Concept study for industrial heat pumps up to 250°C heat sink temperature using radial turbo compressors

(5) Dekarbonisierung: Industriesektor

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Motivation and research question

Driven by decarbonization targets and recent developments on the gas market, the interest in heat pumps for utilizing industrial waste heat is increasing worldwide. However, in contrast to domestic systems, industrial processes require significantly higher sink temperatures and heat loads. Operating temperatures of above 130°C lead to novel application areas for high-temperature heat pumps and a much larger sales market than what was previously common for manufacturers [1][2].
However, to meet these requirements the manufactures have to overcome technological barriers which come with higher temperatures. Nearly all industrial heat pumps are using piston and screw compressors which are heavily depending on the stability of lubricating oil [3][4] that is tending to change its properties and decompose with rising temperatures. Therefore, it is clear to go for oil-free solutions if targeting sink temperatures lie above 180°C. One of these solutions can be the use of a radial turbo compressor which is presently only used for high thermal power (>5MW_{th}) e.g. district heating systems. Therefore, the Austrian Institute of Technology (AIT) – Center for Energy together with TU Wien - Institute of Energy Systems and Thermodynamics are working within the framework of the FFG-Project „NERO" on a concept of industrial heat pumps using radial turbo compressors for heat sink temperatures up to 250°C and heating capacities in the 1 MW_{th} area.
Previously published publications [3] showed already the feasibility of the concept and discussed refrigerant selection and heat-pump cycle configurations.
However, an optimization of the COP by means of a variation of the high-pressure level especially under consideration of the performance of refrigerant blends is still missing and should be targeted in this publication.

Methodology

For the simulation of the heat pump cycle the software Dymola 2022x is used and the components are modeled using the object-oriented, acausal, equation-based open-source modeling language Modelica.
Most of the basic components are modeled using the commercial library TIL 3.10.0 [5] and the material data for the refrigerants are based on REFPROP [6]. To enhance comparability and keep things simple some simplifications are assumed. For instance, the are no pressure loses in the piping's and thermal losses to ambient are neglected. Moreover, the isentropic efficiency of the compressor remains constant for all refrigerants.
Based on the remarkable performance of Pentane but with the downside of very high pressure ratios (>2.5) two refrigerant blends with HFOs are generated by using spline interpolation. The blending ratios were chosen based on investigations on a subcritical cycle for a lower sink temperature (140°C) [7].

Results and conclusions

Figure 1 shows the COP dependency on the high pressure level after the second compressor stage. It can be seen that R600 (n-Butan) und R1336mzz(E) do not perform well compared to the other three. Moreover, the high pressures are significantly above 40 bar_a, which indicates higher equipment costs. The optimal COP of R1233zd(E) is only slightly higher than the one obtained by using R1336mzz(Z) but with a lower pressure ratio per stage of around 8%. The highest COP is obtained by using Pentane

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(R601) but with the trade-off between efficiency and security class as well as pressure ratio, which is higher than that of R1233zd(E).

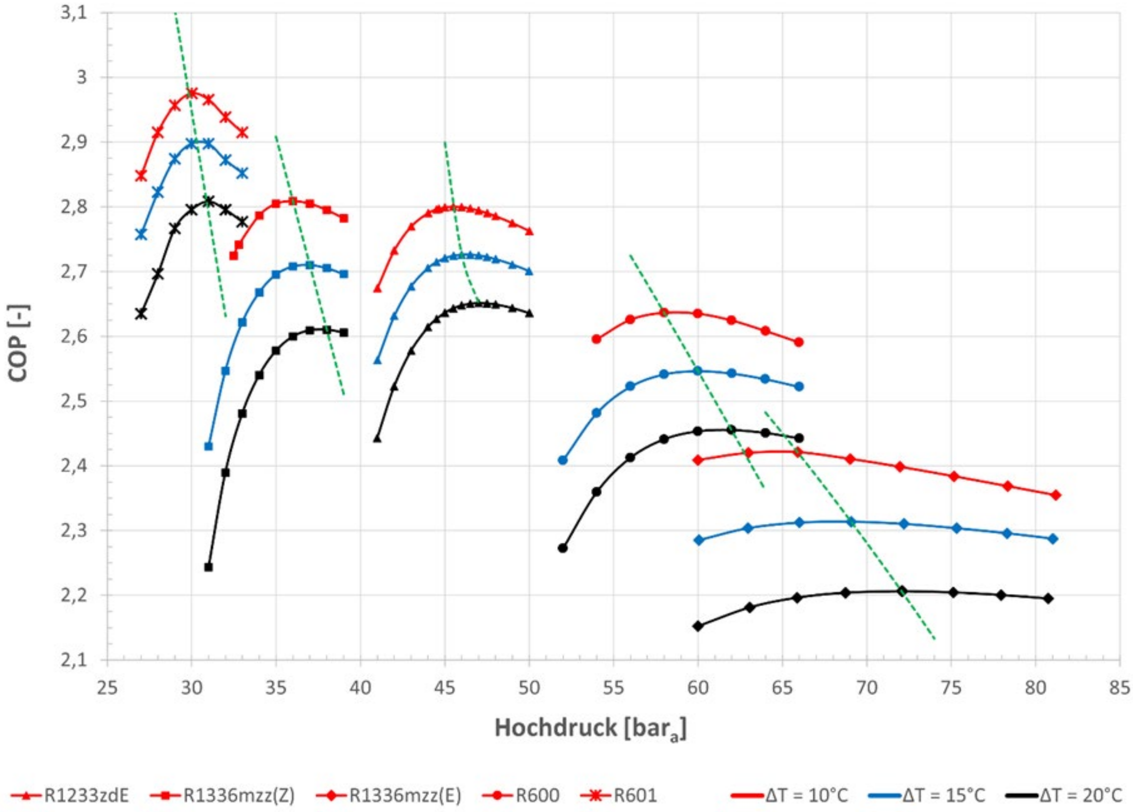

Figure 1: High pressure selection for different refrigerant at variable temperature levels in the IHEX (blends will be added in the long version)

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