OST
Eastern Switzerland
University of Applied Sciences
IES | Institute for Energy Systems

2024

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DTU

Testing and modelling of a steam-generating heat pump at up to 175 °C (SuPrHeat project)

Testing and modelling of a

Steam-generating heat pump at up to 175 °C

Steam Grow Heat Pumps (SGHs)

Kobelco SGH165

R-245fa + R-134a (mixture)

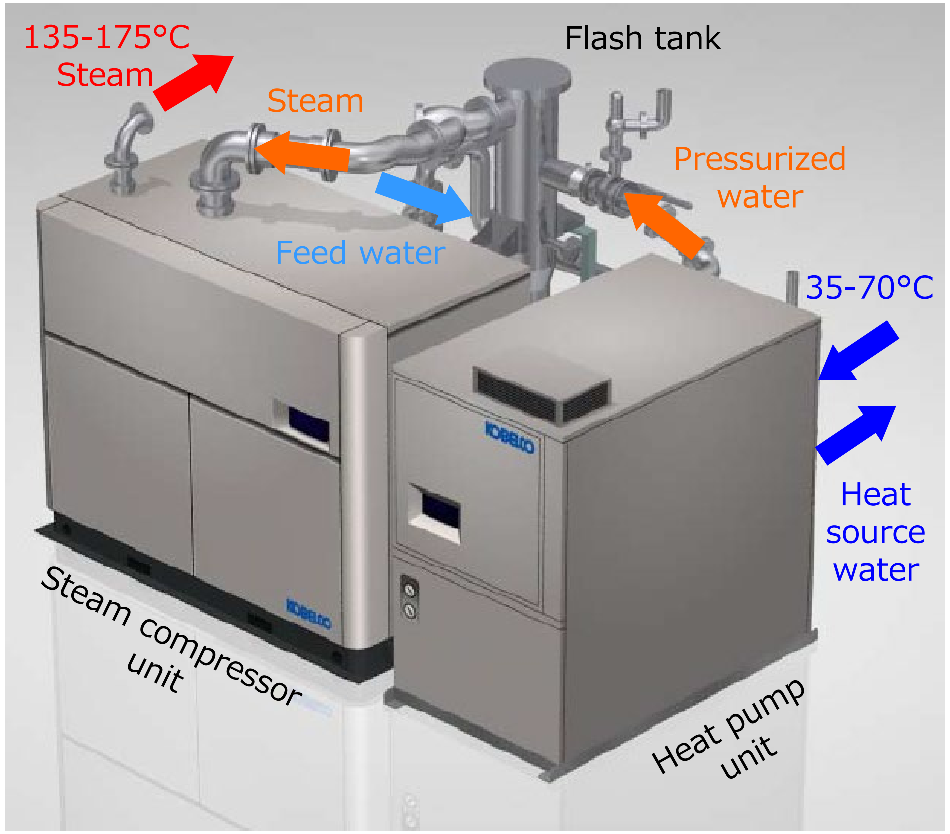
Single-stage screw compressor +
flash tank +
steam compressor

Steam ≤175 °C,

Heat source from 35 °C to 70 °C

Q = 660 kW (0.9 ton/h)

COP = 2.5, for 165 °C steam
70 °C source

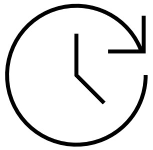


Steam Grow Heat Pumps (SGHs)

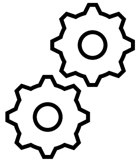
Kobelco SGH165

Already working! But….

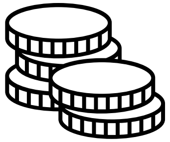
Future-proofing

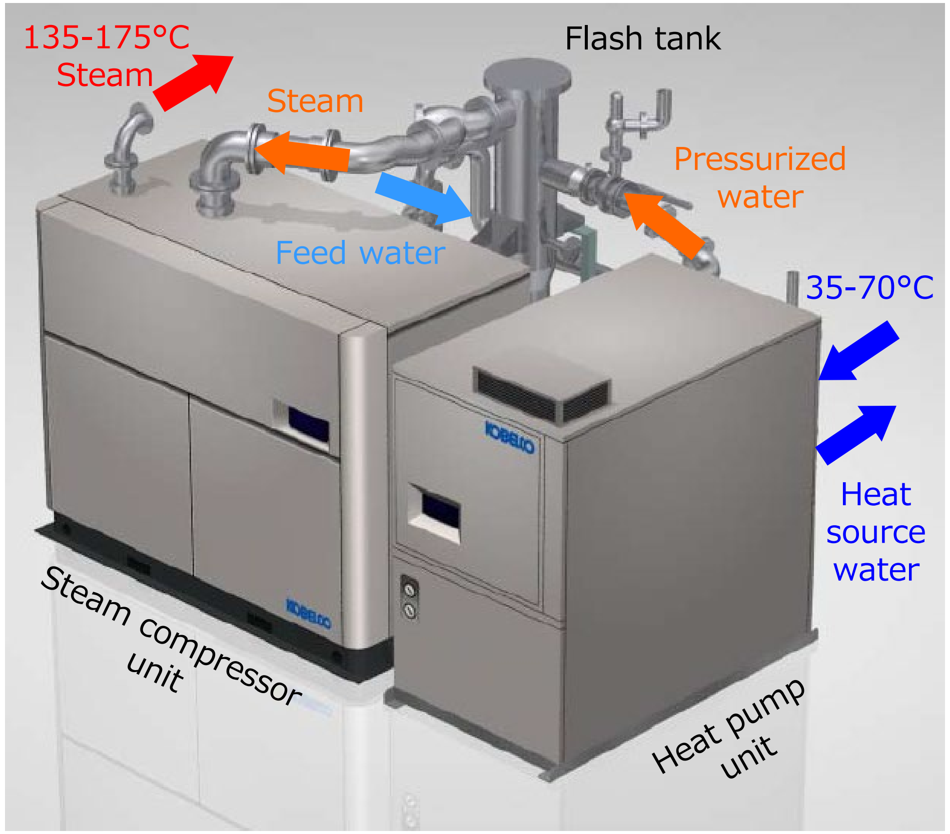


Increase performance



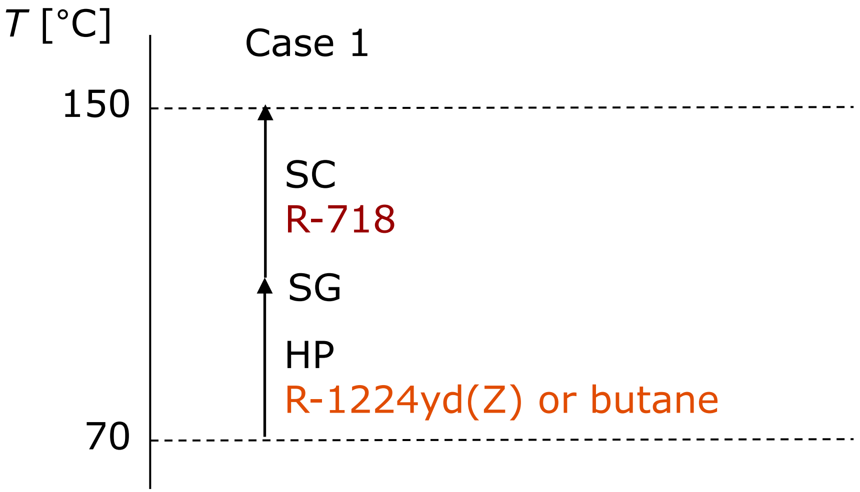
Lower cost





Technology Perspective

- New refrigerants as alternative to R-245fa
- Drop in for BAU:
  - **R-1224yd(Z)**
  - **Butane**



Higher temperatures:

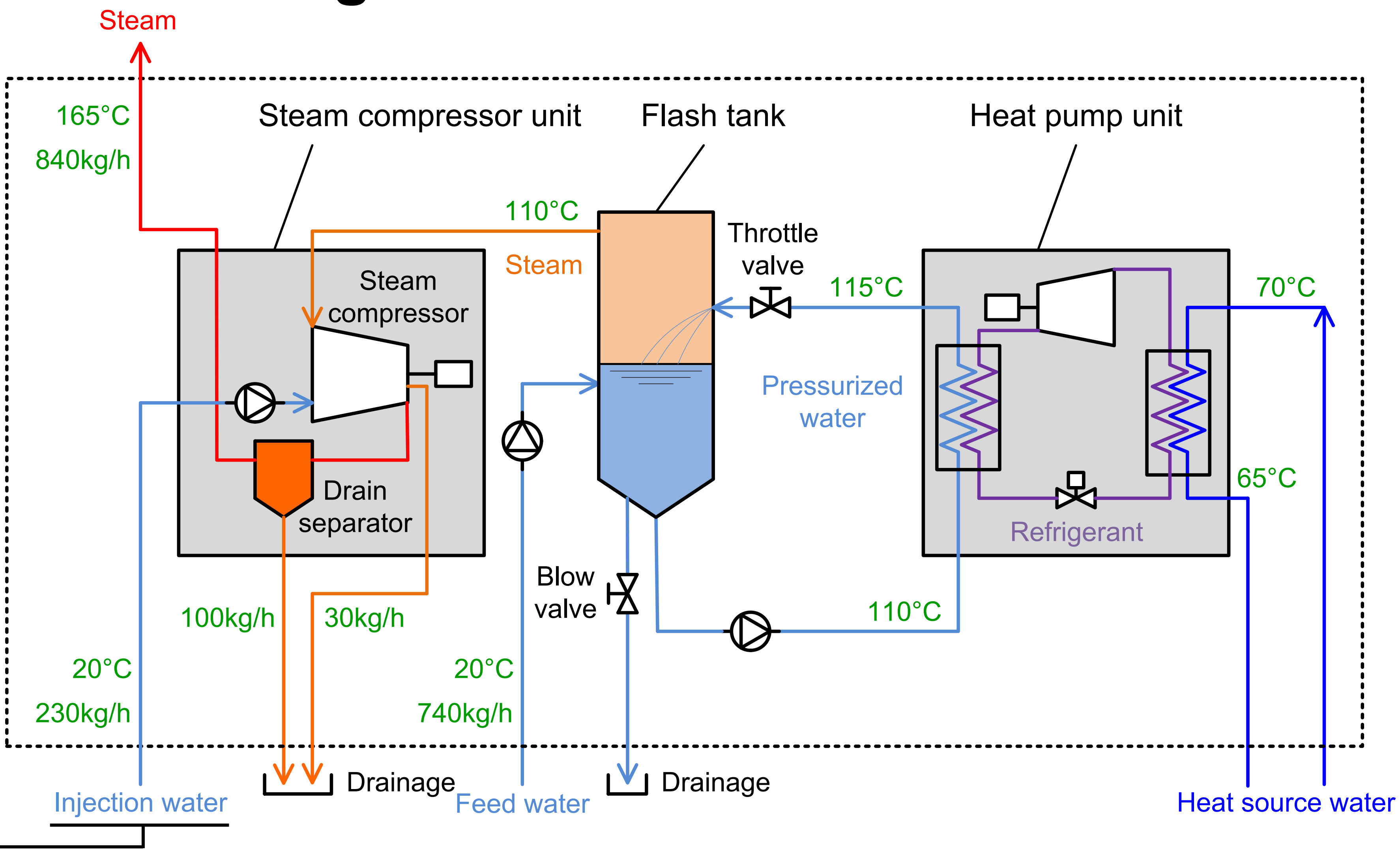
R-1336mzz(Z)

