HEAT PUMPS MAKE STEAM

If waste heat is continuously generated from an industrial process and steam is required at the same time to complete the process, the conditions are favorable for the use of a steam-generating heat pump. A team of researchers from the University of Applied Sciences of Eastern Switzerland has investigated the conditions for the success of this energy-efficient and climate-friendly form of heat supply.

An ammonia heat pump has been in operation in Trondheim, Norway since 2024, providing 120 °C steam with an output of 1.6 MW in a plant for animal feed. Photo: Aneo Industry

A technical report about the results of a research project in the field of Industrial Processes, which is financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine Foodaktuell (issue March 2025).

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The growing popularity of heat pumps over the last two decades is due to the fact that modern new buildings require heating temperatures of just 25 to 35 °C. Heat pumps can provide this amount of heat while consuming less electricity. In recent years, however, heat pump manufacturers have also brought solutions to the market that can achieve much higher temperatures. A number of appliances provide steam in the range of 100 to 165 °C, which is required in a number of industrial operations. These temperatures can even be exceeded by using a steam compressor, but this requires additional energy, which reduces the efficiency of the overall process.

Steam-generating heat pumps work particularly efficiently when they can continuously use a comparatively warm heat source of 50 °C or more. This is possible in many industrial operations where waste heat is generated during cooling, for example. This waste heat is usually released into the environment unused. Typical examples of such processes are distillation processes in food or pharmaceutical manufacturing. Here, heat is needed for distillation, and cold for condensation. The waste heat from cooling can be used by a heat pump to produce steam. In this way, fossil fuels such as oil and natural gas can be substituted in a climate-friendly way.

Steam from lukewarm water

Heat pumps have not yet been used in Switzerland to provide industrial process steam. There are already a few good examples of this energy-efficient type of heat production in other countries, however. In Trondheim, Norway, for example, the animal feed company Felleskjøpet Agri has been using a two-stage heat pump system with a combined cycle (see text box p.3) to provide 120°C steam since 2024.

In the first stage, a heat pump produces 85 °C water vapor using the natural refrigerant ammonia (the process takes place at negative pressure, where the evaporation temperature of water is lower than 100 °C). The water vapor is then brought to 120 °C (1.5 bar) by vapor compression. The heat source is a humid, 30 to 40 °C air, which is generated as waste heat during animal feed production. The system consisting of a heat pump (Aneo Industry) and steam compressors (Piller) works with an efficiency that is familiar from residential

HTHP supplier	Compressor type	Working fluid (Refrigerant)	Max. capacity [MW]	Max. supply temp [°C]	TRL
Spilling (DE)	Piston	R718	15	280	9
Enerin (NO)	Piston	R704	10	250	6
Piller (DE)	Turbo	R718	70	212	8 to 9
Olvondo (NO)	Piston (double acting)	R704	5	200	9
Turboden (IT)	Turbo	Application specific	30	200	7 to 9
ToCircle (NO)	Rotary vane	R717+R718	5	188	6 to 7
Kobelco (JP)	Twin-screw	R245fa/R134a + R718	0.4	175	9
SRM (SE)	Screw	R718	3	165	5
SPH (DE)	Piston	HFOs	5	165	7 to 8
Heaten (NO)	Reciprocating	HFOs	6	165	7 to 9
Weel & Sandvig (DK)	Turbo	R718	5	160	4 to 9
Siemens Energy (DE)	Turbo	R1233zd(E)/R1234ze(E)	70	160	9
ECOP (AT)	Rotational heat pump	ecop fluid 1	0.7	150	6 to 7
Rank (ES)	Screw	R245fa, R1336mzz(Z), R1233zd(E)	2	150	7
Epcon (NO)	Centrifugal fans, blowers	R718	30	150	9
MAN Energy Solutions (CH)	Turbo with expander	R744	50	150	7 to 8
Mitsubishi Heavy Industries (JP)	Two-stage centrifugal	R134a	0.6	130	9
Fuji Electric (JP)	Reciprocating	R245fa	0.03	120	9
Emerson (US)	Scroll and EVI scroll	R245fa, R410a, R718	0.03	120	6
Mayekawa (JP)	Reciprocating	R744	0.1	120	8 to 9
Fenagy (DK)	Reciprocating	R744	1.8	120	5 to 6
Johnson Controls (DK)	Reciprocating	R717+R600 (cascade)	5	120	7 to 8

List of manufacturers of heat pumps that supply steam at 120 °C and higher. Table: Final report IntSGHP

