Customized Absorption Heat Pumps for Utilization of Low-Grade Heat Sources

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Based on established and proven technology of water/lithium bromide absorption chillers, customized single-stage and double-stage heat pump cycles adapted to specific applications can be designed, especially aiming at medium and large heating capacities of 500 kW (1.7×106 Btu/h) and above. These heat pumps can either be fossil-fired or driven by heat from CHP systems or other sources. In terms of primary energy saving, in many cases this is the most suitable technology to utilize the available heat sources. This is demonstrated by three examples of current installations in southern Germany. An analysis of the energetic performance and of the economic situation has been performed.

1. Absorption Heat Pumps: Primary Energy Saving

An absorption heat pump utilizes driving heat in order to lift a low temperature heat flux from an ambient heat source – e.g. waste heat, solar heat, geothermal heat – to a useful temperature level. The driving heat that enters the heat pump at a high temperature is released again at an intermediate temperature level together with the ambient heat that is absorbed at low temperature and upgraded to useful heat temperature.
The absorption heat pumps that are applied in the projects presented below represent customized single-stage and double-stage plants. Single-stage units based on the working pair water/aqueous lithium bromide solution exhibit a thermal efficiency (COP: Coefficient Of Performance = quotient of useful heat output and driving heat input) of about 1.7. Due to the higher temperature of the driving heat, the thermal efficiency of double-stage plants reaches about 2.2. Thus, the application of an absorption heat pump can save about 50% of the primary energy required for the provision of useful heat (Ziegler, 1997). This results in even higher savings of primary energy than in applications of vapor compression heat pumps where additionally the conversion efficiency of the electric power plant has to be taken into account to obtain the primary energy consumption for the provision of useful heat.

2. Practical Examples

Water/lithium bromide plant technology is well established for chilled water production in the field of comfort air-conditioning. The same working fluid and the same basic design of all main components of the heat pumps can be used for any useful heat temperature from about 10°C to 180°C and for heating capacities from about 50 to 5,000 kW. This simplifies the development of customized plants for special applications compared to vapor compression heat pumps where such a customization is always subject to market availability of the suitable refrigerant and the appropriate compressor regarding temperature levels, pressure ratio, capacity, etc.

2.1 Waste Heat Utilization at a Composting Plant

At a municipal waste processing plant in southern Germany a single-stage absorption heat pump has been installed for recovery of the waste heat rejected by the biological, aerobe rotting process of the organic waste. During the rotting process the organic material is moved in about ten steps from heap to heap across the composting plant, starting in “intensive” compost heaps containing the most recent base material with temperatures of the rotting process about 75°C. After about 40 days the rotting process ends at approximately 30°C and the compost leaves the plant sanitized and well decomposed; hence, it can be applied for agricultural uses. During the rotting process the compost heaps are forced-air ventilated in order to maintain an appropriate oxygen supply. The heat content of the warm moist air from the first three heaps is transferred to a cold water loop and serves for heat input to the specially designed absorption heat pump.