Pentane

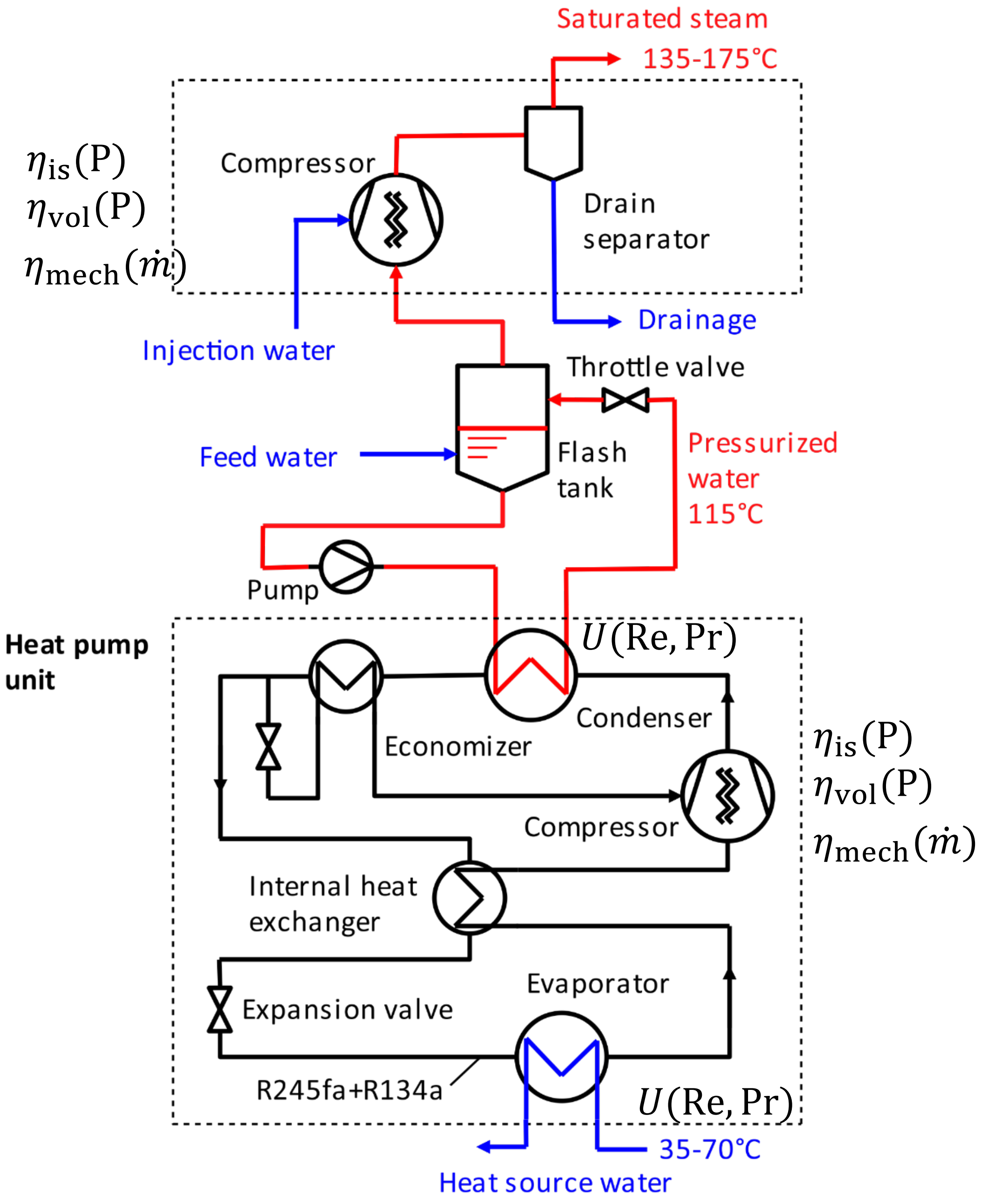
→ Removing expensive steam compressor unit

System Configuration

* Numerical values at the rated condition



- For preventing the superheat of the discharge steam
- For keeping the clearance between rotor and rotor, between rotor and casing

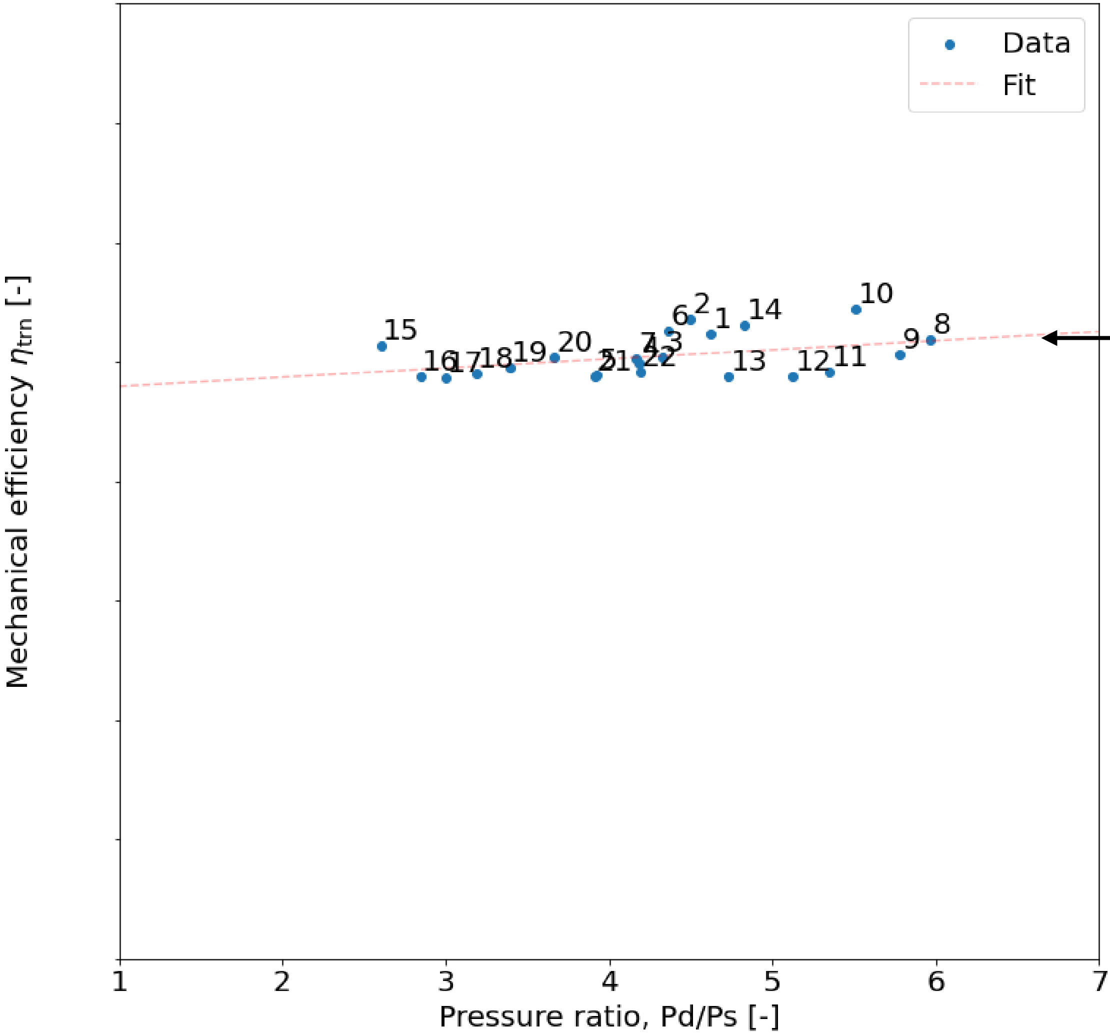


$$\mathrm{COP} = \frac{\dot{m}_{\mathrm{steam}} \cdot \dot{h}_{\mathrm{steam}} \cdot \dot{m}_{in} \cdot h_{in} - \dot{m}_{\mathrm{FW}} \cdot h_{\mathrm{FW}}}{\dot{W}_{\mathrm{HP}} + \dot{W}_{\mathrm{steam,comp}} + \dot{W}_{\mathrm{FT}}}$$

35 °C	Source temperature	70 °C
135 °C	Steam temperature	175 °C
105 °C	Flash tank temperature	114 °C
280 kW	Capacity	535 kW

