CALCULATION, SIMULATION AND APPLICATION OF COMMERCIAL AND LIGHT INDUSTRIAL CO_2 HEAT PUMPS

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refrigerants delivered by mother nature

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- Results of the work
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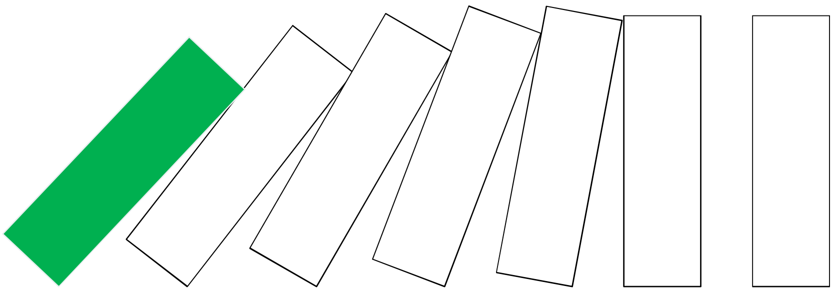
MOTIVATION

Heating and Cooling with Natural Refrigerants – a Way to Decarbonization. The present work is based on an air to water heat pump with CO_2 as refrigerant. In the form of a short analytical study, an attempt is made to identify possible influences that could result from the use of a more efficient compressor in an otherwise unchanged system.



HEAT PUMP APPLICATIONS WITH CO_2 AS REFRIGERANT

Hot or tap water heat pumps with CO_2 as refrigerant are predestined for applications with low water inlet -, high water outlet temperatures and high hot water demand, e.g. for bath loving people in spas and hotels, or in industrial applications.

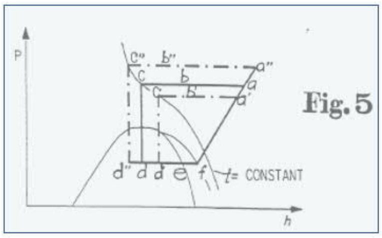
Influences on COP:

- Heat source (air, waste water, etc.)
- Heat source temperature range to decide for monovalent, bivalent design
- Evaporator design
- Control on refrigeration circuit and water side
- Water storage tank and stratification
- Gas cooler design
- Oil return
- Choice of lubricant
- Defrost operation

HEAT PUMP APPLICATIONS WITH CO_2 AS REFRIGERANT

Gustav-Lorentzen-Cycle

- Single stage compression and expansion
- Control of optimum discharge pressure
- No control of superheat – evaporator operates semi-flooded
- Low pressure receiver and internal heat exchanger required



