DEVELOPMENT OF THE WORLD'S FIRST SMALL-SCALE TWO-STAGE ABSORPTION CHILLER/HEATER/HOT-WATER SYSTEM

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ABSTRACT

Ever since the Carrés first introduced absorption refrigeration technology to the world in the 1850s, efforts have been made to successfully develop residential and light commercial absorption heating and cooling systems. There have been some successes, like the ammonia/water systems developed and sold in the U.S. during the 1970s, but they were largely eclipsed by eve- improving vapor compression systems. There have also been failures in trying to overcome today's market price and performance and reliability requirements that have relegated absorption systems to micro-niche markets. Development of the world's first small-scale two-stage absorption chiller/heater/hot-water system seeks to provide constrained energy markets with viable solution to growing electricity demand problems. This paper describes the development of this new technology.

Keywords: ***residential, light-commercial, two-stage, absorption, chiller, heater, hot-water***

1 HISTORY OF ABSORPTION TECHNOLOGY

Edmond Carré (Figure 1) 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.

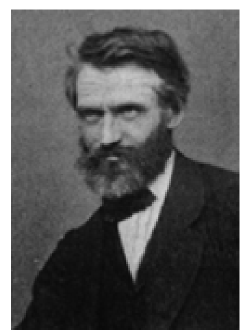


Fig. 1. Edmond Carré

Fig. 2. Natural Gas Utility Ad for Ammonia Absorption Refrigerator

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 thousands of homes until production was stopped in the 1950s.

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 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, 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 are being evaluated differently between historical America and modern Asia when it comes to commercial water chiller technology.

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

But, developing an efficient small absorption cooling and heating device under 105 kW (30 RT) for the light commercial and residential markets has remained elusive. Japan's Ministry of International Trade and Industry (MITI) has been working with industry for 20 years to develop a highly efficient absorption based small heating and cooling system with no market based success. Concurrently, the U.S. Department of Energy, seeking to reduce peak electric demand for air conditioning, sought to develop absorption based heat pump technologies again with no measurable market success.

2 SORPTION TECHNOLOGY OPTIONS: WHICH IS THE RIGHT ONE?

Sorption technology offers several fluids and cycle options including:

- Single-stage
- Two-stage
- Adsorption
- Absorption
- Ammonia/water
- Ammonia/salts
- Ammonia/carbon beds
- Lithium bromide/water
- Air cooled condenser
- Water cooled condenser

There may be several paths to a successful residential/light commercial absorption-based product among these choices. The following describes the path taken by the first company to introduce a residential and light commercial absorption product with a cooling efficiency greater that 1.0 COP HHV.

Fig. 3. Five BCT Units ranging from 16 kW (foreground) to 115 kW center)

2.1 GENERAL PRODUCT DESCRIPTION

The developed product portfolio consists of outdoor chiller/heaters, indoor fan coils and hot water tanks, system integration, field installation process, intelligent controls and network communication.

2.1.1 Development Process

This BCT is the result of building 80 research prototypes to solve a myriad of problems over the course of several years, hundreds of field test units, 40 patented inventions and the complete development of chiller/heater design, fail safe cooling tower integration, air-side product development and building automation system design.

Beside the complete product design, an automated manufacturing process and facility was created resulting in current production levels of 100 BCT systems per day.

2.1.2 Cooling Cycle

When a liquid absorbs heat from its surroundings, it evaporates. For example, when you spread alcohol on your hand, you will feel very cool, as the alcohol absorbs heat from your hand and evaporates into the air. Air conditioning equipment is designed according to this principle. Water boils at 100°C under normal atmosphere pressure (760 mmHg), but it can also boil at very low temperature under vacuum conditions. By creating a vacuum (6 mmHg pressure) in the airtight vessel of BCT outdoor unit, water can boil even at 4°C.

