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Energy Savings by CHCP plants in the Hotel Sector

Absorption chillers

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1. Using recovered heat for absorption cooling

When heat is recovered from a process, e.g. an industrial process or a power production process, it is generally obtained at temperature which is too low for immediate application in that process. This heat may instead be cascaded to a second process with lower requirements on heat quality, i.e temperature, or upgraded by transformation, e.g. using a heat pump.

Absorption cycle chillers and heat pumps have in common the property of being driven by low-temperature heat and may therefore play an important part in a cascading energy system. However, a drawback of all absorption equipment is that the coefficient of performance, utility produced divided by energy input, is low relatively to the coefficient of performance of mechanical chillers, which use high quality energy such as electricity or shaft work. This disadvantage is a consequence of the comparatively small temperature difference between heat source and heat sink.

In the application presently considered, it is planned to use absorption cooling machines to produce chilled water for air conditioning purposes, as part of a trigeneration system for hotels. The primary fuel is natural gas or city gas. An internal combustion engine delivers shaft work to an electric generator, thus generating electricity to cover the needs of the hotel. Waste heat is rejected by the IC engine as hot water from the engine jacket and as hot exhaust gases. This heat is proposed to be used to produce hot sanitary water for the buildings as well as to produce chilled water in an absorption cooling machine.

2. Absorption technology

Absorption cooling, refrigeration and heat pumping technology is today a well-proven technology. The absorption machines that are commercially available are powered by steam, by hot water or by combustion gases. Although a variety of applications may be proposed, the main market in most countries is the production of chilled water in cooling of buildings. As economical conditions vary from country to country, absorption systems may be at the same time a small niche market in one country and the dominant technology in another country.

The basic principle of an absorption cooling machine may be illustrated with Figure 1. In its simplest design the absorption machine consists of an evaporator, a condenser, an absorber, a generator and a solution pump.

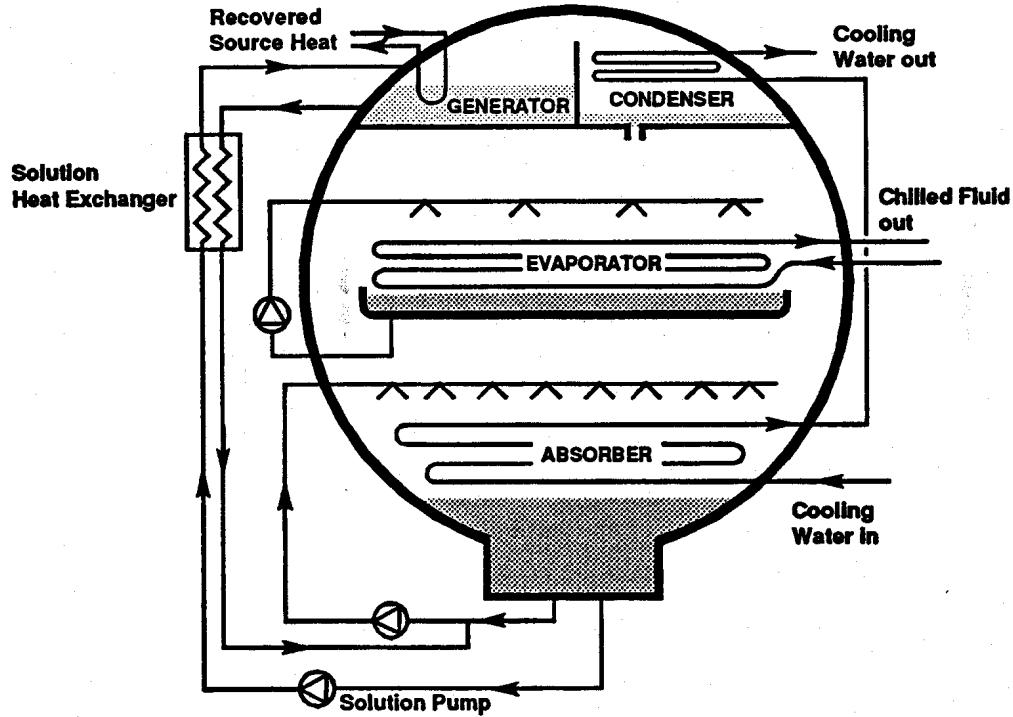


Figure 1. A sketch of the principle of an absorption cooling machine.

