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Heat pump assisted superheated steam drying

Heat pump assisted superheated steam drying

Properties, processes and materials

General properties:

- Low or oxygen-free atmosphere
- Best for sensitive material
- Faster drying speed (above inversion temperature)
- Closed-loop systems
- Lower temperature glide (higher cp)

T [°C]	cp_{Air} $[kJK^{-1}kg^{-1}]$	cp_{steam} $[kJK^{-1}kg^{-1}]$
100	1.01	2.08
150	1.01	2.39
200	1.01	2.99

Processes and materials:

- **Food:** milk powder, orange juice, maltodextrin, coffee extract, cereal products (highly sensitive to aroma loss)
- **Industrial:** coal, biomass, wood, paper, sludge
- **Chemicals:** Detergents, salts, proteins, pharmaceutical powders
- **Processes:**
  - Spray dryer
  - Fluidized bed
  - Rotary dryer
  - Flash dryer
  - Belt dryer

All relevant HAD-processes have a SHSD equivalent

[1],[2],[3]

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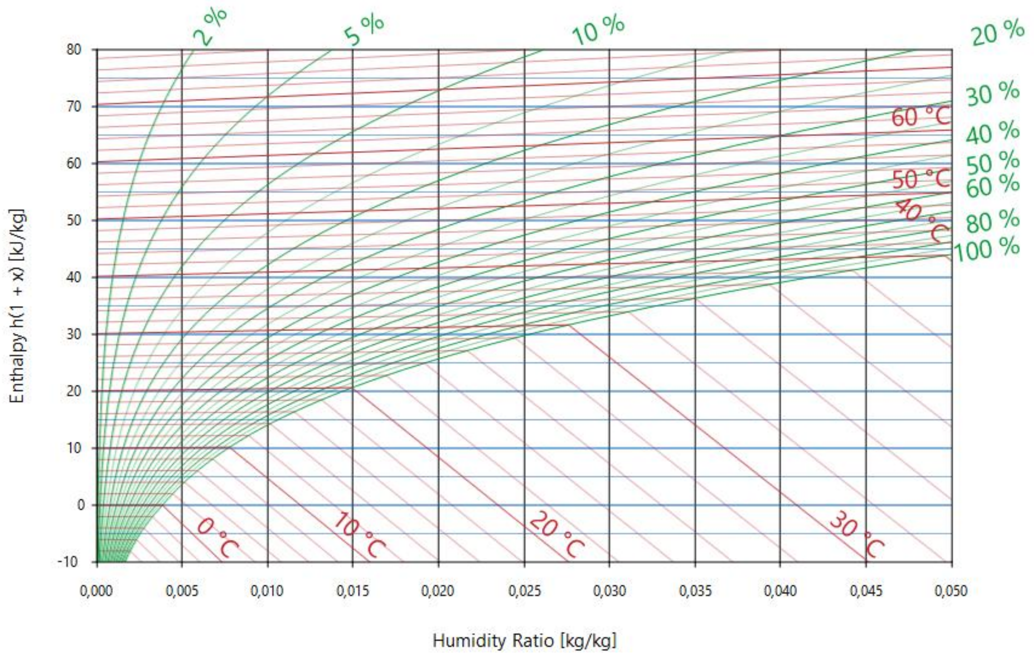
Hot air drying

