



HIGH-TEMPERATURE HEAT PUMPS



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Jonna Tiainen,

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Why high-temperature heat pumps?

Heavy industries requiring process heat are potential applications for high-temperature heat pumps that can utilize waste heat and thereby reduce energy use and CO₂ emissions. The process heat requirement of industrial processes accounts for 29% of global energy demand and 15% of all greenhouse gas emissions (World Business Council for Sustainable Development 2022).

According to the International Energy Agency (IEA), the food and paper industries are prime candidates for deploying industrial heat pumps on a large scale, with their potential of 3,000 industrial heat pumps with a combined capacity of 15 GW (Voswinkel & Gouy 2022). Estimations of the heating capacity of 23 GW and more than 4,000 heat pumps have also been given when the industrial heat pump market potential of up to 200 °C is considered (Marina et al. 2021).

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Although manufacturers of high-temperature heat pumps are emerging, the development of technology and demonstrations are needed for a wider spread of the technology (Arpagaus 2022).

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Design process with compromises

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The project involves specialists in the fields of heat pump process design, electromagnetics, motor cooling, rotor dynamics and bearing design. And the design process is highly iterative as changes in one area affect the others.

Heat pump design starts by defining the application. What is the temperature level of the waste heat source to be upgraded with the heat pump? What is the desired temperature level in the application? What is the required heat capacity?

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The power of the heat pump and temperature levels set the boundaries for the heat pump process design. For a particular application, the optimal working fluid depends on operating temperatures and power scales as well as on the component design (Uusitalo et al. 2020). The most dominant parameter influencing the coefficient of performance (COP) and heating capacity of the heat pump is the critical temperature of the working fluid (Domanski et al. 2014).

The selection of the optimal working fluid is also guided by regulations. For example, Regulation (EU) No 517/2014 of the European Parliament and the Council was adopted to reverse the increase in fluorinated greenhouse gas emissions. This regulation has resulted in an annual decrease in F-gas emissions since 2015. The supply of hydrofluorocarbons (HFCs) decreased by 37% in metric tons and 47% in tons of CO₂ equivalent between 2015 and 2019.

Today, a revision of the current F-gas Regulation 2022/0099 (COD) is under preparation. It aims to prevent F-gas emissions, thereby contributing to EU climate objectives. It also aims to ensure compliance regarding obligations related to HFCs under the Montreal Protocol on substances that deplete the ozone layer. (<https://oeil.secure.europarl.europa.eu/oeil/popups/summary.do?id=1700219&t=d&l=en>, updated January 19, 2023, retrieved January 20, 2023)

Working fluids can be divided into dry and wet fluids. Dry fluids have an overhanging phase boundary in the temperature-entropy diagram. This means that the slope of the saturation curve is positive, indicating that temperature increases with increasing entropy. Wet fluids have a bell-shaped phase boundary with a negative slope, which means temperature decreases with increasing entropy. Dry fluids may create problems during compression if the compression process takes place near the saturation curve and condensation occurs. Liquid droplets can damage the compressor. (Reißner 2015)

For the motor design, one of the important properties of the working fluid is flammability because it can cause explosive atmospheres. The motor may need to meet the requirements laid down in the Directive on ATEX equipment. Another important property is the compatibility of the working fluid with materials such as copper, steel and resins used in the electric motor.

The working fluid also has a significant impact on heat pump compressor dimensions and optimal rotational speed (Uusitalo et al. 2020). The selected rotational speed is a compromise between the compressor, motor, bearing and rotor dynamic design.

When all targets set by the application and the requirements of the different component designs are sufficiently met, the heat pump concept can be taken to the prototyping and testing phase.

In a hermetic design comprising the motor, compressor and active magnetic bearings (AMBs) inside one frame to minimize the working fluid leakages and provide an oil-free solution, the working fluid from the heat pump process is used to cool down the motor. The fluid with the lowest temperature occurs in the evaporator of the heat pump. The cooling fluid can be driven through the active parts of the motor by taking advantage of the pressure differences in the heat pump process. Again, a compromise must be made between the optimal motor and heat pump process designs to enable sufficient cooling of the motor.

