NH_3 - Plant Technology with Reduced and Optimized Refrigerant Operation

RORO® → **R**educed and **O**ptimized **R**efrigerant **O**peration

Schaffhausen, June 27, 2019

eurammon

refrigerants delivered by mother nature

Company and Lecturer

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EXCELLENCE IN REFRIGERATION

Requirements for industrial refrigeration systems

International Regulations:

- > Adaptation of Montreal-Protocol (Kigali) => HFCs - reduction
- > Paris Agreement => climate neutral up to 2050; <2K up to 2100

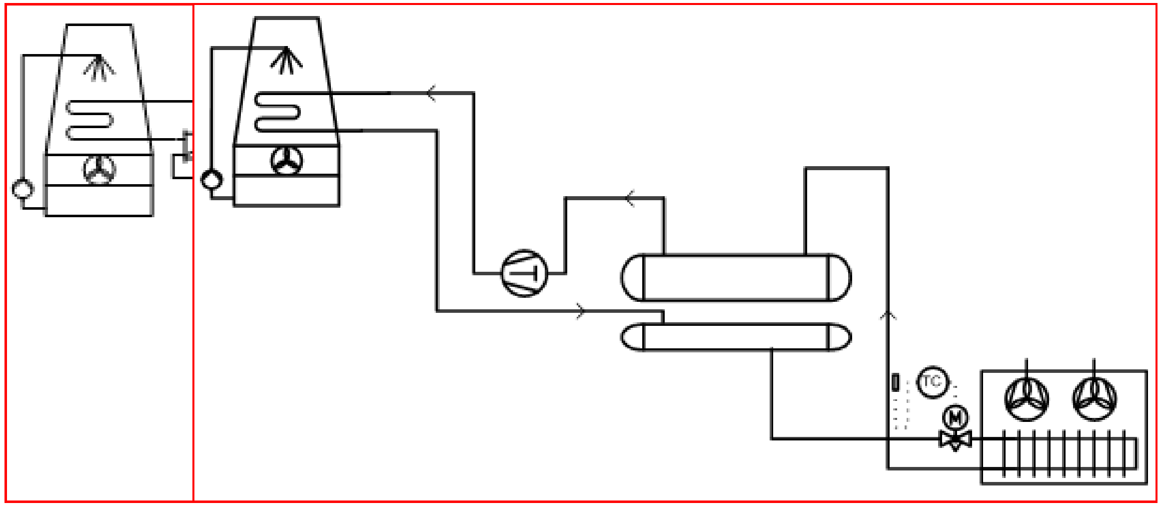
- > HFC Regulation (F-Gas-Verordnung)
- > Federal Imission Protection Law (BImSchG)
- > Energy Efficiency (Energieeinspar-Verordnung)

- > Investment
- > Operating Costs
- > Availability

Objective

- Highest possible energy efficiency
- Minimized refrigerant charge
- Best availability
- Highest possible safety standard
- Attractive investment costs

Ideas and Solutions



- > NH_3 – Pump Circulation System
- > NH_3 – Indirect Cooling System
- > NH_3 – RORO® - Plant Technology

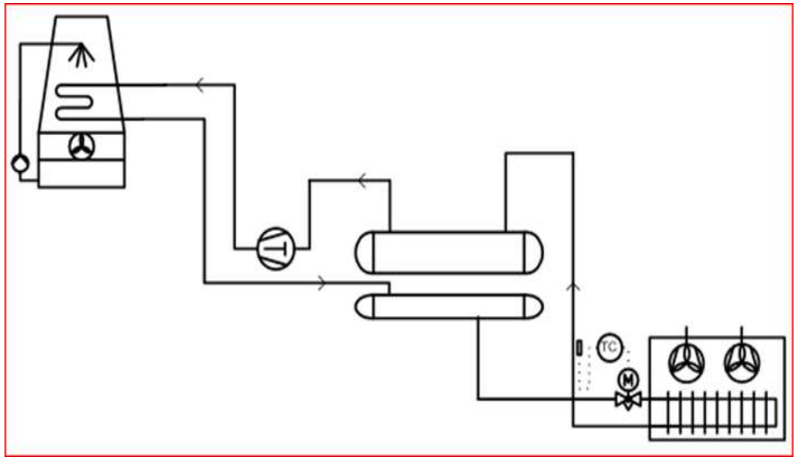
* **RORO®** → **R**educed and **O**ptimized **R**efrigerant **O**peration

Applications of NH_3 - RORO® Plant Technology

- NH_3 – Production cooling
- NH_3 – Feezer
- NH_3 – Medium Temperature - Store
- NH_3 – Low Temperature - Store
- NH_3 – KALINOR® Ice Bank
- NH_3 – Liquid Cooling

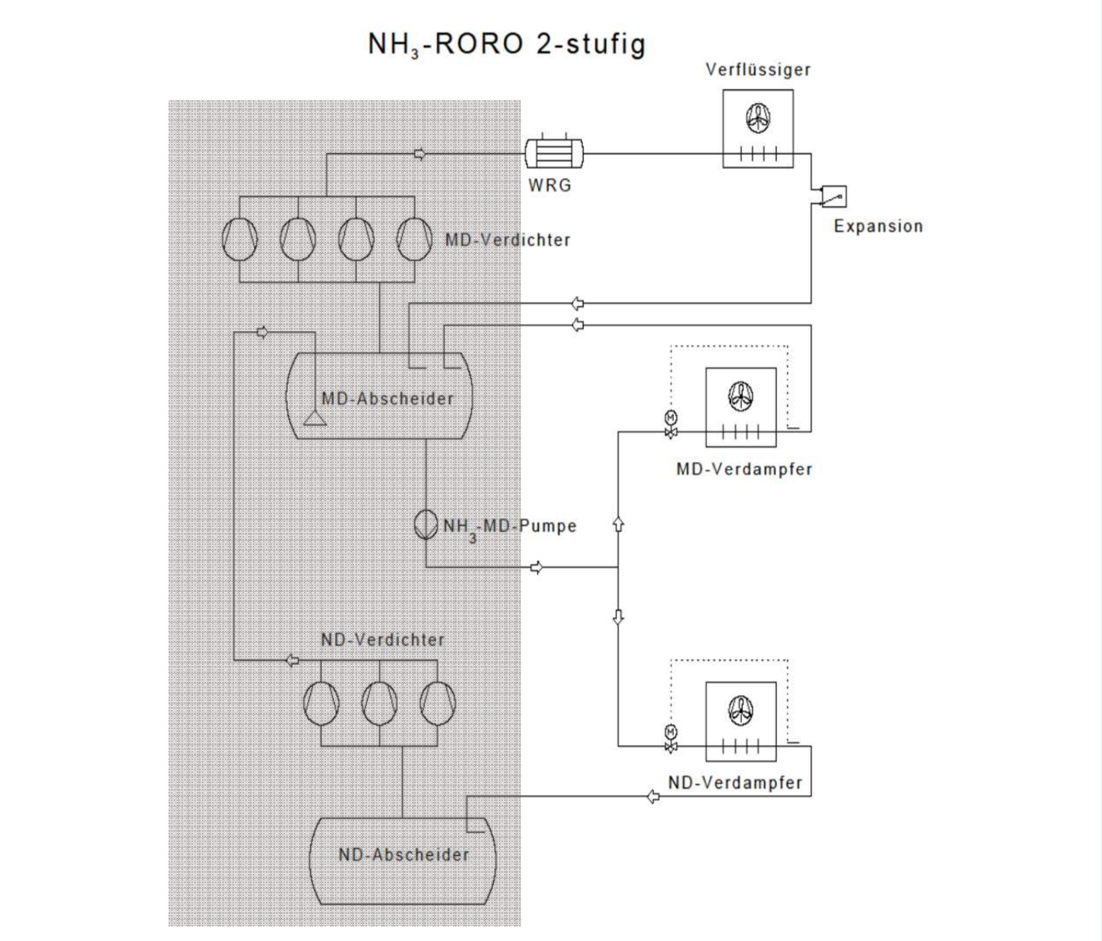
Working Principle: NH_3 - RORO® Plant Technology

