

Transcritical-Transcritical CO₂ High-Temperature Heat Pump Cycle for Dairy Spray Dryers

Picture source:



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Goal and Motivation

- Decarbonising industrial processes that require high-temperature air across a range of 15 °C to 200 °C
- Two-stage dairy spray dryers with fluid beds
- Achieve high temperatures at lower operating pressures than conventional multi-compression cycles
- Achieve better temperature profile matching on heat sink with two gas coolers
- Use of non-flammable, zero ODP and GWP refrigerants (e.g., CO₂ = R744)

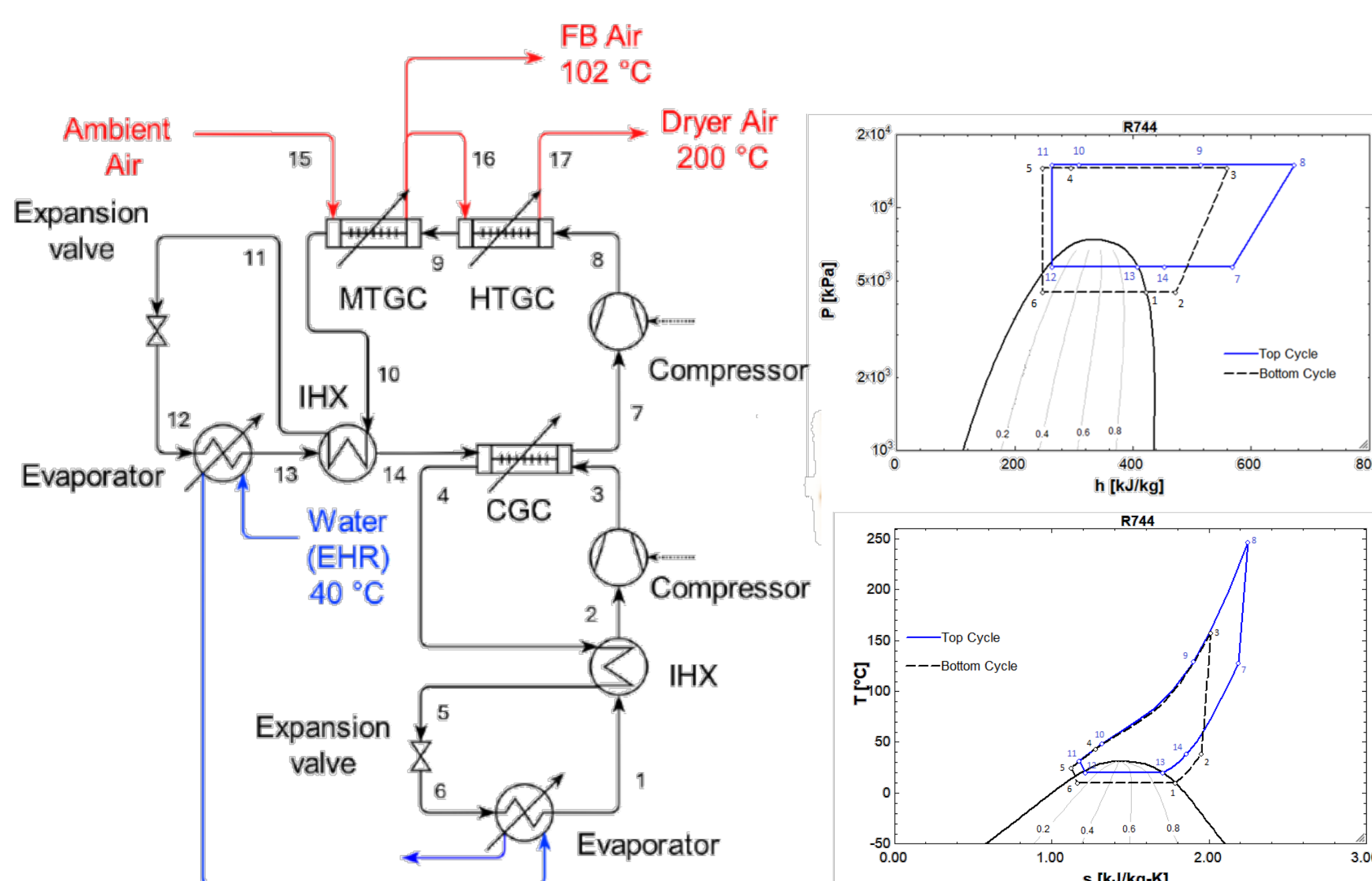


Figure 1: Transcritical-transcritical CO₂ HTHP cycle [1] with log-p-h and T-s diagrams.

