IEA Heat pump program

Austrian contribution to IEA HPP Annex 43

IEA HPP Annex 43
Fuel-driven sorption heat pumps

Deliverable D 4.1
State-of-the-art and research activities

Prepared by

Graz University of Technology
Institute of Thermal Engineering
Inffeldgasse 25/B
8010 Graz, Austria

Authors:

Roman Wechsler
René Rieberer (contact: rene.rieberer@tugraz.at)

AIT – Austrian Institute of Technology
Energy Department
Giefinggasse 2
1210 Wien, Austria

Authors:

Johann Emhofer
Thomas Fleckl (contact: thomas.fleckl@ait.ac.at)

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1 Introduction

Space heating and domestic hot water production are among the most important factors when it comes to the reduction of fossil energy use and CO_2 emissions. In Austria for instance, those domains account for around 30% of the total national energy consumption. For comparison, traffic and manufacturing contribute with about 33% and 30%, respectively (Statistik Austria, 2014). Approximately half of the heat is produced by means of fossil fuels, which are mainly oil and natural gas (Statistik Austria, 2013). In almost all cases, fossil fuels are burned in boilers including condensing and non-condensing designs. On the one hand side, a great share of those existing devices is outdated and hence less efficient than modern condensing boilers; on the other hand side, there is a general technological limit of the achievable efficiency. When simply burning fossil fuels the maximum possible heat output is given by the gross calorific value (in case of a condensing boiler) and cannot be further increased.

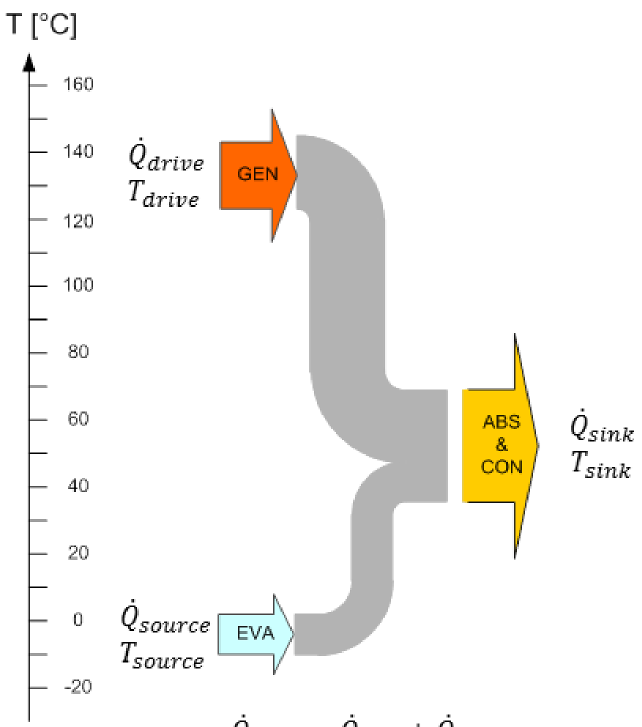
Gas driven sorption heat pumps offer the possibility to draw energy from the environment in addition to the heat released by the combustion of fuel gas (e.g. natural gas). As a consequence the efficiency could be increased by about 60% compared to condensing boilers. This number basically depends on the operating conditions as well as the design of the sorption heat pump and its components. Future appliances will most likely achieve even higher efficiency values. Hence the replacement of existing boilers (especially outdated ones) by gas driven sorption heat pumps would lead to a significant reduction of CO_2 emissions, a saving of costs for fossil fuels, and a reduced dependency on oil and gas delivering countries. The goal of Annex 43 is to stimulate the market entry of gas driven sorption heat pumps for the domestic use, especially for retrofit applications.

The scope of this report is to give an overview of the state-of-the-art of sorption heat pumps and relevant research activities with focus on the situation in Austria. In the following the technological background of both absorption and adsorption heat pumps is discussed. Subsequently gas fired sorption heat pumps available on the Austrian market are described. Finally research projects concerning the topic are presented.

2 State-of the-art

2.1 Heat flows and temperatures

In Figure 1 the general principle of a sorption heat pump is shown. Driving heat $\dot{Q}_{drive}$ at a high temperature level T_{drive} is used to lift heat $\dot{Q}_{source}$ from an environmental heat source with a low temperature level T_{source} to a medium temperature level T_{sink}, at which both the driving and the ambient heat are released to a heat sink (namely the heat supply system). Ambient air or the ground, for instance, can serve as heat source.



$$COP_H = \frac{\dot{Q}_{sink}}{\dot{Q}_{drive}} = \frac{\dot{Q}_{ABS} + \dot{Q}_{CON}}{\dot{Q}_{GEN}} = 1{,}1 - 1{,}6$$

Figure 1: Heat flows in a sorption heat pump

Figure 2 exemplarily depicts the dependency of a sorption heat pump's efficiency on the temperatures of its heat sink and source at a constant drive temperature of 160 °C and a constant generator capacity of 10 kW. The shown data were collected from simulations of an absorption heat pump by using the software EES (Engineering Equation Solver). The simulated cycle is a simple single-stage one as shown in Figure 4 and the model is based on mass and energy balances as well as vapor-liquid equilibrium assumptions. As can be seen, the efficiency increases with decreasing sink temperature and with increasing source temperature; thus small differences between those two temperatures (temperature lift) are favorable. Since the heat source temperature is given by the ambient conditions, only the heat sink temperature can be influenced by the heat distribution system. Hence heat supply systems that require low flow temperatures, such as floor heating systems, are particularly suitable in combination with sorption heat pumps. However, as the influence of the temperature levels on the efficiency of sorption heat pumps is relatively small they are also convenient for heat supply systems with higher demanded flow temperatures. Especially in case of retrofit applications this is an important advantage.

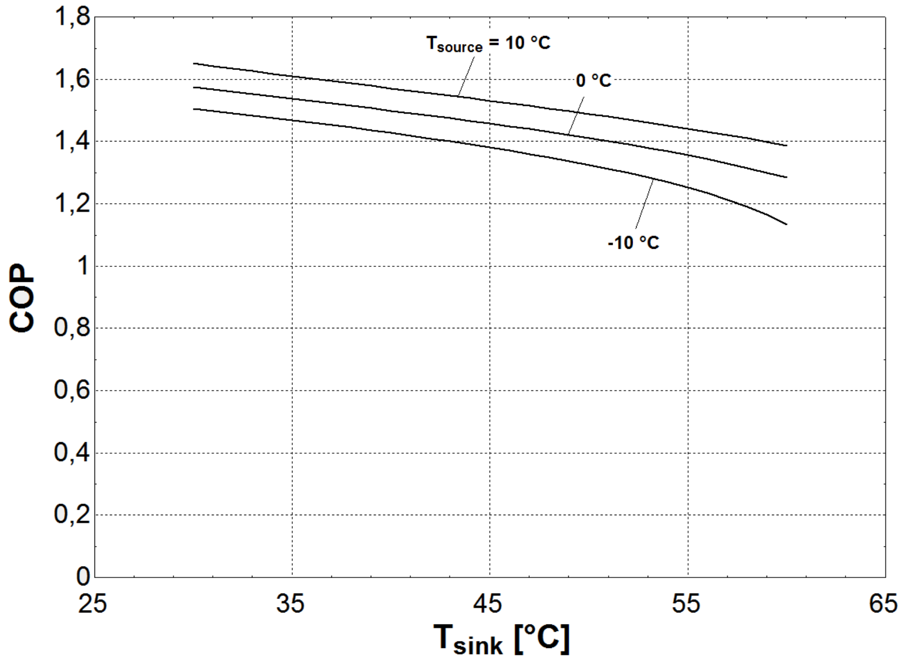


Figure 2: Efficiency of a sorption heat pump as a function of the sink and source temperature

2.2 Efficiency measures

The efficiency of the system can be defined by means of different characteristic values. A detailed discussion of efficiency figures for thermal driven heat pumps considering different system boundaries can be found in the final report of IEA Annex 34 (IEA Heat Pump Centre, 2014).

One of those measures is the Coefficient of Performance (COP), which is the ratio of the heat output $\dot{Q}_{sink}$ and the deployed driving heat (Herold et al., 1996). In case of gas driven sorption heat pumps the latter is generated by burning fuel. Since the heat output is the sum of the driving and the ambient heat (assuming negligible heat losses), the COP is larger than unity. For gas driven sorption heat pumps an alternative measure for the efficiency is the Gas Utilization Efficiency (GUE), which is defined as the ratio of the heat output and the energy content of the consumed fuel gas based on the net calorific value (prEN 12309-4, 2012). While the COP is based only on that amount of heat, which is actually input to the sorption process, the GUE additionally accounts for all kinds of losses that accompany the heat transfer from the combustion gas to the process.

Note that both the COP and the GUE are defined only for one specific operating condition. In reality, however, sorption heat pumps are normally operated at a multitude of different boundary conditions, basically defined by the heat source and the heat sink temperature. Additionally the efficiency is influenced by transient effects, which appear repeatedly in the field. To account for that fact seasonal coefficients of performance, being defined as the ratio of the heat output and the consumed gas energy during a certain period (for instance one year), can be used. A procedure for the calculation of the annual coefficient of performance of gas driven sorption heat pumps can be found in VDI guideline 4650-2 (VDI 4650-2, 2010).

Due to the different qualities of electrical energy and heat (both from an exergetic and an economic point of view), the electrical power demand is usually not included in the above mentioned definitions. It can be specified separately, for instance by means of the Auxiliary Energy Factor (AEF), which is the ratio of the heat output and the electrical power demand (prEN 12309-4, 2012). Another option is to weight the different forms of energy input according to their primary energy factors (standard values: 2.5 for electrical energy and 1.0 for natural gas). The resulting efficiency measure, called primary energy ratio (PER), is the ratio of the heat output and the total primary energy consumption (prEN 12309-1, 2012). This allows a comparison of gas driven heat pumps and other heating devices, such as electrically driven compression heat pumps, on a common basis.

2.3 Absorption heat pumps

2.3.1 Working fluids

Sorption heat pumps operate with a pair of working substances, namely the refrigerant and the sorbent. The refrigerant is a fluid in gaseous and/or liquid state, while the aggregate state of the sorbent is either liquid or solid. Depending on the sorbent, one distinguishes between absorption (liquid sorbent) and adsorption (solid sorbent) heat pumps. In this section the former are discussed, while adsorption heat pumps are dealt with in Section 2.4.

To date only two working pairs have been established in commercial absorption heat pumps, water/lithium bromide and ammonia/water[1]. Water as a refrigerant restricts the minimum possible heat source temperature, thus primarily the second mentioned working pair is normally used in absorption heat pumps for heating purposes. Therefore, we will concentrate on the ammonia/water working pair and its corresponding cycles in the following. However, for cooling applications water/lithium bromide is quite common for temperatures above 0°C.

[1] The first substance denominates the refrigerant while the second one denominates the sorbent.

Mixture properties of ammonia/water are well known. Experimental vapor-liquid-equilibrium (VLE) data are available (Tillner-Roth & Friend, 1998b) as well as mathematical descriptions, for instance in the form of equations of state (EOS) (Ibrahim & Klein, 1993) (Tillner-Roth & Friend, 1998a). In Figure 3 bubble point and dew point lines of the mixture for different ammonia mass fractions are shown. Furthermore there are empirical correlations for transport properties such as thermal conductivity, diffusivity, and viscosity available (M. Conde Engineering, 2006).