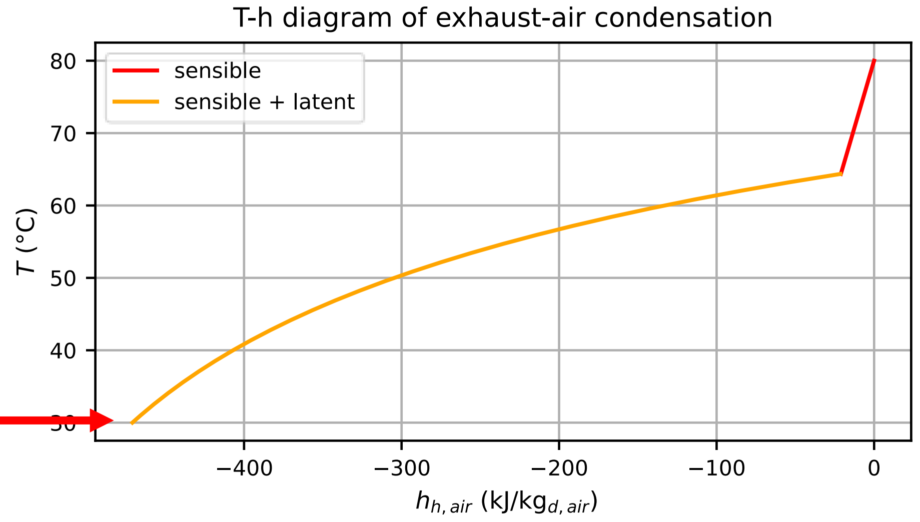
Heat pump integration in hot air drying

Challenges for heat pump integration:

Temperature glide on the source side:

- Energy recovery through condensation of humid air
- Heat pump efficiency relies on lowest temperature of the process





High temperatures on the sink side:

- Low cp of air
- Rapid annealing during drying
- Hot inlet air temperatures
- Usually, water intermediate cycle is adopted

High sink and source glide + high temperature lift → **lower COPs**

Superheated steam drying

Heat pump integration in SHSD

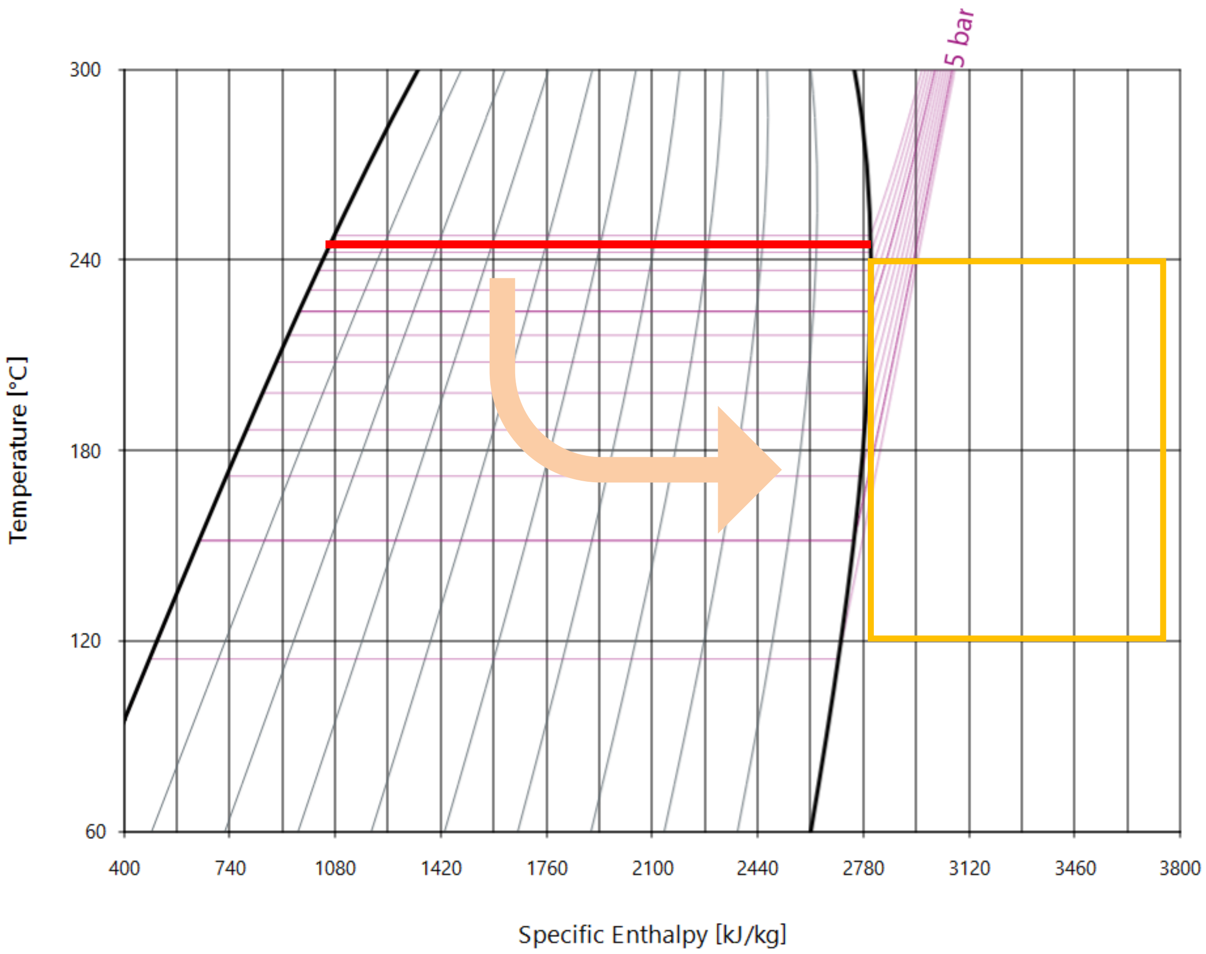
Chances for heat pump integration:

- Drying only possible with superheated steam
- Lower annealing of steam (higher cp)
- Steam generation through isothermal high pressure steam condensation
- Additional usage of high temperature condensate

→ **Lower lift + no sink/source glide** → **higher COPs**

BUT:

- Generally elevated temperature level
- More complex plant equipment
- Higher investment costs



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Case Study: SHSD (I)

Mechanical vapour recompression

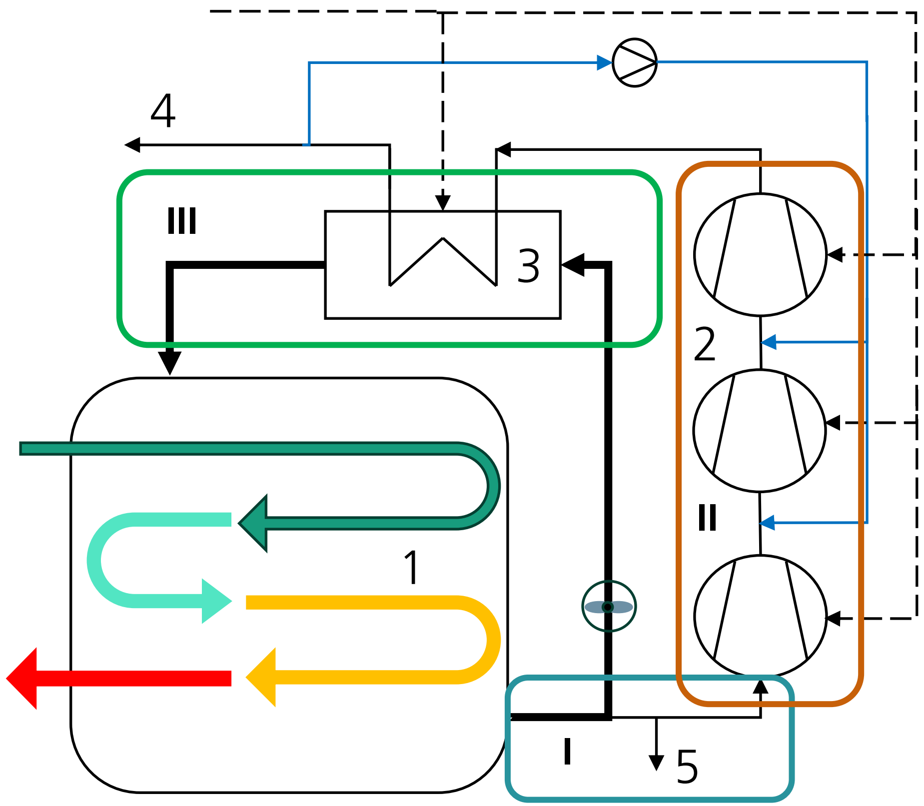
CASE Study with a generic dryer:

1. **SHSD-model (e.g. belt dryer)**
   - Low-pressure environment (mainly)
2. **MVR-system (e.g. turbo-compressors)**
3. **Condenser**
   - High-pressure steam => condensation
   - Low pressure steam => superheating
4. **Condensate discharge**
   - Condensate initial came from moist material
5. **Additional LP steam**
   - As electric power is added to the system

I: Suction of lp superheated steam ($\Delta T_{SH} \approx$ 20 K)

II: Mechanical vapour compression with turbo-compressors

III: Condensation of hp steam to increase the superheating of the steam circulating in the closed loop system.