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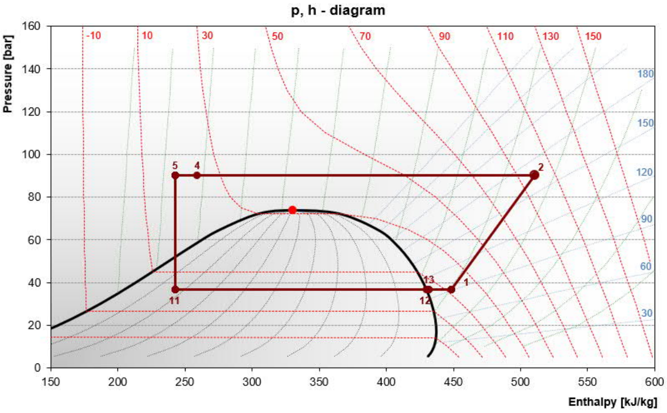
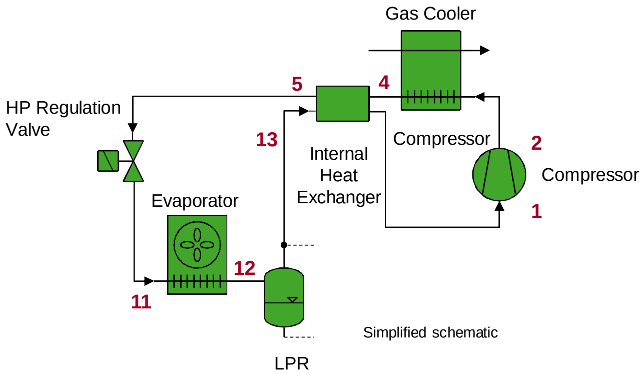
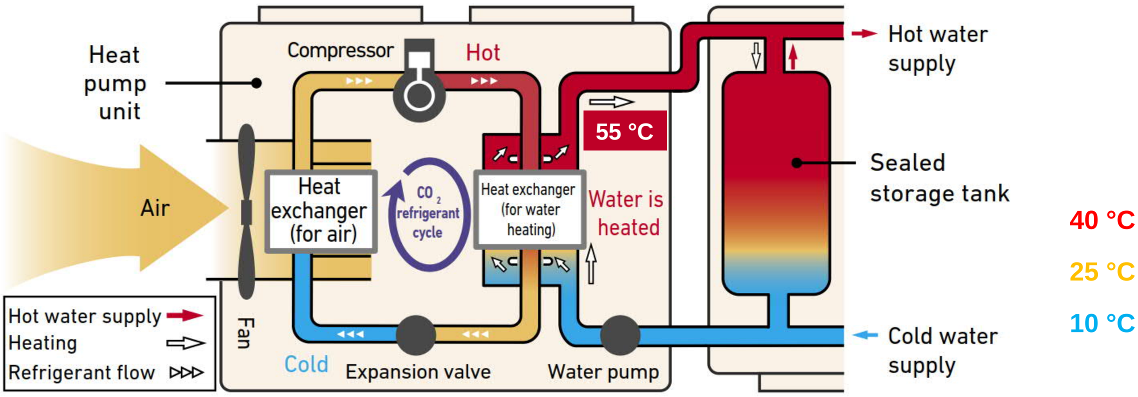




Schematic shows the so-called Gustav-Lorentzen-Cycle

HEAT PUMP APPLICATIONS WITH CO_2 AS REFRIGERANT

- Basic operating modes are charging, re-heating and tapping mode
- Process of water heating is transient
- This work is based on a reference temperature of 55 °C for the water outlet
- Considered water inlet temperatures are 10 °C (start heating), 25 °C and 40 °C (end heating, or re-heating)

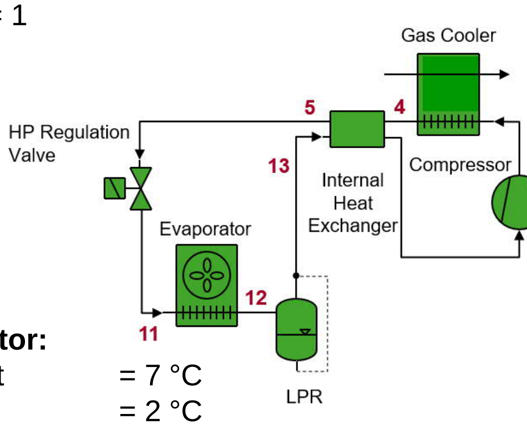


Reference: NIHON ITOMIC, Co. LTD

BOUNDARY CONDITIONS

Internal heat exchanger (IHX):

$T_{oh, min}$ (start value) ≈ 7 K, then T_{oh} f(m_r, ΔTm)
A = 0,46 m²
No. of plates = 22
Water passes = 1

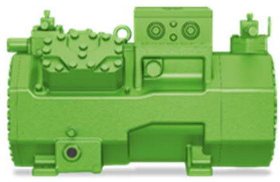


Evaporator:

t ambient = 7 °C
to = 2 °C
$T_{oh, evaporator}$ = 0 K

Gas cooler:

p_{HP} = 80; 85; 90; 95; 100; 120 bara
$t_{water\ inlet}$ = 10; 25; 40 °C
$t_{water\ outlet}$ = 55 °C
$\Delta T_{pinch, min}$ = 3 K*



Compressor: ECOLINE (TE) vs. ECOLINE+ (TE+)

- 4HTE-20Z (TE) with standard asynchronous motor (AS), V_{geo} = 12 m³/h @ 1450 rpm
- 4HTEU-20LZ (TE+) with **L**ine **S**tart **P**ermanent **M**agnet motor (LSPM), V_{geo} = 12,4 m³/h @ 1500 rpm
- Drive gear, including valve plates, equal

