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Coolselector®2
CO_2 systems & Multi Ejectors

Mark Sever
Global Application Manager, Food Retail

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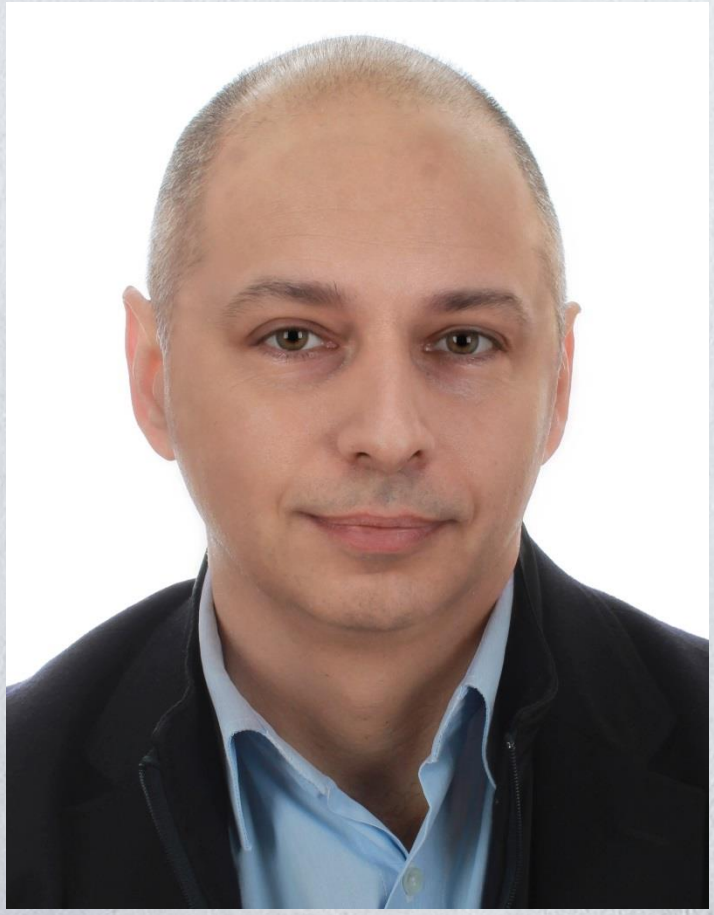
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5. Or **”Question” tab** to type your question
6. This webinar will be **recorded**
7. Webinar recording and a short survey **will be shared**

Mark Sever

Global Applications Expert , Food Retail



> **Mark Sever** joined Danfoss in 1998 covering different technical application positions within heating, refrigeration and Food Retail organization

> Supporting commissioning, educating and developing new solutions for HFC and since 2010 CO2 systems. Until 2018 covering East Europe, Russia and Middle East.
>
> Now working as a Global FR application manager with special focus on development CO2 systems.

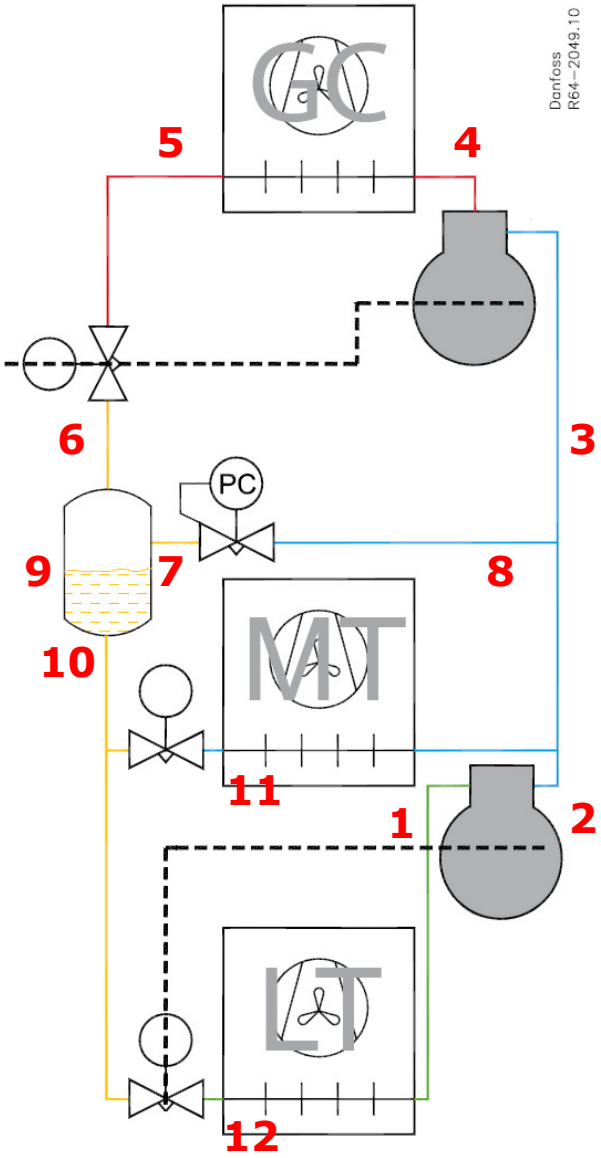
> Mark holds **a Master of Mechanical Engineering** from Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb

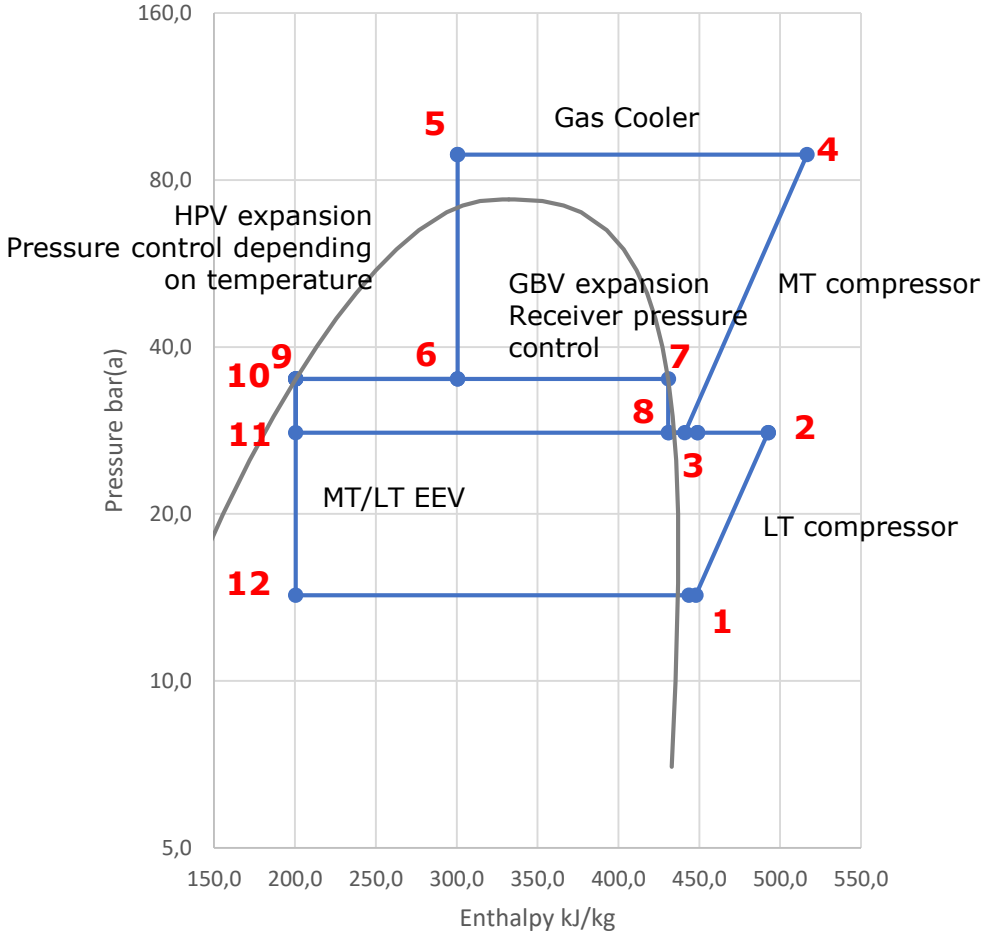
Agenda

Selection with **Coolselector®2**

- Transcritical High Pressure Valves (HPV)
- Transcritical gas bypass valves (GBV)
- Evaporators Electronic Expansion Valves (EEV)
- High Pressure lift ejectors (HP)
- Low Pressure lift ejectors (LP)
- Liquid Ejectors (LE)

CO_2 Transcritical Booster





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Multi Ejector Solution™

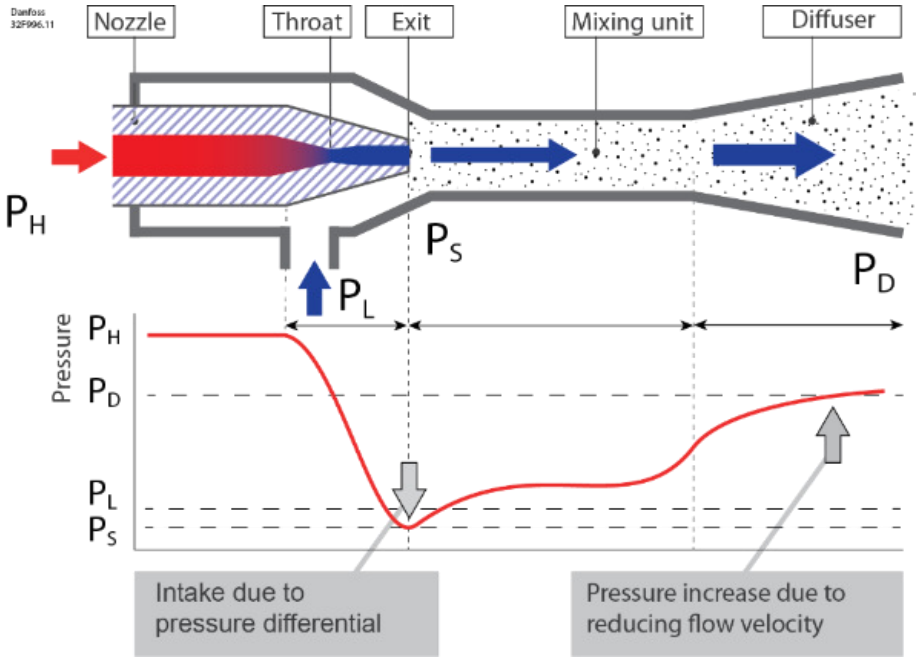
Transcritical CO_2 refrigeration systems across all climates



Technical focus how to use Coolselector®2

Working principal of the Multi Ejector

1. CO2 leaves the gas cooler. The high pressure CO2 (PH) enters the motive nozzle where the expansion takes place.
2. At the nozzle exit, the speed is very high which results in low pressure. The low pressure then drags in gas from the MT suction (PL).
3. From there, the two units are mixed in the mixing unit where the pressure is higher than at the outlet due to the mixing of gas from a higher pressure.
4. After the mix, the flow enters the diffuser and the flow slows down. The shape of the diffuser enables the conversion from kinetic energy (velocity) to potential energy (pressure). After the diffuser, the flow returns to the receiver.



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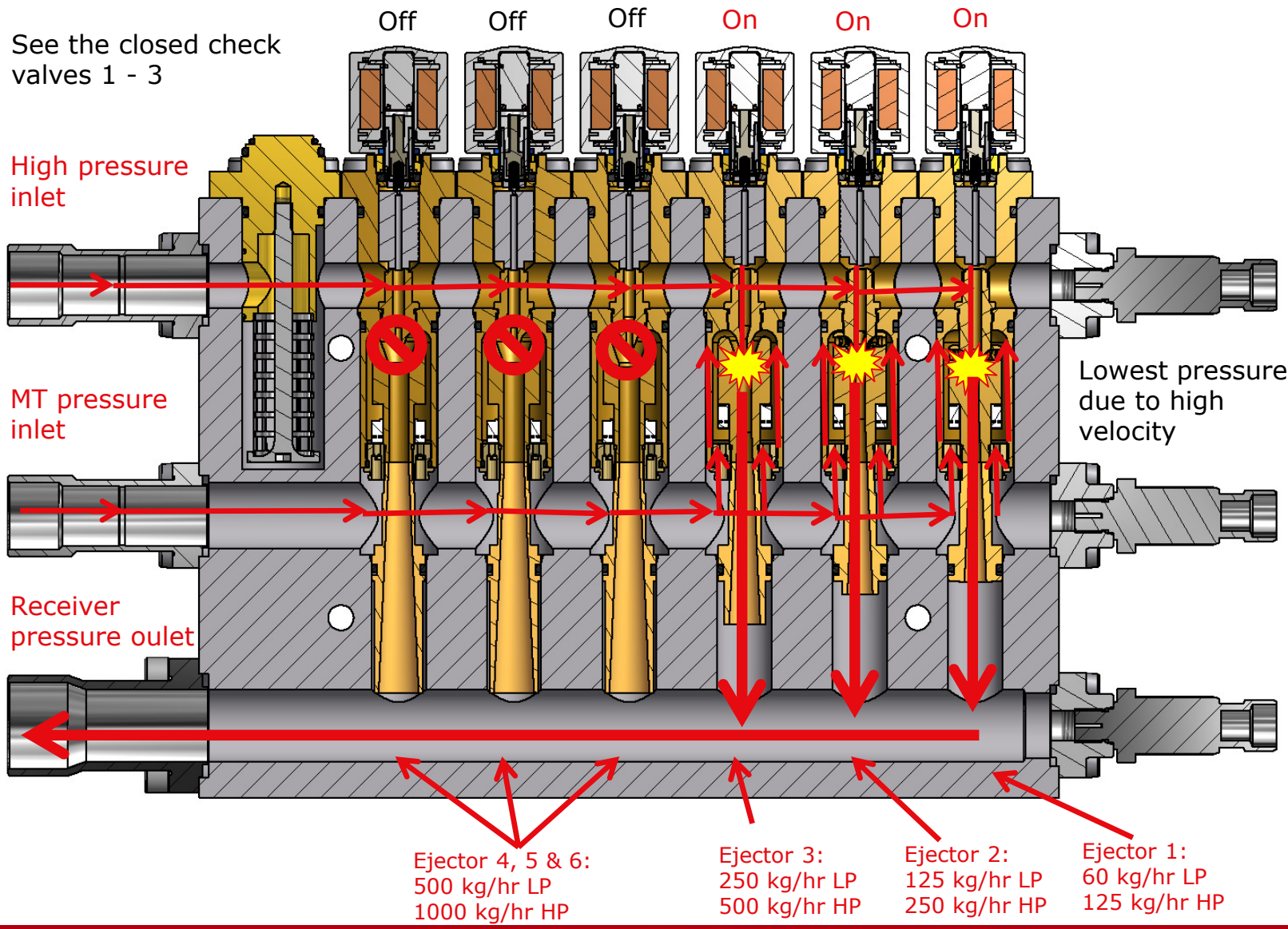
Ejector terms: Entrainment ratio

- Entrainment ratio is the ratio between the suction mass flow of the ejector and the high pressure flow in the nozzle (motive flow) of the ejector.

