ENGINEERING TOMORROW

Danfoss

Application guide

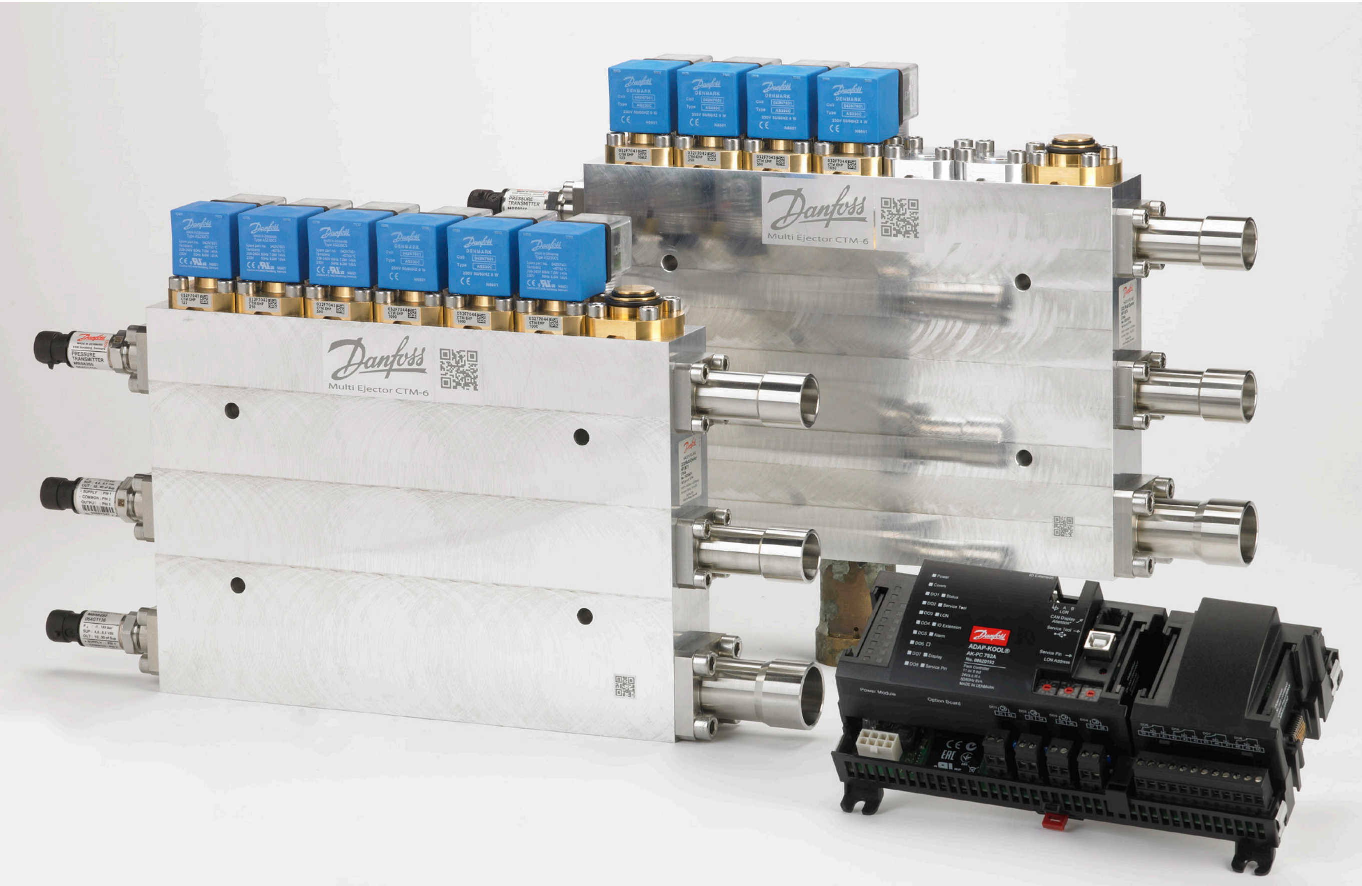
How to design a transcritical CO_2 system with Multi Ejector Solution.

Type CTM 6 High Pressure (HP) and Low Pressure (LP)

Table of content

What is the Danfoss Multi Ejector Solution ?

- Danfoss Multi Ejector Solution is a block if 1-6 ejectors with fixed motive nozzle
- The capacity is matched by using different combinations of ejectors
- Benefit is that the characteristic of the ejector remains the same regardless of capacity on the system (characteristic varies with temperature and pressure in to the ejector)
- The compromise VS. variable ejector is that capacity can not be matched 100%
- Block contains 3 pressure transmitters with round packard plug (Pressure at ejector inlet, MT suction and receiver pressure)
- Each ejector cartridge can be serviced independently of the others (pressure needs to come of the block)
- Easy service of the strainer, which is placed in a seperate port, before inlet
- It always must be installed with an AK-PC 782A, pack controller with ejector software
- The sizes of the different ejectors are binary starting with a cooling capacity at 6 kW (125 kg/hr), 12 kW (250 kg/hr), 25 kW (500 kg/hr) and 50 kW (1000 kg/hr).
- If there is a need for more capacity that 93 kW, there will be added two 50 kW ejectors more to give approx. 193 kW cooling capacity. By doing this it is possible to modulate any capacity between 0 kW and 193 kW with the 6 ejectors with a resolution of 6 kW.
  If more capacity is needed then 2 identical blocks can be added and they can be controlled in parallel. The resolution is this case will then be 12 kW, but on a much larger capacity
- Application guide is covering the design and component selection for at Transcritical CO_2 system with parallel compressor, ejectors and booster systems