COMPRESSORS WITH LSPM MOTOR

Compressors with LSPM motors offer a higher COP. Increased efficiency is based on:

- Higher motor efficiency
- Higher mass flow rates due to synchronous speed
- Higher mass flow rates due to higher suction gas density ⇨ lower superheat across motor

MAIN IFLUENCES ON $COP_{HEATING}$

Control strategy:
- Optimum discharge pressure
- Water flow
- Capacity control

Internal heat exchanger:
- Superheat / evaporation of liquid vs. subcooling

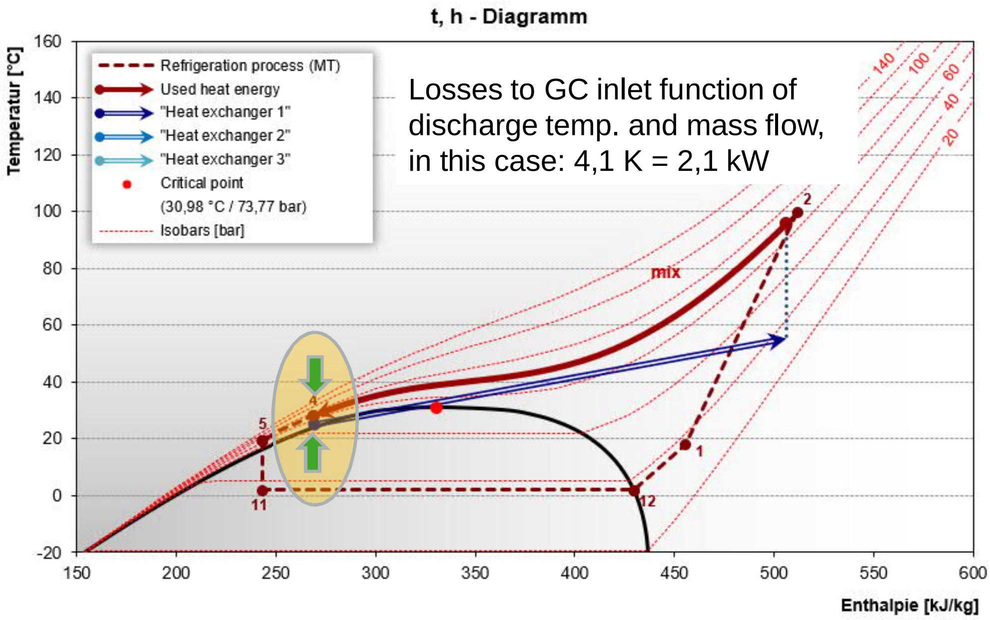
Efficiency of Compressor
- Reduced power input
- Increased mass flow
- Reduced t_{dis}

Gas cooler:
- Pinch point
- Heat transfer
- Pressure drop
- Water pass
- Heat loss
- Water supply

Evaporator:
- Temp. approach
- Heat transfer
- Pressure drop
- Heat source

PINCH POINT AND HEAT LOSS

- Visualisation of gas cooling heat transfer in t, h – diagram



CO_2: 80 bara, t 85->28°C:
t_{water} 25->55°C
ΔT_{pinch} = -2,6 K
$\Delta T_{water\ in}$ = 3,1 K
ΔT_m = 4,9 K

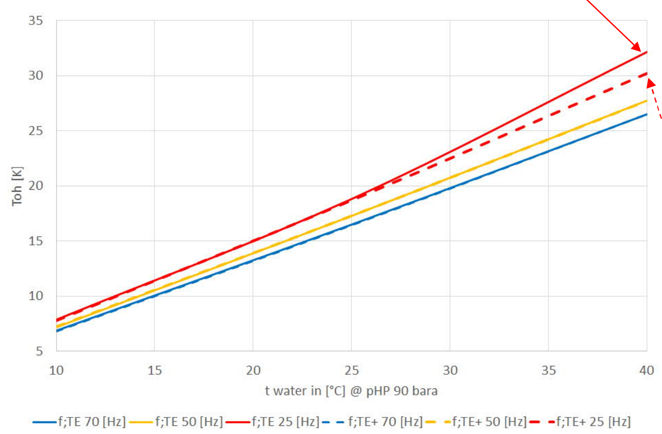
CO_2: 90 bara, t 96->28°C:
t_{water} 25->55°C
$\Delta T_{pinch} = \Delta T_{water\ in}$ = 3,0 K

