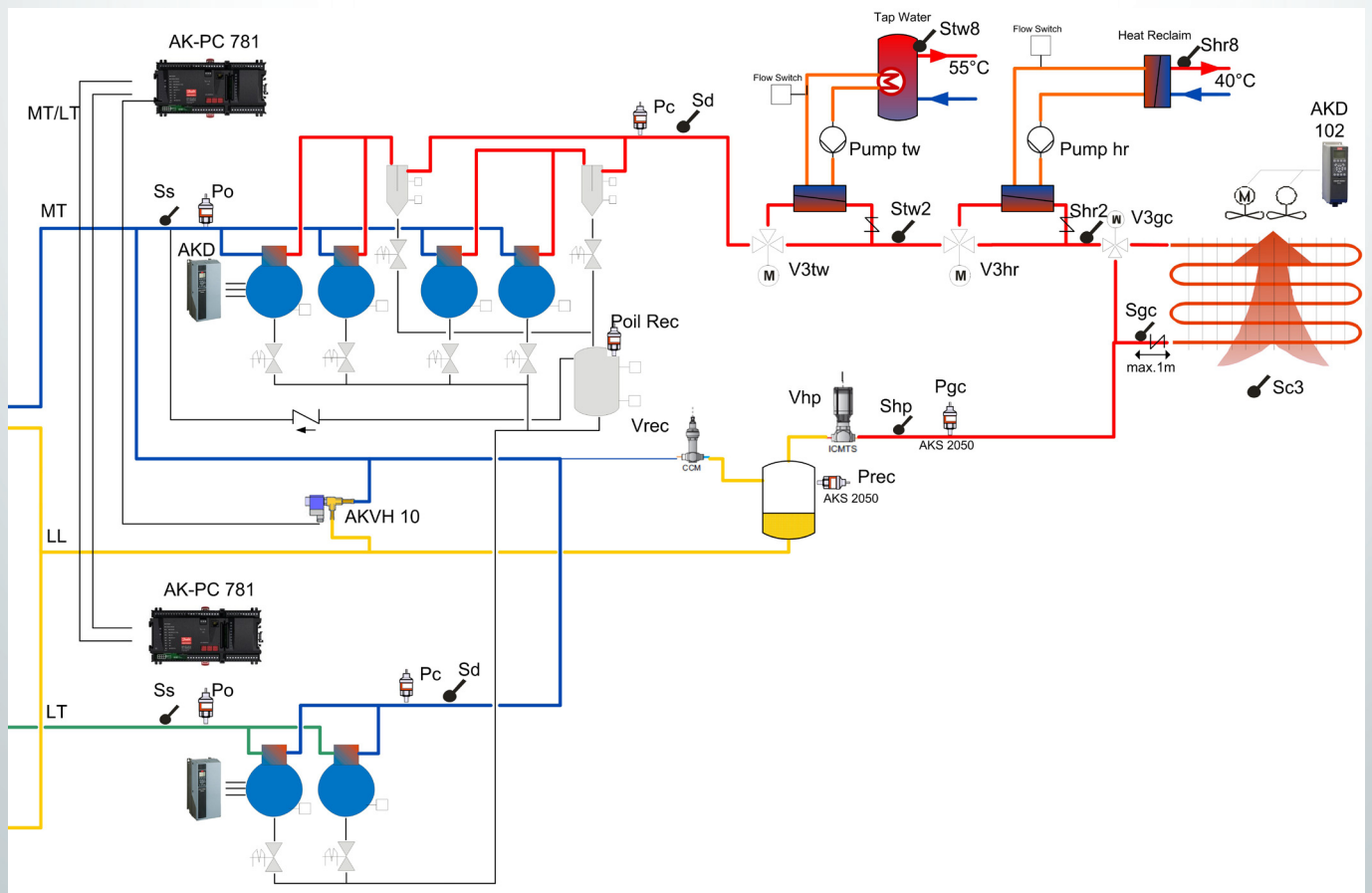


Application Guide

1 and 2 stage Transcritical CO₂ systems

How to control the system

ADAP-KOOL® Refrigeration control systems



General description

With the increased environmental focus CO₂ is becoming more and more attractive as a natural refrigerant due to its low ODP and GWP. One of the most promising systems especially in colder climate is the 2 stage transcritical CO₂ system often called transcritical CO₂ booster system. Energy comparison between R404a systems and CO₂ systems has shown the same or better performance with CO₂ transcritical systems and the design is relatively simple. In addition transcritical CO₂ systems offer unique features for heat reclaim (see application guide "Heat reclaim in transcritical CO₂ system")

The nature of CO₂ with the critical point as low as 31°C at 74 bar puts special requirements on the mechanical design as well as how to control the system.

