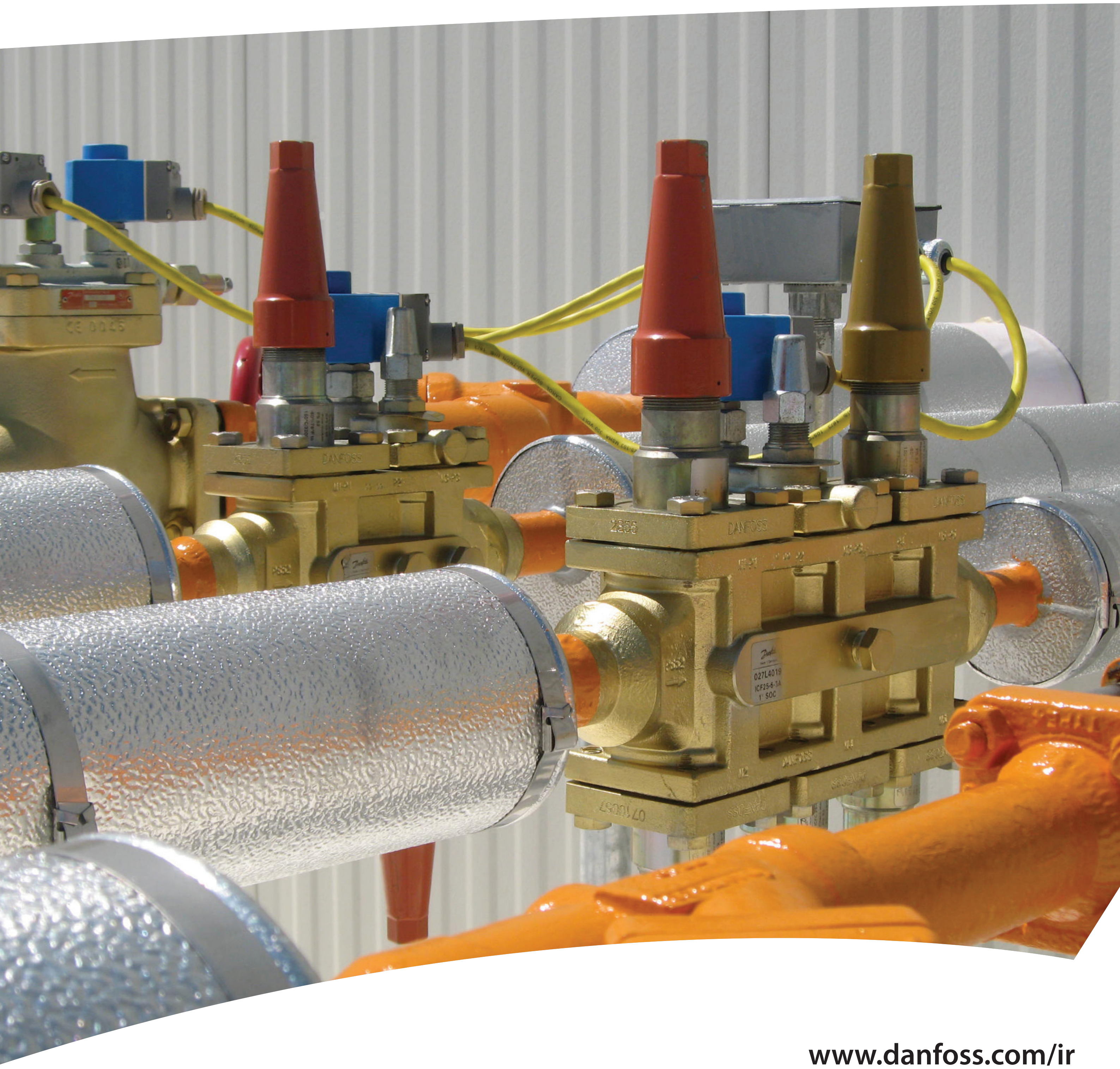
MAKING MODERN LIVING POSSIBLE

Application Handbook

Industrial Refrigeration
Ammonia and CO_2 applications



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HTRS
LIQ
VAP
AMMONIA
LOW
HTRS
AMMONIA
HGD
HTRS
HTRL

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Foreword

This Danfoss application guide is designed to be used as a reference document by all those involved in the workings of industrial refrigeration systems.

This guide aims to provide answers to the various questions relating to industrial refrigeration system control: - Why a type of control method is necessary for the refrigeration system? Why should it be designed in this way? What type of components can be used? How to select control methods for different refrigeration systems? In answering these questions, the principles of the different control methods are introduce followed by same control examples, comprising Danfoss Industrial Refrigeration products.

The main technical data of the components is also provided. Finally, comparisons between different solutions for each control method are made, so that the reader should know how to select a solution.

In this application guide, the pilot-operated servo valve ICS is recommended as a pressure and temperature regulator. Please note that the well established PM valve could also be applied where ICS is used.

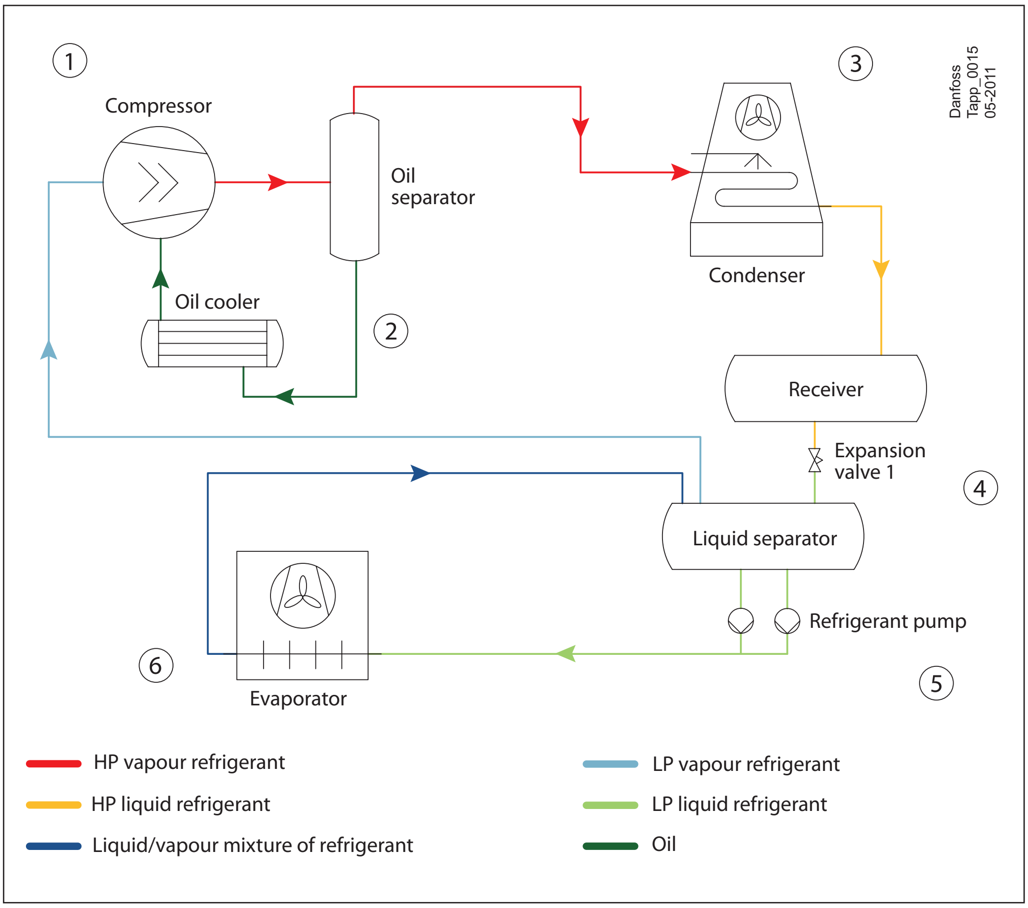
For the final design of the installation it is necessary to use other tools, such as the manufacturer's catalogues and calculation software (e.g. Danfoss Industrial Refrigeration catalogue and DIRcalc software).

DIRcalc is the software for calculation and selection of Danfoss Industrial Refrigeration valves. DIRcalc is delivered free of charge. Please contact your local Danfoss sales company.

Please do not hesitate to contact Danfoss, if you have questions about control methods, application and controls described in this application guide.

1. Introduction

Refrigeration System with Pump Circulation



① Compressor Control

Why?

- Primary: to control the suction pressure;
- Secondary: reliable compressor operation (start/stop, etc.)

How?

- Control the compressor capacity according to the refrigeration load by means of bypassing hot gas from the HP side back into the LP side, compressor ON/OFF step control or controling the rotating speed of the compressor;
- Install check valve on the discharge line in order to prevent reverse flow of the refrigerant to the compressor;
- Keep pressures and temperatures on the inlet and outlet of the compressor within the working range.

② Oil control

Why?

- Keep optimal oil temperature and pressure in order to guarantee reliable compressor operation.

How?

- Pressure: maintain and control the pressure differential across the compressor for oil circulation, maintain the crankcase pressure (only for piston compressors);
- Temperature: bypass some oil around the oil cooler; control the cooling air or water to the oil cooler;
- Level: return the oil in ammonia systems and low temperature fluorinated systems.

1. Introduction
(continued)

③ Condenser Control

Why?

- Maintain the condensing pressure above the minimum acceptable value in order to guarantee sufficient flow through the expansion devices;
- Ensure the right distribution of the refrigerant in the system.

How?

- On/off operation or control the speed of the condenser fans, control the flow of the cooling water, flood the condensers with liquid refrigerant.

④ Liquid Level Control

Why?

- Provide the correct flow of liquid refrigerant from the high pressure side to the low pressure side according to the actual demand;
- Ensure safe and reliable operation of the expansion devices.

How?

- Control the opening degree of the expansion device according to the change of the liquid level.

⑤ Refrigerant Pump Control

Why?

- Maintain the pump running in trouble free mode by maintaining the flow through the pump within the permissible operating range;
- Maintain a constant differential pressure across the pump in some systems.

How?

- Design a bypass loop so that the flow can be maintained above the minimum permissible flow;
- Shut off the pump if it fails to build up enough differential pressure.
- Install a pressure regulating valve.

⑥ Evaporating System Control

Why?

- Primary: maintain a constant media temperature;
- Secondary: optimise operation of the evaporators;
- For direct expansion systems: guarantee that no liquid refrigerant from the evaporators enters the suction line of the compressor.

How?

- Change the flow rate of the refrigerant into evaporators according to the demand;
- Defrost evaporators.

⑦ Safety Systems

Why?

- Avoid unintended pressure of the vessels;
- Protect the compressor from being damaged by liquid hammering, overloading, oil shortage and high temperature, etc;
- Protect the pump from being damaged by cavitation.

How?

- Install safety relief valve on vessels and other necessary places;
- Shut off the compressor and pump if the inlet/outlet pressure or differential is out of permissible range;
- Shut off the system of part of the system when the level in the liquid separator or the receiver exceeds the permissible level.

2. Compressor Controls

The compressor is the "heart" of the refrigeration system. It has two basic functions:

1. Maintain the pressure in the evaporator so that the liquid refrigerant can evaporate at the required temperature;
2. Compress the refrigerant so that it can be condensed at a normal temperature.

The basic function of compressor control, therefore, is to adjust the capacity of the compressor to the actual demand of the refrigeration system so that the required evaporating temperature can be maintained.

If the compressor capacity is bigger than the demand, the evaporating pressure and temperature will be lower than that required, and vice versa.

Additionally, the compressor should not be allowed to operate outside of the acceptable temperature and pressure range, in order to optimise its running conditions.

2.1
Compressor Capacity Control

The compressor in a refrigeration system is normally selected to be able to satisfy the highest possible cooling load. However, the cooling load during normal operation is usually lower than the design cooling load. This means that it is always necessary to control the compressor capacity so that it matches the actual heat load. There are several common ways to control the compressor capacity:

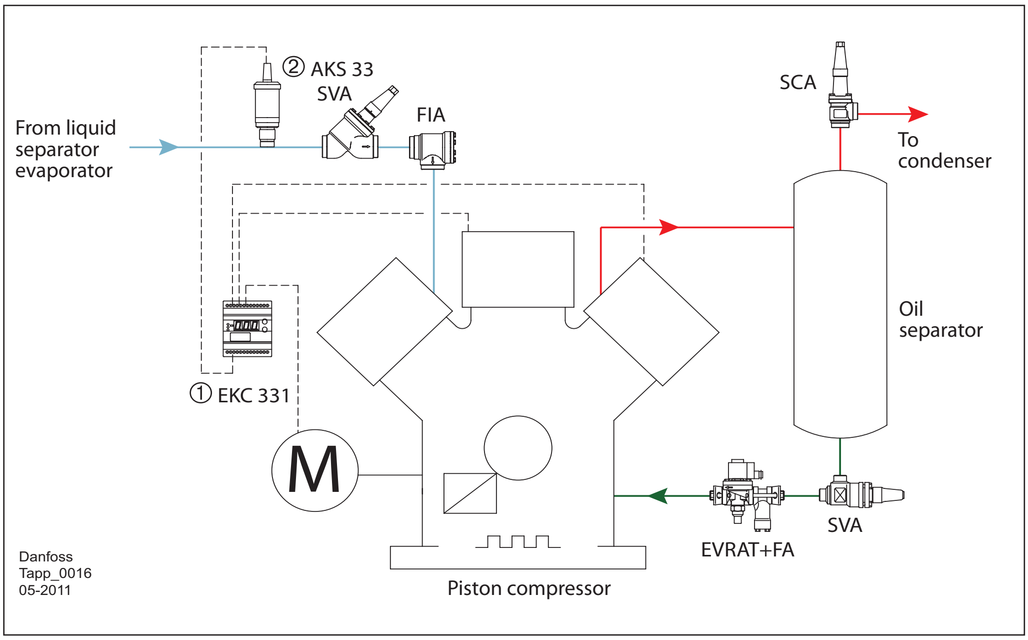
1. Step control.
This means to unload cylinders in a multi-cylinder compressor, to open and close the suction ports of a screw compressor, or to start and stop some compressors in a multi-compressor system. This system is simple and convenient. Furthermore, efficiency decreases very little during part-load. It is especially applicable to systems with several multi-cylinder reciprocating compressors.

2. Slide valve control.
The most common device used to control the capacity of a screw compressor is the slide valve. The action of the oil-driven slide valve allows part of the suction gas to avoid from being compressed. The slide valve permits a smooth and continuous modulation of capacity from 100% down to 10%, but the efficiency drops at part load.

3. Variable speed control.
Variable speed regulation. This solution is applicable to all kinds of compressors, and is efficient. A two-speed electric motor or a frequency converter can be used to vary the speed of the compressor. The two-speed electric motor regulates the compressor capacity by running at the high speed when the heat load is high (e.g. cooling down period) and at the low speed when the heat load is low (e.g. storage period). The frequency converter can vary the rotation speed continuously to satisfy the actual demand. The frequency converter observes limits for min. and max. speed, temperature and pressure control, protection of compressor motor as well as current and torque limits. Frequency converters offer a low start up current.

4. Hot gas bypass.
This solution is applicable to compressors with fixed capacities and more typical for commercial refrigeration. In order to control the refrigeration capacity, part of the hot gas flow on the discharge line is bypassed into the low pressure circuit. This helps to decrease the refrigeration capacity in two ways: by diminishing the supply of liquid refrigerant and releasing some heat into the low pressure circuit.

Application example 2.1.1: Step control of compressor capacity



🟥 HP vapour refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Step Controller
② Pressure Transmitter

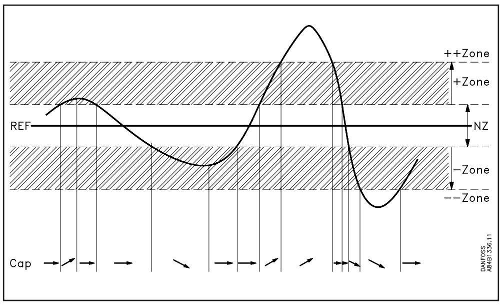
Step control solution for compressor capacity can be achieved by using a step controller EKC 331 ①. EKC 331 is a four-step controller with up to four relay outputs. It controls the loading/unloading of the compressors/pistons or the electric motor of the compressor according to the suction pressure signal from the pressure transmitter AKS 33 ② or AKS 32R. Based on a neutral zone control, EKC 331 can control a pack system with up to four equally sized compressor steps or alternatively two capacity controlled compressors (each having one unload valve).

EKC 331T version can accept a signal from a PT 1000 temperature sensor, which may be necessary for secondary systems.

Neutral Zone Control
A neutral zone is set around the reference value, in which no loading/unloading occurs.
Outside the neutral zone (in the hatched areas "+zone" and "- zone") loading/unloading will occur as the measure pressure deviates away from the neutral zone settings.

If control takes place outside the hatched area (named ++zone and --zone), changes of the cut-in capacity will occur somewhat faster than if it were in the hatched area.

For more details, please refer to the manual of EKC 331(T) from Danfoss.

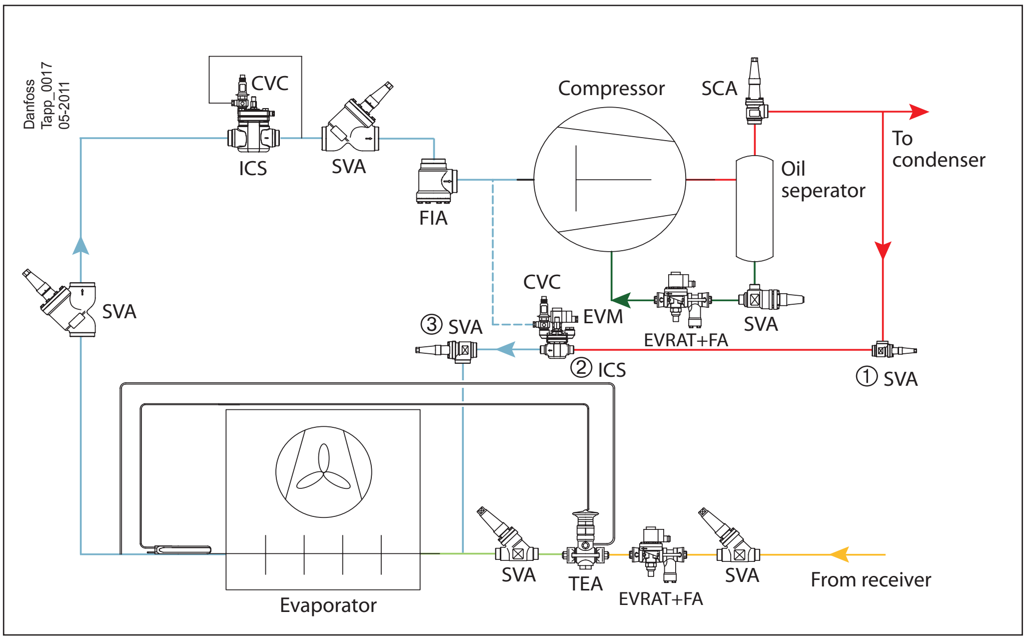


Technical data

	Pressure transmitter-AKS 33	Pressure transmitter-AKS 32R
Refrigerants	All refrigerants including R717	All refrigerants including R717
Operating range [bar]	–1 to 34	–1 to 34
Max. working pressure PB [bar]	55 (depending on operating range)	60 (depending on operating range)
Operating temp. range [°C]	–40 to 85	
Compensated temp. range [°C]	LP: –30 to +40 / HP: 0 to +80	
Rated output signal	4 to 20 mA	10 to 90% of V supply

	Pressure transmitter - AKS 3000	Pressure transmitter - AKS 32
Refrigerants	All refrigerants including R717	All refrigerants including R717
Operating range [bar]	0 to 60 (depending on range)	–1 to 39 (depending on range)
Max. working pressure PB [bar]	100 (depending on operating range)	60 (depending on operating range)
Operating temp. range [°C]	–40 to 80	–40 to 85
Compensated temp. range [°C]	LP: –30 to +40 / HP: 0 to +80	LP: –30 to +40 / HP: 0 to +80
Rated output signal	4 to 20 mA	1 to 5V or 0 to 10V

Application example 2.1.2: Compressor capacity control by hot gas bypass



🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant
🟩 Oil

① Stop valve
② Capacity regulator
③ Stop valve

Hot gas bypass can be used to control the refrigeration capacity for compressors with fixed capacity. The pilot-operated servo valve ICS ② with a CVC pilot valve is used to control the hot gas bypass flow according to the pressure on the suction line. The CVC is a back pressure controlled pilot valve, which opens the ICS and increases the flow of hot gas when the suction pressure is below the set value. In this way, the suction pressure ahead of the compressor is kept constant, therefore the refrigeration capacity satisfies the actual cooling load.