ΔT_m = 11,4 K

Pinch Point

RESULTS: INTERNAL HEAT EXCHAENGER

TE: m_r / t_{dis} / Toh = 352 kg/h / 131,1 °C / 32,2 K



TE+: m_r / t_{dis} / Toh = 380 kg/h / 124,5 °C / 30,1 K

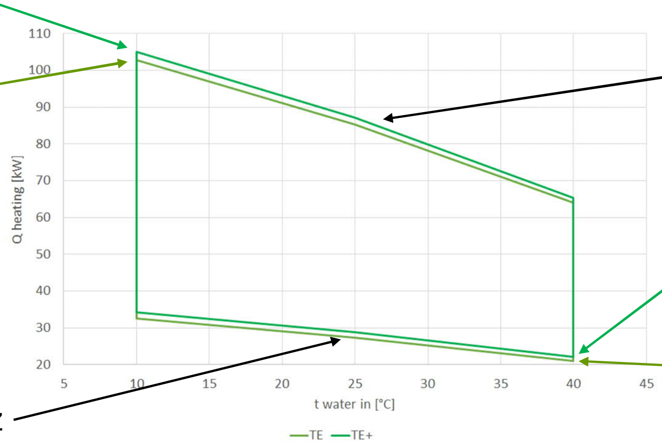
- Superheat is a function of water inlet temperature and compressor speed
- Significant difference in superheat between TE and TE+ compressor especially at high water inlet temperature and low operating frequency
- With increasing torque demand (p_o/p_{HP}), the difference between the rotational speed of an LSPM and AS motor becomes more significant ($f_{operating\ 25\ Hz}$ 750 vs. < 725 rpm)
- The relative slip of the motor increases when the speed is reduced and thus losses and heating of the motor increase as well

RESULTS: CAPACITY MAPS

- Nominal capacity @ t_{amb} / to / p_{HP} / f / $t_{water\ inlet}$ / $t_{water\ outlet}$ = 7 °C / 2 °C / 85 bara / 70 Hz / 10 °C / 55 °C
- Minimum capacity @ t_{amb} / to / p_{HP} / f / $t_{water\ inlet}$ / $t_{water\ outlet}$ = 7 °C / 2 °C / 100 bara / 25 Hz / 40 °C / 55 °C