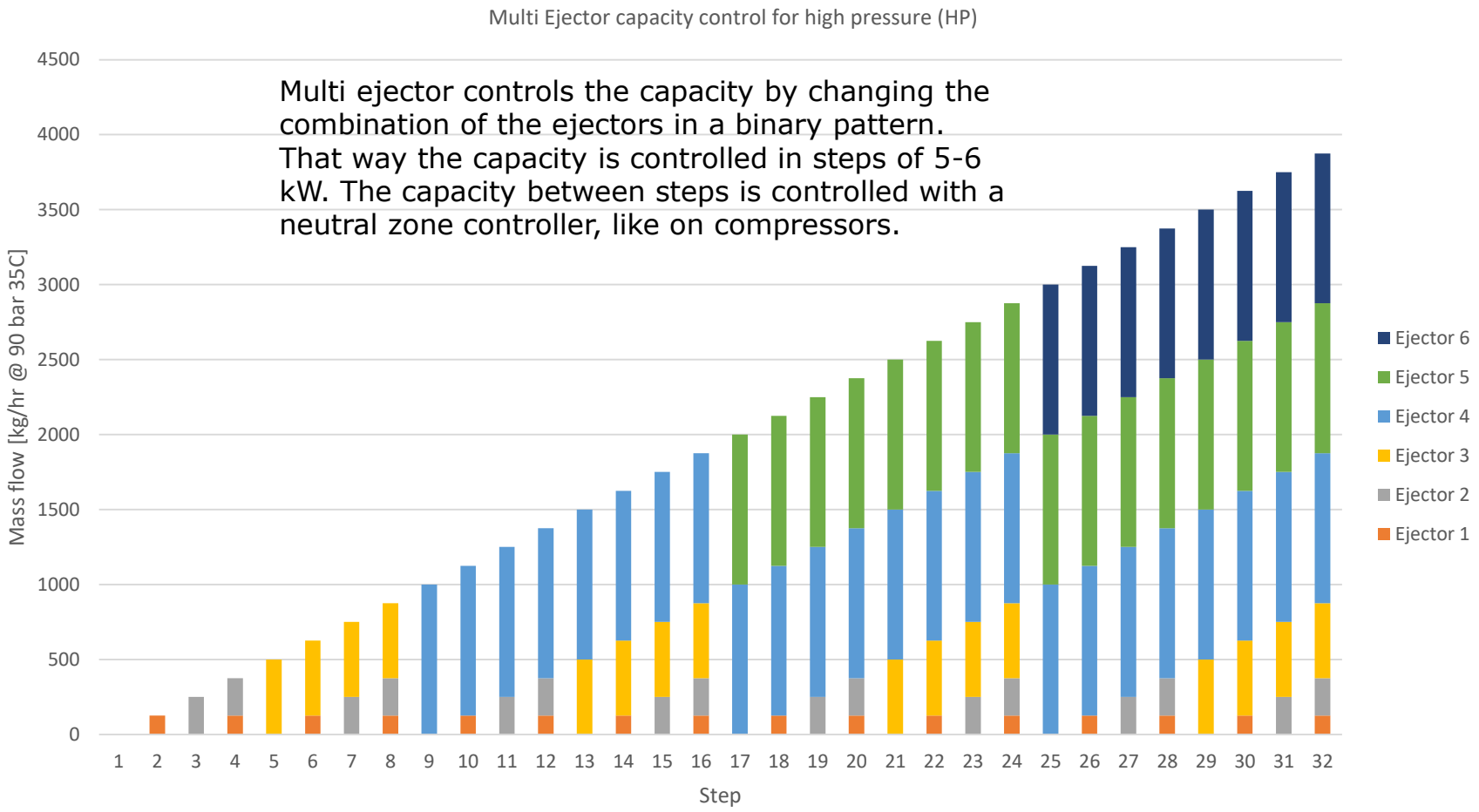
$$\Phi_m = \frac{\dot{m}_{suction}}{\dot{m}_{motive}} = \text{er}$$

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How does the **Multi Ejector work?**



How to control the Multi Ejector



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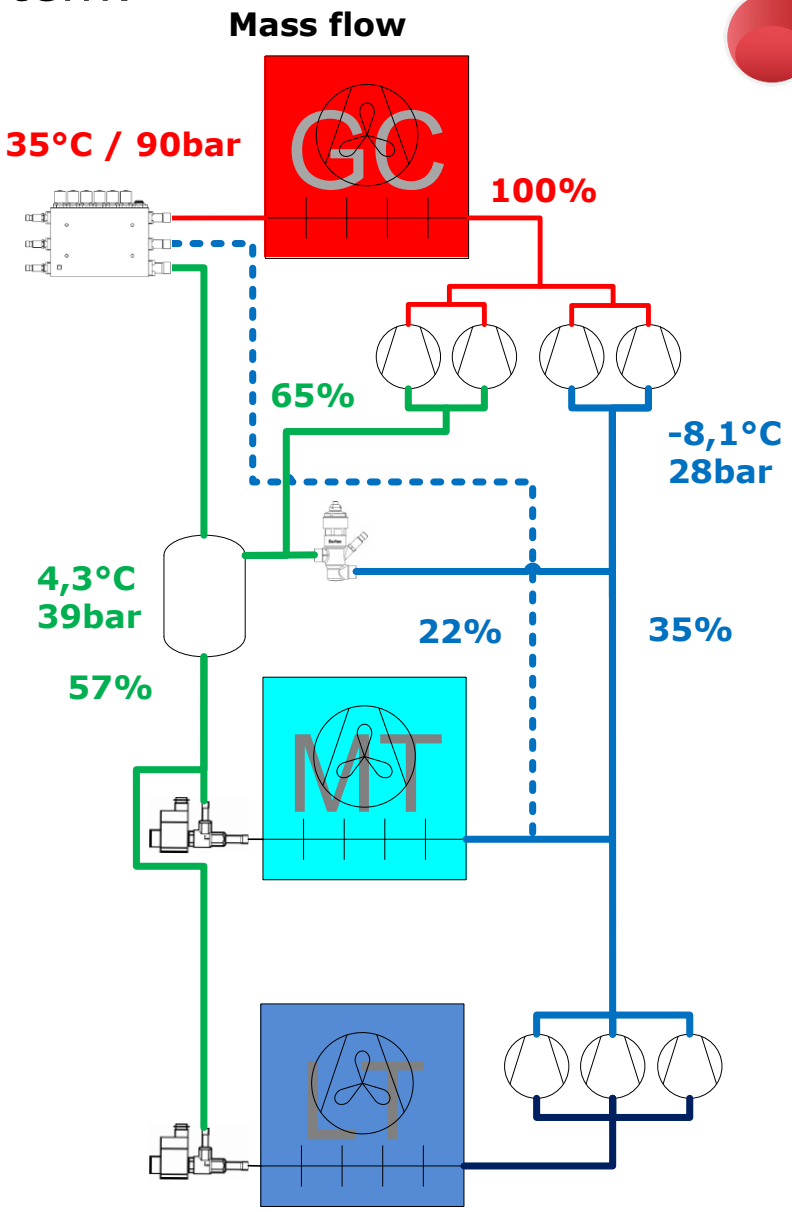
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The Multi Ejector Solution™

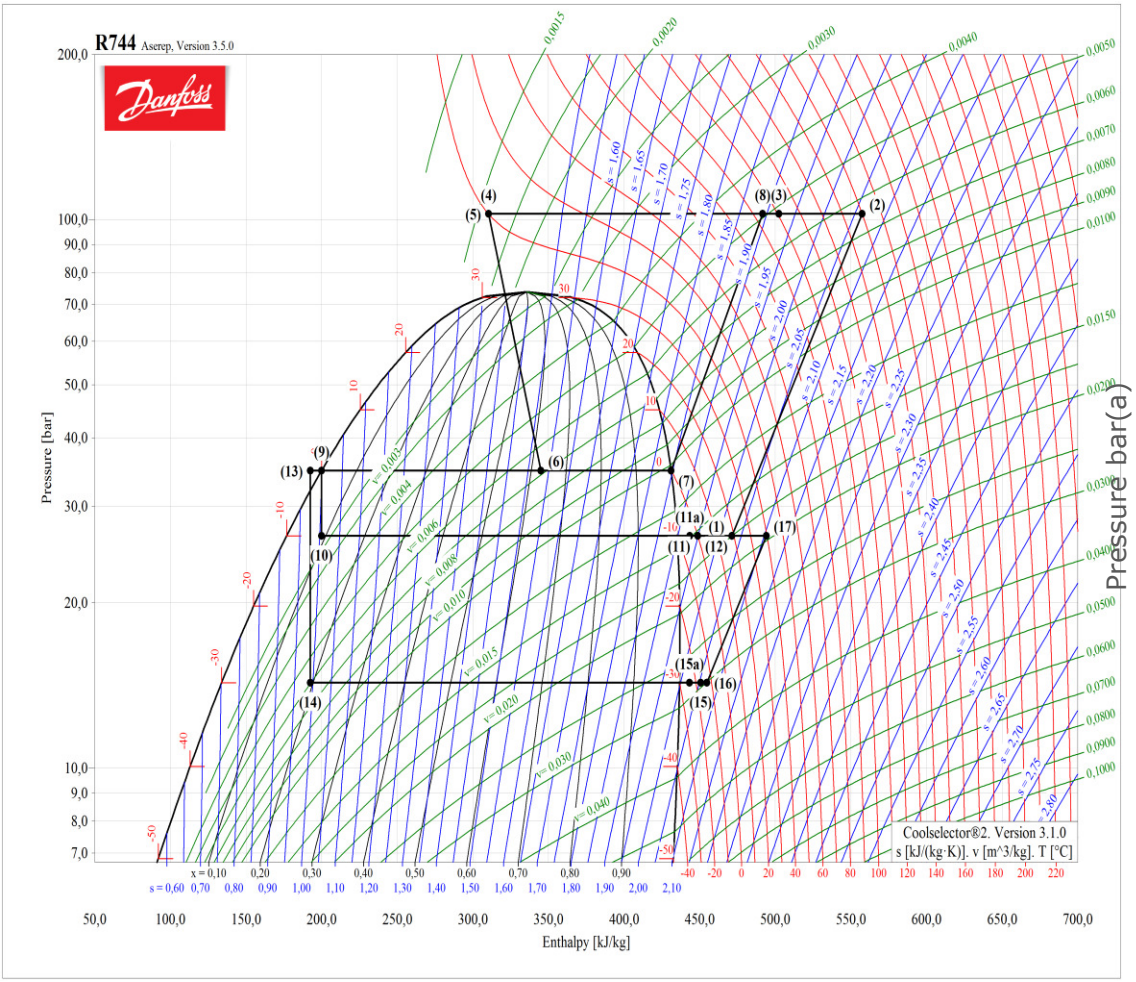
High pressure lift application

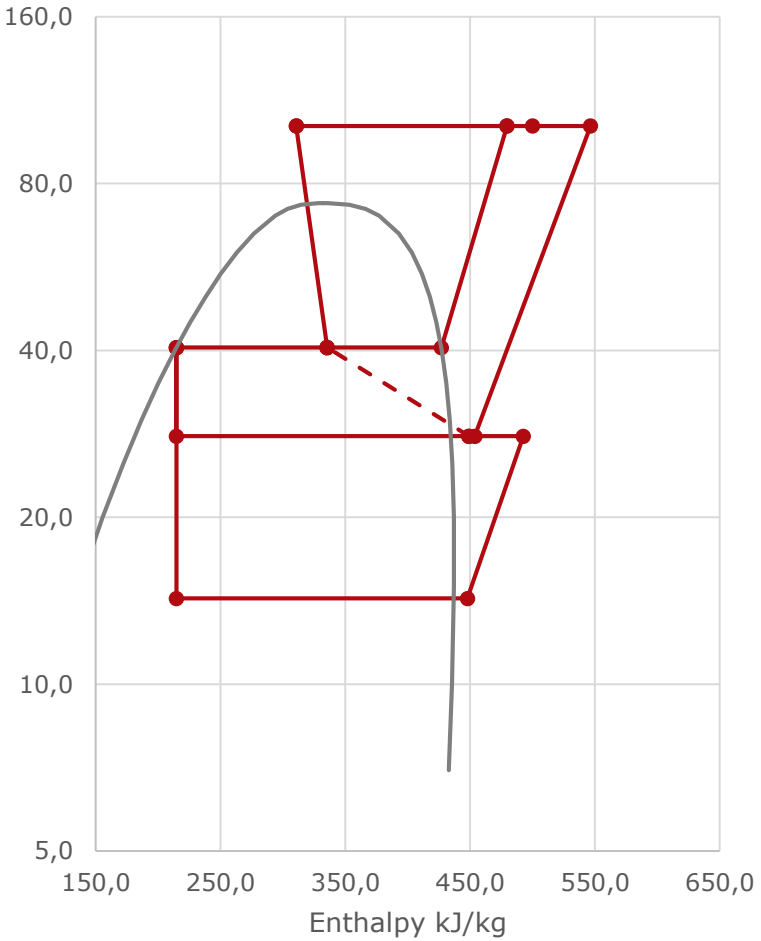
Cycle explanation HP ejector system: warm temperature mode

- When the temperature out of gas cooler is warmer the ejector starts to pump.
- The gas from MT is pumped through the ejector and is lifted to the receiver where it is separated with the gas from the expansion.
- The liquid flows to the evaporators and the gas is moved to the parallel compressors where it is compressed.



HP ejector
Logp-h diagram

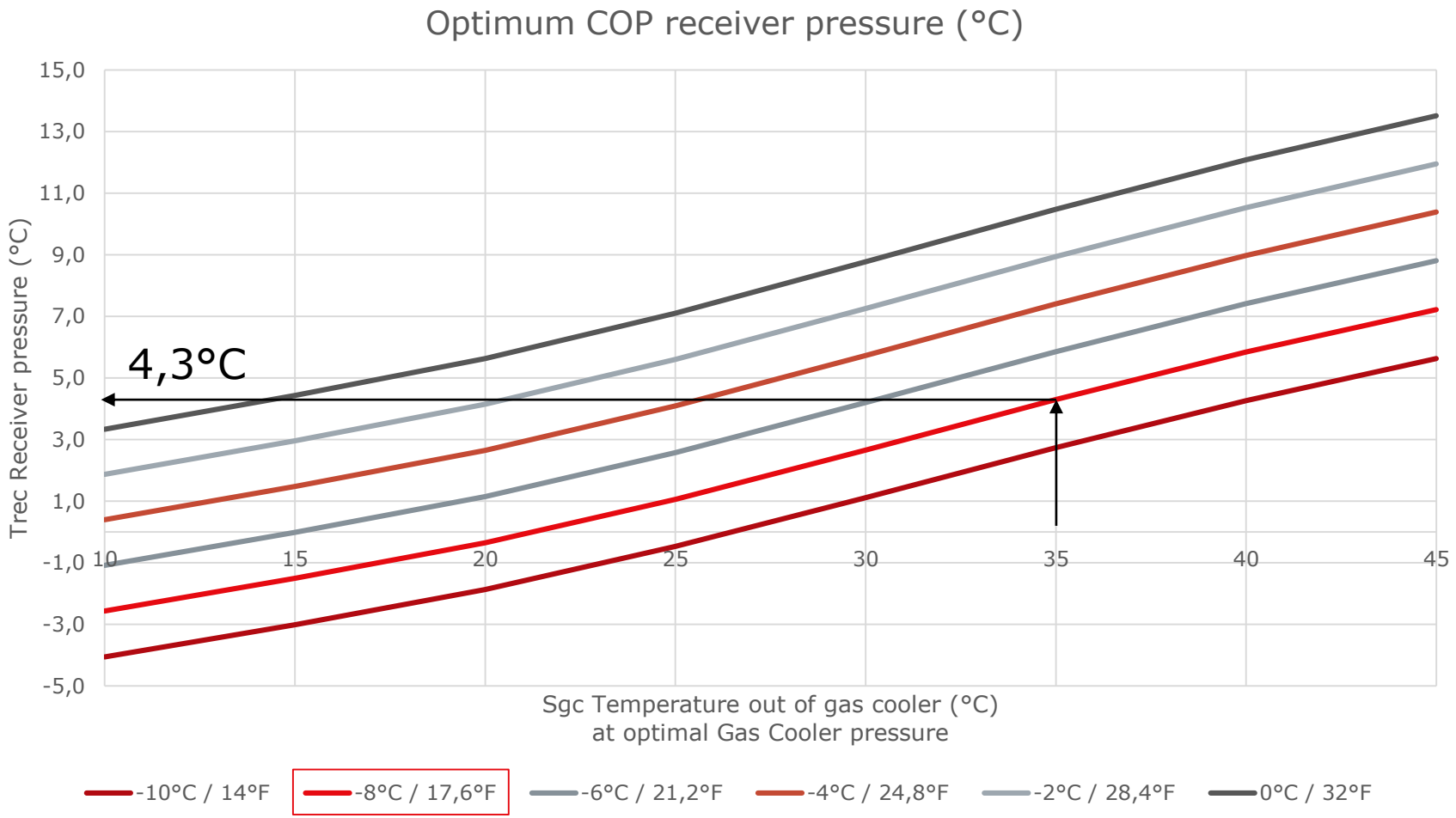




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Optimum COP receiver pressure (°C) vs Sgc