One Stage system:

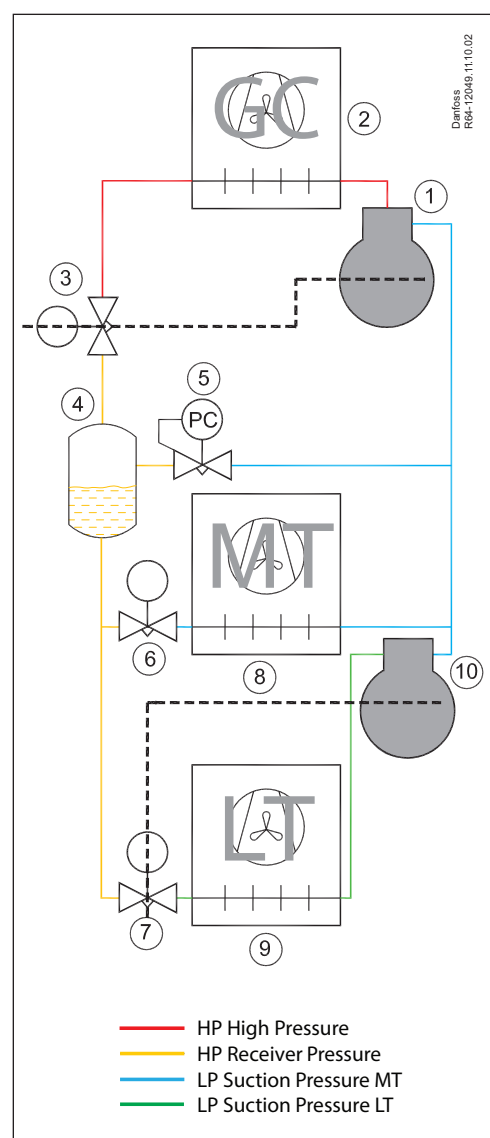
A typical one stage CO₂ transcritical system is divided into two pressure levels; high pressure level and medium pressure level.

The high pressure section begins at the high pressure compressor (1), through the gas cooler (2) to the high pressure control valve (3). The design pressure in this section is usually between 90 and 120 bar.

The medium pressure section begins at the high pressure expansion valve (3) where the flow is separated into gas and liquid in the receiver (4). The gas phase is bypassed to the suction line of the high pressure compressors through a bypass / receiver valve (5) while the liquid flows to the MT expansion valve (6) where it is expanded before the MT evaporators (8). The gas from the MT evaporator is mixed with gas from the gas bypass from where it enters the suction line to the high pressure compressors and completes the circuit.

Two stage system:

A two stage transcritical system includes all the same functions as the 1 stage transcritical system where a low temperature (low pressure) stage is just added. The Liquid flows from the receiver (4) to the LT expansion valve (7) where it is expanded in the LT evaporators (9). The gas from the LT evaporators is compressed in the LT compressor (10) and mixed with the gas from the MT evaporators and the gas bypassed from the receiver.



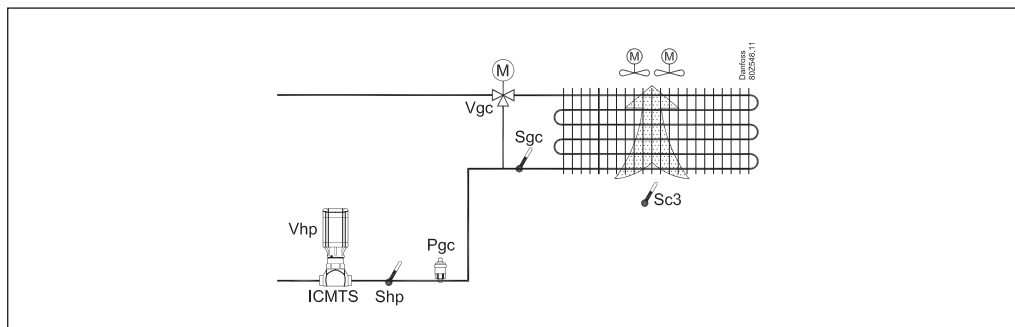
Transcritical booster system with gas bypass

Controls

Controls for a transcritical CO₂ system can be divided into four groups; gas cooler controls, receiver pressure controls, compressor capacity controls and evaporator controls. In applications with heat reclaim a number of control functions around the gas cooler have to be added.

The integrated pack controller AK-PC 781 is specially designed to control all functions in a 1 or 2 stage transcritical CO₂ pack application with advanced heat reclaim (In two stage systems a second AK-PC 781 is added to control the low temperature compressor stage).

Gas cooler controls



At temperatures and pressures above the critical point there is no relationship between pressure and temperature (not tied together as seen in the subcritical refrigeration process) which is temperature and pressure have to be controlled individually.