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Projects

The Switch is participating in the two-year high-temperature heat pump research project led by LUT University and funded by Business Finland. Learn more about the project here: www.lut.fi/fi/uutiset/teollisista-lampopumpuista-haetaan-ratkaisua-paastottomaan-lammontuotantoon.

The Switch is also running its own co-innovation project “Novel Heat Pump MW-class Compressor Motor.” It is funded by Business Finland under the record number 9119/31/2021 and will be carried out between April 1, 2022 and April 30, 2025.

As of December 2022, The Switch has joined the Finnish team in the IEA Heat Pumping Technologies (HPT) Annex 58 regarding high-temperature heat pumps. The overall objective of the Annex is to provide an overview of the technological possibilities and applications as well as to develop concepts and strategies for the transition toward heat pump-based process heat supply. Find out more about Annex 58 from here: <https://heatpumpingtechnologies.org/annex58/>

If you are interested in a detailed review of the interdisciplinary design of a high-speed drivetrain for a kinetic compressor in a high-temperature heat pump, take a look at the open-access article by Kepsu et al. (2021) on www.doi.org/10.1109/ACCESS.2021.3121141

References

Arpagaus, C. (2022) Potentials for High-Temperature Heat Pumps and Market Analysis. HPT Annex 58 about HTHPs – Deep Dive about the application potential of high-temperature heat pumps. Presentation on December 15, 2022, in the webinar of the IEA HPT Annex 58 about HTHP in Teams.

Domanski, P. A., Brown, J. S., Heo, J., Wojtusiak, J. and McLinden, M. O. (2014) A thermodynamic analysis of refrigerants: Performance limits of the vapor compression cycle, *International Journal of Refrigeration*, 38, 71–79.

Kepsu, D., Kurvinen, E., Tiainen, J., Honkatukia, J., Turunen-Saaresti, T. and Jastrzebski, R. P., “Interdisciplinary Design of a High-Speed Drivetrain for a Kinetic Compressor in a High-Temperature Heat Pump,” in *IEEE Access*, vol. 9, pp. 143877-143900, 2021, doi: 10.1109/ACCESS.2021.3121141.

Marina, A., Spoelstra, S., Zondag, H. A. and Wemmers, A. (2021) An estimation of the European industrial heat pump market potential. *Renewable and Sustainable Energy Reviews*, 139, [110545]. doi: 10.1016/j.rser.2020.110545.

Reißner, F. (2015) Development of a Novel High Temperature Heat Pump System. Dissertation. Der Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany. p. 145.

Uusitalo, A., Turunen-Saaresti, T., Honkatukia, J., Tiainen, J. and Jaatinen-Värri, A. (2020) Numerical analysis of working fluids for large scale centrifugal compressor driven cascade heat pumps upgrading waste heat. *Applied Energy*, 269, 115056.

Voswinkel, F. and Gouy, A. (2022) The Role of Industrial Heat Pumps in the Net Zero Scenario. Presentation on December 15, 2022, in the webinar of the IEA HPT Annex 58 about HTHP in Teams.

World Business Council for Sustainable Development (2022) Industrial Heat Pumps: it's time to go electric. Report. Available: <https://www.wbcsd.org/Pathways/Energy/Resources/Industrial-Heat-Pumps-it-s-time-to-go-electric>

About the author:

Jonna Tiainen currently works as Senior Specialist, Thermal Design at The Switch, Finland. She has a background in turbomachinery and over a decade of experience in computational fluid dynamics, measurements, project management and teaching. Tiainen holds a D.Sc. (Tech.) degree in heat transfer and fluid dynamics from LUT University, Finland.

Recommendable links:

<https://heatroadmap.eu>

<https://www.iea.org/reports/heat-pumps>

<https://www.iea.org/reports/the-future-of-heat-pumps>