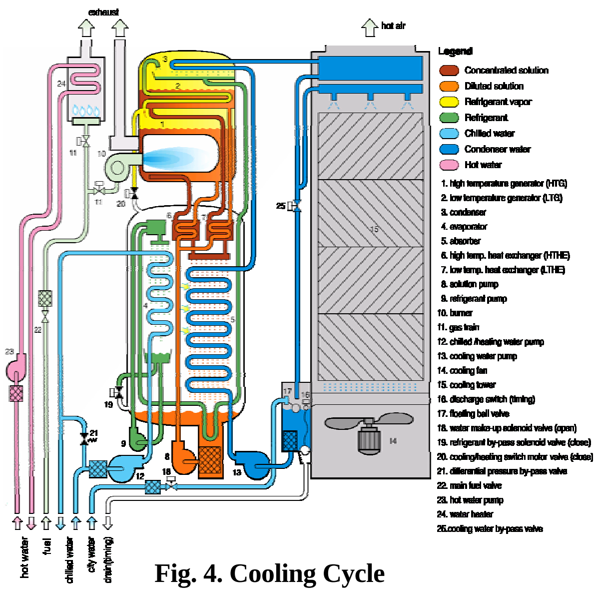


Fig. 4. Cooling Cycle

The BCT outdoor unit utilizes lithium bromide as the absorbent, water as refrigerant and natural gas or other approved fuel as the heating source. As lithium bromide solution is a very strong water absorbent, it can absorb surrounding vapor and maintain low-pressure condition in the evaporator.

Chilled water at 14°C enters the inside of the copper evaporator tubes and the refrigerant water at 4°C is sprayed on the outside of the tubes (under vacuum). The refrigerant water absorbs heat from the chilled water and evaporates (becomes vapor), thereby the chilled water temperature is reduced to 7°C. Concentrated lithium bromide solution in the absorber absorbs the refrigerant vapor and then transfers the heat from the vapor to the cooling water. The cooling water heat is released to the ambient air via the cooling tower. The diluted lithium bromide solution is pumped to the high temperature generator where it is reheated and refrigerant vapor evaporates from the solution making the solution concentrated. The concentrated solution repeats the absorbing process and the refrigerant vapor goes to the condenser where it is condensed and returns to the evaporator to begin the cycle again.

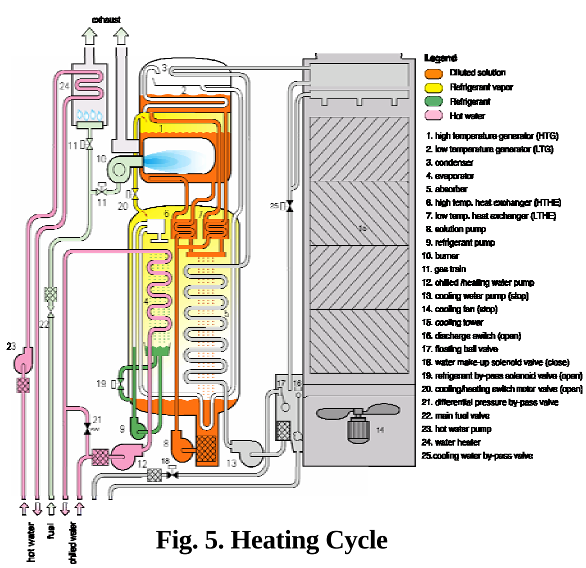


Fig. 5. Heating Cycle

2.1.3 Heating Cycle

Combustion heats the lithium bromide solution in the high temperature generator. The hot vapor produced by the solution migrates to the low pressure vessel heating the water in the heat exchanger tubes to provide space heating. This heat transfer condenses and returns the vapor to the lithium bromide solution and is pumped into the high temperature generator to repeat the cycle.

On the contrary, refrigerant used by absorption technology is natural material refined from seawater, which doesn't pollute air, water, or soil. So it is environment friendly. Without volatilization and reaction with other substances to form new compounds, it could be renewable. It is LiBr solution.

Its molecular formula is LiBr+H_2O. Minimum innocuous and harmless corrosion inhibitors and activators are added in the solution.

2.1.4 Outdoor Unit

The outdoor unit consists of two modular components that can be mates in a single outdoor system of split to allow internal mounting of the absorption section and external mounting of the cooling tower. Figure 6 shows the BCT outdoor systems (chiller/heater/Hot Water system on left and cooling tower on the right).