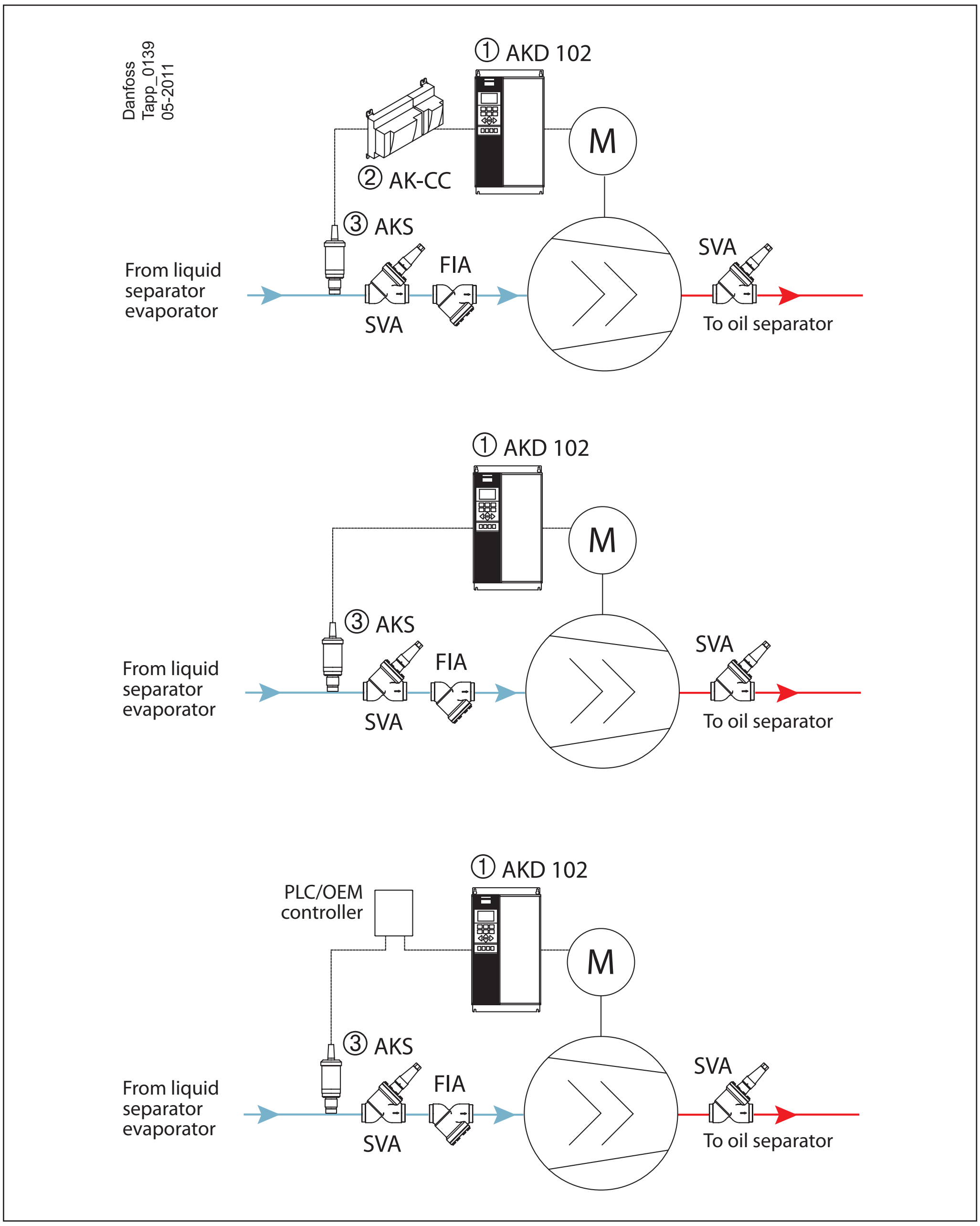
Technical data

	Pilot-operated servo valve - ICS
Material	Body: low temp. steel
Refrigerants	All common refrigerants, incl. R717 and R744
Media temp. range [°C]	–60 to +120
Max. working pressure [bar}	52
DN [mm]	20 to 150

	Pilot valve - CVC (LP)
Refrigerants	All common refrigerants
Media temp. range [°C]	–50 to 120
Max. working pressure [bar]	High pressure side: 28 Low pressure side: 17
Pressure range [bar]	–0.45 to 7
K_v value [m^3/h]	0.2

	Pilot valve - CVC (XP)
Refrigerants	All common refrigerants
Media temp. range [°C]	–50 to 120
Max. working pressure [bar]	High pressure side: 52 Low pressure side: 28
Pressure range [bar]	4 to 28
K_v value [m^3/h]	0.2

Application example 2.1.3: Compressor variable speed capacity control



🟥 HP vapour refrigerant
🟦 LP vapour refrigerant

① Frequency converter
② Controller
③ Pressure transducer

Frequency converter control offer the following advantages:

- Energy savings
- Improved control and product quality
- Noise reduction
- Longer lifetime
- Simplified installation
- Easy to use complete control of the system

Technical data

	Frequency converter AKD 102		Frequency converter VLT FC 102 / FC 302
kW rating	1.1 kW to 45 kW	1.1 kW to 250 kW	Up to 1200 kW
Voltage	200-240 V	380-480 V	200-690 V

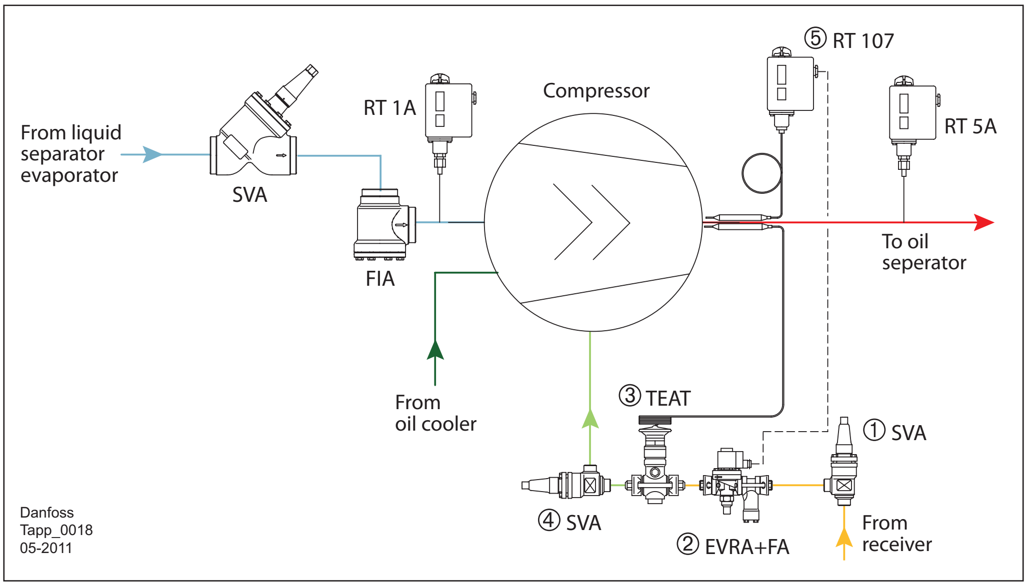
2.2
Discharge Temperature Control with Liquid Injection

Compressor manufacturers generally recommend limiting the discharge temperature below a certain value to prevent overheating of values, prolonging their life and preventing the breakdown of oil at high temperatures.

From the log p-h diagram, it can be seen that the discharge temperature may be high when:

- the compressor runs with high pressure differential.
- the compressor receives highly superheated suction vapour.
- the compressor runs with capacity control by hot gas bypass.

There are several ways to reduce the discharge temperature. One way is to install water cooled heads in reciprocating compressors, another method is liquid injection, by which liquid refrigerant from the outlet of the condenser or receiver is injected into the suction line, the intermediate cooler, or the side port of the screw compressor.



Application example 2.2.1: Liquid injection with thermostatic injection valve

🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant
🟩 Oil

① Stop valve
② Solenoid valve
③ Thermostatic injection valve
④ Stop valve
⑤ Thermostat

When the discharge temperature rises above the set value of the thermostat RT 107 ⑤, RT 107 will energise the solenoid valve EVRA ② which will start liquid injection into the side port of the screw compressor.

The thermostatic injection valve TEAT ③ controls the injected liquid flow according to the discharge temperature, which prevents the discharge temperature from rising further.

Technical data

	Thermostat - RT
Refrigerants	R717 and fluorinated refrigerants
Enclosure	IP 66/54
Max. bulb temp. [°C]	65 to 300
Ambient temp. [°C]	–50 to 70
Regulating range [°C]	–60 to 150
Differential Δt [°C]	1.0 to 25.0

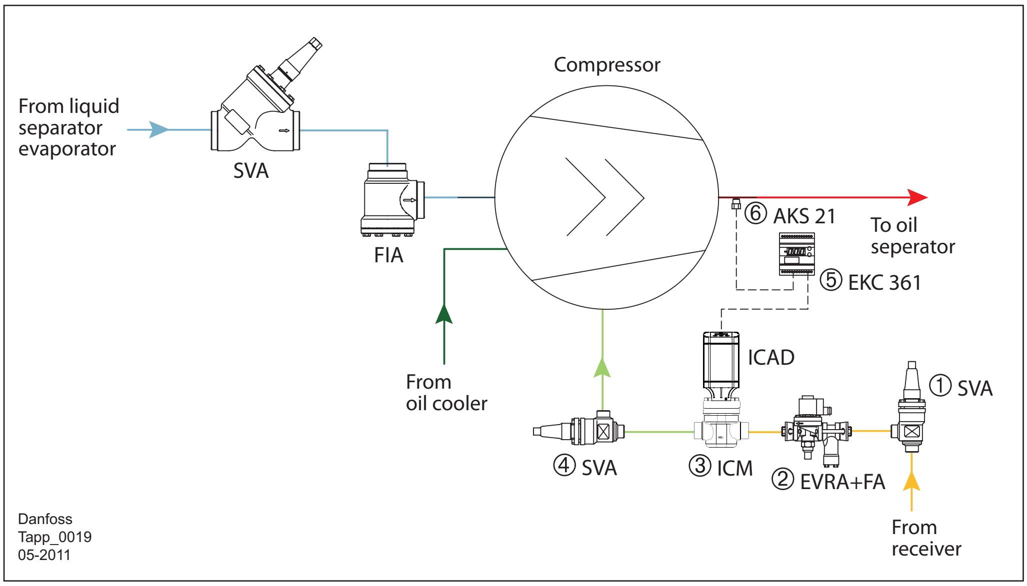
	Thermostatic injection valve - TEAT
Refrigerants	R717 and fluorinated refrigerants
Regulating range [°C]	Max. bulb temp.: 150°C P band: 20°C
Max. working pressure [bar]	20
Rated Capacity [kW]*	3.3 to 274

* Conditions: $T_e = +5°C$, $\Delta p = 8$ bar, $\Delta T_{sub} = 4°C$

Application example 2.2.2: Liquid injection with motor valve

🟥 HP vapour refrigerant
🟧 HP liquid refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant
🟩 Oil

① Stop valve
② Solenoid valve
③ Motor valve
④ Stop valve
⑤ Controller
⑥ Temperature sensor



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An electronic solution for liquid injection control can be achieved with the motorised valve ICM ③. An AKS 21 PT 1000 temperature sensor ⑥ will register the discharge temperature and transmit the signal to the temperature controller EKC 361 ⑤. The EKC 361 controls the ICAD actuator which adjusts to opening degree of the ICM motor valve in order to limit and maintain the required discharge temperature.

Technical data

	ICM for expansion
Material	Body: Low temperature steel
Refrigerants	All common refrigerants including R717 and R744
Media temp. range [°C]	–60 to 120
Max. working pressure [bar]	52 bar
DN [mm]	20 to 80
Nominal Capacity [kW]*	72 to 22,700

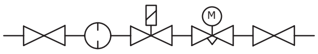
* Conditions: $T_e = -10°C$, $\Delta p = 8.0$ bar, $\Delta T_{sub} = 4K$

	Actuator - ICAD
Media temp. range [°C]	–30 to 50 (ambient)
Control input signal	0/4-10mA, or 0/2-10
Open-close time with maximum selected speed	3 to 45 seconds depending on valve size

Application example 2.2.3:
A compact solution for liquid injection with ICF

🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant
🟩 Oil

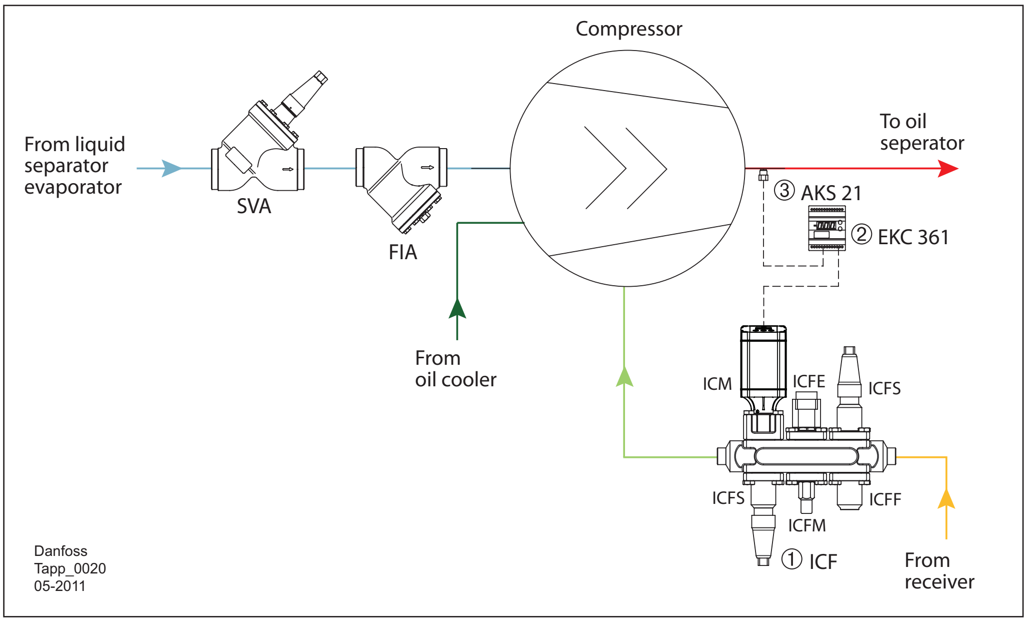
① Valve station with:



Stop valve
Filter
Solenoid valve
Manual opener
Motor valve
Stop valve

② Controller

③ Temperature sensor



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For liquid injection, Danfoss can supply a very compact control solution ICF ①. Up to six different modules can be assembled into the same housing. This solution works in the same way as example 2.2.2, and is very compact and easy to install.

Technical data

	ICF control solution
Material	Body: Low temperature steel
Refrigerants	All common refrigerants including R717 and R744
Media temp. range [°C]	–60 to 120
Max. working pressure [bar]	52 bar
DN [mm]	20 to 40

2.3
Crankcase Pressure Control

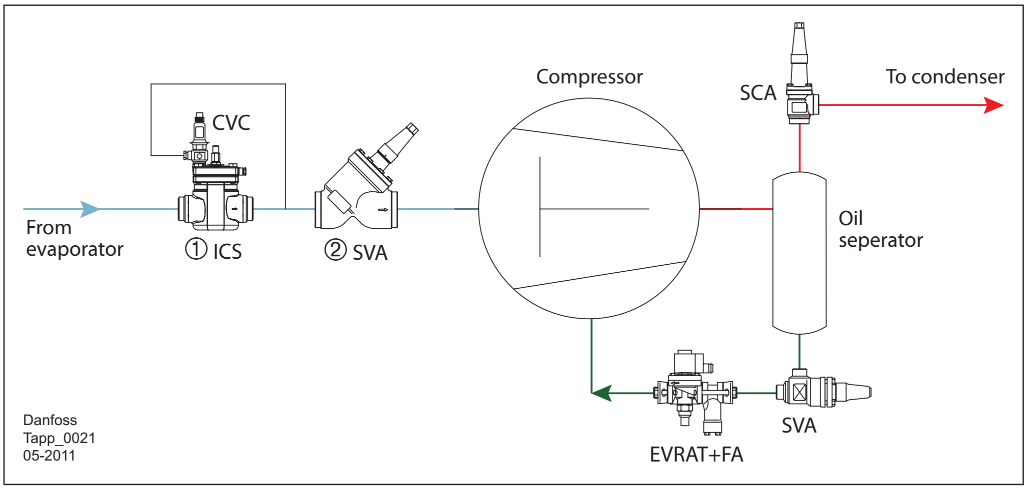
During start-up or after defrost, the suction pressure has to be controled, otherwise it can be too high, and the compressor motor will be overloaded.

The electric motor for the compressor may be damaged by this overloading.

There are two ways to overcome this problem:

1. Start the compressor at part load. The capacity control methods can be used to start compressor at part load, e.g. unload part of the pistons for multi-piston reciprocating compressors, or bypass some suction gas for screw compressors with slide valves, etc.
2. Control the crankcase pressure for reciprocating compressors. By installing a back pressure controlled regulating valve in the suction line, which will not open until the pressure in the suction line drops below the set value, suction pressure can be kept under a certain level.