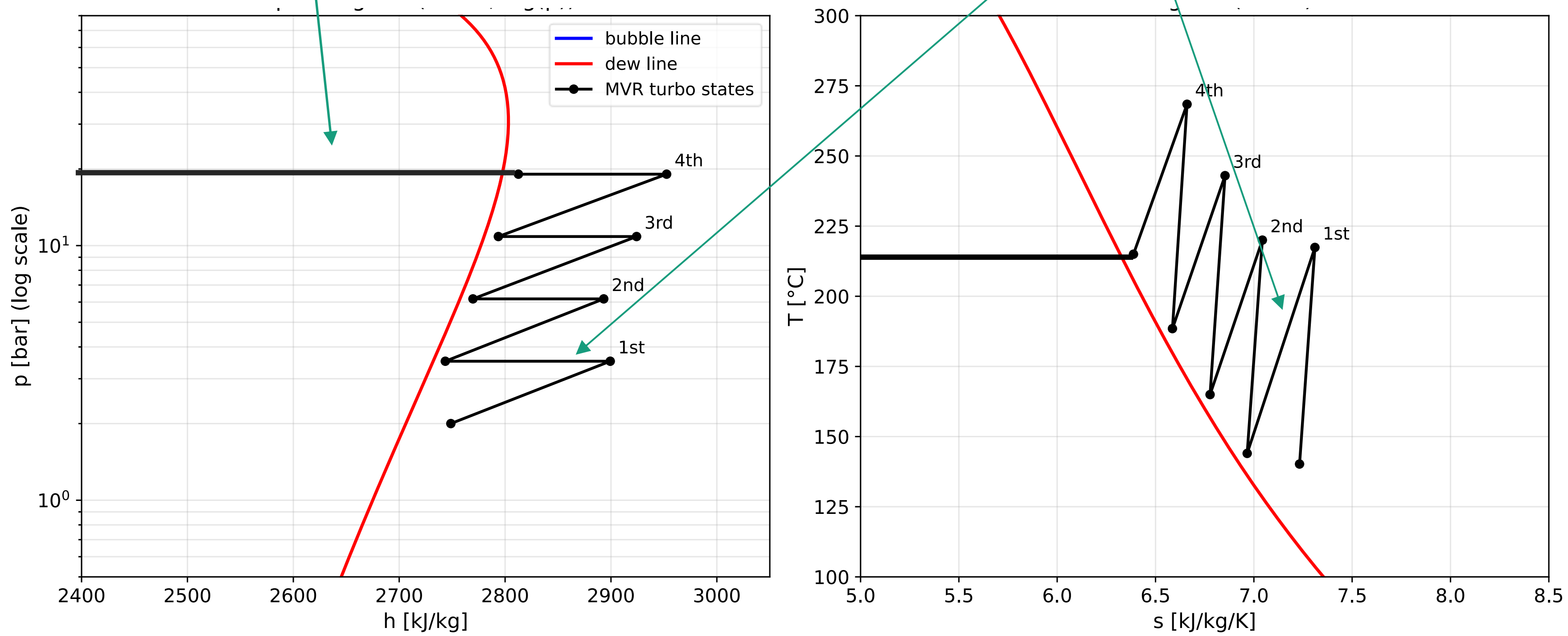
[3]

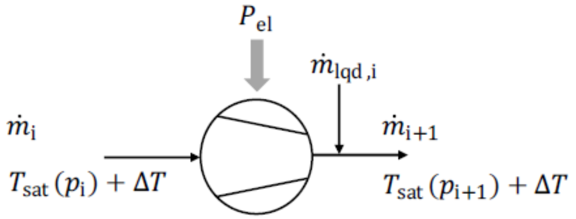
Case Study: SHSD (II)