- Liquid Separator
- Liquid Receiver
- Vessel Pump
- Pref. Piston Compressor



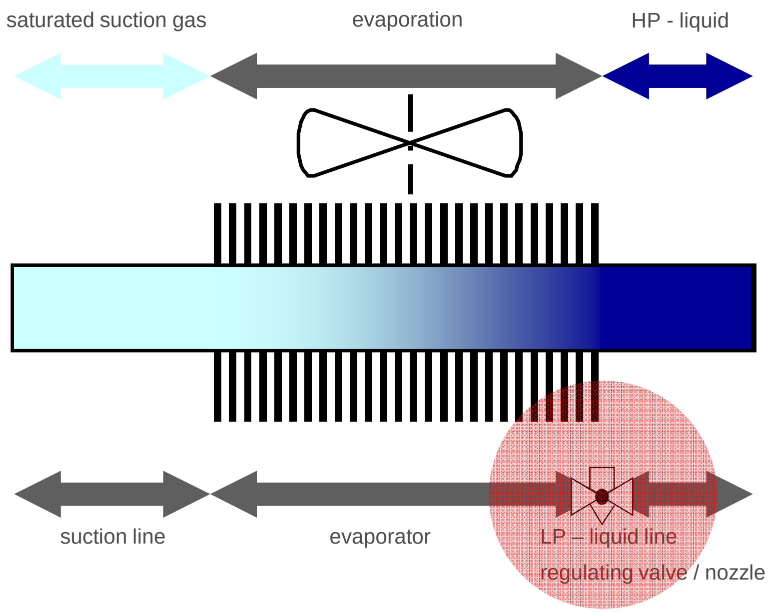
Working Principle: NH_3 - RORO® Plant Technology

- > High Pressure Float Valve
- > LP + MP Liquid Separator
- > MP - Refrigerant Pump
- > MP - 1 Pump Pressure Line
- > LP – Vessel Pump



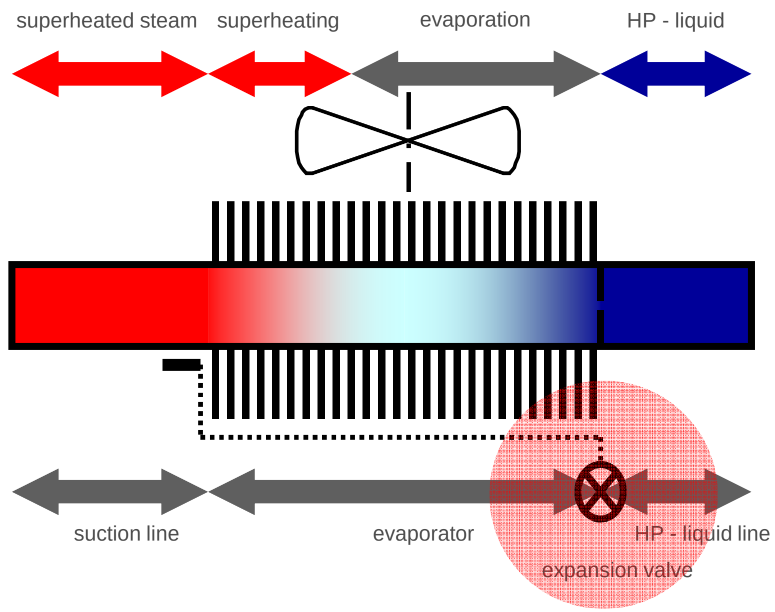
Working principle: NH_3 - RORO® Plant Technology