In a compression cycle chiller, cold is produced in the evaporator where the refrigerant or working medium is vapourized and heat is rejected in the condenser where the refrigerant is condensed. The energy lifting heat from a low temperature to a higher temperature is supplied as mechanical energy to the compressor.

In an absorption cycle chiller, compressing the refrigerant vapour is effected by the absorber, the solution pump and the generator in combination, instead of a mechanical vapour compressor. Vapour generated in the evaporator is absorbed into a liquid absorbent in the absorber. The absorbent that has taken up refrigerant, spent or weak absorbent, is pumped to the generator where the refrigerant is released as a vapour, which vapour is to be condensed in the condenser. The regenerated or strong absorbent is then led back to the absorber to pick up refrigerant vapour anew. Heat is supplied to the generator at a comparatively high temperature and rejected from the absorber at a comparatively low level, analogously to a heat engine. The words "thermochemical compressor" have actually been used in specialised literature to describe the function of the generator and absorber half of the absorption cycle.

Refrigerant and absorbent in an absorption cycle form what is called a working pair. Many pairs have been proposed through the years but only two of them have been widely used: ammonia together with water as absorbent and water together with a solution of lithium bromide in water as absorbent. The ammonia-water pair is mostly found in refrigeration applications, with low evaporation temperatures, below 0°C. The water-lithium bromide pair is widely used for air cooling applications, where it is not necessary to cool below 0°C. The pressure levels in the ammonia-water machine are usually above atmospheric pressure while the water-lithium bromide machines generally operate in partial vacuum.

The heat flows in the basic cycle are the following:

- Heat is supplied, and cooling is produced, at a low temperature level.
- Heat is rejected in the condenser at an intermediate temperature level.
- Heat is rejected from the absorber, also at an intermediate level.
- Heat is supplied to the generator at a high temperature level.

The temperature of the coolant leaving the absorber may be the same as that of the coolant leaving the condenser. If so is the case one could describe the system as a three-temperature system, as is usually done in literature, e.g. (Niebergall, 1961). However, in some applications it may be advantageous to stage the coolant flow through absorber and condenser, in which case one deals in effect with a four-temperature system.

The temperature levels in the machine may not be chosen independently of each other. When an evaporator temperature and a heat rejection temperature has been chosen, the lowest temperature at which heat may be supplied to the generator has also been determined. For example, an evaporation temperature of 2°C and heat rejection to a coolant which is at 37°C dictates that the heat transfer medium supplied to the generator is at the lowest ca 90°C. In practice, considerations on heat transfer rates and heat exchanger areas which may be economically motivated may increase this lowest level to 100°C, or 110°C etc. Generally, attaining these temperature levels in the heat source is not a problem in practical systems as the primary energy may be a fuel and combustion temperatures are much higher than 100°C, or a steam supply system. The quality of the heat, its high temperature, may in some regards be "wasted" but it is compensated for with a more compact or efficient design of equipment.

The basic cycle illustrated in Fig 1 may be modified in several ways. One is to utilize all possible opportunities for heat recovery within the cycle in order to improve the heat economy within the cycle. For example, it is customary to heat exchange the streams of weak absorbent leaving the absorber with the regenerated or strong absorbent that is led back into the absorber. When all heat recovery opportunities that can reasonably be used have been incorporated into the design of a machine, one obtains a cooling coefficient of performance of approximately 0.7 for the water-lithium bromide system and approximately 0.6 for the ammonia-water system.

