Absorption Heat Transformer for waste heat temperature upgrading

שנאי חום לשדרוג טמפרטורת חום שיורי

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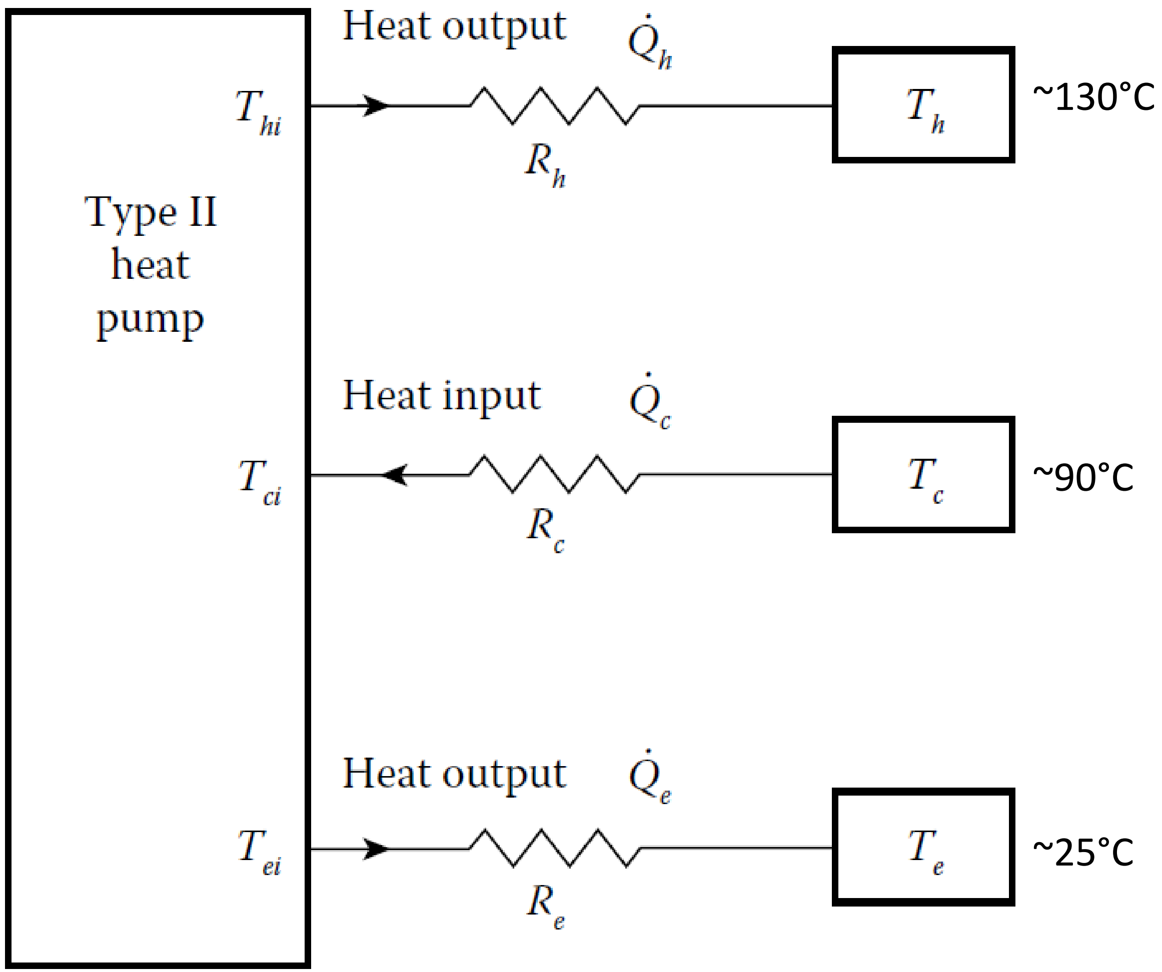
Electricity & Energy 2021

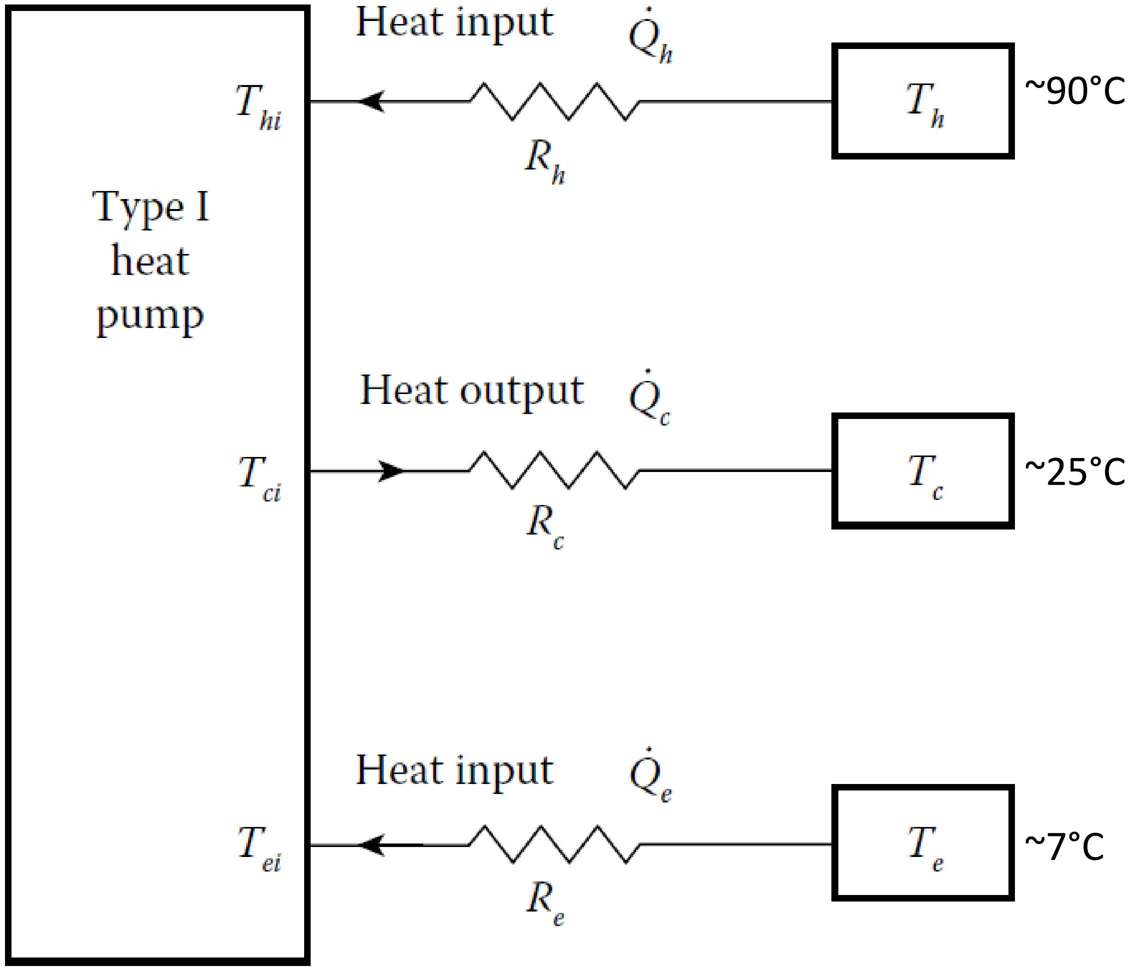
The 21st International Annual Convention of SEEEI

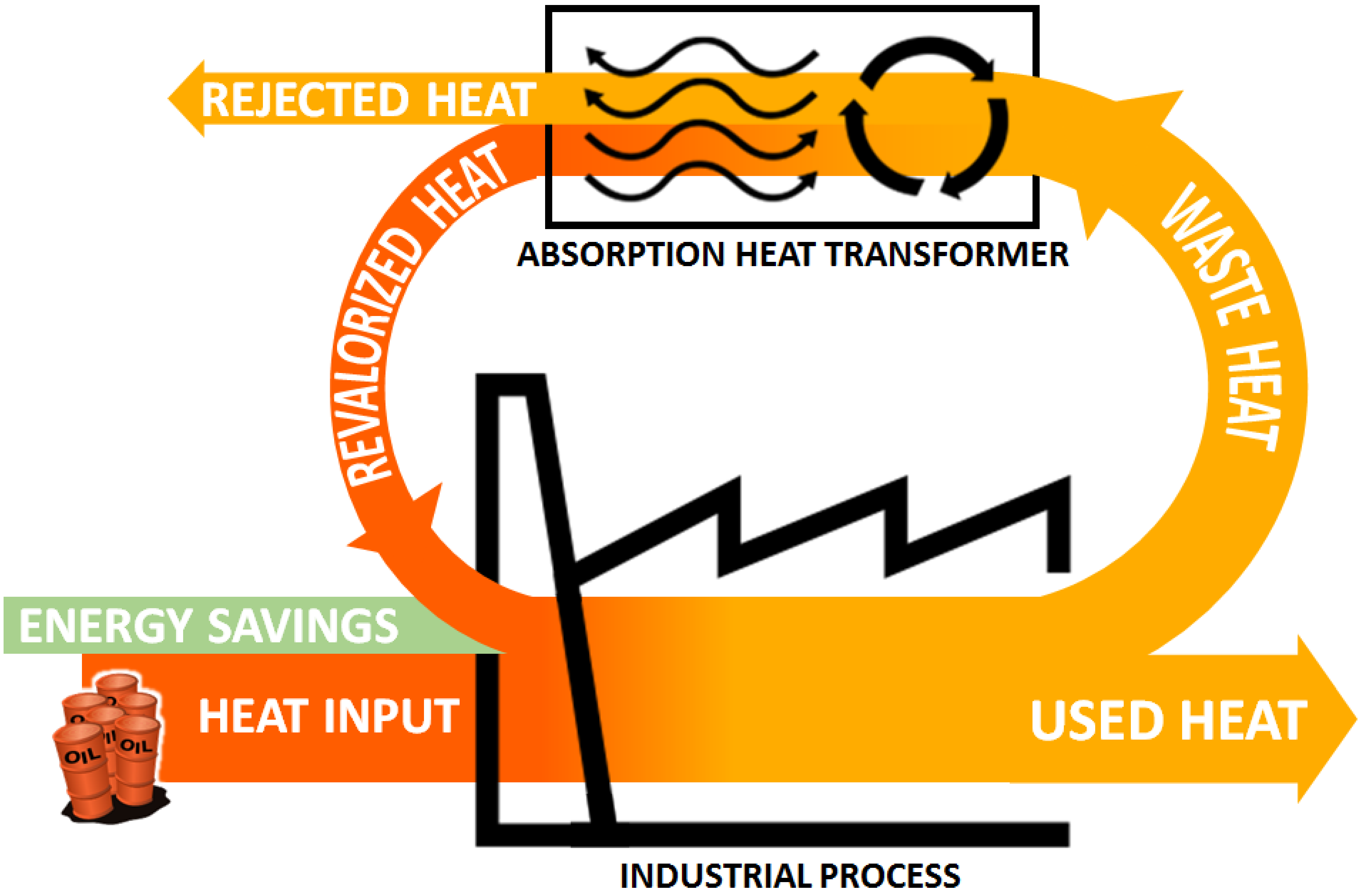
November 9-13, 2021, Eilat, Israel

Two main types of absorption heat pumps



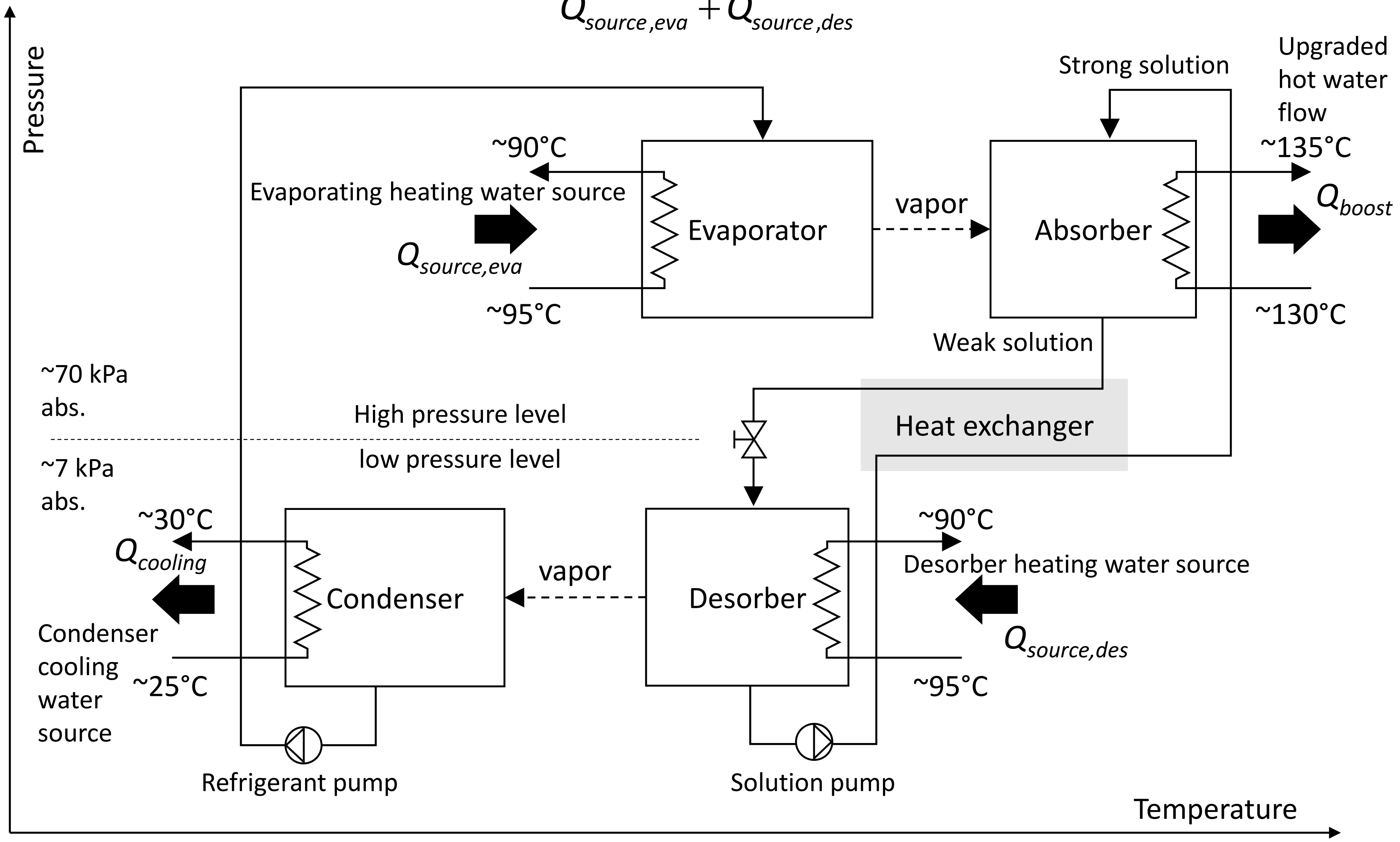
Type I – Absorption refrigerator/chiller (cooling)