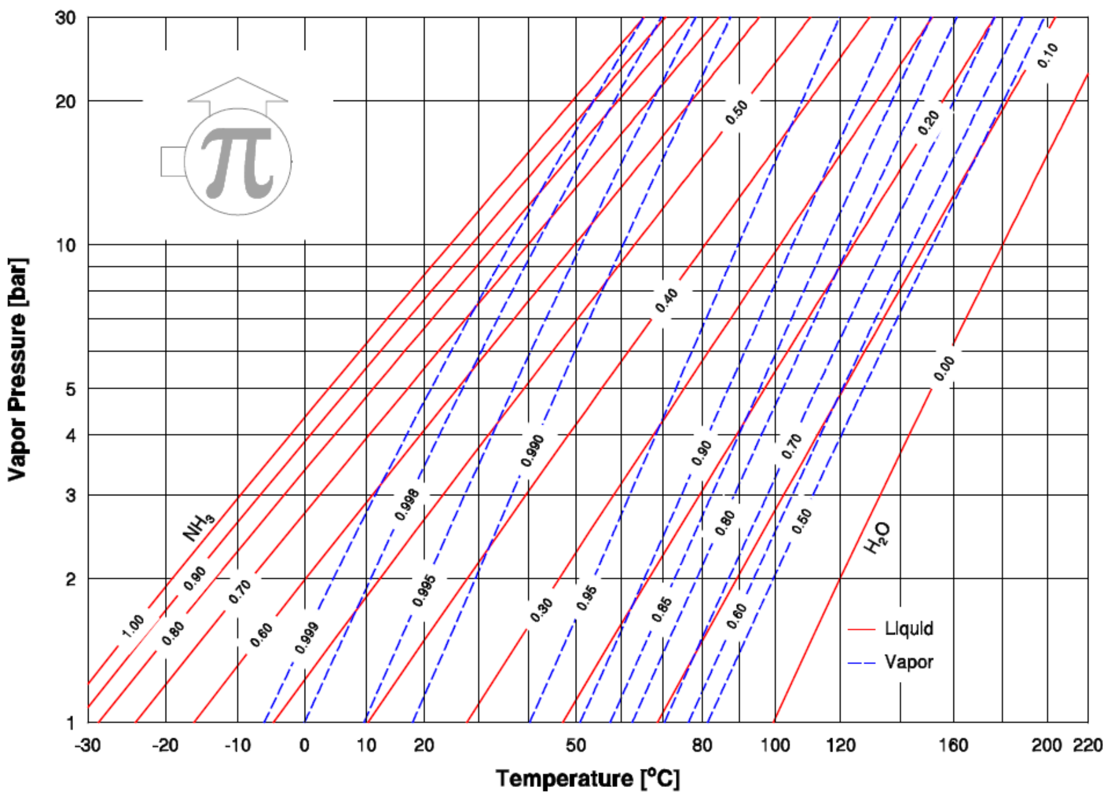


Figure 3: P-T-x-diagram of ammonia/water (M. Conde Engineering, 2012)

Although ammonia/water is generally well suited for the use in absorption heat pumps, there are also some drawbacks. In most cases a sufficient separation of the two components downstream the generator is only possible by means of rectification. This increases the complexity of the system on the one hand side and deteriorates the efficiency on the other hand. Moreover ammonia/water shows corrosive behavior, so that inhibitors have to be used (compare Section 3.4). In order to avoid decomposition phenomena, the mixture temperature must not exceed around 180°C. The toxicity of ammonia is also worth mentioning, although the low perception threshold prevents unnoticed leakages (Ziegler, 1997).

2.3.2 Cycles

Figure 4 depicts the absorption cycle in a pressure-temperature diagram. The process takes place at two pressure levels and at different temperature levels. Starting at the absorber at the low pressure level, the poor solution[2] (PSO) contains a relatively small amount of ammonia. Additional to the poor solution, almost pure ammonia enters the absorber in the gaseous phase (REF). Since the poor solution is not saturated with ammonia at the given temperature and pressure, ammonia is absorbed. During this process, heat is released at a medium temperature level to the heat supply system. The resulting mixture with a relatively high concentration of ammonia, called rich solution (RSO), is pumped to the higher pressure level by the solution pump (PUMP). Due to the small specific volume and the incompressibility of the liquid solution the required electrical power for the pump is quite small compared to the driving heat input and is hence often neglected. This is a major difference compared to an electrically driven compression heat pump, which uses relatively large amounts of electrical energy to compress a gaseous refrigerant. In the generator (GEN) ammonia containing a small fraction of water is partly evaporated out of the mixture using high temperature driving heat. In order to keep the water content downstream the generator as small as possible, a rectification column is used in most of the cases (see Figure 8). The remaining poor solution flows back to the absorber via the solution heat exchanger (SHX) and the solution throttle (STH). In the condenser the evaporated ammonia from the generator condenses and the heat of condensation is transferred to the heat supply system at a medium temperature level. After passing the refrigerant throttle (RTH) the ammonia is evaporated in the evaporator (EVA). The required heat of evaporation is drawn from the environment. Finally the ammonia vapor enters the absorber via the refrigeration heat exchanger (RHX) and the cycle is closed. As isobaric phase change of non-azeotropic mixtures such as ammonia/water takes place at non-constant temperature, desorption in the generator and absorption both show a pronounced temperature glide.

[2] The term „poor” refers to the low mass fraction of ammonia in the solution.

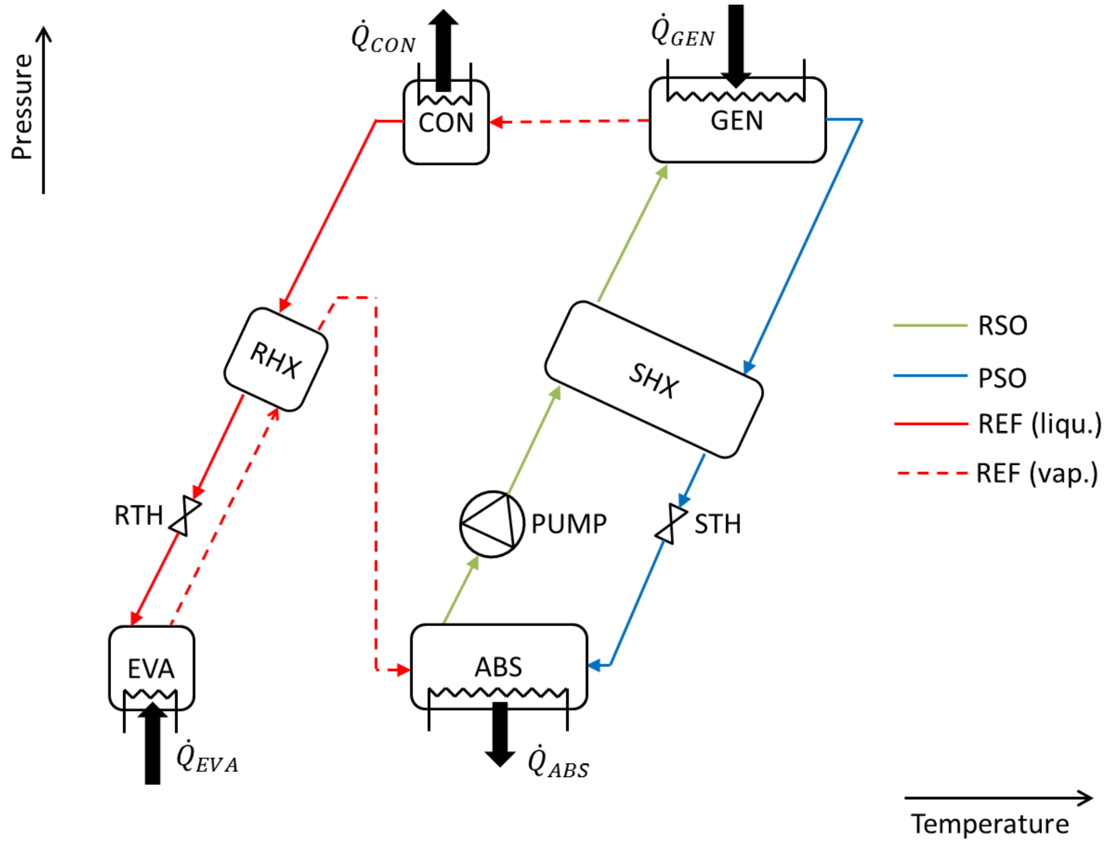


Figure 4: Single-stage absorption cycle with solution and refrigerant heat exchanger

There are several possibilities to increase the efficiency by means of internal heat recovery. In the SHX heat from the hot poor solution coming from the generator is transferred to the rich solution, which is flowing from the absorber to the generator. As a result the rich solution is closer to its bubble point temperature, thus less driving heat is needed. In the refrigerant heat exchanger (RHX), liquid ammonia is precooled by gaseous ammonia before entering the evaporator. Consequently the refrigerant's enthalpy at the evaporator inlet decreases, leading to an increased evaporator capacity.

Another option for internal heat recovery is the so called solution recirculation, see Figure 5. On the one hand side, rich solution is preheated before entering the generator by cooling a part of the absorber. Similar to a SHX this results in a decreased generator capacity as the entering poor solution is closer to its bubble point temperature. On the other hand side, hot poor solution from the generator is used to heat a section of the generator itself leading to a further reduction of required external driving heat.