Mechanical vapour recompression

condensation of hp steam

Intercooling with liquid water





Process: drying of wood pellets with an SHSD temperature range from 130 to 200 °C

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Heat pumps /MVR systems for SHSD

Overview of existing compressor technology

Blowers

- Axial turbo machines
- Low pressure ratio (1,1...1,4)
- Many but simple compressor stages
- Liquid water injection
  - intercooling
  - direct injection
- Market available products

[6]

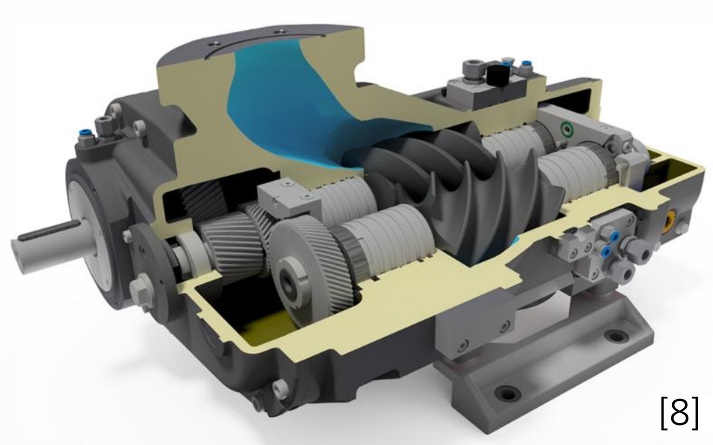
Turbos

- Radial turbo machines
- Medium pressure ratio (1,4…2)
- Liquid water injection
  - Intercooling
- Market available products

[7]

Screws

- Twin screw compressor machines
- High pressure ratio (3..6) per stage
- Cooled by oil or liquid water injection directly in chamber
- Compact but complex and costly machinery



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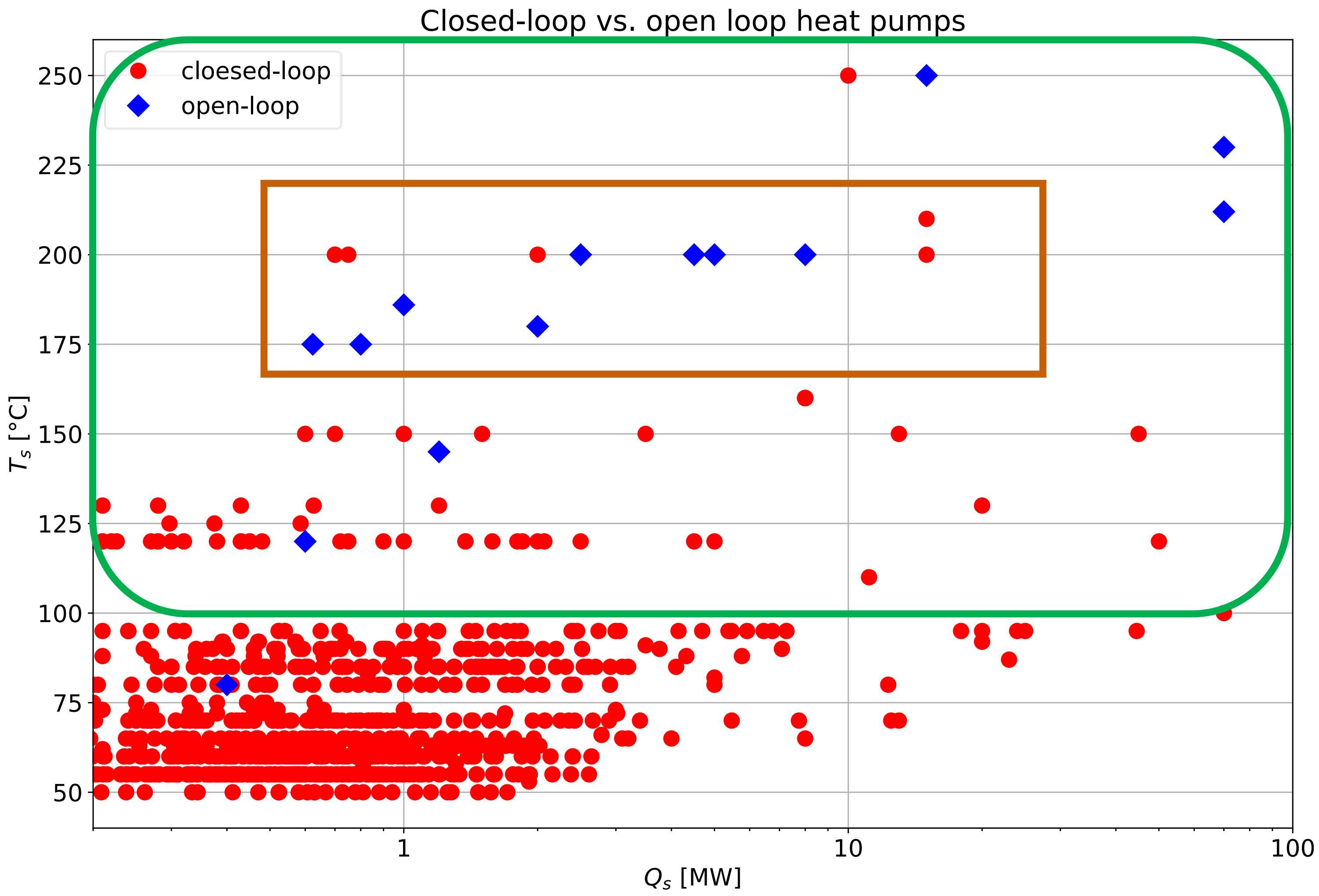
market overview