Application example 2.3.1: Crankcase pressure control with ICS and CVC



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🟥 HP vapour refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Crankcase pressure regulator
② Stop valve

In order to control the crankcase pressure during start-up, after defrost, or in others cases when the suction pressure may run too high, the pilot-operated servo valve ICS ① with the back pressure controlled pilot valve CVC is installed in the suction line. The ICS will not open until the downstream suction pressure falls below the set value of the pilot valve CVC. In this way, the high pressure vapour in the suction line can be released into the crankcase gradually, which ensures a manageable capacity for the compressor.

Technical data

	Pilot-operated servo valve - ICS
Material	Body: low temp. steel
Refrigerants	All common refrigerants, incl. R717 and R744
Media temp. range [°C]	–60 to +120
Max. working pressure [bar]	52
DN [mm]	20 to 150
Capacity [kW]*	11 to 2440

* Conditions: $T_e = -10°C$, $T_l = 30°C$, $\Delta p = 0.2$ bar, $\Delta T_{sub} = 8K$

	Pilot valve - CVC (LP)
Refrigerants	All common refrigerants
Media temp. range [°C]	–50 to 120
Max. working pressure [bar]	High pressure side: 28 Low pressure side: 17
Pressure range [bar]	–0.45 to 7
K_v value [m^3/h]	0.2

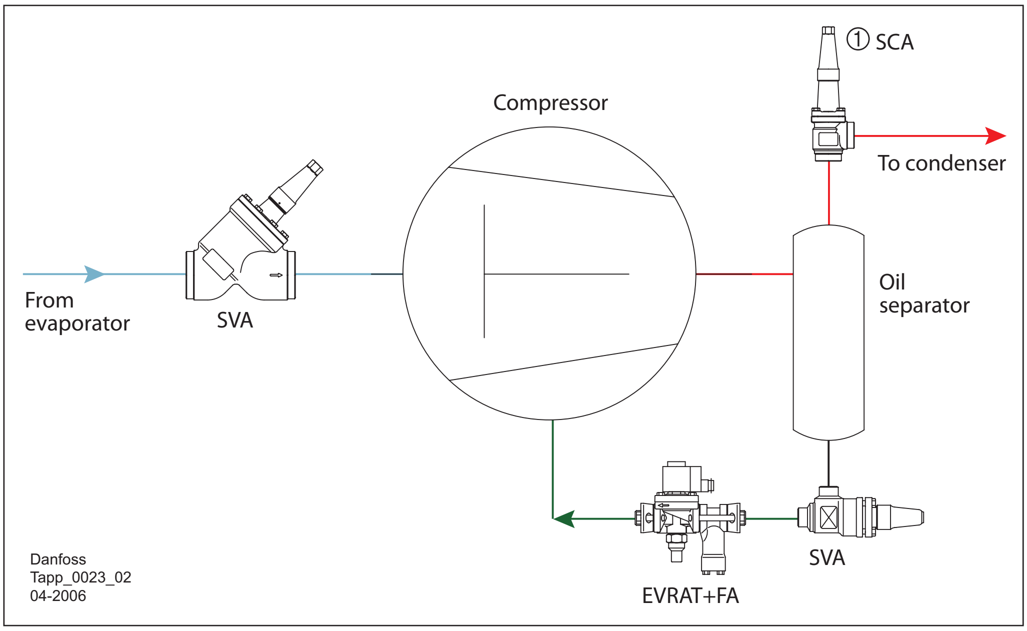
	Pilot valve - CVC (XP)
Refrigerants	All common refrigerants
Media temp. range [°C]	–50 to 120
Max. working pressure [bar]	High pressure side: 52 Low pressure side: 28
Pressure range [bar]	4-28
K_v value [m^3/h]	0.2

2.4
Reverse Flow Control

Reverse flow and condensation of refrigerant from the condenser to the oil separator and the compressor should be avoided at all time. For piston compressors, reverse flow can result in liquid hammering. For screw compressors, reverse flow can cause reversed rotation and damage to the compressor bearings.

Furthermore, migration of refrigeration into the oil separator and further into the compressor at standstill should be avoided. To avoid this reverse flow, it is necessary to install a check valve on the outlet of the oil separator.

Application example 2.4.1:
Reverse flow control



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🟥 HP vapour refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Stop check valve

The stop check valve SCA ① can function as a check valve when the system is running, and can also shut off the discharge line for service as a stop valve. This combined stop/check valve solution is easier to install and has lower flow resistance compared to a normal stop valve plus check valve installation.

When selecting a stop check valve, it is important to note:

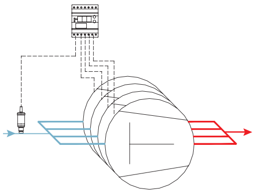
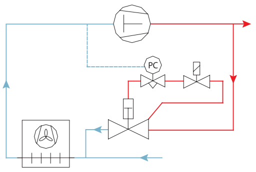
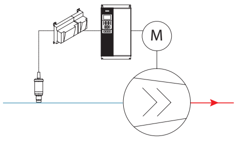
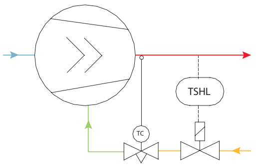
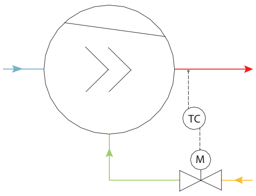
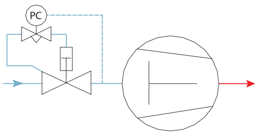
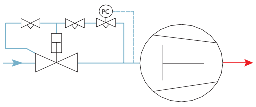
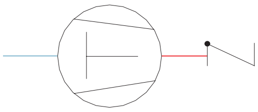
1. Select a valve according to the capacity and not the pipe size.
2. Consider both the nominal and part load working conditions. The velocity in the nominal condition should be near to the recommended value, at the same time the velocity in the part load condition should be higher than the minimum recommended velocity.

For details on how to select valves, please refer to the product catalogue.

Technical data

	Stop check valve - SCA
Material	Housing: special cold resistant steel approved for low temperature operation. Spindle: polished stainless steel
Refrigerants	All common non-flammable refrigerants, incl. R717.
Media temp. range [°C]	–60 to 150
Opening differential pressure [bar]	0.04 (0.3 bar spring availble as spare part)
Max. working pressure [bar]	40
DN [mm]	15 to 125

2.5
Summary

Solution		Application	Benefits	Limitations
Compressor Capacity Control				
Step control of compressor capacity with EKC 331 and AKS 32/33		Applicable to multi-cylinder compressor, screw compressor with multiple suction ports, and systems with several compressors running in parallel.	Simple. Almost as efficient at part load as at full load.	The control is not continuous, especially when there are only few steps. Fluctuations in the suction pressure.
Compressor capacity control with hot gas bypass using ICS and CVC		Applicable to compressors with fixed capacities.	Effective to control the capacity continuously according to the actual heat load.The hot gas can help the oil return from the evaporator.	Not efficient at part load. Energy consuming.
Compressor variable speed capacity control		Applicable to all compressors with the ability to run at reduced speed.	Low start up current Energy savings Lower noise Longer lifetime Simplified installation	Compressor must be suited for reduced speed operation.
Discharge Temperature Control with Liquid Injection				
Mechanical solution for liquid injection with TEAT, EVRA(T) and RT		Applicable to systems where the discharge temperatures may run too high.	Simple and effective.	Injection of liquid refrigerant may be dangerous to the compressor. Not as efficient as intermediate cooler.
Electronic solution for liquid injection control with EKC 361 and ICM		Applicable to systems where the discharge temperatures may run too high.	Flexible and compact. Possible to monitor and control remotely.	Not applicable to flammable refrigerants. Injection of liquid refrigerant may be dangerous to the compressor. Not as efficient as intermediate cooler.
Electronic solution for liquid injection control with EKC 361 and ICF				
Crankcase Pressure Control				
Crankcase pressure control with ICS and CVC		Applicable to reciprocating compressors, normally used for small and medium systems.	Simple and reliable. Effective in protecting reciprocating compressors at start-up or after hot gas defrost.	Gives constant pressure drop in the suction line.
Crankcase pressure control with ICS and CVP				
Reverse Flow Control				
Reverse flow control with SCA		Applicable to all refrigeration plants.	Simple. Easy to install. Low flow resistance.	Gives constant pressure drop in the discharge line.

2.6 Reference Documents

For an alphabetical overview of all reference documents please go to page 104

Technical Leaflet / Manual

Type	Literature no.
AKD 102	PD.R1.B
AKS 21	RK.0Y.G
AKS 32R	RD.5G.J
AKS 33	RD.5G.H
CVC	PD.HN0.A
CVP	PD.HN0.A
EKC 331	RS.8A.G
EKC 361	RS.8A.E
EVRA(T)	PD.BM0.B

Type	Literature no.
ICF	PD.FT0.A
ICM	PD.HT0.B
ICS	PD.HS0.A
REG	PD.KM0.A
SCA	PD.FL0.A
SVA	PD.KD0.A
TEAT	RD.1F.A

Product instruction

Type	Literature no.
AKD 102	MG.11.L
AKS 21	RI.14.D
AKS 32R	PI.SB0.A
AKS 33	PI.SB0.A
CVC	RI.4X.L
CVP	PI.HN0.C
EKC 331	RI.8B.E
EKC 361	RI.8B.F
EVRA(T)	RI.3D.A

Type	Literature no.
ICF	PI.FT0.A
ICM 20-65	PI.HT0.A
ICM 100-150	PI.HT0.B
ICS 25-65	PI.HS0.A
ICS 100-150	PI.HS0.B
REG	PI.KM0.A
SCA	PI.FL0.A
SVA	PI.KD0.B
TEAT	PI.AU0.A

To download the latest version of the literature please visit the Danfoss internet site
http://www.danfoss.com/Products/Literature/RA_Documentation.htm

3. Condenser Controls

In areas where there are large variations in ambient air temperatures and/or load conditions, it is necessary to control the condensing pressure to avoid it from falling too low. Too low condensing pressures results in there being insufficient pressure differential across the expansion device and the evaporator is supplied with insufficient refrigerant. It means that condenser capacity control is mainly used in the temperate climate zones and to a lesser degree in subtropical and tropical zones.

The basic idea of control is to control the condenser capacity when the ambient temperature is low, so that the condensing pressure is maintained above the minimum acceptable level.

This condensing capacity control is achieved either by regulating the flow of circulating air or water through the condenser, or by reducing the effective heat exchange surface area.

Different solutions can be designed for different types of condensers:
3.1 Air cooled condensers
3.2 Evaporative condensers
3.3 Water cooled condensers

3.1 Air Cooled Condensers

An air-cooled condenser consists of tubes mounted within a fin block. The condenser can be horizontal, vertical or V-shaped. The ambient air is drawn across the heat exchanger surface with axial or centrifugal fans.

Air-cooled condensers are used on industrial refrigeration systems where the relative air humidity is high. Controlling the condensing pressure for air-cooled condensers can be achieved in the following ways:

3.1.1 - Step Control of Air Cooled Condensers

The first method was using the required number of pressure controls in the form the Danfoss RT-5 and adjusting them to different set cut-in and cut-out pressures.

The second method of controlling the fans was by using a neutral zone pressure controller in the form of the Danfoss type RT-L. Initially it was used together with a step controller with the required number of contacts for the number of fans.

However this system reacted too fast and timers were used for delaying the cut-in and cut-out of the fans.

The Third method is today's step controller the Danfoss EKC-331.

3.1.2 - Fan speed control of air cooled condensers

This method of condenser fan control is mainly used whenever a reduction in noise level is desired due to environmental concerns.

For this type of installation Danfoss frequency converter AKD can be used.

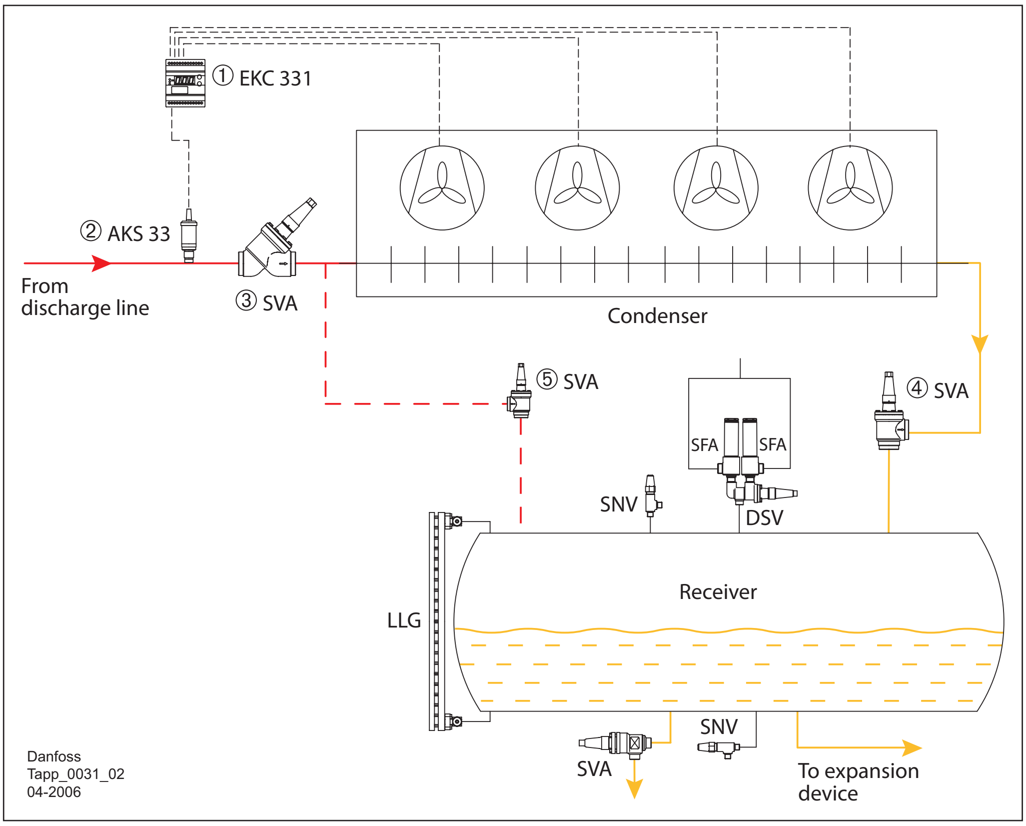
3.1.3 - Area control of air cooled condensers

For area or capacity control of air cooled condensers a receiver is required. This receiver must have sufficient volume to be able to accommodate the variations in the amount of refrigerant in the condenser.

Two ways this condenser area control can be done:

1. Main valve ICS or PM combined with the constant pressure pilot CVP(HP) mounted in the hot gas line on the inlet side to the condenser and ICV combined with a differential pressure pilot CVPP(HP) mounted in the pipe between the hot gas line and the receiver. In the pipe between the condenser and the receiver a check valve NRVA is mounted to prevent liquid migration from the receiver to the condenser.
2. Main valve ICS combined with the constant pressure pilot CVP(HP) mounted in the pipe between the condenser and the receiver and a ICS combined with a differential pressure pilot CVPP(HP) mounted in the pipe between the hot gas line and the receiver. This method is mainly used in commercial refrigeration.

Application example 3.1.1: Step control of fans with step controller EKC 331



Danfoss
Tapp_0031_02
04-2006

🟥 HP vapour refrigerant
🟨 HP liquid refrigerant

① Step controller
② Pressure transmitter
③ Stop valve
④ Stop valve
⑤ Stop valve

EKC 331 ① is a four-step controller with up to four relay outputs. It controls the switching of the fans according to the condensing pressure signal from a pressure transmitter AKS 33 ② or AKS 32R. Based on neutral zone control, EKC 331 ① can control the condensing capacity so that the condensing pressure is maintained above the required minimum level.

For more information on neutral zone control, please refer to section 2.1.

The bypass pipe where SVA ⑤ is installed is an equalizing pipe, which helps balance the pressure in the receiver with the inlet pressure of the condenser so that the liquid refrigerant in the condenser can be drained into the receiver.

In some installations, EKC 331T is used. In this case the input signal could be from a PT 1000 temperature sensor, e.g. AKS 21. The temperature sensor is usually installed in the outlet of the condenser.

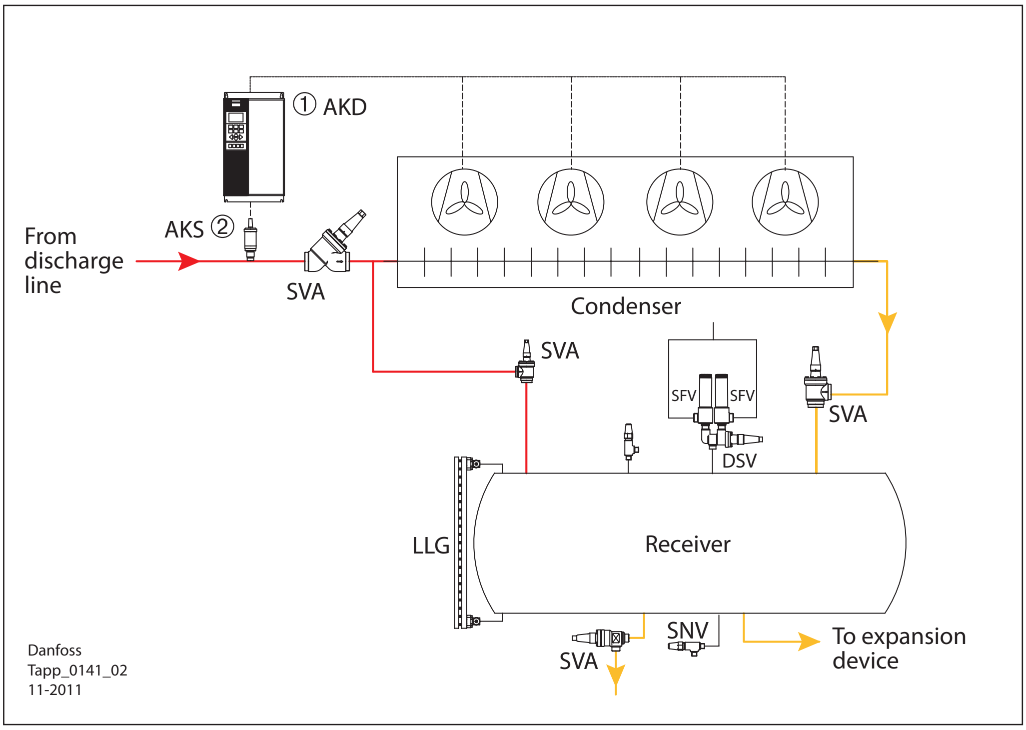
Note! The EKC 331T + PT1000 temperature sensor solution is not as accurate as the EKC 331 + pressure transmitter solution because the condenser outlet temperature may not entirely reflect the actual condensing pressure due to the liquid subcooling or the presence of incondensable gasses in the refrigeration system. If the subcooling is too low, flash gas may occur when the fans start.