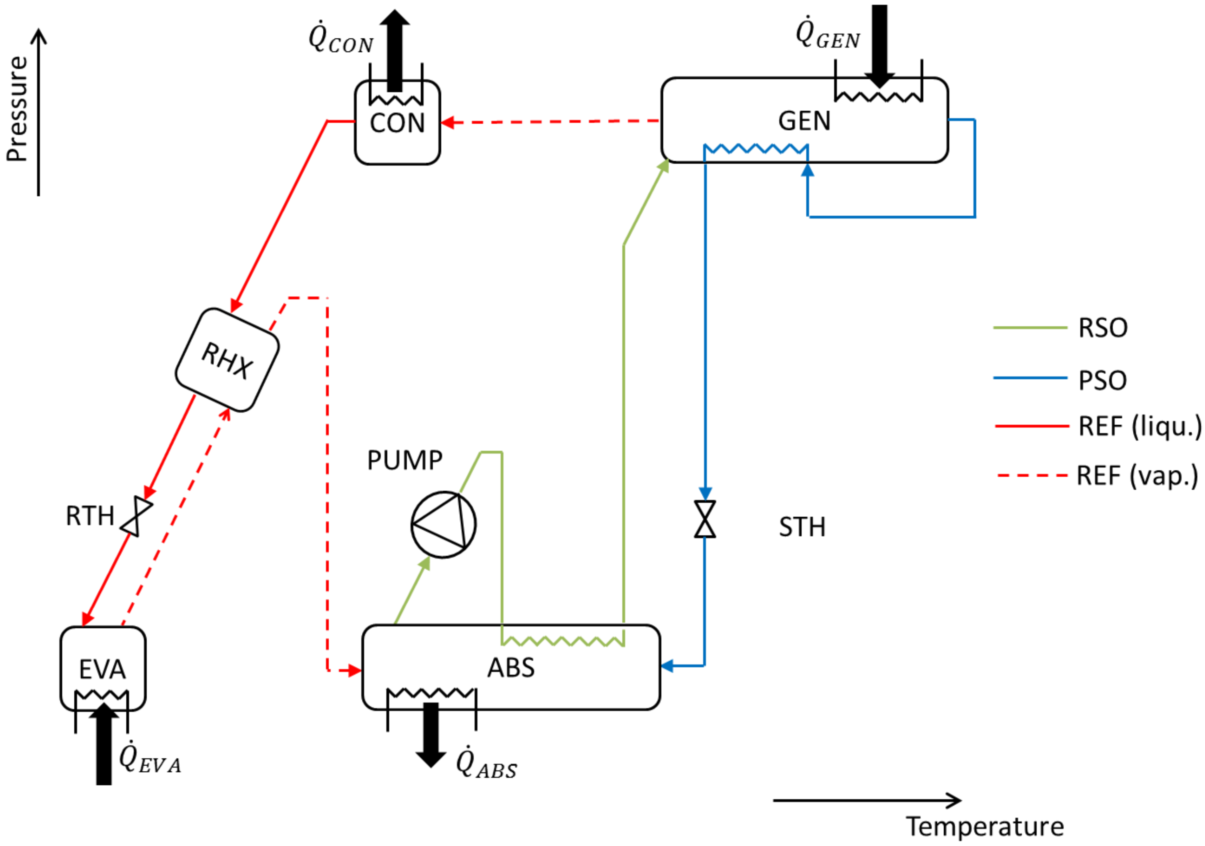


Figure 5: Absorption cycle with solution recirculation

If there is an overlap of the temperature ranges required for absorption and desorption in the generator, a generator/absorber heat exchange (GAX) design can be considered. In contrast to a SHX and solution recirculation, where the rich solution leaving the absorber is preheated but not evaporated, a GAX includes partly evaporation of the rich solution by means of heat of absorption. Similar to the internal heat recovery strategies mentioned above, external driving heat is replaced by internally recovered heat. However compared to a SHX and solution recirculation, where only sensible heat is replaced, phase changes are involved in the case of a GAX. The result is a higher amount of recoverable heat and consequently a greater possible increase of the efficiency.

Several implementations of this principle are possible and one of them is depicted in Figure 6. The heat transfer from the absorber to the generator is realized via a separated cycle in this case. In order to establish a flow in this second cycle an additional pump is required. This is a major drawback, since it increases the complexity and the costs of the system.

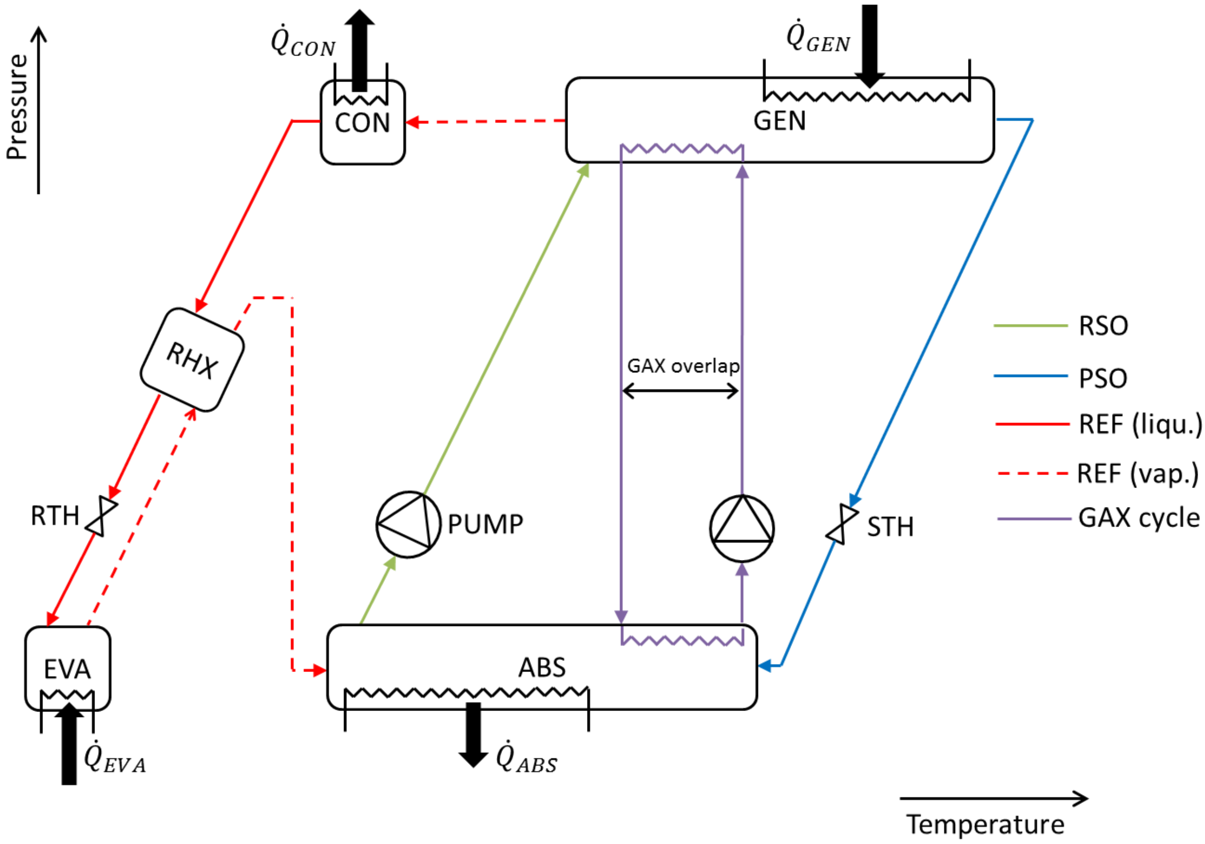


Figure 6: Absorption cycle with separated GAX cycle

A possibility to avoid this second pump while maintaining the advantages of a GAX can be seen in Figure 7. The process is similar to the one with solution recirculation shown in Figure 5, however in this case the rich solution is partly evaporated in the part of the absorber which is cooled by the rich solution. As a result it enters the generator as a two-phase flow. Note that the required temperature range for desorption in the generator is significantly reduced, since the desorption that would take place in the low-temperature section of the generator (dotted line), occurs in the solution cooled part of the absorber instead.

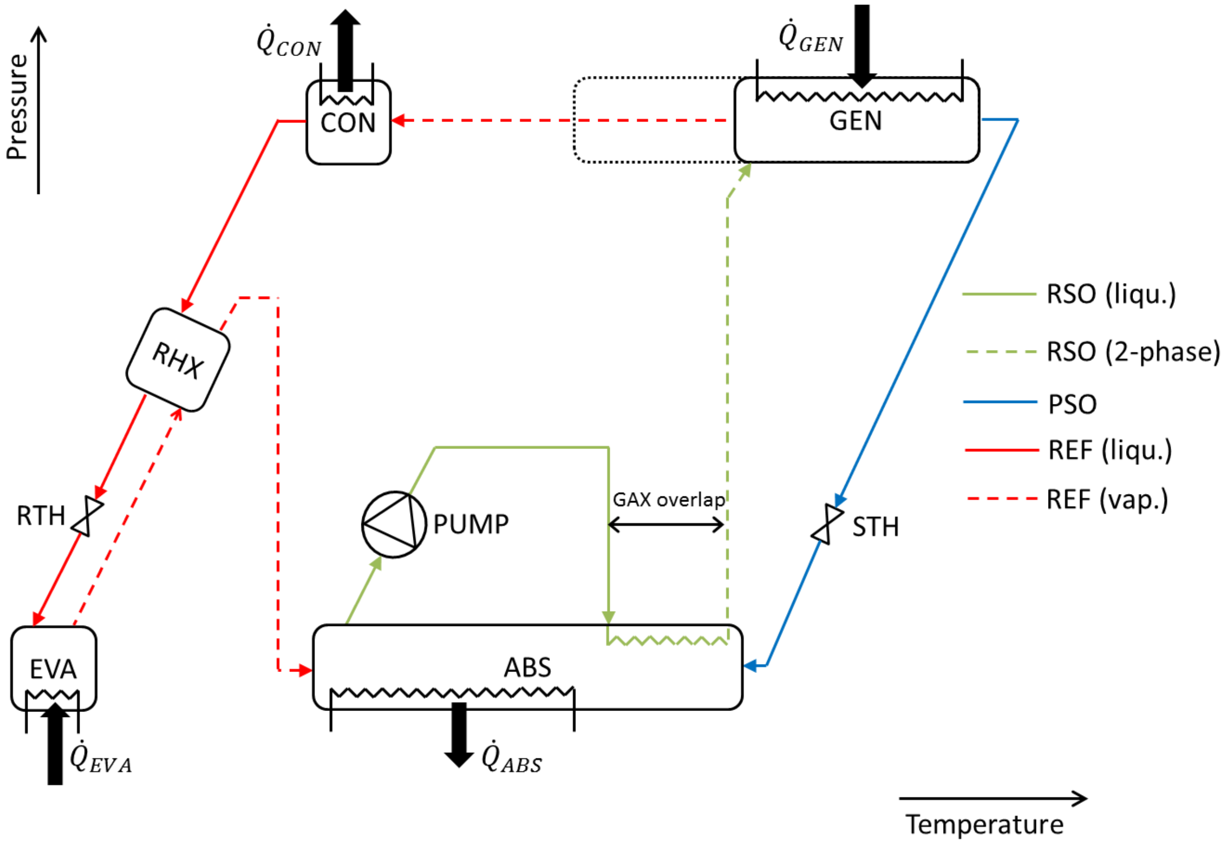


Figure 7: Absorption cycle with modified GAX cycle

When using ammonia/water as working pair, the vapor leaving the generator contains some amount of water besides the ammonia because the vapor pressure of water is not negligible compared to the one of ammonia. This leads to a temperature glide in the evaporator and consequently to several negative effects. On the one hand side, part of the refrigerant does not evaporate resulting in a reduced evaporator capacity and hence in a reduced efficiency. On the other hand side, the low pressure level of the process is decreased, which additionally reduces the efficiency.

In order to avoid those problems, rectification columns are used for the purification of the refrigerant vapor leaving the generator. Those components require a reflux of liquid mixture with a relatively high concentration of water compared to the vapor. This reflux is usually generated by means of a dephlegmator, which is located above the rectification column. In the dephlegmator the vapor is partly condensed and by gravity the condensate flows back into the rectification column. As the reflux has to be evaporated out in the generator before condensing in the dephlegmator an additional amount of driving heat is required. In contrast to the non-condensed fraction of the vapor, the reflux does not contribute to the evaporator capacity; hence a dephlegmator has a negative influence on the efficiency. This can be partially compensated for, however, by cooling the dephlegmator with the rich solution coming from the absorber.

That way the rich solution is in turn preheated and the generator capacity can be decreased, see Figure 8.