TE+ $Q_{Heating}$ = 105,3 kW

TE $Q_{Heating}$ = 102,7 kW



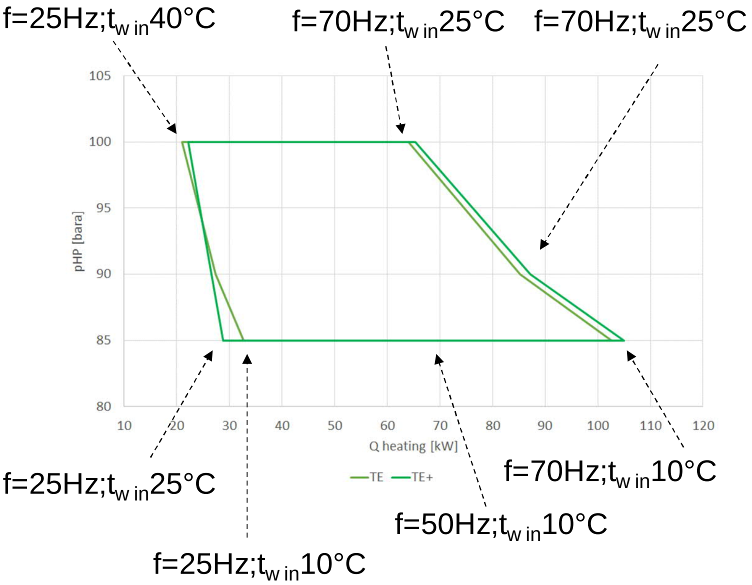
f = 70 Hz

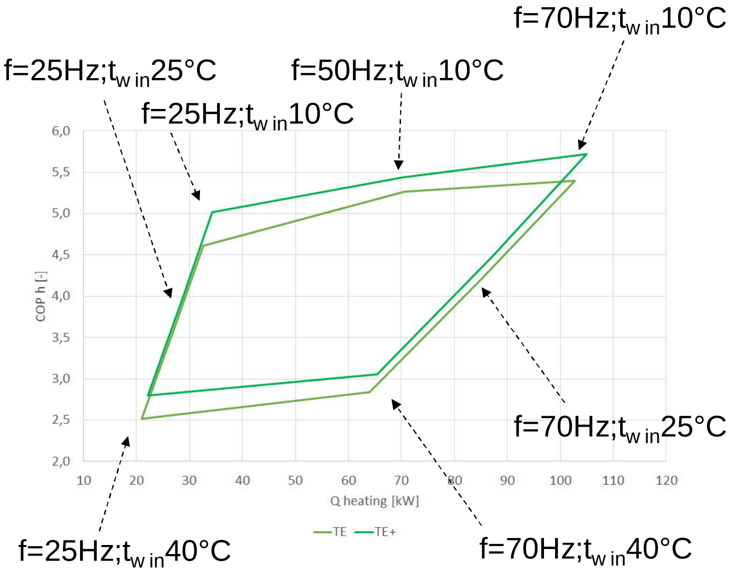
TE+ $Q_{Heating}$ = 22,2 kW

TE $Q_{Heating}$ = 20,9 kW

f = 25 Hz

RESULTS: HIGH PRESSURE AND EFFICIENCY MAPS





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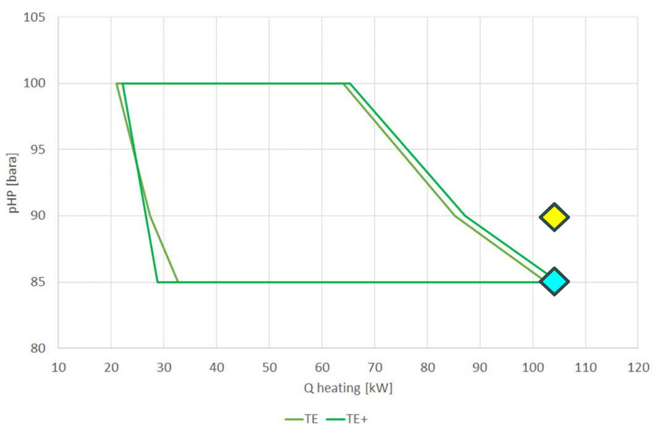
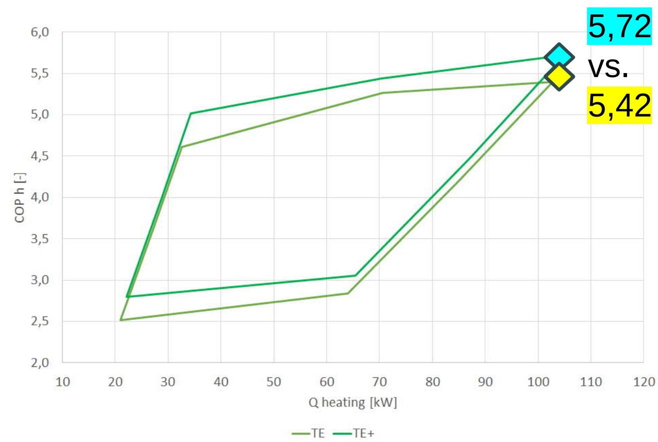
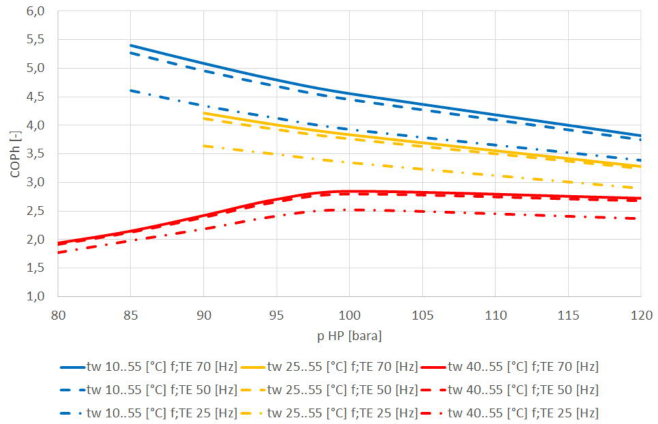
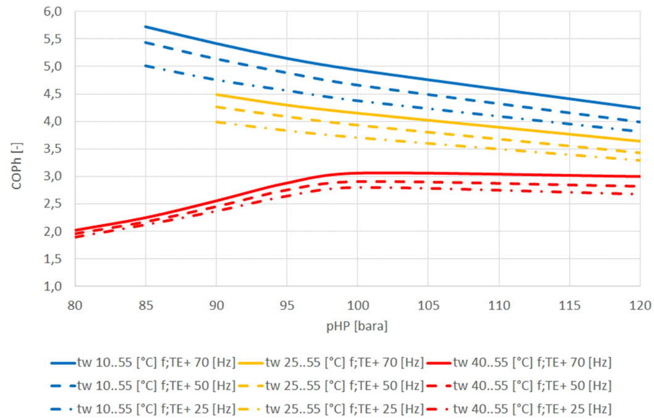