Further improvements may be obtained if one cascades more efficiently the high temperature heat available to power the generator. The so-called double-effect systems incorporate two generator-absorber blocks that are staged, see Figure 2, in order to utilize the heat supplied more or less twice. Heat is supplied at ca 170°C to the first generator and heat rejected by the corresponding condenser is used to power the second generator at a lower level, the ca 100°C of a single-effect machine according to Figure 1. The coefficient performance of such a system with water-lithium bromide as working pair may be ca 1.2, which is significantly better than the 0.7 of the single-effect system. It is not double of the single-effect because of imperfect heat exchange between streams of solution, to some extent, and because the heat of vapourization of the refrigerant is necessarily larger when it evaporates from a solution than when it evaporates from a pure liquid.

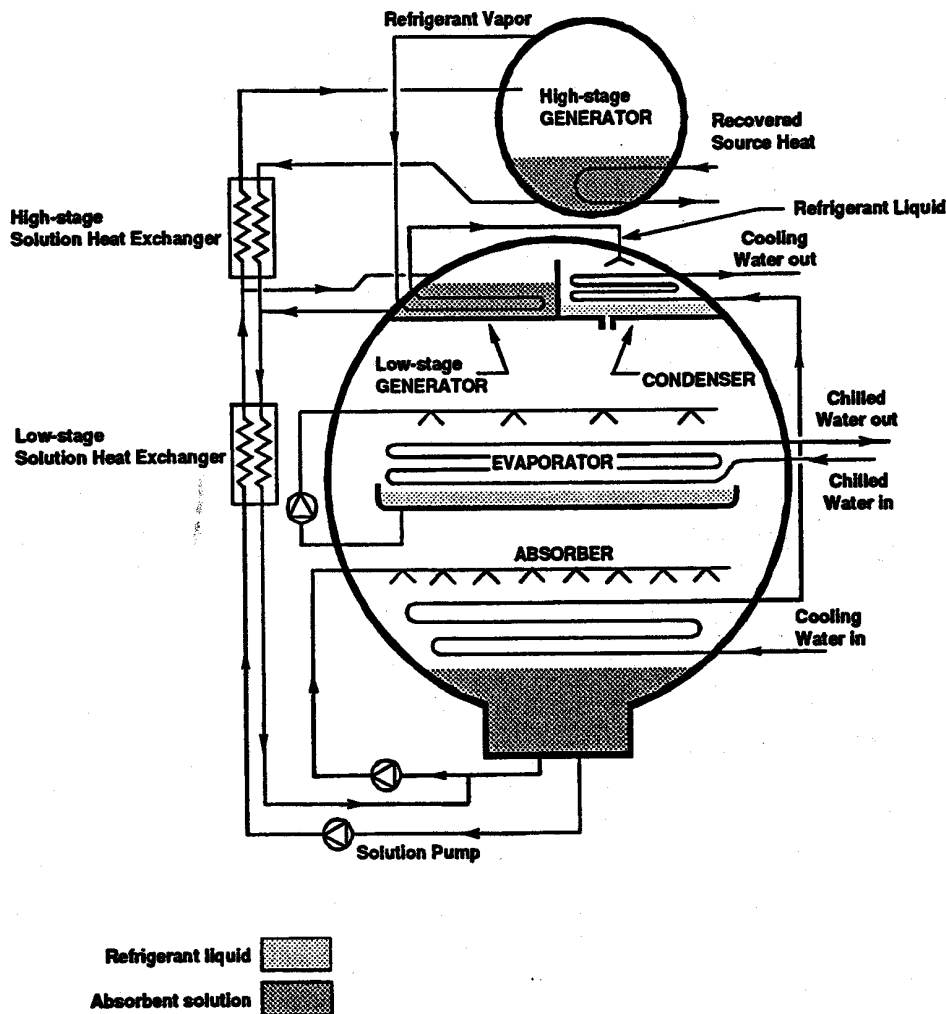


Figure 2. A sketch of a double-effect absorption machine.

A consequence of the higher temperature in part of the machine is that the pressure in this part increases too. This is acceptable in water-lithium bromide machines. It is not in ammonia-water machines as pressures above 20 bar (2

MPa) may pose safety problems. This is the reason why double-effect machine with the ammonia-water working pair utilizing the staging of generators in Figure 2 are seldom seen. Ammonia absorption machines with a somewhat different staging are being developed, with the purpose of obtaining the increase in coefficient of performance that corresponds to the higher generation temperature. However, they are not yet commercially available.

