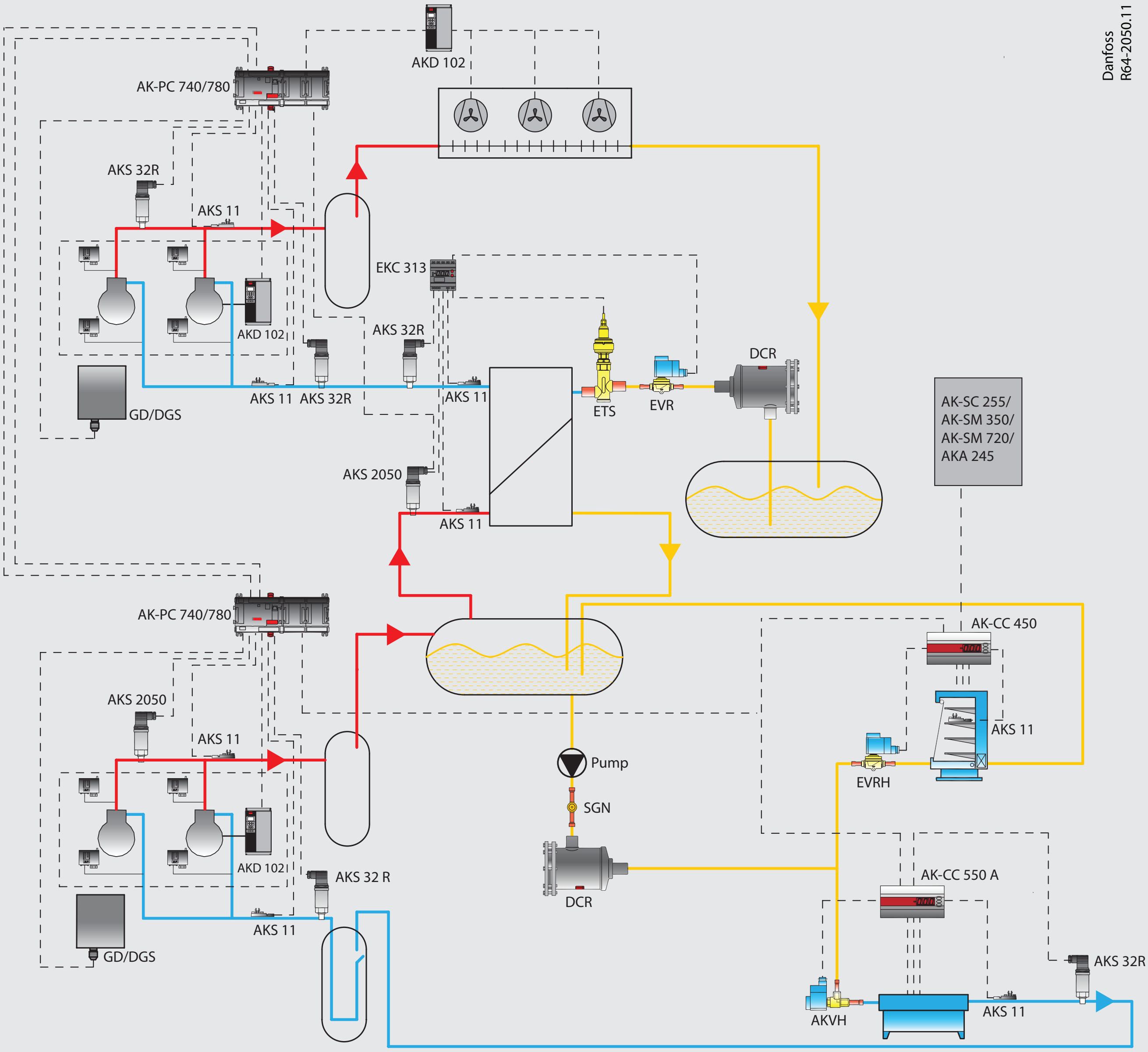
Application guide

Cascade HC/HFC - CO2 system

How to control the system



www.danfoss.com/co2

General description

Cascade systems are typical not used in FR applications with traditional refrigerants. There are a few reasons for this such as the need to maintain two different refrigerants in one system; system control strategy (especially that of a cascade heat exchanger) is more complex. At the same time using CO_2 in cascade systems gives a number of advantages:

- Efficiency of the system is high even in the hot climates
- Only a small amount of refrigerant is needed for high temperature stage
- Temperature difference for cascade heat exchanger is relatively low
- On the high side various refrigerants can be used ex HC/HFC or NH3.