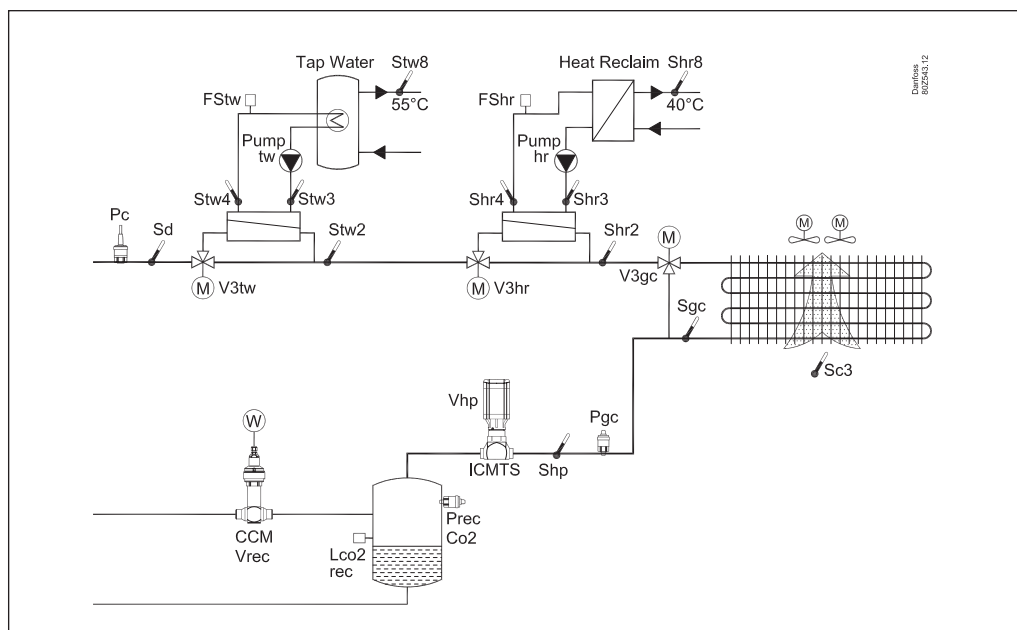
Minimum gas temperature out of the gas cooler is kept by capacity control of gas cooler fans (condenser fans). Best control of fans is obtained with a combination of variable speed and fan steps by using AKD and analogue-/relay outputs from AK-PC 781. The optimum reference for fan control is a user defined minimum temperature difference between "Sc3" Air ON temperature and "Sgc" CO₂ gas temperature measured just at the outlet of the gas cooler.

Important! The Sgc sensor has to be mounted just at the outlet of the gas cooler.

Minimum pressure in the gas cooler is kept by controlling the ICMTS / CCMT high pressure expansion valve (Vhp). The AK-PC781 controller guarantees the system's maximum performance by maintaining the optimal pressure in the gas cooler when regulation takes place. The controller will always optimise to a subcritical state unless heat recovery or other override functions are calling for increased pressure. Both a temperature reading Sgc / Shp (when bypassing the gas cooler in heat recovery mode Shp is used) and a pressure reading Pgc is necessary to control gas cooler pressure.

A feature to automatically increase refrigeration capacity has been build-in. The function will start increasing the gas pressure with a user defined offset after the compressor capacity has reached 100% for more than 5 minutes.

Heat reclaim



The integrated heat reclaim function in AK-PC 781 is able to control the heating temperature in up to two independent circuits, one typically used for hot tap water and a second circuit typically used for room heating at a lower temperature level.

It's possible to increase the pressure in the gas cooler or even by pass the gas cooler to increase the amount of heat that can be reclaimed, without compromising refrigeration of food.

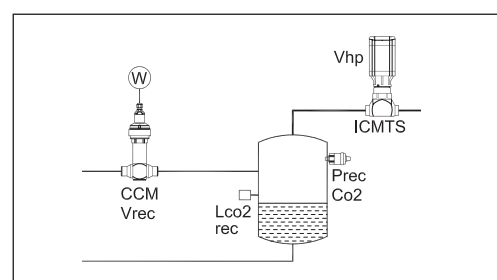
If heat reclaim is setup but no heat reclaim is requested, then the controller will bypass the heat exchangers by means of the valves "V3tw" / "V3hr" and the pumps "Pump tw" / "Pump hr" will be stopped. If no heat reclaim is requested the refrigeration process will be controlled at lowest possible gas temperature "Sgc" depending on ambient temperature "Sc3" and optimum pressure to ensure optimum COP of the refrigeration process.