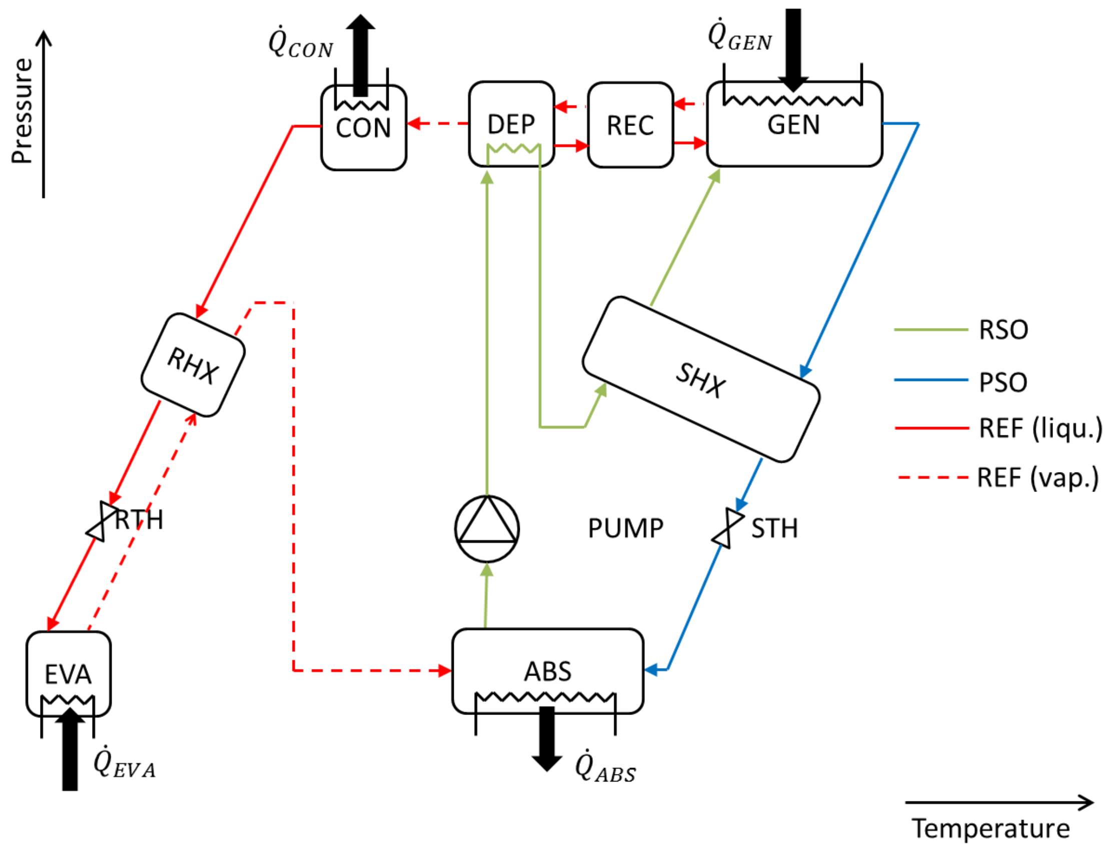


Figure 8: Absorption cycle with internally cooled dephlegmator

In actual realized absorption heat pumps, often several of the above mentioned heat recovery strategies are combined with each other. For instance, one might combine a solution cooled dephlegmator with a SHX, with solution recirculation, and with a GAX respectively.

2.3.3 Components

The components of an absorption heat pump are mainly heat exchangers, which enable the heat transfer between the working substances and the external fluids (combustion gas, heating water, and brine/air) or among the working substances themselves. In almost all of them (except for the solution and refrigerant heat exchanger) additionally mass transfer (phase change) takes place. Different heat exchanger types are possible. Plate heat exchangers offer an excellent heat exchange surface to construction volume ratio and are commercially available in a broad variety. However, their costs are relatively high, so that alternative designs such as pipe-in-pipe heat exchangers can also be found. If the heat source is ambient air, the evaporator is usually a finned heat exchanger to provide a sufficiently large heat exchange surface on the air side.

Figure 9 schematically shows the interconnection of a generator, a rectification column, and a dephlegmator. The generator (K), containing liquid solution, is heated by the combustion gas via a heat exchanger (H), which leads to partial evaporation of the solution. The remaining poor solution leaves the generator through the outlet (b). The generated vapor flows upwards through the rectification column (E). Rich solution enters the rectification column at the inlet (a) and reflux, which is generated in the dephlegmator (R), enters the rectification column via a pipe (d). Consequently liquid mixture flows in counter-current to the vapor resulting in an intensive combined heat and mass transfer between those two phases and an enrichment of the vapor in ammonia on its way upwards the rectification column. In order to enhance the heat and mass transfer by maximizing the phase interface column internals such as trays (T_1, T_2) are used. Alternatively e.g. raschig rings or structured packings can be considered. Finally the vapor leaves the column and enters the dephlegmator (cooled by heating water in this case) where it is partially condensed in order to obtain the reflux. The remaining vapor flows further to the condenser (C). Typically ammonia mass fractions of around 99,5% can be achieved.

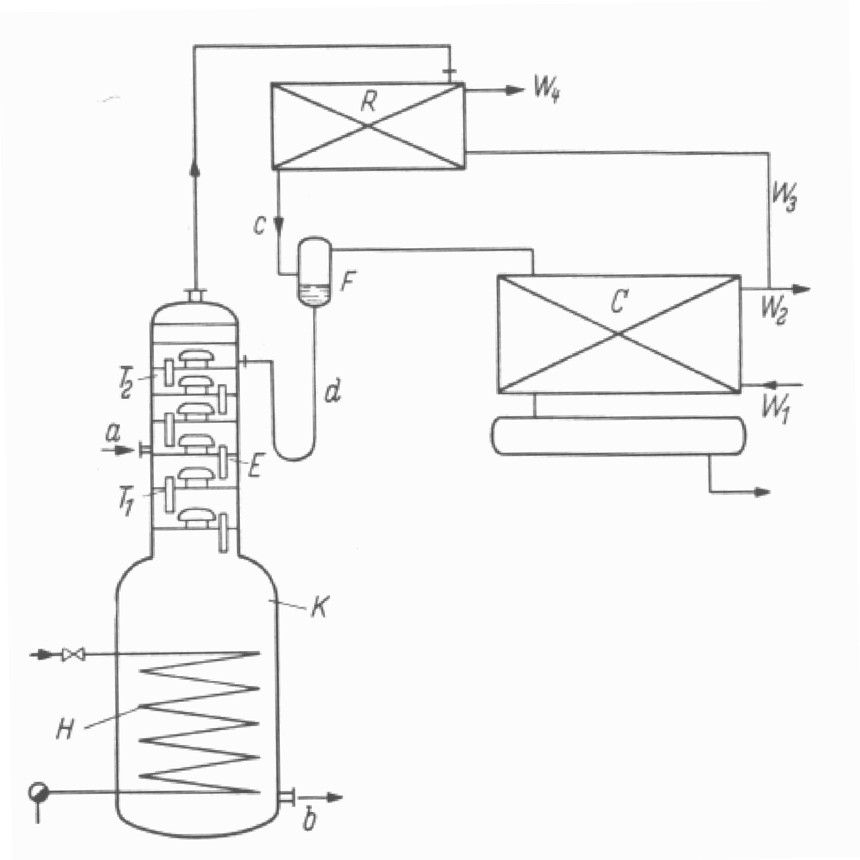


Figure 9: Generator with rectification column and dephlegmator (Niebergall, 1959)

Concerning the absorber two operating modes are available. The first option implies the refrigerant vapor and liquid solution flowing in counter-current. The vapor enters the absorber at the bottom while the poor solution enters at the top. In the absorber heat and mass transfer occurs, leading to absorption of the vapor by the solution. The liquid solution can either form a film on the heat exchange surface (falling film mode) or the absorber can be flooded while the vapor rises in the form of bubbles (bubble mode), see Figure 10. Simulative studies indicate that the bubble mode leads to a more efficient absorption and hence to a reduced required component size (Kang et al., 2000) (Castro et al., 2009).

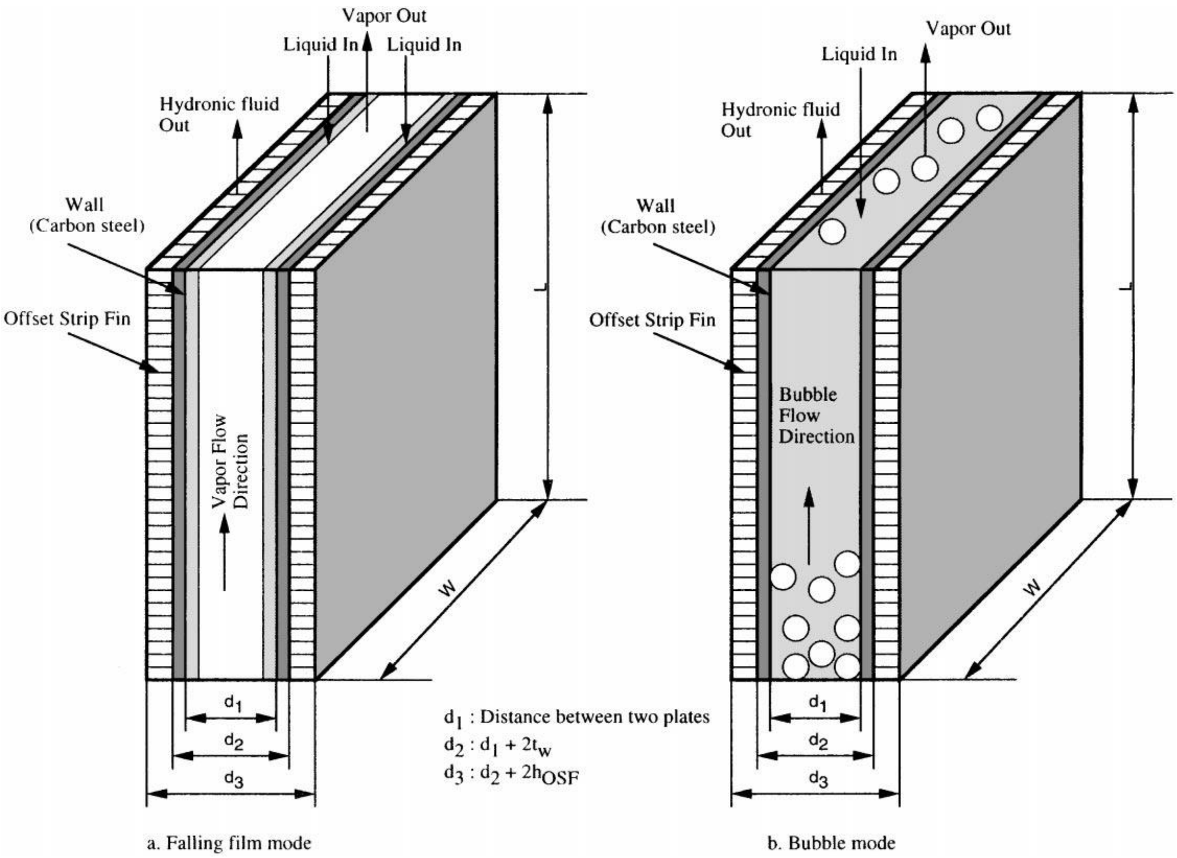


Figure 10: Falling film and bubble absorber (Kang et al., 2000)

If the second option is used, the refrigerant vapor and the poor solution are mixed before entering the absorber. Consequently they enter the absorber as a two-phase flow and the vapor is absorbed while flowing in co-current to the solution.