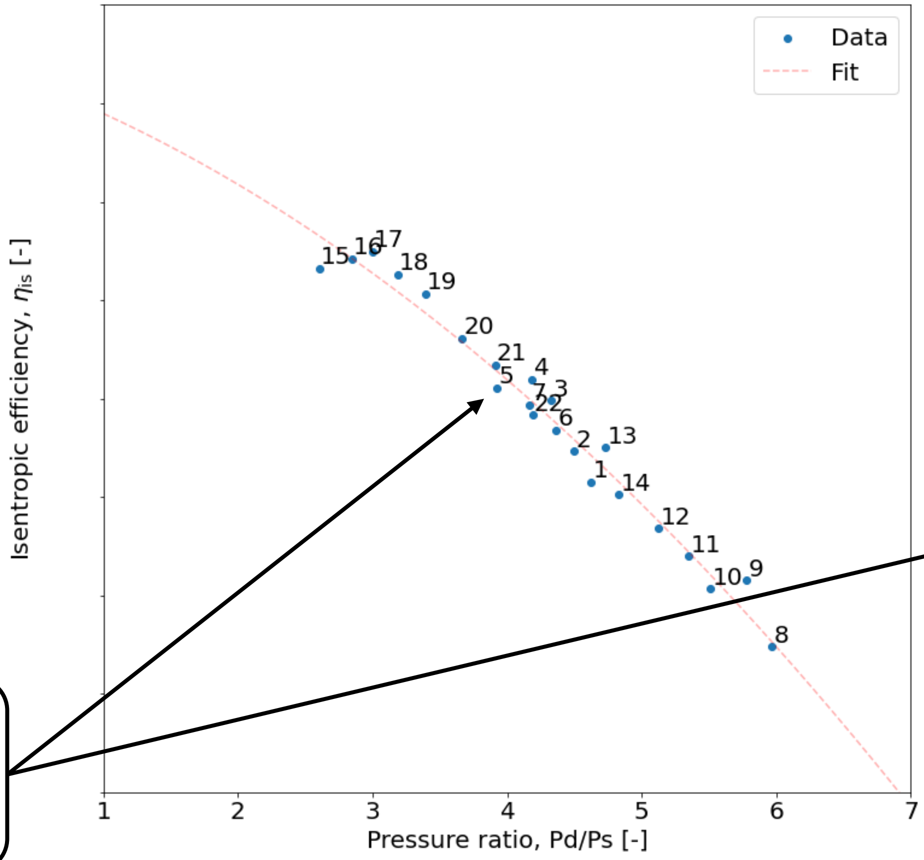
R-245fa R-1224yd(Z) R-1336mzz(E)

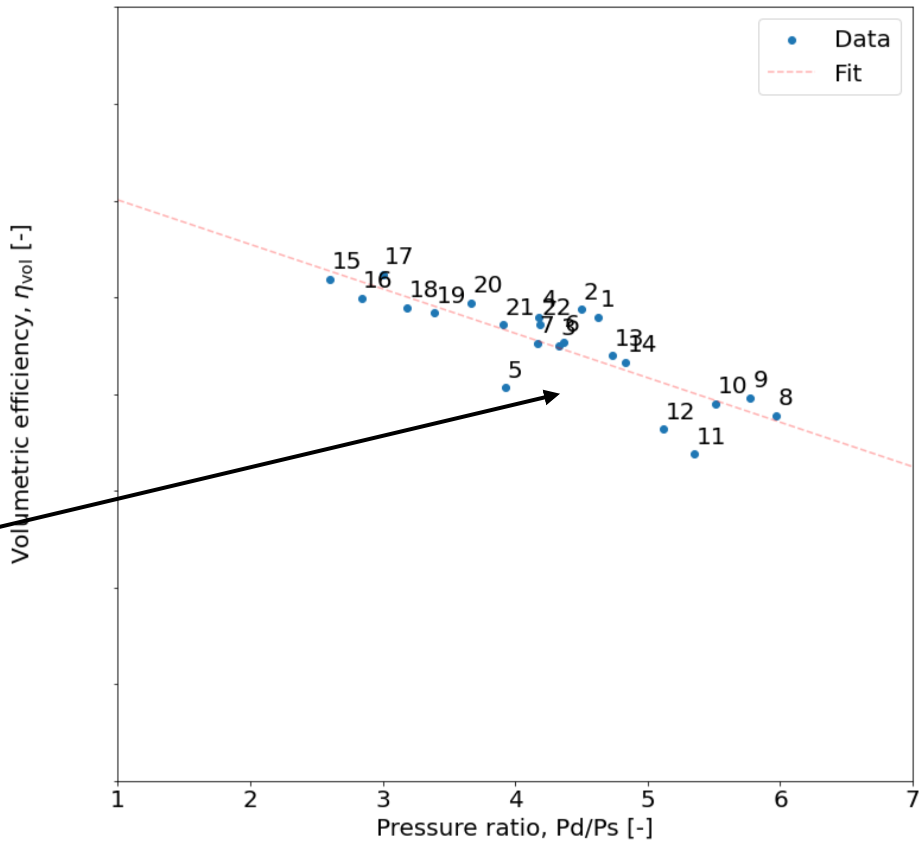
Mechanical and electric efficiency



- Close to constant
- Varying slightly with rotational speed and temperature level