Pump Circulation System



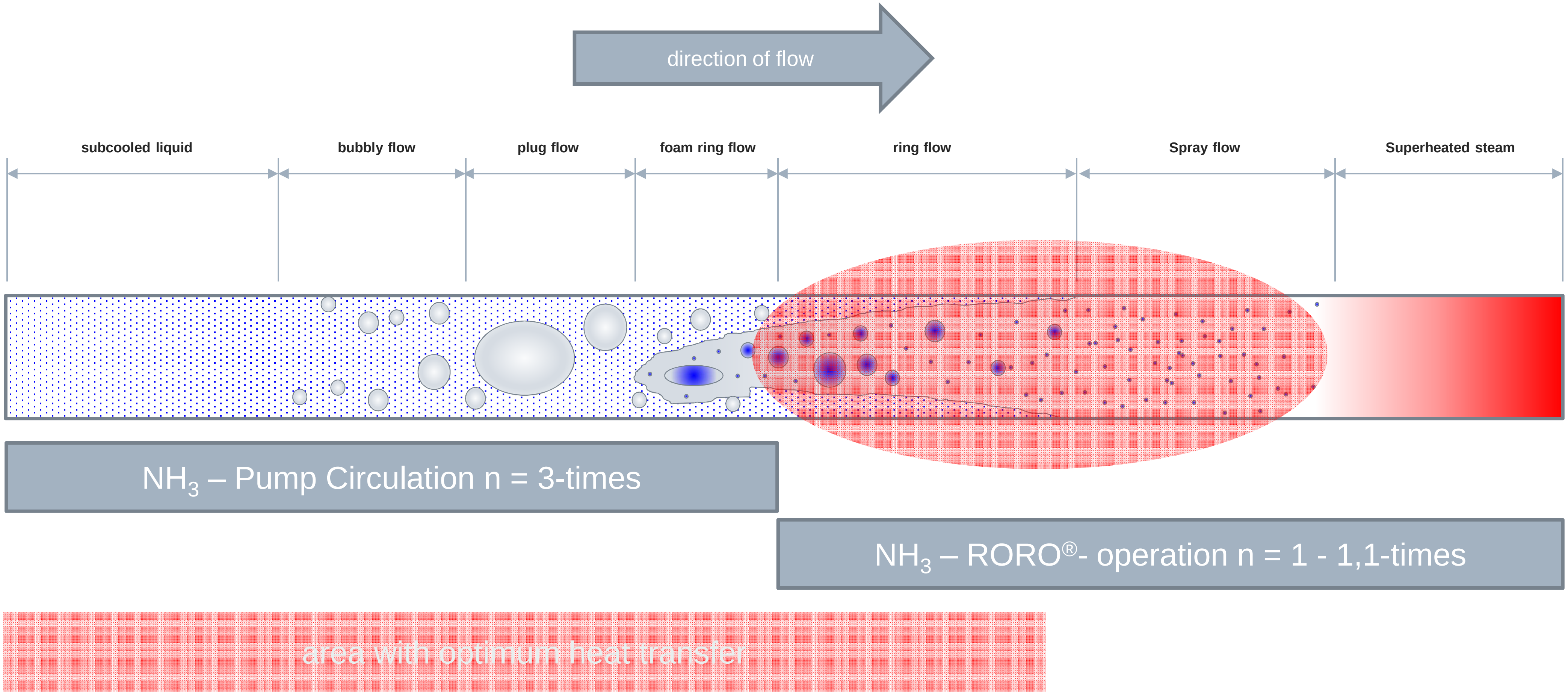
circulation rate approx. 2 to 4

RORO® - System



circulation rate approx. 1 to 1,1

Working Principle: NH_3 - RORO® Plant Technology



Working Principle: NH_3 - RORO® Plant Technology

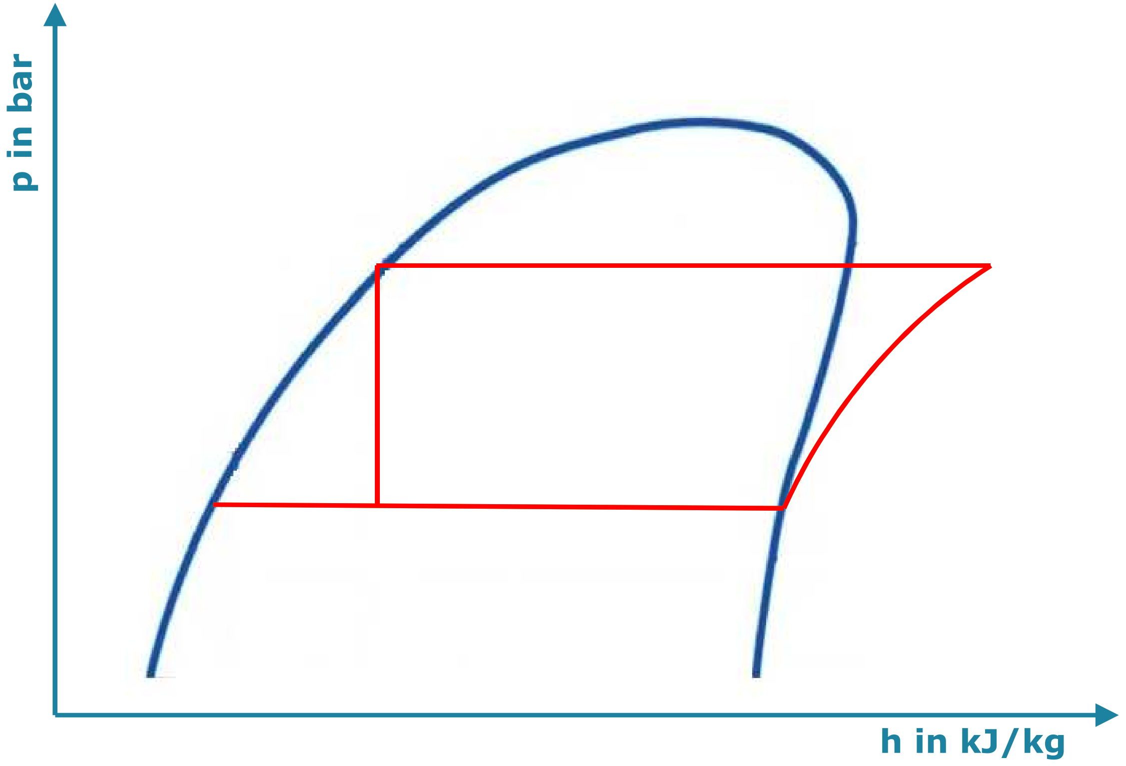
NH_3 – Pump System

$\dot{Q}o = 1448$ kW
tc = +35 °C
to = -6 °C

$\dot{V} = \dot{Q}o/\Delta h \times v''$

$$\dot{V} = \frac{1448 \text{ kW} \times 3600 \text{ s} \times 0{,}361 \text{ m}^3/\text{kg}}{(1454-362) \text{ kWs/kg} \times 1 \text{ h}}$$

$\dot{V} = 1723{,}3$ m³/h



Working Principle: NH_3 - RORO® Plant Technology

NH_3 – RORO® - System

$\dot{Q}o$ = 1448 kW
tc = +35 °C
tu = 10 K
to = -6 °C

$$\dot{Q}u = \dot{m} \times \Delta h$$

$$\dot{Q}u = \frac{4775\ kg/h \times 53\ kWs/kg \times 1\ h}{3600\ s}$$

$$\dot{Q}u = 70{,}3\ kW$$

$$\dot{V}_{Qo} = \frac{\dot{Q}o}{\Delta h}\ v''$$

$$\dot{V}_{Qo} = \frac{1448\ kW \times 3600\ s \times 0{,}361\ m^3/kg}{(1454-362+53)\ kWs/kg \times 1\ h}$$

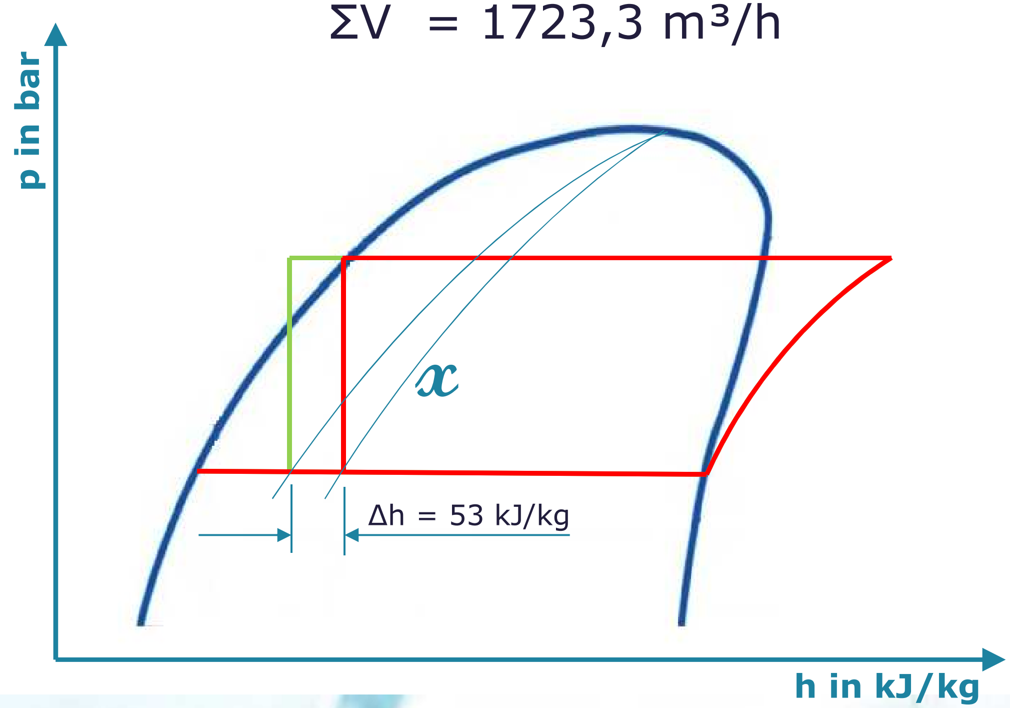
$$\dot{V}_{Qo} = 1643{,}5\ m^3/h$$

$$\dot{V}_{Qu} = \frac{70{,}3\ kW \times 3600\ s \times 0{,}361\ m^3/kg}{(1454-362+53)\ kWs/kg \times 1\ h}$$

$$\dot{V}_{Qu} = 79{,}8\ m^3/h$$

$\dot{V}_{Qo}$ = 1643,5 m³/h
$\dot{V}_{Qu}$ = 79,8 m³/h

$\Sigma\dot{V}$ = 1723,3 m³/h



Efficiencies of NH_3 – RORO® - Plant Technology

Horizontal wet return line – MP:

Pump: Qo = 1448 kW; n = 3-times; to = -6 °C
- DN 150: Δp = 0,256 bar = **2,0 K**

RORO®: Qo = 1448 kW; n = 1-times; to = -6°C; tü = 2 K
- DN 150: Δp = 0,079 bar = **0,6 K**
- DN 125: Δp = 0,178 bar = **1,4 K**

Coolselector2

Vertical wet return line – MP:

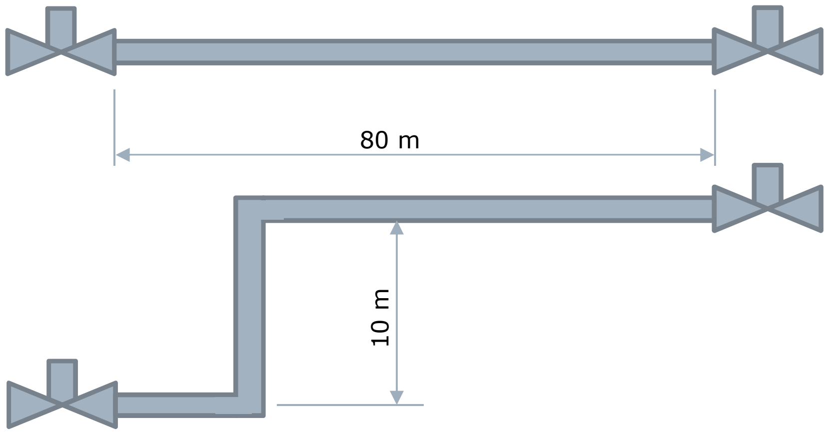
Pump: Qo = 1448 kW; n = 3-times; to = -6 °C
- DN 150: Δp = 0,313 bar = **2,4 K**

RORO®: Qo = 1448 kW; n = 1-times; to = -6°C; tü = 2 K
- DN 150: Δp = 0,083 bar = **0,6 K**
- DN 125: Δp = 0,183 bar = **1,4 K**

Vertical wet return line – LP:

Pump: Qo = 400 kW; n = 3-times; to = -40 °C
- DN 150: Δp = 0,107 bar = **3,0 K**

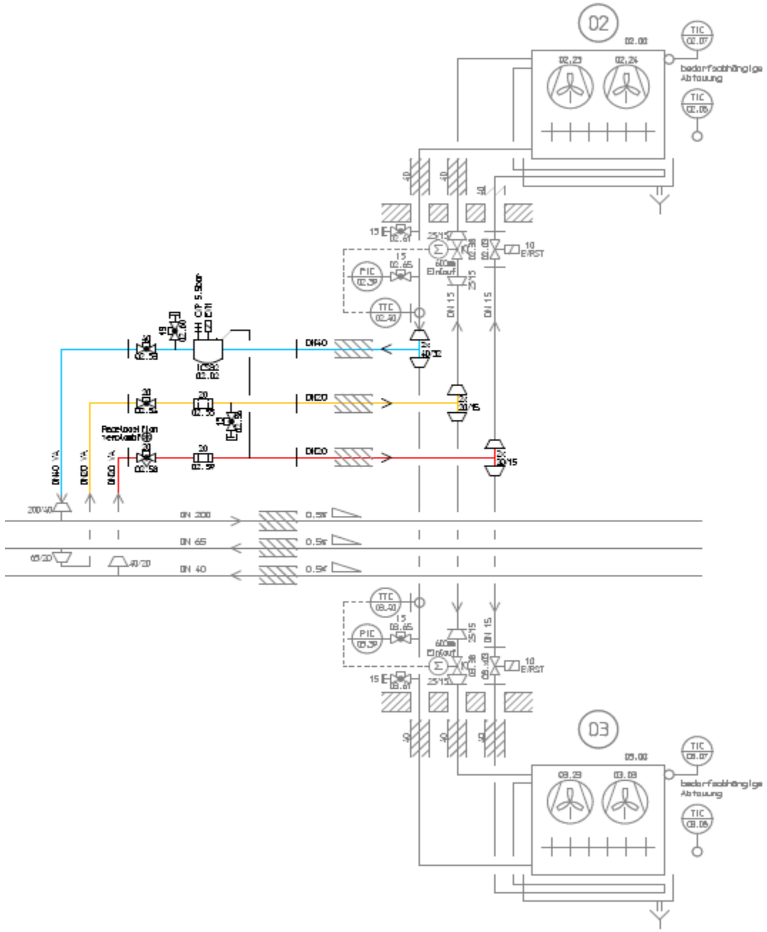
RORO®: Qo = 400 kW; n= 1-times; to = -40°C; tü = 2 K
- DN 150: Δp = 0,025 bar = **0,6 K**
- DN 125: Δp = 0,054 bar = **1,5 K**



+ GOOD TO KNOW

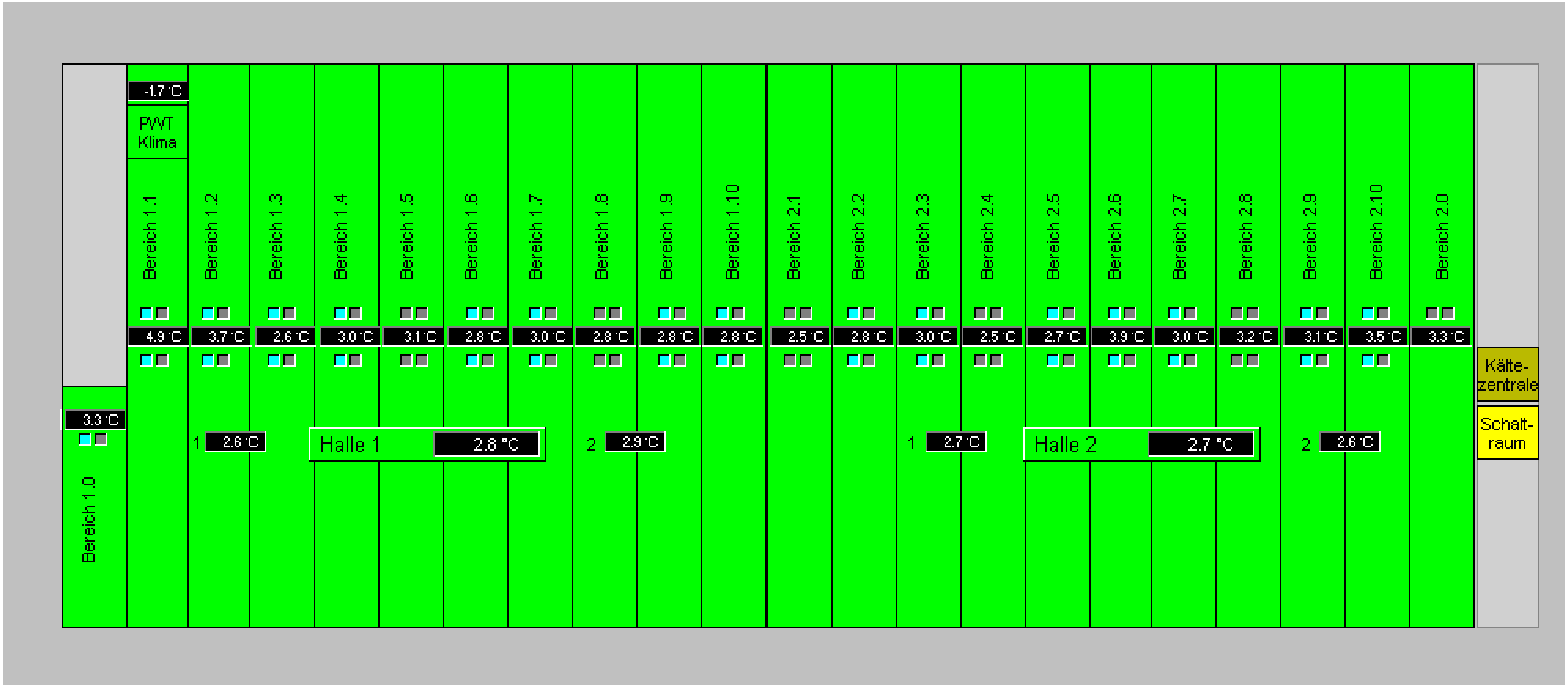
> Compensation of the superheat of 2K
> Approx. 5% efficiency increase at MP
> approx. 8% efficiency increase at LP