For further information see application guide "Heat reclaim in transcritical CO₂ system"

Receiver control

To reduce the pressure in distribution systems, the gas bypass is introduced. After the high pressure expansion, the gas and liquid is separated and the gas is bypassed directly to the suction side of the compressor. The liquid is distributed to the evaporators. This makes it possible to use standard pressure components. The receiver pressure can be controlled by means of AK-PC 781 activating the valve "Vrec" so that pressure is kept at a set reference point. This control requires the installation of a CCM stepper valve, a stepper driver module and an AKS 2050 pressure transmitter "Prec"

Max. and Min. Receiver pressure override:
The most common override function is minimum receiver pressure. If receiver pressure falls close to the suction pressure the differential pressure for the AKVH valves disappears and therefore the load on compressors disappears resulting in compressor stop. In this state the system can't restart by it self which is why it's crucial that this situation does not take place!



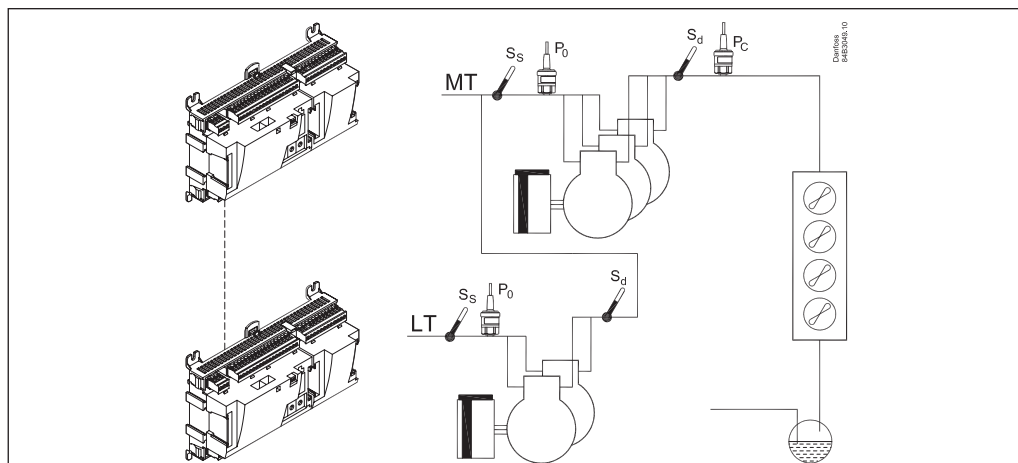
To ensure minimum receiver pressure an override function is present in the AK-PC 781 to gradually open the ICMTS high pressure valve "Vhp" and pressurise the receiver. This function is typically activated during cold periods, but also if there is not enough refrigerant on the system.

To avoid too high receiver pressure an override function is present in the AK-PC 781 to gradually close the ICMTS high pressure valve "Vhp".

Important!

At override the minimum and maximum opening degree which can be set for the high pressure valve will still be respected. The override functions can be disabled by setting the respective P-band equal to 0.

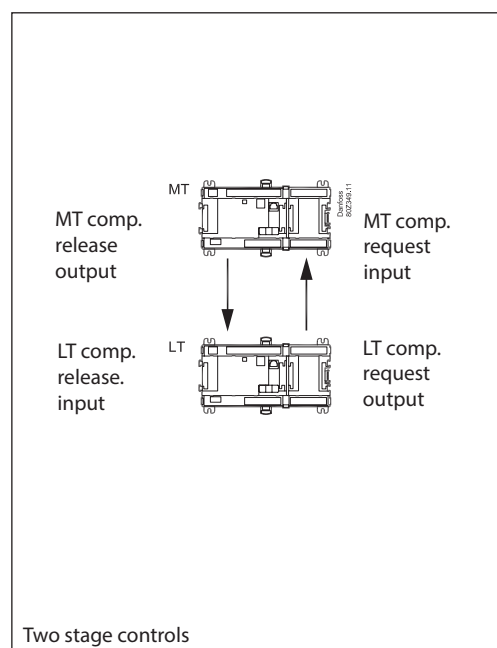
Compressor capacity control



The integrated pack controller AK-PC 781 is able to control the suction pressure by standard capacity control of compressors, un-loaders, and variable speed compressor to a set value eg. -10°C . As control sensor an AKS 2050 "Po" is used.

In a two stage system a low temperature compressor stage (booster) is just added to the one stage transcritical system described above, and a second AK-PC 781 is controlling compressor capacity to a set value of eg. -30°C . To coordinate the control between medium temperature and low temperature compressors it's recommended to utilise the built in LT/MT co-ordination where MT compressors will be forced to start when requested by the low temperature stage.

Since CO_2 is a more dynamic refrigerant than HFC and other known refrigerants it's recommended to install a variable speed drive like AKD on lead compressor to ensure stable control of suction pressure.