THREE WAYS IN WHICH HEAT PUMPS GENERATE STEAM

Today, industry generally uses oil or gas as energy sources to produce steam for industrial processes. With heat pumps, steam can be produced fossil-free using renewable electricity. Three types of construction are available:

Heat pump with closed circuit: This is how most heat pumps on the market today work. They use a refrigerant (see Fig. at the bottom, red lines) that circulates in a closed circuit. The refrigerant is selected so that it vaporizes when it absorbs the heat from the heat source (e.g. industrial waste heat). The vapor is compressed by an electrically driven compressor and thus brought to a higher temperature. This high temperature is used in a heat exchanger to generate steam. The refrigerant condenses and flows back to the starting point.
Advantages/disadvantages: This technology has been tried and tested in heat generation. However, there are only a limited number of refrigerants whose critical temperature (evaporation temperature) is high enough for steam generation, or at least the required 105 degrees.

Heat pump with open circuit: In this system, no extra refrigerant is evaporated and compressed, but rather this is done with water (see blue lines in Fig. at the bottom, center). In order for water to absorb the heat from the heat source by evaporation, an environment with negative pressure is required. A compressor then raises the temperature of the water vapor. A steam compressor raises the temperature by 10 to 20 °C. To get from 45°C to 115°C, for example, around six steam compressors must be connected in series. Once the steam has reached the desired temperature, it can be used directly as process steam.
Advantages/disadvantages: The refrigerant used here is water, which is non-toxic and non-flammable. Because water is used as a refrigerant, a heat exchanger can be dispensed with, which increases system efficiency. As several compressors are required for the temperature shift, the system is expensive and maintenance-intensive and has an increased risk of failure. If the source temperature is below 70 °C, a heat pump with an open circuit operates inefficiently.

Heat pump with combined circuit: This system achieves the desired temperature range from source to useful temperature in two steps: The first is performed by a closed-circuit heat pump, the second by an open-circuit heat pump.
Advantages/disadvantages: This solution is suitable for large temperature shifts, but it is also particularly complex because it combines two technical systems (classic heat pump, vapor compressors). What is needed is a control system for the heat pump and vapor compressors that avoids vibrations in the system. Little real-world experience exists to date.

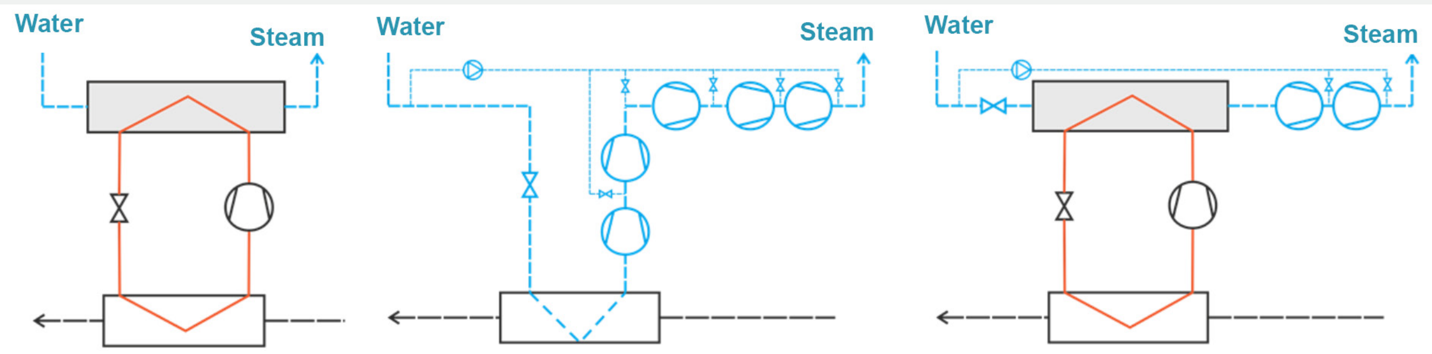


Illustration: Final report IntSGHP

buildings – three times more heat is generated with the same amount of electricity used (Coefficient of Performance/COP 3). The system has an output of 1.6 MW and produces 2 tons of steam per hour.

"Technically mature"

This example could set a precedent in Switzerland: A team of scientists from the University of Applied Sciences of Eastern Switzerland (OST) has investigated the potential of steam-generating heat pumps for Switzerland in a three-year project. "Our study shows that such heat pumps are now technically mature and ready for commercial use," says OST project manager Frédéric Bless. The project, which was financially supported by the SFOE, was recently completed with a final report.