Facilities example: NH_3 – RORO® - Plant Technology

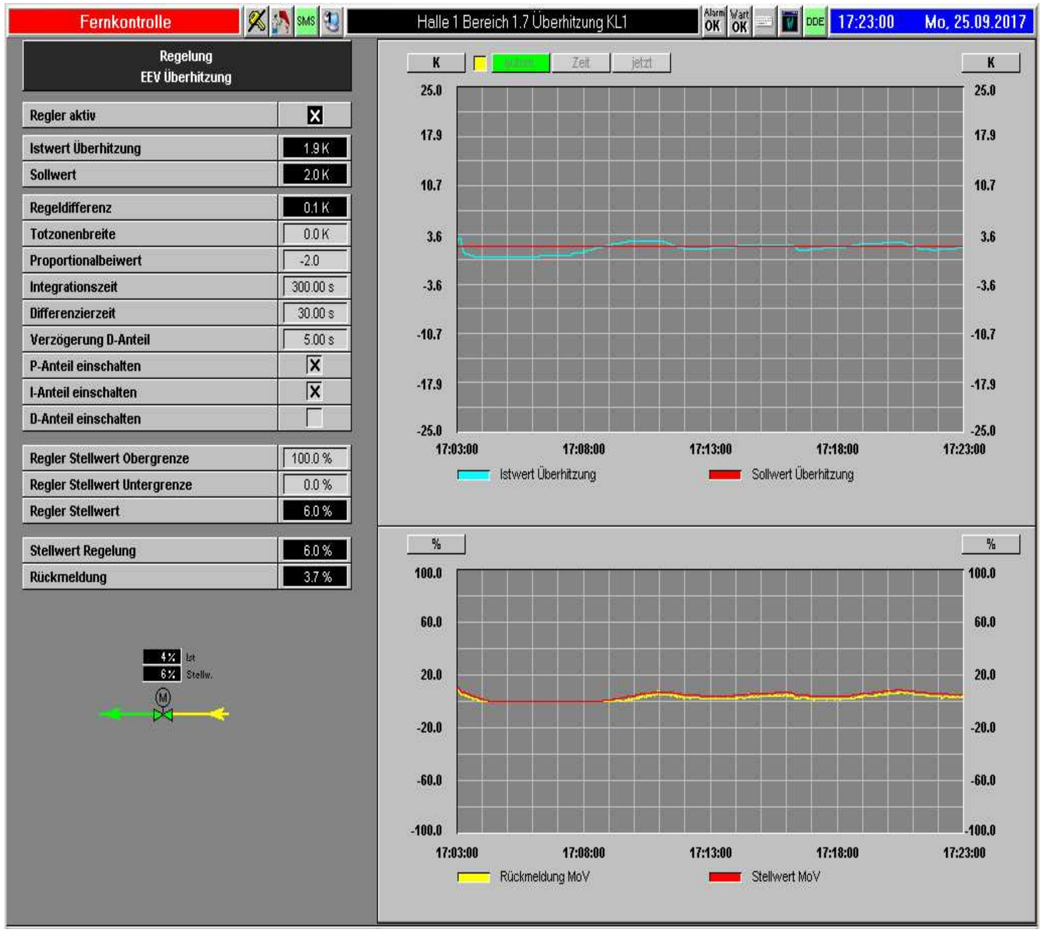


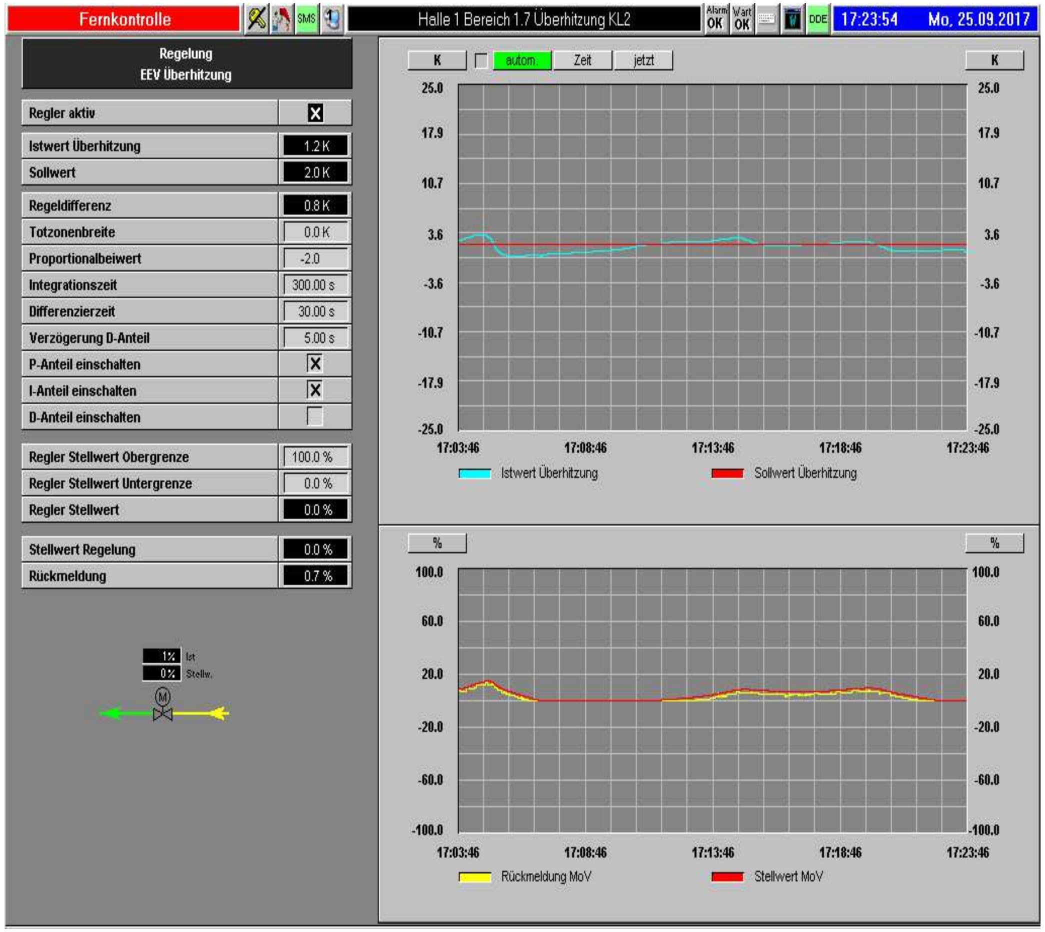
- > Valve station and pipe work outside the cold store
- > Hermetic stainless steel pipe work inside the cold store
- > Zone cooling by connecting of the evaporators pairwise
- > Motor expansion valve with feedback signal of each evaporator
- > Superheat regulation of each evaporator
- > Single defrosting of each evaporator on demand
- > Avoidance of oil contamination by hot gas defrosting
- > Avoidance of dirt contamination by using filters consequently