- ΔT_{pinch} @ 85 bara, 70 Hz, $t_{water\ in}$ 10 °C: TE 3,0 K / TE+ 2,8 K
- ΔT_{pinch} @ 90 bara, 70 Hz, $t_{water\ in}$ 10 °C: in both cases 3,0 K
- At this operating point, the influence of increased pressure for the heating capacity is low, but significant for efficiency. For the TE+ series, the disadvantage would be in the range of -5.5 percent.

RESULTS: COP AS FUNCTION OF DISCHAGRE PRESSURE, WATER INLET TEMPERATURE AND FREQUENCY





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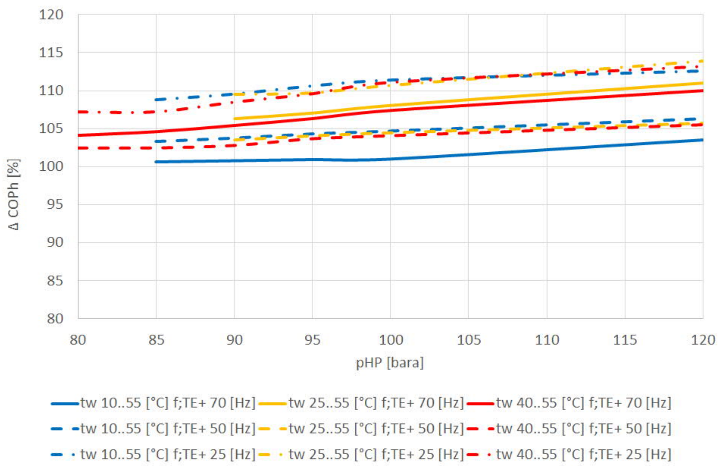
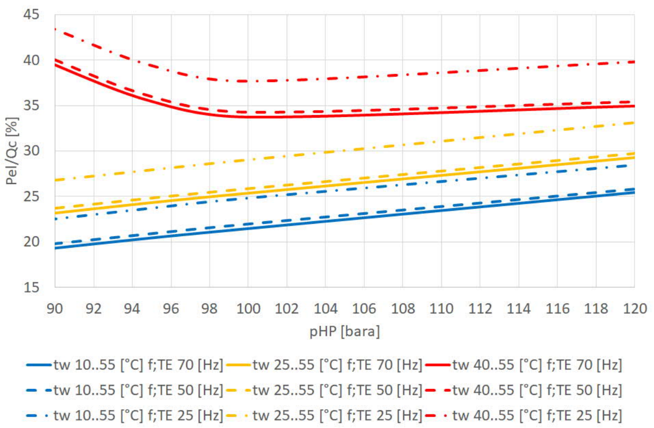
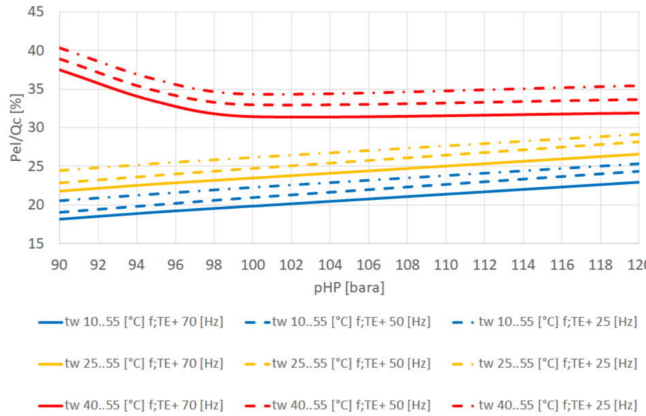