Fig. 6. BCT Outdoor Unit

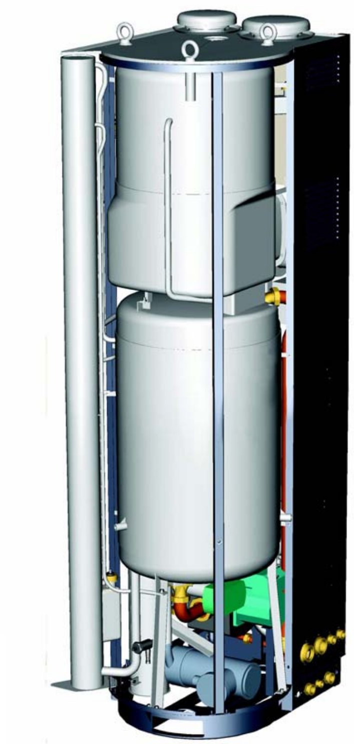


Fig. 7. Two-Stage Absorption Module

The two-stage absorption module consists of a high pressure generator/condenser vessel and a low pressure evaporator/absorber and heat exchanger vessel. Figure 7 depicts the complete absorption module and Figure 8 shows a cutaway of the low pressure vessel.

It should become obvious that the systems are compact and complex at the same time. The key to the successful development of this product resides in the ability to manufacture the product to retain critical system vacuum integrity to permit trouble free operation for the projected 20 year life of the product.

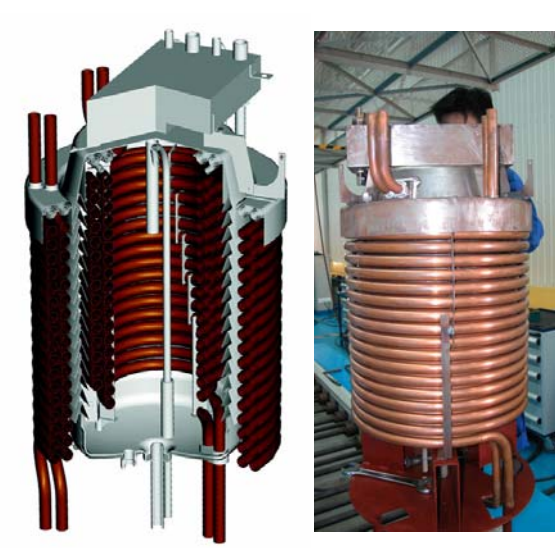


Figure 8. Low Pressure Absorber, Evaporator, and Heat Exchange Vessel

Fig. 9. One of three production lines

2.2 MANUFACTURING

Precision manufacturing is essential to cost effectively build a reliable small absorption product. Figure 9 highlights a portion of the "just-in-time" highly automated production factory that has a 70,000 unit annual capability.

2.3 PERFORMANCE

Table 1 presents system design performance; off-design performance is presented in Fig. 10.

Table 1. BCT Small Absorption Chiller Products

Model	Cooling capacity	Heating capacity	Hot W. capacity
BCT16	16 kW	16 kW	7.7 kW
BCT23	23 kW	23 kW	7.7 kW
BCT70	70 kW	70 kW	39 kW
BCT115	115 kW	115 kW	39 kW

2.4 SYSTEM DESIGNS

There are three basic piping system designs depending on the building structure and air conditioning load. 1) A direct system is for small systems (such as a house) because the resistance of each loop is almost the same and easy to be modulated. 2) A centralized system keeps temperature and water resistance of each indoor unit the same and reduces intermediate connectors and elbows. This system installs the main piping to a place near several indoor units, connecting each indoor unit with a header. 3) A reverse system is for large systems and recommended to keep temperature and water resistance of each indoor unit the same, which is convenient for water flow adjustment; "vertical reverse system" is recommended for multiple floors; "branch reverse system" is recommended for large area of single floor.