Technical data

	Pressure transmitter-AKS 33	Pressure transmitter-AKS 32R
Refrigerants	All refrigerants including R717	All refrigerants including R717
Operating range [bar]	–1 to 34	–1 to 34
Max. working pressure PB [bar]	55 (depending on operating range)	60 (depending on operating range)
Operating temp. range [°C]	–40 to 85	
Compensated temp. range [°C]	LP: –30 to +40 / HP: 0 to +80	
Rated output signal	4 to 20 mA	10 to 90% of V supply

	Pressure transmitter - AKS 3000	Pressure transmitter - AKS 32
Refrigerants	All refrigerants including R717	All refrigerants including R717
Operating range [bar]	0 to 60 (depending on range)	–1 to 39 (depending on range)
Max. working pressure PB [bar]	100 (depending on operating range)	60 (depending on operating range)
Operating temp. range [°C]	–40 to 80	–40 to 85
Compensated temp. range [°C]	LP: –30 to +40 / HP: 0 to +80	LP: –30 to +40 / HP: 0 to +80
Rated output signal	4 to 20 mA	1 to 5V or 0 to 10V

Application example 3.1.2: Fan speed control of air cooled condensers



Danfoss
Tapp_0141_02
11-2011

🟥 HP vapour refrigerant
🟨 HP liquid refrigerant

① Frequency converter
② Pressure transducer

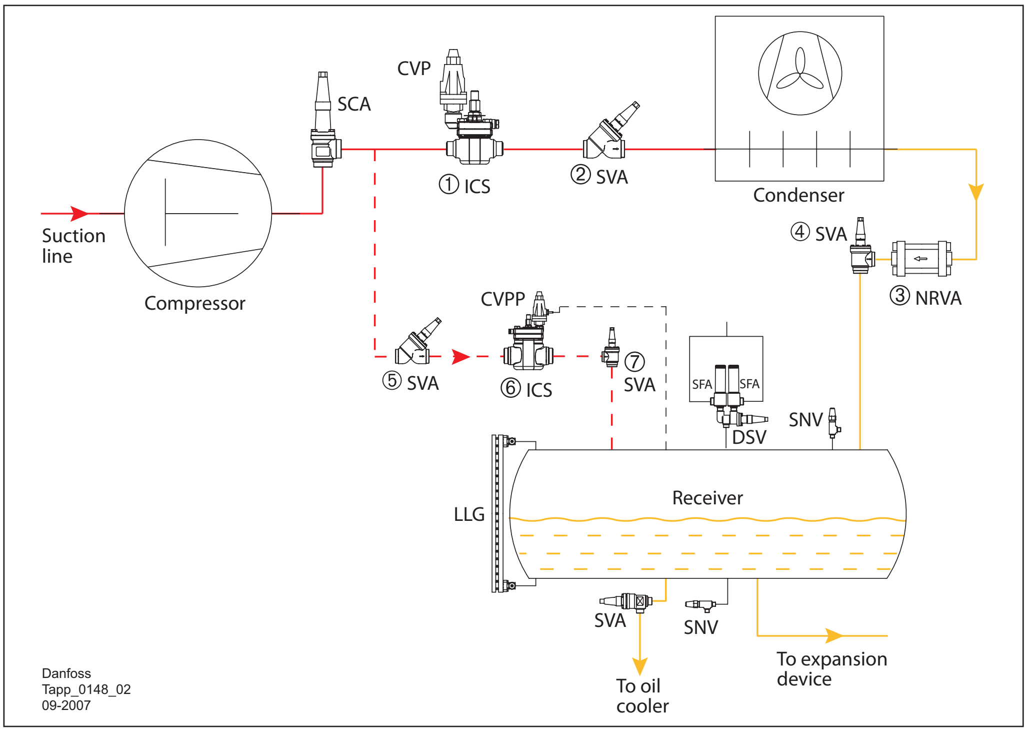
Frequency converter control offer the following advantages:

- Energy savings
- Improved control and product quality
- Noise reduction
- Longer lifetime
- Simplified installation
- Easy to use complete control of the system

Technical data

	Frequency converter AKD 102		Frequency converter VLT FC 102 / FC 302
kW rating	1.1 kW to 45 kW	1.1 kW to 250 kW	Up to 1200 kW
Voltage	200-240 V	380-480 V	200-690 V

Application example 3.1.3: Area control of air cooled condensers



Danfoss
Tapp_0148_02
09-2007

🟥 HP vapour refrigerant
🟨 HP liquid refrigerant

① Pressure regulator
② Stop valve
③ Check valve
④ Stop valve
⑤ Stop valve
⑥ Differential pressure regulator
⑦ Stop valve

This regulating solution maintains the pressure in the receiver at a sufficiently high level during low ambient temperatures.

The ICS pilot-operated servo valve ① opens when the discharge pressure reaches the set pressure on the CVP pilot valve. The ICS pilot-operated servo valve closes when the pressure drops below the set pressure of the CVP pilot valve.

The ICS pilot-operated servo valve ⑥ with the CVPP constant differential pressure pilot maintains sufficient pressure in the receiver. This differential pressure regulator ⑥ could also be an overflow valve OFV.

The NRVA check valve ③ ensures increased condenser pressure by liquid back up within the condenser. This requires a sufficiently large receiver. The NRVA check valve also prevents liquid flow from the receiver back into the condenser when the latter is colder during compressor shut-down periods

Technical data

	Pilot operated servo valve - ICS
Material	Body: low temp. steel
Refrigerants	All common refrigerants, incl. R717 and R744
Media temp. range [°C]	–60 to 120
Max. working pressure [bar]	52
DN [mm]	20 to 150
Nominal capacity [kW]*	On discharge line: 20 to 3950 On HP liquid line: 179 to 37,000

* Conditions: R717, T_{liq}=30°C, $P_{disch.}$=12bar, ΔP=0.2bar, $T_{disch.}$=80°C, T_e=-10°C

	Differential pressure pilot valve-CVPP
Refrigerants	All common non-flammable refrigerants incl. R717
Media temp. range [°C]	–50 to 120
Max. working pressure [bar]	CVPP (LP): 17 CVPP (HP): up to 40
Regulating range [bar]	CVPP (LP): 0 to 7 CVPP (HP): 0 to 22
K_v value m^3/h	0.4

Technical data (continued)

	Constant pressure pilot valve - CVP
Refrigerants	All common refrigerants including R717 and R744
Media temp. range [°C]	–50 to 120
Max. working pressure [bar]	CVP (LP): 17 CVP (HP): up to 40 CVP (XP): 52
Pressure range [bar]	CVP (LP): –0.66 to 7 CVP (HP): –0.66 to 28 CVP (XP): 25 to 52
K_v value m^3/h	CVP (LP): 0.4 CVP (HP): 0.4 CVP (XP): 0.2

	Overflow valve - OFV
Material	Body: steel
Refrigerants	All common refrigerants, incl. R717
Media temp. range [°C]	–50 to 150
Max. working pressure [bar]	40
DN mm	20/25
Opening differential pressure range [bar]	2 to 8

3.2
Evaporative Condensers

An evaporative condenser is a condenser cooled by ambient air combined with water sprayed through orifices and air baffles in counter flow with the air. The water evaporates and the evaporation effect of the water drops adds much to the condenser capacity

Today's evaporative condensers are enclosed in a steel or plastic enclosure with axial or centrifugal fans at the bottom or at the top of the condenser.

The heat exchanger surface in the wet air stream consists of steel pipes.
Above the water spray orifices (in the dry air) it is common to have a de-super heater made of steel pipes with fins to reduce the hot gas temperature before it reaches the heat exchanger in the wet air stream. In this way the building up of calcium scales on the surface of the main heat exchanger pipes is greatly reduced.

This type reduces the water consumption considerably compared to a normal water cooled condenser. Capacity control of an evaporative condenser can be achieved by either two speed fan or variable speed control of the fan and at very low ambient temperature conditions switching off the water circulation pump.

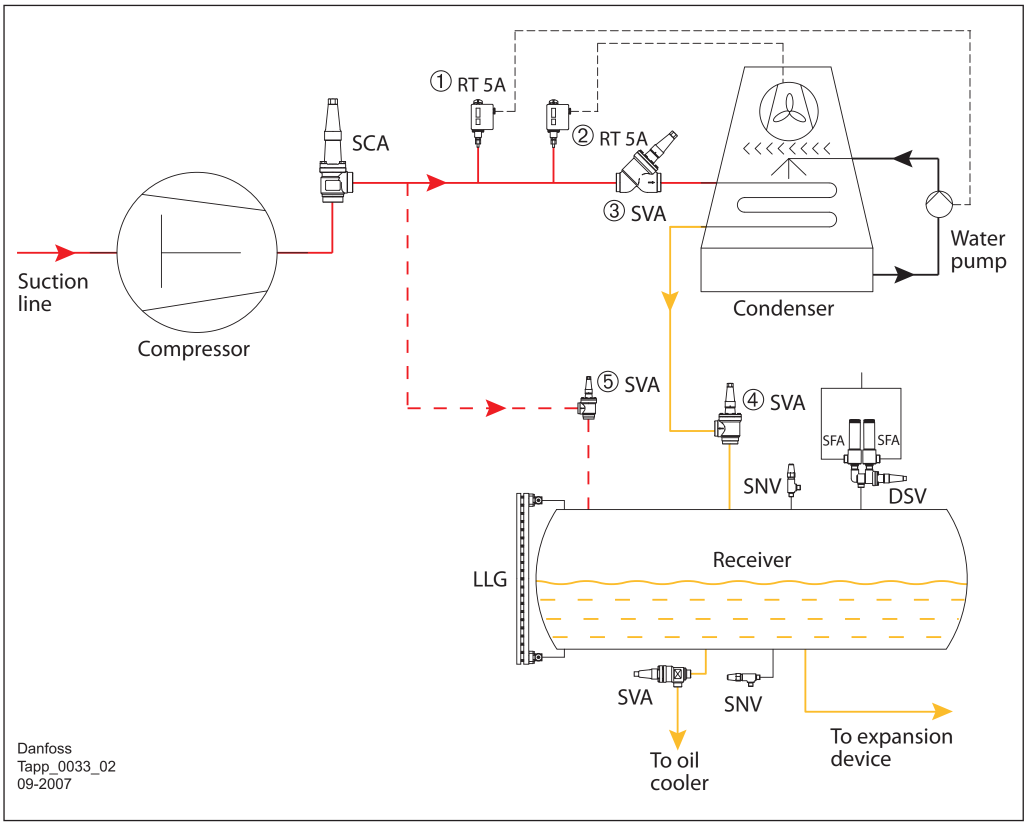
The use of evaporative condensers is limited in areas with high relative humidity. In cold surroundings (ambient temperatures < 0°C) frost damage prevention must be carried out by removing the water in the evaporative condenser.

3.2.1 - Control of Evaporative Condensers

Controlling the evaporative condensers condensing pressure or the condenser capacity can be achieved in different ways:

1. RT or KP pressure controls for fan and water pump control (as it was earlier).
2. RT-L neutral zone pressure control for fan and water pump control.
3. Step controller for controlling two speed fans and the water pump.
4. Frequency converters for fan speed control and water pump control.
5. Saginomiya flow-switch for alarm if water circulation fails.

Application example 3.2.1: Step control of evaporative condenser with pressure controller RT



Danfoss
Tapp_0033_02
09-2007

🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
⬛ Water

① Pressure controller
② Pressure controller
③ Stop valve
④ Stop valve
⑤ Stop valve

This solution maintains the condensing pressure, as well as the pressure in the receiver at a sufficiently high level in low ambient temperature.

When the inlet pressure of the condenser drops below the setting of the pressure controller RT 5A ②, the controller will switch off the fan, to decrease the condensing capacity.

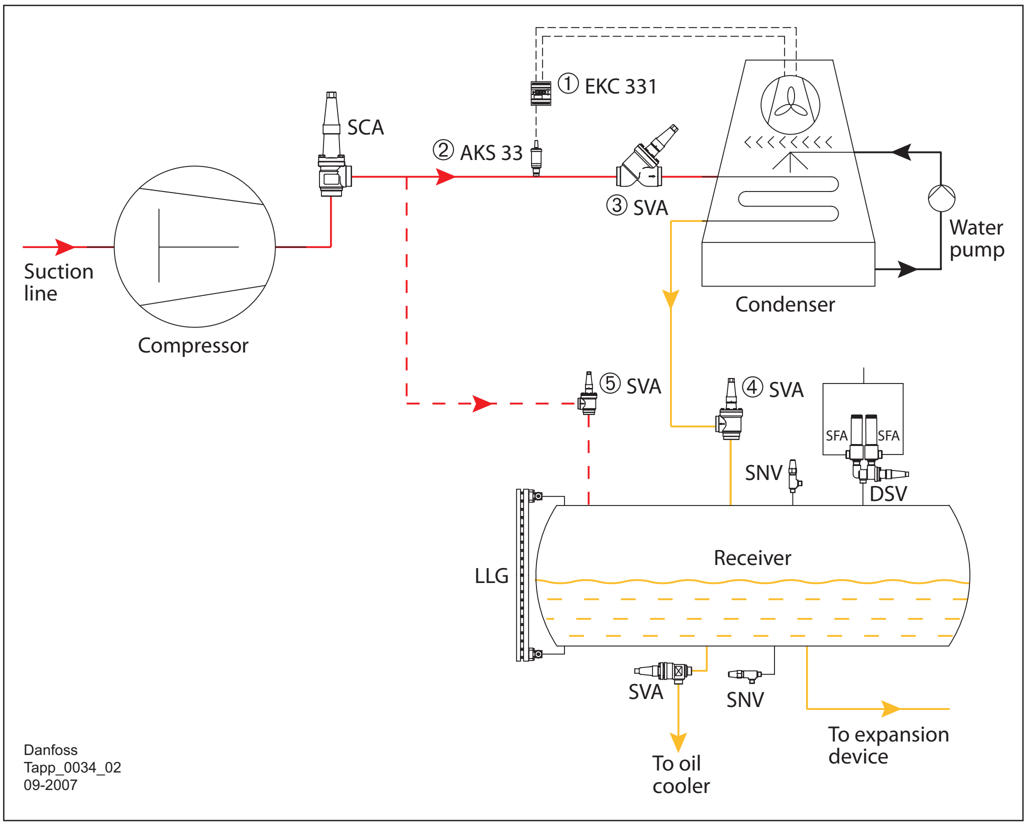
In extremely low ambient temperature, when the condensing pressure drops below the setting of RT 5A ① after all the fans have been switched off, RT 5A ① will stop the water pump.

When the pump is stopped, the condenser and the water pipes should be drained to avoid scaling and freezing.

Technical data

	HP pressure control - RT 5A
Refrigerants	R717 and fluorinated refrigerants
Enclosure	IP 66/54
Ambient temp. [°C]	–50 to 70
Regulating range [bar]	RT 5A: 4 to 17
Max. working pressure [bar]	22
Max. test pressure [bar]	25

Application example 3.2.2: Step control of evaporative condenser with step controller EKC331



🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
⬛ Water

① Step controller
② Pressure transmitter
③ Stop valve
④ Stop valve
⑤ Stop valve

This solution works in the same way as example 3.2.1, but operated via step controller EKC 331 ①. For more information on EKC 331, please refer to page 7.

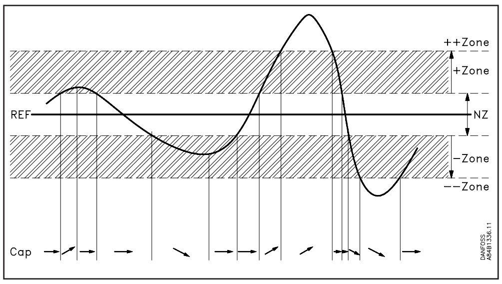
A capacity regulation solution for evaporative condensers can be achieved by using an EKC 331 power regulator and an AKS pressure transmitter. Sequential control for the water pump must be selected as the last step. Sequential control means that the steps will always cut in and out in the same order.

EKC 331T version can accept a signal from a PT 1000 temperature sensor, which may be necessary for secondary systems.

Neutral Zone Control
A neutral zone is set around the reference value, in which no loading/unloading occurs.
Outside the neutral zone (in the hatched areas "+zone" and "- zone") loading/unloading will occur as the measure pressure deviates away from the neutral zone settings.

If control takes place outside the hatched area (named ++zone and --zone), changes of the cut-in capacity will occur somewhat faster than if it were in the hatched area.

For more details, please refer to the manual of EKC 331(T) from Danfoss.



Technical data

	Pressure transmitter-AKS 33	Pressure transmitter-AKS 32R
Refrigerants	All refrigerants including R717	All refrigerants including R717
Operating range [bar]	–1 to 34	–1 to 34
Max. working pressure PB [bar]	55 (depending on operating range)	60 (depending on operating range)
Operating temp. range [°C]	–40 to 85	
Compensated temp. range [°C]	LP: –30 to +40 / HP: 0 to +80	
Rated output signal	4 to 20 mA	10 to 90% of V supply

	Pressure transmitter - AKS 3000	Pressure transmitter - AKS 32
Refrigerants	All refrigerants including R717	All refrigerants including R717
Operating range [bar]	0 to 60 (depending on range)	–1 to 39 (depending on range)
Max. working pressure PB [bar]	100 (depending on operating range)	60 (depending on operating range)
Operating temp. range [°C]	–40 to 80	–40 to 85
Compensated temp. range [°C]	LP: –30 to +40 / HP: 0 to +80	LP: –30 to +40 / HP: 0 to +80
Rated output signal	4 to 20 mA	1 to 5V or 0 to 10V

3.3
Water Cooled Condensers

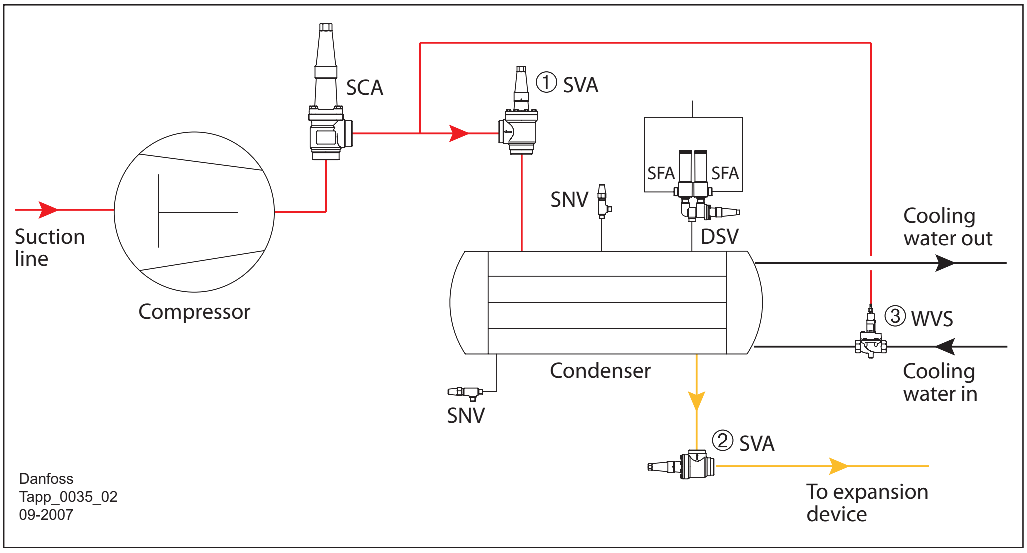
The water cooled condenser was originally a shell and tube heat exchanger, but today it is very often a plate heat exchanger of modern design.