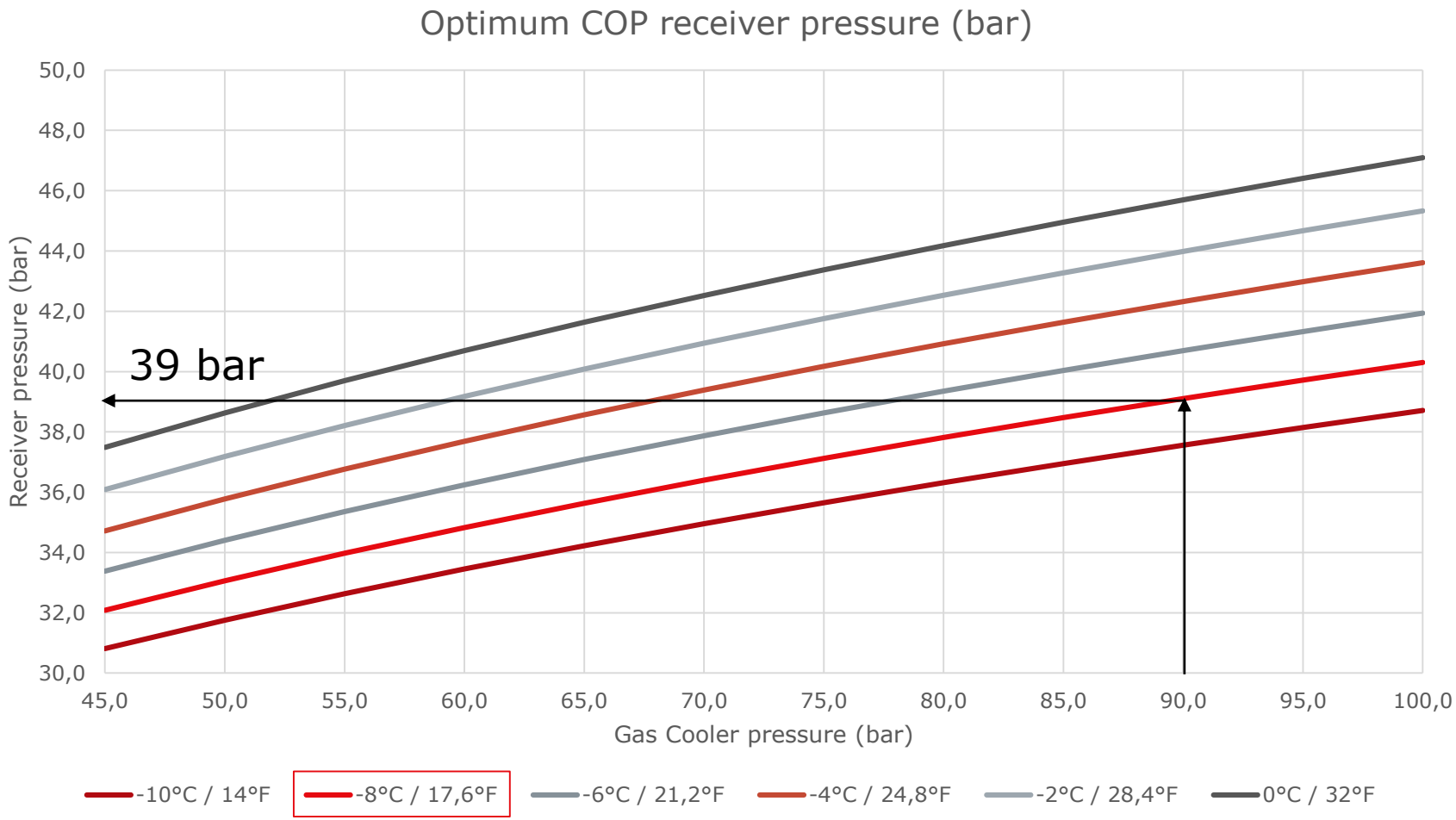
Systems with IT compressors



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Optimum COP receiver pressure (bar) vs Pgc

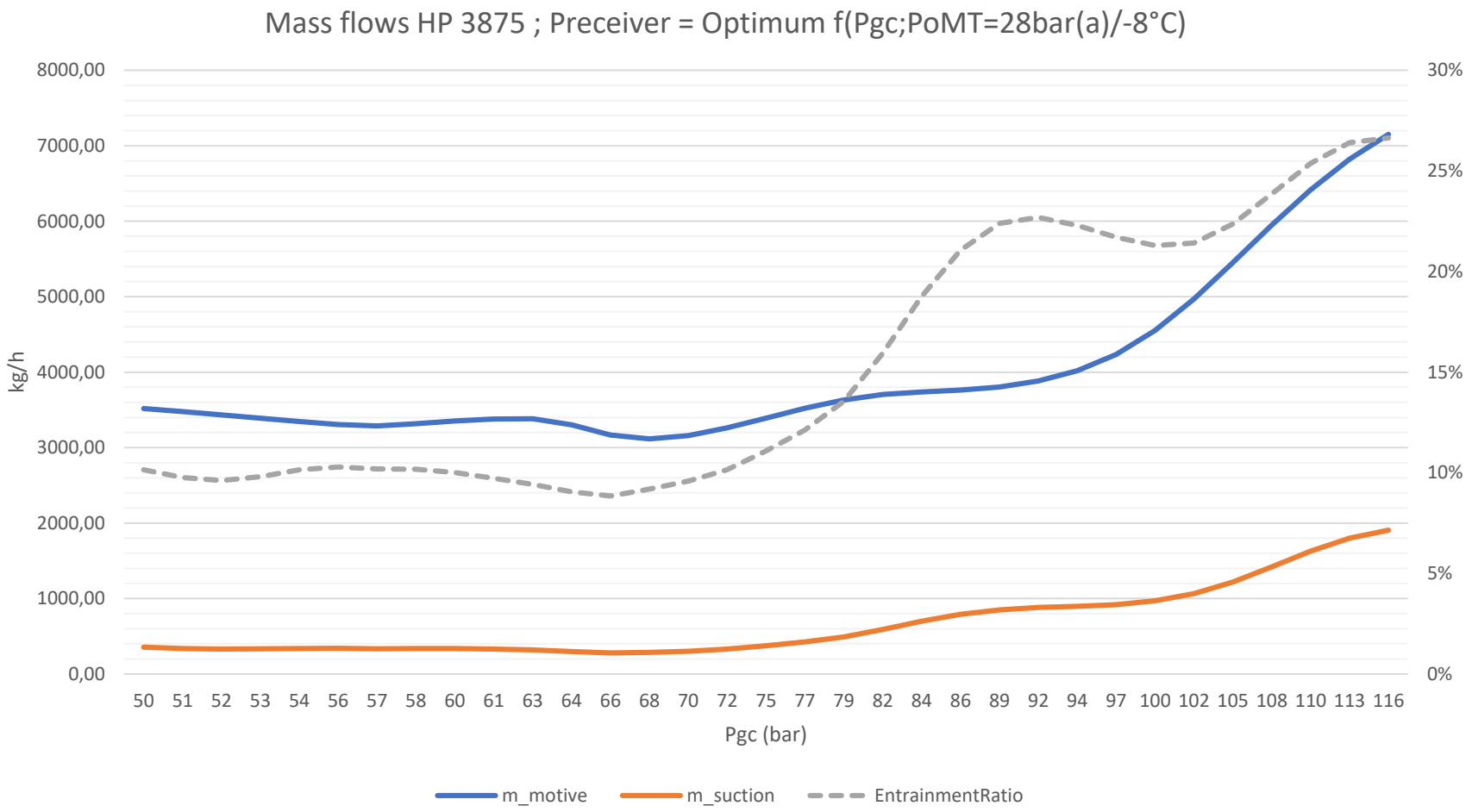
Systems with IT compressors



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Mass flows HP 3875

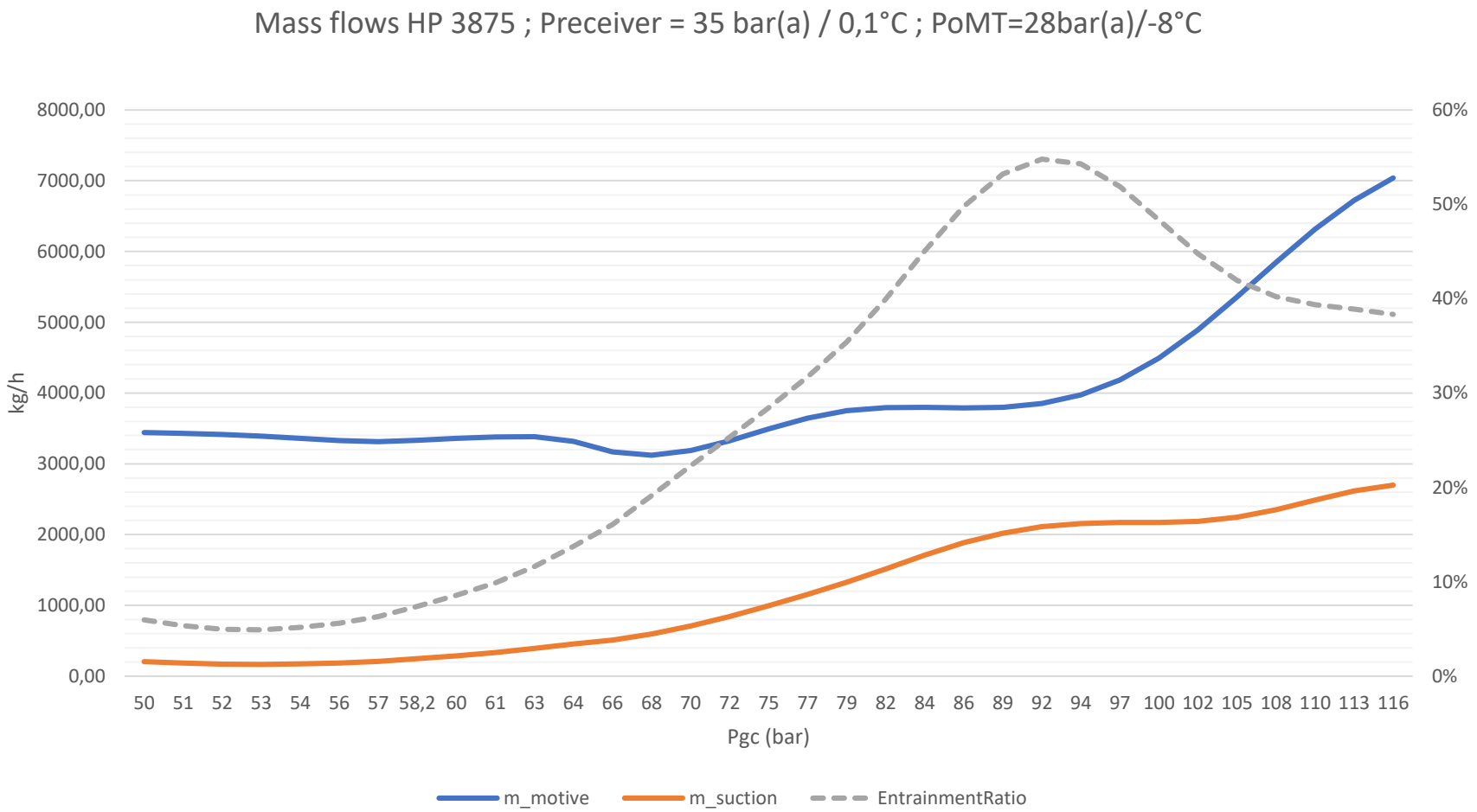
Preceiver = Optimum f(Pgc; PoMT=28bar(a)/-8°C)



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Mass flows HP 3875

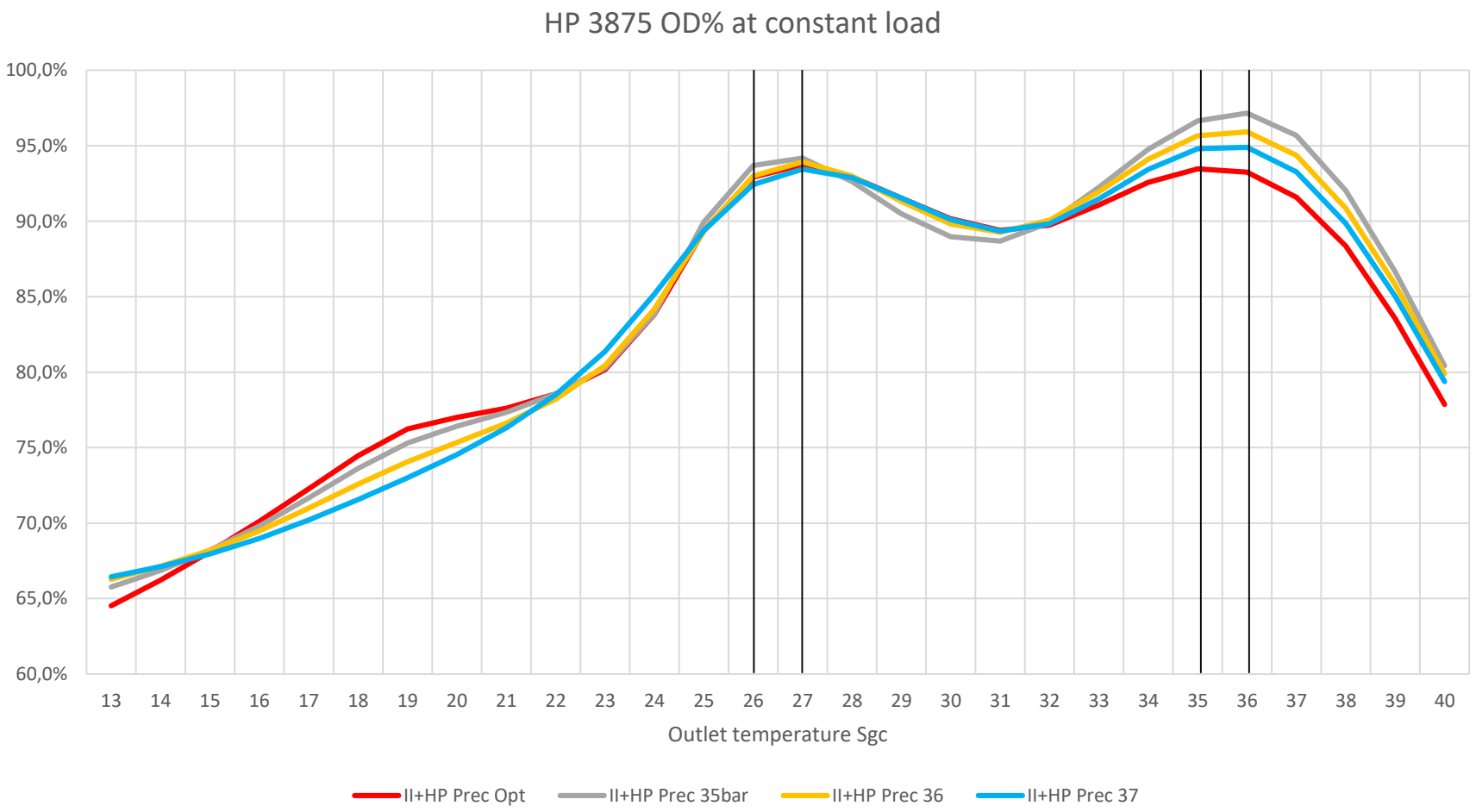
P receiver = 35 bar(a) / 0,2°C ; PoMT=28bar(a)/-8°C



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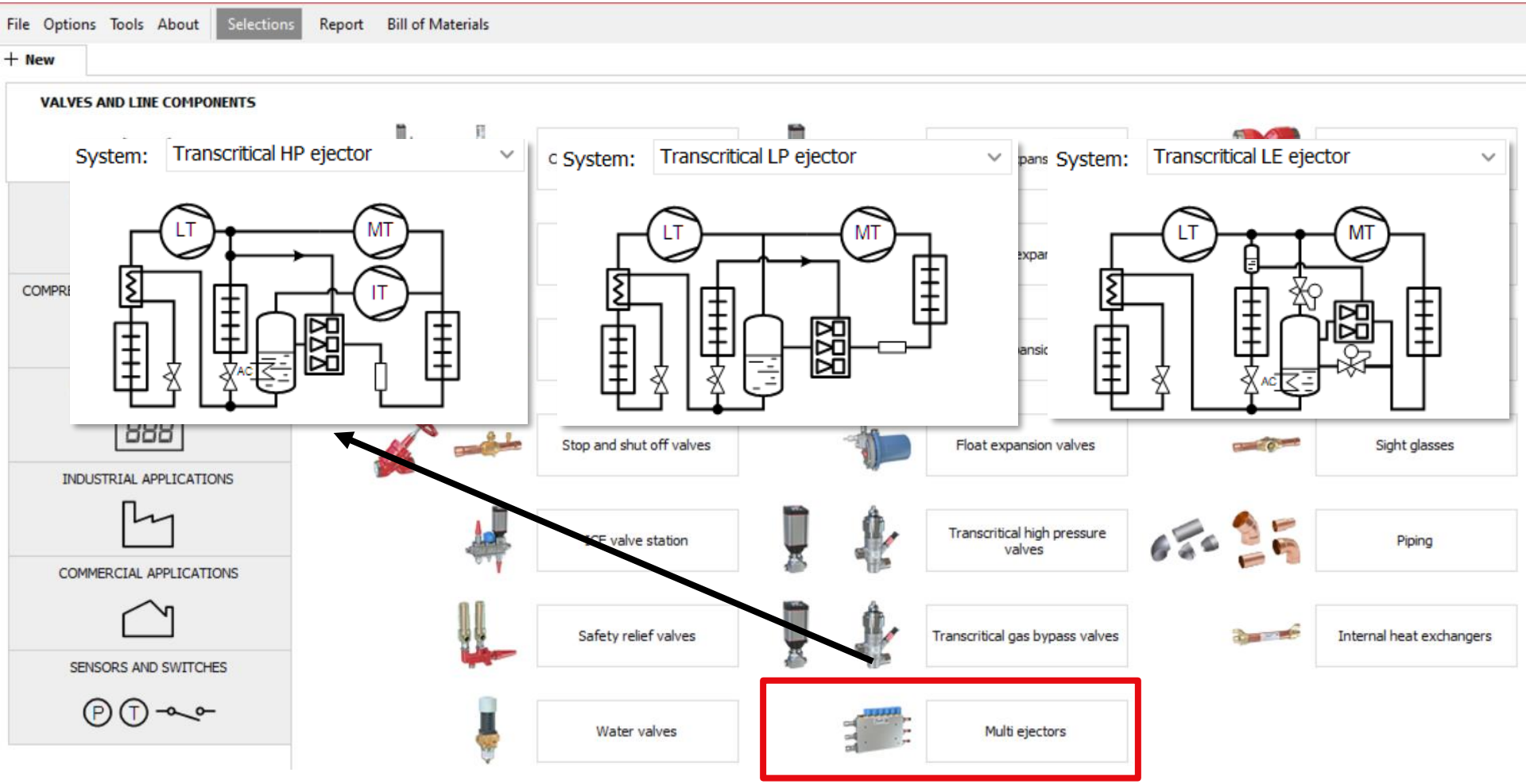
HP 3875 Capacity / OD%