Ammonia/CO_2 cascade systems have the highest efficiency of all. If HFC is to be used at a high temperature stage, R134a is a preferable option due to its thermo dynamical properties and lower (compared to R404A) GWP potential.

Temperatures and pressures in cascade systems

Intermediate temperature in a cascade system is selected based on the required temperature for high temperature cases in a store which means they can be cooled by CO_2 directly. Intermediate temperature can also be optimised for the highest energy efficiency if the system is used for low temperature only.

Since a cascade system actually consists of two different refrigeration systems which are interfaced but isolated at the cascade heat exchanger, the design working pressure for each can be different. CO_2 design pressure is normally based on the availability of components and is equal to 40-45 bar (corresponding to +5 - +10°C).

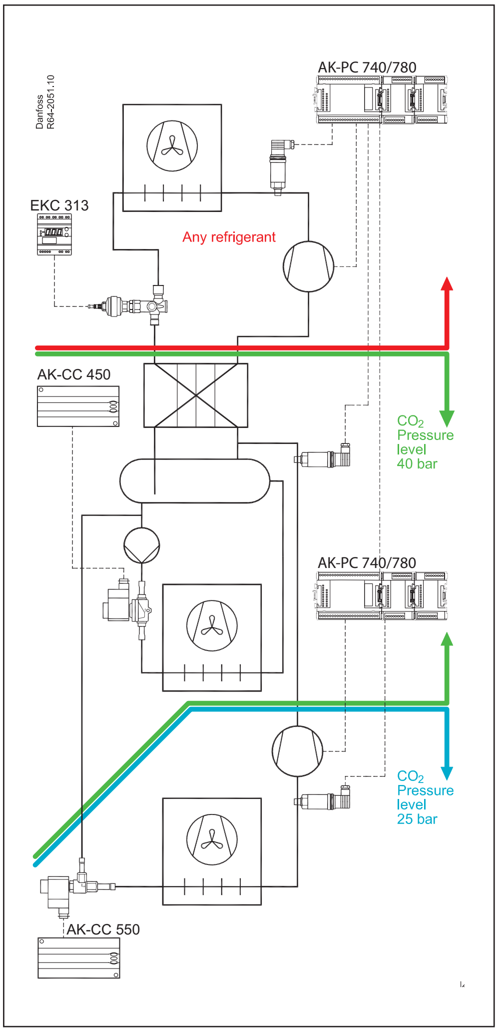
In order to prevent pressure from increasing above the previously mentioned measurements, standstill systems are recommended. Safety valves should have the highest setting. Stand still pressure can be achieved by raising the desing pressure to 80-90 bar.

For example:

CO_2 side

- System design working pressure (saturated suction temperature): 40 bar (+5°C)
- Safety valve settings: 36 bar (-10% MWP)
- System emergency relief setting: 34 bar (-1°C)
- CO_2 discharge pressure setting: 30 bar (-5°C)

The higher the efficiency of the cascade heat exchanger, the lower the difference between the condensation temperature of CO_2 and the evaporating temperature of the refrigerant on the high temperature side. As the temperature difference on the cascade condenser increases, the overall efficiency of the refrigeration system decreases!



Temperatures and pressures in cascade systems (continued)

On systems with low temperatures of the discharge CO2 gas (low superheat), the superheat of the expansion valve can be the dimensioning factor for the heat exchanger.
If a CO2 system has high superheat, then desuper-heaters need to be used in order to reduce the load on the high temperature side.

Optimal intermediate pressure in CO2 cascade systems depends on a number of parameters (high temperature refrigerant, load pattern etc.). Generally 2 cases need to be considered:

1) Systems with load at the medium temperature. In this case intermediate pressure should be as high as possible in order to reduce the load at the high temperature stage. The limitations are therefore required temperature on the intermediate level and pressure rating of the system.

2) Systems without load at medium temperature. In this case the intermediate temperature should be in the range of -10 - 0°C (due to the high pressure of the CO_2 LT) where lower limit is defined by efficiency and higher by system pressure rating

Operating sequence of cascade systems

In Cascade Systems, it is essential that at least one compressor in the high temperature side is running before the first compressor in the low temperature side can start. Otherwise, the compressor in the low temperature side may be cut out due to high pressure.

The same sequence is also valid for filling up the system. First of all, the high temperature circuit needs to be filled with refrigerant and started up. When this is done, the CO_2 can be filled into the low temperature system.

