15TH IEA HEAT PUMP CONFERENCE
MAY 26–29, 2026 | HOFBURG
VIENNA 2026
DECARBONISATION THROUGH INNOVATION

Heat pumps with solution cycle for high temperature applications - natural refrigerants, high efficiency, wide range of applications

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Abstract

Heat pumps with solution cycle are a relatively unknown technology for industrial heat supply and district heating. These heat pumps work with ammonia and water. These natural refrigerants have no greenhouse effect and do not contain PFAS, which means long-term planning security. Thanks to their special thermodynamic cycle, they can provide heat at temperatures of up to 160 °C. In addition, they achieve very high efficiency in applications with large temperature spreads on the heat source and heat sink sides.

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Selection and/or peer-review under the responsibility of the organizers of the 15th IEA Heat Pump Conference 2026.

Keywords: ammonia;Osenbrück cycle; Caldora; absorption; natural refrigerant; efficiency; temperatur spread;high temperature heat pump; industrial heat pump;

1. Introduction

In a conventional heat pump, a refrigerant is evaporated at low pressure by absorbing heat from a heat source. The vaporous refrigerant is then compressed from low pressure to high pressure with a refrigerant compressor. At high pressure, the refrigerant condenses, giving off heat to a heating medium at high temperature. The then liquefied refrigerant is expanded again from high pressure to low pressure by an expansion valve to close the thermodynamic cycle.

In a heat pump with solution cycle, such as the AGO Caldora, the heat exchanger for cooling the heat source is not called an evaporator, but a generator. A solution of ammonia and water is heated in this heat exchanger. The lower-boiling ammonia partially evaporates as a result, with the water remaining liquid. The two phases are separated in a separator that follows. As usual, a refrigerant compressor compresses the refrigerant vapor from low pressure to high pressure. In parallel, a solution pump pumps the ammonia-poor solution from low pressure to high pressure. Both streams are then fed into the absorber together. In this heat exchanger, the ammonia vapor dissolves again in the aqueous solution. This process is called absorption and is an exothermic process. The resulting heat is transferred to the heating medium. The solution, which is then rich in ammonia again, is expanded from high pressure to low pressure in a throttle valve in order to close the cycle.

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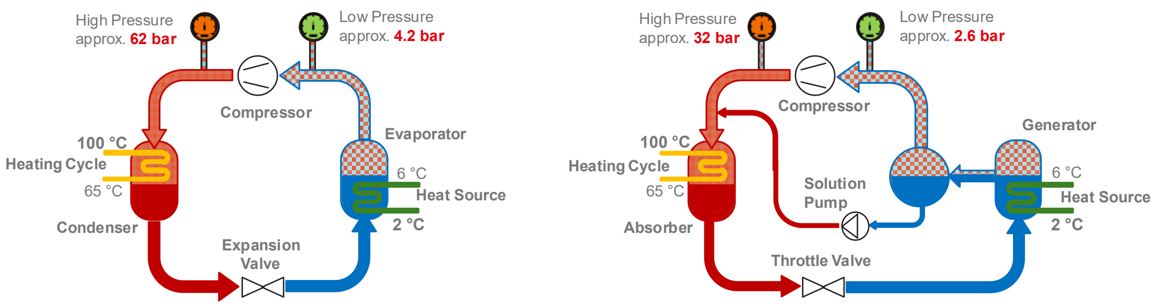

Compression	Process	Compression/Absorption
Ammonia	Refrigerant	Ammonia/Water
14.8	Pressure Ratio	12.3
2.3	COP	2.8

Figure 1. Comparison of heat pumps cycles.

The water content binds the ammonia even at higher temperatures. This means that, depending on the water content, the pressure level is significantly lower than in heat pumps that use pure ammonia as a refrigerant. An ammonia/water solution exhibits a very pronounced temperature glide during phase change. By adjusting the ammonia concentration, the degassing range, the solution circulation and the extent of the temperature glide can be influenced. In applications with a pronounced temperature spread on the heat source and/or heat sink side, a pressure ratio that is 20 to 30% lower than that of heat pumps with a refrigerant without temperature glide can be reached. Since the pressure ratio is proportional to the compressor's power consumption, heat pumps with a solution circuit also achieve a 20 to 30 % higher COP in such applications (Fig 1).