REJECTED HEAT
REVALORIZED HEAT
ABSORPTION HEAT TRANSFORMER
WASTE HEAT
ENERGY SAVINGS
HEAT INPUT
OIL
USED HEAT
INDUSTRIAL PROCESS

LiBr-H_2O Absorption Heat Transformer

$$COP_{thermal} = \frac{Q_{boost}}{Q_{source,eva} + Q_{source,des}} \approx 0.5$$



Horizon 2020

Indus3Es

Industrial Energy and Environment Efficiency (www.indus3es.eu)

Participants

1	TECNALIA	Coordinator and R&D	SPAIN
2	TU BERLIN	R&D	GERMANY
3	TECHNION	R&D	ISRAEL
4	BS NOVA	Manufacturing	GERMANY
5	AIGUASOL	Installation	SPAIN
6	TUPRAS	Industry	TURKEY
7	REPSOL	Industry (replication)	SPAIN
8	FERTINAGRO	Industry (replication)	SPAIN
9	CIRCE	Business	SPAIN
10	PNO	Dissemination	BELGIUM

Tüpraş

- Waste heat is 3-8 t/h of pure steam at ~**100°C.**
- Available cooling water temperature **25°C.**
- Tüpraş is interested in increasing the boiler feed water temperature from 65°C to **above 110°C** (flexible target).
- Capacities are of a much greater scale than the intended Indus3Es AHT prototype goal.

“Lab scale”

10 kW

“Breadboard Scale”

50 kW

Final prototype
“Pilot scale”

200 kW

With focus on:

HPV (high-pressure vessel)

Adiabatic Absorption

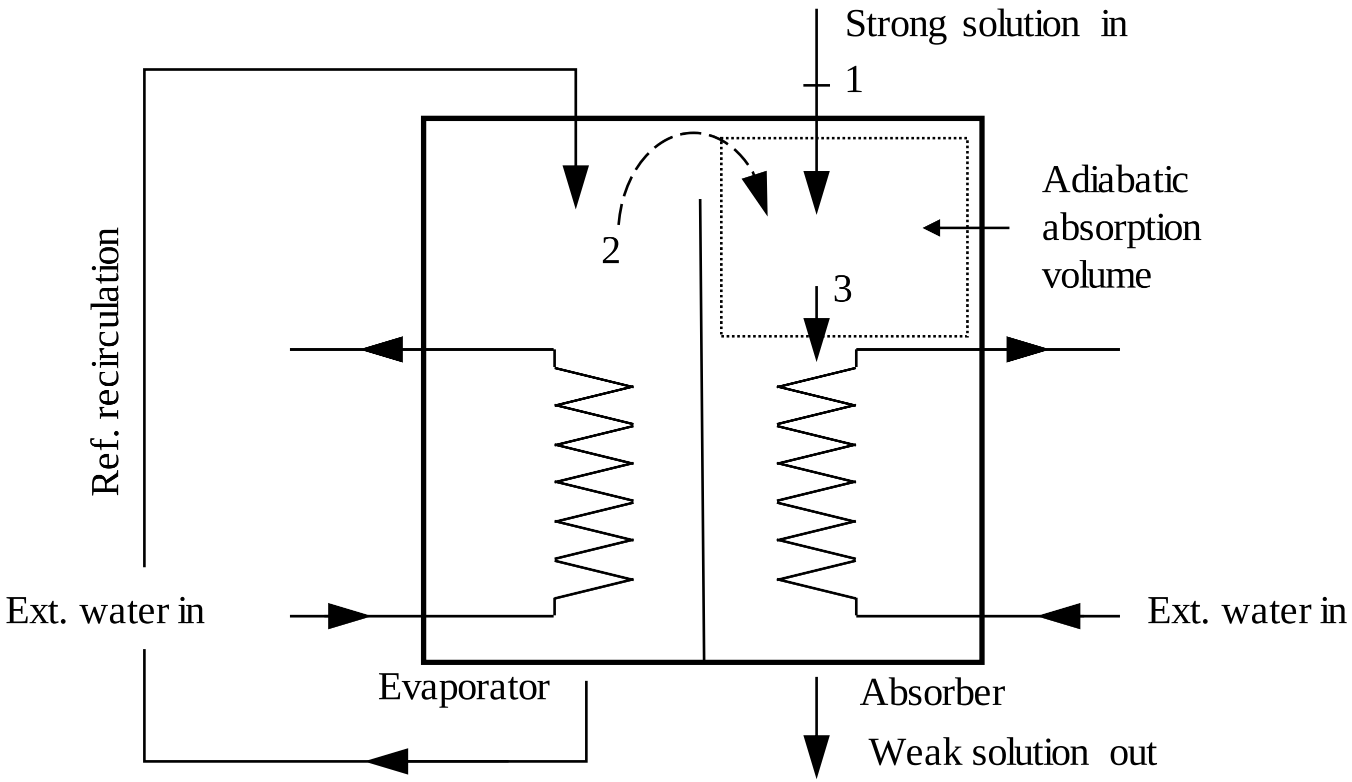
Motor-less Purge System

Alternative configuration and distribution system

Adiabatic absorption

ADIABATIC ABSORPTION

HIGH-PRESSURE VESSEL (HPV)



Mass balance:

$$\dot{m}_1 + \dot{m}_2 = \dot{m}_3$$

$$\dot{m}_1 x_1 = \dot{m}_3 x_3$$

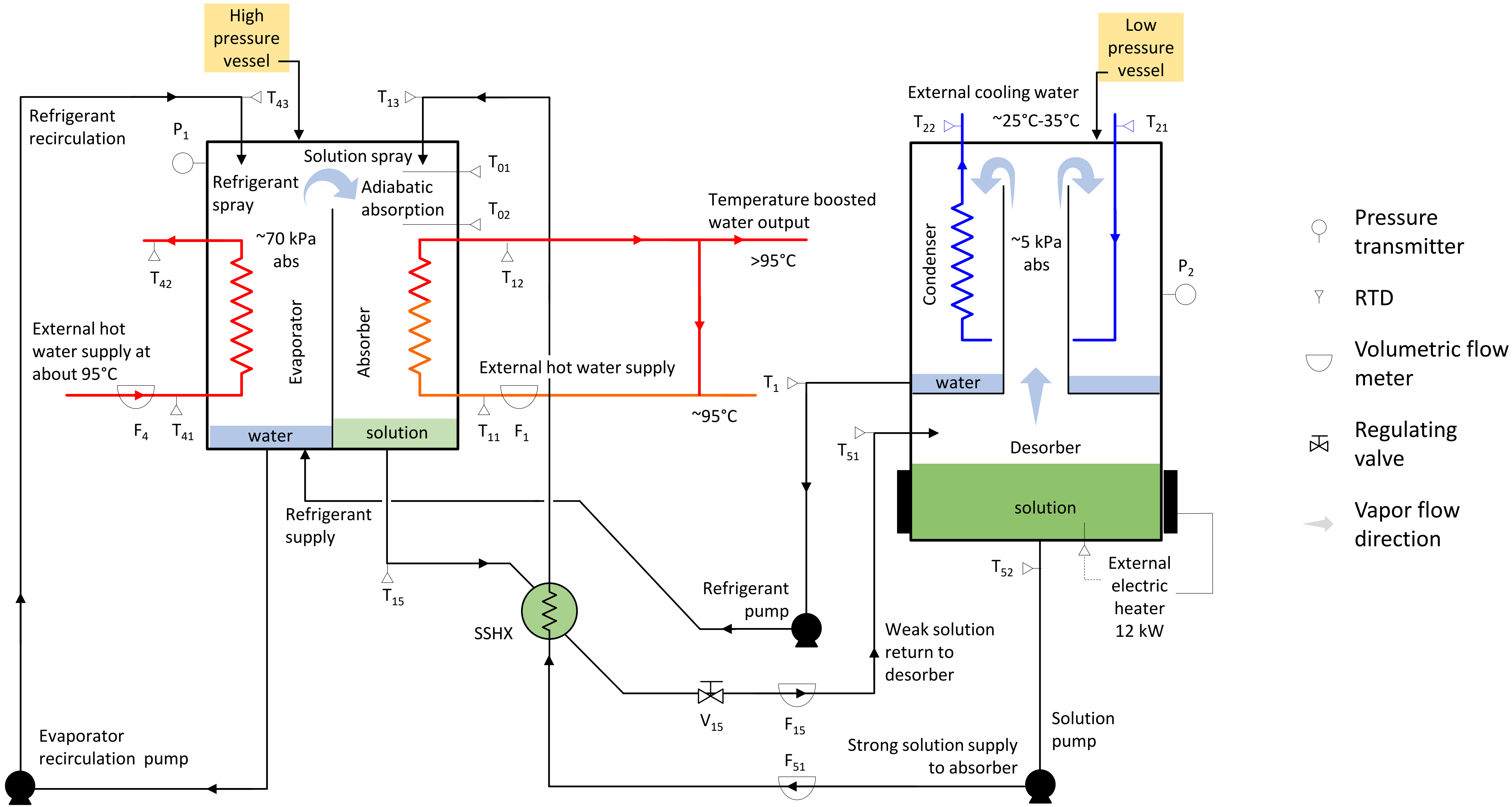
$$h_3 = h_{sat}(x_3, P)$$

$$\Rightarrow \quad T_3 = T_{sat}(h_3, P)$$

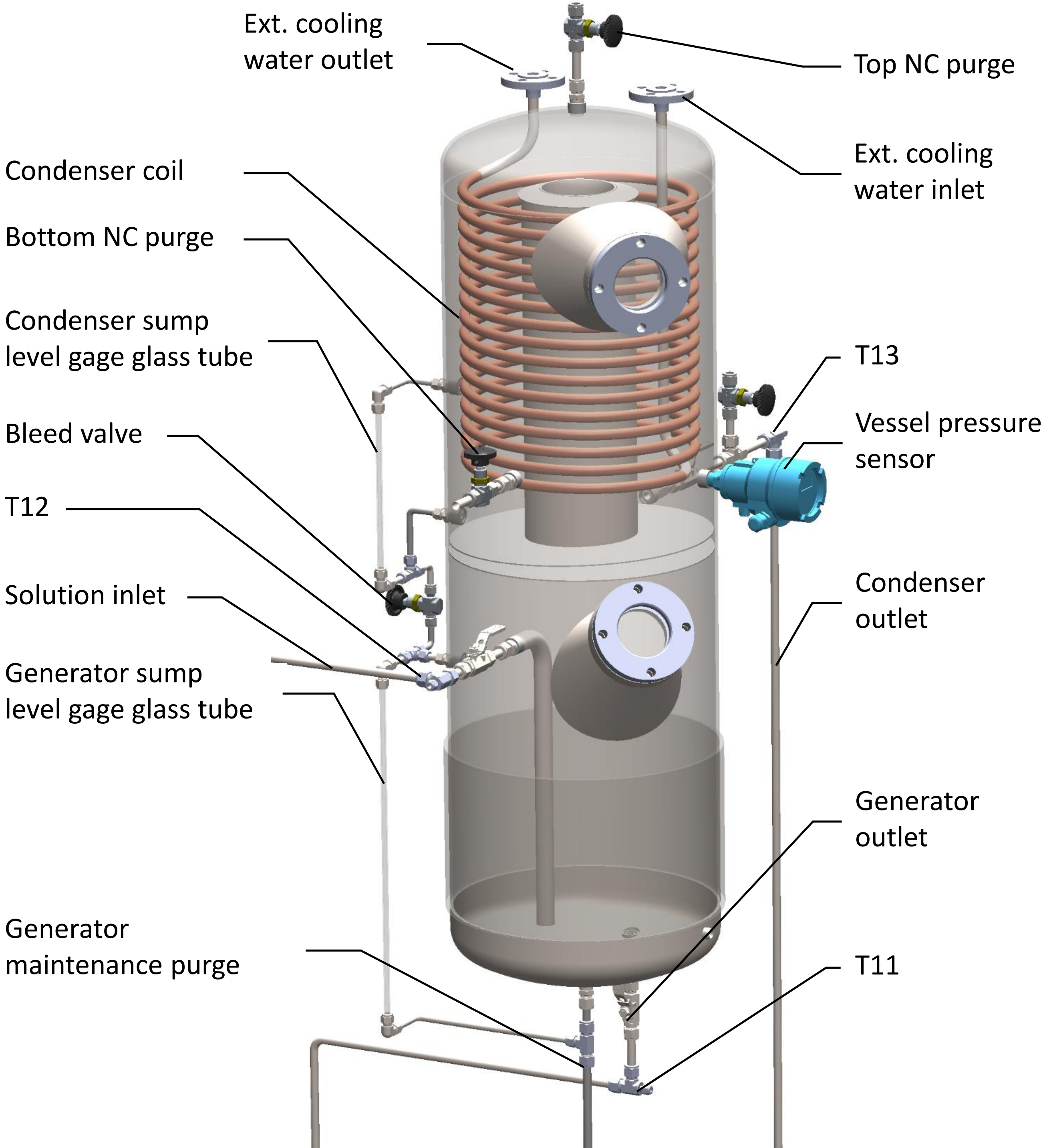
Energy balance:

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3$$

$$h_3 = \frac{x_3}{x_1} h_1 + \left(1 - \frac{x_3}{x_1}\right) h_2$$

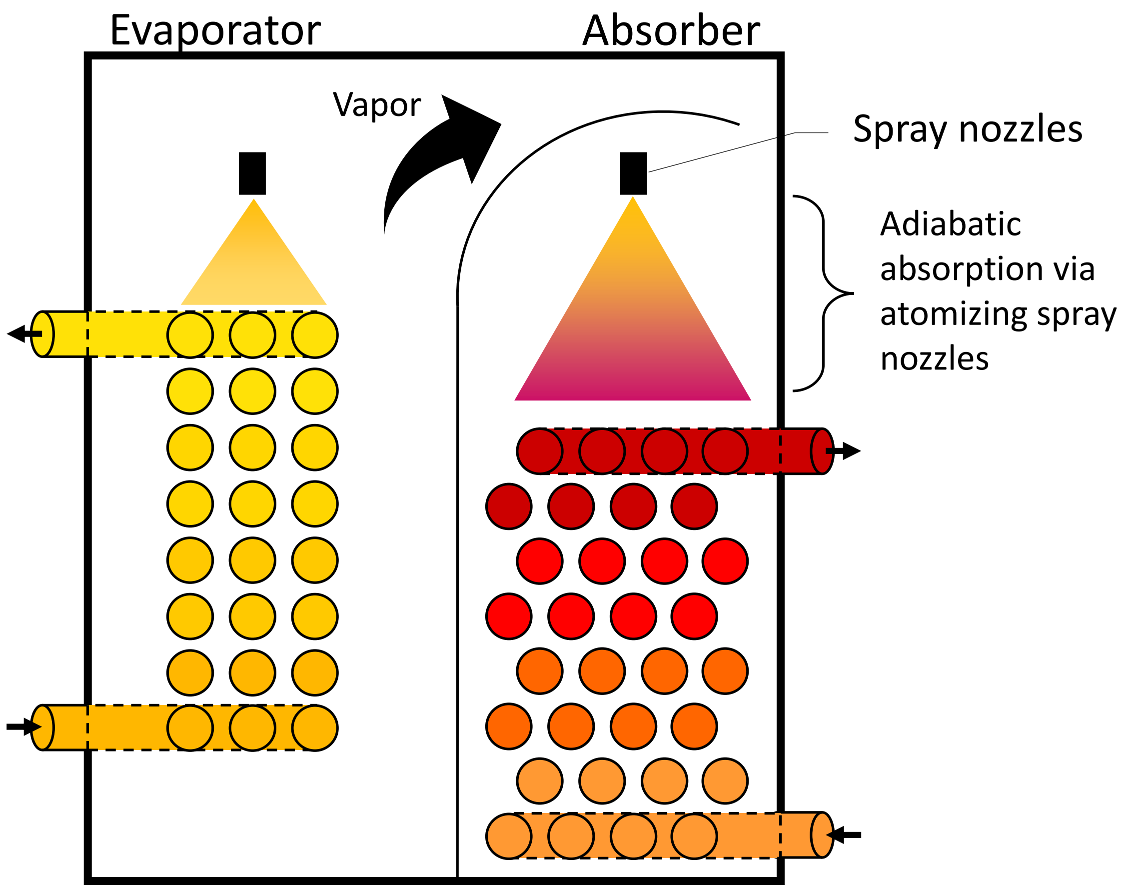


High pressure vessel
Low pressure vessel
Refrigerant recirculation
P1
T43
T13
Solution spray
T01
Refrigerant spray
Adiabatic absorption
T02
~70 kPa abs
T42
Evaporator
Absorber
T12
Temperature boosted water output
>95°C
External hot water supply at about 95°C
External hot water supply
~95°C
F4
T41
water
solution
T11
F1
T1
T51
External cooling water
T22
~25°C-35°C
T21
Condenser
~5 kPa abs
P2
water
Desorber
solution
Refrigerant supply
T15
SSHX
Refrigerant pump
T52
External electric heater 12 kW
Weak solution return to desorber
V15
F15
Solution pump
Strong solution supply to absorber
F51
Evaporator recirculation pump
Pressure transmitter
RTD
Volumetric flow meter
Regulating valve
Vapor flow direction

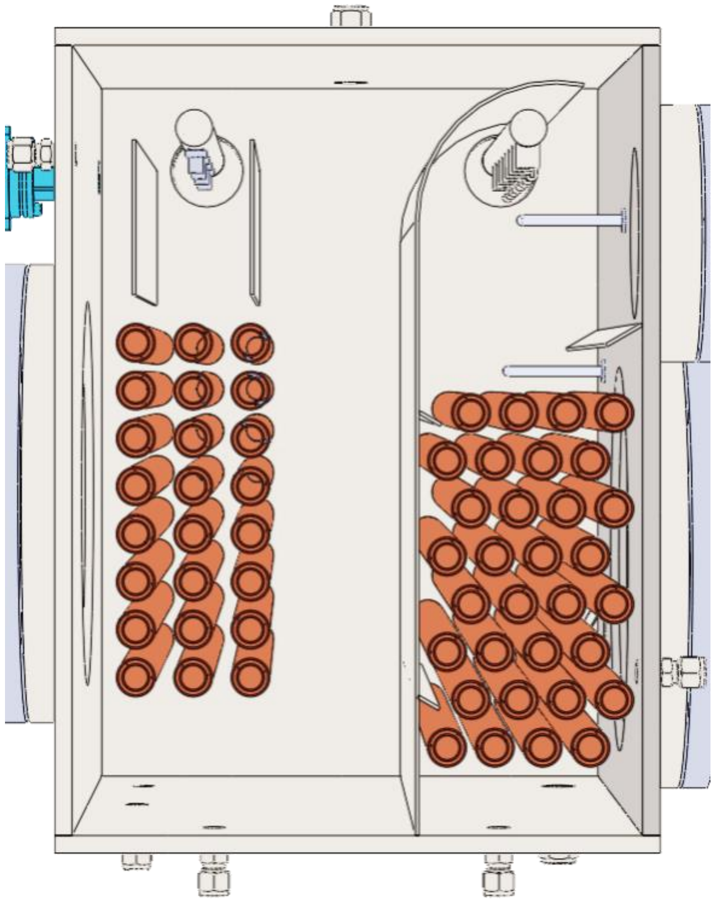

Ext. cooling water outlet
Top NC purge
Ext. cooling water inlet
Condenser coil
Bottom NC purge
Condenser sump level gage glass tube
T13
Vessel pressure sensor
Bleed valve
T12
Solution inlet
Condenser outlet
Generator sump level gage glass tube
Generator outlet
Generator maintenance purge
T11

Lab Scale AHT high-pressure vessel (HPV)