Method

- Develop a static model of two cascaded transcritical CO₂ cycles in EES software (Engineering Equation Solver, F-Chart) (Figure 1)
- Analyse the HTHP cycle through a parametric study
- Fixed parameters:
 - heat source temperatures
 - heat sink heating capacity and air outlet temperatures
 - pinch point temperatures
 - isentropic compressor efficiency
 - refrigerant (CO₂)
- Solve the remaining parameters: e.g., refrigerant mass flow rates, pressure ratios, and COP
- Variation of mass flow ratios, heating capacity distribution, air inlet temperatures, and pressure ratios

Process Data (Reference Conditions)

- Heating Capacity: 470 kW and 360 kW
- COP: 2.55 (optimal) (Figure 2)
- Heat source temperature: 40 °C and 20 °C
- Heat sink air inlet temperature (T_{air,in}): 15 °C
- Heat sink air outlet temperature: 102 °C and 200 °C
- High pressure limit: 15 MPa (150 bar)

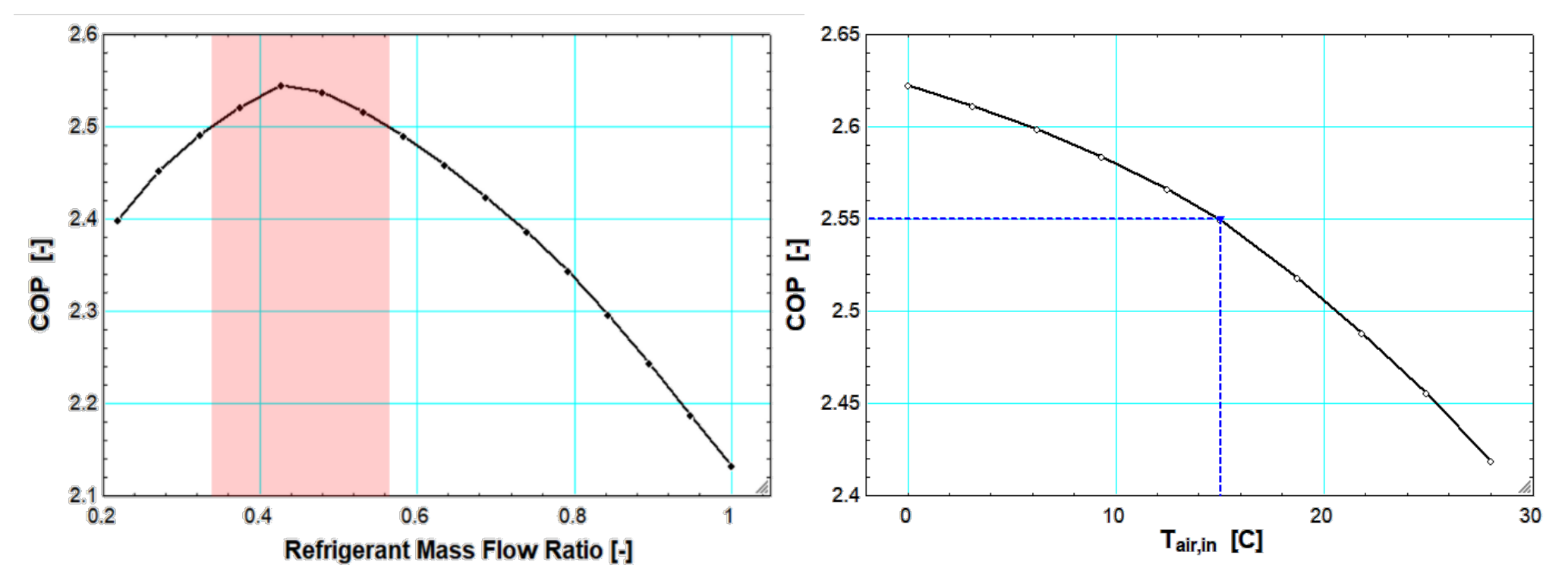


Figure 2: COP vs. refrigerant mass flow ratio and air inlet temperature.

Results and Conclusions

- The proposed cycle achieves supply temperatures above 200 °C at discharge pressures of 150 bar.
- CO₂ is well suited for achieving high supply temperatures.
- Careful compressor selection is critical, e.g., oil-free centrifugal CO₂ compressors for large-scale applications such as dairy spray dryers.
- Stable refrigerant mass flow ratios between the two compressors are required (some margin for manoeuvre).
- Having two gas coolers on the heat sink provides two air streams at different temperature levels simultaneously (as required in dairy spray dryers with fluidized beds).
- Altering the heating capacity ratio between the two gas coolers significantly affects the pinch points of both heat exchangers.
- The cycle is resistant to changes in supply air temperature and thus largely season-independent in moderate climates.

References

- [1] Kong et al. (2025): Advances in High-Temperature Heat Pump Technologies for Industrial Process Applications with Large Temperature Glides: Assessing the potential for carbon dioxide as a refrigerant, *Energy Conversion and Management*, 350, 2026, 120933, <https://doi.org/10.1016/j.enconman.2025.120933>

Project Partner