Efficiency of working fluid compressor

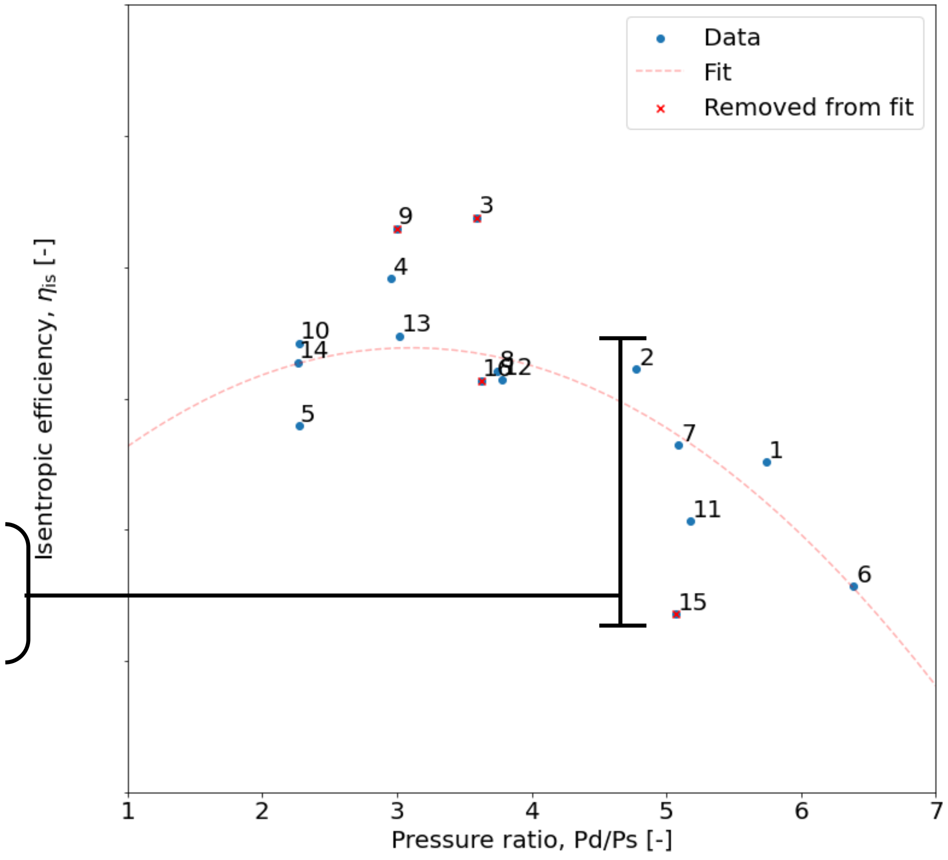


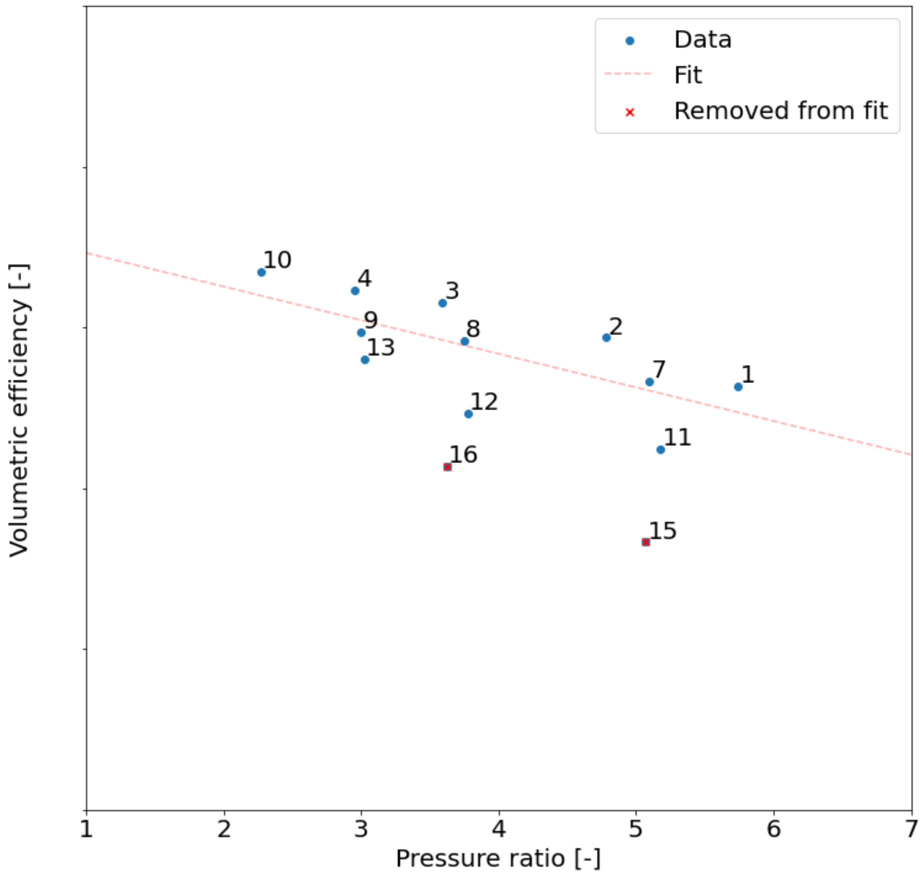


- Clear trend between efficiencies and pressure ratio

Efficiency of steam compressor

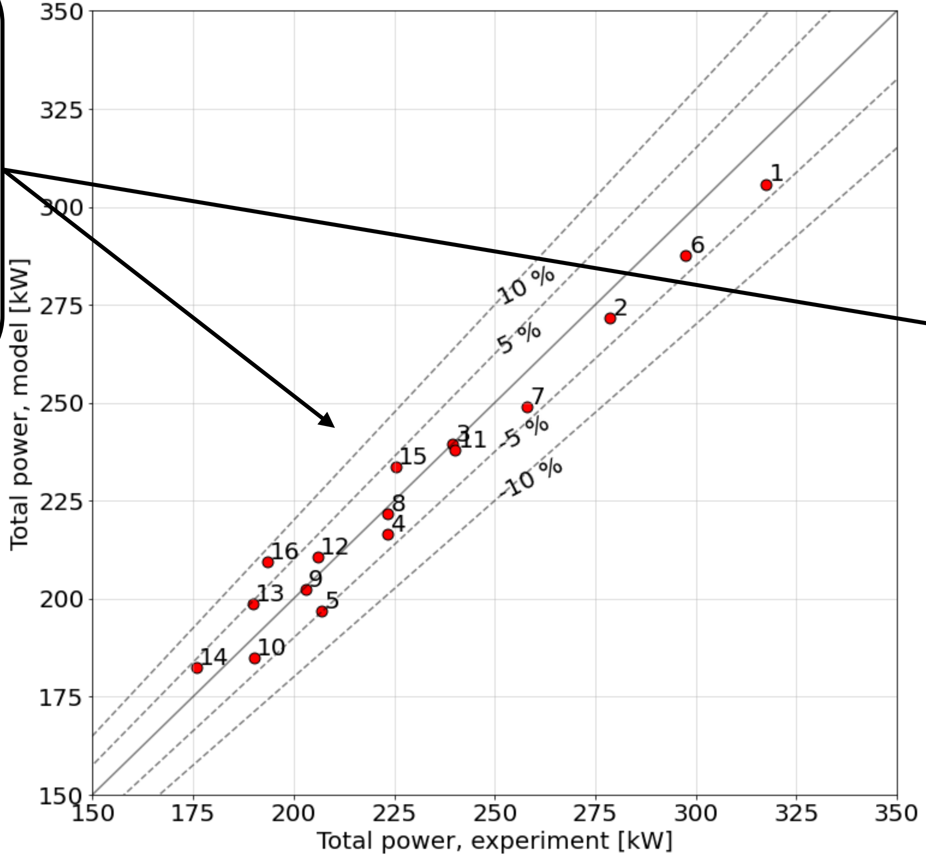
- Varying water injection rates

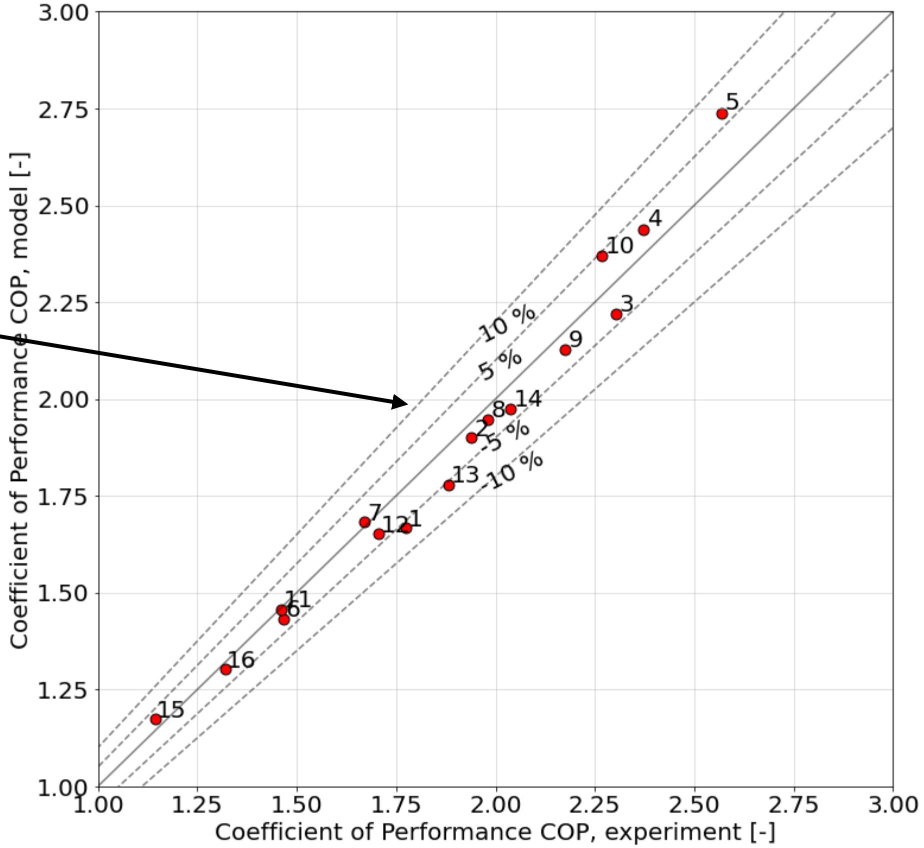




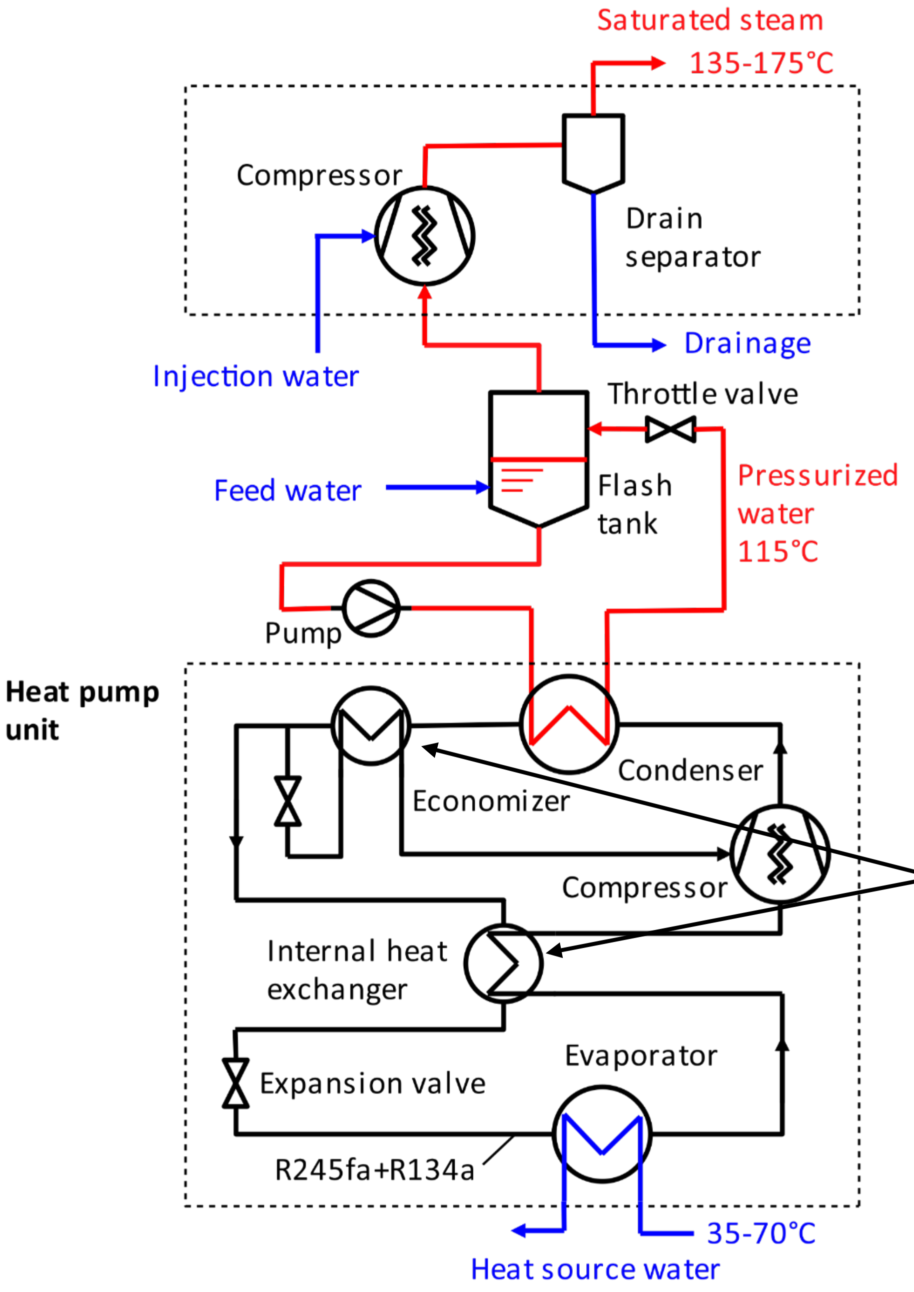
Comparing experimental results modelling