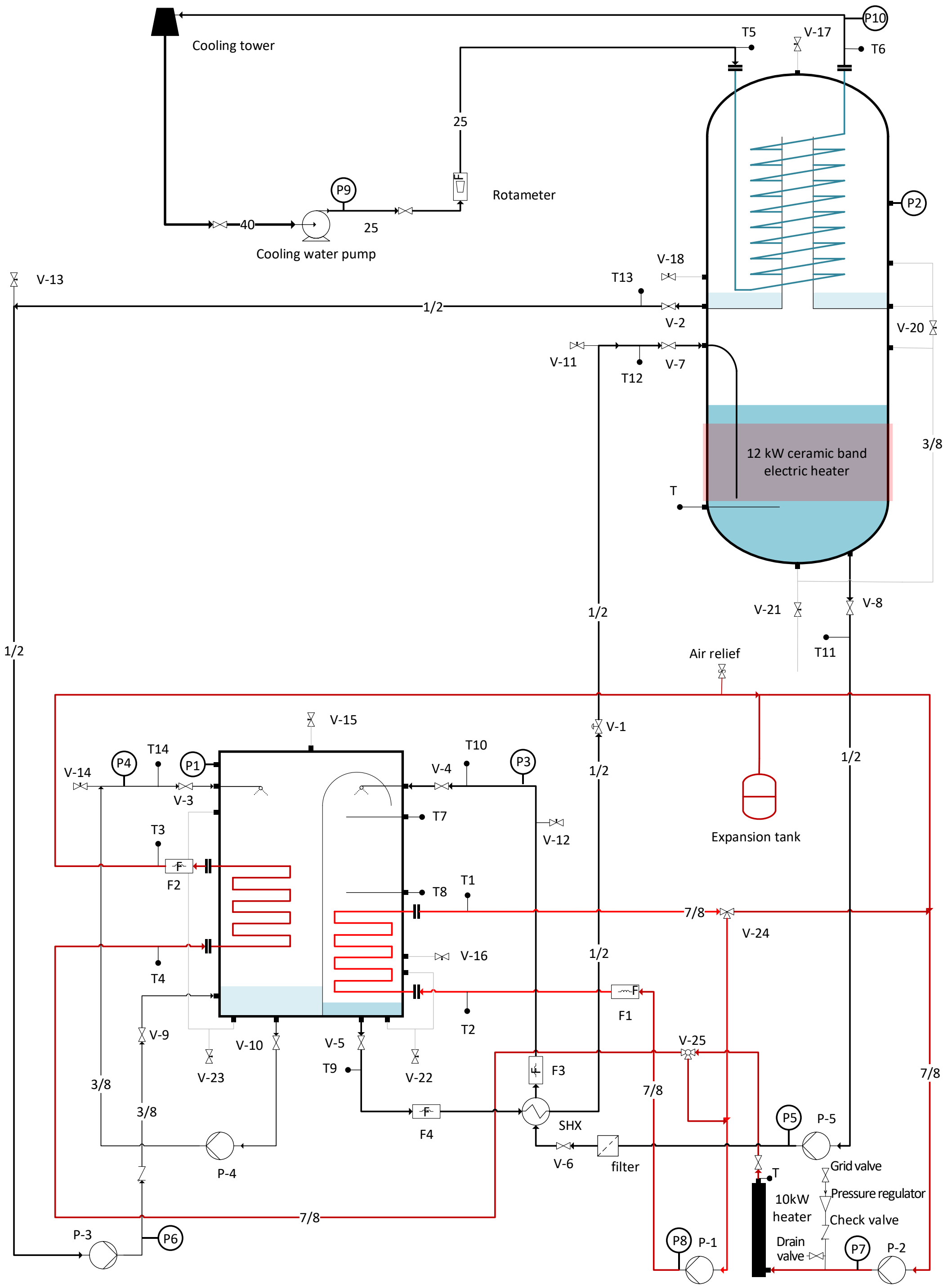
Concept

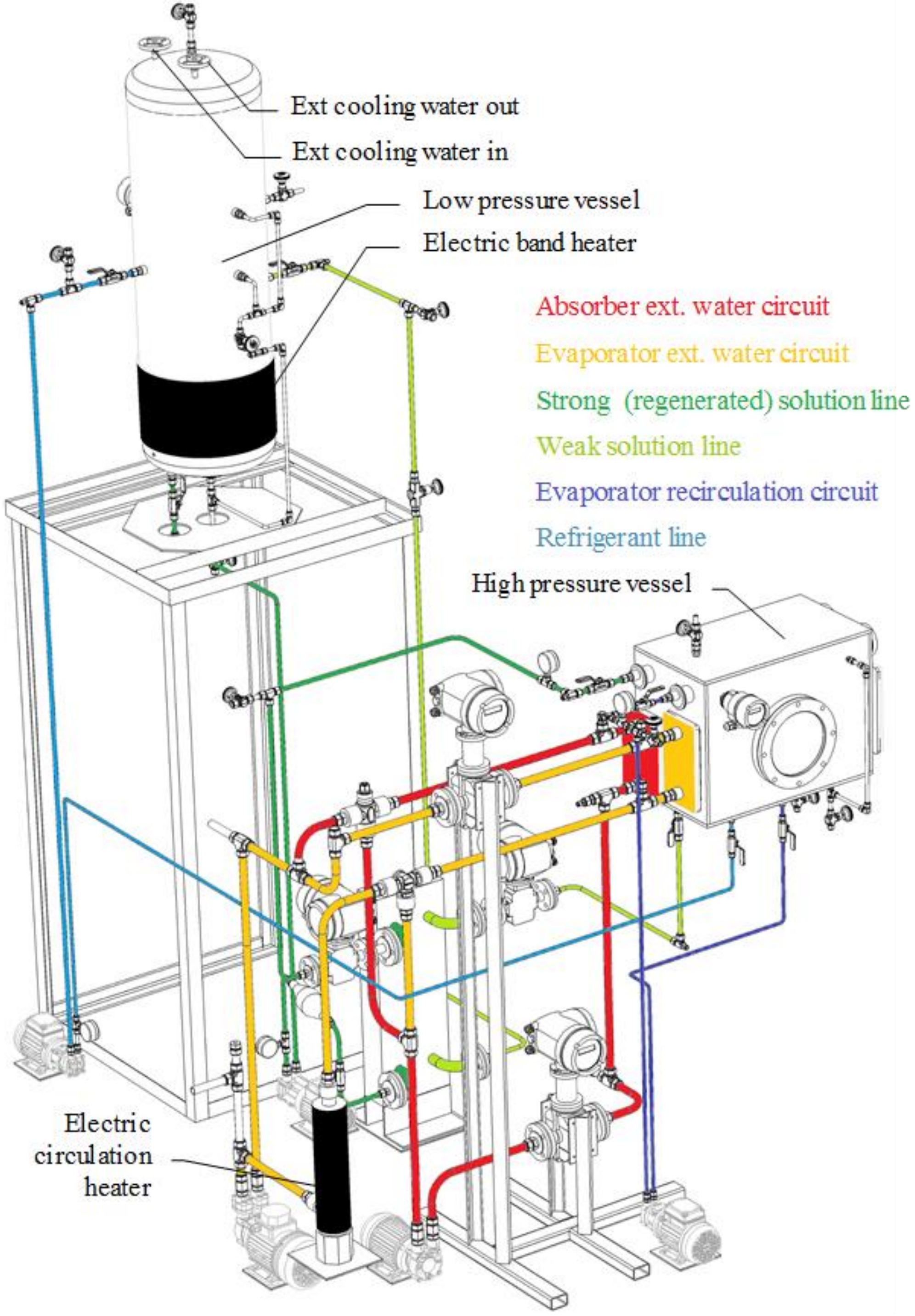


CAD visualization



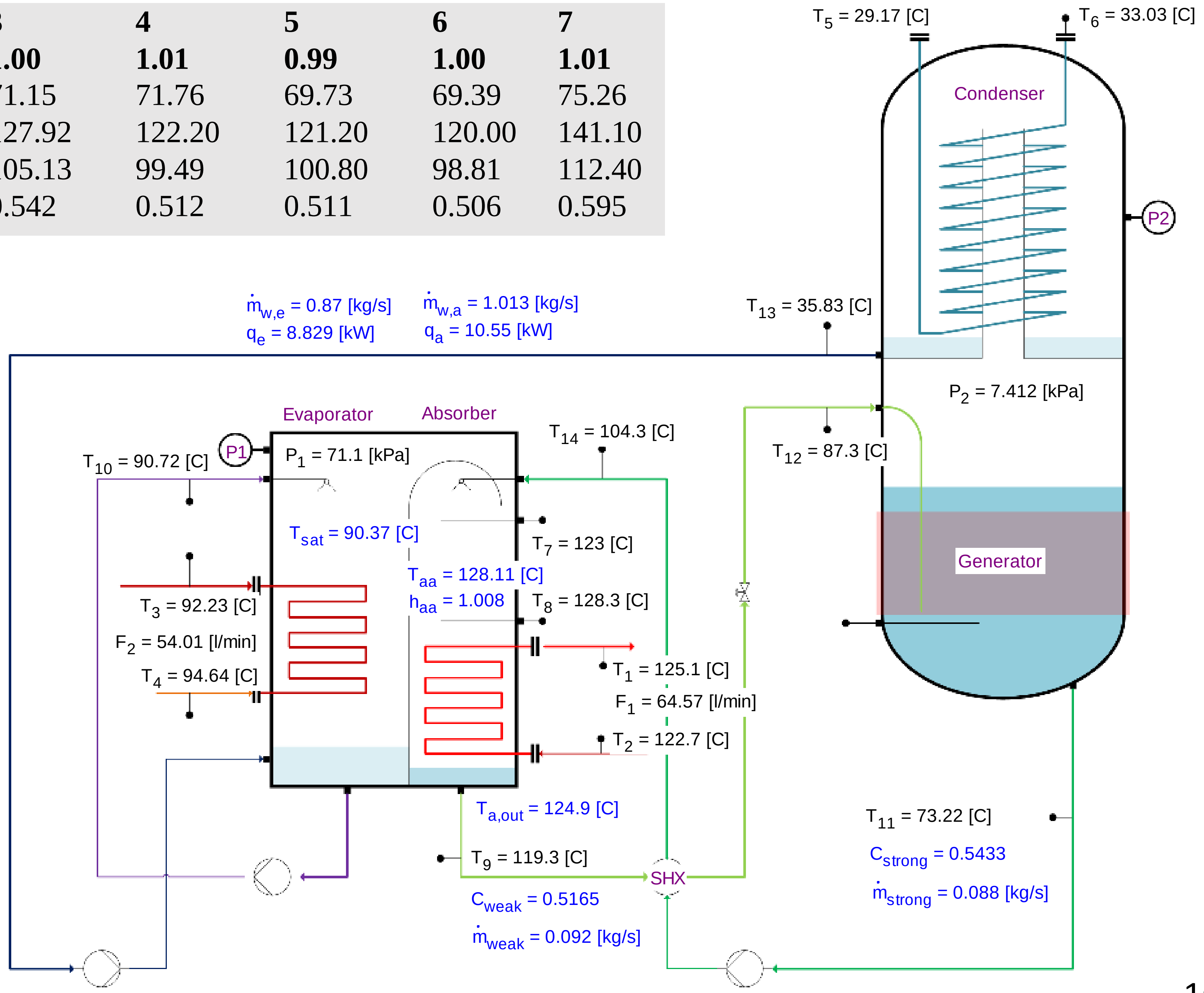



Cooling tower
Cooling water pump
Rotameter
12 kW ceramic band electric heater
Air relief
Expansion tank
SHX
filter
10kW heater
Drain valve
Grid valve
Pressure regulator
Check valve

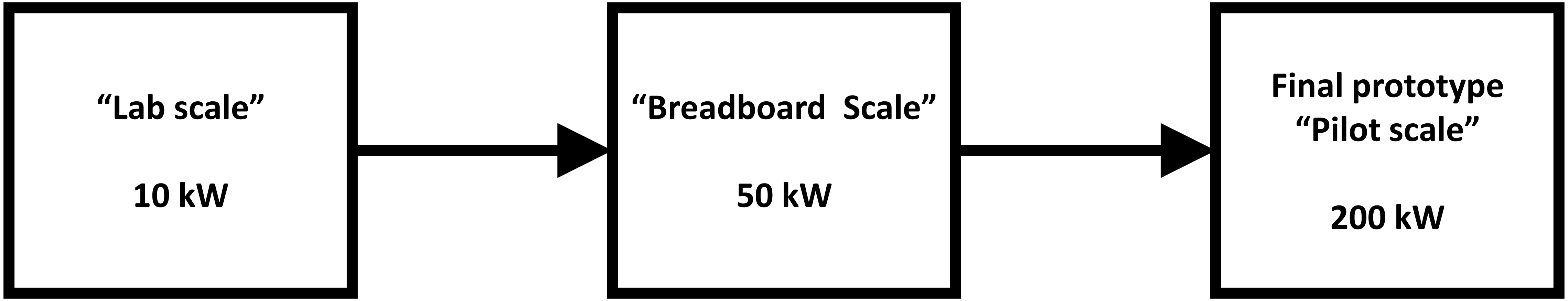

Ext cooling water out
Ext cooling water in
Low pressure vessel
Electric band heater
Absorber ext. water circuit
Evaporator ext. water circuit
Strong (regenerated) solution line
Weak solution line
Evaporator recirculation circuit
Refrigerant line
High pressure vessel
Electric circulation heater

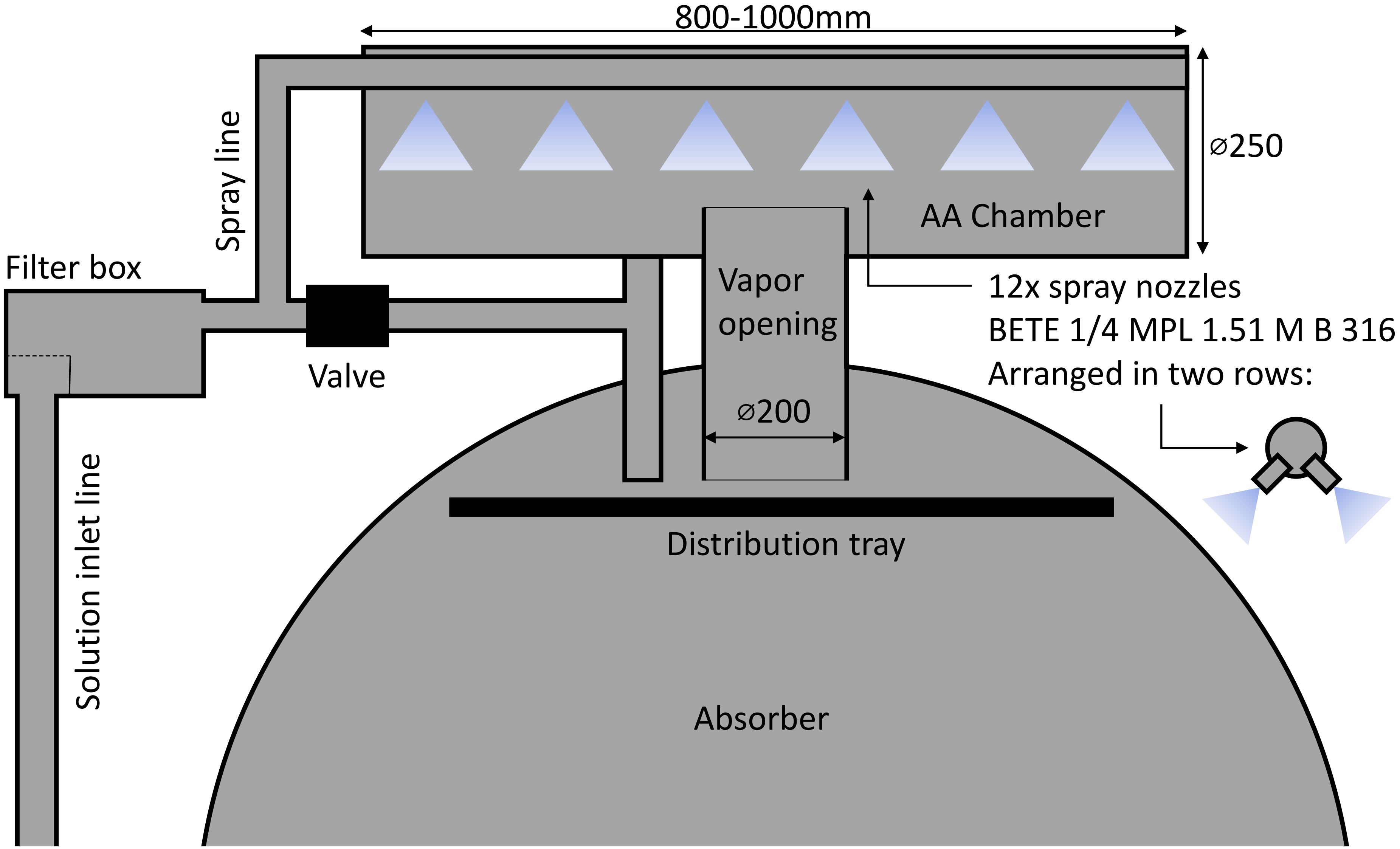
Measurement	1	2	3	4	5	6	7
η_{aa}	**1.01**	**1.00**	**1.00**	**1.01**	**0.99**	**1.00**	**1.01**
P [kPa]	71.09	70.95	71.15	71.76	69.73	69.39	75.26
T_8 [°C]	128.31	128.08	127.92	122.20	121.20	120.00	141.10
T_{14} [°C]	104.25	105.20	105.13	99.49	100.80	98.81	112.40
x_{11}	0.543	0.543	0.542	0.512	0.511	0.506	0.595

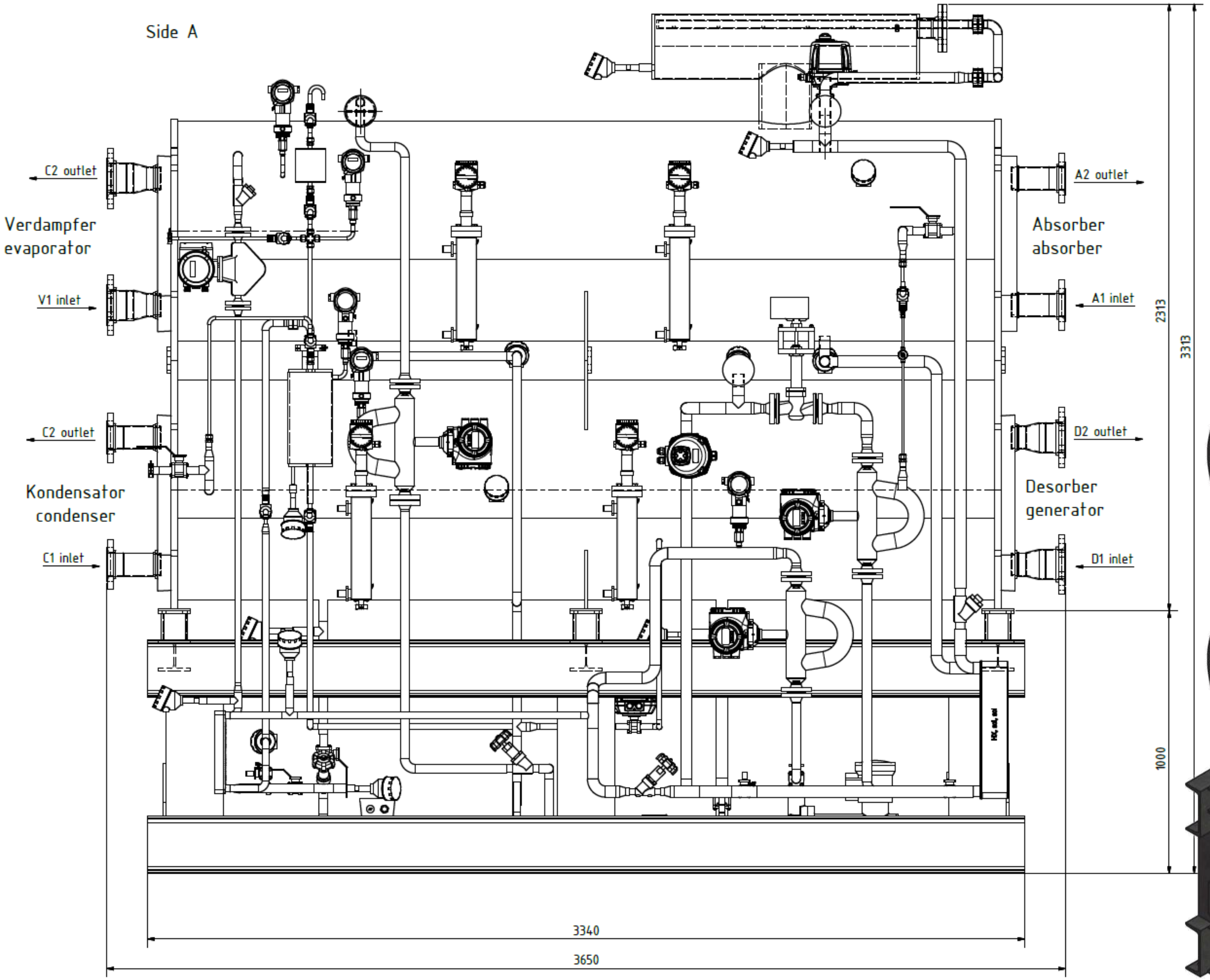
$$\eta_{aa} \equiv \frac{T_8 - T_{14}}{T_{aa} - T_{14}}$$