Water cooled condensers are not commonly used, because in many places it is not allowed to use the large amount of water these types consume (water shortage and/or high prices for water).

Today water cooled condensers are popular in chillers, with the cooling water cooled by a cooling tower and re-circulated. It can also be used as a heat recovery condenser to supply hot water.

The control of the condensing pressure can be achieved by a pressure controlled water valve, or a motorised water valve controlled by an electronic controller to control the flow of the cooling water according to the condensing pressure.

Application example 3.3.1: Water flow control of water cooled condensers with a water valve



Danfoss
Tapp_0035_02
09-2007

🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
⬛ Water

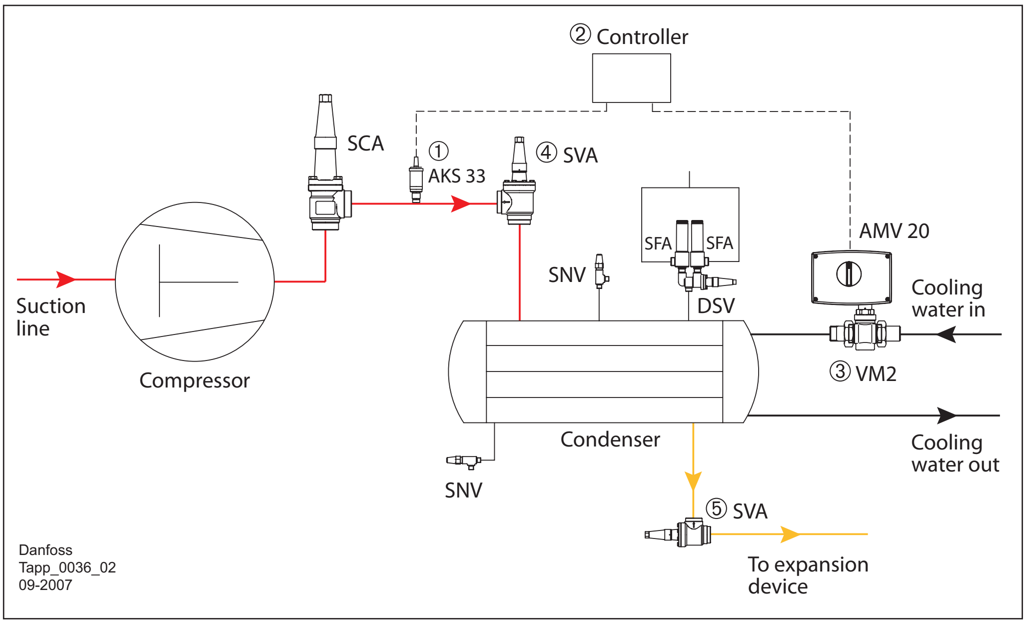
① Stop valve
② Stop valve
③ Water valve

This solution maintains the condensing pressure at a constant level. The refrigerant condensing pressure is directed through a capillary tube to the top of the water valve WVS ③, and adjusts the opening of WVS ③ accordingly. The water valve WVS is a P-regulator.

Technical data

	Water valve - WVS
Materials	Valve body: cast iron Bellows: aluminium and corrosion-proofed steel
Refrigerants	R717, CFC, HCFC, HFC
Media	Fresh water, neutral brine
Media temp. range [°C]	–25 to 90
Adjustable closing pressure [bar]	2.2 to 19
Max. working pressure on refrigerant side [bar]	26.4
Max. working pressure on liquid side [bar]	10
DN [mm]	32 to 100

Application example 3.3.2: Water flow control of water cooled condensers with a motor-valve



Danfoss
Tapp_0036_02
09-2007

🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
⬛ Water

① Pressure transmitter
② Controller
③ Motor-valve
④ Stop valve
⑤ Stop valve

The controller ② receives the condensing pressure signal from the pressure transmitter AKS 33 ①, and sends out a corresponding modulating signal to actuator AMV 20 of the motor valve VM 2 ③. In this way, the flow of cooling water is adjusted and the condensing pressure is kept constant.

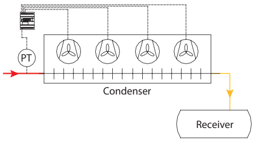
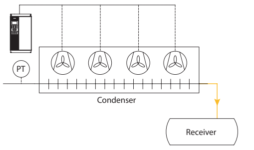
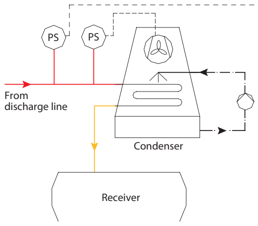
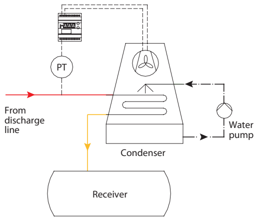
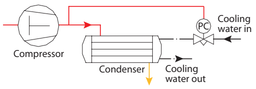
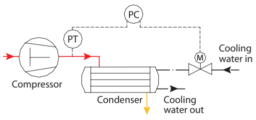
In this solution, PI or PID control can be configured in the controller.

VM 2 and VFG 2 are motor-valves designed for district heating, and can also be used for water flow control in refrigeration plants.

Technical data

	Motor valve - VM 2
Material	Body: red bronze
Media	Circulation water/ glycolic water up to 30%
Media temp. range [°C]	2 to 150
Max. working pressure [bar]	25
DN [mm]	15 to 50

3.4
Summary

Solution		Application	Benefits	Limitations
Air Cooled Condenser Control				
Step control of fans with step controller EKC331		Used mainly in industrial refrigeration in hot climates and to a much lesser degree in colder climates	Control of air volume in steps or with variable fan speed control; Energy saving; No use of water.	Very low ambient temperatures; Fan step control can be noisy.
Fan speed control of air cooled condensers		Applicable to all condensers with the ability to run at reduced speed.	Low start up current Energy savings Lower noise Longer lifetime Simplified installation	Very low ambient temperatures;
Evaporative Condenser Control				
Step control of evaporative condenser with pressure controller RT		Industrial refrigeration with very large capacity requirement	Large reduction in water consumption compared to water cooled condensers and relatively easy to capacity control; Energy saving.	Not applicable in countries with high relative humidity; In cold climates special precaution has to be taken so the water pipe is drained for water during water pump off periods.
Step control of evaporative condenser with step controller EKC331		Industrial refrigeration with very large capacity requirement	Large reduction in water consumption compared to water cooled condensers and relatively easy to capacity control; Possible to control remotely. Energy saving.	Not applicable in countries with high relative humidity; In cold climates special precaution has to be taken so the water pipe is drained for water during water pump off periods.
Water Cooled Condenser Control				
Liquid flow control with a water valve		Chillers, heat recovery condensers	It is easy to capacity control	Not applicable when water availability is a problem.
Liquid flow control with a motor valve		Chillers, heat recovery condensers	It is easy to capacity control the condenser and the heat recovery; Possible to control remotely.	This type of installation is more expensive than a normal set up; Not applicable when water availability is a problem.

3.5
Reference Documents

For an alphabetical overview of all reference documents please go to page 104

Technical Leaflet / Manual

Type	Literature no.
AKD 102	PD.R1.B
AKS 21	RK.0Y.G
AKS 32R	RD.5G.J
AKS 33	RD.5G.H
AMV 20	ED.95.N
CVPP	PD.HN0.A
CVP	PD.HN0.A

Type	Literature no.
ICS	PD.HS0.A
NRVA	RD.6H.A
RT 5A	PD.CB0.A
SVA	PD.KD0.A
VM 2	ED.97.K
WVS	PD.DA0.A

Product instruction

Type	Literature no.
AKD 102	MG.11.L
AKS 21	RI.14.D
AKS 32R	PI.SB0.A
AKS 33	PI.SB0.A
AMV 20	EI.96.A
CVPP	PI.HN0.C
CVP	PI.HN0.C

Type	Literature no.
ICS 25-65	PI.HS0.A
ICS 100-150	PI.HS0.B
NRVA	RI.6H.B
RT 5A	RI.5B.C
SVA	PI.KD0.B
VM 2	VI.HB.C
WVS	PI.DA0.A

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http://www.danfoss.com/Products/Literature/RA_Documentation.htm

4. Liquid Level Control

Liquid level control is an important element in the designing of industrial refrigeration systems. It controls the liquid injection to maintain a constant liquid level.

Two main different principles may be used when designing a liquid level control system:

- High pressure liquid level control system (HP LLRS)
- Low pressure liquid level control system (LP LLRS)

High pressure liquid level control systems are typically characterised by:
1. Focus on the liquid level on the condensing side of the system
2. Critical refrigerant charge
3. Small receiver or even no receiver
4. Applies mainly to chiller units and other systems with small refrigerant charge (for example, small freezers)

Low pressure systems are typically characterized by:
1. Focus on the liquid level on the evaporating side of the system
2. Receiver is usually big
3. Large (enough) charge of refrigerant
4. Mainly applied to de-centralized systems

Both principles can be achieved, using mechanical and electronic components

4.1
High Pressure Liquid Level Control System (HP LLRS)

When designing a HP LLRS, the following points have to be taken into consideration:

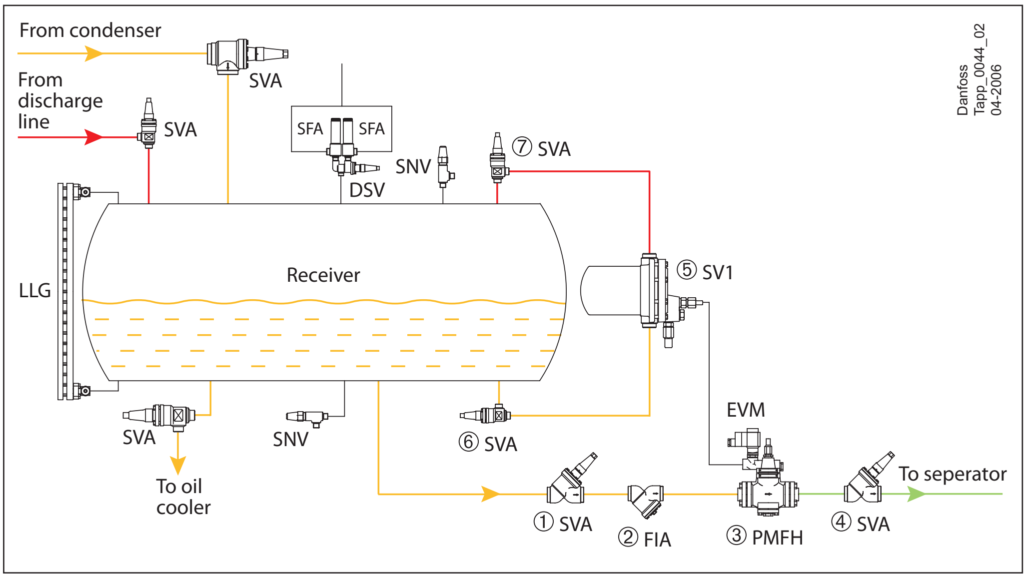
As soon as liquid is “formed” in the condenser the liquid is fed to the evaporator (low pressure side).

The liquid leaving the condenser will have little or no sub-cooling. This is important to consider when the liquid flows to the low pressure side. If there is pressure loss in the piping or the components, flash-gas may occur and cause the flow capacity to be reduced.

The refrigerant charge must be precisely calculated in order to ensure that there is adequate refrigerant in the system. An overcharge increases the risk of flooding the evaporator or the liquid separator causing liquid carry over into the compressor (liquid hammering). If the system is undercharged the evaporator will be starved. The size of the low pressure vessel (liquid separator/ shell-tube evaporator) must be carefully designed so that it can accommodate the refrigerant in all conditions without causing liquid hammering.

Because of the above reasons, HP LLRS are especially suitable for systems requiring small refrigerant charge, like chiller units, or small freezers. Chiller units usually do not need receivers. As a result of the above, HP LLRS are especially suitable for systems requiring a small refrigerant charge, e.g. liquid chiller units, or small freezers. Liquid chiller units usually do not need receivers, however, if a receiver is necessary in order to install pilots and provide refrigerant to an oil cooler, the receiver could be physically small.

Application example 4.1.1: Mechanical solution for HP liquid level control



🟥 HP vapour refrigerant
🟧 HP liquid refrigerant
🟩 LP liquid refrigerant

① Stop valve
② Filter
③ Servo-operated main valve
④ Stop valve
⑤ Float valve
⑥ Stop valve
⑦ Stop valve

On large HP LLRS the SV1 ⑤ or SV3 float valve is used as a pilot valve for a PMFH ③ main valve. As illustrated above, when the liquid level in the receiver rises above the set level, the SV1 ⑤ float valve provides a signal to the PMFH main valve to open.

The receiver's function here is to provide a more stable signal for the SV1 float ⑤ to work with.

Technical data

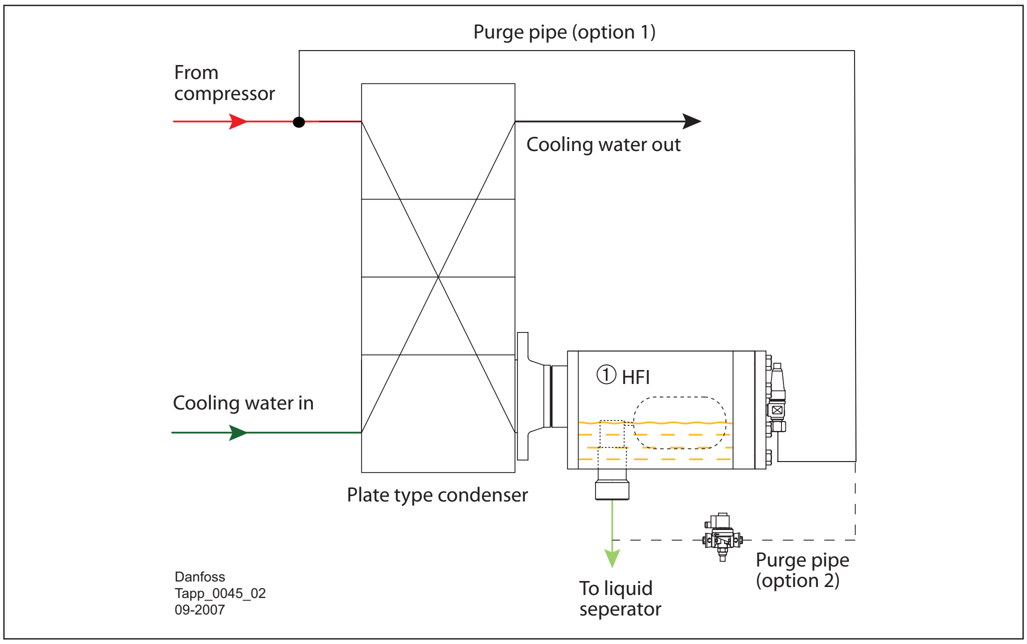
	PMFH 80 - 1 to 500
Material	Low temp. spherical cast iron
Refrigerants	R717, HFC, HCFC and CFC
Media temp. range [°C]	–60 to + 120
Max. working pressure [bar]	28
Max test pressure [bar]	42
Rated capacity [kW]*	139-13900

* Conditions: R717, +5/32°C, T_l = 28°C

	Float valve - SV 1 and SV3
Material	Housing: steel Cover: low temperature cast iron Float: stainless steel
Refrigerants	R717, HFC, HCFC and CFC
Media temp. range [°C]	–50 to + 65
P-band [mm]	35
Max. working pressure [bar]	28
Max test pressure [bar]	36
K_v value [m^3/h]	0.06 for SV 1 0.14 for SV 3
Rated capacity [kW]*	SV1: 25 SV3: 64

* Conditions: R717, +5/32°C, T_l = 28°C

Application example 4.1.2: Mechanical solution for HP liquid level control with HFI



🟥 HP vapour refrigerant
🟧 HP liquid refrigerant
🟩 LP liquid refrigerant
⬛ Water

① HP float valve

If the condenser is a plate heat exchanger, the mechanical float valve HFI ① can be used to control the liquid level.

The HFI is a direct acting high pressure float valve; therefore no differential pressure is required to activate the valve

It may be necessary to connect an equalization line to either the HP or LP side (Option 1 or 2) as shown on the drawing to remove refrigerant vapour from the float housing as this may prevent the liquid entering the float housing and thereby preventing the HFI-valve from opening.

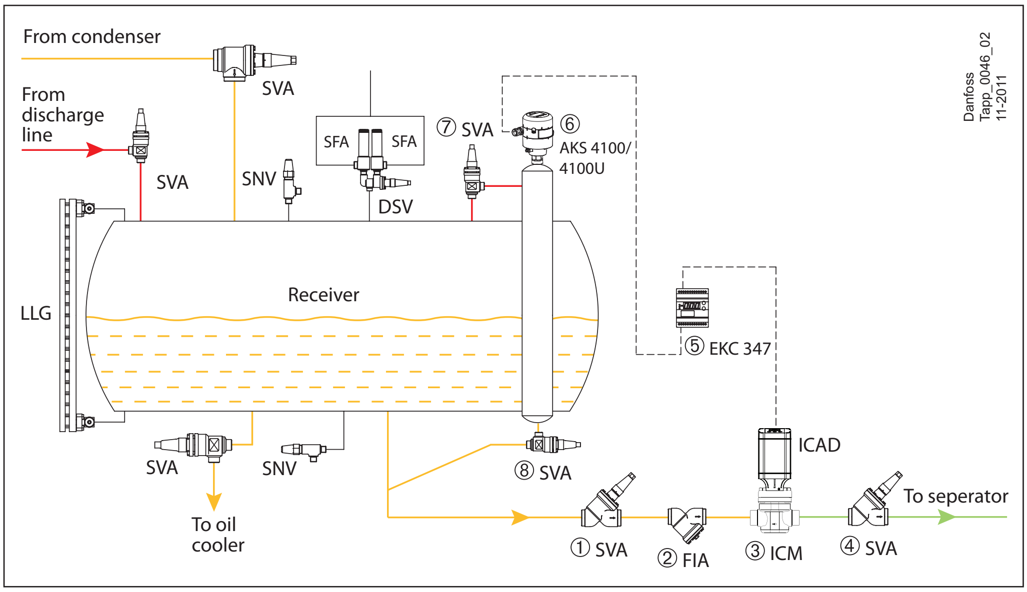
Option 1 is the simplest solution. Option 2 requires that a solenoid valve is installed in the equalisation line.