Danfoss Multi Ejector Solution portfolio

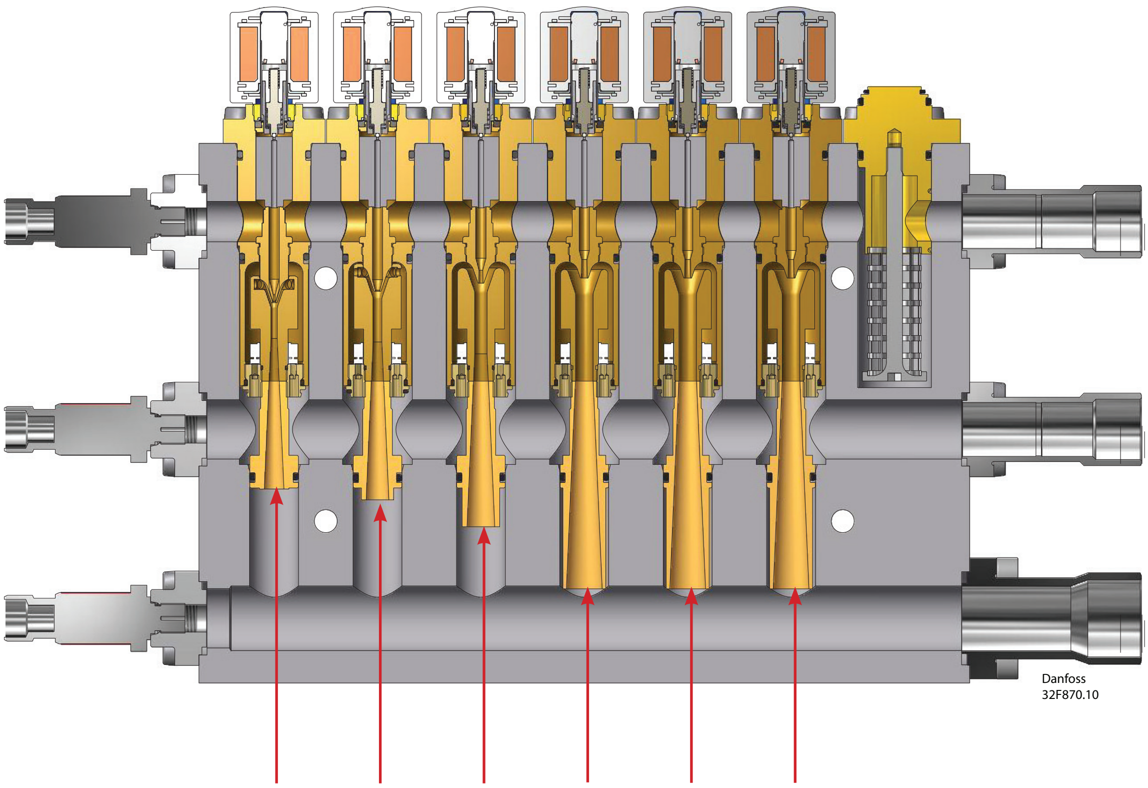
- Danfoss is offering 2 different version:
  - Multi Ejector High Pressure lift is to be used on systems with parallel compression. It can lift a part of the gas from MT suction to receiver where it will be compressed in the parallel compressor. This ejector type is configured in a block with 4 to 6 ejectors depending of the wished capacity
  - Multi Ejector Low Pressure lift is used on booster systems and due to the low pressure lift/high entrainment ratio it can pump all the gas from the evaporators back to the receiver where the compressor is taking the gas.
    This ejector type is configured in a block with 4 to 6 ejectors depending of the wished capacity

Danfoss Multi Ejector Solution overview

Type	Pressure lift / entrainment ratio	Media on suction side
High Pressure lift	6 bar/25% at 23°C 11 bar/25% at 36 °C	CO_2 Gas (up to 10% liquid)
Low Pressure lift	3 bar/63% at 23°C 7 bar/50% at 36°C	CO_2 Gas (up to 10% liquid)

How does the Multi Ejector Solution work?

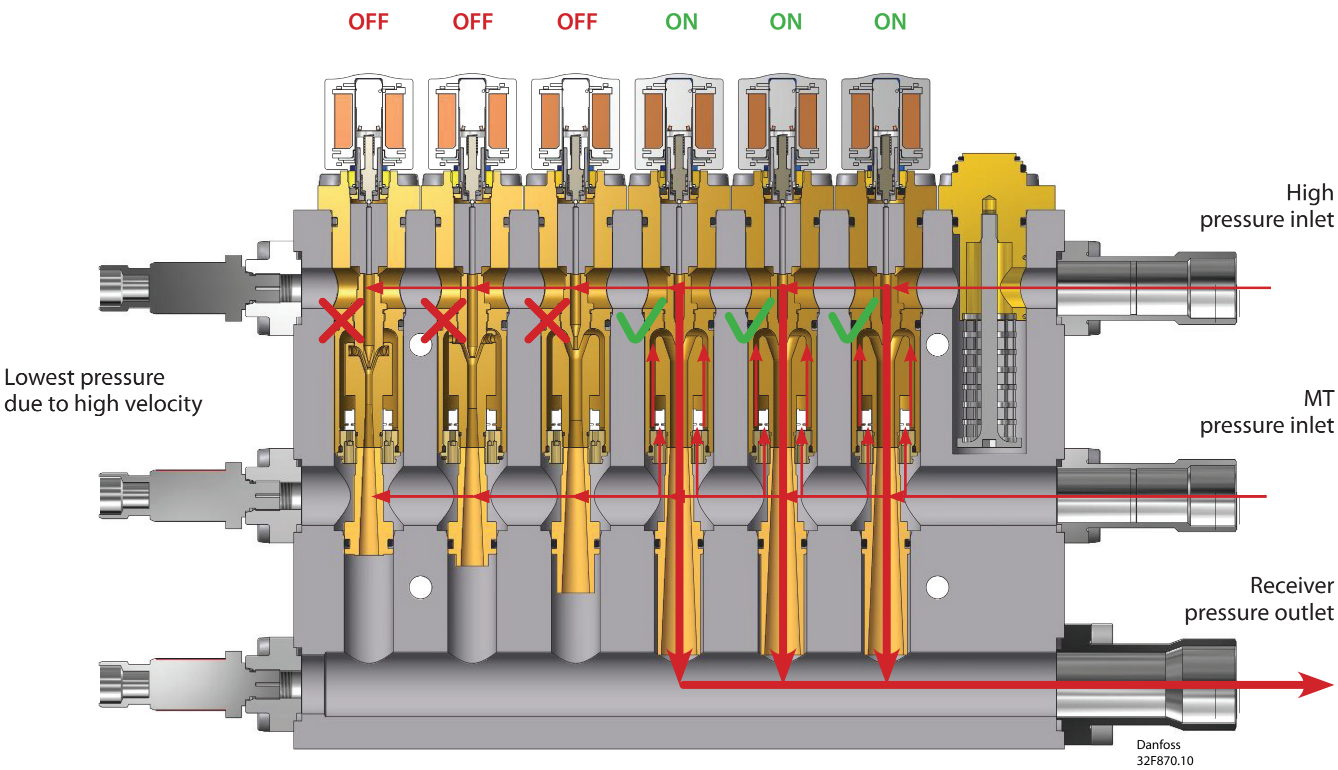
4 different ejector cartridge sizes (approx 125, 250, 500 and 1000 kg/hr for the HP ejector and 60, 125, 250, 500 kg/hr for the LP ejector).
Largest ejectors are placed closest to the connection (from factory).
Control of the ejector is based on binary switching of the ejectors.
If one ejector block can not do the capacity 2 (or more) are mounted in parallel.



