heat from a fuel cell combined with supplemental gas input. The GAX heat pump can then simultaneously provide both cooling and hot water (or even steam) output to the building.   Because of specific unique features of the GAX cycle, the BCHP system can be used to simultaneously provide electricity, air-conditioning, regenerate a desiccant for direct dehumidification of the conditioned space, and provide hot water to the building. Such BCHP combinations are capable of producing exceptionally high overall efficiencies in building applications. Assuming good simultaneous electric and thermal matching of the BCHP-GAX system to the building, overall efficiencies for the BCHP-GAX heat pump system can exceed 100% of the primary fuel input, making such systems potentially the highest efficiency systems for residential and light commercial applications.

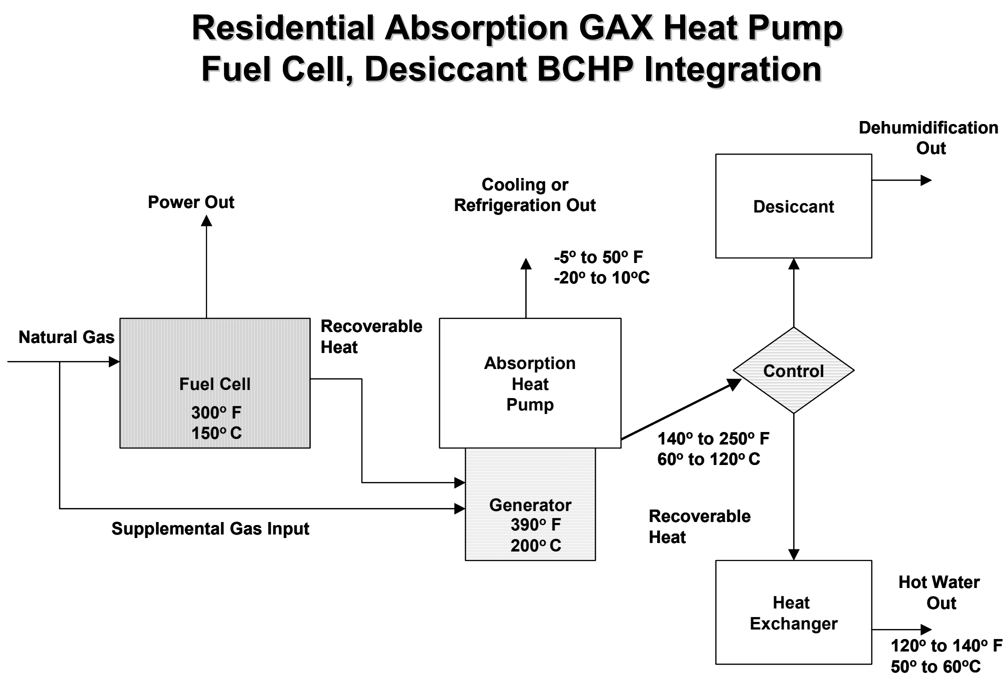


Figure 16. The Ultimate Residential BCHP System:
Fuel Cell Co-Fired Absorption Heat Pump with Desiccant Humidity Control and Domestic Hot Water

CONCLUSION

Since the mid 1970's, absorption technology has largely been sold to niche markets within the United States. By contrast, in Asia, absorption chillers overwhelmingly dominate the large commercial chiller market.

BCHP offers significant opportunities for maximizing fuel efficiency with the help of existing or easily modified absorption equipment for larger commercial applications.

Advanced absorption technology can offer additional advantages for BCHP applications beyond those achievable with the currently manufactured single-effect and double-effect absorption chiller products. Recently developed triple-effect chillers will add significant additional cooling capacity using recovered heat for large commercial building applications.

Development opportunities for other advanced absorption technologies exist for expanding potential BCHP applications. In particular, the development of smaller air-cooled absorption chillers (10 RT to 150 RT sizes) and GAX absorption heat pumps specifically adapted to BCHP applications promise residential and small commercial BCHP systems at the highest possible energy efficiency levels.

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