The solution pump is usually a diaphragm pump driven by an electric motor. This type of pump allows a hermetically sealed absorption cycle and hence reduces the risk of leakage.

2.4 Adsorption heat pumps

Adsorption heat pumps make use of a solid sorbent such as zeolite or silica gel, while mostly water serves as refrigerant. Since the sorbent cannot be circulated as it is possible in absorption heat pumps, the process is a cyclic one. In Figure 11 the two operating phases of such an appliance are shown schematically. Adsorption heat pumps basically consist of two heat exchangers, both of them changing their function depending on the respective operating phase. The desorber/adsorber contains the solid sorbent, while the second heat exchanger works as condenser and evaporator respectively. In the first operation phase the sorbent is not saturated with water, hence the desorber/adsorber acts as adsorber. On the other hand, the condenser/evaporator initially contains liquid water and fulfils the function of an evaporator. Heat required to evaporate the water is been delivered by an ambient heat source at a low temperature level. The generated vapor flows to the adsorber where it is adsorbed by the sorbent. The heat of adsorption is transferred to a heat sink, i.e. to the heat supply system, at a medium temperature. When the sorbent is saturated with water the first phase is finished and the desorption phase begins.

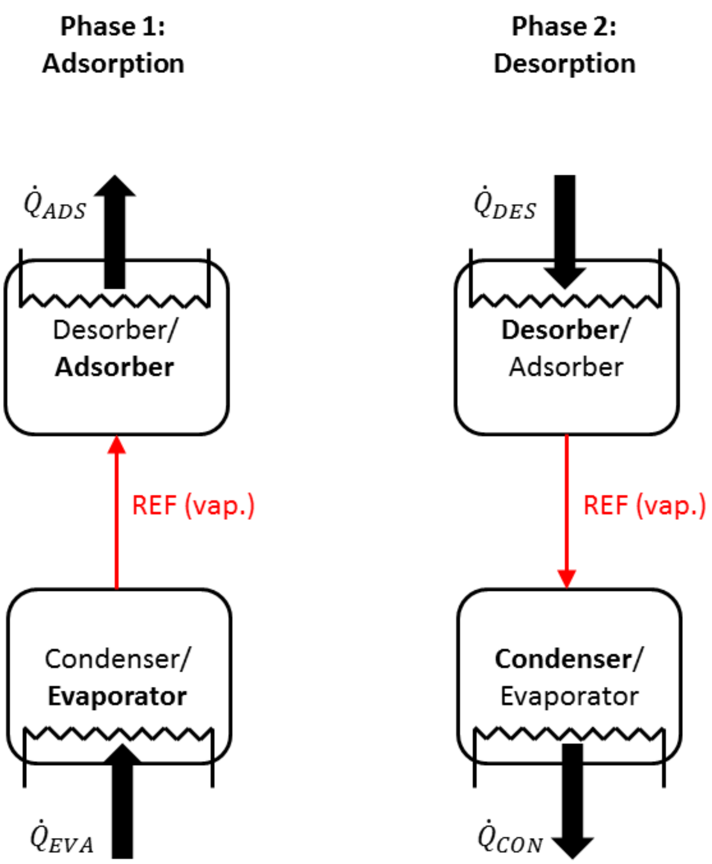


Figure 11: Functional principle of an adsorption heat pump

In this operating phase high temperature driving heat is used to regenerate the sorbent by evaporating out the water, which flows back to the condenser in vapor state. There it is liquefied while the released heat of condensation, which is available at a medium temperature level, is transferred to the heat supply system. Once the water is totally evaporated out of the sorbent, the desorption phase is completed and the adsorption phase restarts.

Note that due to the fact, that the condenser/evaporator heat exchanger has to be cooled down and heated up periodically, internal heat losses will decrease the all-over efficiency of the system. Therefore, systems with three heat exchangers (adsorber/desorber, condenser and evaporator) exist which should eliminate these problems (Dawoud, 2013).

2.5 Suppliers on the Austrian market

2.5.1 Robur

Robur is an Italian manufacturer of gas driven absorption heat pumps and chillers, which sells its products in whole Europe. The company's portfolio comprises ground (E3 GS), water (E3 WS), and air source (E3 A) absorption heat pumps with maximum heat outputs of around 35-40 kW as well as a reversible air source heat pump for both heating and cooling (E3 AR). There are two versions of the air and ground source heat pump available, one optimized for high temperature heat supply systems (HT) and one for low temperature heat supply systems (LT). The chosen process for all offered heat pumps is a modified GAX cycle as shown in Figure 7 with an internally cooled dephlegmator (see Figure 8).

Figure 12 shows a schematic of the air source heat pump E3 A. It is noteworthy that the absorber is divided into two separate parts, one being cooled by the rich solution (GAX) and one by the heating water. The latter and the condenser are combined in a single device and consequently both are cooled by heating water with the same return and flow temperature. Evaporation takes place by cooling ambient air and is supported by a fan. Technical details of the two versions (LT/HT) of the appliance are summarized in Table 1. The manufacturer states the GUE (compare Section 2.2) for different operating points in order to specify the efficiency. Operating points are specified by two letters and two numbers, with the first letter and number referring to the external source fluid and the second letter and number describing the external sink circuit. Letters denote the type of the respective fluid (A=air, B=brine, W=water), while numbers stand for the evaporator inlet temperature (in °C) in case of the source and the flow temperature in case of the sink. Accordingly, the operating point A7W50, for instance, refers to an air source heat pump with a dry-bulb temperature of the surrounding air of 7 °C and a heating water flow temperature of 50 °C.

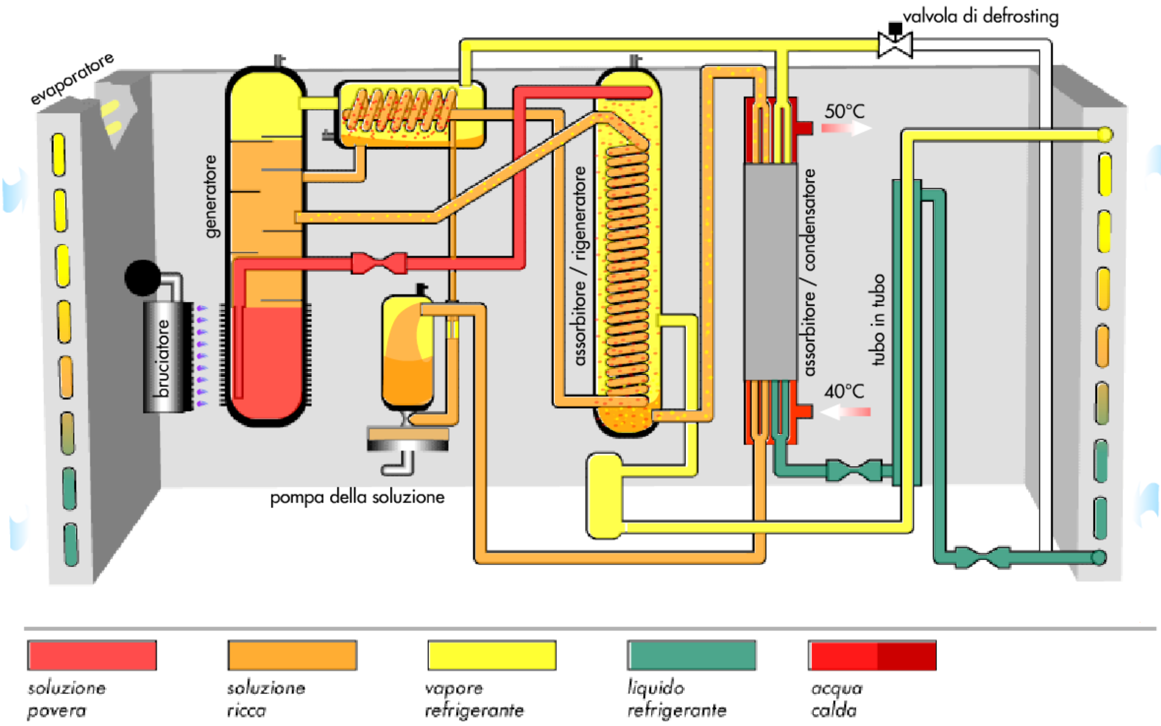


Figure 12: Schematic of the Robur E3 A (Robur GmbH, 2014)

Table 1: Technical details of the Robur E3 A (Robur GmbH, 2014)

		E3 A LT	E3 A HT
Type		Absorption	
Working pair		Ammonia/water	
Application		Heating	
Heat source		Air	
Control		Modulating	
Operating point A7W50	GUE [%]	151	152
	Maximum heat output [kW]	34,9	35,4
Operating point A7W35	GUE [%]	165	-
	Maximum heat output [kW]	38,4	-
Operating point A7W65	GUE [%]	-	119
	Maximum heat output [kW]	-	27,5
Operating point A-7W50	GUE [%]	-	125
	Maximum heat output [kW]	-	31,5
Maximum flow temperature [°C]	Central heating	55	65
	Domestic hot water	70	

A schematic of the ground and water source heat pump is depicted in Figure 13. The process is basically the same as the one of the air source version; however the evaporator is passed through by brine and water respectively, instead of air. Technical details of both the ground source and the water source can be found in Table 2 and Table 3 respectively.