MT load 130kW / PoMT=28bar(a)/-8°C

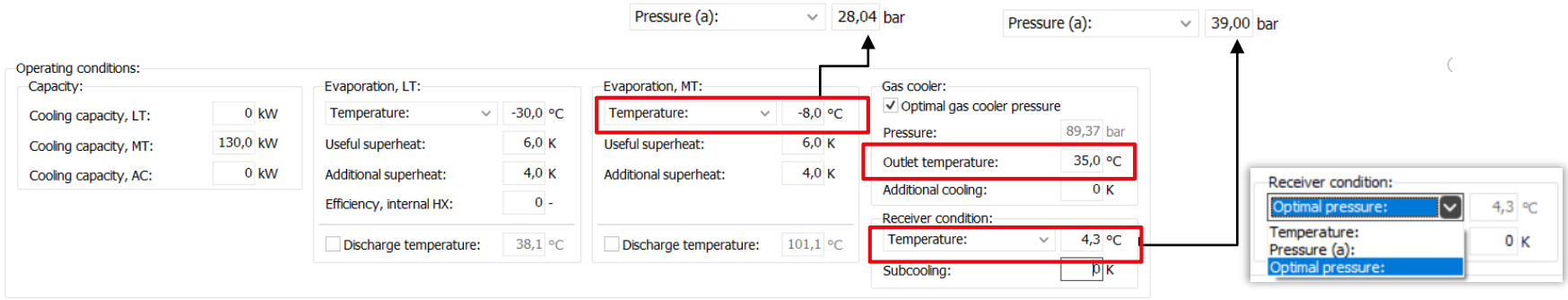


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Multi ejectors

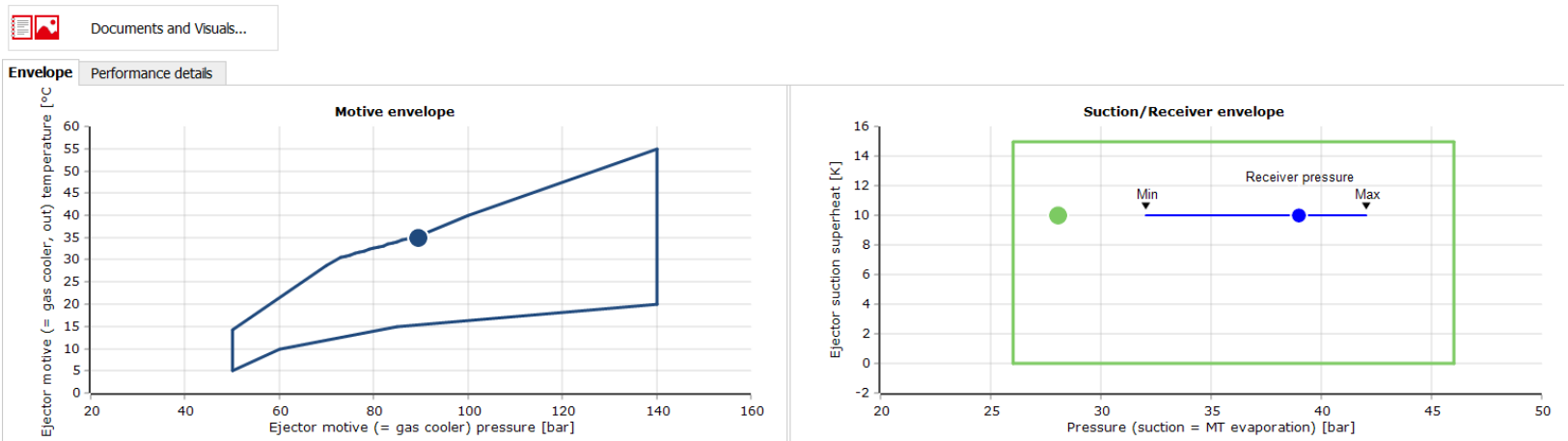


HP ejector selection example



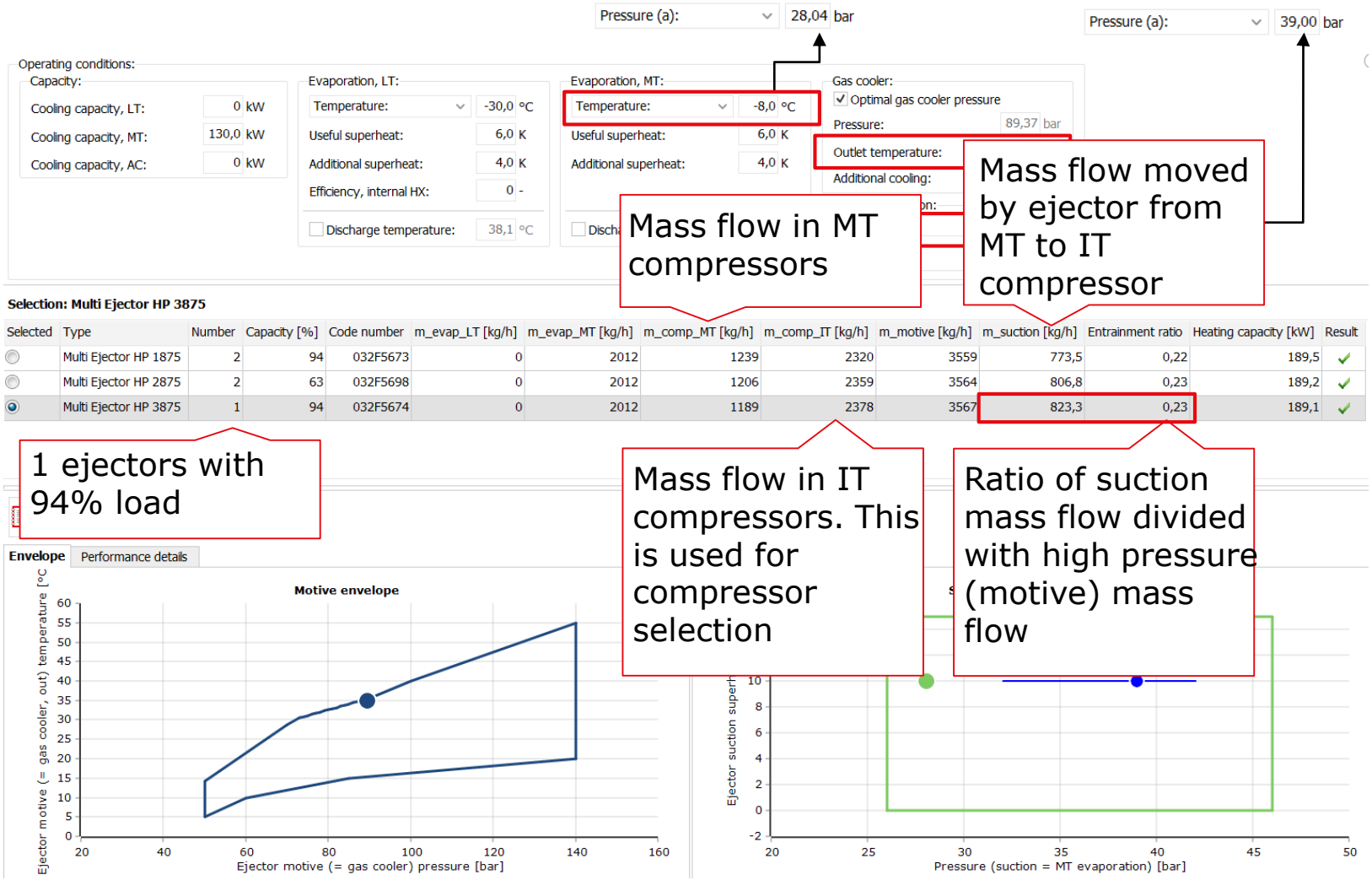
Selection: Multi Ejector HP 3875

Selected	Type	Number	Capacity [%]	Code number	m_evap_LT [kg/h]	m_evap_MT [kg/h]	m_comp_MT [kg/h]	m_comp_IT [kg/h]	m_motive [kg/h]	m_suction [kg/h]	Entrainment ratio	Heating capacity [kW]	Result
○	Multi Ejector HP 1875	2	94	032F5673	0	2012	1239	2320	3559	773,5	0,22	189,5	✓
○	Multi Ejector HP 2875	2	63	032F5698	0	2012	1206	2359	3564	806,8	0,23	189,2	✓
◉	Multi Ejector HP 3875	1	94	032F5674	0	2012	1189	2378	3567	823,3	0,23	189,1	✓



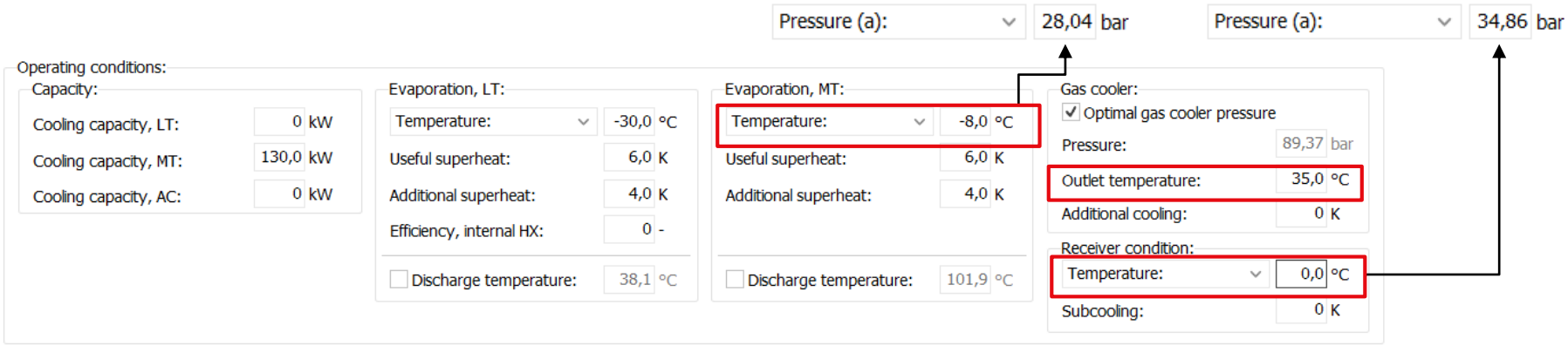
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HP ejector selection example



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HP ejector selection example



Selection: Multi Ejector HP 3875. Ejector suction mass flow limited to LT + MT evaporator mass flow

Selected	Type	Number	Capacity [%]	Code number	m_evap_LT [kg/h]	m_evap_MT [kg/h]	m_comp_MT [kg/h]	m_comp_IT [kg/h]	m_motive [kg/h]	m_suction [kg/h]	Entrainment ratio
○	Multi Ejector HP 1875	2	97	032F5673	0	1925	66,45	3596	3663	1859	0,51
○	Multi Ejector HP 2875	2	65	032F5698	0	1925	0	3720	3720	1925	0,54
◉	Multi Ejector HP 3875	1	100	032F5674	0	1925	0	3782	3782	1925	0,55

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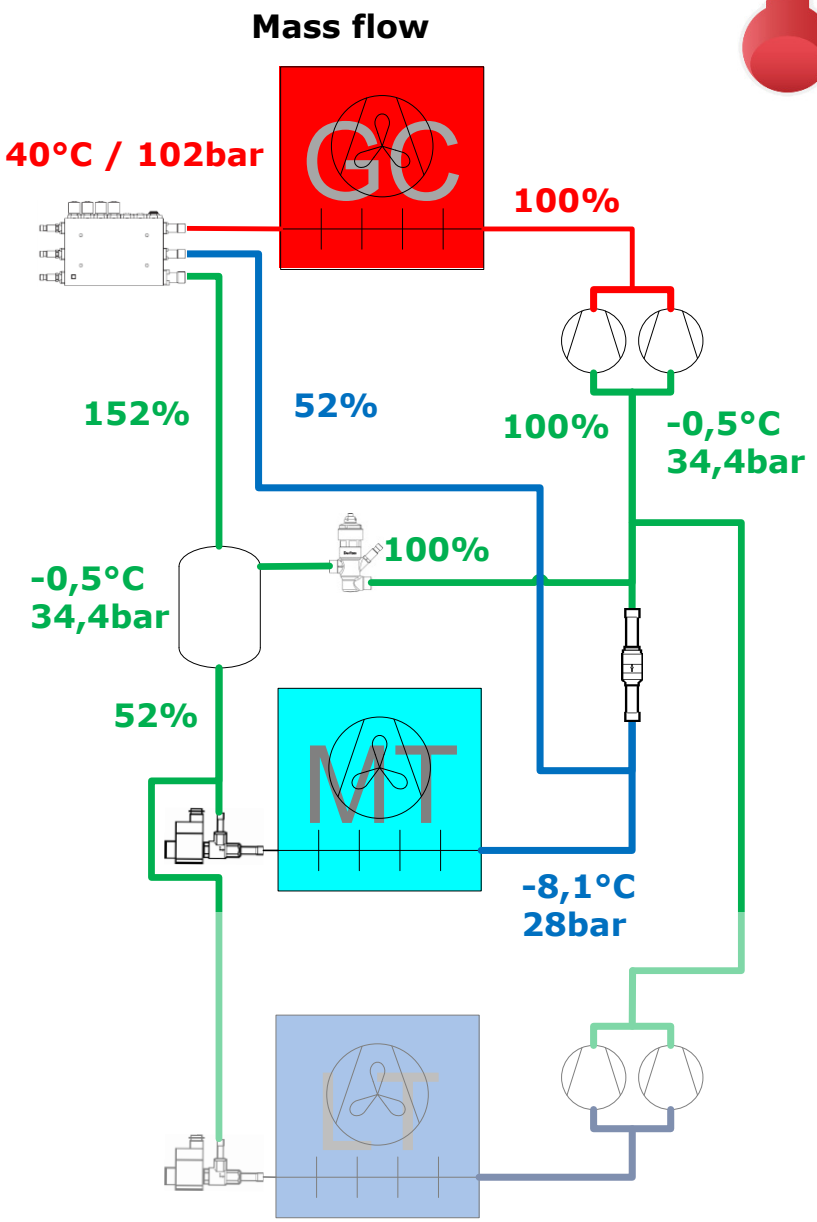
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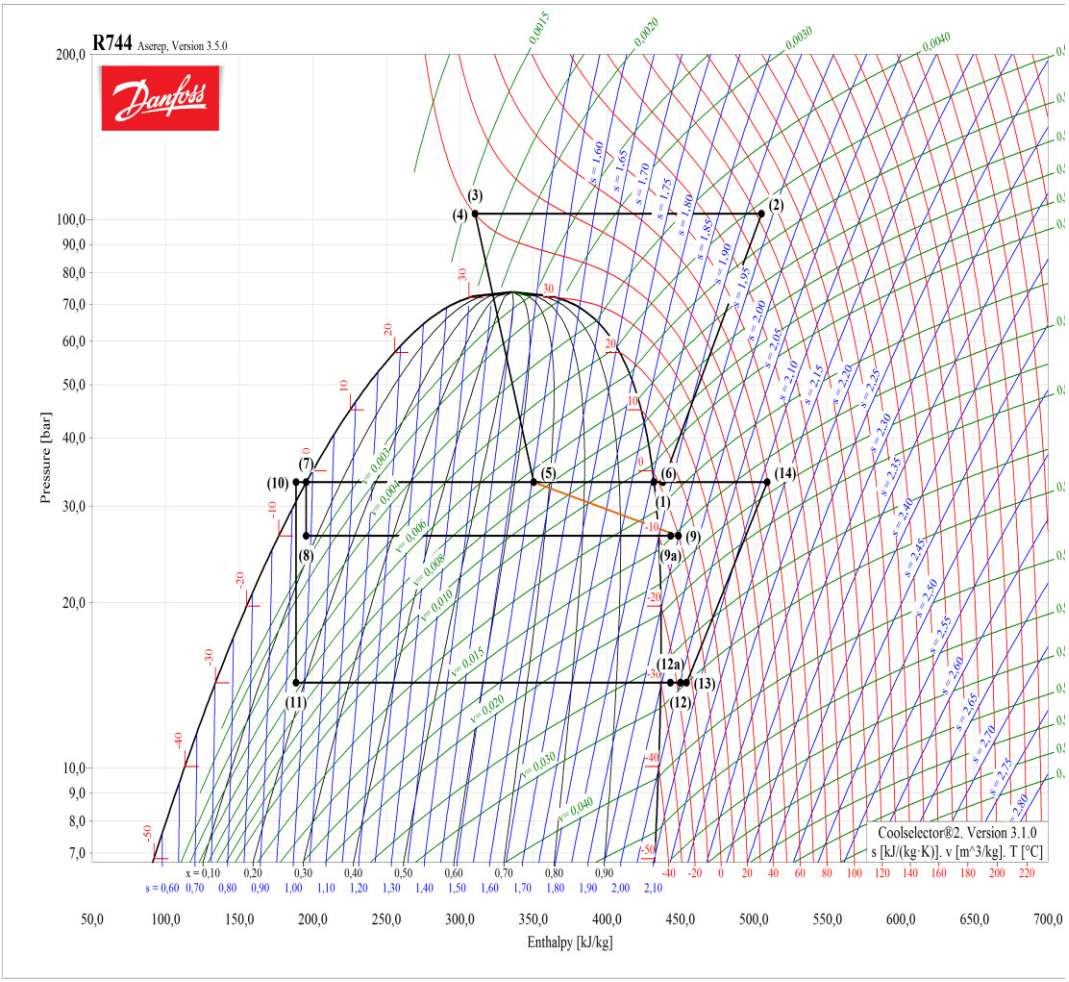
Low pressure lift application