Closed loop vs. open loop

Infoportal-Großwärmepumpe:

[Link: Infoportal für Großwärmepumpen]()

- Many high-temperature heat pumps available
- Figure shows maximum capacity and temperature
- Open loop circuits are suitable for SHSD-application
- Attractive range for SHSD-HP >175°C with a capacity of 0.5 to 15 MW



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Real process layout

Handling Contaminants

Handling particles and product residues:

- The proposed layout postulates a direct compression of low pressure slightly superheated steam from the drying process

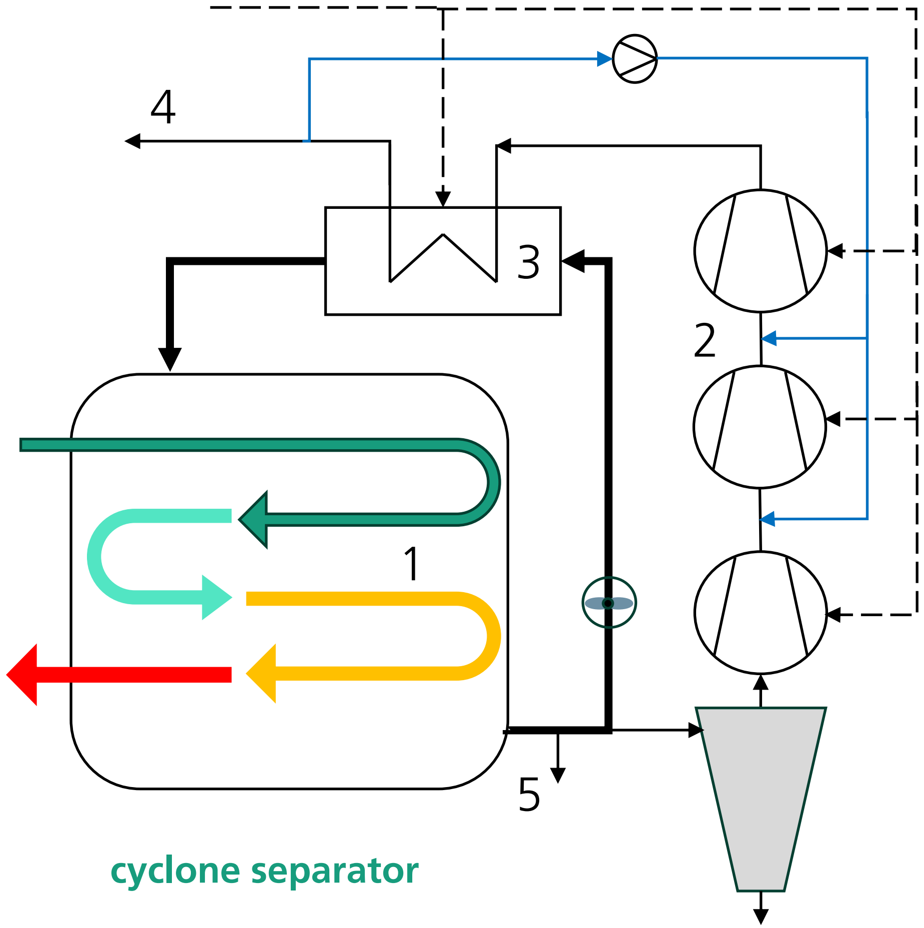
- Particles transported in the flow may deposit in the compressors
  - ➢ Contamination of oil (screws)
  - ➢ Abrasion and erosion of blades or sealings (critical)
  - ➢ Wall deposits in heat exchangers