- Error within 5 %
- One measurement within 7 %
- Due to compressor efficiency



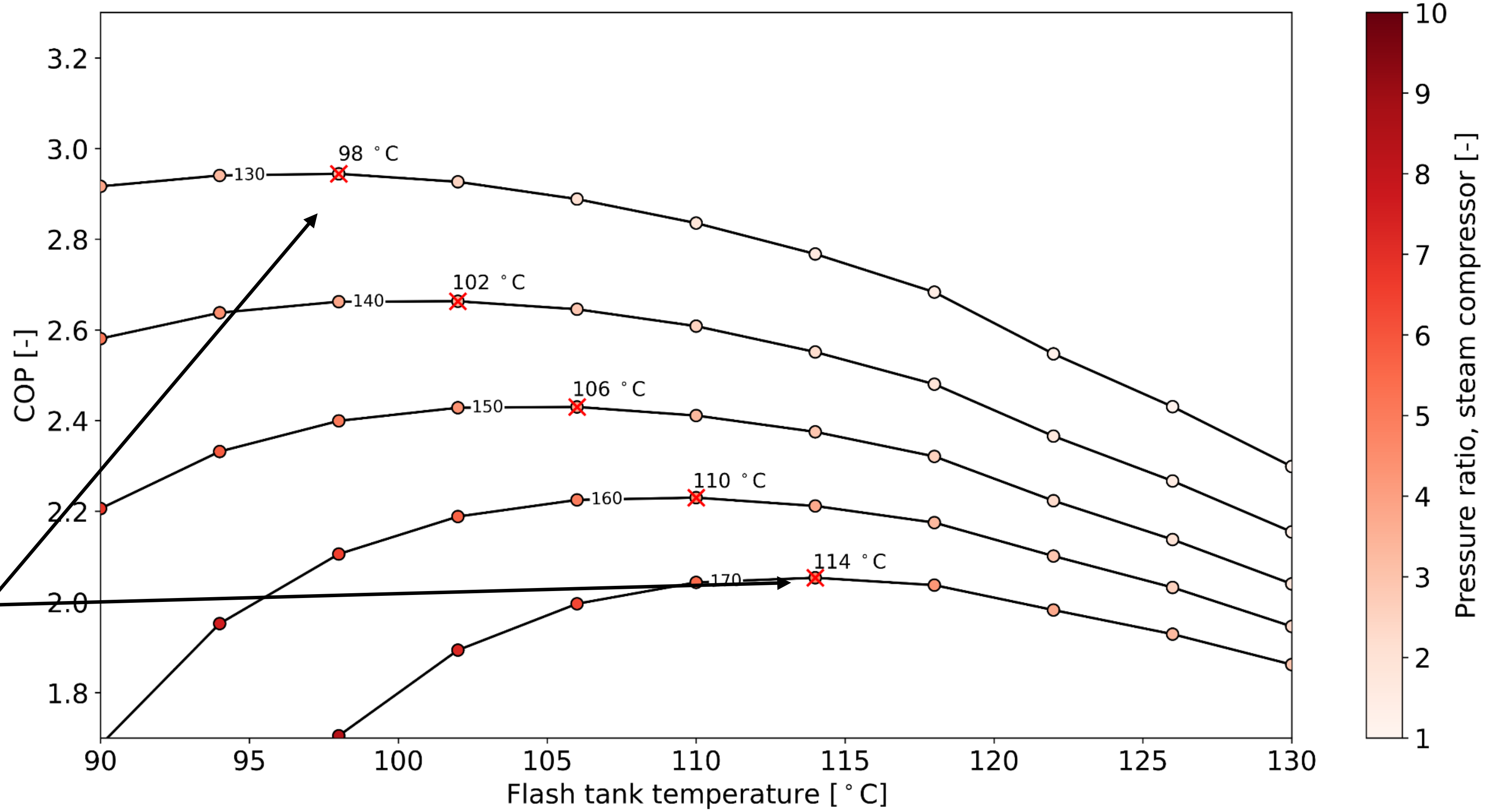


Flash tank temperature

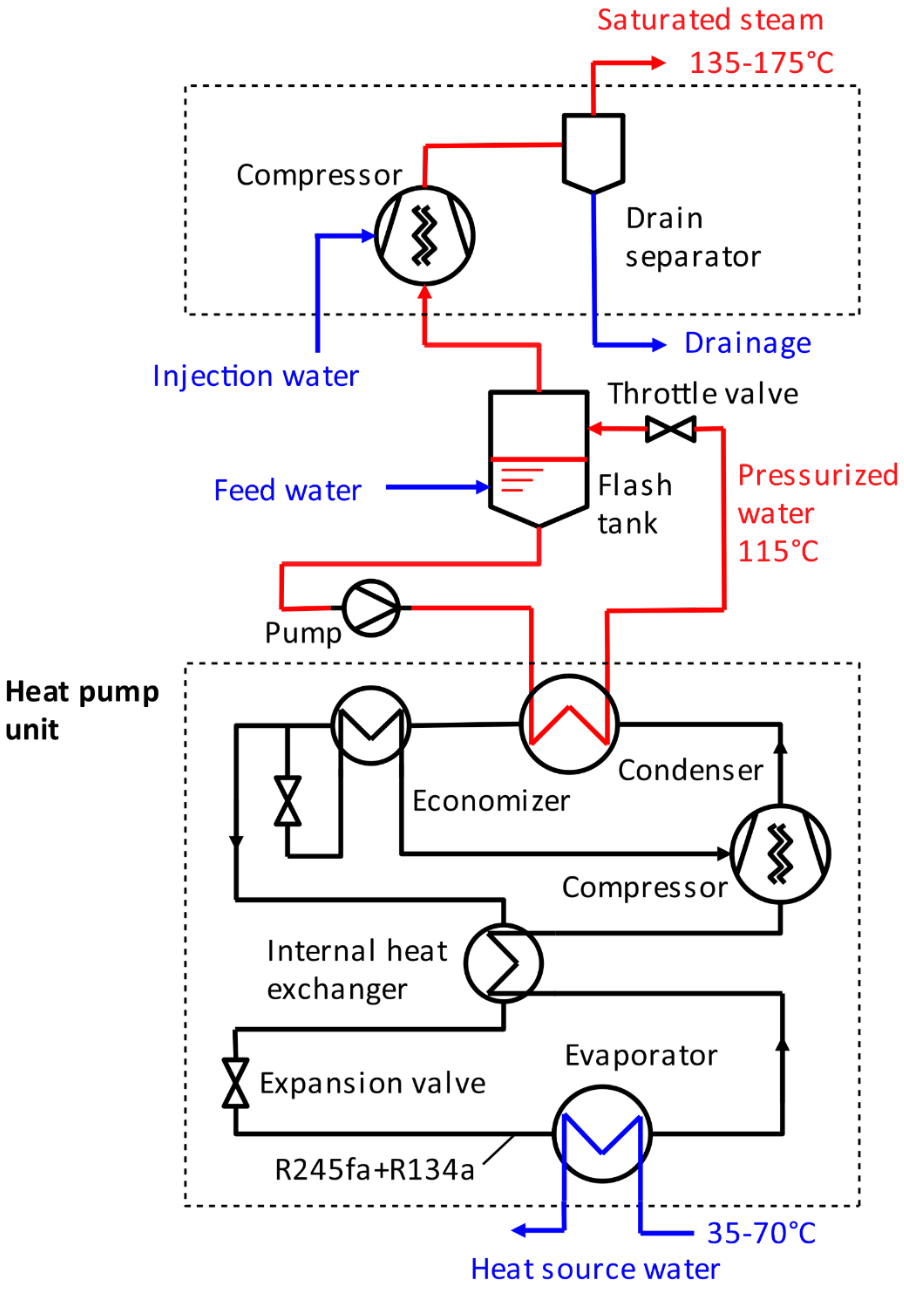


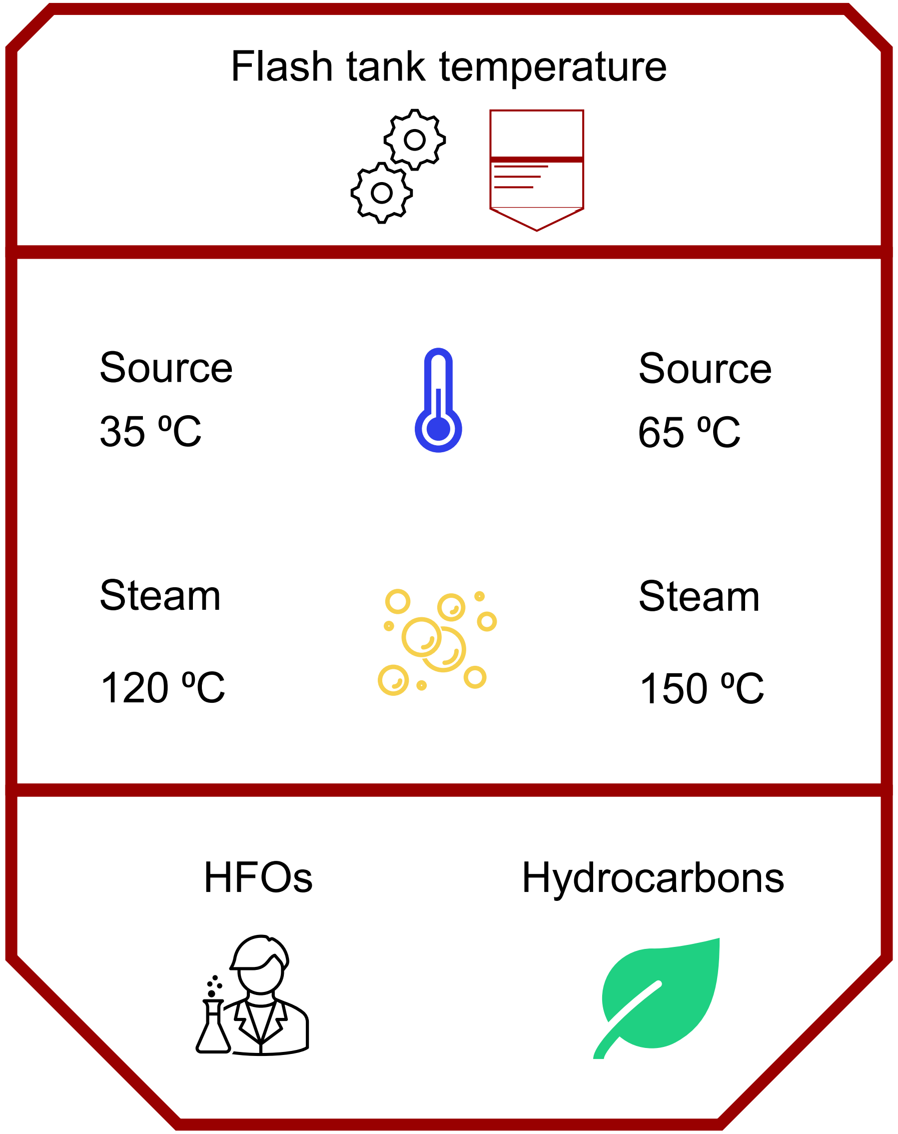
Size of economizer and internal heat exchanger optimized for each simulation

