Background

**Heat pumps with natural refrigerants – energy-efficient technology with future prospects**

The Organisation of Petroleum Exporting Countries (OPEC) expects that around 150% more energy will be needed by 2032 compared to today\(^1\). The growing demand also means higher oil prices and therefore higher costs for the users. The issue of heating costs in particular makes companies literally break out in a sweat. They need energy for water heating, for air-conditioning in offices and workrooms or for manufacturing processes.

Heat pumps constitute one possibility for efficient management of necessary heat energy. Energy can be saved in particular by those applications that are coupled to heat recovery from industrial processes. Waste heat generated in this way can be put to profitable use in the building – a potential that was scarcely used for a long time. “Heat pumps operated with natural refrigerants such as ammonia (NH\(_3\)) are also particularly environment-friendly”, remarks Thomas Spänich, Member of the Board at eurammon, the European initiative for natural refrigerants. “In contrast to synthetic refrigerants, they have either no or only a negligible global warming potential. Heat pumps with natural refrigerants are already being used for cost- and energy-efficient operation. They can be planned and implemented individually depending on the requirements of the particular building and the customer’s specific needs. The market for heat pumps can therefore expect to see further strong growth in the near future.”

**Energy-efficient district heating for Sarpsborg, Norway**

GEA Refrigeration Germany developed a completely new 2 MW heat pump installation for the energy provider Bio Varma Sarpsborg AS in Norway to heat water up to +82°C for the municipal district heating network. The heat pump uses two different waste heat sources to keep energy costs as low as possible. 1.5 MW of power comes from recooling +45°C warm cooling water from a refrigeration system serving the municipal waste incineration plant, with a further 3 MW supplied in the form of +38°C warm water from a biological sewage plant.

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Initially the water is heated using the hot oil in the oil separator. But most of the work is performed by the condenser at a condensation temperature of +82°C maximum. The last few degrees then come from a superheater fed by +105°C hot gas on the jacket side.

The special feature of the large-sized ammonia heat pump is the components that are used. For the first time, this kind of system has been equipped with two large oil filters and an oil pump with an 18.5 kW motor capable to pump just about 900 l/min. GEA has also provided a 1,200 kW high-voltage motor and a frequency converter for motor and oil pump. The centrepiece of the system consists in an R-series high-pressure compressor. However, the high-pressure side of the system had to be rated for a pressure level of 52 bar on account of the high condensation temperatures. This resulted in the need for new components, pipes and mouldings to be procured and in some cases even specially designed. The system started operating in September 2010 and has been running perfectly ever since.

**Combined cooling and heating in Fleischtrocknerei Churwalden (meat drying plant), Switzerland**

Fleischtrocknerei Churwalden AG produces organic quality meat products. Environment-friendly production is part of the corporate philosophy; this also includes ecological efficiency of systems and premises. The refrigeration professionals from SSP Kälteplaner developed a sustainable heating and cooling system for the meat processing centre in Landquart (Switzerland), using heat pumps and refrigerating machines that run on the natural refrigerants ammonia and carbon dioxide. The central aspect of heat generation and refrigeration consists in making energetic use of the groundwater stream of the Alpine Rhine plain. Catchments and groundwater pumps take water from the groundwater stream and then return it in thermally changed state. The energy gained in this way – refrigerating or heat energy, as required – is brought to the required temperatures by refrigerating machines and heat pumps for a wide range of uses.

The production and administration buildings need thermal energy at different temperatures. Heat energy of altogether around 950 kW is needed on two different temperature levels: at medium temperatures of about +60°C as process energy among others for climatic chambers, hot process water or container washing machines, and at lower temperatures of up to +40°C as heat energy for heating purposes, for dehumidification, for pre-heating hot process water and for defrosting the cold storage rooms.

A refrigerating plant capacity of 1,200 kW is needed for maintaining temperatures around freezing point for workrooms, and also for temperatures of -8°C in chilled storage rooms and maturing plants, as well as temperatures of -25°C in the deep-freeze storage rooms.
A two-stage ammonia heat pump is used for heating purposes according to the different temperature levels, using groundwater at +12°C and +8°C. Each stage is fitted with two York/Sabroe reciprocating compressors, which are regulated in a stepless manner by frequency changers. Cassette-welded plate heat exchangers by Alfa Laval are used as evaporators and condensers. The ammonia charge in the heat pump amounts to approx. 300 kg. The production systems are rated for temperatures in the medium range of +60°C. The motor waste heat and compression heat from the compressed air and vacuum generation system is fed directly into the system, while the ammonia heat pump generates the necessary remaining energy. The ammonia heat pump also plays a supportive role at the lower temperature level of +40°C and generates the necessary remaining energy. The “warm” groundwater basin acts as heat source.

