



Vacuum drying

If you are faced with the problem of wanting to remove water from a food such as coffee, for example, you have to do this at low temperatures in the vacuum range. In this context, one therefore speaks of vacuum drying.

The sublimation curve for water vapor below the triple point has the following values:

Pressure (Pa)	Temperature (°C)
0.001600	-100.00
0.009330	-90.00
0.053330	-80.00
0.258000	-70.00
1.076000	-60.00
3.939000	-50.00
12.870000	-40.00
38.101000	-30.00
103.450000	-20.00
259.980000	-10.00
611.657000	(Triple point) 0.01

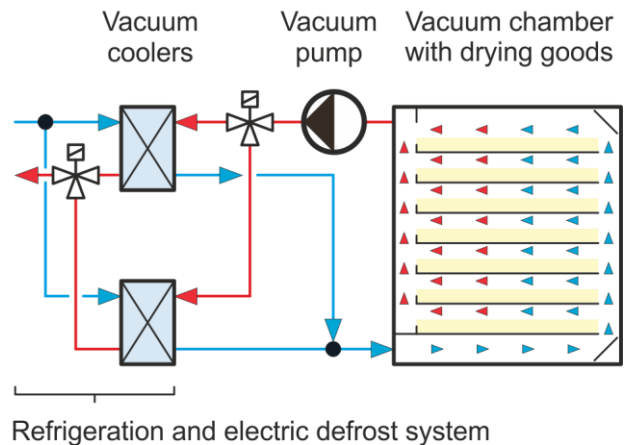
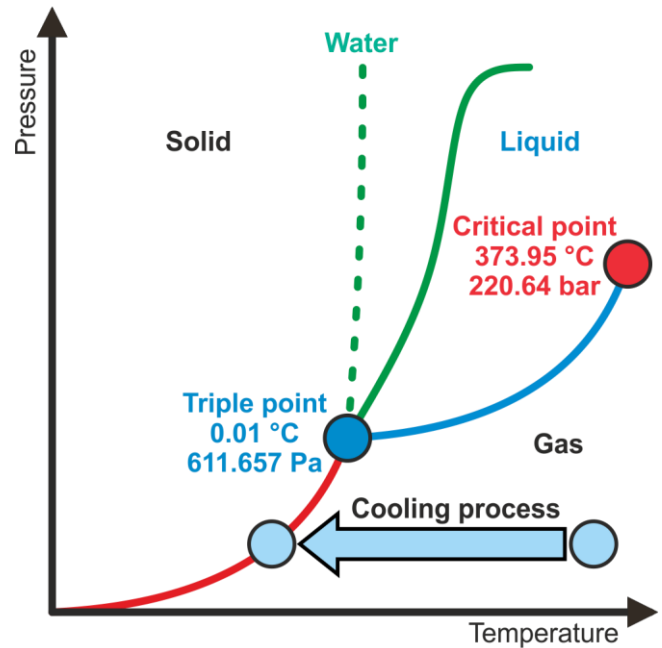
The sublimation temperature can be calculated using the following equations:

$$x = \ln(p)$$

$$t = a + bx + cx^2 + dx^3 + ex^4 + fx^5 + gx^6 + hx^7 + ix^8 + jx^9 + kx^{10}$$

Parameter	Value
a	-6.053723E+01
b	7.315247E+00
c	2.567964E-01
d	9.762705E-03
e	2.361356E-04
f	-8.667065E-06
g	-2.935758E-06
h	-7.793570E-07
i	3.308187E-07
j	4.686146E-08
k	-9.344898E-09

This is where the application of the HEH-VAC software for finned heat exchangers for the purpose of freezing the water vapor with subsequent defrosting is located. Two finned heat exchangers are required for this. When one cools and water vapor accumulates on the tubes and fins to form ice, the other cyclically defrosts the ice with electric heating rods.

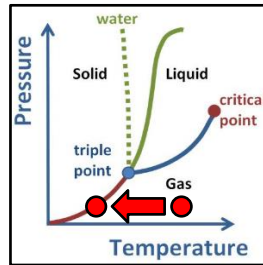


In the following examples, a cycle of 15 minutes was configured, which means, that the defrosting time must be less than 15 minutes by the amount required by the switching valves. We have set aside 4 minutes for this. If you want a shorter defrost time, the electric defrost system has to do more, which would cost more. The water vapor pressure loss should also be kept very small towards the end of the cycle, otherwise the vacuum pump has to work harder.