Optimal Flash Tank temperature

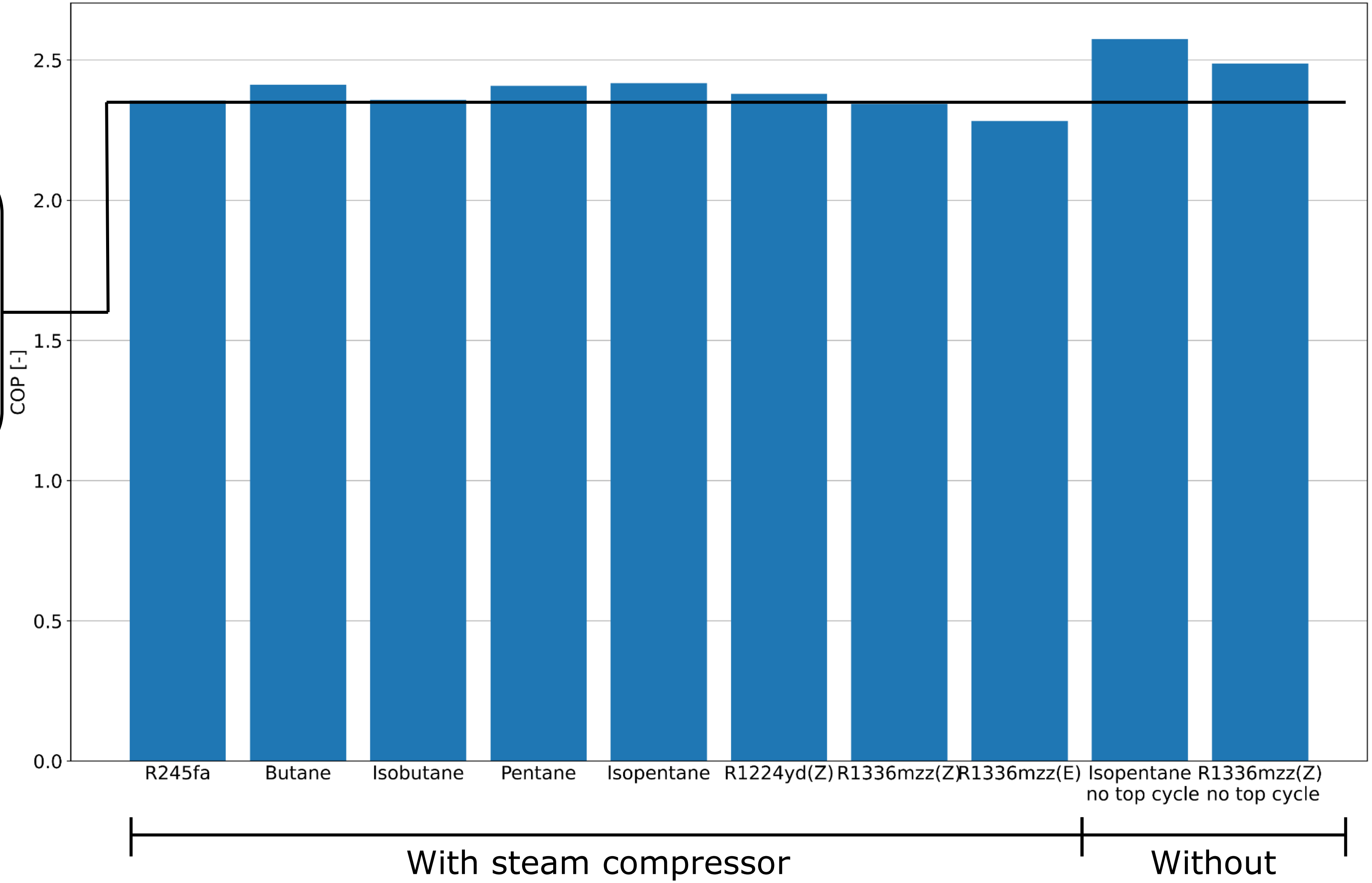


- Optimal flash tank temperature varies with steam temperature
- Optimum depends heavily on compressor efficiencies


Saturated steam
135-175°C
Compressor
Drain
separator
Drainage
Injection water
Throttle valve
Feed water
Flash
tank
Pressurized
water
115°C
Pump
Heat pump
unit
Condenser
Economizer
Compressor
Internal heat
exchanger
Evaporator
Expansion valve
R245fa+R134a
35-70°C
Heat source water

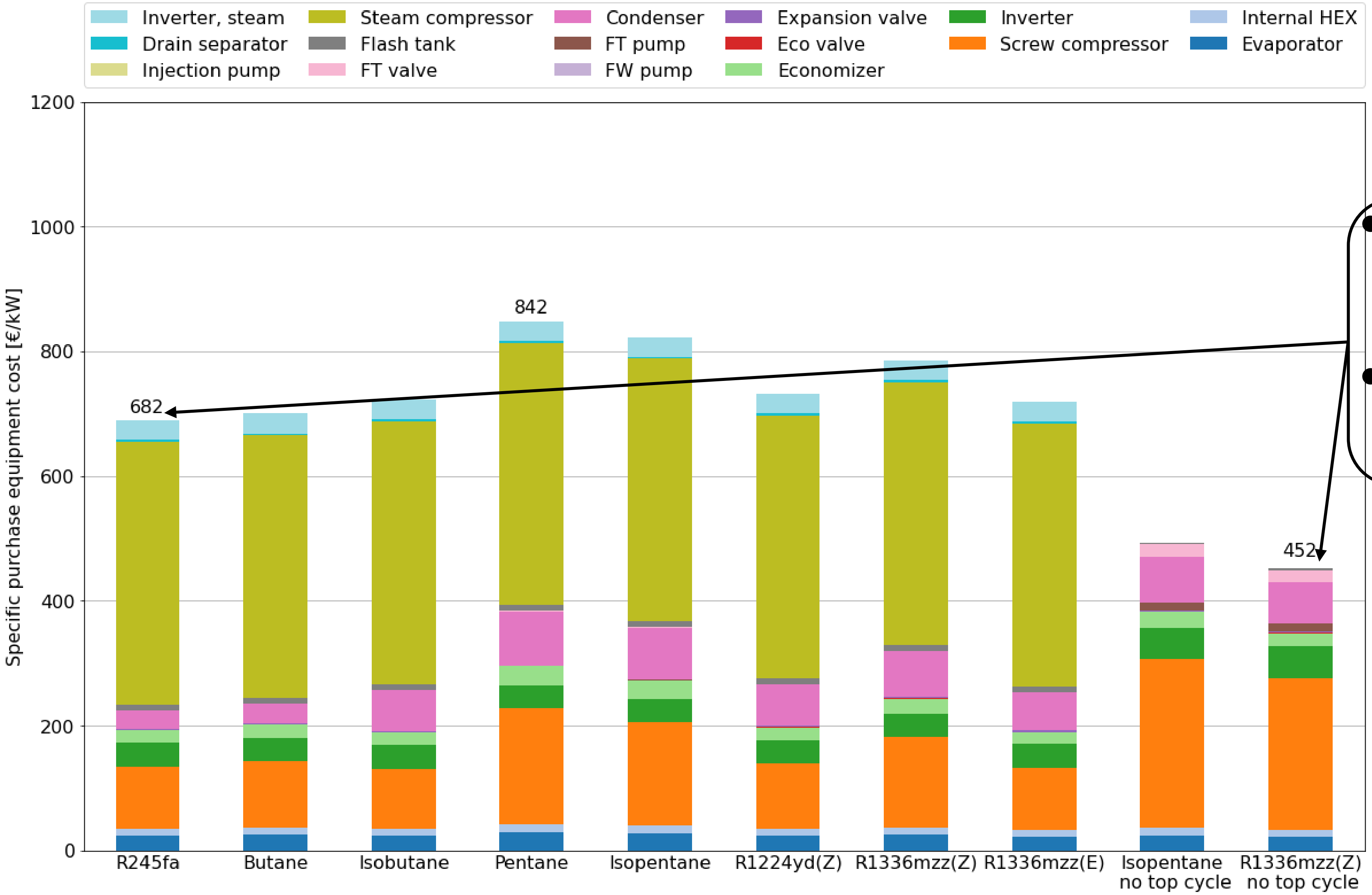

Flash tank temperature
Source
35 ºC
Source
65 ºC
Steam
120 ºC
Steam
150 ºC
HFOs
Hydrocarbons

- Minor difference between working fluids
- Slight edge to Hydrocarbons
- Better without steam compressor