Type	Code no.	Product name	Ejector 1	Ejector 2	Ejector 3	Ejector 4	Ejector 5	Ejector 6
CTM 6	**032F5673**	CTM Multi Ejector HP 1875	CTM EHP 125	CTM EHP 250	CTM EHP 500	CTM EHP 1000	Dummy	Dummy
CTM 6	**032F5674**	CTM Multi Ejector HP 3875	CTM EHP 125	CTM EHP 250	CTM EHP 500	CTM EHP 1000	CTM EHP 1000	CTM EHP 1000
CTM 6	**032F5678**	CTM Multi Ejector LP 935	CTM ELP 60	CTM ELP 125	CTM ELP 250	CTM ELP 500	Dummy	Dummy
CTM 6	**032F5679**	CTM Multi Ejector LP 1935	CTM ELP 60	CTM ELP 125	CTM ELP 250	CTM ELP 500	CTM ELP 500	CTM ELP 500

How does the Multi Ejector Solution work?

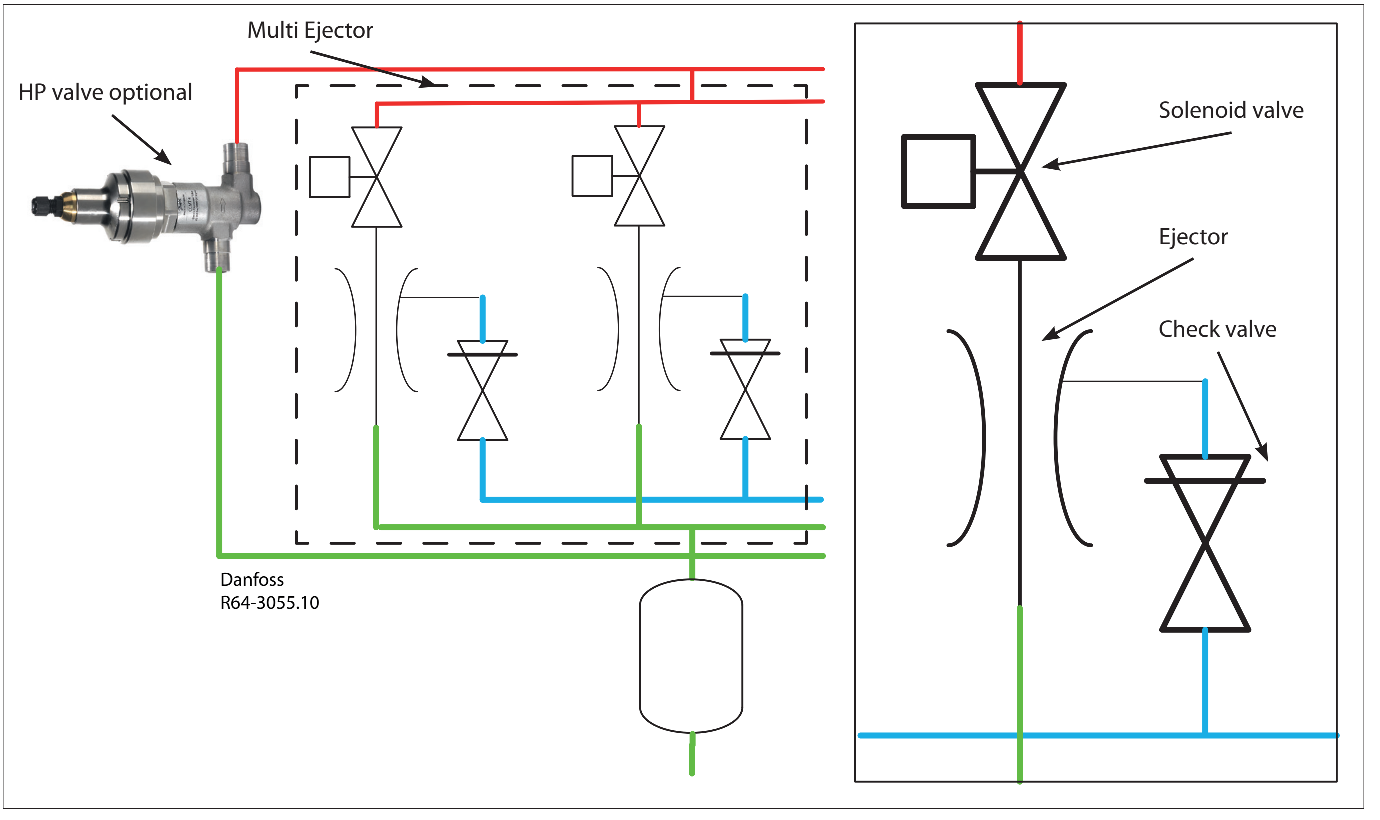
The flow enters the Multi Ejector through the strainer in front of the high pressure inlet. The AK-PC 782A controllers which ejectors is activated to meet the requested capacity. Through the open nozzel the high pressure flow is transformed into high violosity flow. The high violosity creates a very low pressure, making the suction of the MT possible.
The flow from the MT suction inlet enters the ejector through the check valve, mixing with the high violosity flow. The mixed flow is slowed down in the defuser part of the ejector, transforming the violosity to pressure. From here the mixed flow is lead to the receiver and thereby recovering a part of the expansion work.