Technical data

	HFI
Material	Special steel approved for low temperature application
Refrigerants	R717 and other non-flammable refrigerant. For the refrigerants with density greater than 700kg/m^3, please consult Danfoss.
Media temp. range [°C]	–50 to 80
Max. working pressure [bar]	25 bar
Max test pressure [bar]	50 bar (without float)
Rated capacity [kW]*	400 to 2400

* Conditions: R717, –10/35°C

Application example 4.1.3: Electronic solution for HP liquid level control



🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟩 LP liquid refrigerant

① Stop valve
② Filter
③ Motor valve
④ Stop valve
⑤ Controller
⑥ Level transmitter
⑦ Stop valve
⑧ Stop valve

When designing an electronic LLRS solution the liquid level signal can be given either by an AKS 38 which is a level switch (ON/OFF) or an AKS 4100/4100U which is a level transmitter (4-20 mA).

The electronic signal is sent to an EKC 347 electronic controller which controls the injection valve.

The liquid injection can be controled in several different ways:

- With a modulating motor valve type ICM with an ICAD actuator.
- With a pulse-width-modulating expansion valve type AKVA. The AKVA valve should be used only where the pulsation from the valve is acceptable.
- With a regulating valve REG acting as an expansion valve and an EVRA solenoid valve to implement ON/OFF control.
- The system illustrated is an AKS 4100/4100U ⑥ level transmitter which sends a level signal to an EKC 347 ⑤ liquid level controller. The ICM ③ motor valve acts as an expansion valve.

Technical data

	Motor valve - ICM for expansion
Material	Body: Low temperature steel
Refrigerants	All common refrigerants including R717 and R744
Media temp. range [°C]	–60 to 120
Max. working pressure [bar]	52
DN [mm]	20 to 80
Nominal capacity [kW]*	73 to 22,700

* Conditions: R717, T_e = –10°C, Δp = 8.0 bar, ΔT_{sub} = 4K;

	Level transmitter - AKS 4100/4100U
Material	Thread and pipe: stainless steel Top part: cast aluminium
Refrigerants	R717, R22, R404a, R134a, R718, R744
Media temp. range [°C]	–60 to 100
Process pressure	-1 bar g to 100 bar g (-14,5 psig to 1450 psig)
Measuring range [mm]	800 to 8000

4.2
Low Pressure Liquid Level Control System (LP LLRS)

When designing a LP LLRS, the following points have to be taken into consideration:

The liquid level in the low pressure vessel (liquid separator/ shell-tube evaporator) is maintained at a constant level. This is safe to the system, since a too high liquid level in the liquid separator may cause liquid hammering to the compressor, and a too low level may lead to cavitation of the refrigerant pumps in a pump circulation system.

The receiver must be big enough to accumulate the liquid refrigerant coming from the evaporators when the content of refrigerant in some evaporators vary with the cooling load, some evaporators are shut off for service, or part of the evaporators are drained for defrosting.

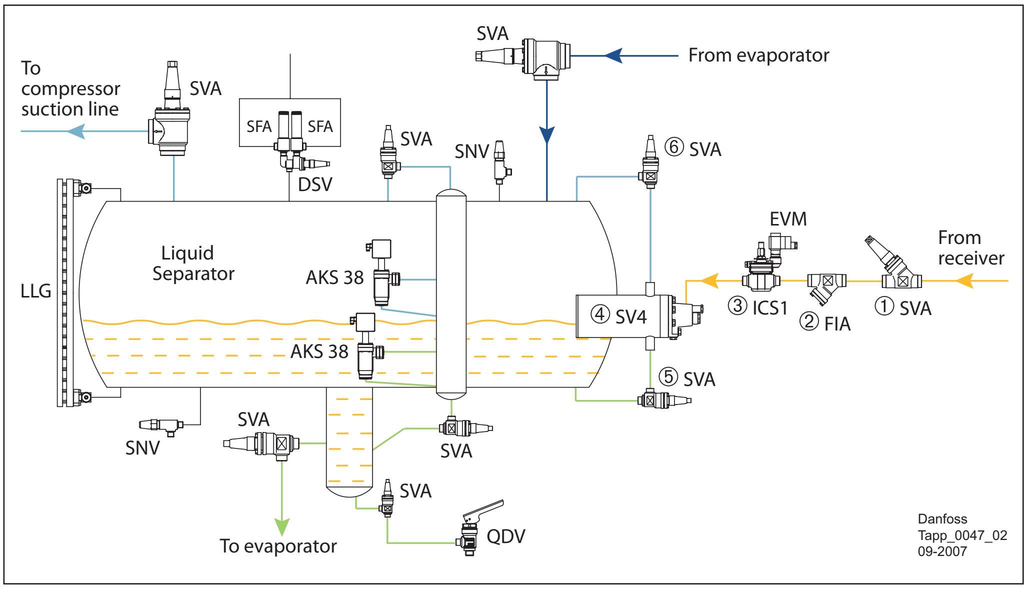
As a result of the above, LP LLRS are especially suitable for de-centralised systems in which there are many evaporators, and the refrigerant charge is large, like cold stores. With LP LLRS, these systems could run safely even though the refrigerant charge is impossible to be precisely calculated.

In conclusion, HP LLRS are suitable for compact systems like chillers; the advantage is the reduced cost (small receiver or no receiver). While LP LLRS are very suitable for de-centralised systems with many evaporators and long piping, like a large cold storage; the advantage being the higher safety and reliability.

Application example 4.2.1: Mechanical solution for LP liquid level control

🟧 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant

① Stop valve
② Filter
③ Solenoid valve
④ LP float valve
⑤ Stop valve
⑥ Stop valve



SV float valves "monitor" the liquid level in low pressure vessels. If the capacity is small the SV ④ valves can directly act as an expansion valve in the low pressure vessel as shown.

Technical data

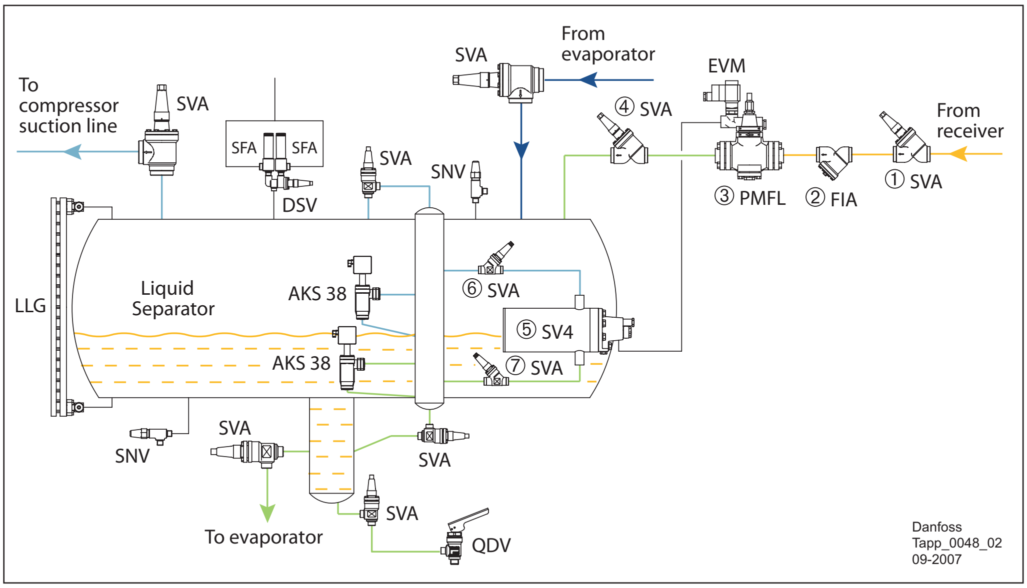
	SV 4-6
Material	Housing: steel Cover: low temperature cast iron(spherical) Float: stainless steel
Refrigerants	R717, HFC, HCFC and CFC
Media temp. range [°C]	–50 to +120
P-band [mm]	35
Max. working pressure [bar]	28
Max test pressure [bar]	42
K_v value [m^3/h]	0.23 for SV 4 0.31 for SV 5 0.43 for SV 6
Rated capacity [kW]*	SV4: 102 SV5: 138 SV6: 186

* Conditions: R717, +5/32°C, ΔT_{sub} = 4K.

Application example 4.2.2: Mechanical solution for LP liquid level control

🟧 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant

① Stop valve
② Filter
③ Servo-operated main valve
④ Stop valve
⑤ LP float valve
⑥ Stop valve
⑦ Stop valve



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If the capacity is large, the float valve SV ⑤ is used as a pilot valve for the PMFL main valve. As illustrated above, when the liquid level in the receiver falls below the set level, the float valve SV ⑤ provides a signal to the PMFL value to open.

Technical data

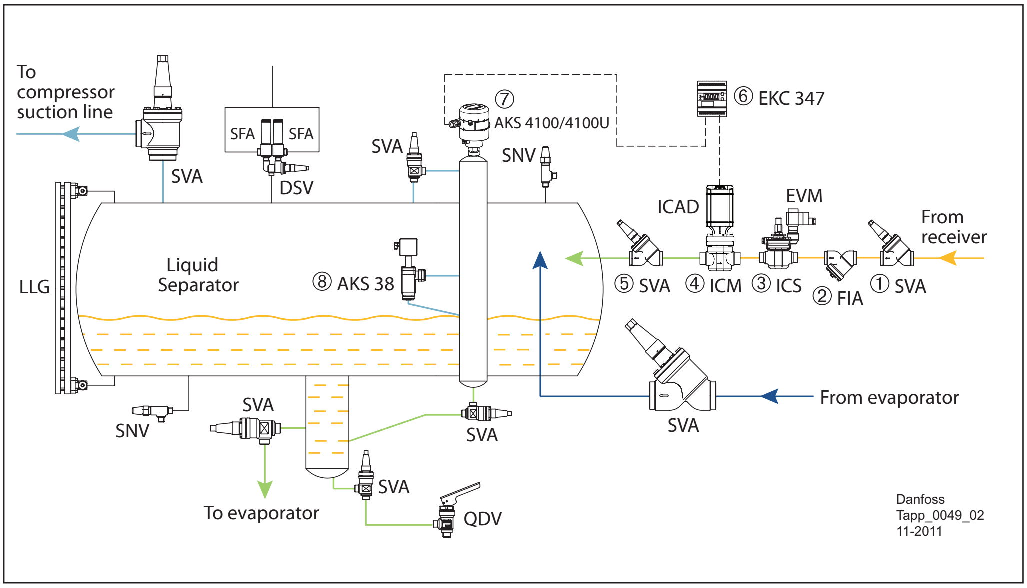
	PMFL 80 - 1 to 500
Material	Low temp. spherical cast iron
Refrigerants	R717, HFC, HCFC and CFC
Media temp. range [°C]	–60 to +120
Max. working pressure [bar]	28
Max test pressure [bar]	42
Rated capacity [kW]*	139-13,900

* Conditions: R717, +5/32°C, ΔT_{sub} = 4K.

Application example 4.2.3: Electronic solution for LP liquid level control

🟧 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant

① Stop valve
② Filter
③ Solenoid valve
④ Motor valve
⑤ Stop valve
⑥ Controller
⑦ Level transmitter
⑧ Level switch



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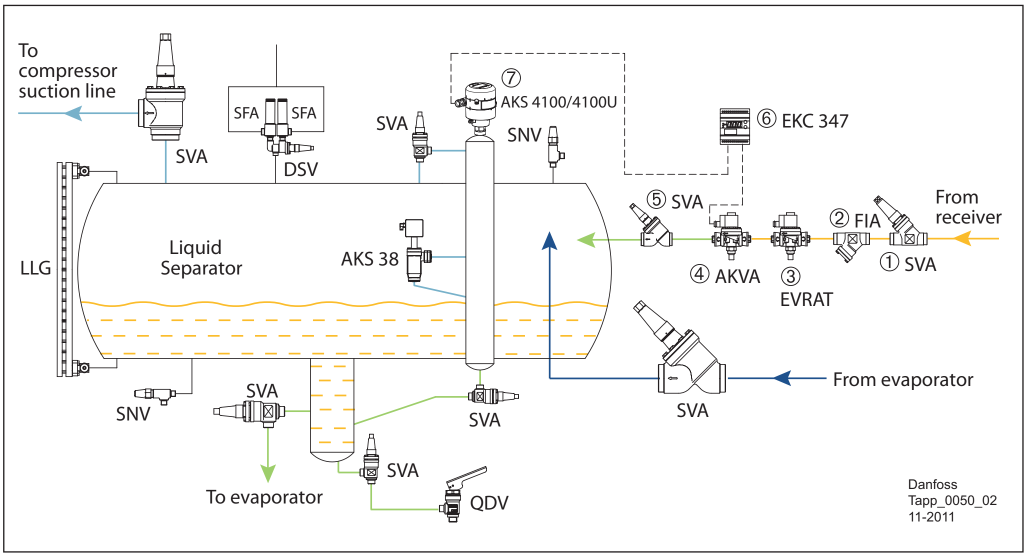
The level transmitter AKS 4100/4100U ⑦ monitors the liquid level in the separator and sends a level signal to the liquid level controller EKC 347 ⑥, which sends a modulating signal to the actuator of the motor valve ICM ④. The ICM motor valve acts as an expansion valve.

The liquid level controller EKC 347 ⑥ also provides relay outputs for upper and lower limits and for alarm level. However, it is recommended that a level switch AKS 38 ⑧ is fitted as a high level alarm.

Application example 4.2.4: Electronic solution for LP liquid level control

▬ HP liquid refrigerant
▬ Liquid/vapour mixture of refrigerant
▬ LP vapour refrigerant
▬ LP liquid refrigerant

① Stop valve
② Filter
③ Solenoid valve
④ Electronically operated expansion valve
⑤ Stop valve
⑥ Controller
⑦ Level transmitter



This solution is similar to solution 4.2.3. However, with this example the motor valve ICM is replaced by a pulse width electronically operated expansion valve AKVA. The servo valve EVRAT ③ is being used as an additional solenoid valve to ensure 100% closure during "off" cycles.

The liquid level controller EKC 347 ⑥ also provides relay outputs for upper and lower limits and for alarm level. However, it is recommended that a level switch AKS 38 is fitted as a high level alarm.

Technical data

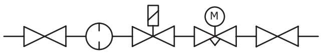
	AKVA
Material	AKVA 10: stainless steel AKVA 15: cast iron AKVA 20: cast iron
Refrigerants	R717
Media temp. range [°C]	AKVA 10: –50 to +60 AKVA 15/20: –40 to +60
Max. working pressure [bar]	42
DN [mm]	10 to 50
Nominal capacity [kW]*	4 to 3150

* Conditions: R717, +5/32°C, ΔT_{sub} = 4K.

Application example 4.2.5: Electronic solution for LP liquid level control

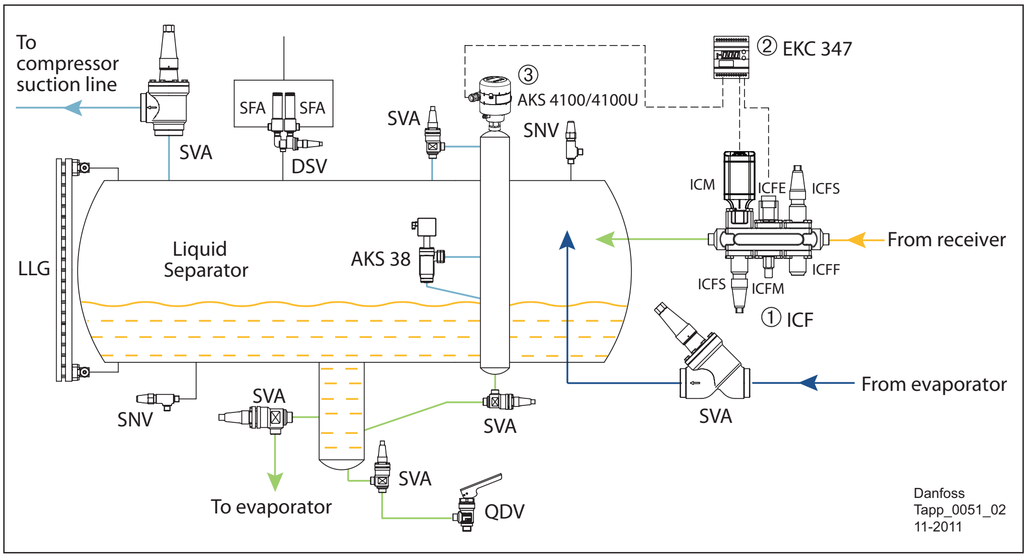
▬ HP liquid refrigerant
▬ Liquid/vapour mixture of refrigerant
▬ LP vapour refrigerant
▬ LP liquid refrigerant

① ICF valve station including:



Stop valve
Filter
Solenoid valve
Manual opener
Motor valve
Stop valve

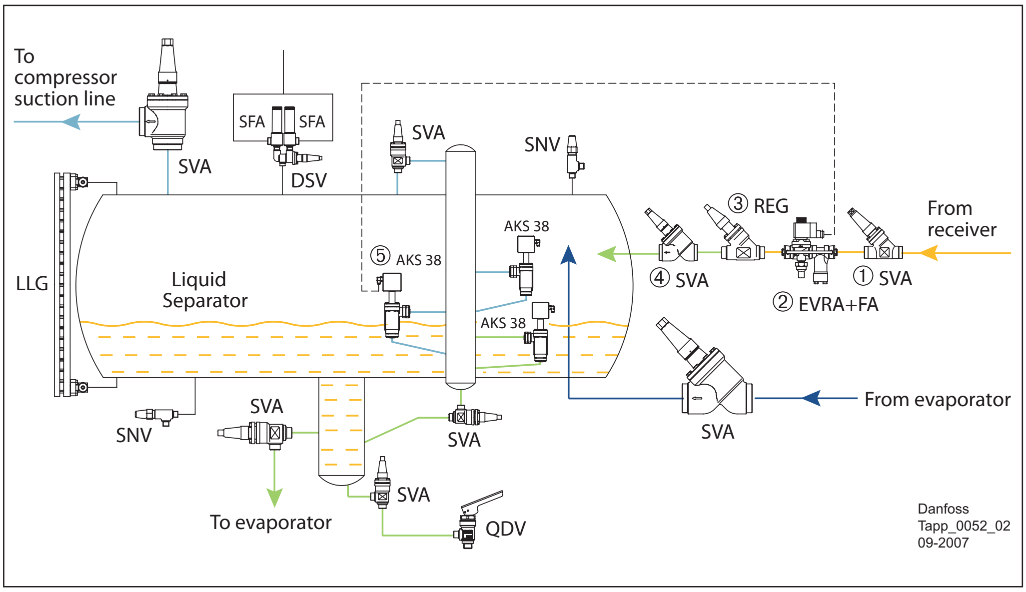
② Controller
③ Level transmitter



Danfoss can supply a very compact valve solution ICF ①. Up to six different modules can be assembled into the same housing, which is easy to install.

The module ICM acts as an expansion valve and the module ICFE is a solenoid valve.
This solution works in an identical manner to example 4.2.3. ICF solution similar to example 4.2.4 is also available. Please refer to ICF literature for further information.

Application example 4.2.6: Electronic solution for LP liquid level control



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🟨 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant

① Stop valve
② Solenoid valve
③ Hand regulating valve
④ Stop valve
⑤ Level switch

This solution controls the liquid injection using on/off control. The level switch AKS 38 ⑤, controls the switching of the solenoid valve EVRA ②, in accordance with liquid level in the separator. The hand regulating valve REG ③ acts as the expansion valve.