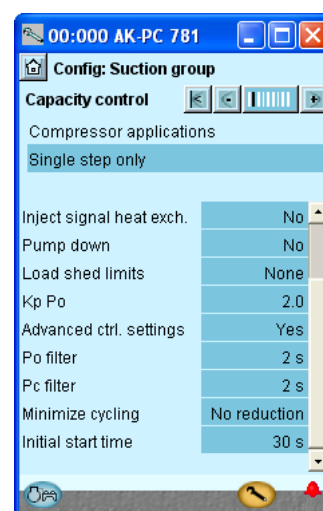
Two stage controls

Compressor capacity stability

As CO_2 is a more dynamic refrigerant than HFC and other known refrigerants the standard settings are not always robust enough to secure a safe and reliable control.

There are mainly 2 parameters that need to be addressed. The AK-PC 781 compressor capacity control is based on a PI control algorithm, but it looks more or less like a neutral zone controller where the time in the zones is a kind of integration time and the width of the zones is proportional band. The standard settings are often acceptable, but if the controller needs to react faster the best solution is often to increase the "KpPo" to somewhere between 4 and 10 depending on system dynamics.

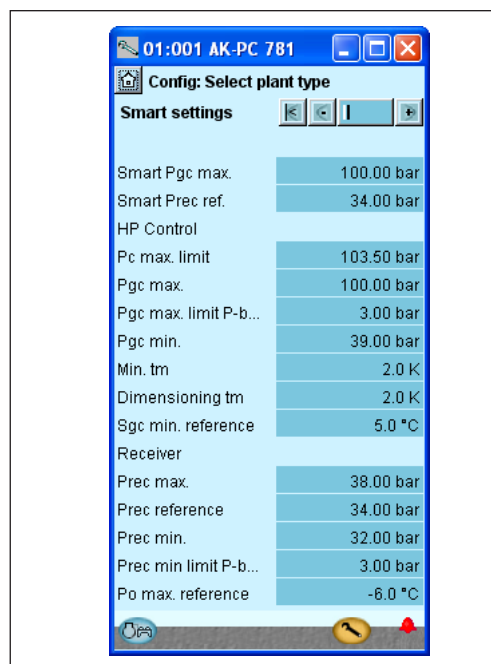
Another parameter that often has to be changed in CO_2 booster systems is "Initial start time" (can be found in "Advanced ctrl. Settings" set to Yes). This is the time the first compressor step has to run before the PI controller starts to count up for the next step. The problem is mainly seen during start up of the system because the controller will react too slowly. A value of 5 seconds is normally used without causing problems.



Smart set-up of high pressure control and receiver pressure control settings

In a transcritical CO₂ system a number of settings are dependent of each other. To secure robust control a number of settings can automatically be set by only adjusting two settings "Smart Pgc max." and "Smart Prec ref."

All related settings that are automatically suggested by the controller can afterwards be manually adjusted in the different menus where they are shown if requested.



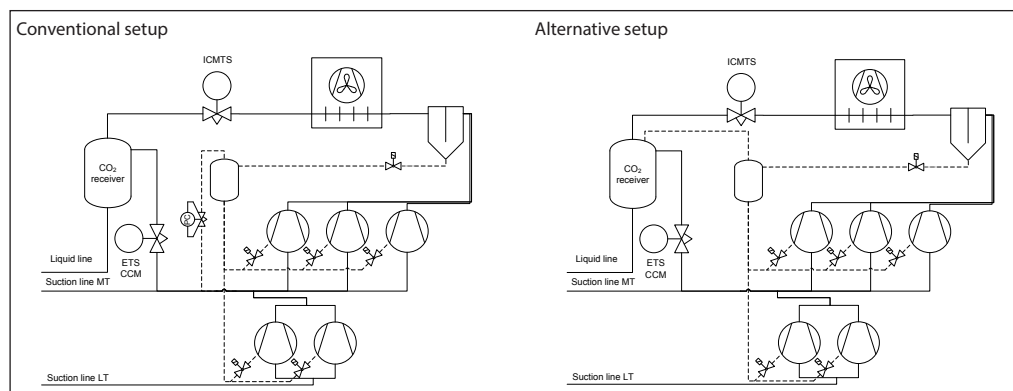
Oil Management / oil equalisation

AK-PC 781 offers a built in oil management function that supports high savings for the users. The built in oil management system covers most systems found on the market today and can be used with CO₂ as well as all other conventional refrigerants and supports 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.

In transcritical CO₂ systems the refrigerant receiver pressure is typically approx 10 bar higher than the evaporation pressure, and at a level where the pressure in the oil and refrigerant receiver is at roughly the same level. This makes it possible to connect a pipe between the two receivers (or put the oil receiver inside the refrigerant receiver) to have the same pressure level. By doing this we take out the spring loaded check valve often used to ensure that the pressure is approx 3-5 bar higher in the oil receiver than suction line. This valve fails from time to time resulting in no pressure differential and thereby no oil supply to compressors.