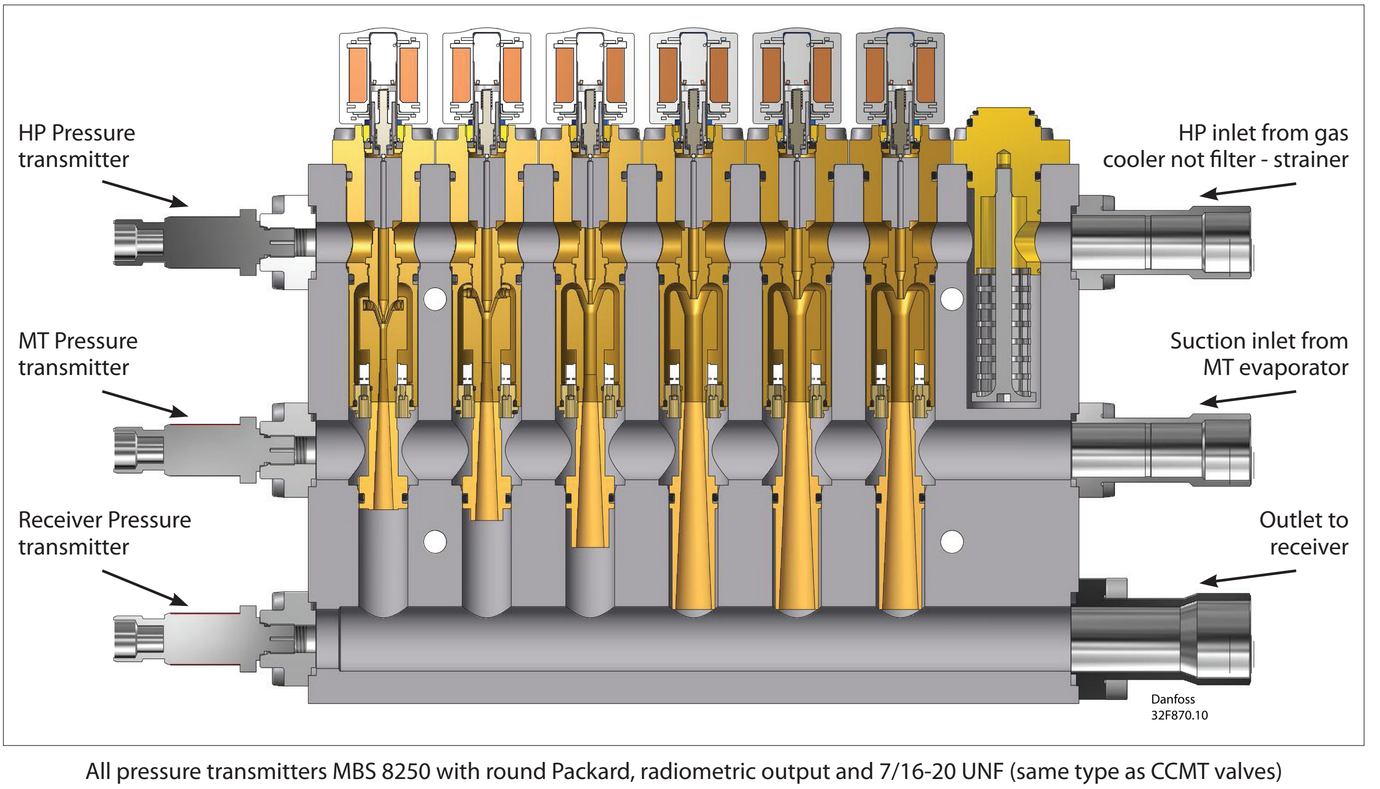
Electrical connections

Use the solid state relays for the 4 small ejectors (due to life time).
Ejector 5 (and higher) is placed on the mechanical relays.
If more than one bock is needed two (or more) identical blocks can be connected in parallel.

How does the Multi Ejector Solution work?



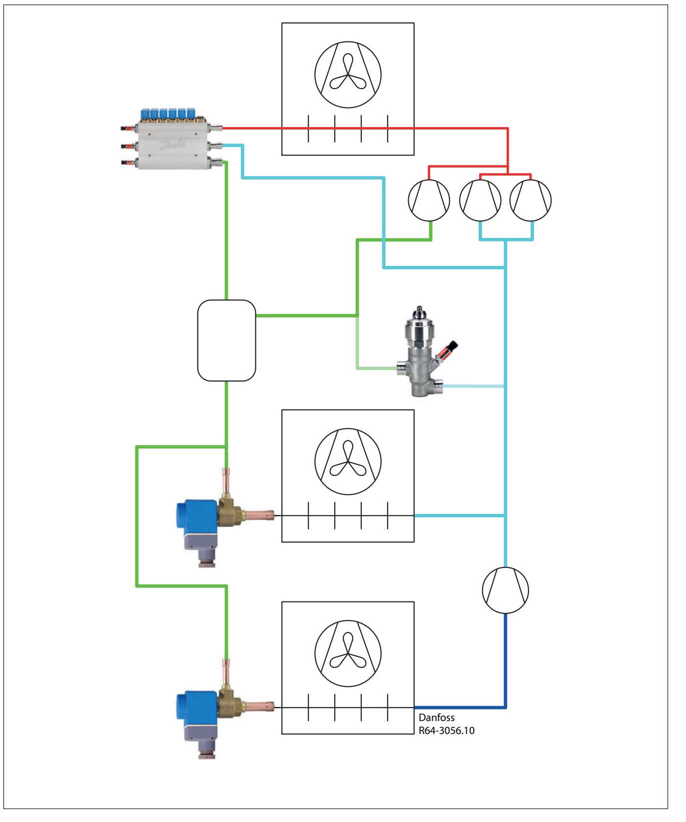
Coils adv. (230V DIN and 120V UL all 50-60 hz)



All pressure transmitters MBS 8250 with round Packard, radiometric output and 7/16-20 UNF (same type as CCMT valves)