- $t_{water\ inlet}$ 10 and 25 °C : Highest COP with min ΔT_{pinch} and pHP
- $t_{water\ inlet}$ 40 °C : Highest COP with approx. 100 bar
- TE+: Highest increase in COP with 25 Hz and highest pressure ratio

RESULTS: SHARE OF POWER CONSUMPTION





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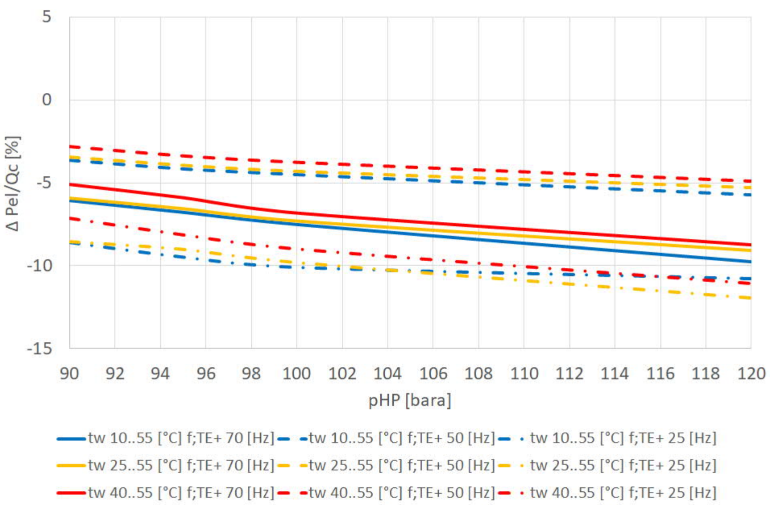

- TE+: Share of power consumption in heat capacity is reduced
  - Share reduced with increasing pressure ratio
  - Most significant with 25 Hz operating frequency
  - Lowest change with 50 Hz
- Increased mass flow and potentially higher cooling capacity shows the basis for higher heating capacity of the unit with the TE+ compressor

SUMMARY & CONCLUSIONS – USING A MORE EFFICIENT COMPRESSOR WITH LSPM MOTOR IN AN OTHERWISE UNCHANGED SYSTEM

Within the scope of this work, a more efficient compressor with LSPM motor offers:

- Benefit in COP_h, especially with 25 Hz operating frequency of the compressor
- Increased heating capacity

However, it is important to note, that:

- The share of power consumption in the heat capacity decreases
- The level of discharge gas temperatures decreases as well
- The increase in heat output is achieved by an increase in mass flow and thus in cooling capacity
- The pinch point temperature difference is affected in a negative way with 10 and 25 °C water inlet temperature and discharge pressures < 90 bara

For the conditions considered:

- The trend of the optimum high pressures are the same
- A significant difference in superheat is generated by the IHX, especially at 40 °C water inlet temperature and 25 Hz operating frequency

THANK YOU FOR YOUR ATTENTION!

Oliver Javerschek
BITZER Kühlmaschinenbau GmbH
Application Engineering and Product Performance
Peter Schaufler-Straße 3
oliver.javerschek@bitzer.de

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