Facilities example: homogeneous cold store temperature



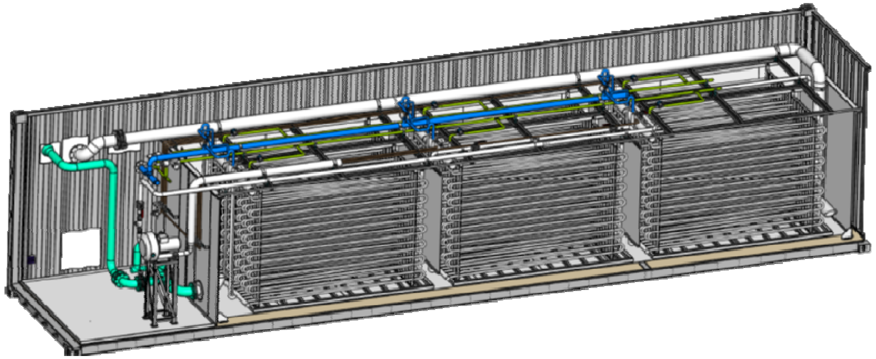
Facilities example: Superheat regulation





Applications

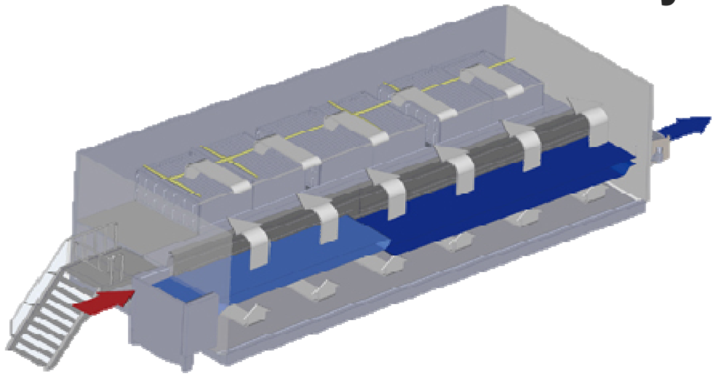
NH_3 – KALINOR® Ice Bank



GOOD TO KNOW

- Approx. 80% reduction of NH_3-charge
- Homogeneous clear ice-creation guarantees a high storage capacity
- High constant melt down capacity guarantees by air injection

NH_3 – RORO® - Fluidized Bed System



GOOD TO KNOW

- Approx. 80% reduction of NH_3-charge
- No boiling retardation
- Minimum pressure loss in the wet return line
- Optimized hot gas defrosting

Advantages of the RORO® - Plant Technology

GOOD TO KNOW

- Very low superheat at the evaporator of 2K possible, due to additional liquid separator
- Entrained droplets in the suction line caused a saturation on evaporation temperature
- No negative effect on discharge temperature due to minimal superheating
- Loss of power of approx. 0,5 % related to the total refrigeration capacity caused by superheat of less 2K
- Pressure loss in wet return line towards separator will be minimized – efficiency advantage approx. 5 - 8%
- Reduction of pipe diameter (1 nominal width) is of economical interest
- At two stage plants the LP - pump pressure line is not necessary
- At LP - application, especially at freezers a minimized boiling retardation is expected
- Very low ammonia charge of less 1 kg/kW => “Federal Imission Protection Law” (BImSchG) can be avoided
- Optimized heat exchanging will compensate superheat area and reduced heat transfer surface
- Highest possible safety standard is guaranteed at the cold store and at the production area, due to the use of non corrosive materials and hermetic design without detachable connections and valves
- In case of accident maximum 5 kg NH_3 will leak. At a store size of 64,000 m³ => approx. 100 ppm (annoyance > 250 ppm / tolerability 500-1000 ppm)

Efficiency Determination: NH_3 – RORO® - Plant Technology

Energy Efficiency Tool - Version 2.0

Energieeffizienzbericht nach VDMA 24247

Forschungsrat Kältetechnik

Projektinformationen			
Bearbeiter:	elsen	erstellt am:	18.10.2017 12:01:28
Programmversion:	2.0.7.7	erstellt im Modus:	Basis
Projektname:	Beispiel 1 RORO Basis	Name der Variante:	RORO Basis
Erstellt durch:			
Firma:	-	Postleitzahl:	-
Adresse:	-	Ort:	-
Anlageninformationen			
Name der Anlage:	System New		
Bereich:			
Bemerkung:		Branche:	
Konfiguration			
Kälteleistung [kW]:	2149,7	Kältemittel:	R717
Leistungsaufnahme Verdichter [kW]:	524,8	Verdichtertyp:	offener Kolbenverdichter
Leistung der Hilfsaggregate [kW]:	114,610	Überhitzungsregelung:	elektronisches EV
Konfiguration kalte Seite:	direkte Verdampfung luftbeaufschlagt	Konfiguration warme Seite:	Verdunstungsverf luessiger
Nutztemperatur [°C]:	3,0	Lastprofil:	LP6 Lebensmittellager ung
Verdampfungstemperatur [°C]:	-6,0	Verflüssigungstemperatur [°C]:	30,0
Überhitzung [K]:	5,0	Leistungsregelung:	variabel
	fest		variabel