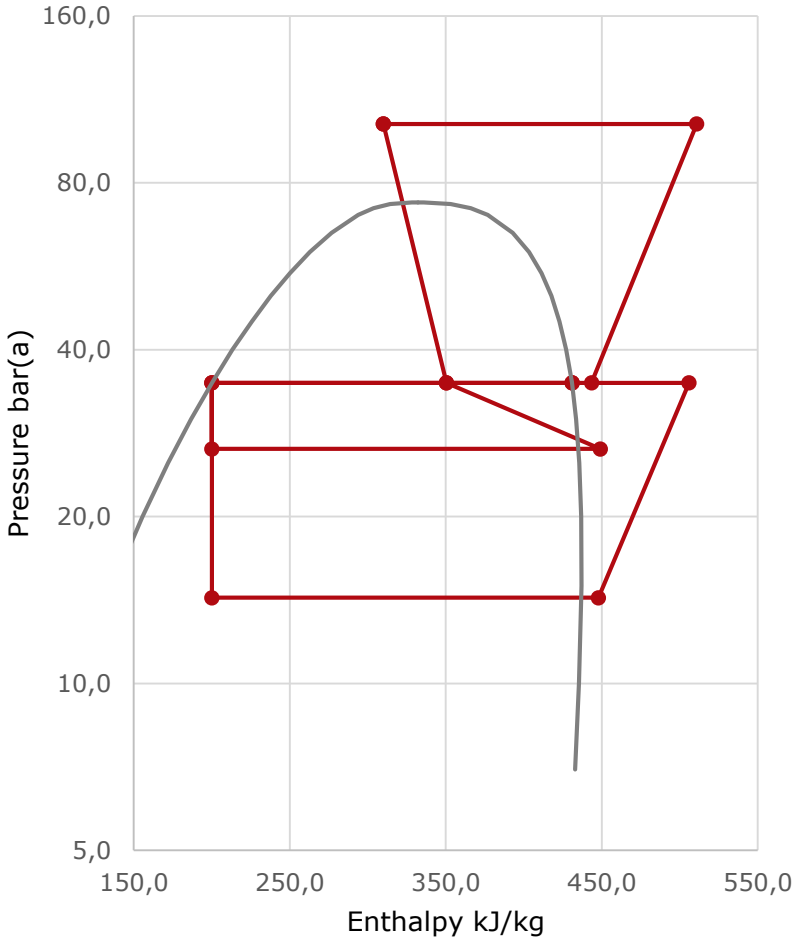
Cycle explanation LP ejector system: warm temperature mode

- In warm temperature mode the temperature out of the gas cooler is so high that the ejector is capable of lifting all the gas from evaporators through the ejector and to the receiver (check valve in suction line between compressors and evaporators is closed due to pressure difference).
- Inside the ejector the gas from the evaporators is mixed with the gas/liquid flow from the gas cooler and flows to the receiver.
- In the receiver the gas and liquid is separated and the liquid is expanded in the evaporators and the gas flows through the gas by pass valve, which is fully open and has a very low pressure difference.
- The compressors is sucking the gas directly from the receiver and compressing to the high pressure. The flow is then cooled in the gas cooler and expanded in the ejector.



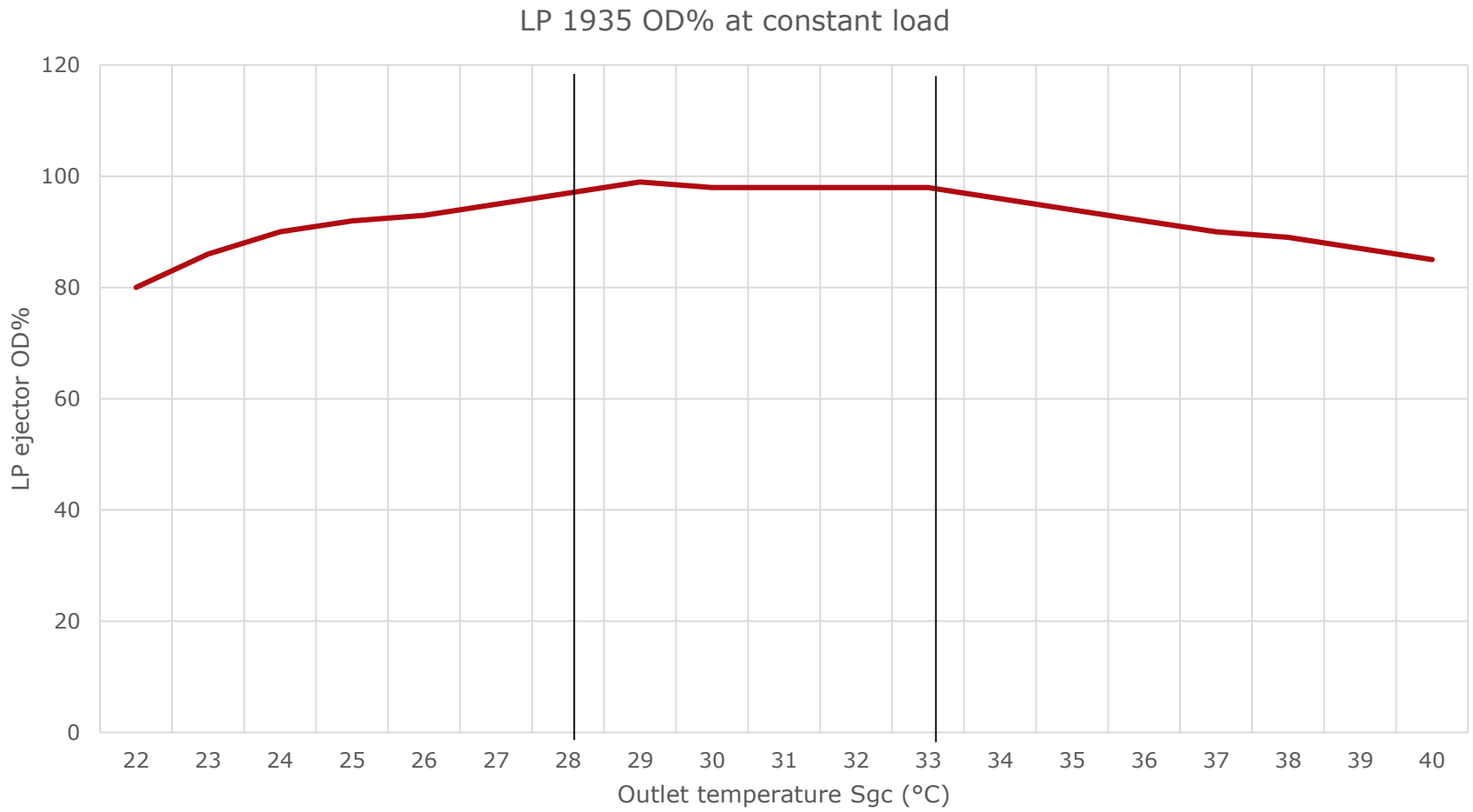
LP ejector
Logp-h diagram





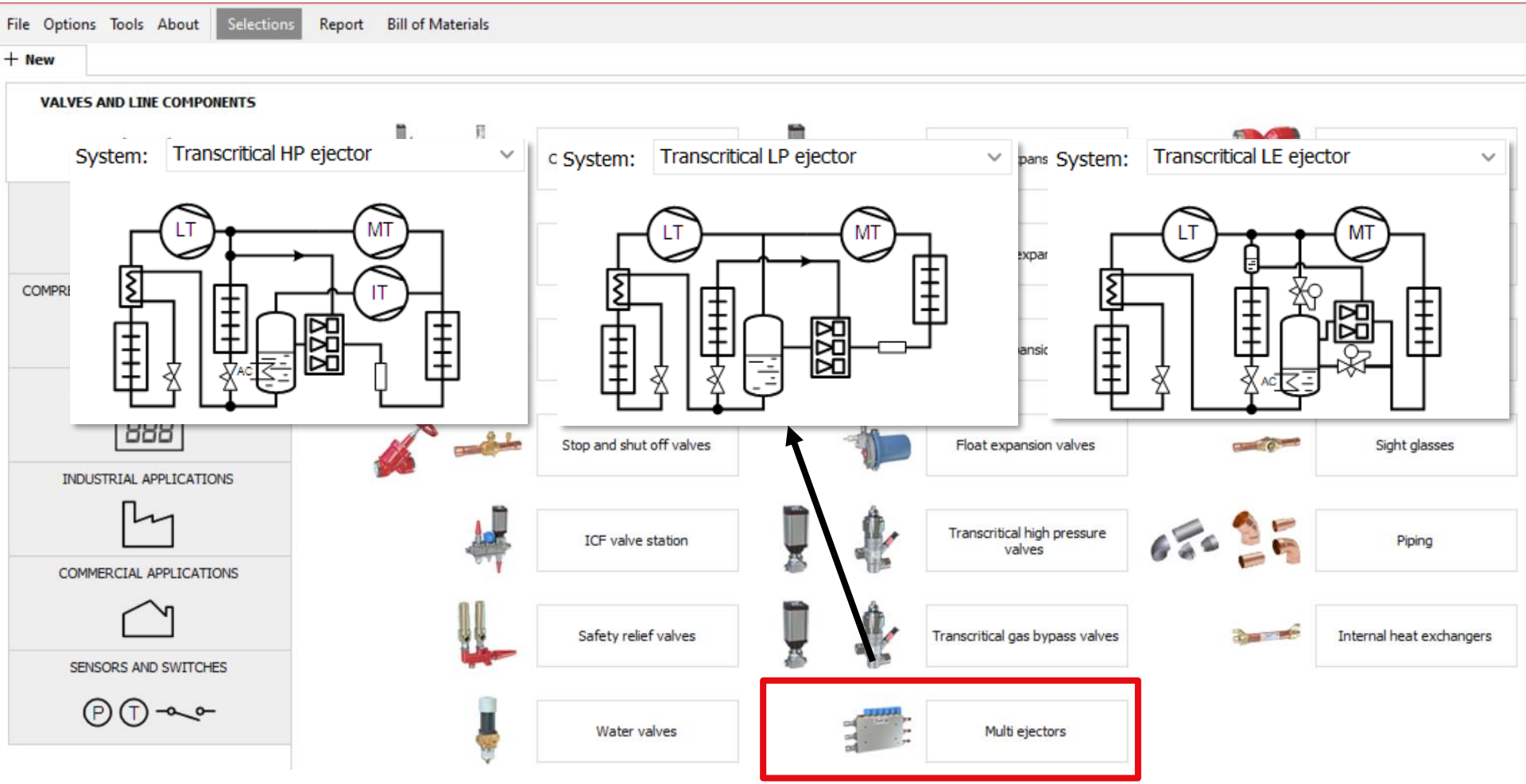
LP 1935 Capacity / OD%

MT load 60kW / PoMT=28bar(a)/-8°C



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Multi ejectors



LP ejector selection example

Prec-Po = 3,9 bar

Pressure (a): 28,04 bar

Operating conditions:

Capacity:
- Cooling capacity, LT: 0 kW
- Cooling capacity, MT: 60,00 kW

Evaporation, LT:
- Temperature: -30,0 °C
- Useful superheat: 6,0 K
- Additional superheat: 4,0 K
- Efficiency, internal HX: 0 -
- Discharge temperature: 38,1 °C

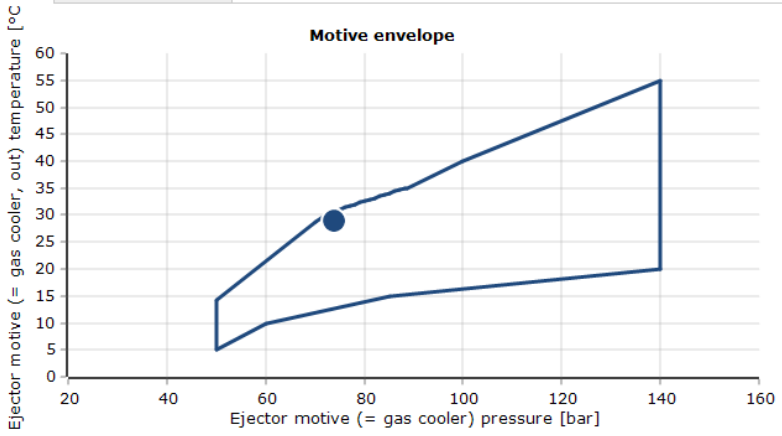
Evaporation, MT:
- Temperature: -8,0 °C
- Useful superheat: 6,0 K
- Additional superheat: 4,0 K
- Discharge temperature: 83,9 °C

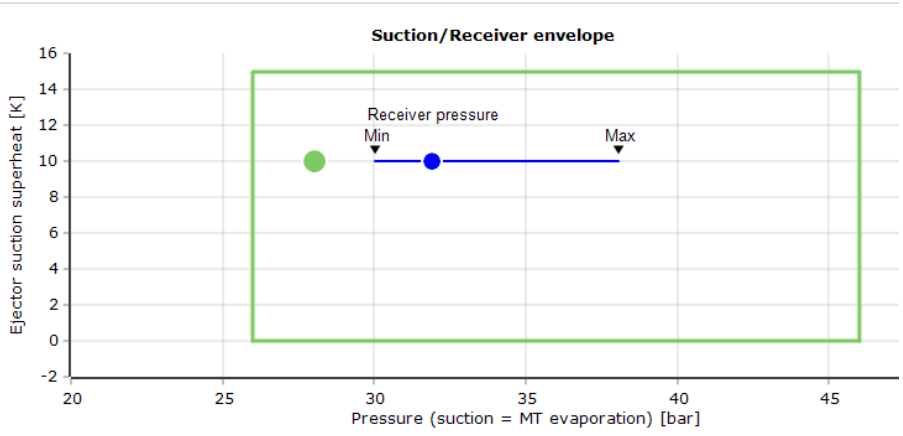
Gas cooler:
- Optimal gas cooler pressure
- Pressure: 73,77 bar
- Outlet temperature: 29,0 °C
- Additional cooling: 0 K

Receiver condition:
- Subcooling: 0 K

Selection: Multi Ejector LP 1935

Selected	Type	Number	Capacity [%]	Code number	m_evap_LT [kg/h]	m_evap_MT [kg/h]	m_BP [kg/h]	m_comp_MT [kg/h]	Entrainment ratio	P_receiver [bar]	T_receiver [°C]
○	Multi Ejector LP 935	2	100	032F5678	0	861,3	1515	1515	0,57	31,97	-3,2
◉	Multi Ejector LP 1935	1	99	032F5679	0	860,6	1515	1515	0,57	31,89	-3,3





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LP ejector selection example

Prec-Po = 3,9 bar

Pressure (a): 28,04 bar

Operating conditions:

Capacity:
- Cooling capacity, LT: 0 kW
- Cooling capacity, MT: 60,00 kW

Evaporation, LT:
- Temperature: -30,0 °C
- Useful superheat: 6,0 K
- Additional superheat: 4,0 K
- Efficiency, internal HX: 0 -
- Discharge temperature: 38,1 °C

Evaporation, MT:
- Temperature: -8,0 °C
- Useful superheat: 6,0 K
- Additional superheat: 4,0 K
- Discharge tempera

Gas cooler:
- Optimal gas cool
- Pressure:
- Outlet temperature:
- Additional cooling:
- Receiver condition:

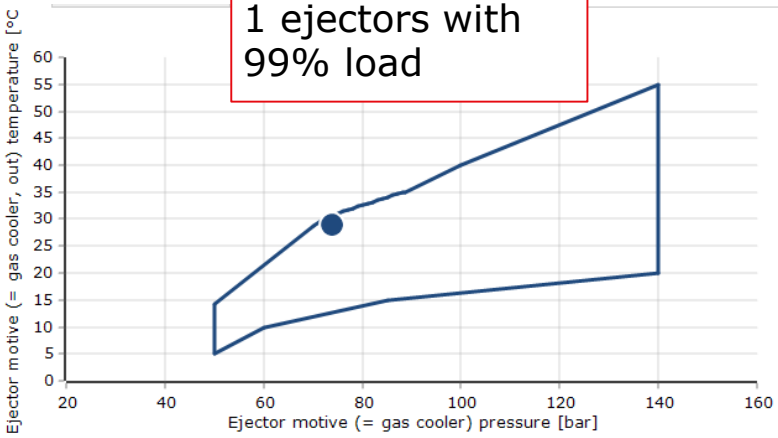
Receiver pressure. The suction pressure of the MT compressors is in this case lifted 4,7K