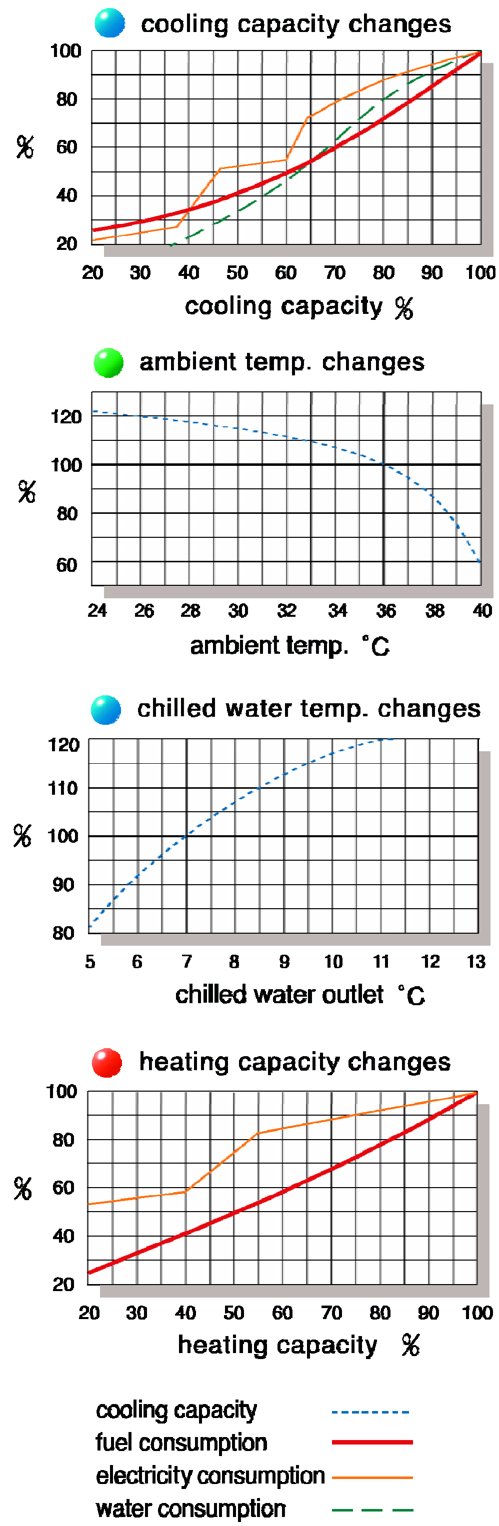


Fig. 10. Off-Design Performance

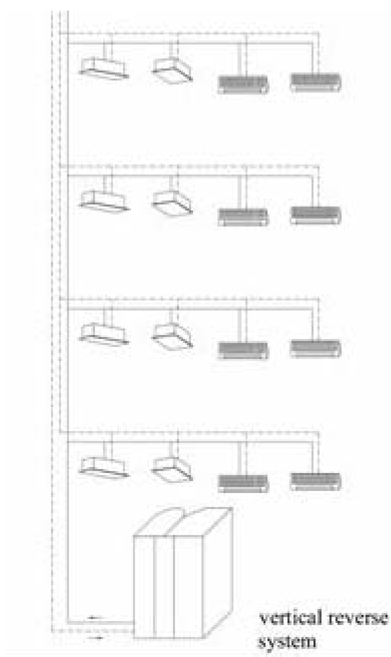
2.5 SYSTEM INTEGRATION

The key to system and operational integrity for the BCT system is a complete integrates approach making the BCT system fully integrated to provide automated control of all elements of heating, cooling, air filtration and domestic hot water systems.

The systems is provides with building level automates system controls, wired individual component controllers and wireless handheld controls. Figure 12 provides a schematic view of a fully integrated home automated comfort system.

2.6 LESSONS LEARNED

One can imaging the many issues that have been encountered and solved in creating a whole new class of technology. The issues that remain are focused on reducing field installation, costs of the terminal air side system including reducing piping and BAS labor.