3. The trigeneration system considered

Trigeneration implies the simultaneous production of power (electricity), heat and cooling. If CHP, combined heat and power production is a well-known acronym for cogeneration, CHCP may be a less familiar acronym for trigeneration, combined heat, cooling and power production. A modern American acronym is BCHP, Building Cooling, Heating and Power, for trigeneration applications in buildings. In German, the corresponding acronyms are KWK, Kraft-Wärme Kopplung or BHKW, Brennstoff Heizkraftwerk, and KWKK, Kraft Wärme Kälte Kopplung respectively.

A trigeneration system may actually consist of a variety of technologies: fuel cells, IC engines, gas turbines, centrifugal chillers etc. These may furthermore be combined in different ways in order to provide an optimal utilization of the primary energy, generally fuel, to produce the desired mix of electricity, heat and cooling.

For the present application, trigeneration in hotels, the following system is considered:

- Natural gas fuels an IC engine which provides shaft work to an electric generator, converting thus natural gas to electricity.
- The heat in the exhaust gases is recovered in e.g. a heat recovery steam generator (HRSG), and supplied to an absorption cooling machine as steam or as hot water.
- Heat rejected to the coolant in the jacket of the engine is to be used as sanitary hot water. When it is not needed, the heat in the water jacket is rejected to ambient by means of a cooling tower.
- The absorption cooling machine is fed with steam, or with hot water, and produces chilled water while rejecting heat to a cooling circuit.
- The heat rejected by the absorption machine is disposed of to the ambient by means of a cooling tower.

The following constraints are valid for the system:

- Exhaust gases leave the IC engine at a temperature of 250 to 550°C.
- The exhaust gases may not be cooled in the heat recovery heat exchanger below 175°C. The heat of condensation of water vapour in the exhaust gas is not recovered.
- Chilled water leaves the absorption machine at 6 to 7°C and is returned to the machine at ca 12°C.
- Heat from the absorption machine is rejected to a 32/37°C cooling tower, i.e. the coolant leaves the absorption machine at 37°C, is cooled to 32°C in the cooling tower and returned to the absorption machine.

Thus, the components in the trigeneration system that are specific to the absorption cycle are: a heat recovery heat exchanger, an absorption cooling machine and a cooling tower. The cooling demand determines the capacity of the cooling machine, which in its turn determines the size of heat exchanger and cooling tower.

It may be expected that electricity, heat and cooling demands placed on the trigeneration system will vary widely depending on location, on size etc. In order to determine which range of cooling capacities is relevant, experience within the organisations taking part in the present project and available statistics have been surveyed. It was decided to use for this study a set of five cooling capacities, 200 kW_{th}, 400 kW_{th}, 600 kW_{th}, 1000 kW_{th} and 1400 kW_{th} that spans the range from small hotels to large hotels.

In the CHCP system considered above it is assumed that only exhaust heat is utilised to power the absorption cooling machine. This is true in the case of a gas turbine, the exhaust of which is used to produce steam in a HRSG. However, as written in the document "Energy savings by CHCP plants in the hotel sector", other solutions may be considered. One is utilising both heat from the cooling jacket and exhaust heat to produce hot water that powers the absorption machine.

4. Survey of the absorption cycle market

There are several suppliers of absorption cooling equipment and absorption refrigeration equipment throughout the world. Not all of them supply to the European market. Firms that have manufactured absorption cycle equipment for many years and are well-known may have discontinued activities in this domain. New firms may have recently started activities. Although our ambition has been to be as complete as possible, it has not been feasible to get into contact with all manufacturers that were known to us.

Furthermore, not all relevant suppliers that for example offer gas-fired absorption machines also offer steam-driven machines or hot water-driven machines.