The high temperature expansion valve (ETS) to the cascade heat exchanger should begin simultaneously with the high temperature compressors. After this, the valve controls the superheat of the high temperature gas. LT compressors are then started up by the CO_2 pressure increase on the suction line.

Danfoss pack controllers such as AK-PC 740 and AK-PC 780 are specially designed with built in control functions to coordinate these operations.

Injection into cascade heat exchanger

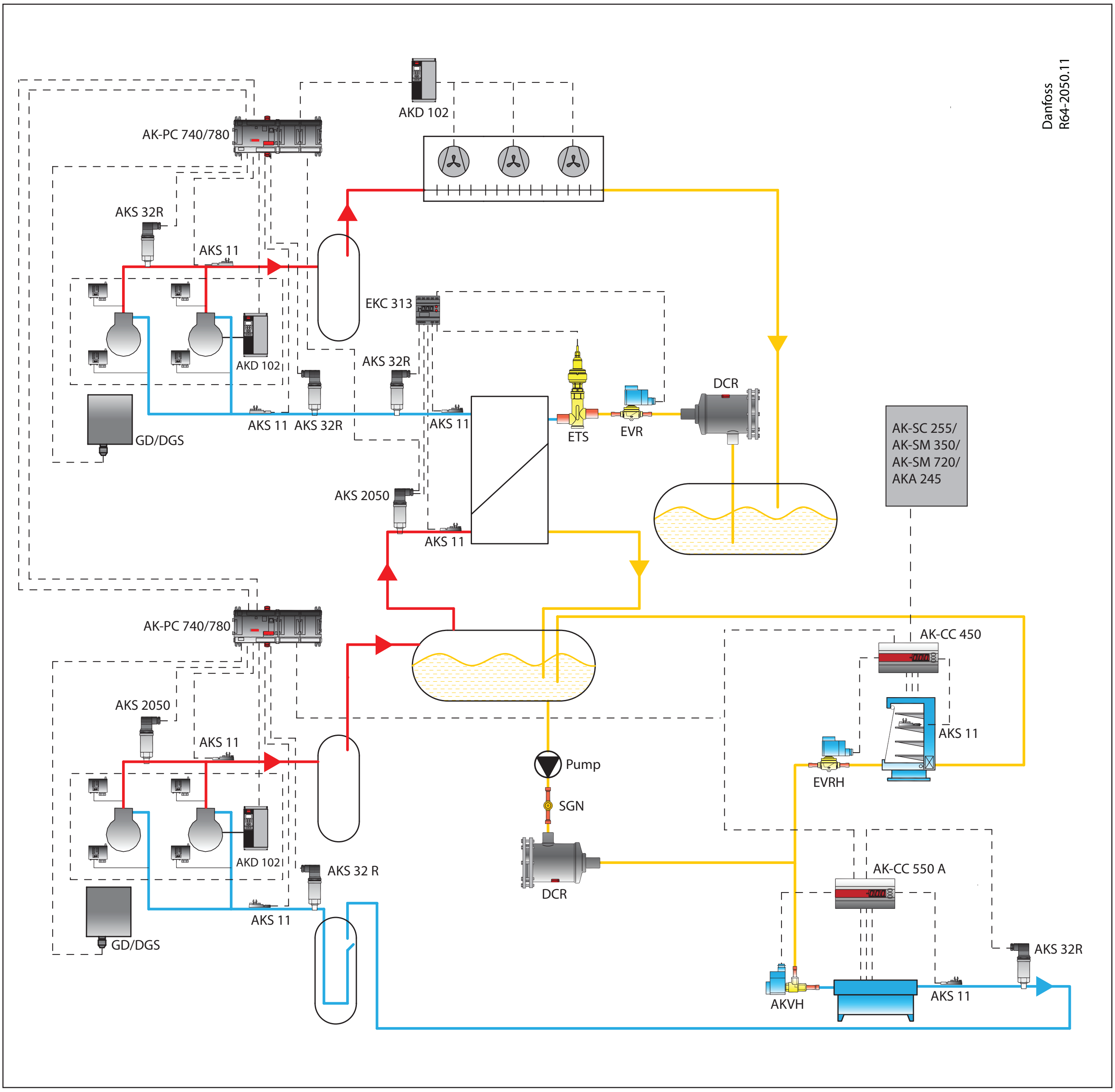
Injecting liquid into a plate heat exchanger is not a trivial matter. The heat exchanger is often compact and therefore the time constant is very low. AKV valves are not recommended for this application.