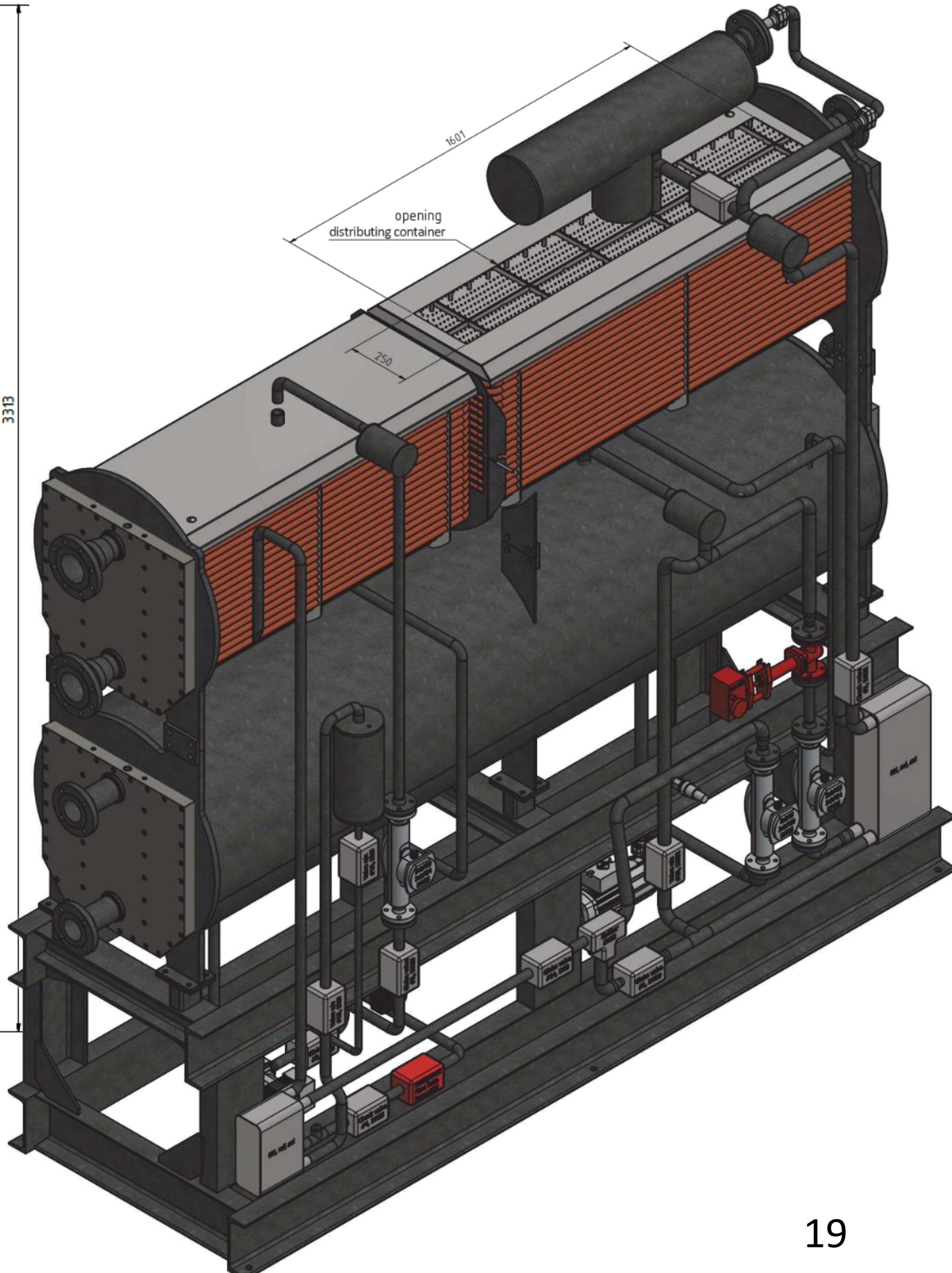


Evron, Y., Gommed, K., and Grossman, G. (April 10, 2020). "Adiabatic Absorption by Absorbent Atomization for Improving Absorption Heat Transformer Performance." ASME. *J. Heat Transfer*. May 2020; 142(5): 052906. https://doi.org/10.1115/1.4046789


“Lab scale”
10 kW
“Breadboard Scale”
50 kW
Final prototype
“Pilot scale”
200 kW


800-1000mm
⌀250
Spray line
AA Chamber
Filter box
Vapor opening
12x spray nozzles
BETE 1/4 MPL 1.51 M B 316
Arranged in two rows:
Valve
⌀200
Solution inlet line
Distribution tray
Absorber


Side A
C2 outlet
Verdampfer
evaporator
V1 inlet
C2 outlet
Kondensator
condenser
C1 inlet
A2 outlet
Absorber
absorber
A1 inlet
D2 outlet
Desorber
generator
D1 inlet
2313
3313
1000
3340
3650


1601
opening
distributing container
250

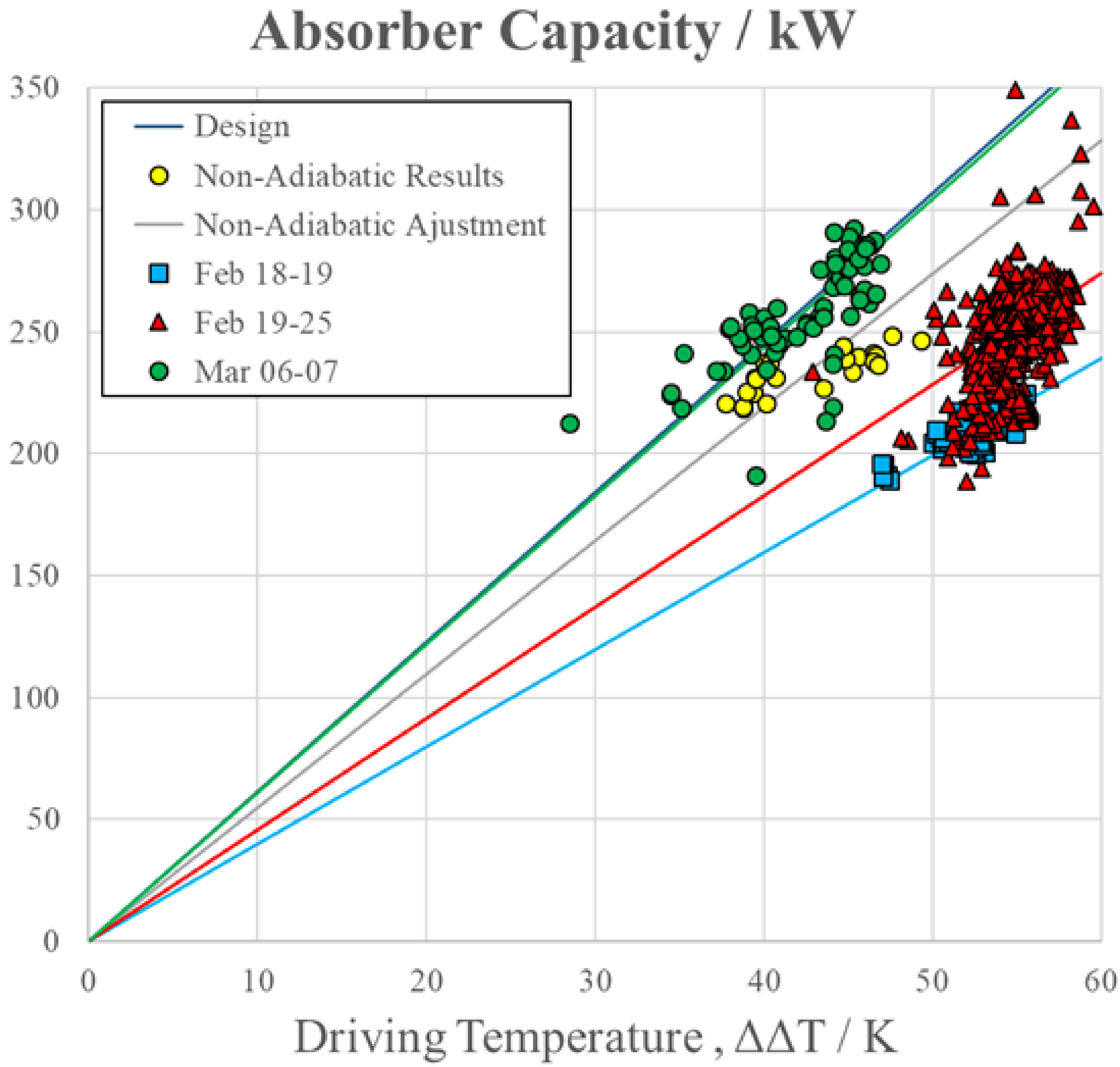

OZLER

[redacted]

Measurements from November 2019 to March 2020.

Adiabatic absorption shows about 12% increase of the AHT heating power.

Covid-19 halted the project's progress and caused cancelation of scheduled control algorithm debugging and purge system fixing and commissioning.



$$\Delta\Delta T = R \cdot (t_{eva} - t_{con}) - (t_{abs} - t_{gen})$$

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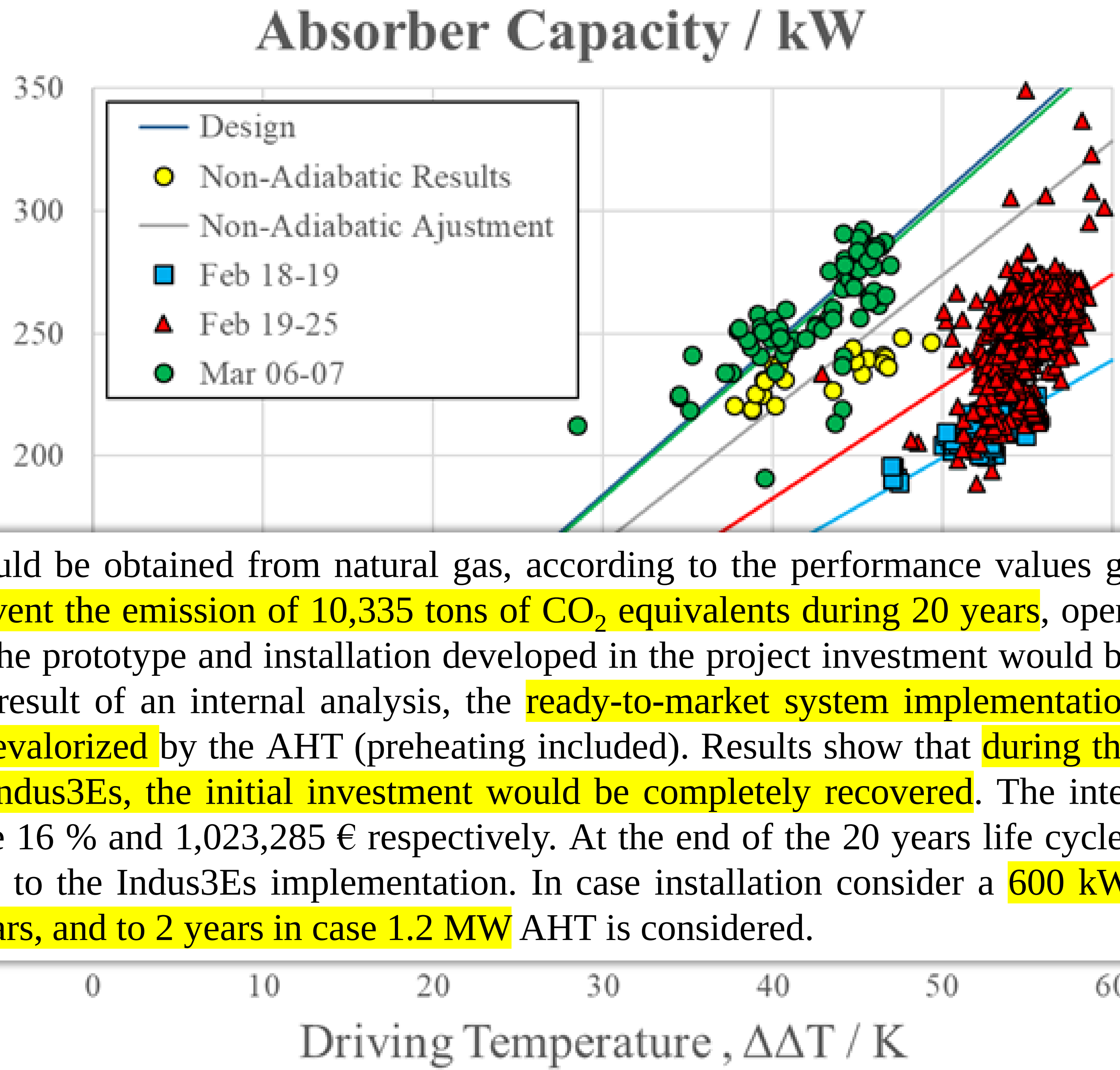
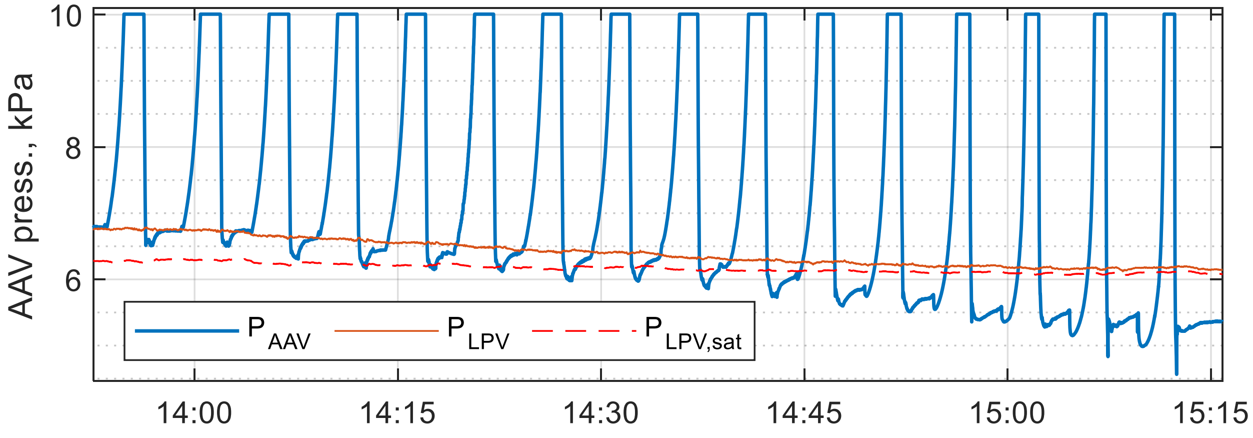


…Considering that the saved energy would be obtained from natural gas, according to the performance values given by the final users, the Indus3Es system will prevent the emission of 10,335 tons of CO_2 equivalents during 20 years, operating 8,760 hours per year. Considering the costs of the prototype and installation developed in the project investment would be recovered in between 10 – 11 years. However, as result of an internal analysis, the ready-to-market system implementation would be about 420.000 €, i.e. about 1.500 €/kW revalorized by the AHT (preheating included). Results show that during the sixth year after the implementation of the market Indus3Es, the initial investment would be completely recovered. The internal rate of return and the net present value would be 16 % and 1,023,285 € respectively. At the end of the 20 years life cycle, more than 1.7 million euros would be saved thanks to the Indus3Es implementation. In case installation consider a 600 kW prototype, payback period would be reduced to 3 years, and to 2 years in case 1.2 MW AHT is considered.