How will this affect the control of the oil management?

Basically it will not effect the oil management in the controller, but there is a possibility that it can enhance and make functionality better. The oil management software has a possibility to utilise a pressure transmitter mounted in the oil receiver. Since the oil receiver and refrigerant receiver is at the same pressure, the pressure transmitter used in the receiver can be used. This means that

if the pressure in the oil and refrigerant receiver is too low, the valve to the oil separator will open to pressurise the oil receiver. As a positive side effect the refrigerant receiver will also be pressurised. This will work as an extra protection for low receiver pressure in cold climates and the system is not involving extra components but just making more clever use of the existing refrigerant receiver pressure transmitter.

Evaporator injection controls in cases and rooms

Superheat control of CO₂ in evaporators is slightly more difficult than HFC and other refrigerants. The reason for this is mainly that many of the evaporators on the market today are not designed for CO₂, but often adapted. Therefore the selection and setup of the case controller is very important.

There are 2 case/room controllers in the Danfoss portfolio that have a special algorithm for CO₂ that detects and reacts faster to low super heat. The two controllers are AK-CC 550A and AK-CC 750.

General settings

It's recommended to use 6 K as min. superheat and 12 K as max.

SH close should not be set lower than 2 K.

It is also recommended to use the MOP function. The MOP function closes the valve when the pressure is at the MOP temperature. A setting of -3°C is normally a good value for medium temperature, and -20°C for low temperature. This

function is very helpful when starting the system the first time or after a major system power failure.

Injection ON is also a feature that can be helpful. The Injection ON signal is sent from the pack controller to the case/room controllers if the pack is not able to run and the valves will be kept closed. This feature can be enabled in the system manager. The System Manager can also be used to stage in the evaporator controllers so that full load is not placed on the pack immediately.

It's important to select a pressure transmitter for superheat measuring covering the full pressure range ex. In a 40 bar system a pressure transmitter AKS 2050 -1 ->59 bar has to be selected!

When to use AKV or AKVH valves

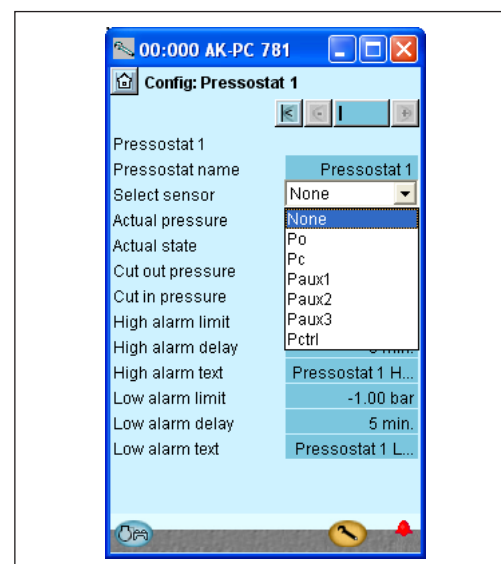
Both HT and LT side of the system can use standard 52 bar AKV valves for 40 bar liquid system.

When a 60 bar liquid system is implemented then the AKVH 90 bar valves should be used.

Safety and emergency solutions

A number of safety functions have been built into the AK-PC 781 controller and as long as there is power to the controller and related control valves, the controller will try to keep the system running. In case of too high pressures or temperatures measured against set values; compressor capacity will be reduced, high pressure valves overridden, or gas cooler fans overridden. To ensure integrity of food the controller makes use of already installed sensors which are utilised as redundancy sensors i.e. "Shp" that is used in case "Sgc" fails.

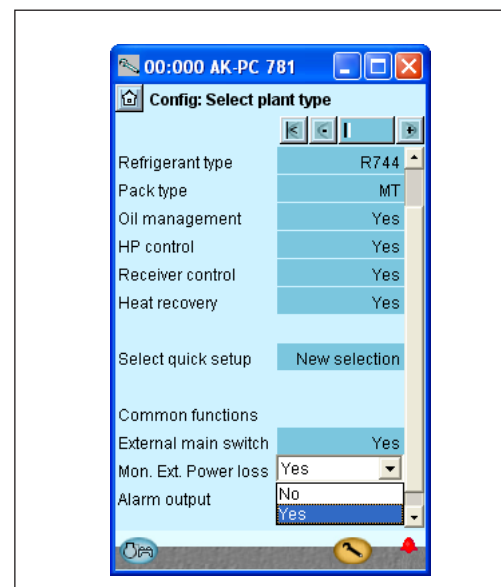
The general purpose pressostats and thermostats can be setup to activate relay outputs based on pressure transmitters or temperature sensors that again could activate solenoid valves for opening or closing parts of the refrigeration circuit to avoid activation of safety valves and thereby loss of refrigerant.