2. Influence of temperature spreads

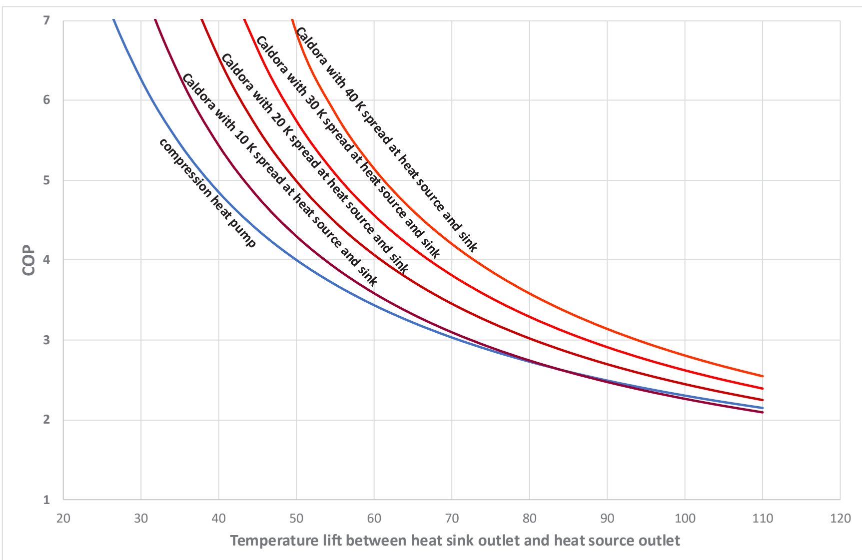

Figure 2. Comparison of heat pumps cycles.

The spread on the heat source and heat sink side has an enormous influence on the efficiency and selection of the most economical heat pump technology. Heat pumps with a solution circuit are more expensive than conventional ammonia heat pumps due to their more complex cycle. However, under certain circumstances, they achieve significantly higher COPs and higher temperatures. If the average temperature spread of the heat source and heat sink is around 10 K, a heat pump with a solution circuit is not significantly more efficient than alternative heat pump technologies. However, it is considerably more expensive. In applications with an average temperature spread significantly above 30 K on the heat source and heat sink side, however, the efficiency is significantly higher. However, it is generally accepted that the temperature lift has a greater influence than the spread and the heat pump technology. Therefore, the aim should always be to reduce the temperature lift as much as possible (see Fig. 2).

3. Application example: Drying process

The properties of a heat pump with a solution circuit prove advantageous in many applications, e.g. in drying processes. Drying processes such as brick drying, malt production, paper production, wood drying and many more can be decarbonised in future with the aid of heat pumps. The moist, warm exhaust air from the dryer is usually discharged unused through the roof. This exhaust air contains almost all of the energy from the drying process in the form of water vapour. Since the temperature of the exhaust air is usually higher than that of environmental heat sources, this moist, warm exhaust air represents a very interesting heat source.