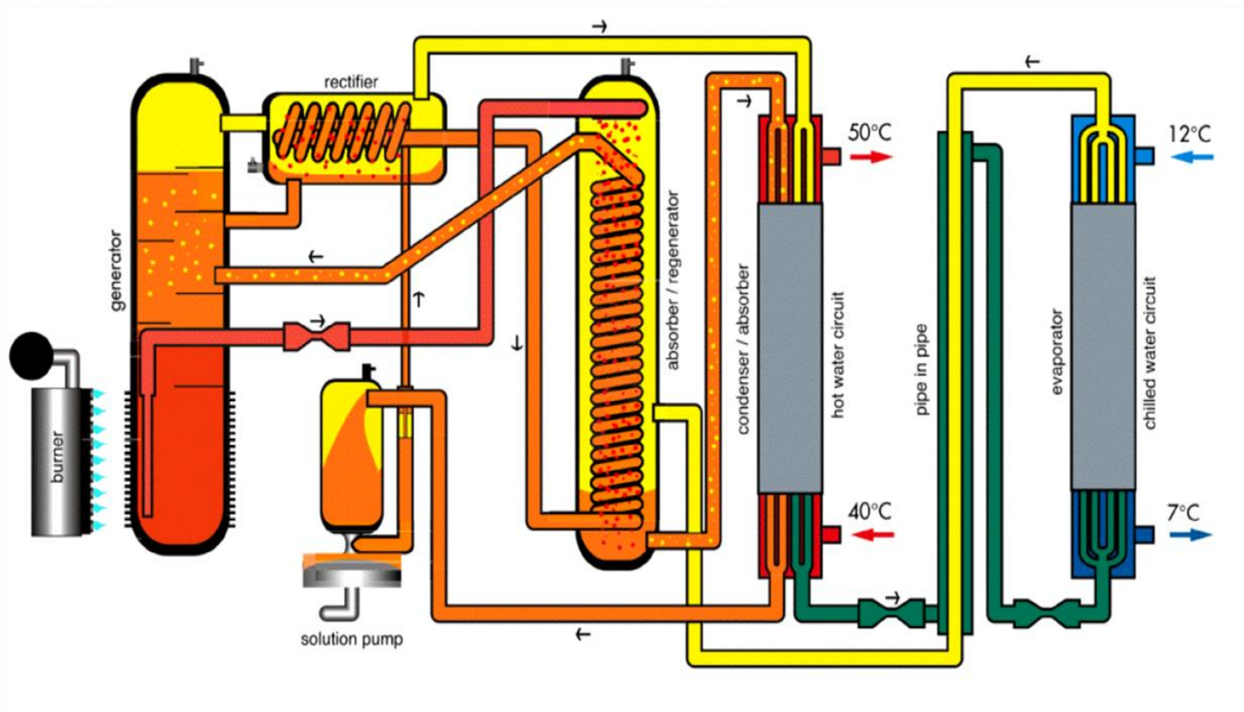


Figure 13: Schematic of the Robur E3 GS/WS (Ainardi & Guerra, 2008)

Table 2: Technical details of the Robur E3 GS (Robur GmbH, 2014)

		E3 GS LT	E3 GS HT
Type		Absorption	
Working pair		Ammonia/water	
Application		Heating	
Heat source		Brine	
Control		Modulating	
Operating point B0W50	GUE [%]	150	149
	Maximum heat output [kW]	37,7	37,6
Operating point B0W35	GUE [%]	170	-
	Maximum heat output [kW]	42,6	-
Operating point B0W65	GUE [%]	-	125
	Maximum heat output [kW]	-	31,5
Maximum flow temperature [°C]	Central heating	55	65
	Domestic hot water	70	

Table 3: Technical details of the Robur E3 WS (Robur GmbH, 2014)

		E3 WS
Type		Absorption
Working pair		Ammonia/water
Application		Heating
Heat source		Water
Control		Modulating
Operating point W10W50	GUE [%]	166
	Maximum heat output [kW]	41,6
Operating point W10W65	GUE [%]	143
	Maximum heat output [kW]	35,8
Maximum flow temperature [°C]	Central heating	65
	Domestic hot water	70

In order to allow for reversible operation with an air source heat pump the function of the heat exchangers have to be switched. While in heating mode the ambient air is used as heat source, in cooling mode it serves as heat sink. Accordingly the heat exchanger being in contact with the ambient air has to act as evaporator in the first case and as condenser/absorber in the second case. On the other hand the heat exchanger, which is the condenser/absorber during heating, becomes the evaporator during cooling. This is realized by a complex switching valve, see Figure 14. Table 4 lists specifications of the reversible heat pump. Note that the GUE for cooling –in contrast to the GUE for heating– is defined as the ratio of the evaporator capacity (cooling output) and the gas capacity.

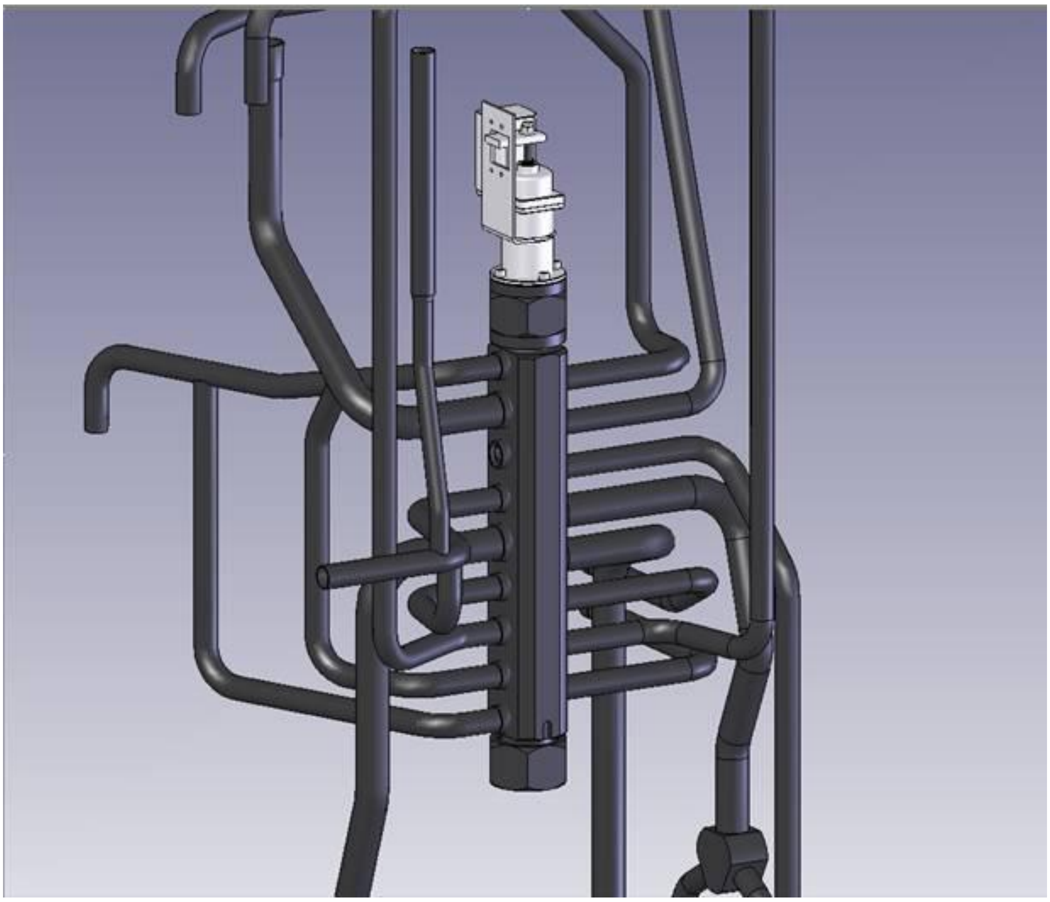


Figure 14: Switching valve for reversible operation (Ainardi & Guerra, 2008)

Table 4: Technical details of the Robur E3 AR (Robur GmbH, 2014)

		E3 AR
Type		Absorption
Working pair		Ammonia/water
Application		Heating/cooling (reversible)
Heat source/sink		Air
Control		Modulating
Heating	GUE [%]	140
	Maximum heat output [kW]	35,3
	Maximum flow temperature [°C]	60
Cooling	GUE [%]	67
	Maximum cooling output [kW]	16,9

2.5.2 Oertli

Oertli, a company with Swiss roots, sells gas driven absorption heat pumps that are based on the above described Robur devices. Correlations between the Oertli and the Robur identifiers can be found in Table 5.

Table 5: Gas driven absorption heat pumps offered by Oertli (Oertli-Rohleder Wärmetechnik GmbH, 2014) and corresponding Robur names

Oertli	Robur	Technical details
GAWP 35 LW LT	E3 A LT	see Table 1
GAWP 35 LW HT	E3 A HT	see Table 1
GAWP 40 SW LT	E3 GS LT	see Table 2
GAWP 40 SW HT	E3 GS HT	see Table 2

Complementary to those heat pumps Oertli offers different products for the realization of bivalent heat supply systems (optionally including cascades of heat pumps and/or peak boilers). Amongst those are different condensing boilers (GMR 5000, GSR 230), storage tanks that are designed especially for the use in combination with heat pumps (PS 500 WP, PS 802 WP), and a system controller (OE-tronic 4). Figure 15 shows the hydraulic diagram of such a heat supply system, consisting of two gas driven air source heat pumps, two peak boilers, a storage tank (buffer), a DHW storage, and 4 heating circuits. One of the heat pumps acts as lead heating device. In case it cannot deliver enough heat to achieve the desired temperature in the buffer tank after a defined time, the second heat pump and the two peak boilers consecutively kick in.

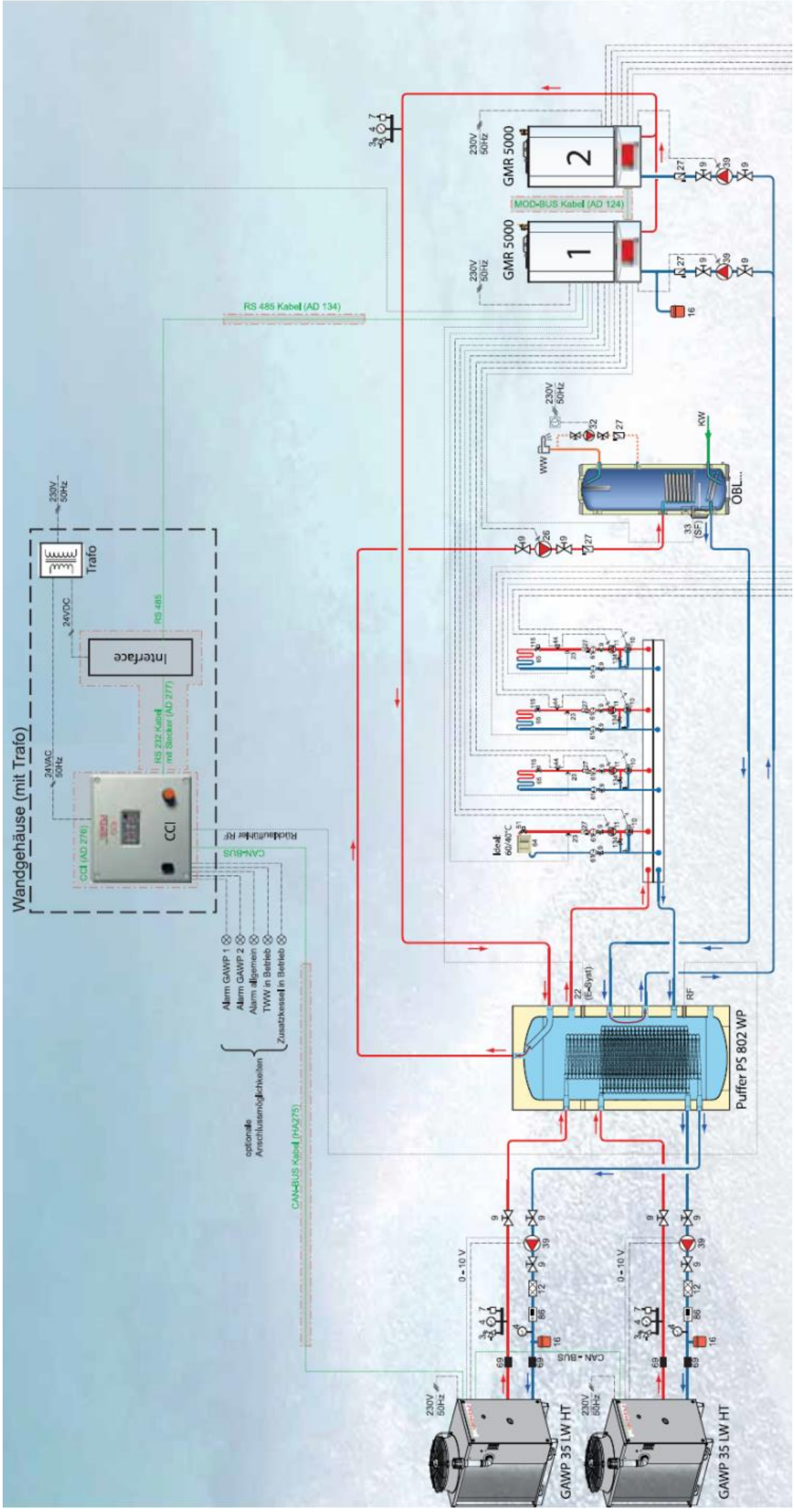


Figure 15: Bivalent heat supply system with Oertli components (Oertli-Rohleder Wärmetechnik GmbH, 2014)

2.5.3 Vaillant

Vaillant, a German heating equipment manufacturer, offers two versions of a gas adsorption heat pump for heat outputs between 1,5 and 10 kW (zeoTHERM VAS 106/4) and between 1,5 and 15 kW (zeoTHERM VAS 156/4) respectively. The working pair is zeolite/water and solar heat is used as heat source. A schematic including the adsorption and desorption phase is shown in Figure 16. Technical details can be found in Table 6. The efficiency is specified by means of the annual coefficient of performance according to VDI guideline 4650-2 (compare Section 2.2) for a heat supply system with nominal temperatures of 35 °C (flow) and 28 °C (return), respectively.