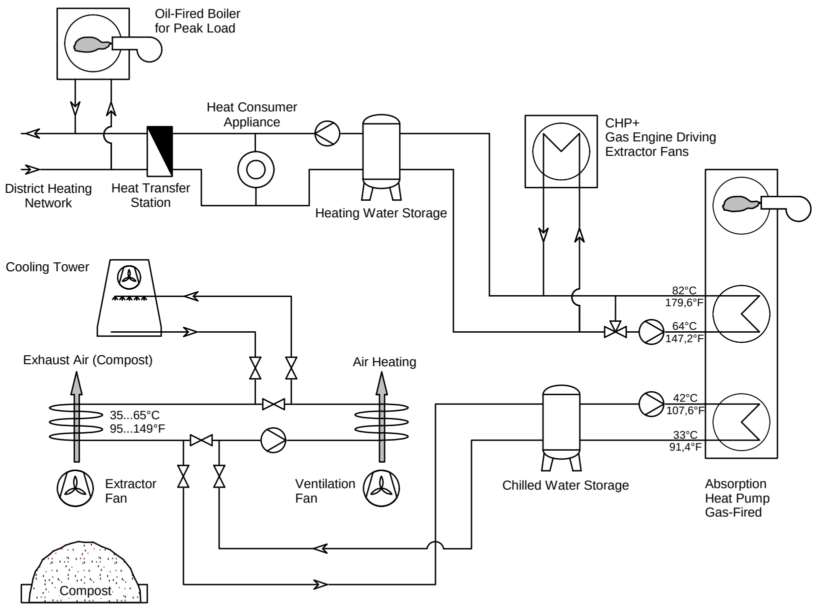

Figure 1: Energy supply system of the waste processing plant and integration of the gas fired absorption heat pump in Warngau, Germany.

The scheme in Figure 1 shows the integration of the gas-fired absorption heat pump into the energy supply system at the waste processing plant. Due to the intermittent processes of forced-air ventilation and moving of the compost heaps, the exhaust air temperature and the heat load on the cold water loop show significant variations over time. Thus, a chilled water buffer storage with a volume of 3,500 L has been integrated in order to maintain a constant temperature level of the cold water loop with supply/return temperature 34/42°C, serving for heat input into the evaporator of the heat pump. The heat pump provides a constant outlet temperature of the heating water loop of 82°C after passing absorber and condenser of the heat pump irrespective of the current operating condition. In order to achieve the large temperature lift from heat source to useful heat of about 50°C the heat pump is equipped with a gas-fired generator. The gas burner capacity is modulated from 325 to 600 kW, depending on the operating condition of the heat pump. The heat pump has been designed for a cycle COP about 1.6 at 50% part load, increasing up to 1.65 at full load. Taking into account a burner efficiency about 88% in part load and about 85% in full load a PER of about 1.45 is accomplished.

Operation of the heat pump since winter 2005/2006 has shown good accordance with the specified thermal design. Yet, further modifcations in the system installation are requried in order to increase the heat output to the district heating network assuring continuous utilization of the heat pump at high load.

2.2 Heat supply for a swimming bath with combined cooling, heating, and power generation

At a municipal swimming bath in Southern Germany an innovative central energy supply is errected for space heating of the building and heat supply to four swimming pools at temperatures between 24°C and 34°C with average heating demand of 600 to 800 kW and a peak load of all heat consumers about 2 MW.

On site, a thermal spring delivers 24 m³/h of warm thermal water at a temperature of 25.5°C. The availability of a geo-thermal heat source initiated the application of a double-effect absorption heat pump, which is driven by heat from a co-generation engine, serving for combined generation of cooling, heating, and electrical power (CCHP).

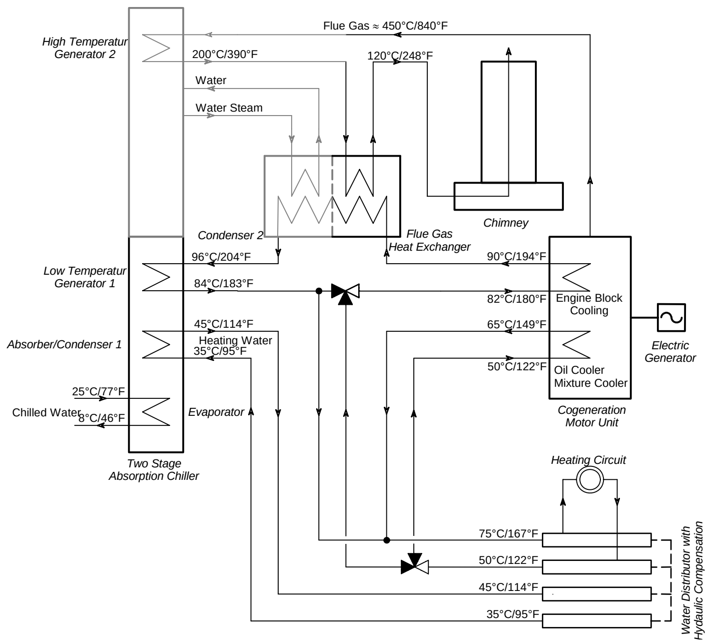

Figure 2: Heat supply of swimming bath Bodenseetherme in Konstanz, Germany: Innovative system configuration with motor engine and Double-Effect/Single-Effect absorption heat pump.