- Page 2:** Cooling with a brine
- Page 3:** Cooling with an injection evaporator
- Page 4:** Cooling with a pump circulation evaporator



Capacity total	kW	117.696
Capacity sensible	kW	25.724
Frost capacity	kW	91.972
Surface reserve	%	0.694
Present surface	m2	1594.783
Required surface	m2	1583.794
k-coeff.	W/m2K	2.523
Average temp. diff.	K	29.456



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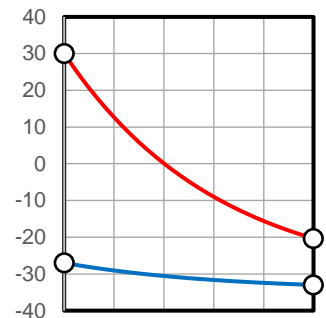
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Plant
Object
Position

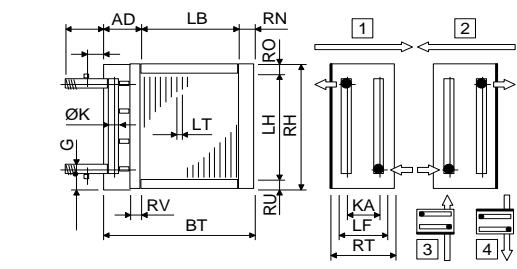
Water-Steam (ff=0.00005 m2K/W)		Inlet	Outlet
Pressure	Pa	100.000	100.000
Temp.	°C	30.000	-20.353
Density humid	kg/m3	7.149E-03	8.573E-03
Enthalpy humid	kJ/kg	55.310	-37.295
Volume flow humid	m3/h	139878.621	116645.676
Mass flow dry	kg/h	1000.000	1000.000
Condensate flow	kg/h	1000.000	1000.000
Surface temperature	°C	-3.004	-27.676
Velocity	m/s	4.317	3.600
Pressure drop dry	Pa		9.589
Pressure drop frost:	Pa		15.105

Temper -40 (ff=0.00005 m2K/W)		Inlet	Outlet	Selection
Temp.	°C	-33.000	-27.000	-23.801
Density	kg/m3	1225.525	1223.923	1222.995
Spec. heat	kJ/kgK	2.860	2.888	2.902
Heat cond.	W/mK	0.407	0.414	0.417
Viscosity	Pas	2.977E-02	1.951E-02	1.588E-02
Volume flow	m3/h	19.858	19.884	19.899
Velocity	m/s	0.373	0.374	0.374
Reynolds	---	298.105	454.881	558.693
Pressure drop	kPa		44.935	



Technical data Frost thickness 1.36 mm - Defr. cycle 0.25 h - Defr. time 0.18 h - Availability 29.85 %

Tubes total	Piece	1000	Tubes:	smooth	AISI 304
Tubes blank	Piece	0	Tubes:		in line
Int. vent./drains	Piece	0	Collectors:	1.49 m/s	AISI 304
Tube rows on the depth	Piece	20	Connections:	1.49 m/s	AISI 304
Tube rows on the height	Piece	50	Fins:	smooth	AlMg3
Tube coupling in series	Piece	20	Frame:	4.00 mm	AISI 304
Number of circuits (NC)	Piece	50	Protection:		without
Volume	l	962	Protection:		---
Weight	kg	2032	Circulations:	1	Default
Connections	G	2 1/2"	Air flow direction:		horizontal
Frame height	RH	mm 3080			
Frame width	BT	mm 3274			
Frame depth	RT	mm 1250			
Finned height	LH	mm 3000			
Finned width	LB	mm 3000			
Finned depth	LF	mm 1200			
Frame on top	RO	mm 40			
Frame on bottom	RU	mm 40			
Frame in front	RV	mm 30			
Frame on back (~86mm)	RN	mm 86			
Collector-Diameter	K	mm 76			
Collector covering	AD	mm 188			
Collector distance	KA	mm 1140			
Fin spacing	LT	mm 13.714			
Fin thickness	LD	mm 0.300			
Tube diameter	Da	mm 20.400			
Tube thickness	S	mm 0.500			
Tube interval on the height	S1	mm 60.000			
Tube interval on the depth	S2	mm 60.000			

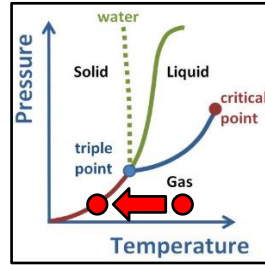


El. heat rods: 69 x ø 8.4 x 3100 mm à 1900 W
Frost thickness: 1.363 mm
Fin spacing: 2x48.0+2x24.0+16x12.0 mm