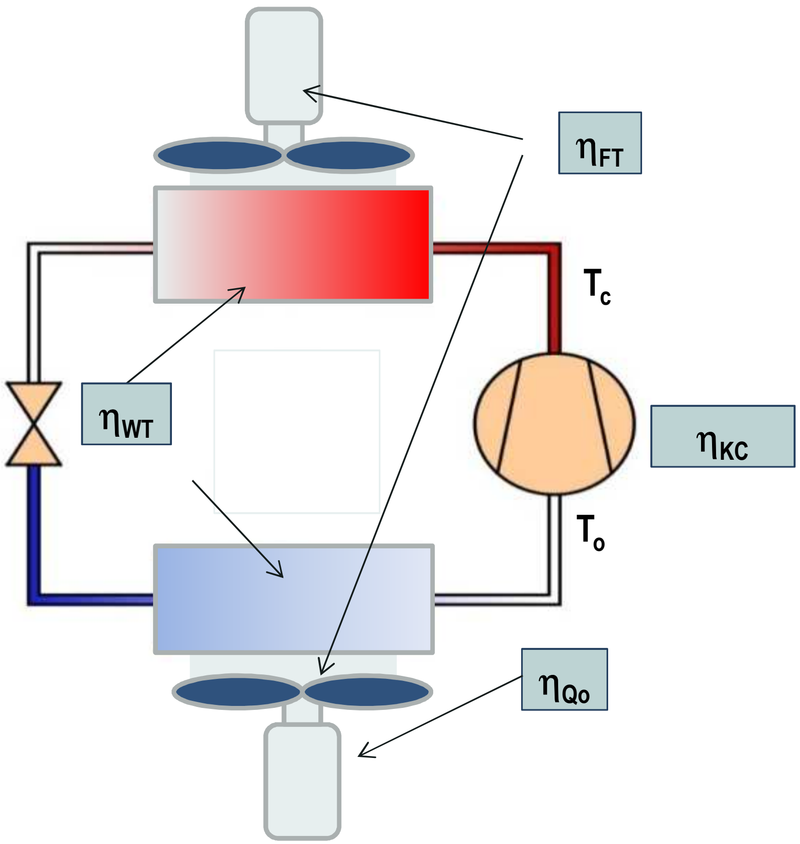
Efficiency Determination: NH_3 – RORO® - Plant Technology

VDMA - Standard Sheet 24247

- Energy Efficiency η_{KC} of **Refrigeration capacity**
- Energy Efficiency η_{WT} of **Heat transfer**
- Energy Efficiency η_{FT} of **Fluid transport**
- Energy Efficiency η_{Qo} additional **Refrigeration capacity to compensate the energy input**
- **Total Energy Efficiency**

$$\eta_{ges} = \eta_{KC} \times \eta_{WT} \times \eta_{FT} \times \eta_{Qo}$$

➡ **Information about the efficiency of the components**



Efficiency Determination: NH_3 – RORO® - Plant Technology

Results

<u>Depiction:</u>

> Single efficiencies
> Total efficiency
> Total result

<u>Total Result:</u>

> Annual energy consumption = 1.339.375 kWh
> Cost of electricity = 200.906,- €
> Seasonal Energy Efficiency Ratio SEE(I)R = 3,26

Efficiency Determination: NH_3 – RORO® - Plant Technology

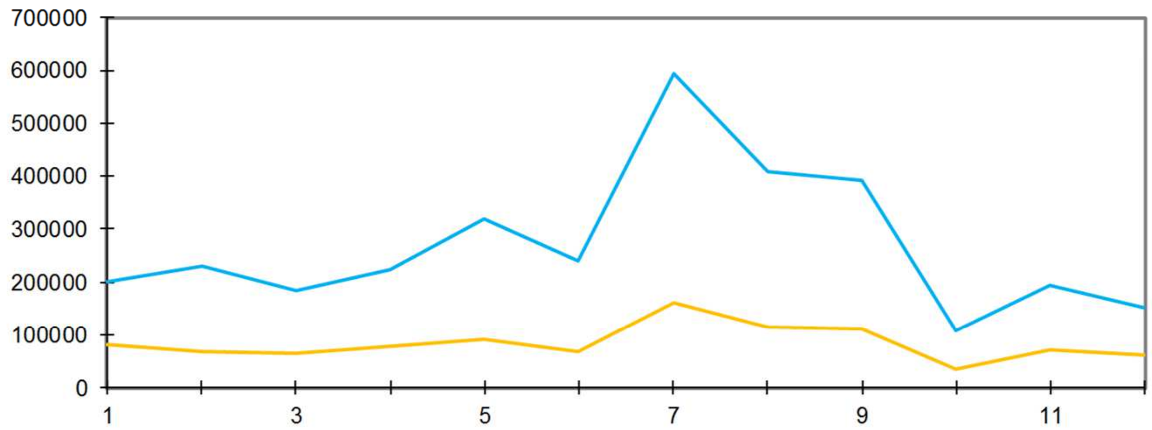
Measurement Report

Sample-System: Food storage - Location Frankfurt a.M.
Technology: NH_3 - RORO
Protocol (monthly): Energy measurement System
Date: 2016

Kreutzträger KÄLTETECHNIK

Tag	Refrigerant capacity in kWh	electrical current consumption in kWh
1	200055	80092
2	230743	68965
3	184857	66441
4	223770	77204
5	320796	91325
6	241007	67981
7	592259	161249
8	407669	114546
9	391612	112228
10	108500	35452
11	194712	72036
12	149521	62864
sum	**3245501**	**1010383**
Energy Efficiency Tool:	**4365478**	**1339375**

Energy measurement refrigeration plant



SEE(I)R = 3,21

SEE(I)R = 3,26

Efficiency Comparison: NH_3 – RORO® - Plant Technology

NH_3 – RORO® - Plant Technology

EINGABEDATEN:

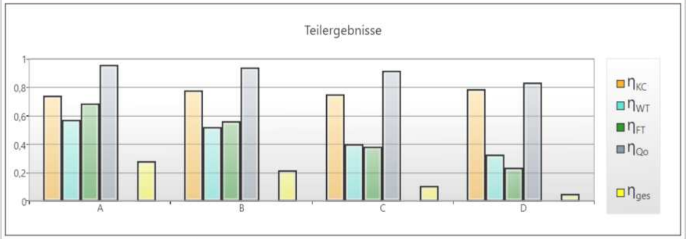
Name	L	w	t_N [°C]	t_U [°C]	t_{cmin} [°C]	$t_U{}^*$ [°C]	dt_k [K]	dt_w [K]	t_o [°C]	t_{02} [°C]	t_{V1} [°C]	t_c [°C]	t_{sc} [K]
A	100	0.3	3	35	14	23	9	5	-6	-4	-4	28	10
B	75	8.98	3	25	14	18	7.5	5.5	-4.5	-2.5	-2.5	23.5	10
C	50	35.83	3	15	14	11	5.7	6	-2.7	-0.7	-0.7	17	10
D	25	54.89	3	5	14	8	4.3	7	-1.3	0.7	0.7	14	10

Name	L	w	P_{FT_k} [kW]	$\dot{Q}_{FT\_k}$ [kW]	$\dot{Q}_{H\_k}$ [kW]	P_{FT_w} [kW]	$P_{elAuxCtrl}$ [kW]	$\dot{Q}_o$ [kW]	P_{el} [kW]
A	100	0.3	0	0	4.224	0	0	1448	249.2
B	75	8.98	0	0	2.218	0	0	1086	145.2
C	50	35.83	0	0	0.718	0	0	724.1	70.6
D	25	54.89	0	0	0.063	0	0	362.1	26

TABELLE TEILERGEBNISSE

Name	COP_{oc}	COP_{ocC}	COP_{NUC}	η_{KC}	η_{WT}	η_{FT}	η_{Qo}	η_{ges}	$\dot{Q}_{iso}$ [kW]	$\dot{Q}_{oN}$ [kW]	$P_{el\ ges}$ [kW]
A	5.811	7.857	13.807	0.740	0.569	0.685	0.955	0.275	0	1383	363.8
B	7.480	9.595	18.410	0.780	0.521	0.559	0.942	0.214	0	1023	259.8
C	10.256	13.728	34.519	0.747	0.398	0.381	0.914	0.104	0	662.2	185.2
D	13.925	17.768	55.230	0.784	0.322	0.230	0.831	0.048	0	300.8	113.2