According to the state-of-the-art in CCHP, single-effect chillers are applied to absorb all co-generated heat of the motor engine, which is transferred via a conventional hot water loop. Aiming at increased energetic efficiency and flexibility, an innovative system concept is applied, as shown in Figure 2.

Low temperature heat demand in the temperature range 30 to 45°C will be covered by heat output from the absorber and condenser of the two-stage absorption heat pump with a heating capacity of 710 kW. The warm water from the geothermal well entering the evaporator of the heat pump with a temperature of 25°C will be cooled down to 8°C and then discharged to the nearby Lake of Konstanz. With respect to the high temperature lift from chilled water outlet 8°C to 45°C useful heat supply temperature, a so-called twin design of the low-pressure stage of the heat pump is applied. By that means, the chilled water is cooled by two evaporators in series. Analogously, absorption takes place in two absorbers operating at slightly different pressure levels.

According to the innovative CCHP concept (Plura et al., 2005; Plura et al. 2006), the high-temperature stage (double-effect) of the two-stage absorption heat pump is directly driven by hot flue gas (about 450°C) released by the motor engine, serving for optimum utilization of the exergy content of the co-generated heat. In a second step, the flue gas drives the low-temperature stage (single-effect) of the heat pump. The low temperature heat of the co-generation engine released by the mixture cooler, the lube oil cooling and the engine jacket cooling is supplied to the single-effect chiller in addition to the low temperature flue gas heat. By super-imposing double-effect cycle (DE, heating COP=2.2) and single-effect cycle (SE, heating COP=1.7) an overall heating COP about 1.95 will be accomplished, allowing for a 30% increase in heat intake from the thermal heat source as compared to standard single-effect absorption technology. Thus, by use of the thermal heat source via the DE/SE heat pump the heat output of the CHP unit is approximately doubled.

Conceptual design of the energy system started in fall 2004. Start-up of the Tri-Generation system is scheduled for early summer 2007.

2.3 Solar-assisted district heating system with seasonal heat storage and heat pump

In Munich, presently a solar-assisted local district heating system is installed in a new housing development area with about 300 accommodation units. In all roofs with south orientation, solar flat plate collectors are integrated; a total collector area of 3,600 m² is installed. At site, a seasonal hot water storage tank with a capacity of about 5,700 m³ and a total height of about 16 m is erected. This storage will allow to provide a part of the heating demand during the winter months by solar heat that was stored during the summer at temperatures up to 90°C.

In order to increase the storage efficiency, an absorption heat pump is integrated in the novel solar-assisted district heating system. Following the direct utilization of the hot water storage, low-grade heat from the storage in a temperature range from about 40°C down to 10°C will be used as heat input into the evaporator of the heat pump. Thus, the annual share of utilized solar heat in the local heating system is increased and the amount of additionally required non-solar heat from an alternative source can be reduced – without increasing the size of the most costly components, solar field and storage tank. The absorption heat pump will be driven by hot water from the supply line of the municipal district heating system. Figure 3 shows a simplified scheme of the solar-assisted district heating system.

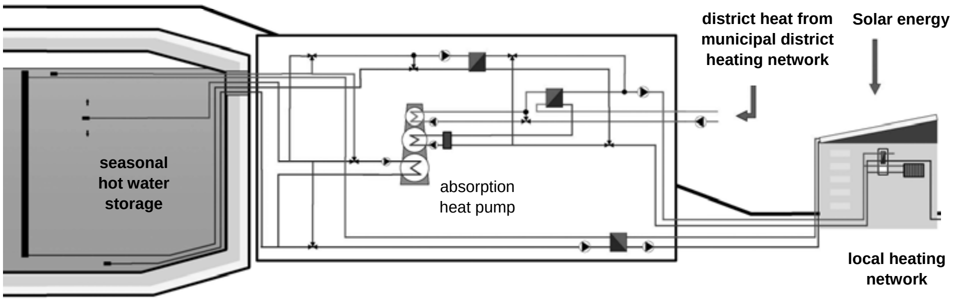

Figure 3: Scheme of the solar-assisted district heating system at Ackermannbogen Munich.