- Measures against particle contamination are:
  - ➢ Additional cyclone separator before MVR-stages
  - ➢ Additional source direct evaporator with fresh feed water

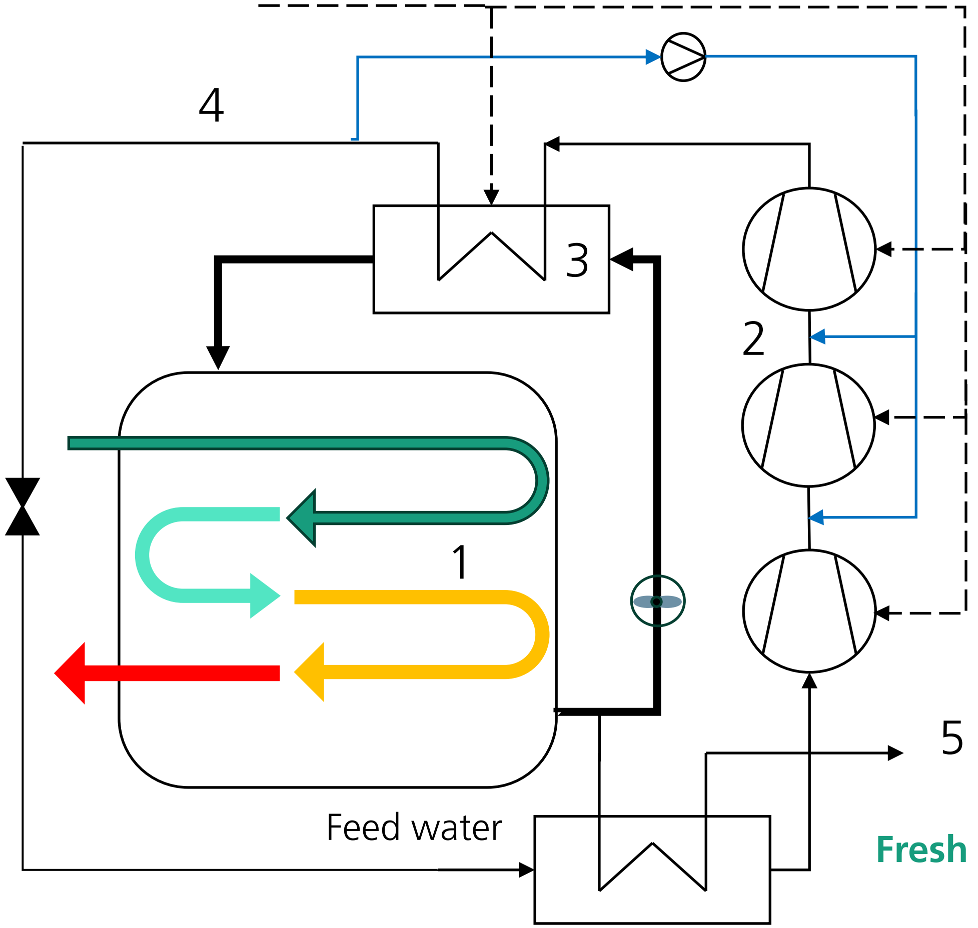
- these measures lead to a lower Cop due to higher pressure or exergy losses