Delivery: 5-6 weeks
 Validity: 12 weeks
 Condit.: net, prepaid address
 Payment: 30 days net
Price net: With el. rods EUR 55164.00



Capacity total	kW	117.696
Capacity sensible	kW	25.724
Frost capacity	kW	91.972
Surface reserve	%	4.418
Present surface	m2	1594.783
Required surface	m2	1527.313
k-coeff.	W/m2K	2.658
Average temp. diff.	K	28.992



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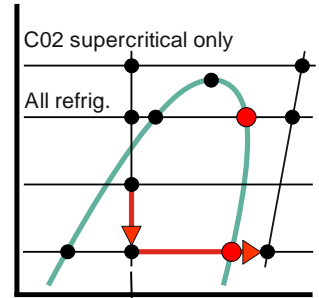
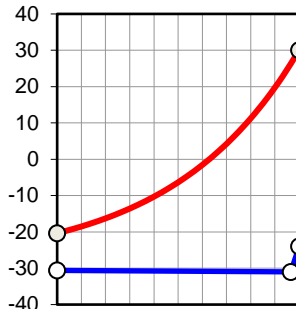
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Water-Steam (ff=0.00005 m2K/W)		Inlet	Outlet
Pressure	Pa	100.000	100.000
Temp.	°C	30.000	-20.353
Density humid	kg/m3	7.149E-03	8.573E-03
Enthalpy humid	kJ/kg	55.310	-37.295
Volume flow humid	m3/h	139878.621	116645.676
Mass flow dry	kg/h	1000.000	1000.000
Condensate flow	kg/h	1000.000	1000.000
Surface temperature	°C	-2.773	-26.577
Velocity	m/s	4.317	3.600
Pressure drop dry	Pa		9.589
Pressure drop frost:	Pa		15.105

R744 (CO2) Evaporation 13.804 bar (ff=0.00005 m2K/W)		
Condensate"	°C	10.000
Condensate'	°C	10.000
Subcooling	°C	7.000
Evaporation"	°C	-31.000
Superheating	°C	-24.000
Mass flow	kg/h	1873.678
Volume flow	m3/h	52.337
Velocity	m/s	2.459
Pressure drop Evaporation	K	0.393
Pressure drop Capillary	bar	0.920

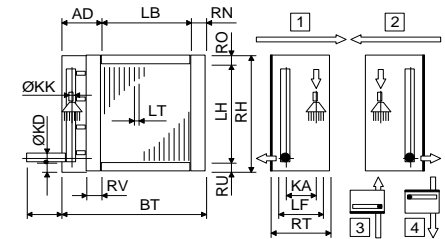


Part of steam on the inject point 28.13 %

Technical data Frost thickness 1.36 mm - Defr. cycle 0.25 h - Defr. time 0.18 h - Availability 29.85 %

Tubes total	Piece	1000
Tubes blank	Piece	0
Tube rows on the depth	Piece	20
Tube rows on the height	Piece	50
Tube coupling in series	Piece	50
Number of circuits (NC)	Piece	20
Volume	l	945
Weight	kg	2012
Cond. connection	KK	mm 42
Steam connection	KD	mm 60
Frame height	RH	mm 3080
Frame width	BT	mm 3258
Frame depth	RT	mm 1230
Finned height	LH	mm 3000
Finned width	LB	mm 3000
Finned depth	LF	mm 1200
Frame on top	RO	mm 40
Frame on bottom	RU	mm 40
Frame in front	RV	mm 30
Frame on back (~86mm)	RN	mm 86
Collector covering	AD	mm 172
Collector distance	KA	mm 1140
Fin spacing	LT	mm 13.714
Fin thickness	LD	mm 0.300
Tube diameter	DA	mm 20.400
Tube thickness	S	mm 0.500
Tube interval on the height	S1	mm 60.000
Tube interval on the depth	S2	mm 60.000

Tubes:	smooth	AISI 304
Tubes:		in line
Collectors:		AISI 304
Connections:		AISI 304
Fins:	smooth	AlMg3
Frame:	4.0 mm	AISI 304
Circulations:	1	Default
Protection:		without
Protection:		---
Air flow direction:		horizontal

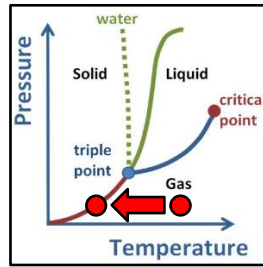


El. heat rods: 69 x ø 8.4 x 3100 mm à 1900 W
Frost thickness: 1.363 mm
Fin spacing: 2x48.0+2x24.0+16x12.0 mm