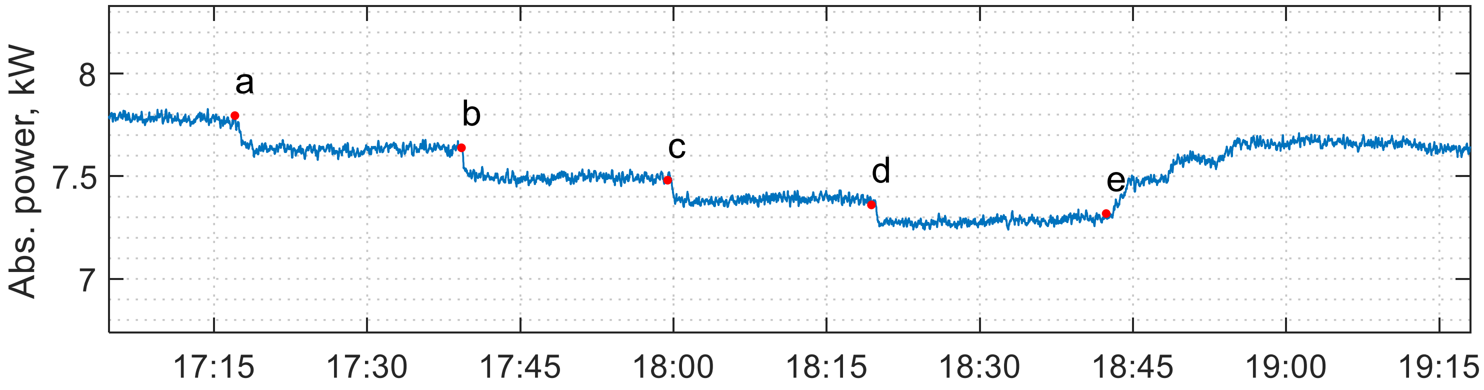
$$\Delta\Delta T = R \cdot (t_{eva} - t_{con}) - (t_{abs} - t_{gen})$$

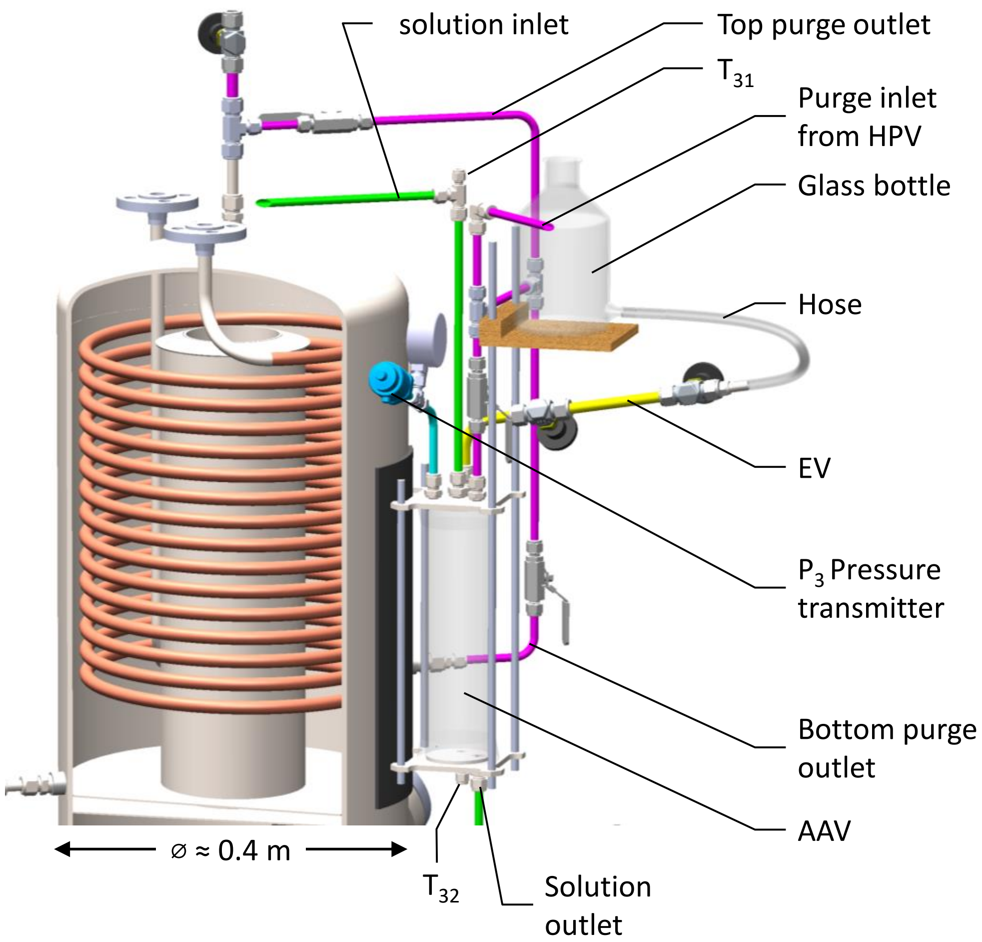
Motor-less non-absorbable purge system

LPV pressure reduces and approaches the expected vapor saturation pressure as purging is performed.



HPV performance recovery as a consequence of purging (e), after multiple N_2 injections (a, b, c, and d)

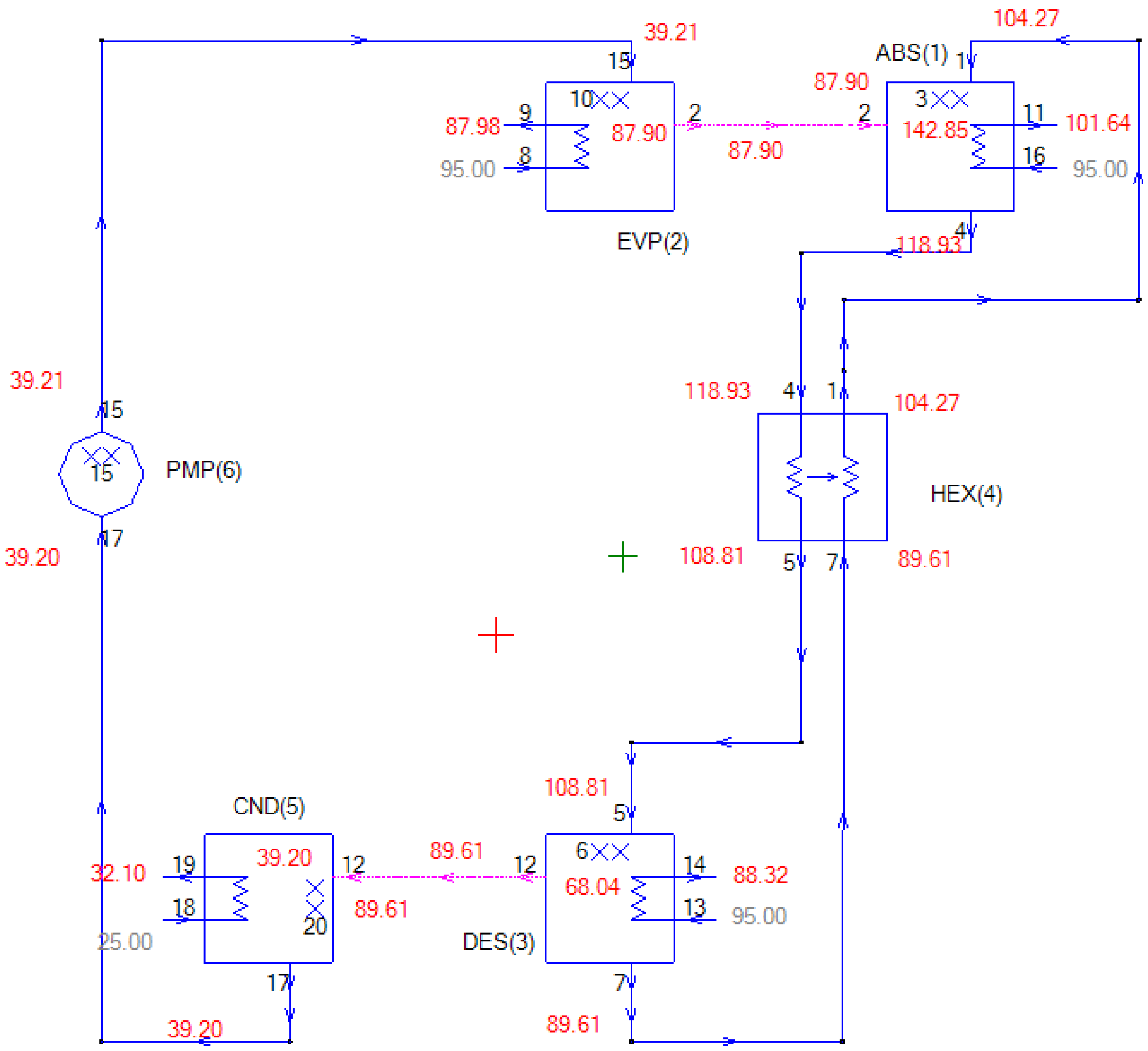


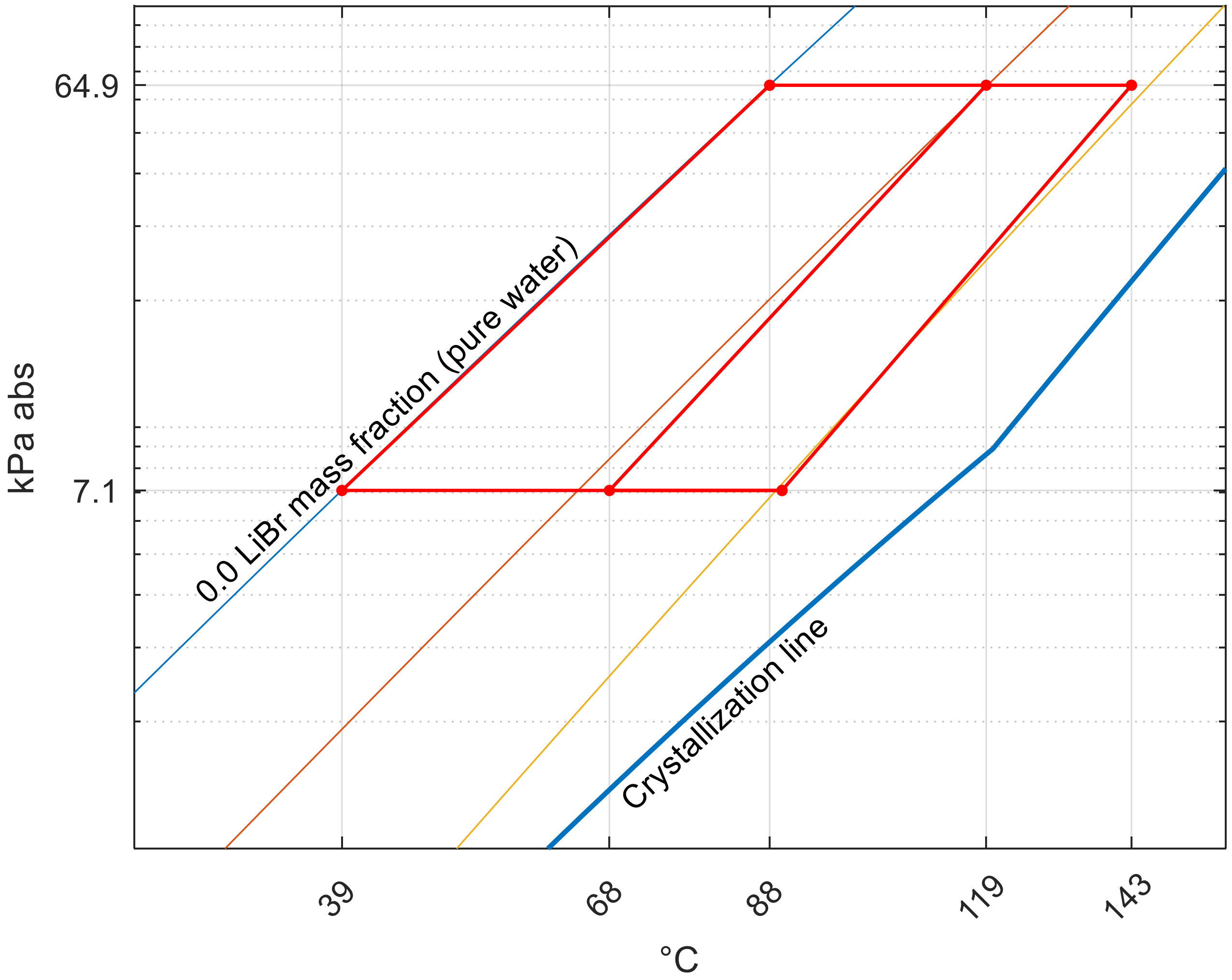


Evron, Y., Gommed, K., and Grossman, G., "Non-absorbable gasses motor-less purge system for absorption heat transformers" in *International Journal of Refrigeration*, Volume 120, December 2020, Pages 81-89.