It is recommended to use motor valves or other valves that give constant flow. Desuper-heating of CO_2 gas entering the cascade heat exchanger can also be recommended for three reasons.

One reason is that the gas is often 60°C and therefore the heat can be rejected to the ambient or used for heat recovery without problems. The second reason is to reduce thermal stress in the heat exchanger. The third reason is that the CO_2 gas gives very high heat fluxes which therefore create unstable conditions on the evaporation side. Therefore it is recommended to reduce the superheat on the CO_2 side.

Distribution on the CO_2 side is also a critical issue. This is why the heat exchanger has to be designed for direct expansion to make sure the mixture of gas and liquid is evenly distributed to the heat exchanger.

When the heat exchanger is designed for reasonable pressure drop at part load, the oil transport and distribution should work under most conditions.



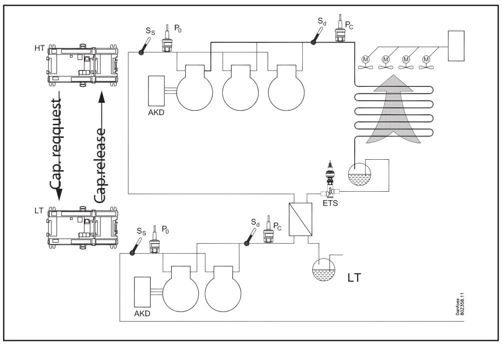
Cascade HFC - CO_2 system

Controls of Cascade system

Control of cascade systems can be divided into:
• Condenser capacity control
• Compressor capacity control
• Cascade injection control
• MT evaporator CO2 flow control
• LT evaporator injection control

Condenser capacity control

Capacity control of the condenser can be accomplished via step regulation or speed control of the fans.
As regulating sensor for the capacity distributor the condenser pressure should be selected. The reference for the regulation can be defined in two ways. Either as a fixed reference or as a reference that varies according to the outdoor temperature. The reference for the condensing pressure is set in °C (°F).



Compressor capacity controls

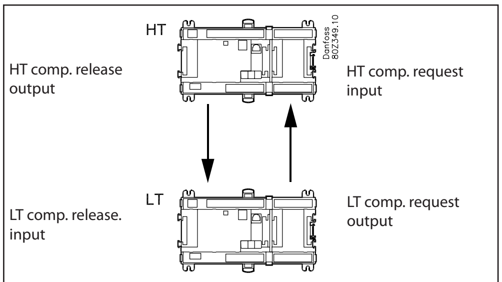
Pack controller AK-PC 740 (up to 4 compressors) or AK-PC 780 (up to 8 compressors) controls the LT suction pressure and is a standard controller for controlling one suction group in any refrigeration system. The controller is capable of regulating variable speed of two compressors combined with one-step compressors of the same or different sizes, depending on the choice of coupling pattern.

A unique feature in the AK-PC 740/780 make it possible to use the Pc pressure in the LT CO_2 side as control sensor for the HT suction pressure. This to ensure fast and stable control of the condensing pressure of LT CO_2 side.

Low-pressure / high-pressure coordination

The AK-PC 740/780 is also able to coordinate the LT and HT start to ensure a smooth operation. Here the high-pressure compressors can start either as a result of:
- Load on the high-pressure circuit
- Requirements from the low-pressure circuit

The high-pressure circuit will still ensure that the low-pressure circuit is only permitted to start when at least one high-pressure compressor has started. It will also ensure that security timers and compressor timers are complied with.



Here both a relay output and an On/off input are used on both controllers.

Oil Management / Oil equalisation

The build in oil management system covers most systems found on the market to day. Can be used with CO_2 as well as all other conventional refrigerants and support input signals from :
• Level switch on compressor
• Level switch on oil separator
• Level switch on oil receiver
• Pressure transmitter on oil receiver

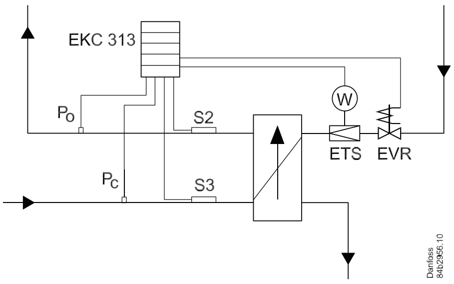
Oil supply to the compressors is managed by activating solenoid valves with user defined ON/Off pulse sequences.