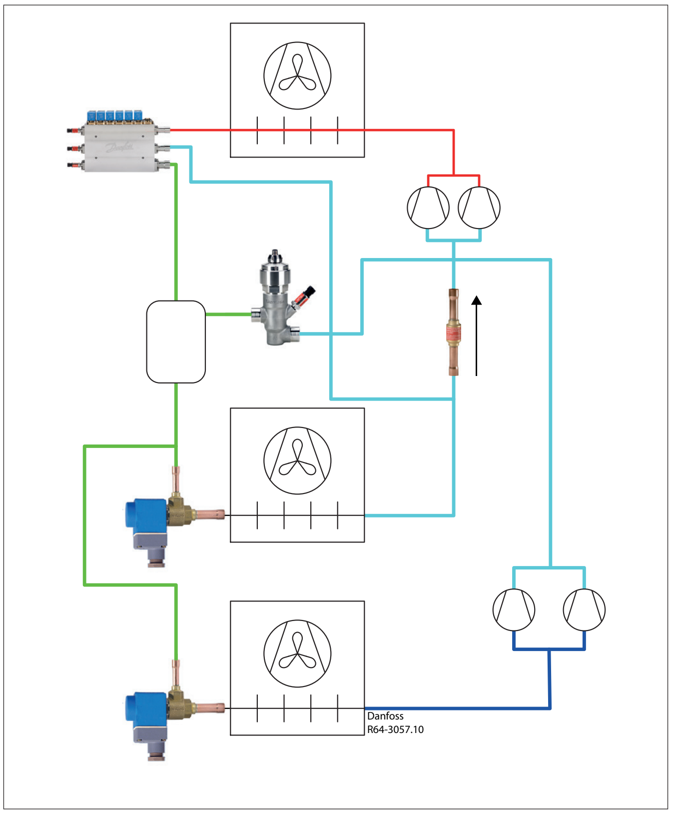
High Pressure lift application

- High Pressure lift ejectors are always used in systems with parallel compression
- Enhance the energy consumption with up to 9% (on annually basis) in warm climates compared to parallel compression and up to 17% compared to booster system
- A saving on swept volume of up to 15-35% is also possible (largest in warm climates)
- In large systems first costs can be reduced, thanks to a need of smaller and even fewer compressors
- System target size 100-150 kw and up



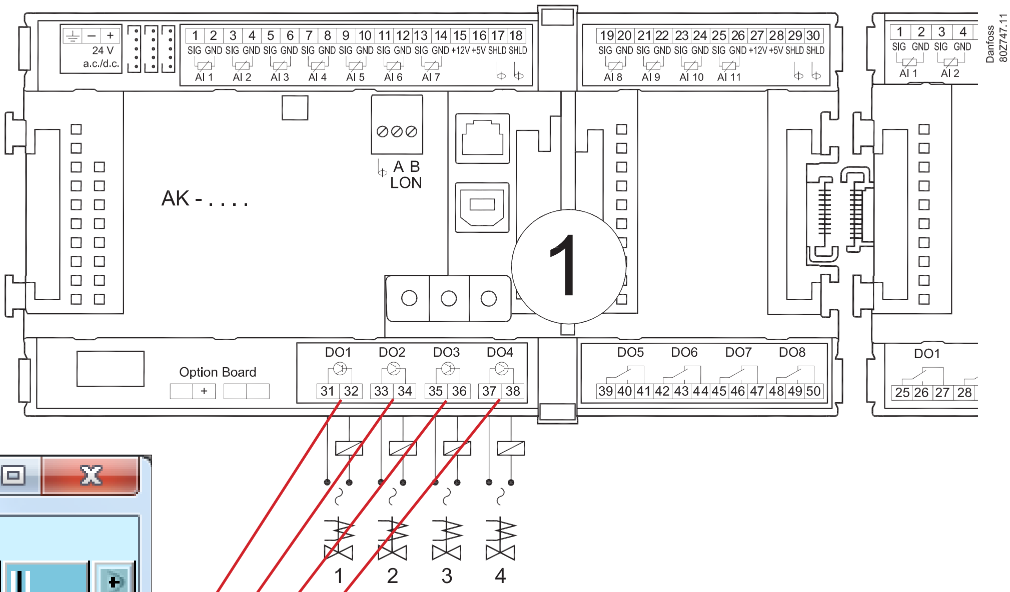
Low Pressure lift application

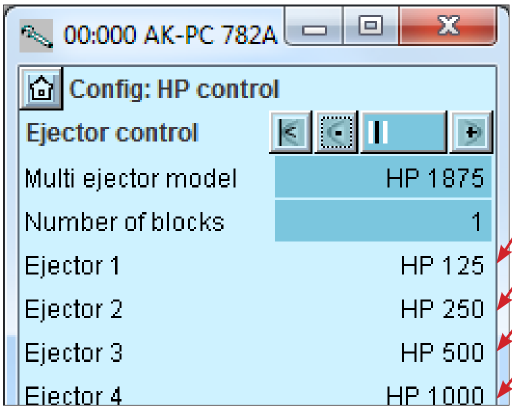
- Low Pressure lift application is used in booster systems
- Energy data indicates energy consumption on the same level as for the system with parallel compression
- A saving on swept volume of up to 15 – 35% is also possible (largest in warm climates)
- Cost can be reduced due to only one suction group and higher suction pressure
- System target size up to 40 – 150 KW