Delivery:	5-6 weeks
Validity:	12 weeks
Condit.:	net, prepaid address
Payment:	30 days net
Price net: With el. rods	EUR 54576.00



Capacity total	kW	117.696
Capacity sensible	kW	25.724
Frost capacity	kW	91.972
Surface reserve	%	0.921
Present surface	m2	1594.783
Required surface	m2	1580.235
k-coeff.	W/m2K	2.704
Average temp. diff.	K	27.544



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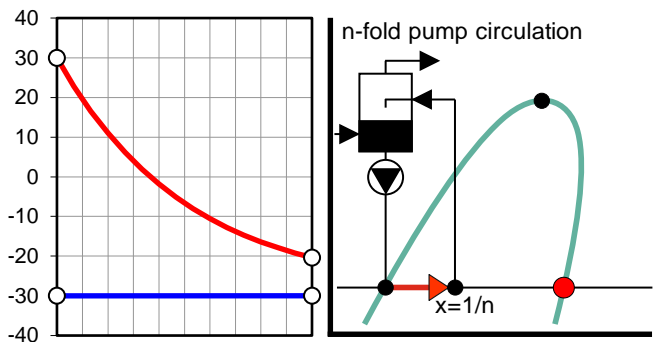
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Air humid (ff=0.00005 m2K/W)		Inlet	Outlet
Pressure	Pa	100.000	100.000
Temp.	°C	30.000	-20.353
Density humid	kg/m3	7.149E-03	8.573E-03
Enthalpy humid	kJ/kg	55.310	-37.295
Volume flow humid	m3/h	139878.621	116645.676
Mass flow dry	kg/h	1000.000	1000.000
Condensate flow	kg/h	1000.000	1000.000
Surface temperature	°C	-6.377	-26.202
Velocity	m/s	4.317	3.600
Pressure drop dry	Pa		9.589
Pressure drop frost:	Pa		15.105

R744 (CO2) Evaporation 14.278 bar (ff=0.00005 m2K/W)

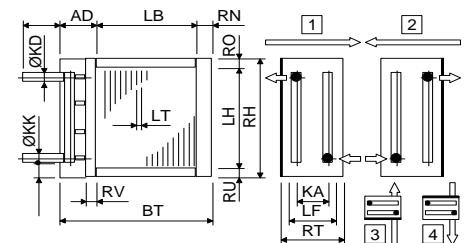
Inlet	°C	-29.982
Outlet	°C	-30.000
Pump circulation factor	n	3.000
Mass flow	kg/h	4209.414
Volume flow in	m3/h	3.917
Volume flow out	m3/h	40.490
Velocity in	m/s	0.074
Velocity out	m/s	0.761
Pressure drop Evaporation	K	0.018



Technical data Frost thickness 1.36 mm - Defr. cycle 0.25 h - Defr. time 0.18 h - Availability 29.85 %

Tubes total	Piece	1000
Tubes blank	Piece	0
Tube rows on the depth	Piece	20
Tube rows on the height	Piece	50
Tube coupling in series	Piece	20
Number of circuits (NC)	Piece	50
Volume	l	950
Weight	kg	2032
Cond. connection	KK mm	48
Steam connection	KD mm	76
Frame height	RH mm	3080
Frame width	BT mm	3274
Frame depth	RT mm	1250
Finned height	LH mm	3000
Finned width	LB mm	3000
Finned depth	LF mm	1200
Frame on top	RO mm	40
Frame on bottom	RU mm	40
Frame in front	RV mm	30
Frame on back (-86mm)	RN mm	86
Collector covering	AD mm	188
Collector distance	KA mm	1140
Fin spacing	LT mm	13.714
Fin thickness	LD mm	0.300
Tube diameter	DA mm	20.400
Tube thickness	S mm	0.500
Tube interval on the height	S1 mm	60.000
Tube interval on the depth	S2 mm	60.000

Tubes:	smooth	AISI 304
Tubes:	in line	
Collectors:		AISI 304
Connections:		AISI 304
Fins:	smooth	AlMg3
Frame:	4.0 mm	AISI 304
Circulations:	1	Default
Protection:		without
Protection:		---
Air flow direction:		horizontal



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Frost thickness: 1.363 mm
Fin spacing: 2x48.0+2x24.0+16x12.0 mm

Delivery:	5-6 weeks
Validity:	12 weeks
Condit.:	net, prepaid address
Payment:	30 days net
Price net: With el. rods	EUR 55164.00