4.1 Lithium bromide machines

The following suppliers of absorption machines with water – lithium bromide as working pair have been identified:

- Carrier (USA)
- York (USA)
- Trane (USA)
- McQuay (USA), under license from Sanyo
- Yazaki (Japan), small capacity units
- Sanyo (Japan)
- Ebara (Japan), which has ties with Carrier
- Mitsubishi Heavy Industries (Japan), which has ties with York
- Toshiba (Japan)
- Hitachi (Japan)
- Kawasaki Heavy Industries (Japan), ties with Matsushita Electric (Japan)
- Thermax (India), former licensee of Sanyo
- Entropie (France/Germany)
- LG Machinery (Korea)
- Kyung Won Century (Korea)
- Broad (China), only gas-fired machines

The list is certainly not exhaustive. Daikin (Japan) withdrew from the absorption cycle field in the 1980'ies, but it seems from recent reports that some activities have been taken up again. In addition to these in the list, there are manufacturers that supply large units for industrial use, e.g. Hitachi Shipyard (Japan).

Most absorption equipment based on the water-lithium bromide working pair is designed for air cooling applications. For historical reasons capacities are given in US RT (Refrigeration Tons), one US ton of ice per hour, in literature from manufacturers. One RT corresponds to ca 3.5 kW_{th} cold production.

4.1.1 Single-effect machines

Most manufacturers offer single-effect machines in the range ca 100 RT to ca 1500 RT, i.e. 350 kW_{th} to ca 5.2 MW_{th}. These can be "fired" with steam at 135 to 205 kPa g (1-2 bar gauge, 2-3 bar), which corresponds to a steam temperature of 110 to 120°C. Alternatively they can be "fired" with hot water at 115 to 150°C and a maximum pressure of 9 bar. The coefficient of performance is in the range 0.6 to 0.7.

The steam consumption of a single-effect machine is approximately 2.3 kg/h per kW_{th}. The hot water flow required is in the range 30 to 72 kg/h per kW_{th} depending on the temperature drop allowed.

4.1.2 Double-effect machines

The double-effect machines are approximately in the same range of capacities. The lowest cooling capacity offered by some manufacturers is slightly higher: 200 RT for one firm and 350 RT for another firm (700 and 1200 kW_{th} respectively). Steam appears used to be the preferred medium with which such a machine is "fired". The steam should be at 9 to 10 bar gauge, 10-11 bar, or 1100 to 1200 kPa, which corresponds to temperatures in the range of 175 to 185°C. According to information received, it is also possible to "fire" a double-effect machine with hot water, the temperature of which should then be in the range 155 to 205°C. The coefficient of performance in either case is 0.9 to 1.2.

The steam consumption of double-effect machine is ca 1.4 kg/h per kW_{th}.

4.1.3 Single-effect, low temperature and small capacities

There are thus single-effect as well as double-effect "steam-fired" absorption chillers in the upper part of the range of cooling capacities required, above ca 300 kW_{th}. There are also "hot-water-fired" units in the same range, single-effect and probably also double-effect in the same range. There does not appear to exist any absorption chiller with characteristics as above with a cooling capacity of 200 kW_{th} in the product range of some of the manufacturers that we have been in contact with.

However, both Sanyo and Yazaki offer hot water "fired" single-effect machines with cooling capacities below 100 RT or 350 kW_{th} and slightly different characteristics. Yazaki has two models, one at 10 RT and one at 30 RT (35 and 105 kW_{th} respectively). Sanyo's smallest unit is a 30 RT unit (105 kW_{th}) and its largest a 525 RT unit (ca 1800 kW_{th}). All of these are low temperature units designed for e.g. solar energy applications. Hot water is supplied to the absorption machines at ca 90°C and leaves the machines at ca 85°C. The flow rate is ca 240 kg/h per kW_{th}. Literature from the manufacturers states that they should be connected to the cooling jacket of the engine in order to minimize pipe drawing and piping connections.

4.1.4 Other points

All these commercially available absorption cycle machines reject heat to a cooling tower circuit. In most cases the temperatures in the cooling tower circuit is 32/37°C. The low-temperature hot water units of Sanyo and Yazaki require a lower temperature: 30/35°C.

Gas-fired absorption chillers which reject heat directly to the ambient air, without utilizing a cooling tower circuit, have been developed. However, it has not been possible to obtain information about their availability with steam as prime mover or about their performance, price, etc...