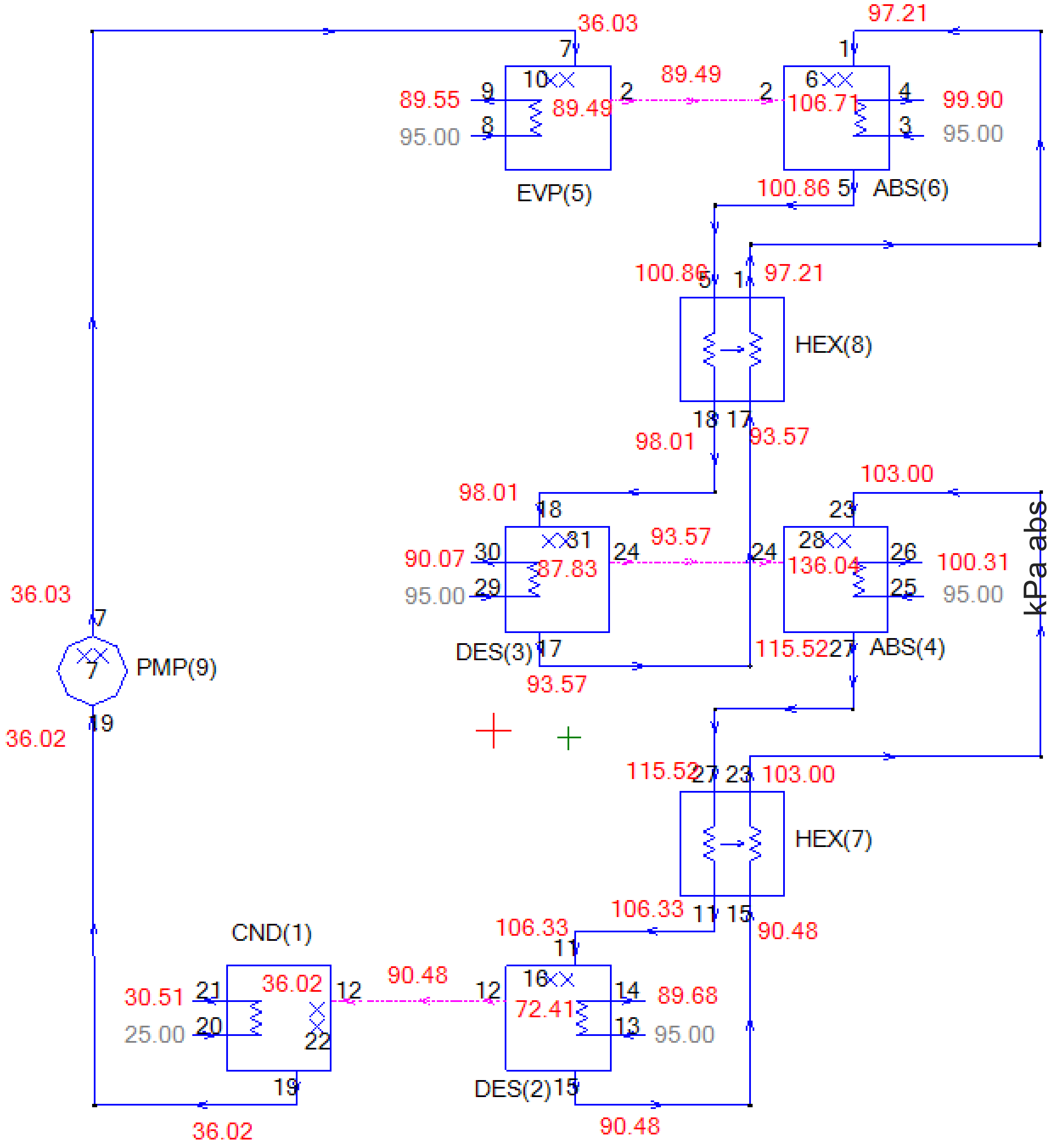
Multi-stage AHT

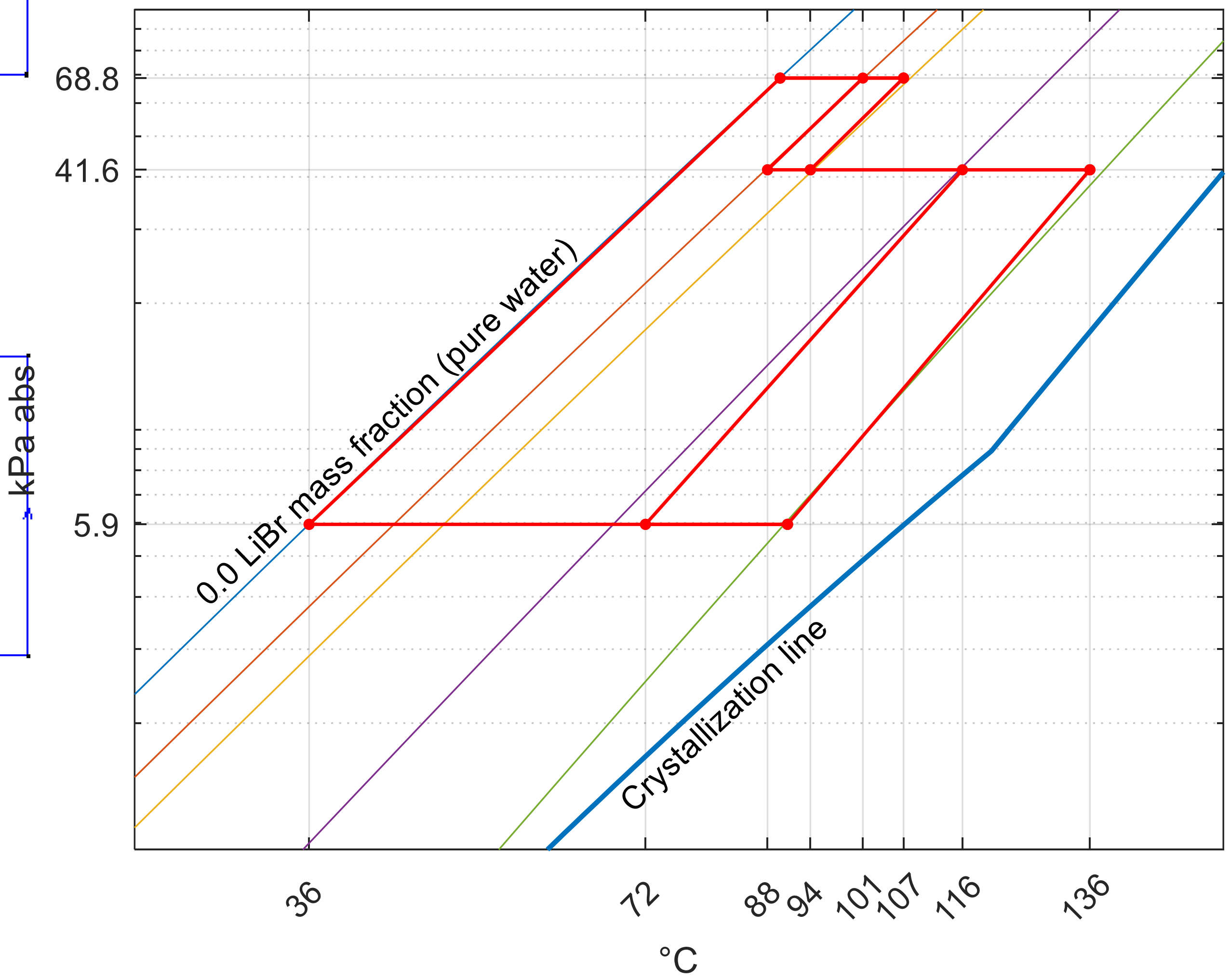
For applications requiring low temperature lifts