The results include two case studies that were used to investigate the use of steam-generating heat pumps in existing industrial plants. The first study concerns a production facility built by UCB Farchim in Bulle in the canton of Fribourg in 2014. The biotech company requires steam (110 °C, 1.5 bar) for a distillation process, which is generated using a gas boiler so far. Using pinch analysis (see text box p.5) and further simulations, the OST research team was able to show that the steam could be provided in an energy-efficient and environmentally friendly way using a heat pump.

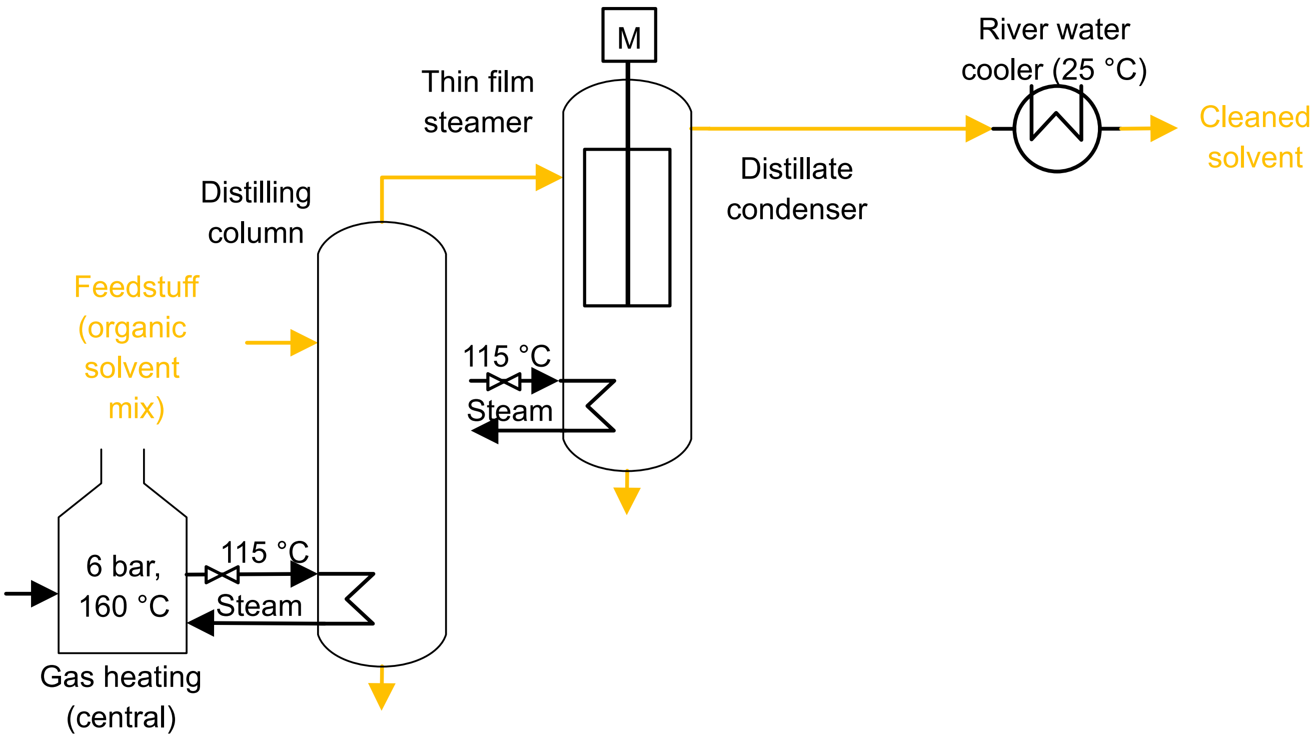
Steam for the distillation process

The researchers proposed a heat pump with a combined cycle, consisting of an ammonia heat pump (500 kW, 0.8 tons of steam per hour) and two steam compressors. The heat source used in Bulle would be 25 °C waste heat. It is the same system concept that was implemented in the above-mentioned animal feed factory in Trondheim.

The OST researchers calculated a COP of 2.9 for the efficiency of the system. UCB Farchim was hesitant to purchase the heat pump at the time because the technology had not yet been tested, particularly the controlled interaction between the heat pump and vapor compressor. As an alternative, the OST researchers proposed a solution in which two heat pumps from a Swiss manufacturer with a closed circuit are connected in cascade; the first uses ammonia as the refrigerant, the second butane. This solution is somewhat less efficient than the original proposal and uses flammable butane, which requires special fire protection measures. However, the system comes from a single manufacturer and therefore the parts should work together as if they were a single unit. Both variants have now been submitted to USB Farchim for a decision.