Technical data

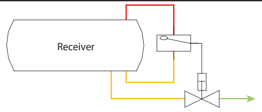
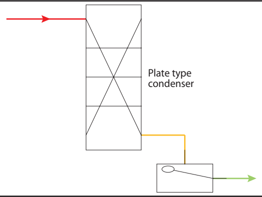
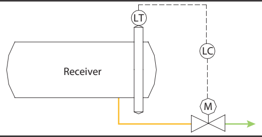
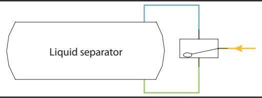
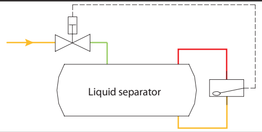
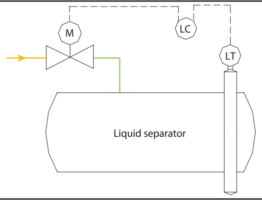
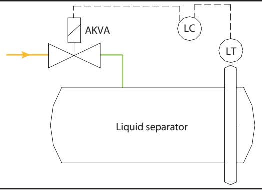
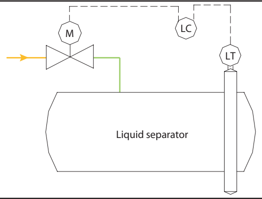
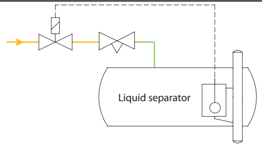
	AKS 38
Material	Housing: zinc chromate cast iron
Refrigerants	All common non-flammable refrigerants, including R717.
Media temp. range [°C]	–50 to +65
Max. working pressure [bar]	28
Measuring range [mm]	12.5 to 50

	REG
Material	Special cold resistant steel approved for low temperature operation
Refrigerants	All common non-flammable refrigerants, including R717.
Media temp. range [°C]	–50 to +150
Max. working pressure [bar]	40
Test pressure [bar]	Strength test: 80 Leakage test: 40
DN [mm]	6 to 65
K_v value [m^3/h]	0.17 to 81.4 for fully open valves

	EVRA
Refrigerants	R717, R22, R134a, R404a, R410a, R744, R502
Media temp. range [°C]	–40 to +105
Max. working pressure [bar]	42
Rated capacity [kW]*	21.8 to 2368
K_v value [m^3/h]	0.23 to 25.0

* Conditions: R717, –10/+25°C, $\Delta p = 0.15$ bar

4.3
Summary

Solution		Application	Benefits	Limitations
High pressure mechanical solution: SV1/3 + PMFH		Applicable to systems with small refrigerant charges, like chillers.	Pure mechanical. Wide capacity range.	Unable to control remotely, the distance between SV and PMFH is limited to several meters. A little bit slow in response.
High pressure mechanical solution: HFI		Applicable to systems with small refrigerant charges and with plate type condensers only.	Pure mechanical. Simple solution. Especially suitable for plate heat exchanger	Unable to provide thermosyphon oil cooling.
High pressure electronic solution: AKS 4100/4100U+EKC 347 + ICM		Applicable to systems with small refrigerant charges, like chillers.	Flexible and compact. Possible to monitor and control remotely. Covers a wide range of capacity.	Not allowed for flammable refrigerant.
Low pressure mechanical solution: SV4-6		Applicable to small systems.	Pure mechanical. Simple, low cost solution.	Limited capacity.
Low pressure mechanical solution: SV 4-6 + PMFL		Particularly applicable to de-central systems, like cold stores.	Pure mechanical. Wide capacity range.	Unable to control remotely, the distance between SV and PMFL is limited to several meters. A little bit slow in response.
Low pressure electronic solution: AKS 4100/4100U + EKC 347 + ICM		Particularly applicable to de-central systems, like cold stores.	Flexible and compact. Possible to monitor and control remotely. Covers a wide range of capacities.	Not allowed for flammable refrigerant.
Low pressure electronic solution: AKS 4100/4100U + EKC 347 + AKVA		Particularly applicable to de-central systems, like cold stores.	Flexible and compact. Possible to monitor and control remotely. Wide capacity range. Faster than motor valve. Fail safe valve (NC).	Not allowed for flammable refrigerant. The system needs to allow for pulsations.
Low pressure electronic solution: AKS 4100/4100U + EKC 347 + ICF		Particularly applicable to de-central systems, like cold stores.	Flexible and compact. Possible to monitor and control remotely. Covers a wide range of capacities. Easy to install.	Not allowed for flammable refrigerant.
Low pressure electronic solution: AKS 38 + EVRA + REG		Particularly applicable to de-central systems, like cold stores.	Simple. In-expensive.	Just 40 mm for level adjustment. Very dependant on the adjustment of the REG valve. Not suitable for systems with big capacity fluctuations.

4.4
Reference Documents

For an alphabetical overview of all reference documents please go to page 104

Technical Leaflet / Manual

Type	Literature no.
AKS 38	PD.GD0.A
AKS 4100/ 4100U	PD.SC0.C
AKVA	PD.VA1.B
EKC 347	RS.8A.X
EVRA(T)	PD.BM0.B
ICM	PD.HT0.B

Type	Literature no.
PMFH/L	PD.GE0.C
ICF	PD.FT0.A
REG	PD.KM0.A
SV 1-3	PD.GE0.B
SV 4-6	PD.GE0.D

Product instruction

Type	Literature no.
AKS 38	RI.5M.A
AKS 4100/ 4100U	PI.SC0.D PI.SC0.E
AKVA	PI.VA1.C / PI.VA1.B
EKC 347	RI.8B.Y
EVRA(T)	RI.3D.A
ICM 20-65	PI.HT0.A

Type	Literature no.
ICM 100-150	PI.HT0.B
PMFH/L	RI.2C.F / PI.GE0.A
ICF	PI.FT0.A
REG	PI.KM0.A
SV 1-3	PI.GE0.C
SV 4-6	RI.2B.B

To download the latest version of the literature please visit the Danfoss internet site
http://www.danfoss.com/Products/Literature/RA_Documentation.htm

5. Evaporator Controls

The evaporator is the part of the refrigeration system where the effective heat is transferred from the media you want to cool down (e.g. air, brine, or the product directly) to the refrigerant.

Therefore, the primary function of evaporator control system is to achieve the desired media temperature. Furthermore, the control system should also keep the evaporator in efficient and trouble-free operation at all times.

Specifically, the following control methods may be necessary for evaporators:

- Liquid supply control Section 5.1 and 5.2 describes two different types of liquid supply-direct expansion (DX) and pumped liquid circulation.
- Defrost (Section 5.3 and 5.4), which is necessary for air coolers operating at temperatures below 0°C.
- Multi-temperature changeover (Section 5.5) for evaporators that need to operate at different temperature levels.
- Media temperature control (Section 5.6) when the media temperature is required to be maintained at a constant level with high accuracy.

When introducing media temperature control and defrost, direct expansion (DX) evaporators and pumped liquid circulation evaporators are discussed separately, because there are some differences in the control systems.

5.1
Direct Expansion Control

To design liquid supply for direct expansion evaporators, the following requirements should be satisfied:

- The liquid refrigerant supplied to the evaporator is completely evaporated. This is necessary to protect the compressor against liquid hammer.
- The media “off” temperature from the evaporator is maintained within the desired range.

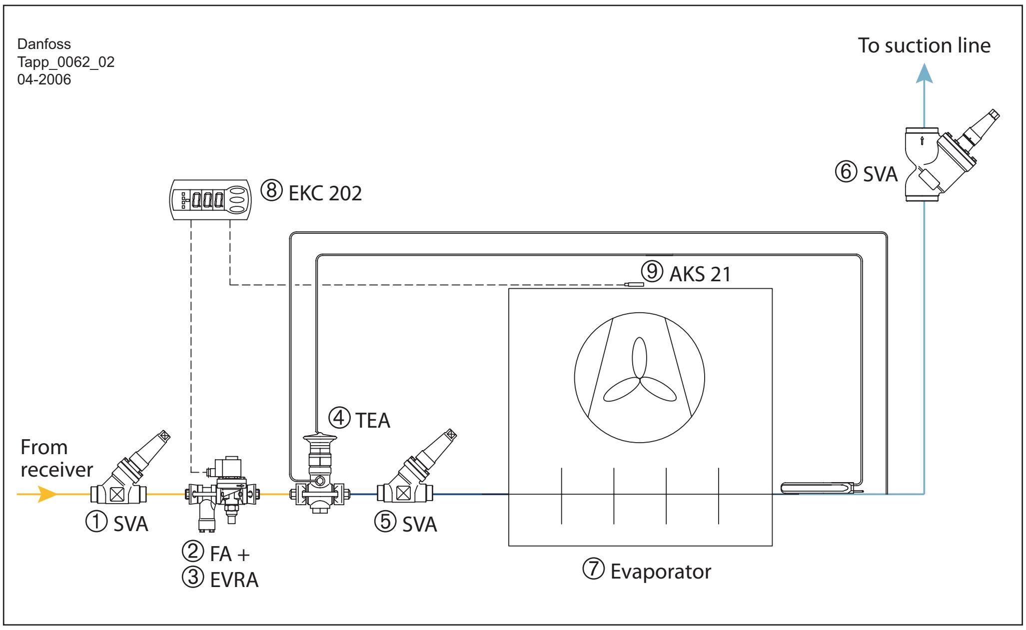
The liquid injection is controled by a superheat-controlled expansion valve, which maintains the superheat at the outlet of the evaporator within a desired range. This expansion valve can be either a thermostatic expansion valve, or an electronic expansion valve.

The temperature control is normally achieved by ON/OFF control, which starts and stops the liquid supply to the evaporator according to the media temperature.

Application example 5.1.1:
DX evaporator, thermostatic expansion

▬ HP liquid refrigerant
▬ Liquid/vapour mixture of refrigerant
▬ LP vapour refrigerant

① Stop valve liquid inlet
② Filter
③ Solenoid valve
④ Thermostatic expansion valve
⑤ Stop valve evaporator inlet
⑥ Stop valve suction line
⑦ Evaporator
⑧ Digital thermostat
⑨ Temperature sensor



Application example 5.1.1 shows a typical installation for a DX evaporator without hot gas defrosting.

The liquid injection is controled by the thermostatic expansion valve TEA ④, which maintains the refrigerant superheat at the outlet of the evaporator at a constant level. TEA is designed for ammonia. Danfoss also supply thermostatic expansion valves for fluorinated refrigerants.

The media temperature is controlled by the digital thermostat EKC 202 ⑧, which controls the on/off switching of the solenoid valve EVRA ③ according to the media temperature signal from the PT 1000 temperature sensor AKS 21 ⑨.

This solution can also be applied to DX evaporators with natural or electric defrost.

Natural defrost is achieved by stopping the refrigerant flow to the evaporator, and keeping the fan running. Electric defrost is achieved by stopping the refrigerant flow to the evaporator and the fan and at the same time switching on an electric heater inside the evaporator fin block.

Evaporator Controller EKC 202
The digital thermostat will control all functions of the evaporator including thermostat, fan, defrost and alarms.

For more details, please refer to the manual of EKC 202 from Danfoss.

Technical data

	Thermostatic expansion valve - TEA
Refrigerants	R717
Evaporating temp. range [°C]	–50 to 30
Max. bulb temp. [°C]	100
Max. working pressure [bar]	19
Rated Capacity [kW]*	3.5 to 295

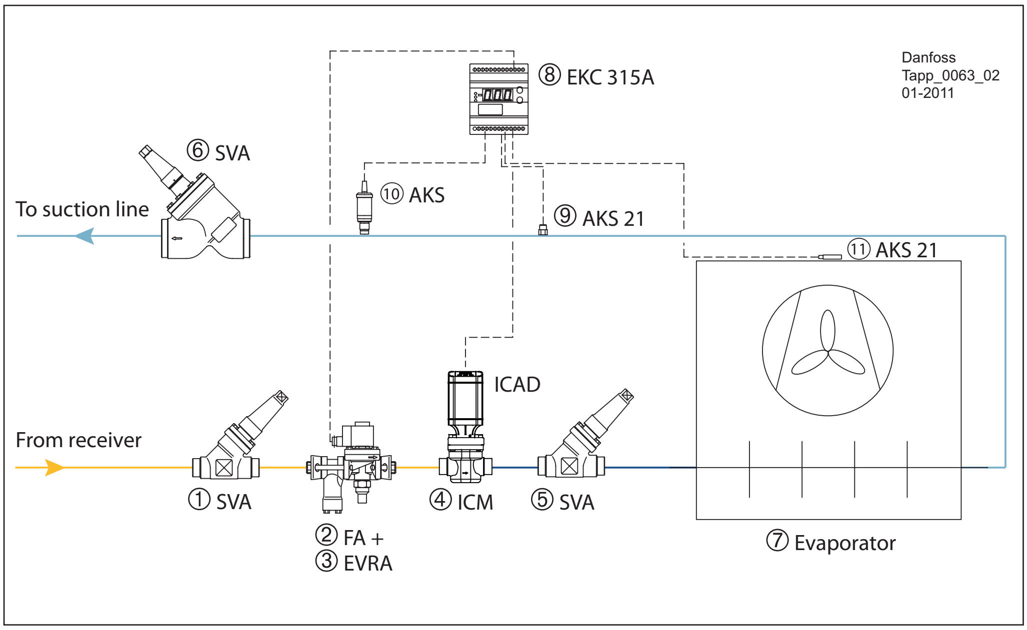
* Conditions: –15°C/+32°C, ΔT_{sub} = 4°C

	Solenoid valve - EVRA(T)
Refrigerants	R717, R22, R134a, R404a, R410a, R744, R502
Media temp. range [°C]	–40 to +105
Max. working pressure [bar]	42
Rated capacity [kW]*	21.8 to 2368
K_v value [m^3/h]	0.23 to 25.0

* Conditions: R717, –10/+25°C, Δp = 0.15 bar

	Strainer - FA
Refrigerants	Ammonia and fluorinated refrigerants
Media temp. range [°C]	–50 to +140
Max. working pressure [bar]	28
DN [mm]	15/20
Filter insert	150µ stainless steel weave
K_v value [m^3/h]	3.3/7.0

Application example 5.1.2:
DX evaporator, electronic expansion



- 🟧 HP liquid refrigerant
- 🟦 Liquid/vapour mixture of refrigerant
- ▬ LP vapour refrigerant

① Stop valve liquid inlet
② Filter
③ Solenoid valve
④ Electronic expansion valve
⑤ Stop valve evaporator inlet
⑥ Stop valve suction line
⑦ Evaporator
⑧ Controller
⑨ Temperature sensor
⑩ Pressure transmitter
⑪ Temperature sensor

Application example 5.1.2 shows a typical installation for an electronically controlled DX evaporator without hot gas defrost.

The liquid injection is controled by the motor-valve ICM ④ controlled by the evaporator controller type EKC 315A ⑧. The EKC 315A controller will measure the superheat by means of the pressure transmitter AKS ⑩ and the temperature sensor AKS 21 ⑨ on the outlet of the evaporator, and controlling the opening of the ICM in order to maintain the superheat at the optimum level.

At the same time, the controller EKC 315A operates as a digital thermostat, which will control the on/off switching of the solenoid valve EVRA ③ depending on the media temperature signal from the temperature sensor AKS 21 ⑪.

Compared with the solution 5.1.1, this solution will operate the evaporator at an optimised superheat and constantly adapt the opening degree of the injection valve to ensure maximum capacity and efficiency. The surface area of the evaporator will be fully utilised. Furthermore, this solution offers a more accurate media temperature control.

Evaporator Controller EKC 315A
The Digital controller will control all functions of the evaporator including thermostat, expansion and alarms.

For more details, please refer to the manual of EKC 315A from Danfoss.

Technical data

	Motor valve - ICM for expansion
Material	Body: Low temperature steel
Refrigerants	All common refrigerants including R717 and R744
Media temp. range [°C]	–60 to 120
Max. working pressure [bar]	52
DN [mm]	20 to 80
Nominal capacity [kW]*	73 to 22700

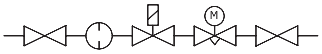
* Conditions: R717, $T_e = -10$°C, $\Delta p = 8.0$ bar, $\Delta T_{sub} = 4$K;

	Pressure transmitter - AKS 3000	Pressure transmitter - AKS 32
Refrigerants	All refrigerants including R717	All refrigerants including R717
Operating range [bar]	0 to 60 (depending on range)	–1 to 39 (depending on range)
Max. working pressure PB [bar]	100 (depending on operating range)	60 (depending on operating range)
Operating temp. range [°C]	–40 to 80	–40 to 85
Compensated temp. range [°C]	LP: –30 to +40 / HP: 0 to +80	LP: –30 to +40 / HP: 0 to +80
Rated output signal	4 to 20 mA	1 to 5V or 0 to 10V

Application example 5.1.3: DX Evaporator, Electronic expansion with ICF control solution

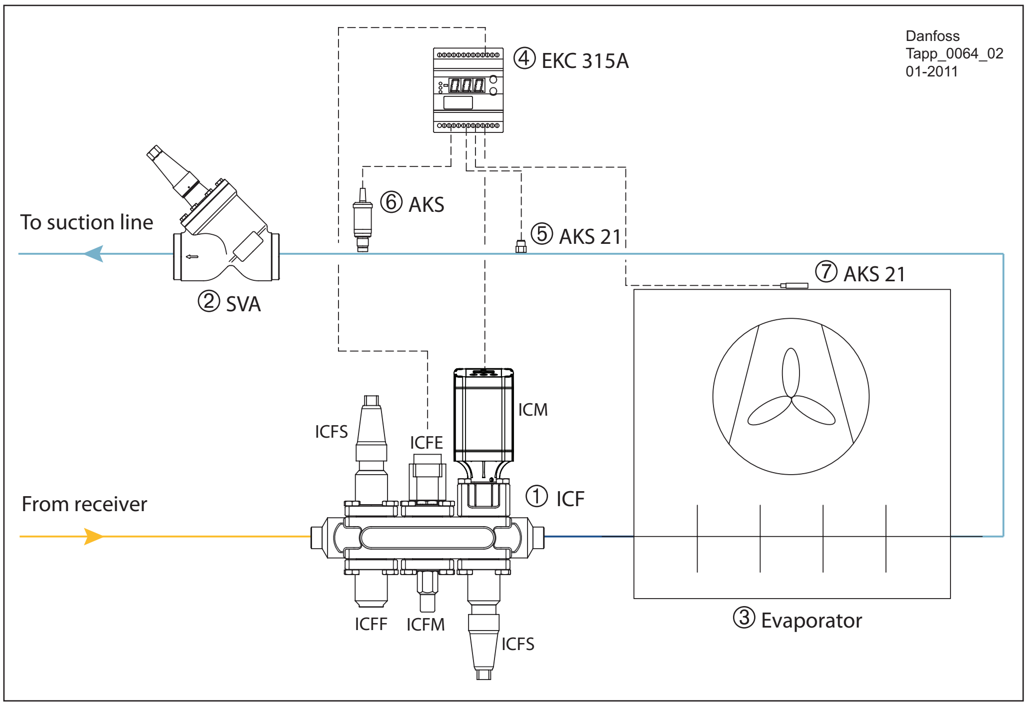
🟨 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟦 LP vapour refrigerant

① ICF control solution with:



Stop valve liquid inlet
Filter
Solenoid valve
Manual opening
ICM electronic exp. valve
Stop valve evaporator inlet

② Stop valve suction line
③ Evaporator
④ Controller
⑤ Temperature sensor
⑥ Pressure transmitter
⑦ Temperature sensor



Application example 5.1.3 shows the new ICF control solution for an electronically controlled DX evaporator without hot has defrost similar to the example 5.1.2.