Electrical connections: 4 ejectors in one block

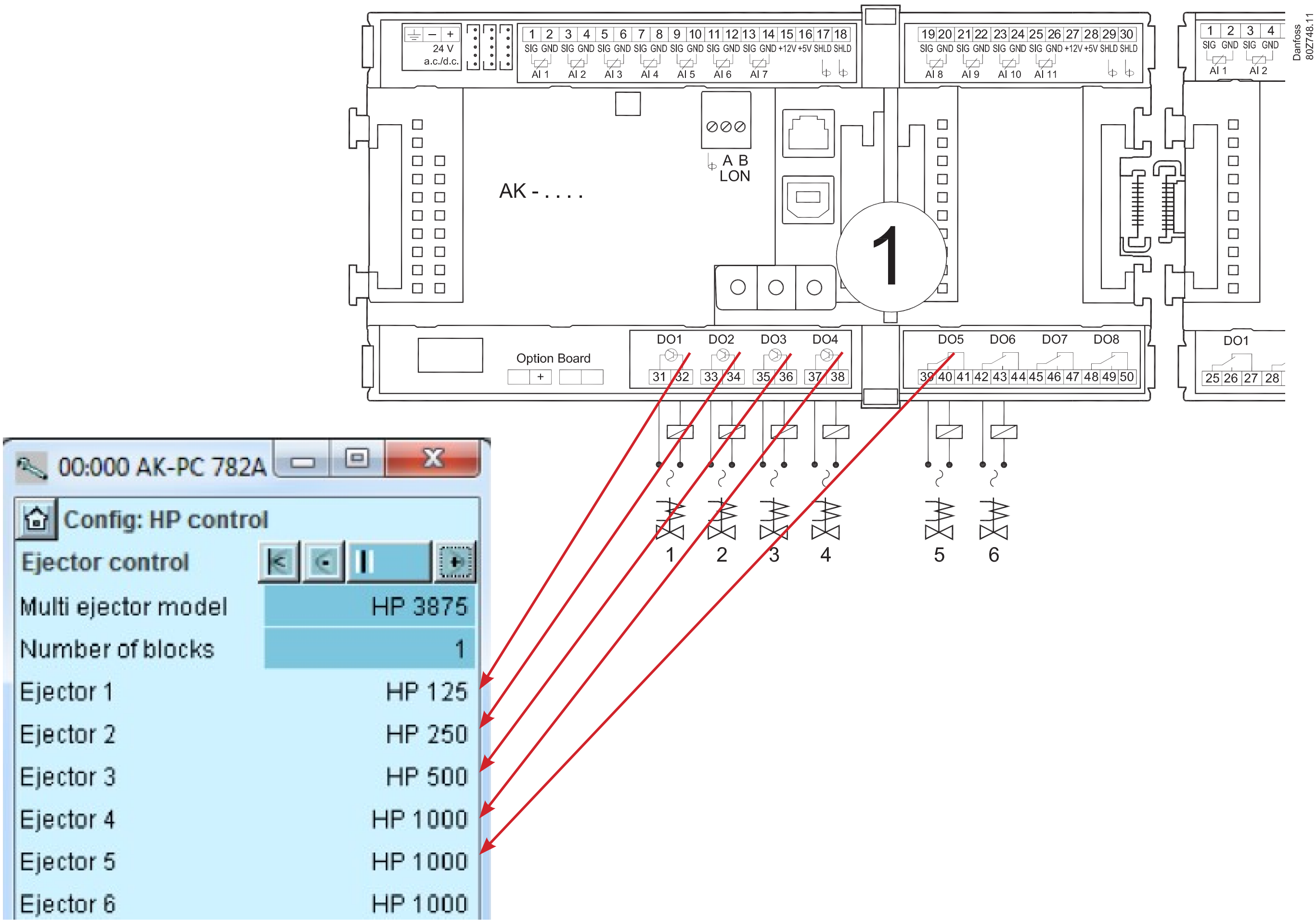
AK-PC 782A
The Multi Ejector configuration with the AK-PC 782A is via a simple drop-down selection.
The electrical connection is assigned manually to the desired output terminals.
When assigning the output for controlling the Multi Ejector, the four smallest ejector valves, that are controlled on/off more frequently than the larger ejector valves, must be controlled by solid state relays. The mechanical relays will not be able to withstand this high number of couplings.





- Use solid state relays for first 4 ejectors
- Same electrical connections for LP and HP ejectors

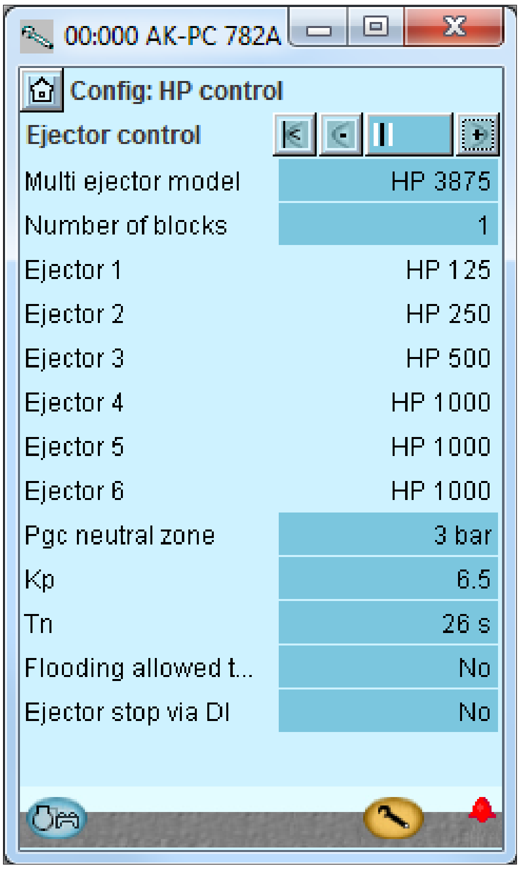
Electrical connections: 5 ejectors in one block



- Use solid state relays for first 4 ejectors
- Each solid state relay will handle 2 identical ejectors
- Ejector 5 and 6 in each block will in the controller be seen as one ejector (4 ejectors in total)
- Use relay for the last ejectors (4 ejectors)
- Same electrical connections for LP and HP ejectors