Consistent use is made of any generated waste heat. Where possible, it is fed directly into the heat distribution system and distributed again immediately. This is used for cooling motors, including those used for example for generating compressed air or in the central vacuum system. Waste heat on the lower level is dissipated into the “warm” groundwater basin. This includes condensation waste heat from the refrigeration and tool cooling at the packaging machines in the framework of the cooling water circuit.

Two ammonia refrigerating machines are responsible for refrigeration and are cooled with groundwater. After cooling, the water is fed to the “warm” groundwater basin. When the need arises, the heat pump can bring the waste heat from the basin up to a higher temperature. Refrigerating energy of 0°C and -8°C is generated in each case by a refrigerating machine using NH₃ as refrigerant and two industrial reciprocating compressors. One of the respective compressors in each case is equipped with a frequency changer. The energy is transported to the refrigeration sites using a water/glycol blend as secondary refrigerant. The recooling energy is taken from the “cold” groundwater basin. Exchanging the water from the heat pump to the refrigerating machine and vice versa achieves maximum efficiency ratios, while keeping the drive motors and refrigerant circuits as small as possible. Buffer storage facilities with a volume of 30,000 l each have been installed for both secondary refrigerant networks in order to optimise operations.

The natural refrigerant carbon dioxide is used in the deep-freeze storage rooms. The refrigerant is evaporated directly with electronic expansion valves in the room chillers, before passing to the reciprocating compressor where it is liquefied to subcritical state in a cascade condenser. The waste heat from the systems is dissipated to the glycol network at a temperature of -8°C where the heat can be put indirectly to further use.
In summer, needed cooling energy is taken from the “cold” groundwater basin and used directly for room cooling in ventilation systems, cooling ceilings or in server rooms. Apart from the pump conveying energy, no primary energy is used for air-conditioning refrigeration.

**Heat pump supplies chocolate factory with hot water free of cost**

In 2010, refrigeration professionals Star Refrigeration won an order from Nestlé to develop a heat pump solution for a chocolate factory in the British branch in order to bring about significant reductions in the energy costs for refrigeration and heating applications. It replaced existing R22 packaged chillers and a central coal-operated steam generation unit which supplied all terminal devices and systems using and dissipating hot steam during their work processes. The new concept entailed taking waste heat from the cooling circuit and boosting it to provide process water heating up to the required temperature. Star Refrigeration's “Neatpump” heat pump was to provide water up to a temperature of +60 °C which was to be fed as preliminary heat also to processes needing higher temperatures.

Given the food manufacturer's commitment to keeping its carbon emissions as small as possible, above all, environment-friendly heat pump technology had to be used here. But apart from the fact that heat pumps were still mainly operated with HFCs, for the most part any system using natural refrigerants uses reciprocating compressors or screw compressors, which caused high maintenance costs or worked constantly at their limit.

In cooperation with Vilter Manufacturing Inc. (USA) and Cool Partners (DK), Star Refrigeration developed a high-pressure heat pump solution that works both with ammonia as an environment-friendly, highly energy-efficient refrigerant and also with screw compressors to a temperature of +90 °C. The system offers a convenient solution for extracting the waste heat at -5 °C from the glycol as the secondary refrigerant from the refrigeration process and raising this to the main heating demand at +60 °C. A new gas-fired boiler is used to increase the +60 °C water temperature for a number of smaller heating demands on site.

The heat and refrigeration load profiles of the existing systems ascertained in advance showed that the heat pump compressors had to generate about 1.25 MW of high temperatures to satisfy the total demand for hot water. The new solution was therefore chosen with 914 kW refrigeration capacity and 346 kW absorbed power rating from the waste heat. The COP in the framework of combined refrigeration/heating application (COP_{hc}) is a moderate 6.25. The additional energy required to raise the condensing temperature from design summer ambient conditions with air cooled condenser to a temperature suitable for
+60°C hot water production was only 108 kW. This results in an incremental COP\textsubscript{hc} (energy to create +60°C water minus energy to reject cooling load heat at design conditions) of 11.57.

Using the waste heat from the refrigeration applications pays off for Nestlé: Since starting operations in May 2010, the system uses and heats around 54,000 litres of municipal water per day, thus saving around £30,000 in gas costs each year. Since the end of 2010, the site has also been using a further 250 kW in waste heat for its self-contained cooling circuits. The heat provided by the system even doubled by the middle of last year. In this way, the company saves an estimated approx. £143,000 in heating costs while reducing its carbon emissions by 119,100 kg. Moreover, the costs for electrical operation of the plant are reduced by around £120,000 p.a., despite combined refrigeration and heat generation.