Power failure

In case of system power failure the gas by pass valve and the high pressure valve will be left in the position they have at that moment. This is a problem in case the low pressure side has a lower design pressure than the high pressure side of the receiver. As a consequence of this the system will equalise the pressure and very often this will result in a safety valve opening on the low pressure side. To make sure this is not happening the valve has to be closed. The most cost effective way is to use a UPS unit that supplies the controllers and valves with power to make sure the valves can close.

A feature in AK-PC 781 to monitor "External Power loss" can be activated to generate a digital input. When this digital input is activated a power loss alarm will be generated but all other alarms will be disabled. By activating both the external main switch and the power loss input the controller will stop all control and fully close both the high pressure valve and the by-pass valve.



Stand still pressure

It's important to put special attention to the stand still pressure (when the system is not in operation), i.e. if temperature in the LT or MT side increase to ambient temperature (22°C equal to 60 bar for CO₂) the system has to be designed to match this pressure or emergency cooling has to be activated to avoid activation of safety valves and thereby loss of refrigerant.

In case the main switch is set to off all control functions will be stopped and both the high pressure valve and the bypass / receiver valve will be closed. If the system (i.e. the receiver) is not designed for stand still pressure and no other functionality has been installed to keep pressure below design limits the safety valve will open as soon as pressure reaches the relief pressure of the safety valve.

Hint for initial start-up of CO₂ Transcritical booster systems

When refrigerant has been filled in the system the following steps should be taken into consideration at first initial start up of plant:

1. Increase minimum pressure in the gas cooler from typical 45 bar to a fixed reference at eg 80 bar.
2. Start HP pack (compressors and gas cooler fans) eventual manual override of compressors is needed)

3. Sequentially start MT evaporators until all evaporators are running with stable load
4. Start LT compressor pack (Compressors)
5. Sequentially start LT evaporators until all evaporators are running with stable load
6. Release operation of gascooler to normal operation.

Through the whole start-up sequence refrigerant level in the receiver should be monitored and in case of low level CO₂ should be topped up.

AK-PC 781 Pack controller

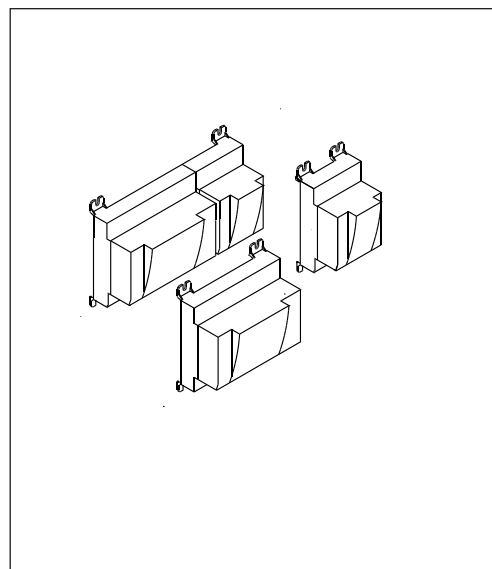
Flexible controller for capacity control of compressors and condenser fans (gas cooler fans). High pressure control and gas cooler control functionality with advanced heat reclaim is integrated and can be activated for CO₂ transcritical applications. Number of I/O can be extended with AK-XM extension modules.

Pack control functionality

- 8 compressors with up to 3 un-loaders
- 8 fans.
- Variable speed control on one or two lead compressors as well as condenser fans.
- Built in oil Management functions
- Max. 120 inputs/outputs.

Integrated functionality for trans critical CO₂

- High pressure control to ensure optimum COP
- Gas cooler control (fans control)
- Receiver pressure control (gas bypass valve)



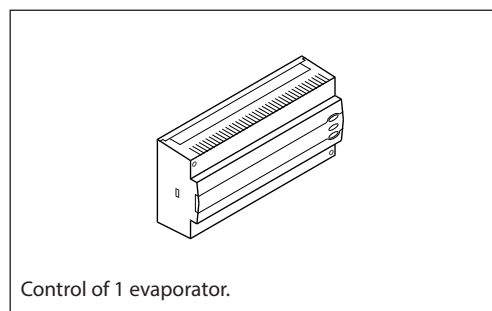
AK-CC 550A Single evaporator controller

Dedicated refrigeration appliance control with great flexibility to adapt to all types of refrigeration appliances and cold storage rooms.