From 45 directly to 115 °C

The OST team carried out the second case study for DSM Nutritional Products. The company produces food chemicals in Sisseln. It also uses a distillation process that requires 115 °C



Simplified illustration of the distillation process at DSM Nutritional Products: Steam required for the process is currently obtained from a central gas boiler that generates steam at 160 °C and 6 bar. Graphic: Final report IntSGHP

Refrigerant	Critical Pressure [bar]	Critical Temperature [°C]	Pressure ratio for 70°C/ 120°C	Density gas @ 70°C	Cp Gas @ 70°C	Flammable	Toxicity	GWP	ODP
R717 (ammonia)	83.2	132.3	2.8	26.4	4.7	(slightly)	yes	0	0
R600a (iso-butane)	36.4	134.7	2.6	28.4	2.3	yes	no	<5	0
R600 (n-butane)	38.0	152.0	2.7	20	2.2	yes	yes	<5	0
R718 (water)	220.6	373.9	6.4	0.2	2.0	no	no	0	0
R1336mzz(Z)	29.0	171.3	3.4	21	21.0	no	no	2	0
R1233zd(E)	35.7	165.6	3.1	27	27.0	no	no	1	~0.00034

For a refrigerant to be used for steam generation, the temperature of the refrigerant must be at least 5 °C higher than the process temperature. The table shows the respective disadvantages, such as flammability, toxicity, global warming potential and ozone potential.
Table: Final report IntSGHP

steam, which is currently produced using a wood-fired boiler. As waste heat at 45 °C is available in this plant, the OST researchers recommended a heat pump with an open circuit based on their calculations. This means that the 45 °C water is evaporated at negative pressure and then gradually brought to 115 °C by eight steam compressors. A COP of 3.3 was calculated for the efficiency of the process.

According to the OST researchers, the solution is technically feasible. But with estimated investment costs of €730,000, it is more expensive than a solution using wood (€370,000) or biogas (€ 550,000). However, this would be offset by the lower operating costs of the heat pump solution, and the company could also benefit in other ways: Not only could it generate steam, but it would also have a welcome use for its waste heat, which until now has been discharged into the Rhine. The use of the Rhine for cooling purposes is controversial because of the environmental impact, it may affect fish stocks, for example. Companies are not allowed to use the river for cooling purposes for periods during the summer to avoid endangering the fish. If the waste heat is used in the companies themselves, this problem no longer arises.

The trend toward natural refrigerants

In their study, the authors also provide in-depth information on steam-generating heat pumps. For example, they list which heat pumps for vapor generation are currently available on the market and provide an overview of the refrigerants used. The final project report states: "There is no perfect refrigerant for vapor-generating heat pumps. The main future-proof options are natural refrigerants R600 (n-butane), R600a (iso-butane), R717 (ammonia) and R718 (water) and chlorofluorocarbons (HFO): HCFO-R1233zd€, HFO-R13336mzz(Z). All these refrigerants have no (or only low) ozone depletion potential and low global warming potential; in addition, each has its advantages and disadvantages" (see Table at the top).

Despite the hurdles, Frédéric Bless believes in the use of heat pumps in industrial environments: "Steam-generating heat pumps are still more expensive than fossil-fuel systems for steam generation, but they offer industrial companies an option for climate-friendly production," says the OST scientist. Bless believes that the biggest obstacle that has so far prevented companies from using this decarbonization technology is the lack of examples that demonstrate the reliable long-term operation of this form of heat generation: "We need demonstration plants in Switzerland with multi-year monitoring that proves the reliability of these systems. This will give companies that are still hesitant about switching over proof that the technology is functional and operational, which can be decisive for the internal decision-making process."

PINCH-ANALYSIS

Pinch analysis is a systematic method that aims minimize the energy required to provide cooling and heating in industrial processes. This is primarily achieved by ideally combining existing cooling and heating flows.

↗ www.pinch.ch

- The **final report** on the SFOE research project 'IntSGHP - Integration of steam-generating heat pumps in industrial sites (retrofit)' is available at: https://www.aramis.admin.ch/Texte/?ProjectID=49319.

- **Information** is available from Elena-Lavinia Niederhäuser (elena-lavinia.niederhaeuser@bfe.admin.ch), head of the SFOE's Industrial Processes program, and Stephan Renz (info@renzconsulting.ch), external head of the SFOE's Heat Pumps and Cooling research program.

- Further **articles** on research, pilot, demonstration and flagship projects in the field of industrial processes can be found at: www.bfe.admin.ch/ec-prozesse.

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