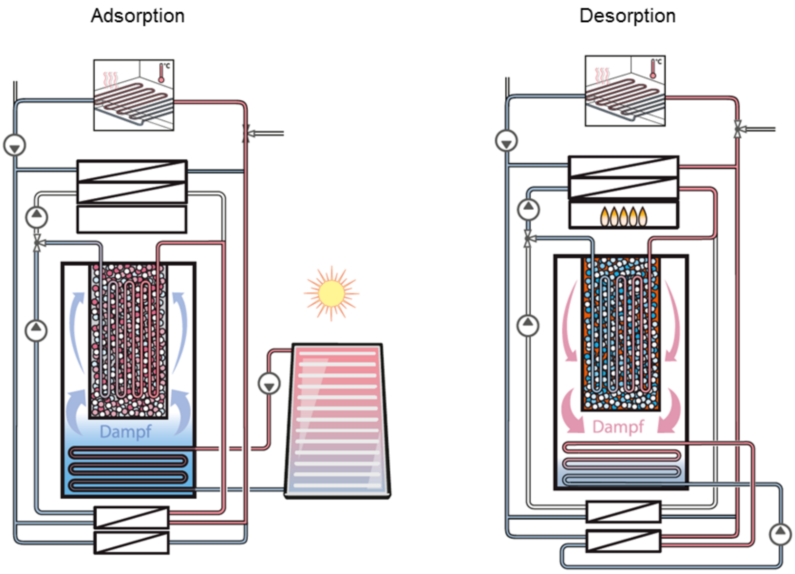


Figure 16: Schematic of the Vaillant zeoTHERM (Vaillant GmbH, 2014)

Table 6: Technical details of the Vaillant zeoTHERM (Vaillant GmbH, 2014)

	zeoTHERM VAS 106/4	**zeoTHERM VAS 156/4**
Type	Adsorption	
Working pair	Water/zeolite	
Application	Heating	
Heat source	Brine (solar)	
Control	Modulating	
Minimum heat output [kW]	1,5	1,5
Maximum heat output [kW]	10	15
Annual coefficient of performance (VDI 4650-2, 35/28°C) [%]	135	131
Maximum flow temperature [°C]	75	

The heat pump is embedded in a hybrid heat supply system, consisting of the adsorption heat pump, solar collectors, a storage tank for domestic hot water, and a solar station, see Figure 17. The installed heating system is shown schematically in Figure 18. Depending on the temperatures in the solar collectors and in the storage tank, solar heat can be used to charge the storage tank, directly for space heating, or as heat source of the heat pump. The latter (heat pump) mode is active if the temperature in the solar collector is too low for direct solar heating or charging of the storage. An integrated gas burner delivers the driving heat during desorption phase. It can also be used for direct heating in case the collector temperature is too low for heat pump operation or if the heat pump is not able to meet the total heat demand.

Figure 17: Components of the overall heat supply system (left to right: zeolite gas heat pump, solar storage, solar station, solar collectors) (Vaillant GmbH, 2014)

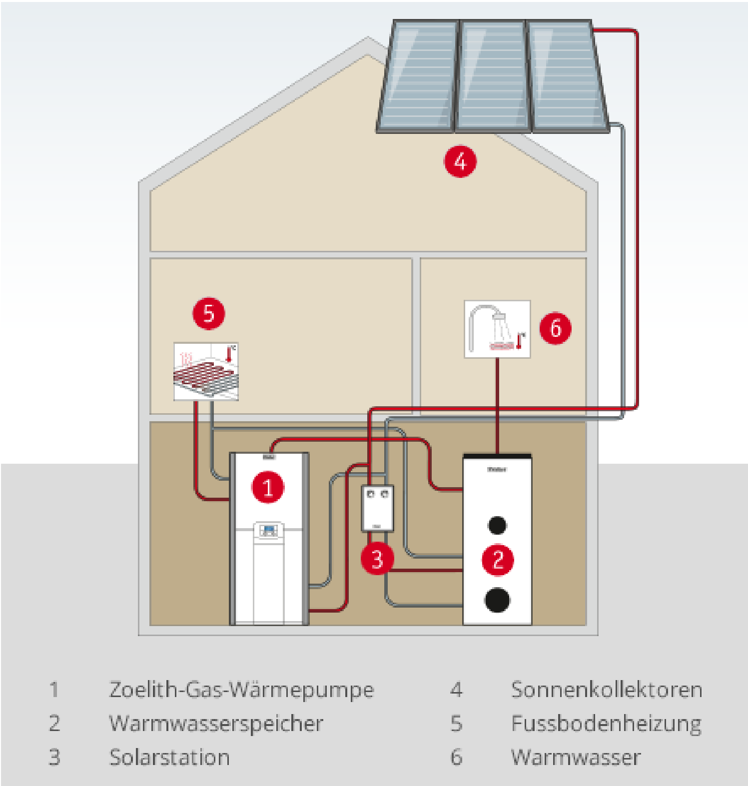


Figure 18: Installed overall heating system (Gravag Erdgas AG, 2014)

2.6 Appliances in development

2.6.1 E-Sorp/Heliotherm

Although there is a small-scale adsorption heat pump on the market (Vaillant zeoTherm, see Section 2.5.2), no absorption heat pump with a heat output below ca. 35 kW is available up to now. The Austrian company E-Sorp is currently developing such an appliance, see Figure 19. E-Sorp, a 100% subsidiary of Heliotherm GmbH, is exclusively responsible for research and development, while Heliotherm takes over distribution under its own name.

Figure 19: Pre-series unit of the E-Sorp/Heliotherm appliance (E-Sorp GmbH, 2014)

Technical details are listed in Table 7. A pre-series unit, designed as GAX cycle, showed a GUE of 174 % at the operating point B10W35 in laboratory measurements. The appliance shall be suitable to both new buildings and retrofit applications. In order to increase the maximum flow temperature (which might be necessary in the retrofit case), a boiler mode is implemented. A possible integration of the appliance into a heating system including one heating circuit, two buffer tanks, and a solar panel, is shown in Figure 20. Planned future steps include certifications (CE marking, TÜV, etc), efficiency measurements by external testing institutes, field tests, and optimization of the control system.

Table 7: Technical details of the E-Sorp/Heliotherm appliance in development (E-Sorp GmbH, 2014)

Type	Absorption
Application	Heating/cooling
Heat source	Brine/air/water
Control	Modulating
Minimum heat output [kW]	5
Maximum heat output [kW]	18
GUE (pre-series unit, operating point B10W35) [%]	174
Maximum flow temperature (boiler mode) [°C]	70

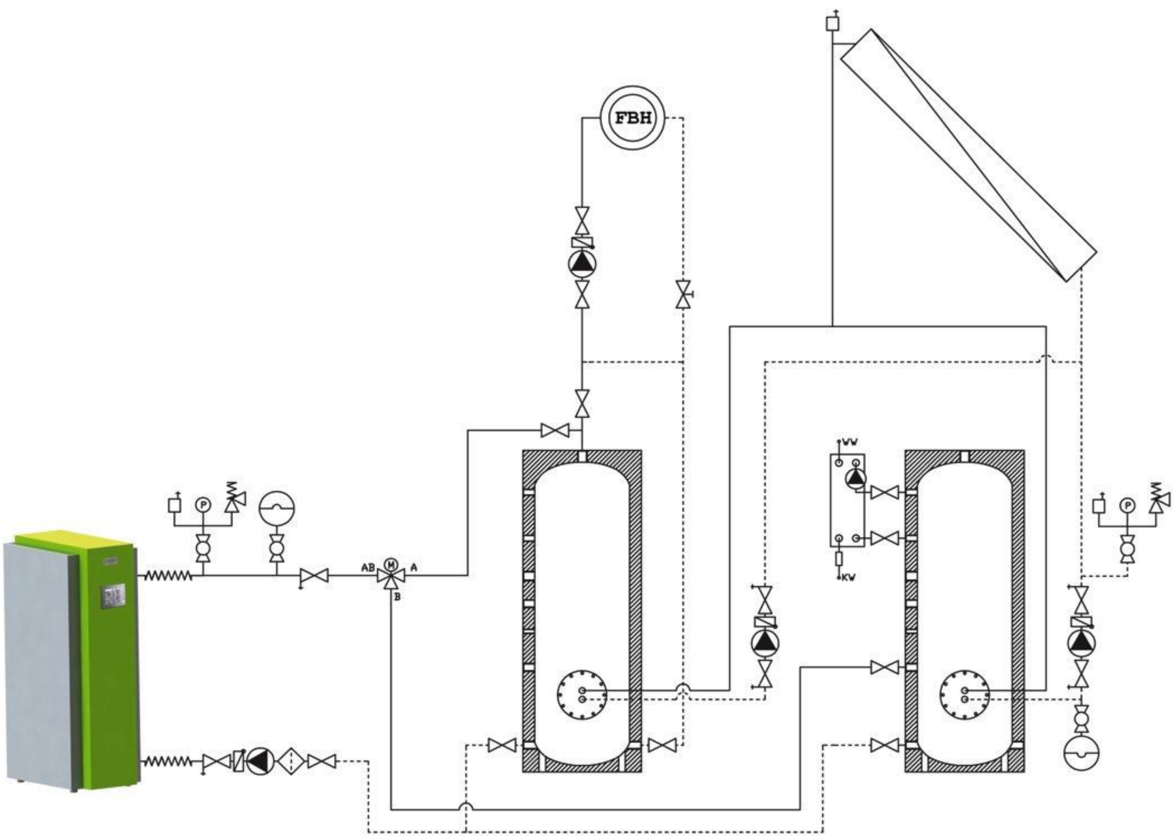


Figure 20: Possible integration into a heating system (E-Sorp GmbH, 2014)

3 Research activities

Amongst institutions in Austria that conduct research concerning sorption heat pump technology are the Austrian Institute of Technology (AIT) and the Institute of Thermal Engineering (IWT) at the Graz University of Technology. Examples of ongoing and lately completed research projects at those two institutes are listed below.