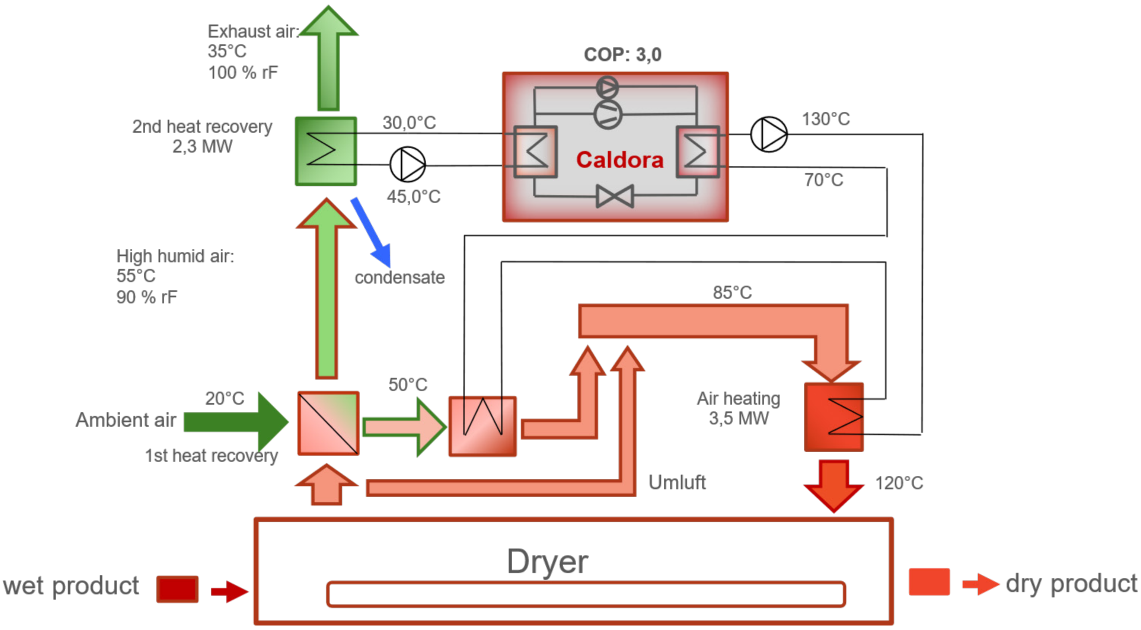

Figure 3. Heat pump for drying processes

The heat pump cools the warm, humid exhaust air to the dew point, thereby recovering the condensation heat and raising it back to a temperature level at which the dry supply and recirculating air of the dryer can be heated (see Fig. 3).

4. Application example: Heat pumps in combination with deep geothermal energy plant for district heating

Geothermal energy is a sustainable technology for decarbonising district heating networks. In many regions of Europe, there are aquifers at depths that can be reached by drilling, with temperatures ranging from 50 °C to over 120 °C in some cases. This hot thermal water can be used to supply district heating networks. Central European district heating networks often have a return temperature of around 60 °C. Through direct heat transfer with the thermal water, this can be cooled to just over 60 °C. By combining it with a heat pump, the thermal water can be cooled significantly further, increasing the geothermal output by up to 100%. If the heat pump is not only connected in parallel but also switchable in series to the thermal water heat exchanger, it can additionally increase the temperature, e.g. in winter when high flow temperatures are required. Since large temperature spreads occur on the heat source side and on the heat sink side in such applications, heat pumps with a solution cycle achieve very interesting COPs (see Fig. 4.).