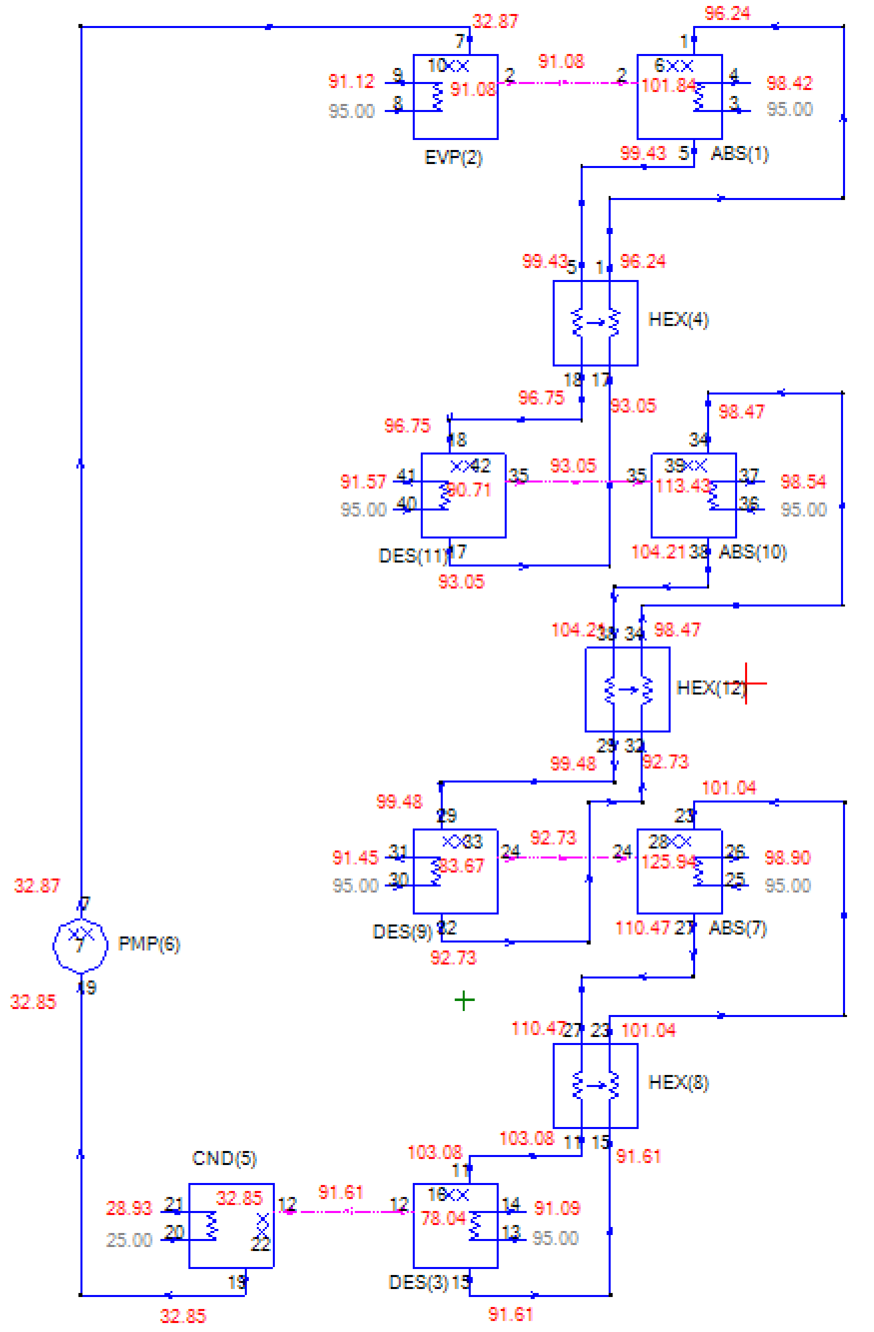


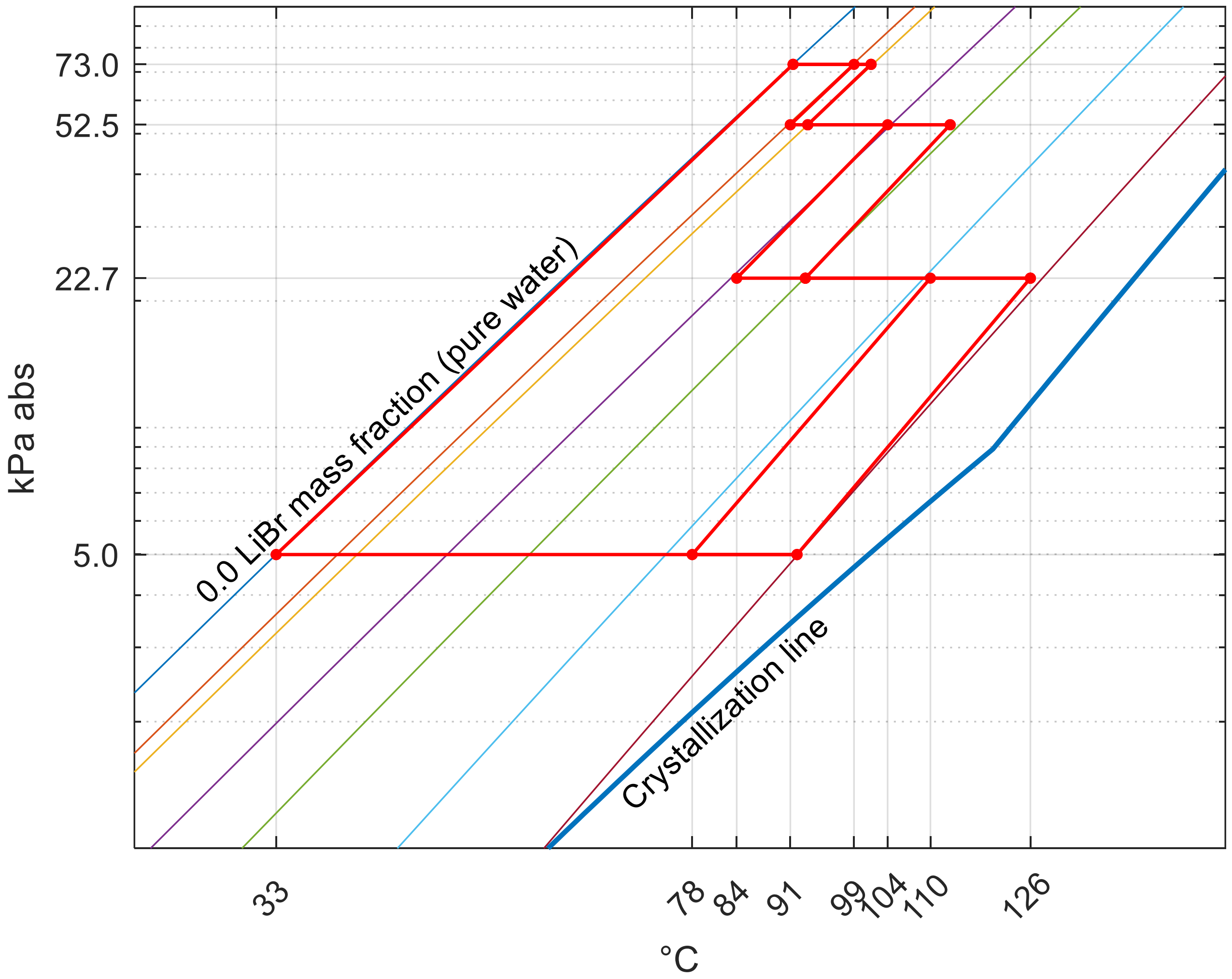


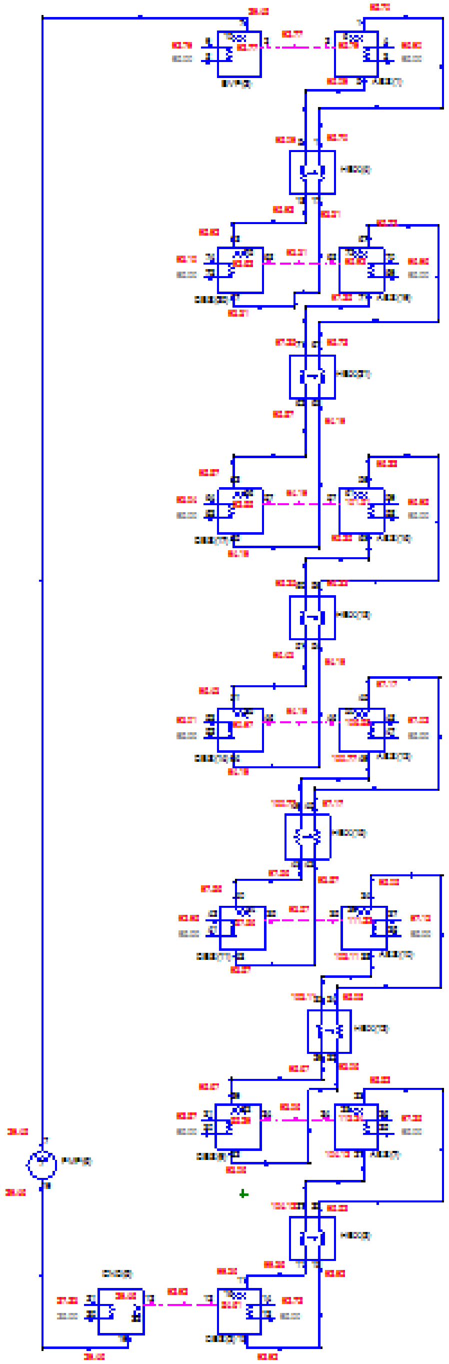
Evron, Y., Gommed, K., and Grossman, G., "ABSIM–modular simulation of advanced absorption systems: Recent software enhancements" in International Journal of Refrigeration, Volume 93, September 2018.

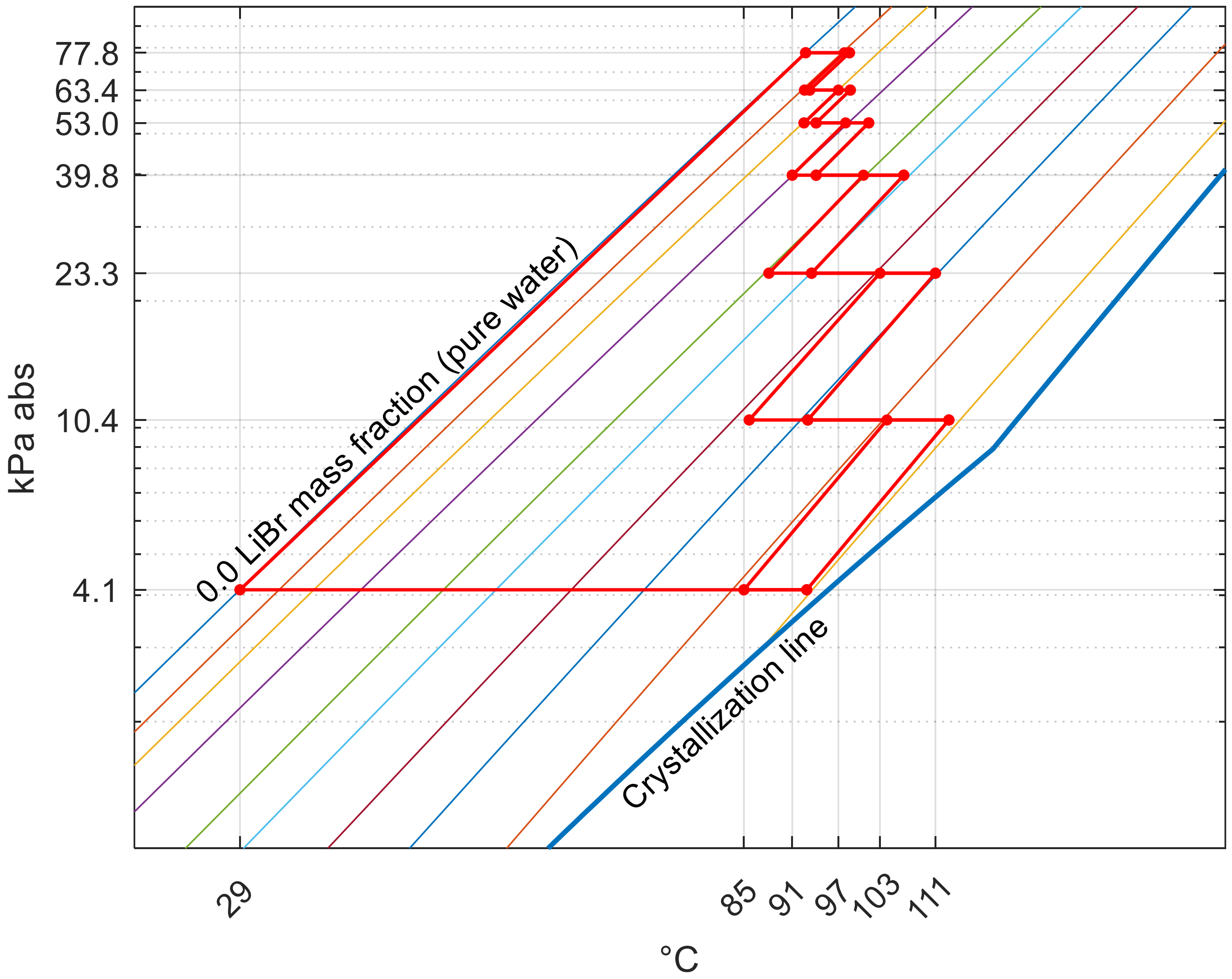

EVP(5)
ABS(6)
HEX(8)
DES(3)
ABS(4)
PMP(9)
HEX(7)
CND(1)
DES(2)
36.03
97.21
89.49
89.55
95.00
89.49
106.71
99.90
95.00
100.86
100.86
97.21
98.01
93.57
103.00
98.01
93.57
90.07
87.83
95.00
136.04
100.31
95.00
115.52
93.57
36.03
36.02
115.52
103.00
106.33
106.33
90.48
90.48
30.51
36.02
89.68
72.41
25.00
95.00
36.02
90.48


68.8
41.6
5.9
kPa abs
0.0 LiBr mass fraction (pure water)
Crystallization line
36
72
88
94
101
107
116
136
°C


EVP(2)
ABS(1)
HEX(4)
DES(11)
ABS(10)
HEX(12)
DES(9)
ABS(7)
HEX(8)
PMP(6)
CND(5)
DES(3)

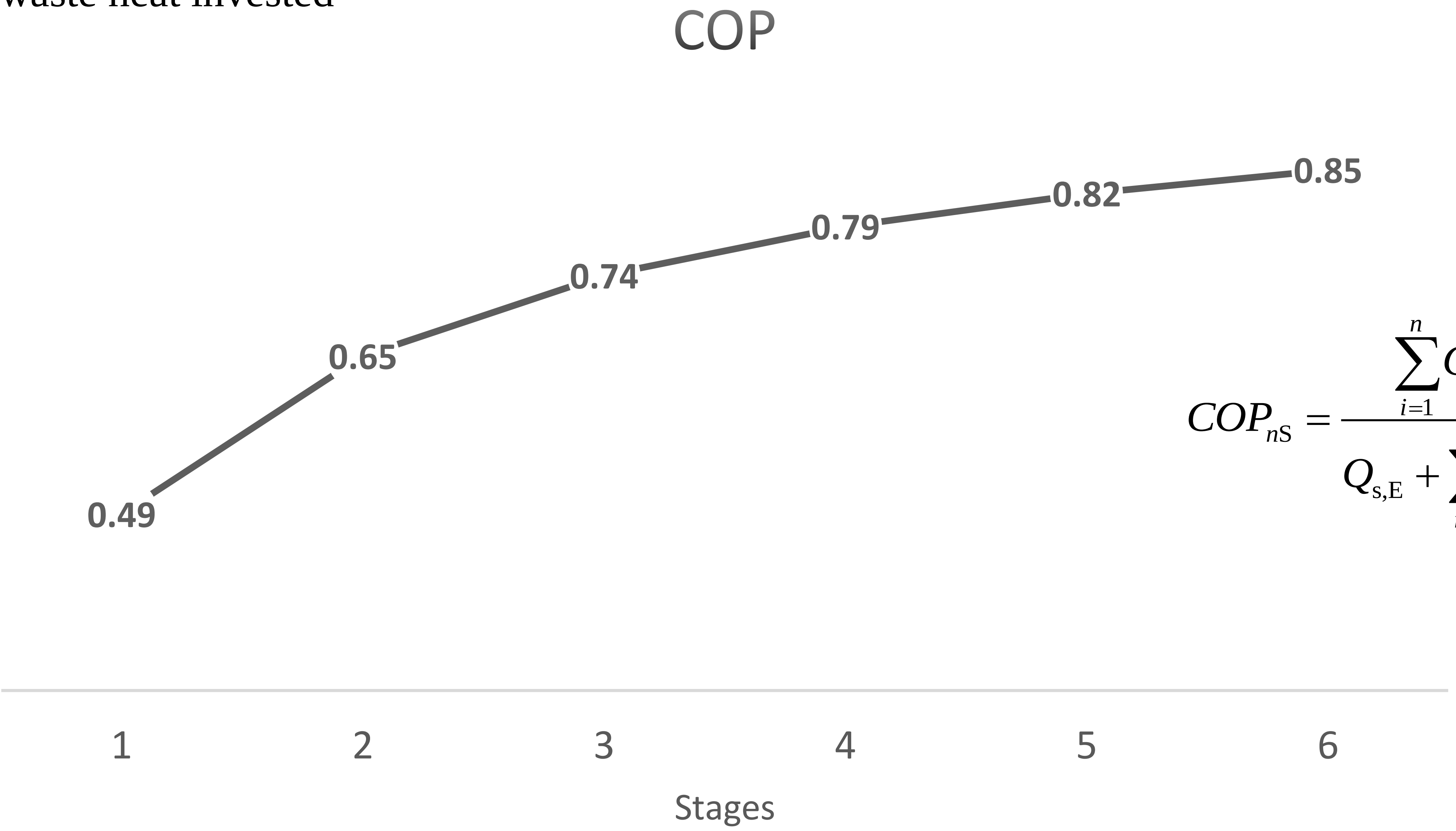

73.0
52.5
22.7
5.0
kPa abs
0.0 LiBr mass fraction (pure water)
Crystallization line
33
78
84
91
99
104
110
126
°C





77.8
63.4
53.0
39.8
23.3
10.4
4.1
kPa abs
0.0 LiBr mass fraction (pure water)
Crystallization line
29
85
91
97
103
111
°C

$$COP \equiv \frac{\text{useful heat produced}}{\text{waste heat invested}}$$



$$COP_{n\mathrm{S}} = \frac{\sum_{i=1}^{n} Q_{\mathrm{b,A,0}i}}{Q_{\mathrm{s,E}} + \sum_{i=1}^{n} Q_{\mathrm{s,D,0}i}}$$

...between 1981 and 2019, 48 absorption heat transformers have been installed in 42 plants with a total capacity of ≈134MW...

…More than 74% of the installations were in Asia. Approximately 61% of the heat transformer installations were applied into the chemical industry.

Europe for instance, has implemented the heat transformer technology in a few cases in the 1980s followed by no new system commercialization or operative plants until 2014, except for the installations in Netherlands (1991), Sweden (1995) and Germany (1998).

These installations worked only for a few years because of corrosion problems. Owing to the technical issues related to conventional working fluids (such as corrosion at high temperature, crystallization and purge of non-condensable gases),…

Cudok, F., Giannetti, N., "Absorption heat transformer - state-of-the-art of industrial applications" in Renewable and Sustainable Energy Reviews, Volume 141, May 2021.

CONCLUSIONS

Advancements in AHT technology:

1. Obtaining **adiabatic absorption** via atomizing spray nozzles (which also serves as a liquid distribution system),
2. Patented **automatic motor-less non-absorbable gasses purge system**, experimentally proven.
3. New **multi-stage AHT** configuration option found **for low temperature lift** applications - simulation results show potential to **improve AHT efficiency by more than 10% for double-stage, and more than 20% for triple-stage** (or higher).

FUTURE WORK

1. Optimize atomization level for adiabatic absorption.
2. Demonstrate a fully-automated purge system, and optimize vapor flow rate for proper non-absorbable gasses entrainment.
3. Build and operate a multi-stage AHT to demonstrate improved efficiency for lower temperature lifts.