Real process layout

Handling Contaminants



cyclone separator



Fresh feed water cycle

Energetic performance evaluation

Case studies with relevant products

Modelling approach:

- Fluid properties using Cool Prop
- Turbo compressors $\prod_{max} = 2$
- Isentropic efficiency of 75 %
- Minimum 20 K superheating in the SHSD-process

Simulation assumption:

- Process parameters from literature
- EU electricity mix 195 gr_{CO2}/ kWh_{el}
- Gas spec. emissions 215 gr_{CO2}/ kWh_{th}
- 20% heat loss through walls and product
- Efficient gas boiler η=95 % (configuration with economizer)

Product	p_{dry}	T_{SHS}	SEC	SMER	COP	CO_2	ΔCO_2	ΔQ_{rec}	T_{rec}
	bar	°C	kWh/kg	kg/kWh		g/kg	%	%	°C
Beet pulp	1	150	0.17	5.88	4.63	32.9	-77.5	10.5	100
Paper	1	250	0.31	3.23	1.85	59.7	-59.2	46.8	100
Wood chips	2	200	0.21	4.76	3.34	40.3	-71.8	23.3	120

[2],[3],[5]

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Benefits of superheated steam drying

Conclusions and learnings

- **Many products benefit from SHSD due to fewer quality, aroma and oxidation losses**
- **SHSD is suitable for many products and processes – especially spray or fluidized bed dryers**
- **But SHSD-plants are more complex and costly to install**
- **SHSD is beneficial for heat pumps as there is no source glide**
- **Closed loop dryers are feasible**
- **Open loop heat pumps are required**
- **Particles can be removed with a cyclone or through a separate evaporator**
- **MVR-blowers, -turbos and screw-compressors seem suitable and are already market available**
- **SHSD offers high CO2-reduction potentials - even without green electricity**
- **Additional Waste heat recovery is possible - when thermal plant losses are low**
- **High COPs enable competitive operation costs.**

Sources

- [1]: T. Fleiter, M. Rehfeldt, S. Hirzel, L. Neusel and A. Aydemir, "Endbericht: CO2-neutrale Prozesswärmeversorgung," Fraunhofer-Institut für System und Innovationsforschung, Karlsruhe, 2023.
- [2]: Romdhana H., Bonazzi C., Decloux M., 2015. „Superheated-Steam Drying: An Overview of Pilot and Industrial Dryers with a Focus on Energy Efficiency," Drying Technology, DOI: 10.1080/07373937.2015.1025139
- [3]: Tolstorebrov I., Bantle M., Hafner A., Kuz B., Eikevik T., 2014. „ Energy efficiency by vapor compression superheated steam drying systems," In Gustav Lorentzen Conference on Natural Refrigerants, China
- [4]: Sobulska M, Wawrzyniak, P., Woo M.. Superheated Steam Spray Drying as an Energy-Saving Drying Technique: A Review, energies, 2022, vol 15,8546, doi.org/10.3390/en15228546
- [5]: Bell I., Wronski J., Quoilin S., Lemort V., 2014. "Pure and Pseudo-pure Fluid Thermophysical Property Evaluation and the Open-Source Thermophysical Property Library CoolProp," Industrial & Engineering Chemistry Research, vol. 6, no. 53.
- [6] PILLER VapoFan® 1.0 - Modulares MBV-Komplettsystem
- [7] PILLER VapoFlex® - Kundenspezifische MBV-Verdichter
- [8] SteamScrew - Fraunhofer IEG

Thank you for your attention

Questions or comments?

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