Mass flow in MT compressors

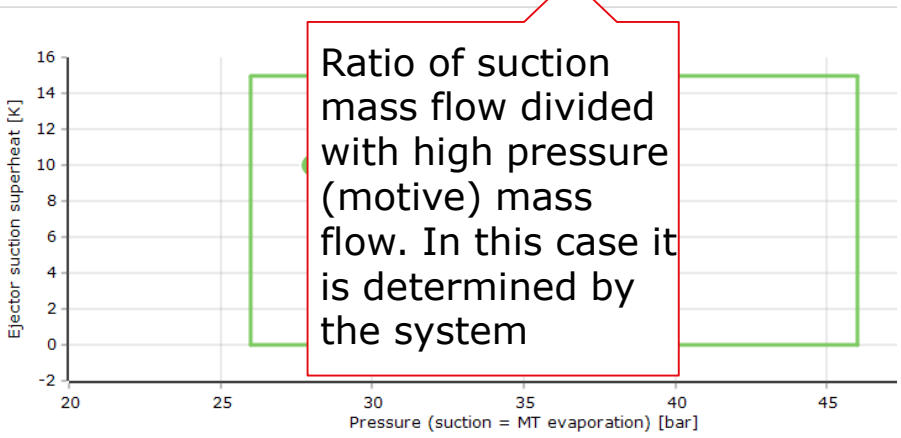
Selection: Multi Ejector LP 1935

Selected	Type	Number	Capacity [%]	Code number	m_evap_LT [kg/h]	m_evap_MT [kg/h]	m_BP [kg/h]	m_comp_MT [kg/h]	Entrainment ratio	P_receiver [bar]	T_receiver [°C]
○	Multi Ejector LP 935	2	100	032F5678	0	861,3	1515	1515	0,57	31,97	-3,2
◉	Multi Ejector LP 1935	1	99	032F5679	0	860,6	1515	1515	0,57	31,89	-3,3

1 ejectors with 99% load

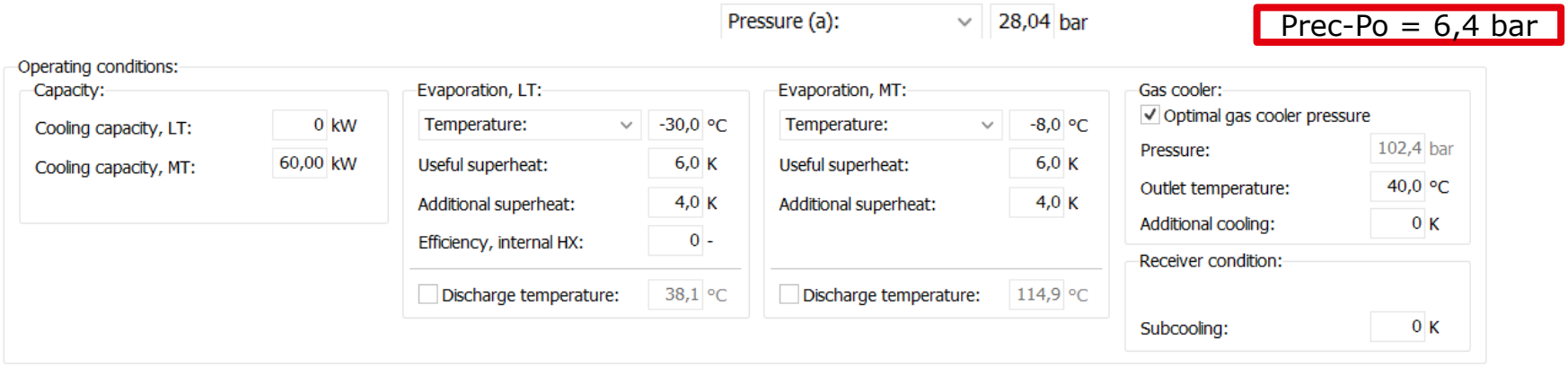


Ratio of suction mass flow divided with high pressure (motive) mass flow. In this case it is determined by the system



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LP ejector selection example



Selection: Multi Ejector LP 1935

Selected	Type	Number	Capacity [%]	Code number	m_evap_LT [kg/h]	m_evap_MT [kg/h]	m_BP [kg/h]	m_comp_MT [kg/h]	Entrainment ratio	P_receiver [bar]	T_receiver [°C]
○	Multi Ejector LP 935	2	86	032F5678	0	884,2	1825	1825	0,48	34,42	-0,5
◉	Multi Ejector LP 1935	1	85	032F5679	0	883,8	1824	1824	0,48	34,37	-0,5

Receiver pressure. The suction pressure of the MT compressors is in this case lifted 7,5K

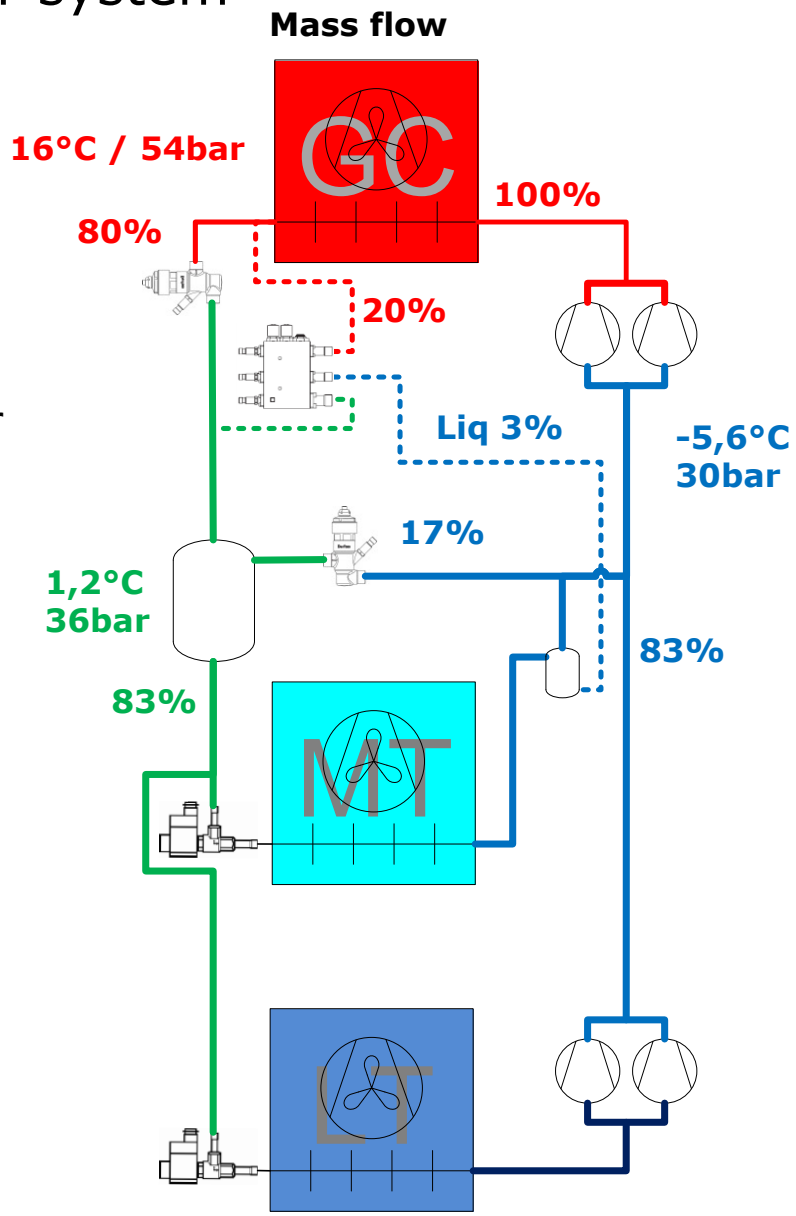
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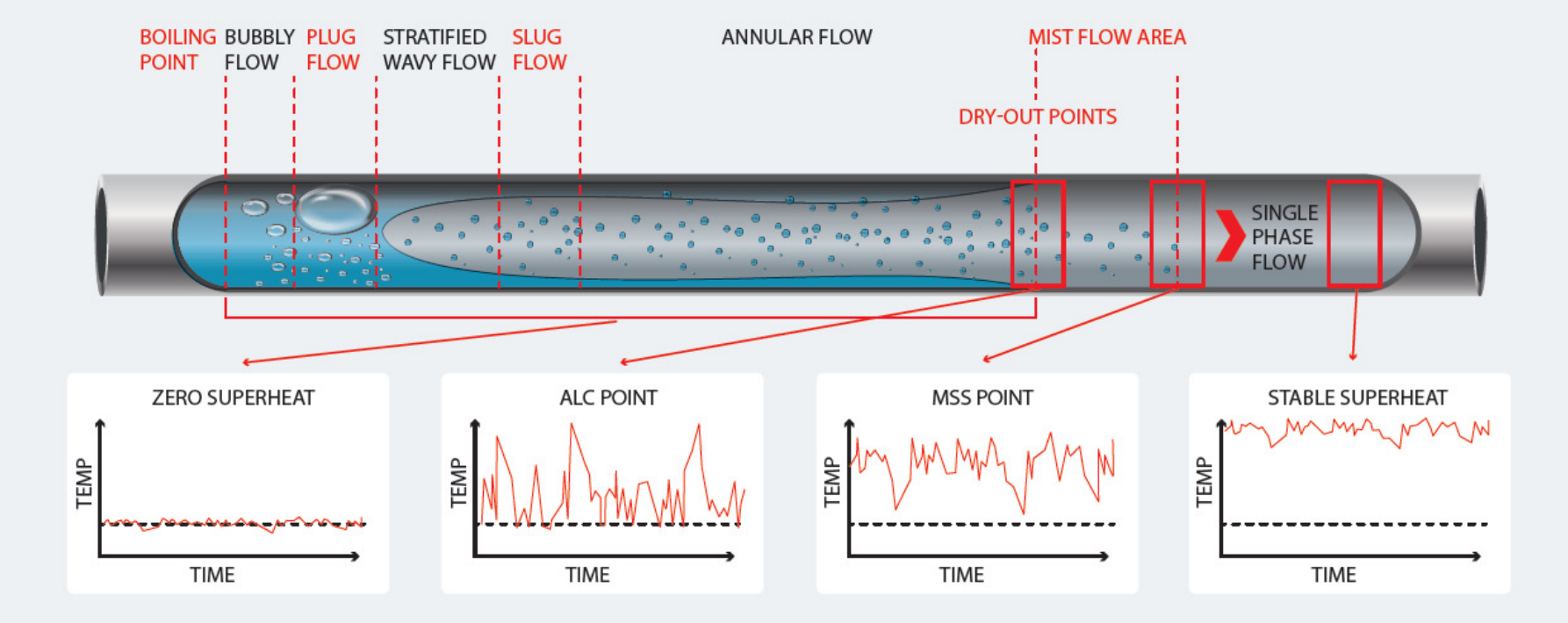
Liquid ejector application
application for all temperatures

Cycle explanation liquid ejector system

- Liquid ejectors can be added to any type of system (booster, LP and HP ejector systems)
- The Adaptive Liquid Control (ALC) of the evaporators is managed by the case/evap controller and the amount of liquid coming back from the evaporators in supermarket application is approx. 2-3%.
- Liquid is collected in the suction accumulator and the gas is passed on to the MT compressors.
- The liquid ejector is pumping the liquid from a low point in the suction accumulator back to the receiver.
- The liquid ejectors can give a lift of 5 bar even at very low high pressures (down to 50 bar in the gas cooler).
- In case the ejector can not pump the liquid the evaporators is asked to return to DX mode.
- In case of LP and HP ejectors present in the system a common suction from the suction accumulator is used and the gas ejectors will pump the liquid in warm periods due to higher efficiency.



Adaptive Liquid Control (ALC) & Minimum Stable Superheat (MSS)

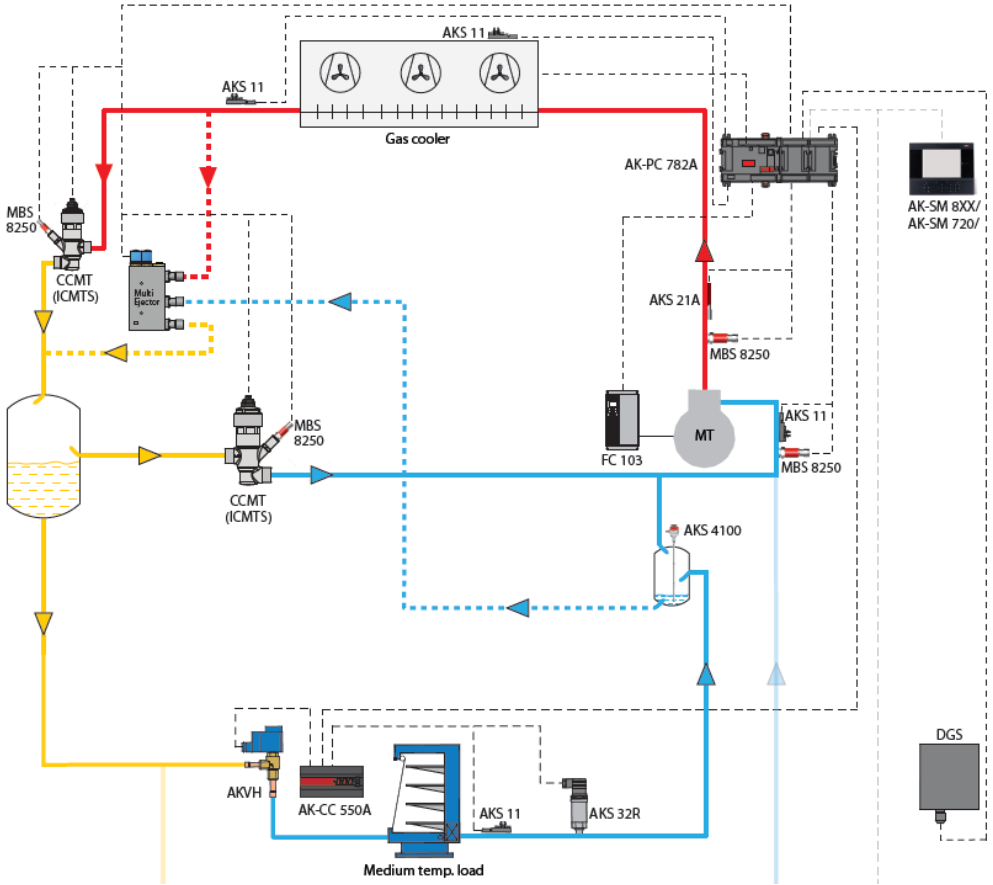


- **Stable superheat** can be measured when the superheat is higher than the MSS point.
- **MSS point** (Minimum Stable Signal) can be found on the borderline between the Mist Flow area and the Single Phase Flow – With MSS control the highest evaporator efficiency is achieved while all liquid is evaporated and only superheated gas is leaving the evaporator – A safe situation compressor wise.
- **ALC point** (Adaptive Liquid Control point) can be found about the Dry-Out point on the borderline between the Annular Flow area and the Mist Flow area – With ALC the highest evaporator efficiency is realized but with droplets of refrigerant leaving the evaporator – Not a safe situation compressor wise.
- **Zero superheat** can be measured in all the part of the evaporator where fluid exist (until Dry-Out point)

System with Liquid Ejector

System design:

- High Pressure expansion valve
- Liquid Ejector
  (Liquid pumping function)



System Control

Pack control:

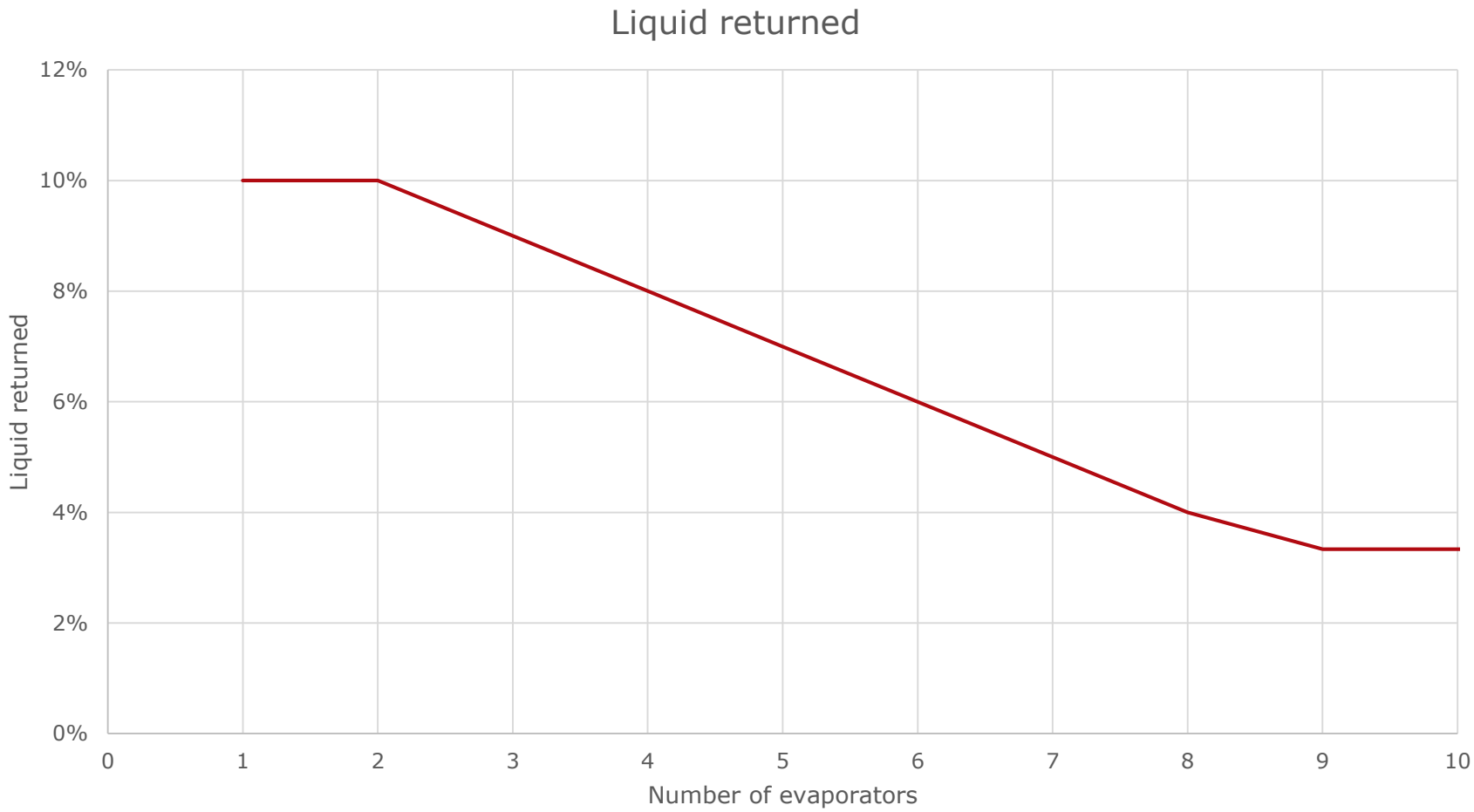
- **Po optimization**

Evaporators control:

- **Modulated thermostat**
- Adaptive SH (MSS)
- Adaptive Liquid Control (ALC)
- Only most loaded will operates in either with zero (ALC) superheat (SH) or at the minimum SH (depending on settings)

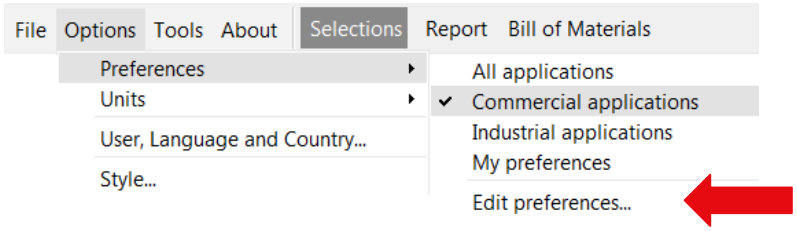
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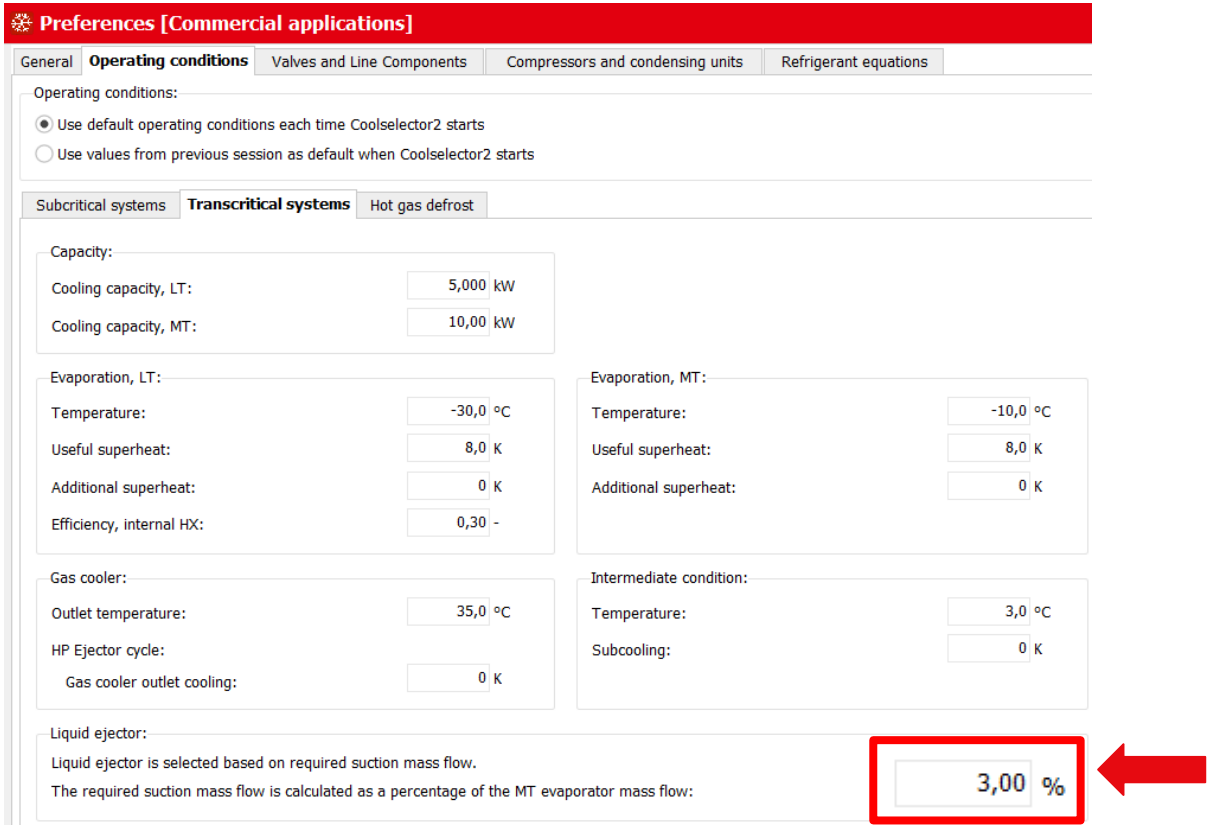
How much liquid can be generated from ALC?



Only the **most loaded evaporators** are releasing liquid to suction line, and this evaporators are releasing **up to 10%** liquid of total evaporator flow. But, typically in systems with **multiple evaporators** approximately 30% of evaporators are considered as most loaded so resulting in 10% x 30% = **3% liquid returning to the suction accumulator if more than 10 evaporators are in the system**. If system have less evaporators % liquid return will be higher.

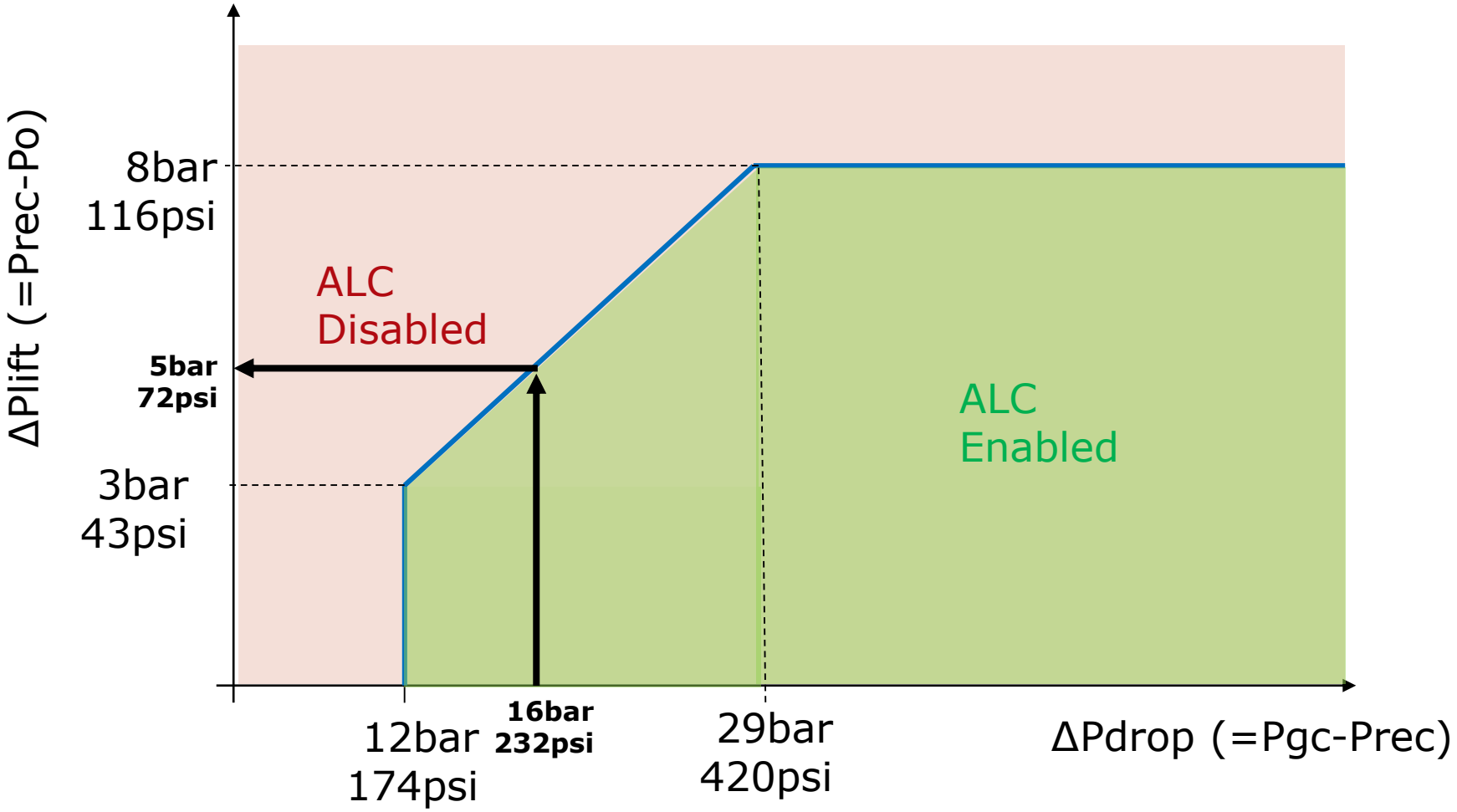
Required liquid suction mass flow as a percentage of the MT evaporator mass flow





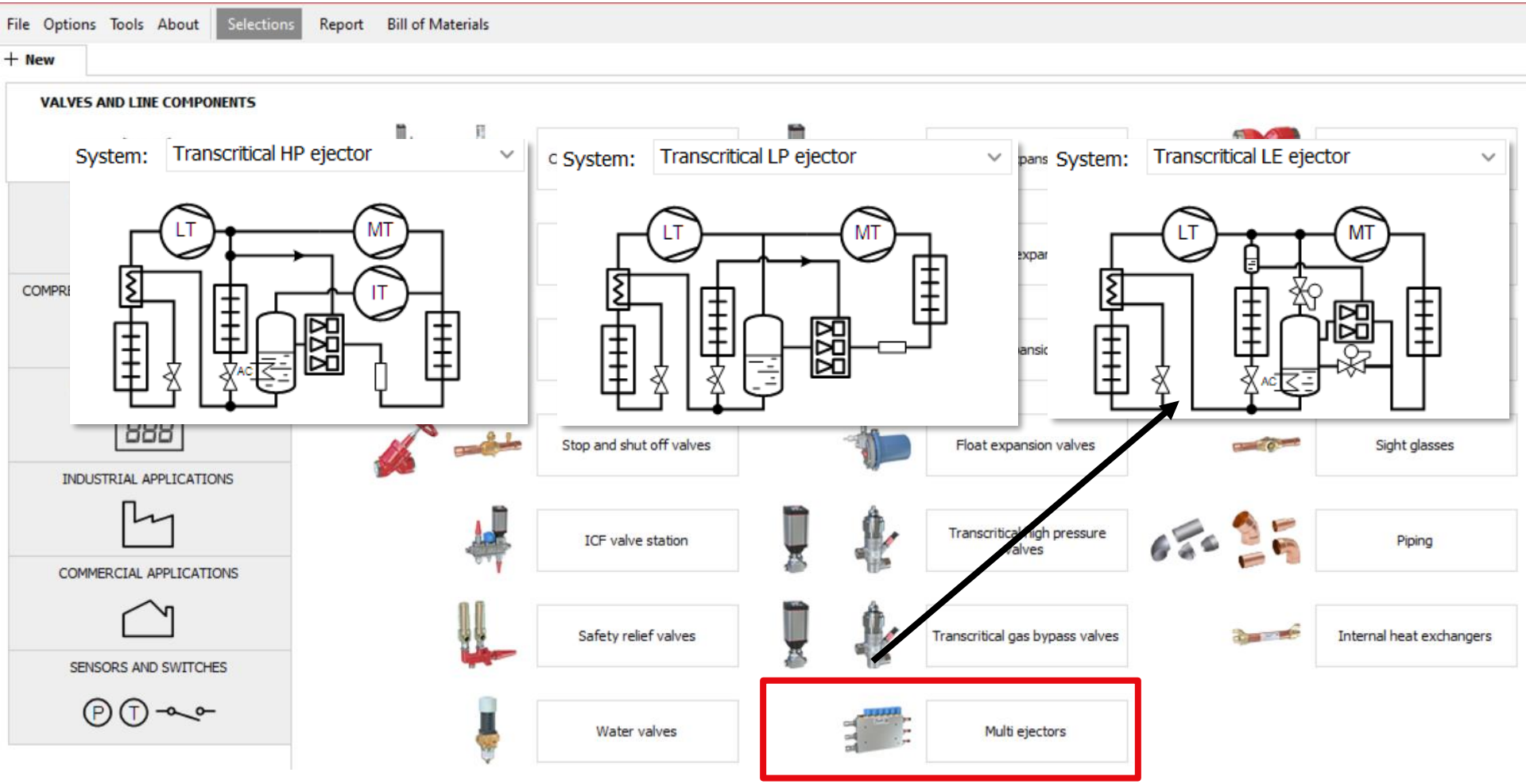
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Liquid ejector envelop



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Multi ejectors



LE ejector selection: Example

LT Load not influence on LE selection, as m_motive is limited to MT mass flow capacity

Pgc-Prec =16 bar / 232 psi
Prec-Po = 5 bar / 72 psi

Operating conditions:

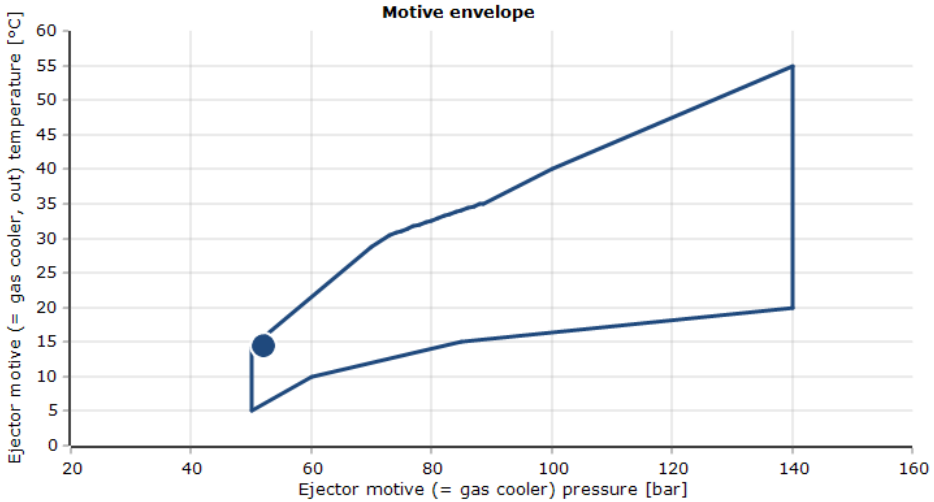
Capacity:
- Cooling capacity, LT: 50,00 kW
- Cooling capacity, MT: 250,0 kW
- Cooling capacity, AC: 0 kW

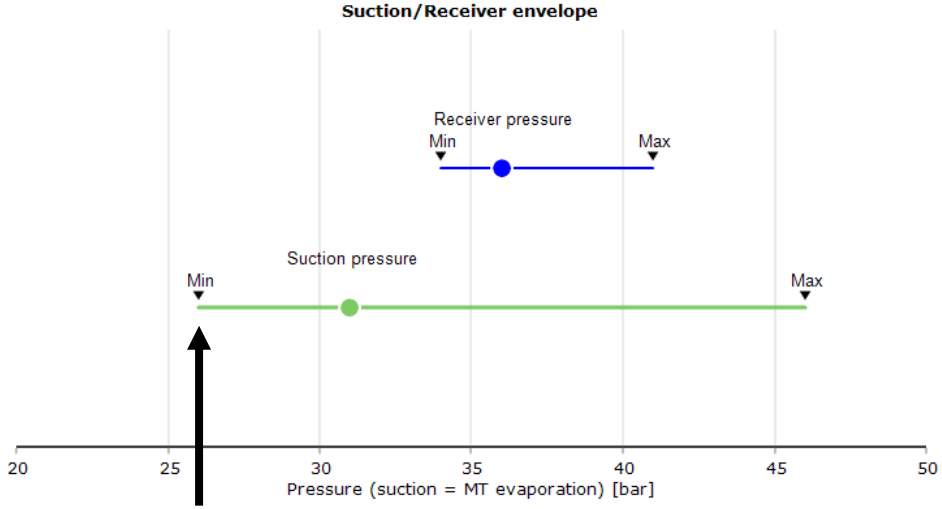
Evaporation, LT:
- Temperature: -30,0 °C
- Useful superheat: 6,0 K
- Additional superheat: 4,0 K
- Efficiency, internal HX: 0,30 -
- Discharge temperature: 54,4 °C