DIAGRAMM TEILERGEBNISSE



Jahreskühllast: 4365478 kWh/a Jahreskondensationswärme: 5373464 kWh/a

Jahreselektroenergiebedarf: 1339375 kWh/a Kosten Elektroenergie: 200906 €/a

SEE(I)R: 3.26

Annual electric energy demand = 1.339.375 kWh/a
Cost of electricity (15ct/kWh) **= 200.906,- €/a**
SEE(I)R = 3,26

NH_3 – Secondary Refrigerant - Plant

EINGABEDATEN:

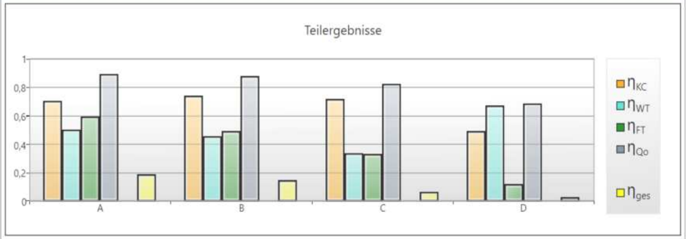
Name	L	w	t_N [°C]	t_U [°C]	t_{cmin} [°C]	$t_U{}^*$ [°C]	dt_k [K]	dt_w [K]	t_o [°C]	t_{02} [°C]	t_{V1} [°C]	t_c [°C]	t_{sc} [K]
A	100	0.3	3	35	11	23	13	5	-10	-9.5	-7.5	28	1
B	75	8.98	3	25	11	18	10.9	5.5	-7.9	-7.5	-5.5	23.5	1
C	50	35.83	3	15	11	11	9	6	-6	-5.8	-3.8	17	1
D	25	54.89	3	5	11	9.75	2	1.25	1	1	3	11	1

Name	L	w	P_{FT_k} [kW]	$\dot{Q}_{FT\_k}$ [kW]	$\dot{Q}_{Hotgas}$ [kW]	P_{FT_w} [kW]	$P_{elAuxCtrl}$ [kW]	$\dot{Q}_o$ [kW]	P_{el} [kW]
A	100	0.3	0	0	5.913	0	0	1448	296.4
B	75	8.98	0	0	3.168	0	0	1086	173.8
C	50	35.83	0	0	1.267	0	0	724.1	87.45
D	25	54.89	0	0	0.211	0	0	362.1	26.9

TABELLE TEILERGEBNISSE

Name	COP_{oc}	COP_{ocC}	COP_{NUC}	η_{KC}	η_{WT}	η_{FT}	η_{Qo}	η_{ges}	$\dot{Q}_{iso}$ [kW]	$\dot{Q}_{oN}$ [kW]	$P_{el\ ges}$ [kW]
A	4.886	6.925	13.807	0.706	0.502	0.594	0.891	0.187	10.99	1291	499
B	6.249	8.447	18.410	0.740	0.459	0.490	0.877	0.146	8.177	952.1	355
C	8.280	11.615	34.519	0.713	0.336	0.329	0.825	0.065	5.417	597.2	266.1
D	13.459	27.415	40.911	0.491	0.670	0.119	0.687	0.027	2.641	248.6	225.9

DIAGRAMM TEILERGEBNISSE



Jahreskühllast: 3852602 kWh/a Jahreskondensationswärme: 5454417 kWh/a

Jahreselektroenergiebedarf: 2213864 kWh/a Kosten Elektroenergie: 332080 €/a

SEE(I)R: 1.740

Annual electric energy demand = 2.213.864 kWh/a
Cost of electricity (15ct/kWh) **= 332.080,- €/a**
SEE(I)R = 1,74

NH_3 – Pump System

EINGABEDATEN:

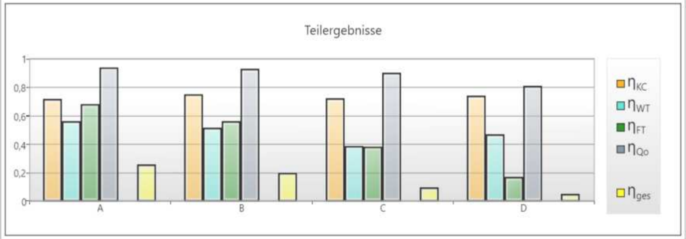
Name	L	w	t_N [°C]	t_U [°C]	t_{cmin} [°C]	$t_U{}^*$ [°C]	dt_k [K]	dt_w [K]	t_o [°C]	t_{02} [°C]	t_{V1} [°C]	t_c [°C]	t_{sc} [K]
A	100	0.3	3	35	11	23	9.5	5	-6.5	-6	-4	28	1
B	75	8.98	3	25	11	18	8	5.5	-5	-4.5	-3	23.5	1
C	50	35.83	3	15	11	11	6.2	6	-3.2	-3	-2	17	1
D	25	54.89	3	5	11	9	4.6	2	-1.6	-1.5	-1	11	1

Name	L	w	P_{FT_k} [kW]	$\dot{Q}_{FT\_k}$ [kW]	$\dot{Q}_{Hotgas}$ [kW]	P_{FT_w} [kW]	$P_{elAuxCtrl}$ [kW]	$\dot{Q}_o$ [kW]	P_{el} [kW]
A	100	0.3	0	0	4.224	0	0	1448	263
B	75	8.98	0	0	2.218	0	0	1086	154.3
C	50	35.83	0	0	0.718	0	0	724.1	75.34
D	25	54.89	0	0	0.063	0	0	362.1	22.7

TABELLE TEILERGEBNISSE

Name	COP_{oc}	COP_{ocC}	COP_{NUC}	η_{KC}	η_{WT}	η_{FT}	η_{Qo}	η_{ges}	$\dot{Q}_{iso}$ [kW]	$\dot{Q}_{oN}$ [kW]	$P_{el\ ges}$ [kW]
A	5.506	7.729	13.807	0.712	0.560	0.682	0.942	0.256	10.84	1365	385.7
B	7.040	9.409	18.410	0.748	0.511	0.557	0.929	0.198	6.065	1010	276.9
C	9.611	13.364	34.519	0.719	0.387	0.381	0.901	0.095	2.68	652.3	197.9
D	15.949	21.552	46.025	0.740	0.468	0.167	0.809	0.047	0.666	292.9	136.1

DIAGRAMM TEILERGEBNISSE



Jahreskühllast: 4285774 kWh/a Jahreskondensationswärme: 5380019 kWh/a

Jahreselektroenergiebedarf: 1503724 kWh/a Kosten Elektroenergie: 225559 €/a

SEE(I)R: 2.850

Annual electric energy demand = 1.503.724 kWh/a
Cost of electricity (15ct/kWh) **= 225.559,- €/a**
SEE(I)R = 2,85

Summary

GOOD TO KNOW

> Proven technology for 1- and 2-stage operation
> Usable efficiently and reliably in medium temperature, low temperature and freezers
> Built 11 plants in 6 years - one more at this time in commissioning
> Refrigerant content reduced by 2/3
> Optimized heat transfer at the heat exchangers
> Low-risk system technology
> Easy to maintain
> Highest energy efficiency (independently verified)
> Highest energy efficiency even with two-stage systems

Eurammon is always available as a sparring partner for questions on refrigeration with natural refrigerants.

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