In order to cope with varying operating conditions throughout the heating season, the heat pump has been designed for return temperatures of the local heating network in the range of 20-40°C entering the absorber of the heat pump and condenser outlet temperature about 55°C. In the chilled water loop (heat source/seasonal storage), during the heating season the evaporator inlet temperature drops from 45°C to 10°C. The evaporator outlet temperature is expected to be in the range of 5 to 10°C at the end of the heating season to ensure a complete utilization of the heat capacity of the seasonal storage. The temperature of the driving district heating network varies as a function of the ambient temperature between 120 and about 90°C.

In order to achieve the large temperature lift of approximately 45°C between evaporator outlet and condenser outlet temperature and large temperature glides in the three external heat carrier loops, i.e. about 10°C in chilled water, 25°C in cooling water, 30°C in hot water, a serial coupling of two single-stage cycles has been chosen. This plant concept comprises a total of eight main heat exchangers and four pressure levels, i.e. two different evaporator pressures plus two different condenser pressures, with each external water loop passing consecutively to both absorption cycles. It was shown that such a coupling scheme results in a reasonable size of the total surface area of the eight main heat exchangers and in a good COP of about 1.7 of the heat pump. The two absorption cycles have been integrated into a single machine with only two main shells on a single base frame. Commissioning of the system is scheduled for spring 2007.

3. Economic Analysis

The detailed planning of the absorption heat pumps described above has been carried out in cooperation with an experienced manufacturer of standard absorption chillers and heat pumps, resulting in a reliable plant design and market-oriented plant cost.

A detailed economic analysis of the projects described in this article (Kren et al., 2007) showed, that in cases where the heat pump replaces a fossil fired boiler, payback periods of only a few years can be achieved, strongly depending on the annual utilization of the heat pump system.

In the case of the waste heat utilization of the composting plant, where the operation of the heat pump is limited to the heating period, a payback period of 5.4 years has been found. At the thermal swimming bath, due to a continuous operation of the heat pump return of the investment is reached after 2.6 years. In both cases the specific cost for the supply of useful heat is reduced substantially in comparison to the application of a fossil boiler. In the composting plant the cost for the useful heat provided by the heat pump is 0.041 Euro/kWh; in the thermal bath even 0.028 Euro/kWh are to be expected. Whereas heat from a fossil boiler is available for about 0.045 Euro/kWh.
The system with seasonal heat storage of course yields a higher specific cost for the useful heat output, due to the limited availability of ambient heat input from the seasonal storage and an accordingly short annual utilization. Yet, the specific cost for the additional solar heat (0.16 Euro/kWh) gained by integrating an absorption heat pump is lower than the cost of solar heat achieved in former installations without absorption heat pump.

4. Summary and Conclusion

Based on established and proven technology of water/lithium bromide absorption chillers, various customized single-stage and double-stage heat pump cycles adapted to specific applications can be designed. These heat pumps can either be fossil fired or driven by heat from CHP systems or other sources.
Single-stage heat pumps reach thermal efficiencies around 1.7, double-stage cycles reach efficiencies above 2.0; i.e. about 40-50% of the supplied useful heat originate from the ambient heat source instead of the driving heat. For direct-fired machines however, also the boiler efficiency has to be taken into account to determine the primary energy ratio PER.
This paper reports on three recent applications of customized absorption heat pumps in southern Germany. In situations with high annual utilization of the heat pump, the achieved high energetic efficiency results in short pay back periods of only a few years.
Future activities will focus on the implementation of ground-coupled systems for energy-efficient supply of heating and cooling for buildings.

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