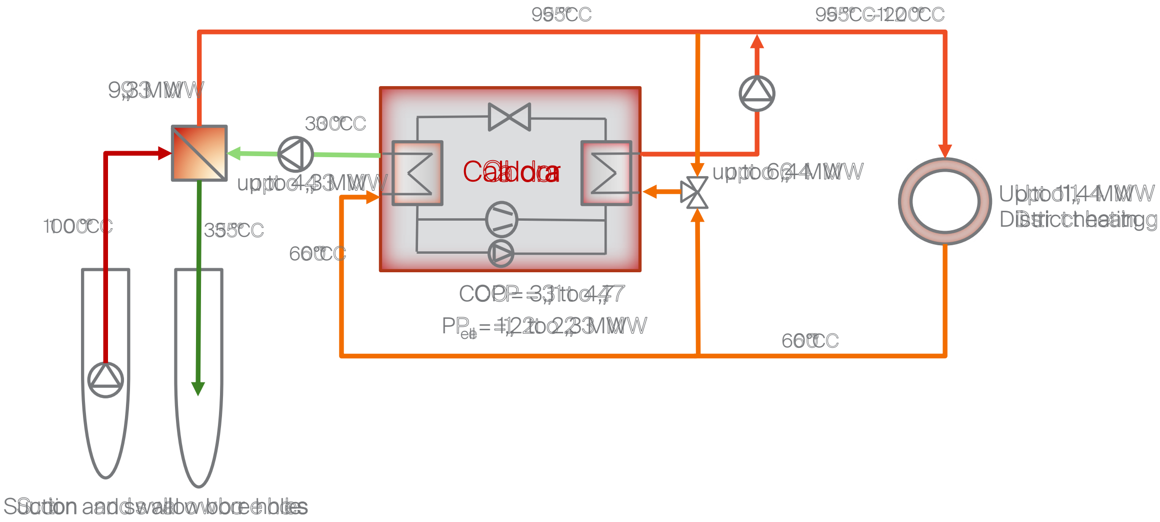

Figure 4. Heat pump with geothermal bore holes for district heating

5. Application example: Steam generation for paper industry

Heat pumps with a solution cycle are also suitable for generating steam. If the heat source is significantly below 80 °C, it often does not make sense for technical and economic reasons to generate steam in vacuum, which would then have to be brought up to the nominal pressure through often multi-stage mechanical steam compression (MVR). Due to the low density of steam under negative pressure, such systems often become uneconomically large. A multi-stage heat pump combination offers an alternative to this. In an example of steam generation for the paper industry, this could look as follows:

The heat pump cools the moist, warm hood exhaust air below the dew point, thereby recovering the energy contained in the exhaust air. A heat pump with a solution circuit can then use this heat to generate steam at a pressure of approx. 1.5 bar a. A steam compressor can then compress this low-pressure steam to the pressure level required by the process. At a steam pressure of approx. 1.5 bar, the density of the steam is significantly higher than in the vacuum range, which is why such a combination often offers advantages over pure steam compression from the vacuum (see Fig 5.).

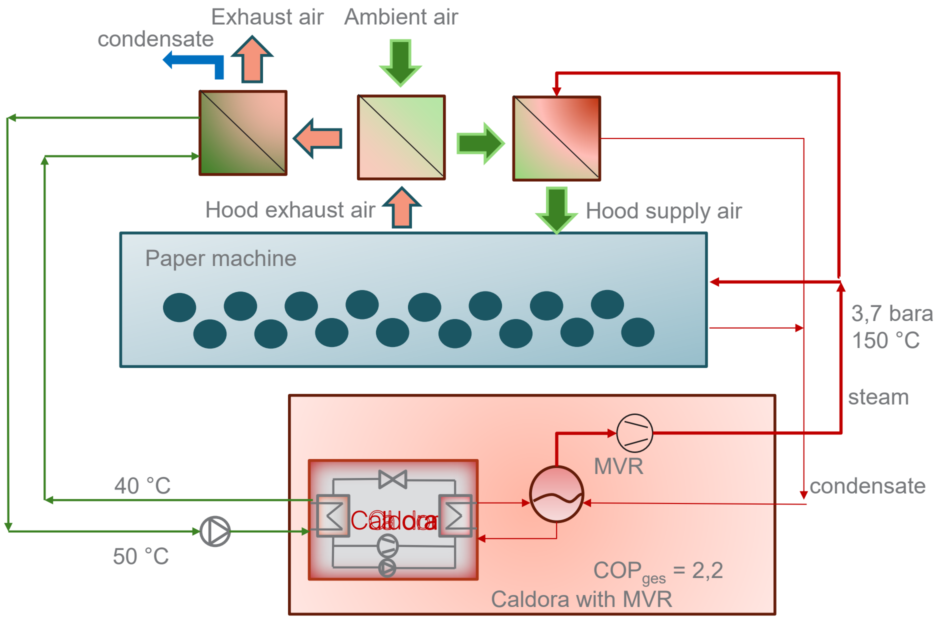

Figure 5. Heat pump with geothermal bore holes for district heating

6. Conclusion

Due to the specific thermodynamic cycle, heat pumps with solution cycle have specific properties.

Heat pumps with solution cycle:

- work with the natural refrigerants ammonia and water
- can reach high water supply temperatures up to 160 °C
- can supply steam and in combination with MVR steam pressures until 10 bar
- can reach unique high COPs at applications with big temperature spreads on heat sink and heat source side.
- are beneficial for many district heating and industrial applications
- use standard components from the refrigeration industry
- can economically offered in the capacity range of 1 MW to approx. 10 MW