**Heat pumps with natural refrigerants on the advance**

Heating and energy consumption are topics of interest not just to industry: Home owners are also on the look-out for suitable technologies for keeping overheads as low as possible and saving energy. “Hot water heat pumps using CO\textsubscript{2} as refrigerant are particularly interesting”, says Thomas Spänich. “They can make full use of the characteristics of the supercritical refrigerant process. Optimum adjustment to the heating up process permits excellent performance ratios with very high water output temperatures of up to +90°C in some cases”, the member of the eurammon Board continues. “In Germany, this solution has only seen isolated use hitherto. By contrast, in Japan the Japanese government subsidises purchases of CO\textsubscript{2} heat pumps so that around two million units had been sold throughout the country already by the end of 2009. This number should reach 10 million by 2020.”
Annex

Ammonia (NH₃)
Ammonia has been successfully used as a refrigerant in industrial refrigeration plants for over 100 years. It is a colourless gas, liquefies under pressure, and has a pungent odour. In coolant technology, ammonia is known as R 717 (R = Refrigerant) and is synthetically produced for use in refrigeration. Ammonia has no ozone depletion potential (ODP = 0) and no direct global warming potential (GWP = 0). Thanks to its high energy efficiency, its contribution to the indirect global warming potential is also low. Ammonia is flammable. However, its ignition energy is 50 times higher than that of natural gas and ammonia will not burn without a supporting flame. Due to the high affinity of ammonia for atmospheric humidity it is rated as “hardly flammable”. Ammonia is toxic, but has a characteristic, sharp smell which gives a warning below concentrations of 3 mg/m³ ammonia in air possible. This means that ammonia is evident at levels far below those which endanger health (>1,750 mg/m³). Furthermore ammonia is lighter than air and therefore rises quickly.

Carbon dioxide (CO₂)
Carbon dioxide is known in refrigeration technology as R 744 and has a long history extending back to the mid 19th century. It is a colourless gas that liquefies under pressure, with a slightly acidic odour and taste. Carbon dioxide has no ozone depletion potential (ODP = 0) and negligible direct global warming potential (GWP = 1) when used as a refrigerant in closed cycles. It is non-flammable, chemically inert and heavier than air. Carbon dioxide has a narcotic and asphyxiating effect only in high concentrations. Carbon dioxide occurs naturally in abundance.

Ozone Depletion and Global Warming Potential of Refrigerants

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<th>Ozone Depletion Potential (ODP)</th>
<th>Global Warming Potential (GWP)</th>
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<tbody>
<tr>
<td>Ammonia (NH₃)</td>
<td>0</td>
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<tr>
<td>Carbon dioxide (CO₂)</td>
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<tr>
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Hydrocarbons (HFCs)

**Ozone Depletion Potential (ODP)**

The ozone layer is damaged by the catalytic action of chlorine, fluorine and bromine in compounds, which reduce ozone to oxygen and thus destroy the ozone layer. The Ozone Depletion Potential (ODP) of a compound is shown as chlorine equivalent (ODP of a chlorine molecule = 1).

**Global Warming Potential (GWP)**

The greenhouse effect arises from the capacity of materials in the atmosphere to reflect the heat emitted by the Earth back onto the Earth. The direct Global Warming Potential (GWP) of a compound is shown as a CO$_2$ equivalent (GWP of a CO$_2$ molecule = 1).

**About eurammon**

eurammon is a joint European initiative of companies, institutions and individuals who advocate an increased use of natural refrigerants. As a knowledge pool for the use of natural refrigerants in refrigeration engineering, the initiative sees as its mandate the creation of a platform for information sharing and the promotion of public awareness and acceptance of natural refrigerants. The objective is to promote the use of natural refrigerants in the interest of a healthy environment, and thereby encourage a sustainable approach in refrigeration engineering. eurammon provides comprehensive information about all aspects of natural refrigerants to experts, politicians and the public at large. It serves as a qualified contact for anyone interested in the subject. Users and designers of refrigeration projects can turn to eurammon for specific project experience and extensive information, as well as for advice on all matters of planning, licensing and operating refrigeration plants. The initiative was set up in 1996 and is open to European companies and institutions with a vested interest in natural refrigerants, as well as to individuals e.g. scientists and researchers.

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