Source
65 ºC

Steam
150 ºC

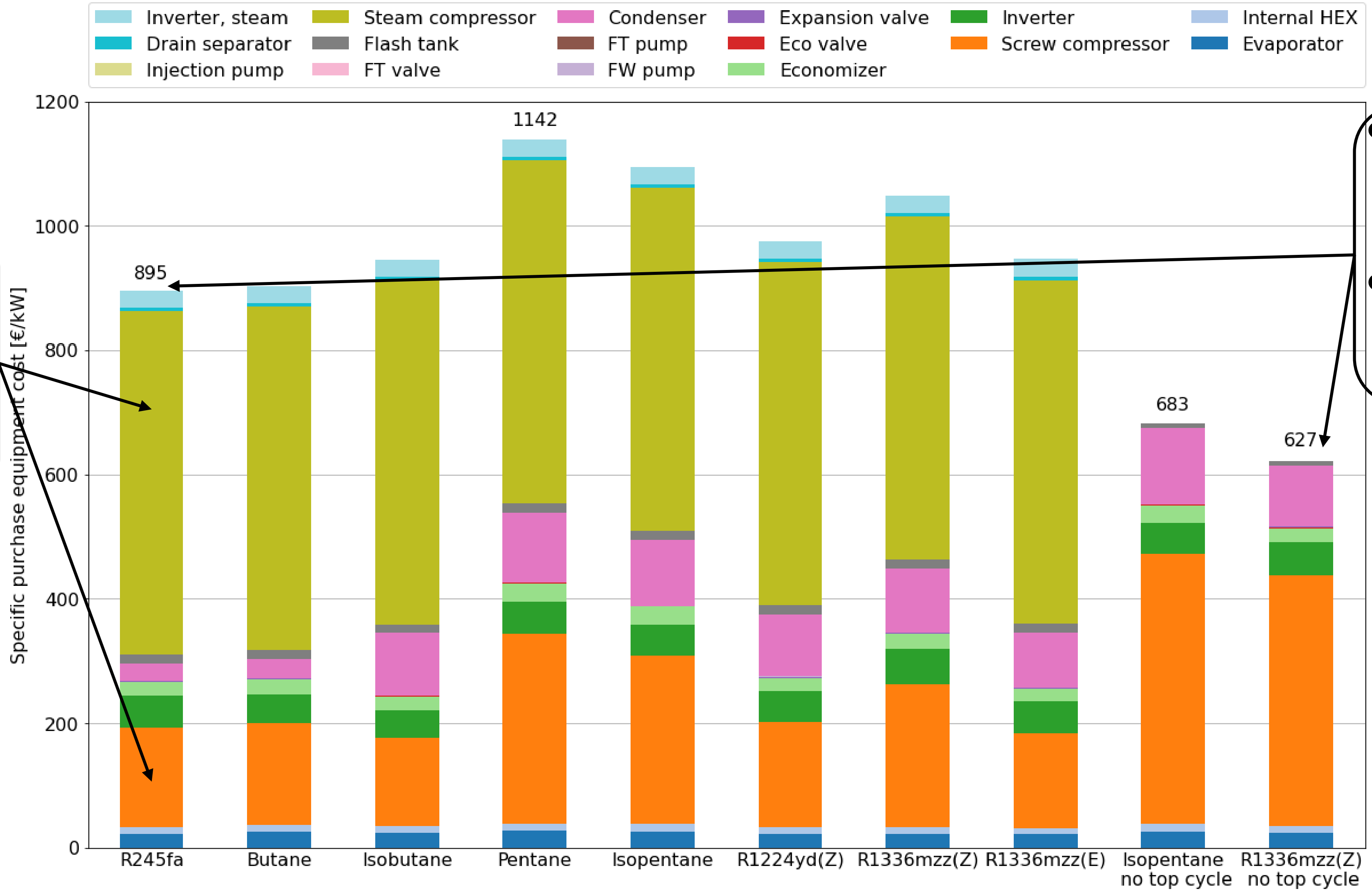


- Lowest cost by R-1336mzz(Z) w.o. steam compressor
- Lowest cost by R-245fa in current setup.

Source
65 ºC

Steam
150 ºC

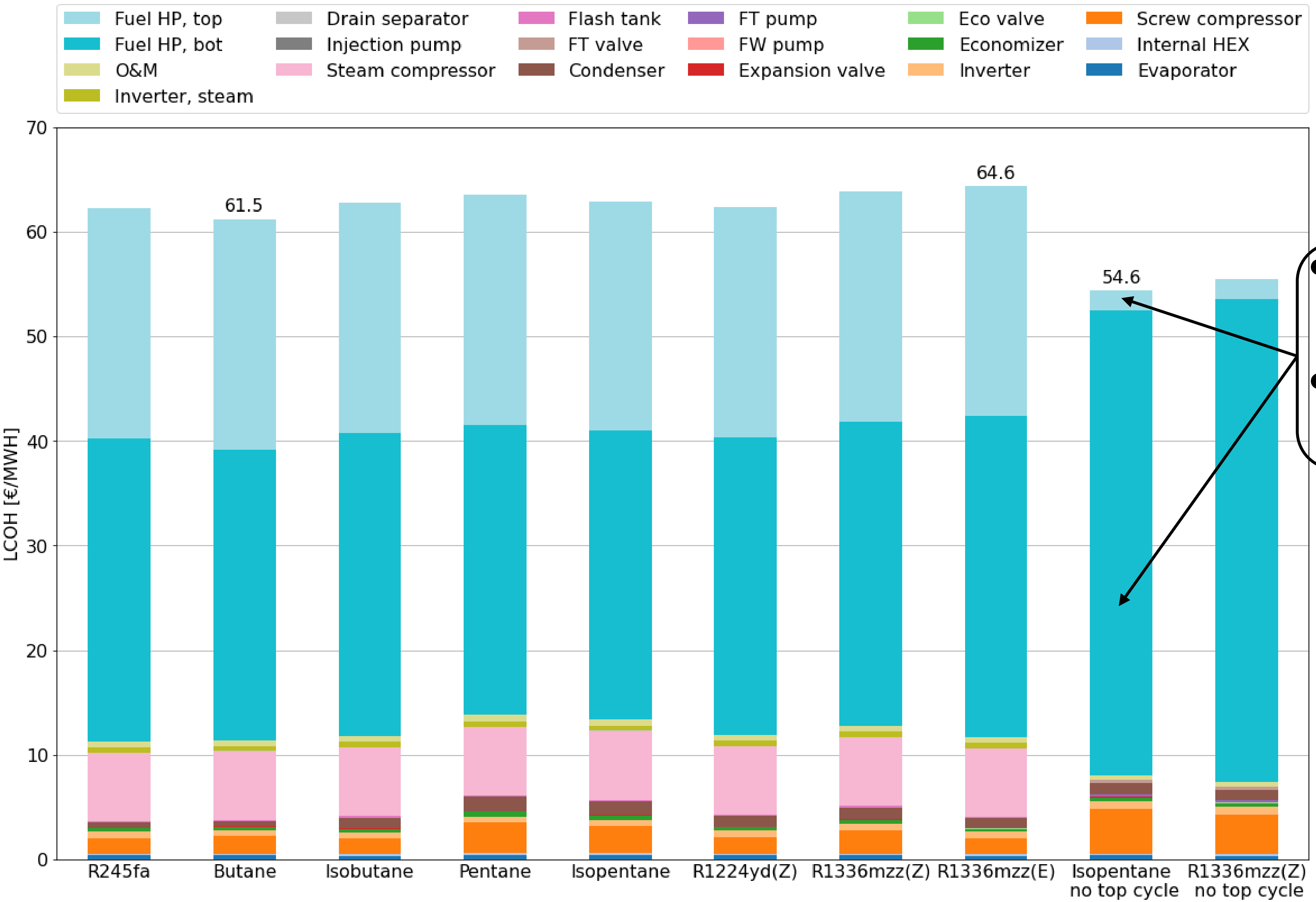
- Steam compressor most expensive
- Then screw compressor, followed by condenser



- Lowest cost by R-1336mzz(Z) w.o. steam compressor
- Lowest cost by R-245fa and butane in current setup.

Source 35 ºC

Steam 120 ºC

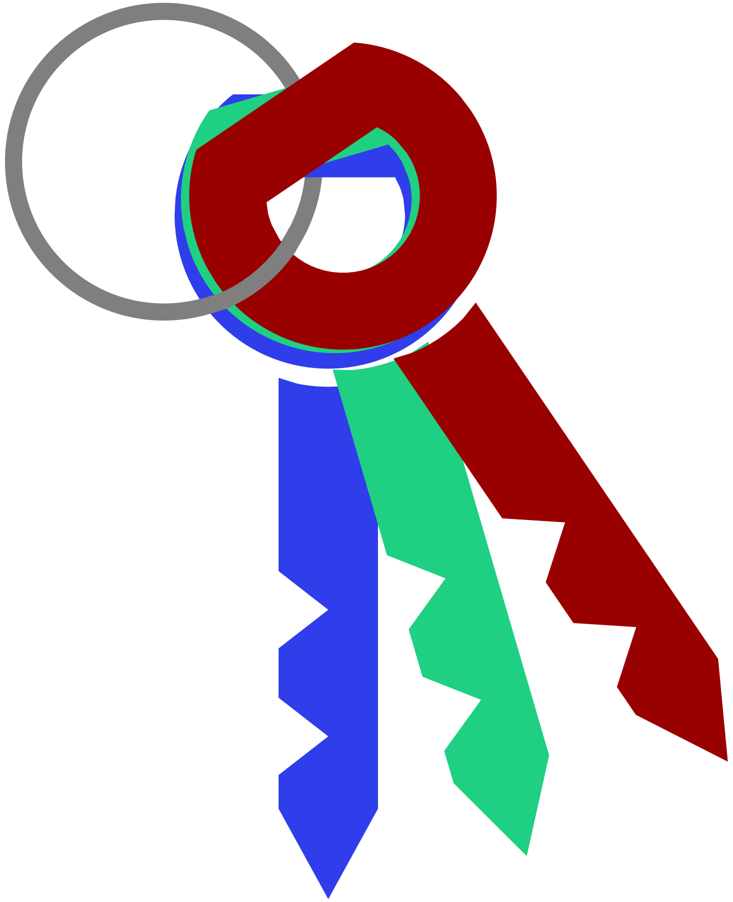


- Little power consumption of flash tank
- Fuel is dominating overall LCOH

Source
65 ºC

Steam
150 ºC

Keys to improve performance



1

Successful drop-in of new working fluid

Low GWP fluid was implemented without changes to the SGH components or controlsystem.