Cascade injection control

In systems with cascade regulating and CO_2 as refrigerant on the low temperature circuit EKC 313 can regulate liquid injection (by means of an ETS stepper expansion valve) into the cascade heat exchanger in one of two ways:

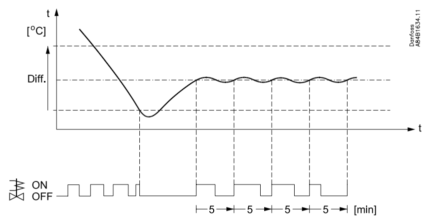
- Optimize superheat
- Regulate the condensation pressure at the low temperature circuit while ensuring that the superheat does not become too low.

If there are no evaporators on the high temperature circuit the cascade controller should be set in control mode 1 to optimise superheat. In this application the condensation pressure on the low temperature circuit should be controlled by the compressor capacity controller in the high temperature circuit. Here the LT PC signal is received at the HT P0 input.



MT evaporator CO_2 flow control

The air temperature in the medium temperature display cases or rooms is controlled by opening/closing a solenoid valve/motor valve in the CO_2 supply to the evaporator. The actual temperature control can take place in two ways: as ordinary ON/OFF regulation with a differential, or as modulating control (PWM) where the temperature variation will not be nearly as big as in ON/OFF control.
In a system with several evaporators supplied by the same CO_2 liquid pump, modulating temperature control should be chosen as this also provides a more constant flow of CO_2 to the CO_2 pump.



Period time, n63

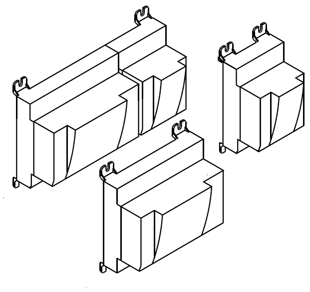
LT evaporator injection control

Injection control for the low temperature case and cold room evaporators is an AK-CC 550A utilizing pulse-width-modulating injection valves AKVH and patented adaptive software algorithms to optimise system performance and operation.

Pressure control

The Danfoss CO_2 controllers have more pressure safety functions which prevents safety valves to open and hereby loss of charge.

AK PC 740 pack controller
A max compressor discharge pressure safety function will reduce compressor capacity

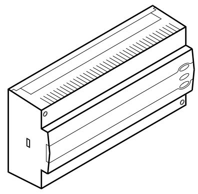


AK-PC 740
Flexible controller for capacity control of compressors and condenser fans. Number of I/O can be extended with AK-XM extension modules.

- 4 compressors with up to 3 un-loaders
- 6 fans
- Max. 60 inputs/outputs
- Variable speed control on lead compressor and condenser fans
- Build in oil Management functions
- Release-request function for coordination between high-pressure and low-pressure compressors.

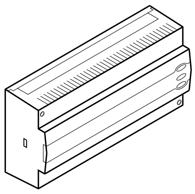
AK-PC 780
As AK-PC 740 plus:

- 8 compressors with up to 3 un-loaders
- 8 fans.
- Max. 100 inputs/outputs.



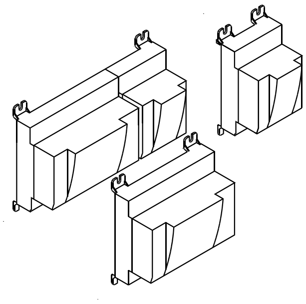
AK-CC 450
Complete refrigeration appliance control with great flexibility to adapt to all types of refrigeration appliances and cold storage rooms.

- For cooling with brine or pumped CO_2
- For use with a thermostatic expansion valve.
- Energy optimisation of the whole refrigeration appliance
- One controller for several different refrigeration appliances
- Natural, electric or hot gas defrost

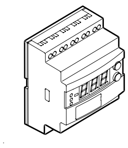


AK-CC 550A
As AK-CC 450 +

- For cooling with Electronic expansion valve
- Adaptive control of superheat
- Adaptive defrosting based on evaporator performance

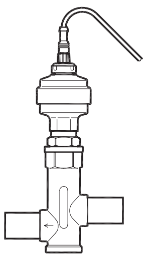


AK-CC 750
Flexible refrigeration appliance controller for control of up to 4 evaporators.



EKC 313
Controller for liquid injection in cascade heat exchangers with CO_2 as refrigerant on the low temperature circuit.

- Stepper motor driver for ETS or CCM expansion valve.
- 0 - 10 V output for ICMTS valves



ETS
ETS is a series of electrically operated (stepper motor) expansion valve

- Electrically operated expansion valves for precise liquid injection in evaporators
- Fully balanced, providing bi-flow feature as well as solenoid tight shut-off function in both flow directions.

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