Capacity of an absorption machine may be controlled using the flow rate of the hot media, or its temperature, or flow-rate and temperature of the circuit to which heat is rejected, or using flow-rate or temperature of the chilled water. A detailed map of the dependence of coefficient of performance and capacity will involve many variables and diagrams. The part load behaviour may, however, be described in a simplified way. If a design condition is defined, capacity at part load follows energy input in a linear fashion. The coefficient of performance is almost independent of load down to 60% of design load, after which value the COP decreases linearly.

4.2 Ammonia-water machines

The list of manufacturers is much smaller for absorption refrigerating machines using the ammonia-water working pair:

- Hans Güntner GmbH Absorptionskälte KG (Germany)
- Colibri-Stork (Netherlands)

The well-known firms Linde and Borsig have ceased activities in the absorption cycle domain. Deutsche Babcock-Borsig has transferred its absorption activities to the heat exchanger manufacturer Hans Güntner GmbH. We did not make special efforts to identify other manufacturers in addition to the two in the list.

The ammonia-water machines are designed primarily for industrial refrigeration applications, e.g. freezing food or process refrigeration, with evaporator temperatures as low as -60°C . The temperature at which steam has to be provided to "fire" a unit depends on the available coolant temperature and on the refrigeration temperature to be achieved, see Figure 3 for an illustration.

It may be noticed that temperatures typical of air cooling applications, see above, fall outside of the range of variables and parameters in the diagram of Figure 3. If one extrapolates the relationships in the diagram, one could conclude that a coefficient of performance exceeding 0.6 may be expected in the present application.

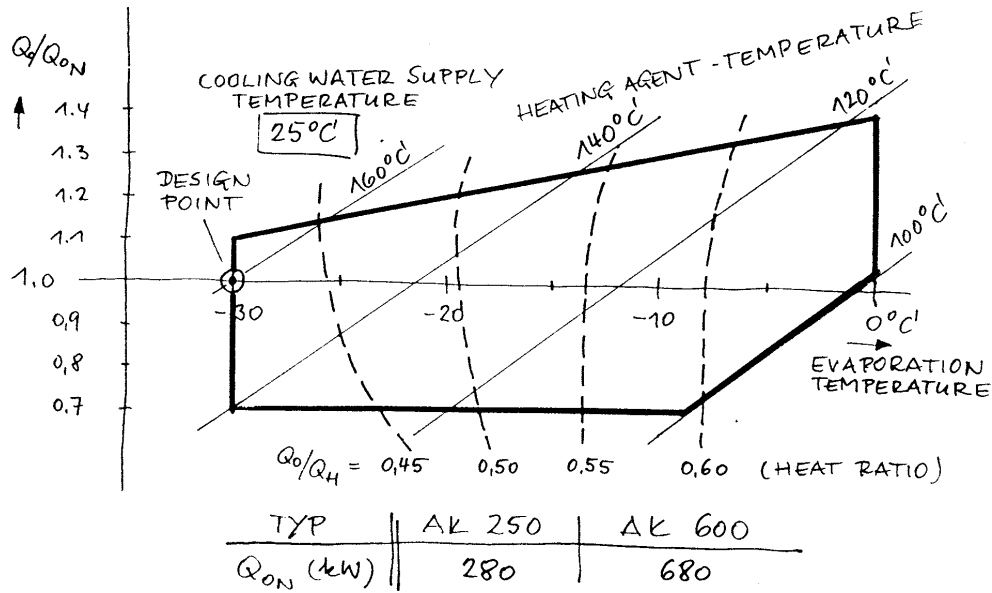


Figure 3. The coefficient of performance of an ammonia-water absorption refrigeration system as a function of evaporation temperature, steam temperature and part load (Q_0/Q_{0N}) as parameters. (Hans Güntner GmbH).

If one wishes to consider an ammonia-water cycle instead of the water-lithium bromide single-effect cycle above, one could reasonably expect performance, heat demand, temperature requirements to be basically the same as for a water-lithium bromide cycle.

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