2

Hydrocarbons are capable

Hydrocarbon as working fluid are capable of delivering highest performance across all temperature conditions when considering life time economics

3

Compressor efficiency is key

Greater performance heavily rely on the development of more efficient compressors.
The best performance was exhibited when dropping the steam compressor.

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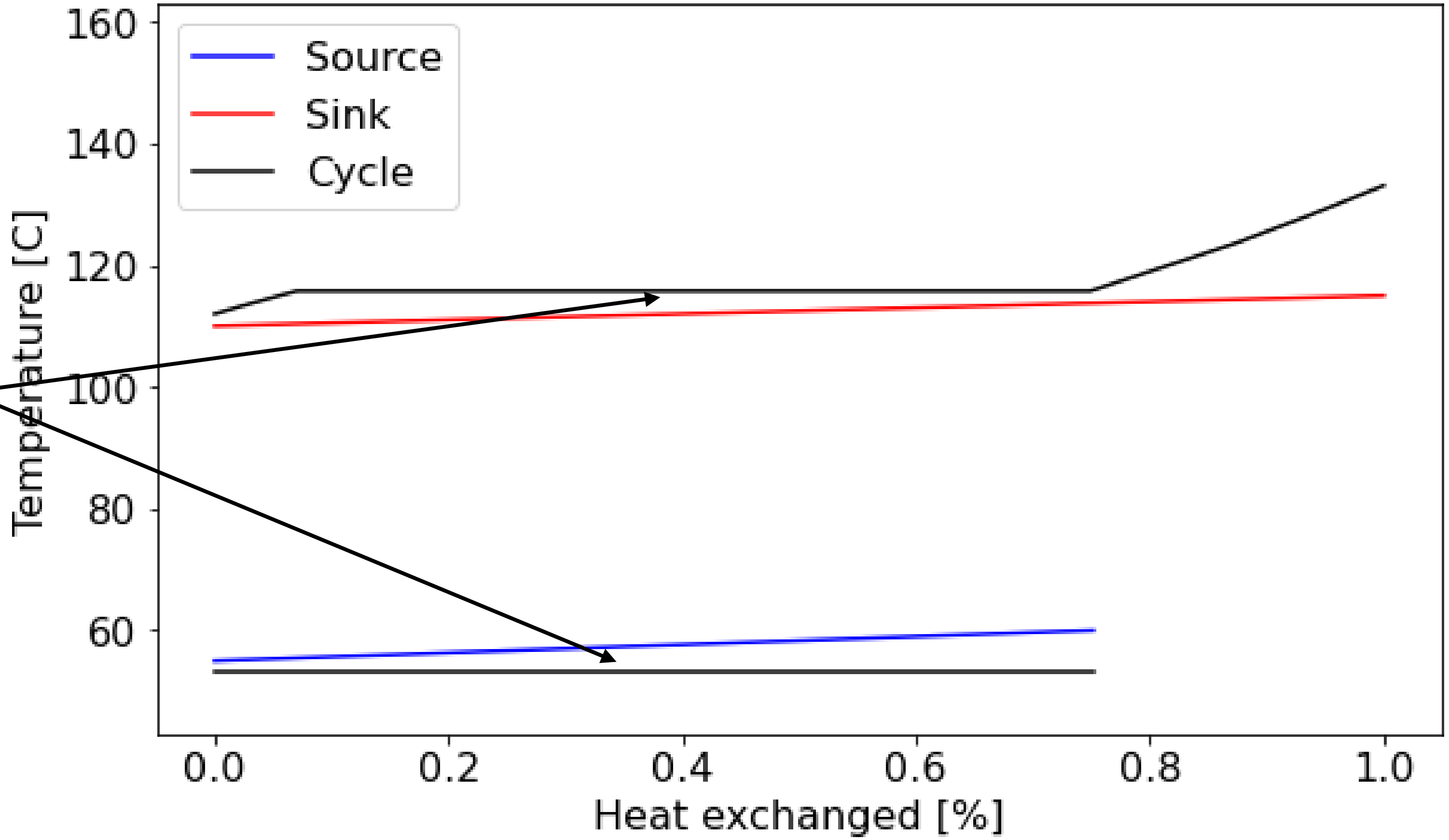
SuPrHeat

EUDP

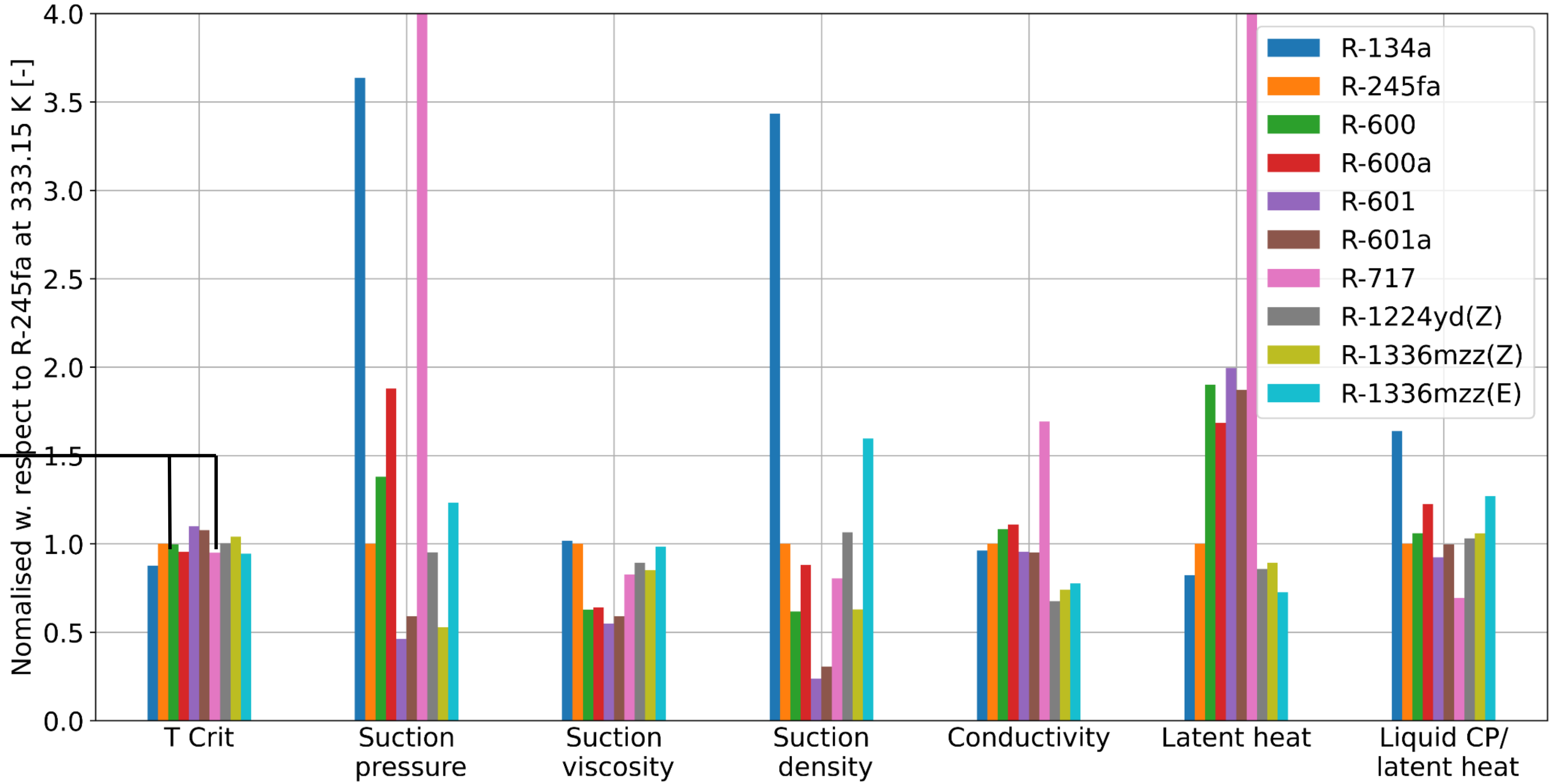
The Energy Technology Development and Demonstration Programme

- Minor losses in evaporator and condenser
- Compressor efficiencies become more important



- COP=2.5 (3.45)
- R1336mzz(E)

- No testing of hydrocarbons due to restrictions on oil import
- Ammonia not compatible with current seals and metals



Component	Variable	CEPCI	F	Cost function, CB_0
FW pump	Volume flow [l/s]	726	1.5	$\frac{510}{4} \cdot \dot{V}$
FT pump	Volume flow [m^3/s]	-	-	-
Injection pump	Volume flow [m^3/s]	-	-	-
FT valve	Mass flow [kg/s]	567	2	$114.5 \cdot \dot{m}$
Economizer valve	Mass flow [kg/s]	-	-	-
Expansion valve	Mass flow [kg/s]	-	-	-
Flash tank	Inlet volume flow [m^3/s]	610	1	$1444 \cdot \left(\frac{\dot{V}}{0.089}\right)^{0.63}$
Steam compressor	Suction flow [m^3/hr]	500	1	$0.9 \cdot 1 \cdot \dot{V}^{0.38}$
Screw compressor	Shaft power [W]	325	1	$f_{flam} \cdot 0.9 \cdot 1490 \cdot \left(\frac{P}{745.7}\right)^{0.71}$
Double screw compressor	Shaft power [W]	-	-	1.3 · Screw compressor
Inverter steam compressor	Input power [W]	567	1.5	$10710 \cdot \left(\frac{P}{250000}\right)^{0.65}$
Inverter screw compressor	Input power [W]	-	-	-
Evaporator	Area [m^2]	551	1.16	$0.88 \cdot (1600 + 210 \cdot A^{0.95})$
Condenser	Area [m^2]	-	-	-
Internal HEX	Area [m^2]	-	-	-
Economizer HEX	Area [m^2]	-	-	-

$f_{flam} = 1.2$ for flammable refrigerants

$$CBM = 1.1 \cdot F \cdot CB_0$$

$$CAPEX = 1.77 \cdot f_{sale} \cdot \sum CBM$$

$$f_{sale} = 1.2$$