Electronic expansion valve control of Danfoss AKV or AKVH valves

Day/night thermostat with ON/OFF or modulating principle

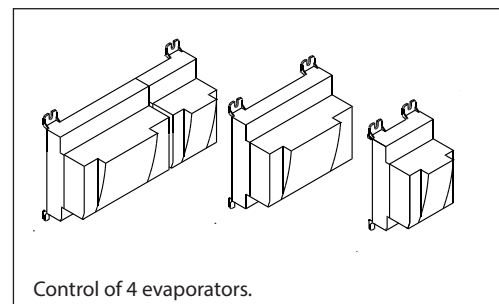
- Adaptive control of superheat
- Adaptive defrosting based on evaporator performance
- Natural, electric or hot gas defrost
- Case cleaning function for documentation of HACCP procedure
- Door function
- Light control



Control of 1 evaporator.

AK-CC 750
Multiple Evaporator control-
ler

Flexible refrigeration appliance controller for control of up to 4 evaporators.



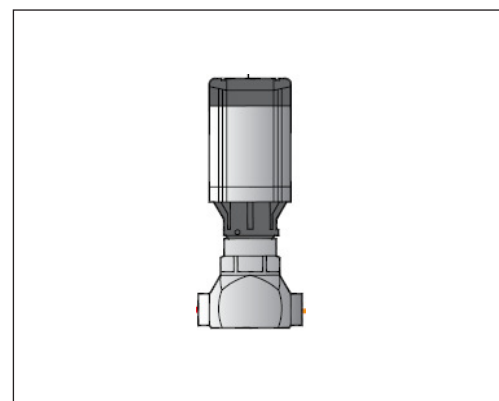
ICMTS

Direct operated motorised valve driven by actuator type ICAD 600TS.

0/4->20 mA

0/2->10 Volt

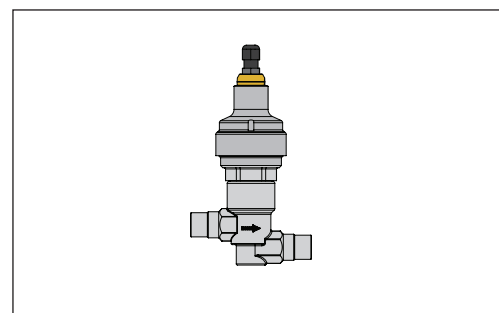
- Designed for high pressure CO₂ systems with applications for a maximum working pressure of 140 bar / 2030 psig.
- Regulating cone ensures optimum regulating accuracy, particularly at part load.
- Manual opening possible via ICAD 600TS or Multifunction tool.
- The PTFE seat provides excellent valve tightness.
- Magnet coupling - real hermetic sealing.



CCMT

Electrically operated stepper valve

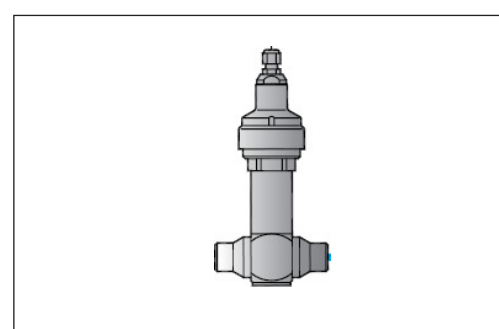
- Designed for high pressure CO₂ systems with applications for a maximum working pressure of 140 bar / 2030 psig.
- The valve is capable of functioning either as an expansion valve, as a pressure regulator for the gas cooler or as a gas bypass valve with back-pressure regulation.
- MOPD up to 90 bar (1305 psi).



CCM

Electrically operated stepper valve

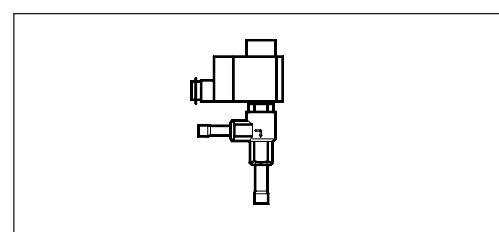
- Specifically designed for operation in CO₂ systems as an expansion valve, or as a gas bypass valve in subcritical applications.
- Up to 90 bar (1305 psi) working pressure
- Precise positioning for optimal control of intermediate pressures
- Possibility of bi-flow operation
- MOPD up to 50 bar (725 psi).



AKV /AKVH

PWM (Pulse Width Modulating) electronic expansion valve.

- Specifically designed for supermarket applications
- Can be used for all HFC as well as CO₂ refrigerants
- Max working pressure: AKV Up to 52 bar, AKVH up to 90 bar stand still pressure.



AKS 2050

Pressure transmitter.
Specifically designed for operation on CO₂ systems:

- 1 to 59 bar
- 1 to 99 bar
- 1 to 159 bar.
- Highly developed sensor technology means great regulation accuracy
- Built-in voltage stabilizer
- Robust construction gives protection against mechanical influences such as shock, vibration, and pressure surge.