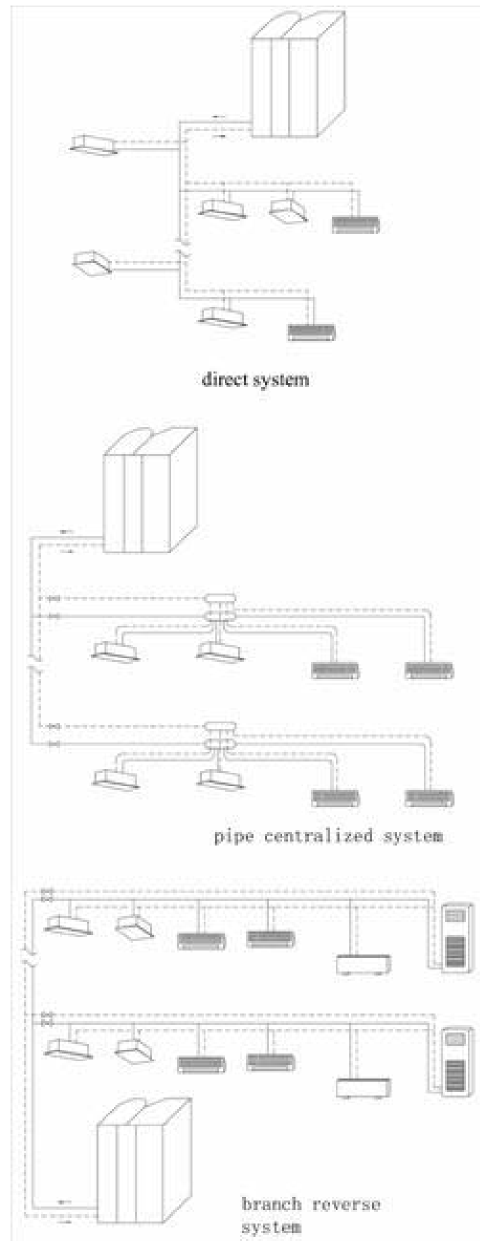


Fig. 11. Air-side piping systems

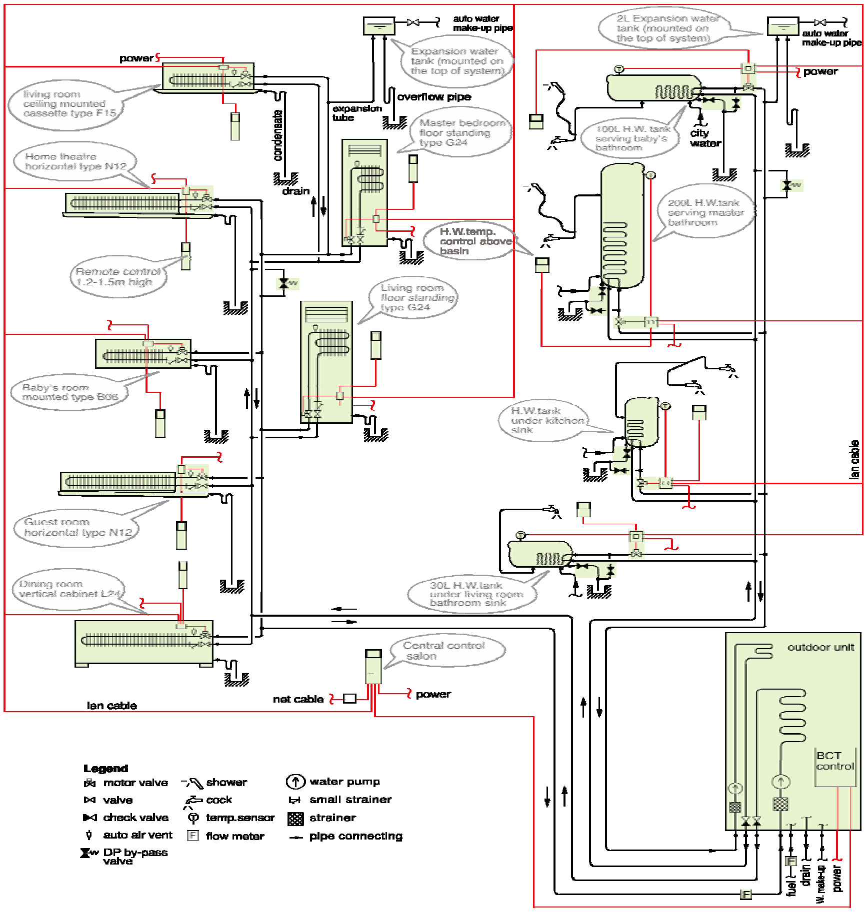


Fig. 12. BCT Whole House Comfort System