AK-PC 782A - with ejector controller setup

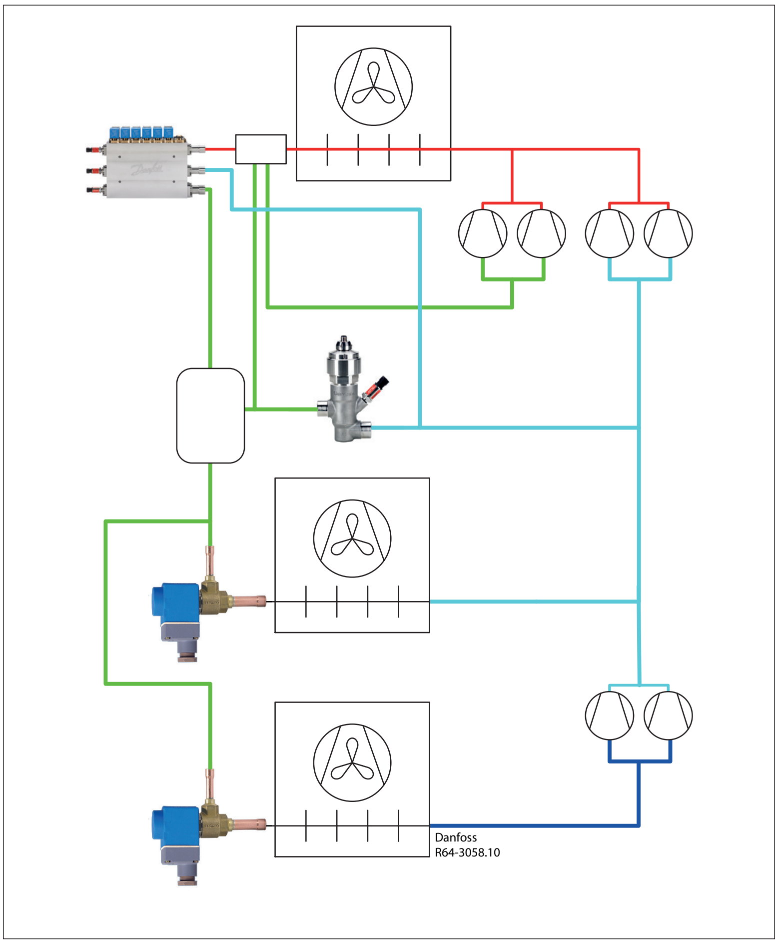
- Only difference with standard controller is the ejector control
- Setup No. of ejector steps will be 4 with a 4 ejector block, 5 with a 6 ejector block, and the same with 2 blocks in parallel
- Add ejector sizes. Remember binary sizing in this version
- Neutral zone
- Kp and Tn is normal PI parameters used to control the high pressure



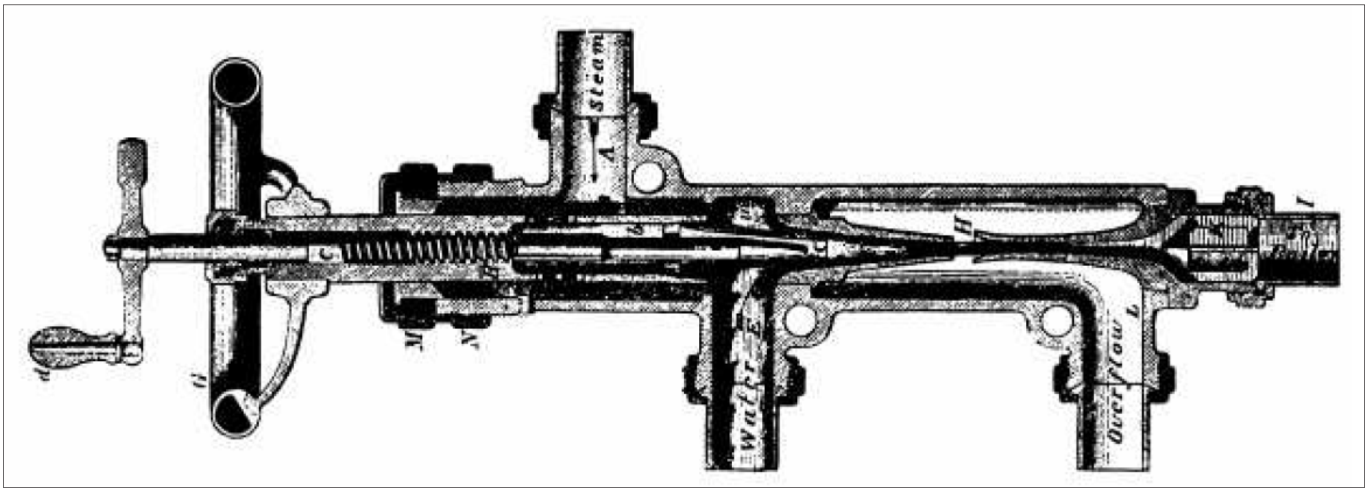
Description of Ejector system

The system contains two or three suction groups, One for MT, One for parallel/receiver pressure (IT) and one for LT if needed.
LT compressors compress from LT evaporators up (dark blue) to the pressure of the MT suction pressure.
At this pressure (light blue) the discharge gas is mixed with gas from the MT evaporators and the gas bypass valve. If the ejector is able to suck gas and lift it to the receiver. The rest of the gas is compressed by the MT compressors to the gas cooler pressure (red).

On the discharge the gas from MT and parallel compressors are mixed and go to the heat recovery system (not on the drawing) and gascooler. At the exit of the gascooler the gas is used to superheat the gas for the parallel compressor before entering the ejector.
In the receiver (green) the gas and liquid is separated and the liquid is going to the AKVH electric expansion valves. The gas is going to the gas by pass valve or the parallel compressor. The pack controller AK PC 781 and AK PC 782A is able to control this switching.



Working principal of the ejector

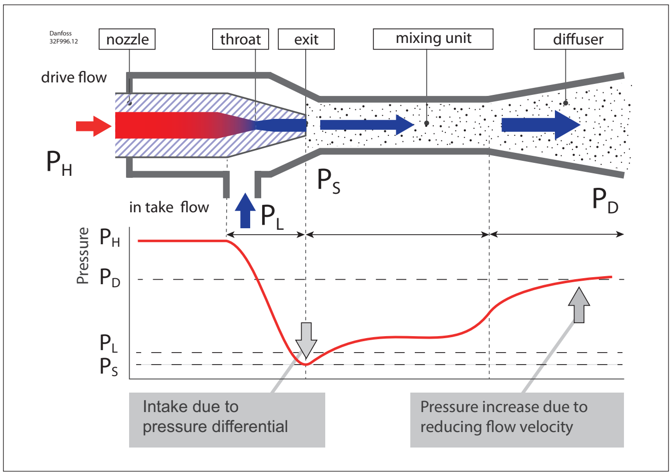


Ejector from Henri Griffard (1864), with integrated spindle valve for control of motive flow rate

An ejector is a device that uses expansion energy to compress another fluid.
In our case with the transcritical system there is approx. 20% of the compressor work that can theoretically be recovered in the expansion.
Currently we are able to recover up to 35% of the expansion work.