- BubblePlate - New concept of a high performance micro channel absorber for high-pressure absorption heat pumps (AIT)
- NexGen - Gas absorption heat pump of the next generation (AIT, IWT)
- ThermoPump - Thermally driven solution Pump (IWT)
- Inert Gases – Thermal decomposition and corrosion in NH_3/H_2O heat pumps (IWT)

In the following those projects are described in detail.

3.1 BubblePlate

The aim of the project was to design, build and test a more efficient but at the same time inexpensive absorber for ammonia absorption heat pumps and cooling devices. Whereas research and design were done at AIT, the testing was carried out by two Austrian industrial companies, Pink GmbH and Heliotherm GmbH, which were part of the consortium. The basic design was a channel plate heat exchanger run in bubble mode. The whole system should have had a capacity from 5 to 50 kW (Austrian Institute of Technology, 2014).

3.2 NexGen

This project is a cooperation between the AIT, the IWT, and the Austrian company E-Sorp GmbH. The goal is an evaluation of different GAX implementations (for examples see Figure 6 and Figure 7) for small-scale absorption heat pumps with respect to their efficiency. Additionally control strategies for such an appliance shall be developed.

Based on simulations of possible GAX cycles, the concepts promising the most interesting potential to improve the system’s efficiency are identified. Subsequently selected concepts are built as laboratory prototypes in order to validate the simulation assumptions and collect experimental data (see Figure 21). Finally a prototype including a control system shall be constructed offering the possibility to test the appliance’s performance related to its efficiency and control behavior.

Figure 21: A combined generator-absorber set-up to verify the simulations in the NexGen Project.

3.3 ThermoPump

The goal of this project, which is a cooperation of the IWT and the two Austrian companies Pink GmbH and Heliotherm GmbH, is the development of a thermally driven solution pump as an alternative to the nowadays common electrical solution pump in absorption heat pumps. Possible advantages of such a concept are lower operating costs and independency from the electrical net on the one hand side and a more robust pump due to the absence of power transmission devices (such as a shaft) on the other hand side (Zotter et al., 2011).

Figure 22 shows a thermally driven solution pump integrated in an absorption cycle. A portion of the refrigerant bypasses the cooling circuit (condenser, refrigerant throttle, and evaporator), but is expanded in the thermo pump instead. In doing so, energy, which is used to increase the rich solution’s pressure, is released. As this refrigerant does not contribute to the evaporator capacity, the efficiency of the heat pump is reduced. On the other hand the use of electrical energy, which is more valuable from an exergetic point of view and also more expensive than heat, can be avoided.

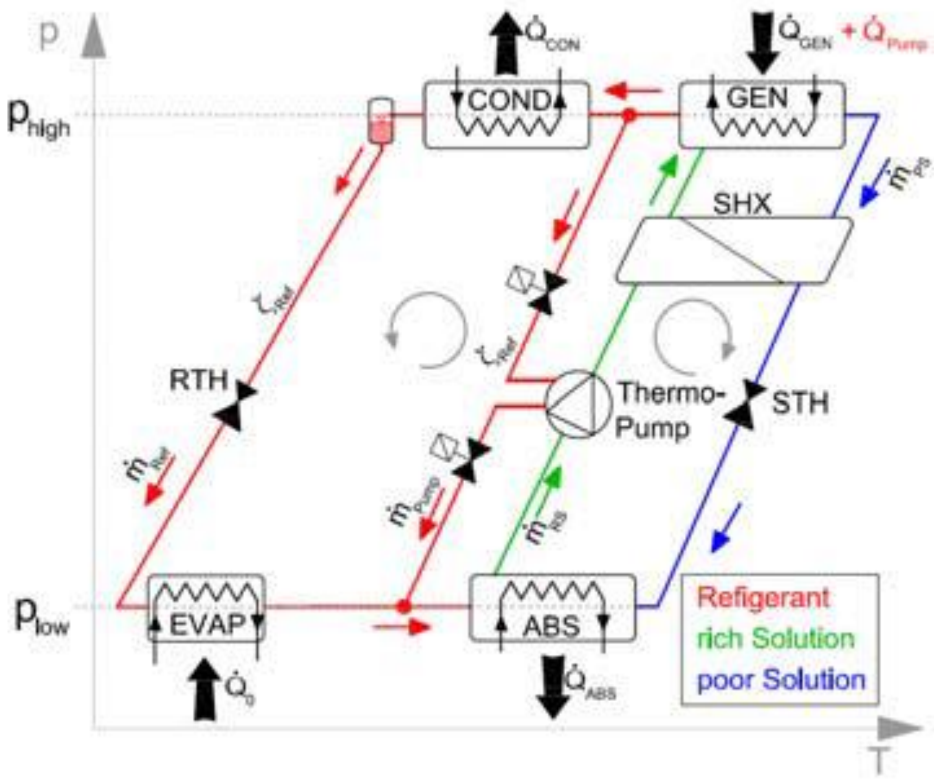


Figure 22: Thermally driven solution pump as part of the absorption cycle (Zotter & Rieberer, 2013)

3.4 Inert Gases

This project was executed within the framework of IEA HPP Annex 34. For detailed information see the according report (Rieberer et al., 2013). The scope was an experimental examination of the formation of inert gases in ammonia-water absorption heat pumps by both corrosion and decomposition of ammonia. The goal was to quantify the formed inert gases depending on temperature as well as used materials, surface treatment, inhibitors, and water quality.

For that purpose a test rig was built (see Figure 23) in which the desorption and absorption process of NH3/H2O mixtures are reproduced under similar conditions as in absorption heat pumps. Different materials can be positioned in the solution and the desorber (generator) temperature can be controlled by means of an electric heater, so that tests concerning corrosion and decomposition behavior can be performed. Additionally 16 autoclaves were produced using 4 different materials and 4 different surface treatment procedures, filled with NH3/H2O solution, and placed in an oven at a defined temperature for a certain time.

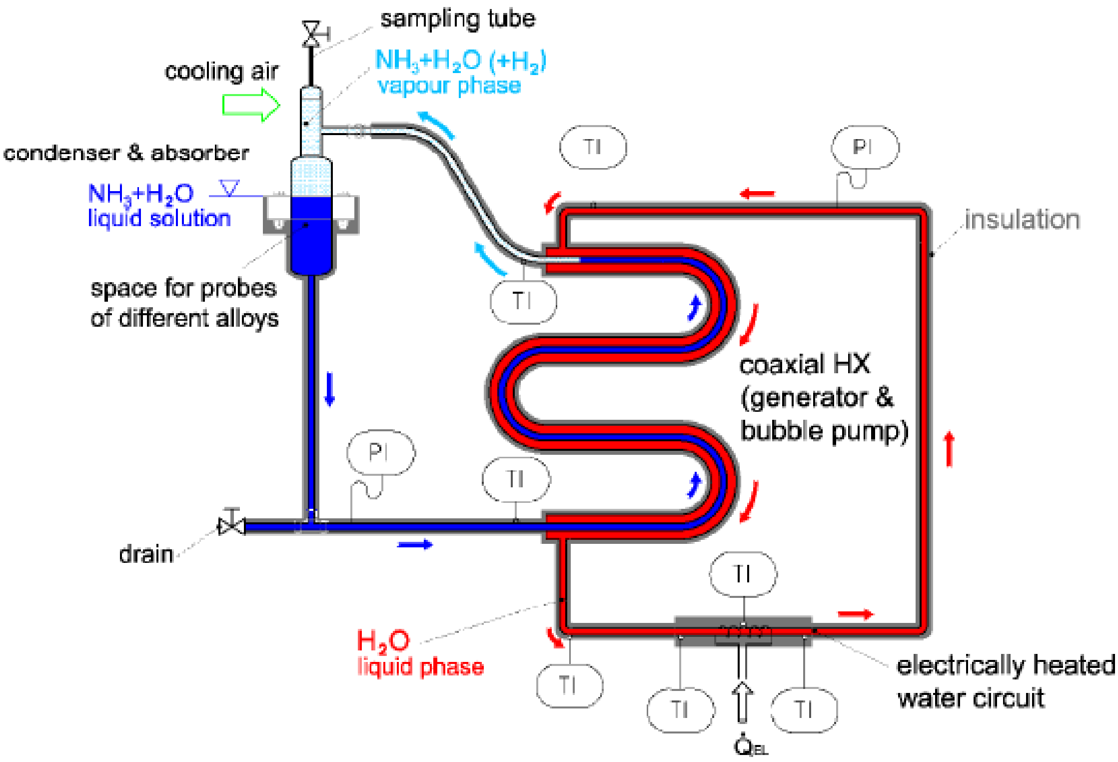


Figure 23: Schematic of the decomposition test rig (Rieberer et al., 2013)

Probes from the gas phase in the test rig and the autoclaves were taken, gaseous NH3 contained in the probe was washed out, and eventually the probe was analyzed with a gas chromatograph. As hydrogen is formed by both corrosion and decomposition while nitrogen is only formed by decomposition, the origin of the inert gases can be determined quantitatively considering the according reaction equations.

The following observations were made:

- No significant amounts of nitrogen were measured up to 290°C. Hence no decomposition takes place at those temperatures and the present hydrogen was formed exclusively by corrosion.
- Considerable less amounts of hydrogen were measured when using carbon steel instead of stainless steel.
- The production of hydrogen was high at the beginning of the tests and dropped significantly over the course of time.
- The water quality seems to have no effect on the formation of inert gases.
- Two chrome free inhibitors were tested and both showed a slightly positive influence on the avoidance of inert gases.

4 Conclusion

This report discusses the state-of-the-art of gas driven absorption heat pumps for space heating and domestic hot water as well as related research projects in Austria. A general overview of sorption heat pumping technology is given, appliances that are on the market are presented, and research projects are described.

There are sorption heat pumps with different heat outputs commercially available. Robur and Oertli offer absorption heat pumps with a maximum heat output around 35-40 kW for several heat sources, such as ground, water, and air. Additionally a reversible heat pump for both heating and cooling can be purchased. Lower maximum heat outputs (10/15 kW) are covered by the Vaillant zeoTHERM, an adsorption heat pump with solar energy as heat source, which is part of a hybrid heat supply system containing solar collectors and a storage tank. Furthermore an absorption heat pump with similar maximum heat output (18 KW) is under development (E-Sorp/Heliotherm).

Research is conducted by the Austrian Institute of Technology (AIT) and the Institute of Thermal Engineering (IWT) at the Graz University of Technology. Ongoing and lately completed projects deal with newly designed or optimized components (BubblePlate), evaluation of the potentials of different GAX cycles (NexGen), the development of a thermally driven solution pump as an alternative to the common electrically driven ones (ThermoPump), and the formation of inert gases by corrosion and decomposition phenomena.

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