Evaporation, MT:
- Temperature: -4,4 °C
- Pressure (a): 31,00 bar
- Useful superheat: 0 K
- Additional superheat: 0 K
- Discharge temperature: 45,6 °C

Gas cooler:
- Optimal gas cooler pressure
- Pressure: 52,00 bar
- Min outlet temperature: 14,5 °C
- Additional cooling: 0 K

Receiver condition:
- Pressure (a): 36,00 bar
- Subcooling: 0 K
- Temperature: 1,2 °C





Media temp. range: -10 °C – +50 °C / +14 °F – 122 °F

LE ejector selection: Example

LT Load not influence on LE selection, as *m_motive* is limited to MT mass flow capacity

Pgc-Prec =16 bar / 232 psi
Prec-Po = 5 bar / 72 psi

Operating conditions:

Capacity:
- Cooling capacity, LT: 50,00 kW
- Cooling capacity, MT: 250,0 kW
- Cooling capacity, AC: 0 kW

Evaporation, LT:
- Temperature: -30,0 °C
- Useful superheat: 6,0 K
- Additional superheat: 4,0 K
- Efficiency, internal HX: 0,30 -
- Discharge temperature: 54,4 °C

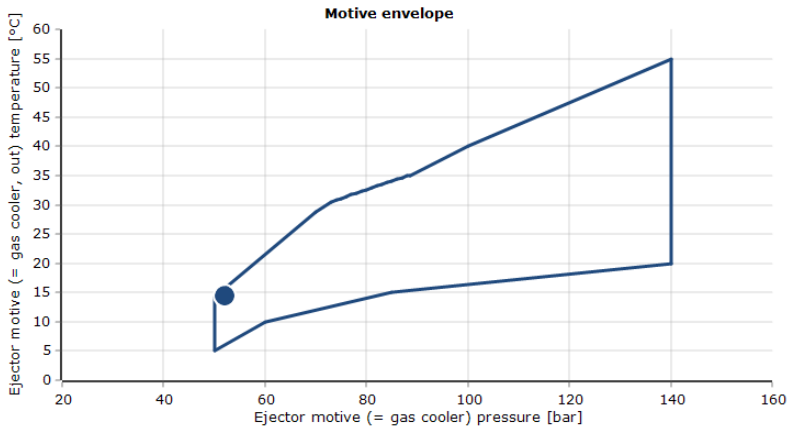
Evaporation, MT:
- Temperature: -4,4 °C
- Pressure (a): 31,00 bar
- Useful superheat: 0 K
- Additional superheat: 0 K
- Discharge temperature: 45,6 °C

Gas cooler:
- Optimal gas cooler pressure
- Pressure: 52,00 bar
- Min outlet temperature: 14,5 °C
- Additional cooling: 0 K

Receiver condition:
- Pressure (a): 36,00 bar
- Subcooling: 0 K
- Temperature: 1,2 °C

Selection: CTM 2 LE 600

Selected	Type	Number	Capacity [%]	m_evap_LT [kg/h]	m_evap_MT [kg/h]	m_comp_MT [kg/h]	m_BP [kg/h]	m_motive [kg/h]	m_suction [kg/h]	m_suction_required [kg/h]	Entrainment ratio
○	CTM 1 LE 200	10	95	725,7	3909	5470	835,5	208,6	12,31	117,3	0,06
○	CTM 1 LE 400	2	55	725,7	3909	5470	835,5	399,4	106,3	117,3	0,27
◉	CTM 2 LE 600	1	99	725,7	3909	5470	835,5	608,1	118,6	117,3	0,20



LE motive mass flow

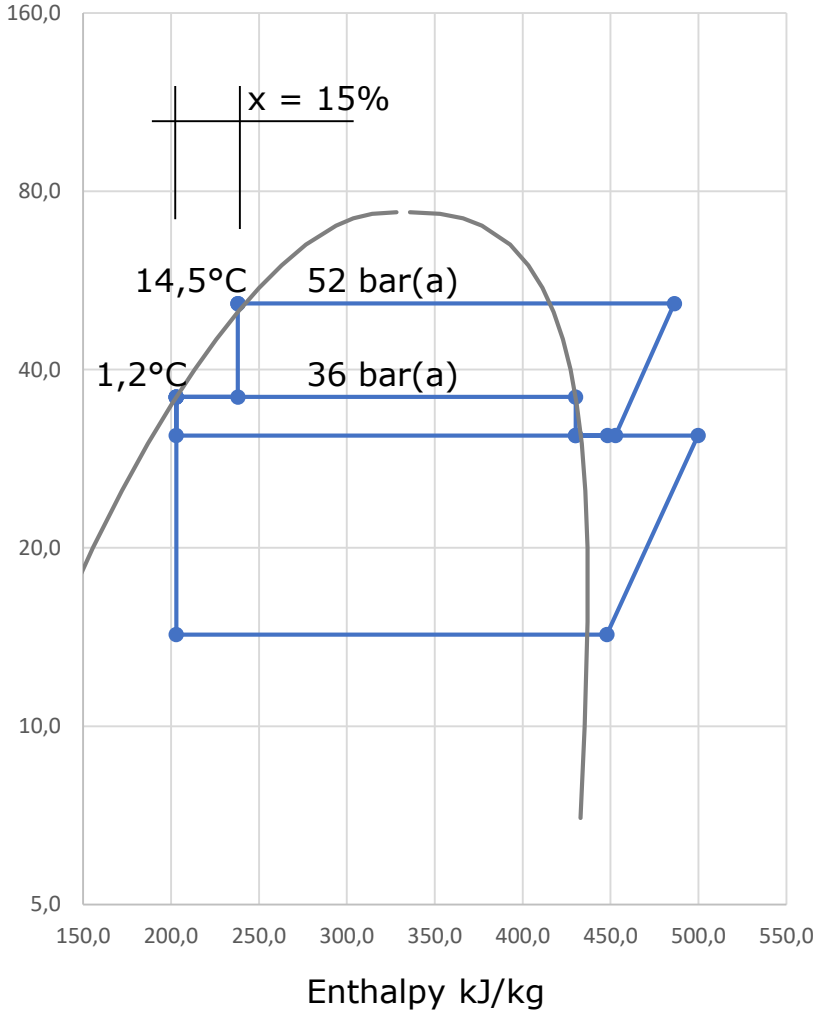
Liquid mass flow LE will lift

Liquid coming from MT evap based on 3% assumption

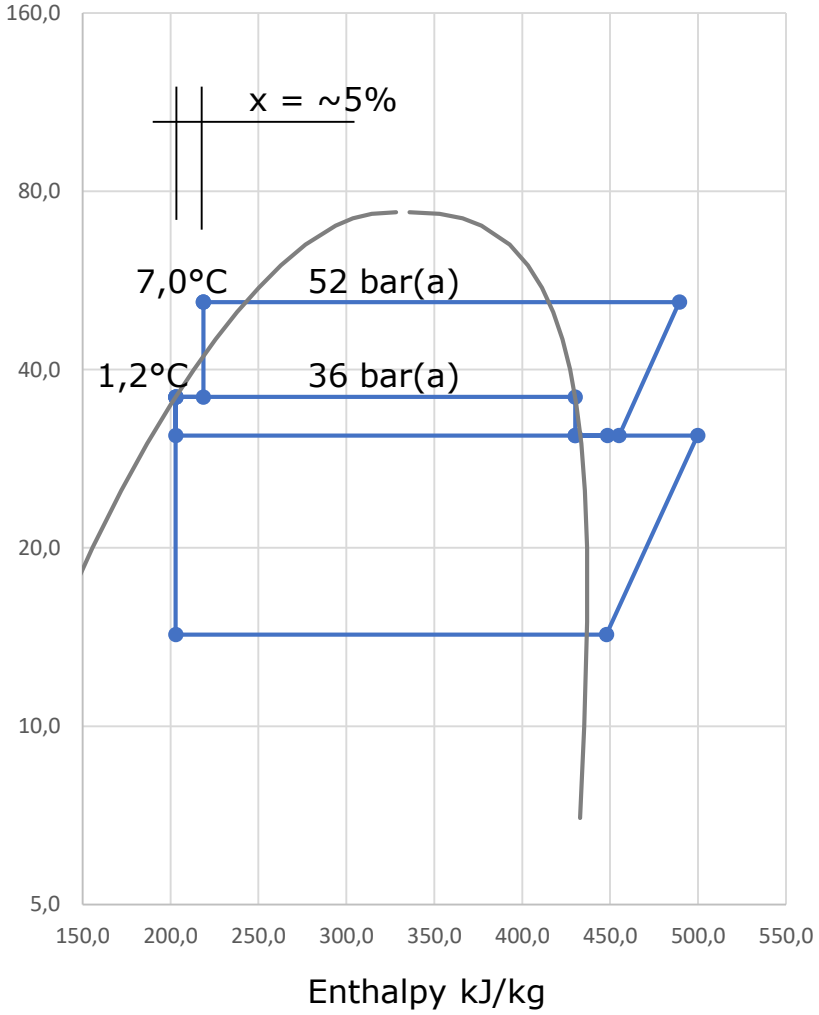
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Robust Control with Low Receiver Pressure

AK-PC 782A 1.52 – 1.85



AK-PC 782A 2.08, 2-12 ; min x=5%
AK-PC 782A 2.21 adjustable min x=0-10%



LE ejector selection: Example

LT Load not influence on LE selection, as m_motive is limited to MT mass flow capacity

Pgc-Prec =16 bar / 232 psi
Prec-Po = 5 bar / 72 psi

Operating conditions:

Capacity:
- Cooling capacity, LT: 50,00 kW
- Cooling capacity, MT: 250,0 kW
- Cooling capacity, AC: 0 kW

Evaporation, LT:
- Temperature: -30,0 °C
- Useful superheat: 6,0 K
- Additional superheat: 4,0 K
- Efficiency, internal HX: 0,30 -
- Discharge temperature: 56,4 °C

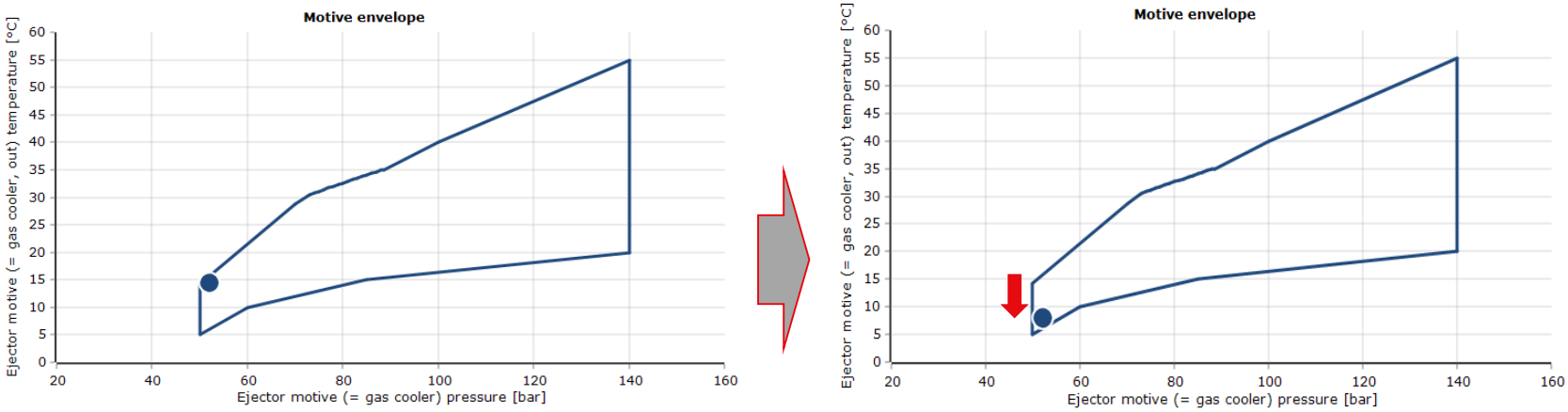
Evaporation, MT:
- Temperature: -4,4 °C
- Pressure (a): 31,00 bar
- Useful superheat: 0 K
- Additional superheat: 0 K
- Discharge temperature: 47,9 °C

Gas cooler:
- Optimal gas cooler pressure
- Pressure: 52,00 bar
- Min outlet temperature: 7,0 °C
- Additional cooling: 0 K

Receiver condition:
- Pressure (a): 36,00 bar
- Subcooling: 0 K
- Temperature: 1,2 °C

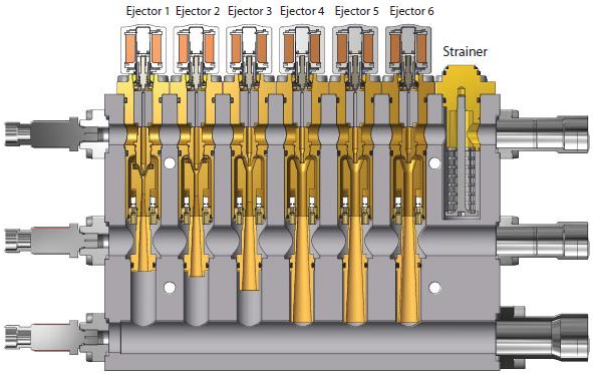
Selection: CTM 2 LE 600

Selected	Type	Number	Capacity [%]	m_evap_LT [kg/h]	m_evap_MT [kg/h]	m_comp_MT [kg/h]	m_BP [kg/h]	m_motive [kg/h]	m_suction [kg/h]	m_suction_required [kg/h]	Entrainment ratio
○	CTM 1 LE 200	4	80	725,7	3909	4913	278,7	264,8	36,70	117,3	0,14
○	CTM 1 LE 400	1	51	725,7	3909	4913	278,7	517,1	231,9	117,3	0,45
◉	CTM 2 LE 600	1	44	725,7	3909	4913	278,7	781,9	268,6	117,3	0,34

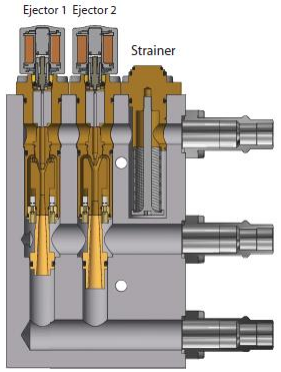


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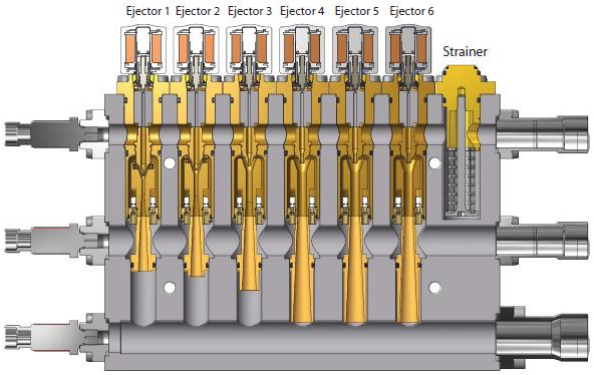
Ejectors HP & LE



Code no.	Product name	Ejector #1 kg/h	Ejector #2 kg/h	Ejector #3 kg/h	Ejector #4 kg/h	Ejector #5 kg/h	Ejector #6 kg/h
032F5673	CTM Multi Ejector HP 1875	125	250	500	1000		
032F5698	CTM Multi Ejector HP 2875	125	250	500	1000	1000	
032F5674	CTM Multi Ejector HP 3875	125	250	500	1000	1000	1000
032F5675	CTM Combi HP 1875 LE 400	125	250	500	1000	200	200
032F5676	CTM Combi HP 2875 LE 200	125	250	500	1000	1000	200
032F5677	CTM Combi HP 2875 LE 400	125	250	500	1000	1000	400
032F5683	CTM Multi Ejector LE 200	200					
032F5684	CTM Multi Ejector LE 400 CTM 1	400					
032F5694	CTM Multi Ejector LE 400 CTM 2	200	200				
032F5685	CTM Multi Ejector LE 600	200	400				
032F5695	CTM Multi Ejector LE 800	400	400				



Multi Ejector range
Low Pressure lift



Code no.	Product name	Ejector #1 kg/h	Ejector #2 kg/h	Ejector #3 kg/h	Ejector #4 kg/h	Ejector #5 kg/h	Ejector #6 kg/h
032F5678	CTM Multi Ejector LP 935	60	125	250	500		
032F5693	CTM Multi Ejector LP 1435	60	125	250	500	500	
032F5679	CTM Multi Ejector LP 1935	60	125	250	500	500	500