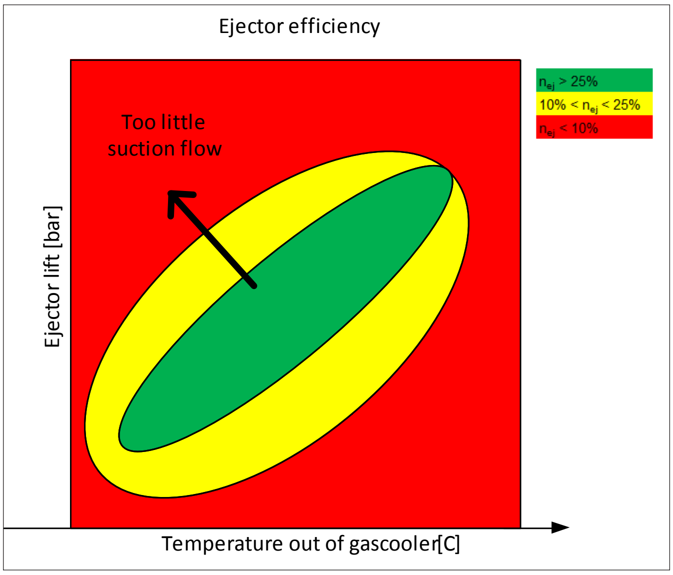
Working principal of the ejector

- CO_2 leaving the gascooler. The high pressure CO_2 (PH) is entering the motive nozzle where the expansion is taking place
- In the expansion the high pressure (potential energy) is converted to high speed (kinetec energy)
- At the exit of the nozzle the speed is very high ad as a consequence of that the pressure is low. This low pressure is used to drag in gas from the MT suction (PL)
- From there the two flows are mixed in the mixing unit where the pressure will be higher than at the outlet due to the mixing of gas from a higher pressure
- After the mixing the flow enters the diffuser where the flow is slowed down. The shape of the diffuser enables the conversion from kinetic energy (velocity) to potential energy (pressure)
- After the diffuser the flow is returned to the receiver



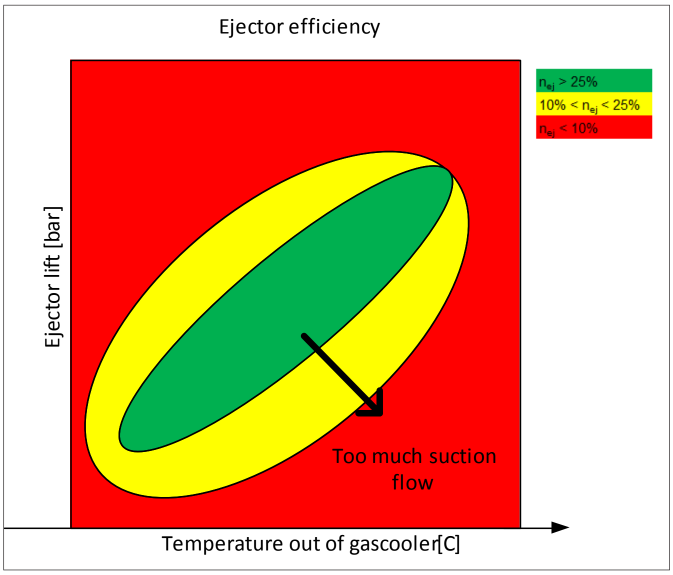
Ejector terms: Stall

- If the ejector is forced to give a lift that is significant higher than what it is designed for the ejector will stall
- Stalling will result in a rapid decrease of the suction flow, and a flow backwards through the suction line of the ejector if this is not prevented (in the Multi Ejector there are individual check valves for each ejector to prevent this)
- In cold ambient where the high pressure is low, there is not enough energy to make the lift we need to feed the expansion valves, and in this case the ejector will stall
- It is not dangerous in any way or damaging the ejector that is designed for it, but there is no pumping in this situation



Ejector terms: Choke flow

- The opposite of stall is choke flow
- This occours if the high pressure is high, and the ejector is capable of making a high lift, but for some reason the suction pressure to the ejector is low (low pressure lift)
- Then the ejector mixing unit cannot accommodate the high mass flow and is therefore choked
- This will show as a decrease in performance, and is not a problem, for the ejector or the system other that it is losing efficiency



Ejector terms: Entrainment ratio

- Entrainment ration is also one of the terms that will be heard. Entrainment ration is the ratio between the suction mass flow of the ejector and the high pressure flow in the nozzle (motive flow) of the ejector
- In the design of a system with parallel compression the optimum entrainment ratio is approx 25% and this is where the ejector should be selected and run for the majority of the time
- For systems with out parallel compressor the LP ejector is used. Here the entrainment ratio is determined by the system, because and the pressure lift will be the result of the high pressure and the load

$$\Phi_m = \frac{\dot{m}_{sn}}{\dot{m}_{mn}}$$

Ejector terms: Pressure ratio

- Pressure ratio is defined as the pressure at the diffuser outlet divided with the pressure at the suction port of the ejector. But other definitions can also be found in literature
- Very often the pressure lift at a pressure difference between ejector suction and ejector outlet (evaporation pressure and receiver pressure) is used

$$\Pi_s = \frac{P_{diff,\ out}}{P_{SN,\ in}}$$

Ejector terms: Efficiency

- There are many definitions of efficiency, but the one Danfoss is using is based on the ration between the isentropic compression work the ejector is performing divided with the isentro pic expansion work available for the ejector
- If the receiver pressure in the system in controlled in a reasonably good way the efficiency will typically be between 25 and 35%
- In the design of the system the ejector efficiency is not important. Here Entrainment ration is the key number

$$\eta_{ejec} = \frac{\dot{m}_{suction}}{\dot{m}_{motive}} \cdot \frac{(h_C - h_D)}{(h_A - h_B)}$$