The ICF will accommodate up to six different modules assembled in the same housing offering a compact, easy to install control solution.

The liquid injection is controled by the motor-valve ICM which is controlled by the evaporator controller type EKC 315A ④. The EKC 315A controller will measure the superheat by means of the pressure transmitter AKS ⑥ and the temperature sensor AKS 21 ⑤ on the outlet of the evaporator, and control the opening of the ICM valve in order to maintain the superheat at the optimum level.

At the same time, the controller EKC 315A operates as a digital thermostat, which will control the on/off switching of the solenoid valve ICFE depending on the media temperature signal from the temperature sensor AKS 21 ⑦.

Similar to the example 5.1.1, this solution will operate the evaporator at an optimised superheat, and constantly adapt the opening degree of the injection valve to ensure maximum capacity and efficiency. The surface area of the evaporator will be fully utilised. Furthermore, this solution offers a more accurate media temperature control.

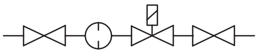
Evaporator Controller EKC 315A
The Digital controller will control all functions of the evaporator including thermostat, expansion and alarms.

For more details, please refer to the manual of EKC 315A from Danfoss.

Application example 5.1.4:
DX evaporator and electronic expansion with ICF control

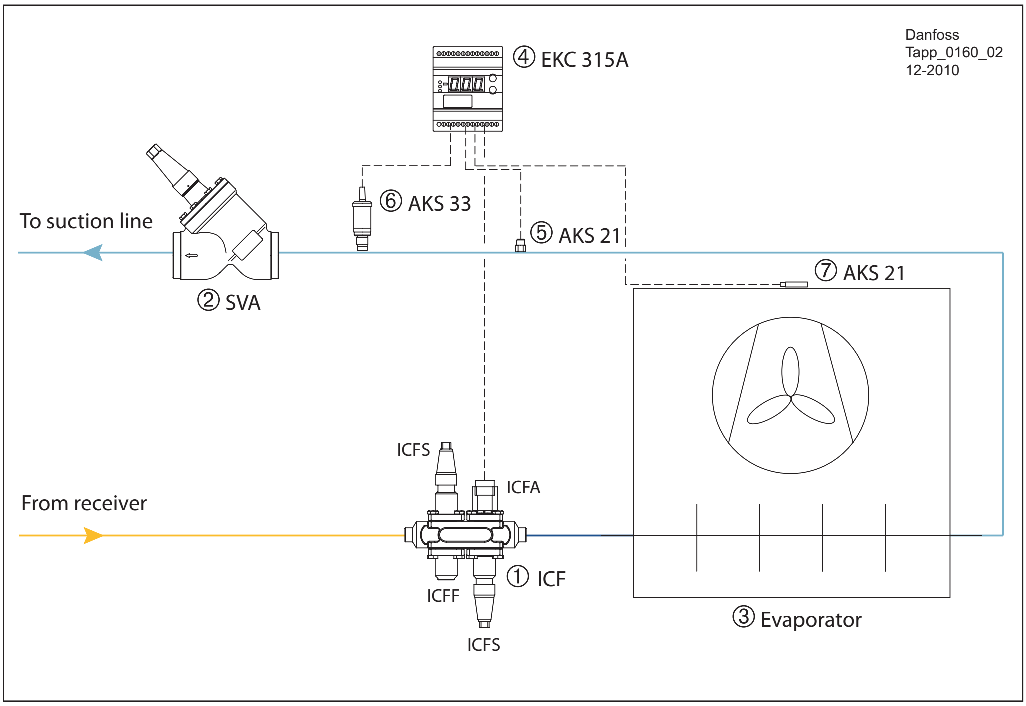
▬ HP liquid refrigerant
▬ Liquid/vapour mixture of refrigerant
▬ LP vapour refrigerant

① ICF control solution with:



Stop valve liquid inlet
Filter
Expansion valve
Evaporator inlet stop valve

② Suction line stop valve
③ Evaporator
④ Controller
⑤ Temperature sensor
⑥ Pressure transmitter
⑦ Temperature sensor



This application example shows an ICF control solution for an electronically controlled DX evaporator without hot gas defrost.

The ICF can accommodate up to six different models in the same housing, offering a compact, easy to install control solution.

Liquid injection is controlled by the ICFA electronic expansion valve, which is controlled by the EKC 315A evaporator controller ④. The EKC 315A controllor measures the superheat by means of the pressure transmitter AKS 33 ⑥ and the temperature sensor AKS 21 ⑤ on the outlet of the evaporator, and controls the opening of the ICFA valve in order to maintain the superheat at the optimum level.

This solution operates the evaporator with optimised superheat and constantly adapts the opening degree of the injection valve to ensure maximum capacity and efficiency. The surface area of the evaporator is fully utilised. Furthermore, this solution provides more accurate media temperature control.

EKC 315A Evaporator Controller
The digital controller controls all evaporator functions, including thermostat, expansion and alarms.

For more details, please see the Danfoss EKC 315A manual.

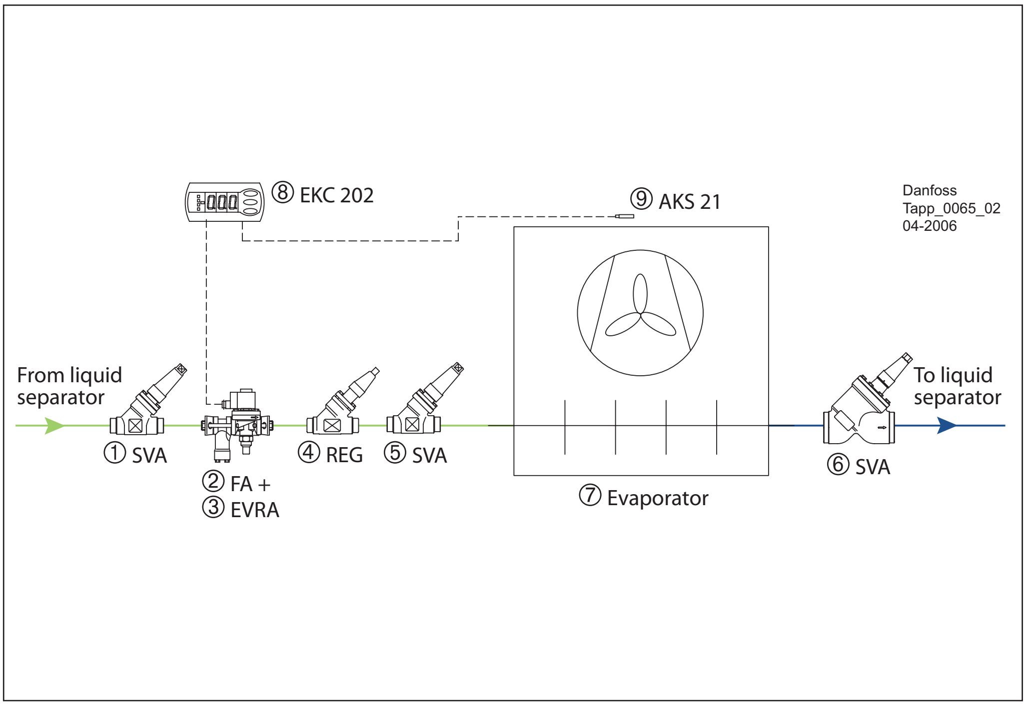
The ICF control solution shown here can also be replaced by a conventional valve solution (SVA stop valve, FA/FIA filter, AKVA electronic expansion valve and a SVA stop valve).
The controller EKC 315A can be used with ICF and with a conventional valve solution.

5.2
Pumped Liquid Circulation Control

When compared to ammonia DX systems, ammonia pump circulation systems control becomes simpler as a well-dimensioned pump separator protects compressors against hydraulic shock.

The pump separator ensures that only "dry" refrigerant vapour is returned to the compressors. The evaporation control is also simplified as only a basic on/off liquid control to the evaporators is required.

Application example 5.2.1: Pumped liquid circulation evaporator, without hot gas defrost



▬ Liquid/vapour mixture of refrigerant
▬ LP liquid refrigerant

① Stop valve liquid inlet
② Filter
③ Solenoid valve
④ Hand expansion valve
⑤ Stop valve evaporator inlet
⑥ Stop valve suction line
⑦ Evaporator
⑧ Digital thermostat
⑨ Temperature sensor

Application example 5.2.1 shows a typical installation for a pumped liquid circulation evaporator without hot has defrost, and can also be applied to pumped liquid circulation evaporators with natural or electric defrost.

The media temperature is maintained at the desired level by the digital thermostat EKC 202 ⑧, which controls the on/off switching of the solenoid valve EVRA ③ according to the media temperature signal from the PT 1000 temperature sensor AKS 21 ⑨.

The amount of liquid injected into the evaporator is controled by the opening of the hand regulating valve REG ④. It is important to set this regulating valve at the right opening degree.

Too high an opening degree will lead to frequent operation of the solenoid valve with resultant wear. Too low an opening degree will starve the evaporator of liquid refrigerant.

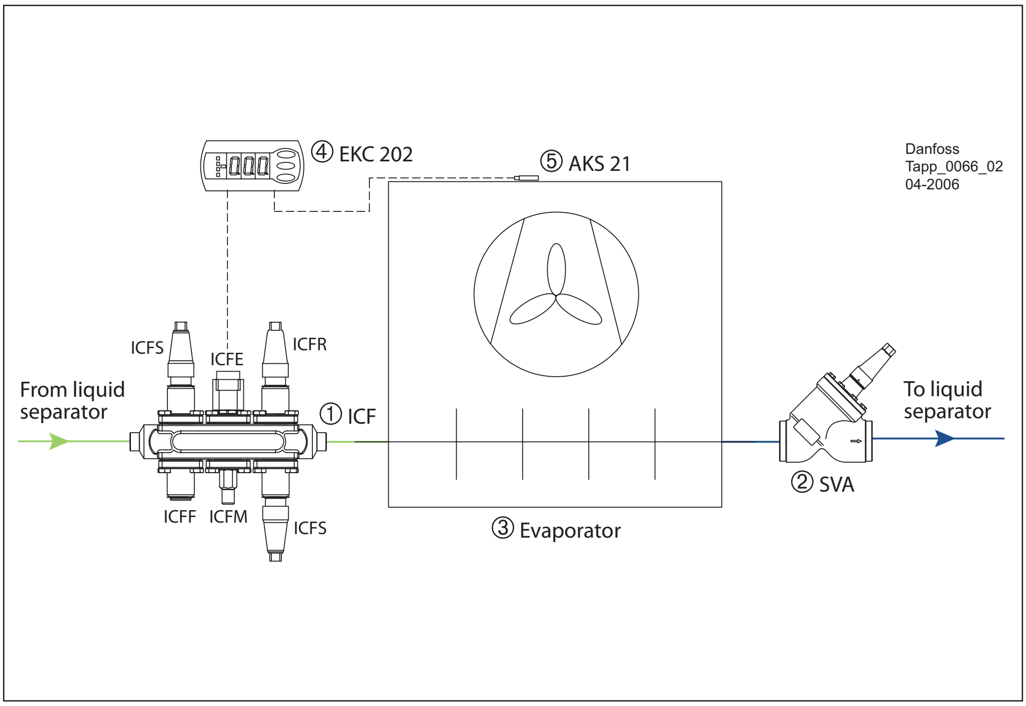
Evaporator Controller EKC 202
The Digital thermostat will control all functions of the evaporator including thermostat, fan, defrost and alarms.

For more details, please refer to the manual of EKC 202 from Danfoss.

Technical data

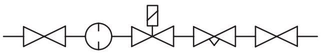
	REG
Material	Special cold resistant steel approved for low temperature operation
Refrigerants	All common non-flammable refrigerants, including R717.
Media temp. range [°C]	–50 to +150
Max. working pressure [bar]	40
Test pressure [bar]	Strength test: 80 Leakage test: 40
DN [mm]	6 to 65
K_v value [m^3/h]	0.17 to 81.4 for fully open valves

Application example 5.2.2: Pumped liquid circulation evaporator, ICF control solution, without hot gas defrost



🟦 Liquid/vapour mixture of refrigerant
🟩 LP liquid refrigerant

① ICF control solution with:



Stop valve liquid inlet
Filter
Solenoid valve
Manual opening
Hand expansion valve
Stop valve evaporator inlet

② Stop valve suction line
③ Evaporator
④ Digital thermostat
⑤ Temperature sensor

Application example 5.2.2 includes for the new ICF control solution operating identically to example 5.2.1 and can also be applied to pumped liquid circulation evaporators with natural or electric defrost.
The ICF will accommodate up to six different modules assembled in the same housing offering a compact, easy to install control solution.

The media temperature is maintained at the desired level by the digital thermostat EKC 202 ④, which controls the on/off switching of the solenoid valve ICFE in the ICF according to the media temperature signal from the PT 1000 temperature sensor AKS 21 ⑤.

The amount of liquid injected into the evaporator is controlled by the opening of the hand regulating valve ICFR. It is important to set this regulating valve at the right opening degree. Too high an opening degree will lead to frequent operation of the solenoid valve with resultant wear. Too low an opening degree will starve the evaporator of liquid refrigerant.

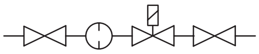
Evaporator Controller EKC 202
The digital thermostat will control all functions of the evaporator including thermostat, fan, defrost and alarms.

For more details, please refer to the manual of EKC 202 from Danfoss.

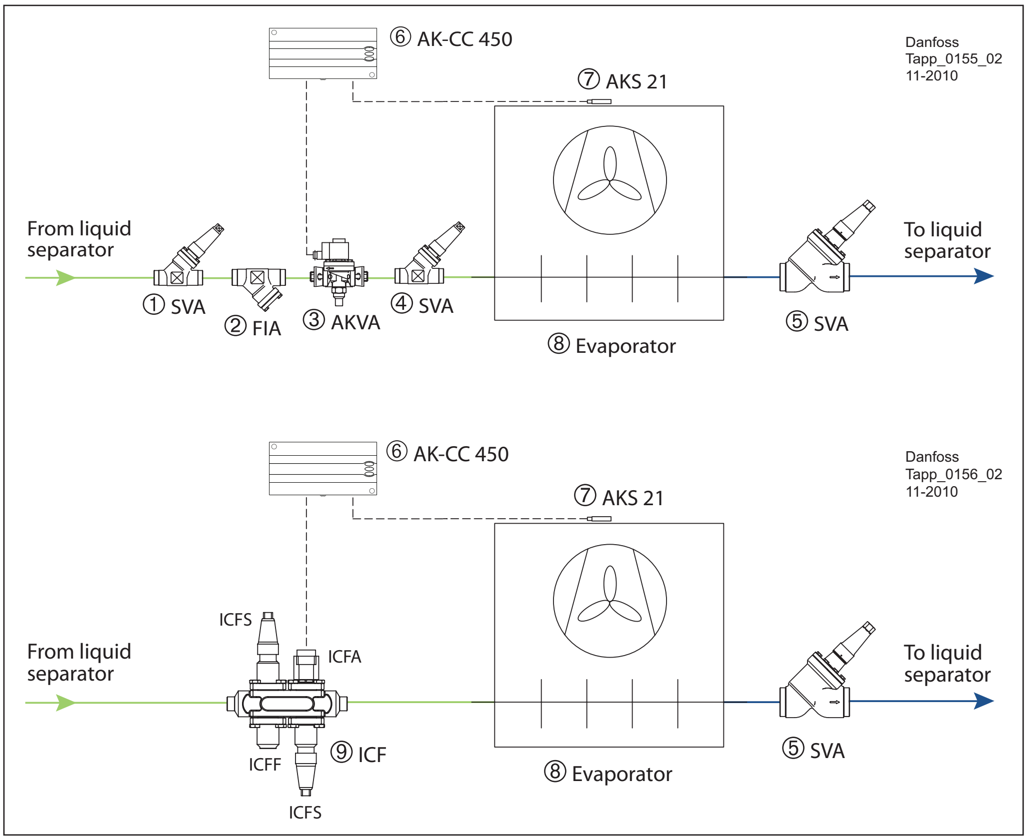
Application 5.2.3 Injecting liquid in an air cooler in a flooded system using pulse width modulation valve AKVA/ICFA, with electrical or brine defrost

🟦 Liquid/vapour mixture of refrigerant
🟩 LP liquid refrigerant

① Liquid line stop valve
② Filter
③ Electronically operated expansion valve
④ Evaporator inlet stop valve
⑤ Suction line stop valve
⑥ Digital thermostat
⑦ Temperature sensor
⑧ Evaporator
⑨ ICF control solution with:



Stop valve
Filter
Electronic expansion valve
Stop valve



In a traditional flooded system, liquid injection is controlled by a thermostat which constantly measures the air temperature.

The solenoid valve is opened for several minutes or longer until the air temperature has reached the set point. During injection the mass of the refrigerant flow is constant.

This is a very simple way to control the air temperature, but the temperature variation caused by the thermostat may cause unwanted side effects in some applications, such as dehumidification or inaccurate control.

Instead of injecting periodically, as described above, one can also constantly adapt the liquid injection to the actual need. This can be done with a PWM AKVA valve ③ or an ICF ⑨ with and ICFA solenoid module.

The air temperature is constantly measured and compared to the reference temperature.
When the air temperature reaches the set point, the AKVA valve ③ opening is reduced. This decreases the degree of opening during the cycle, resulting in less capacity. The cycle time is usually 3 to 6 seconds.

In a flooded system this means that the average refrigerant flow is constantly controlled and adapted to demand. When less refrigerant is injected, the circulation rate decreases.

The result of this is that more refrigerant will be evaporated, creating a certain amount of superheated gas in the air cooler.

A direct effect of this is a cooler average surface temperature, resulting in a smaller ΔT between the refrigerant and the air.

This approach to liquid injection in a flooded system is very versatile. The amount of injected liquid can be controlled exactly, which increases the accuracy and the energy efficiency of the system.

5.3
Hot Gas Defrost for DX Air Coolers

In applications where the air cooler operates at evaporating temperatures below 0°C, frost will form on the heat exchange surface, with its thickness increasing with time. The frost build up leads to a drop in performance of the evaporator by reducing the heat transfer coefficient and blocking the air circulation at the same time. Therefore, these air coolers should be defrosted periodically to keep their performance at a desired level.

Different types of defrost commonly used in industrial refrigeration are:

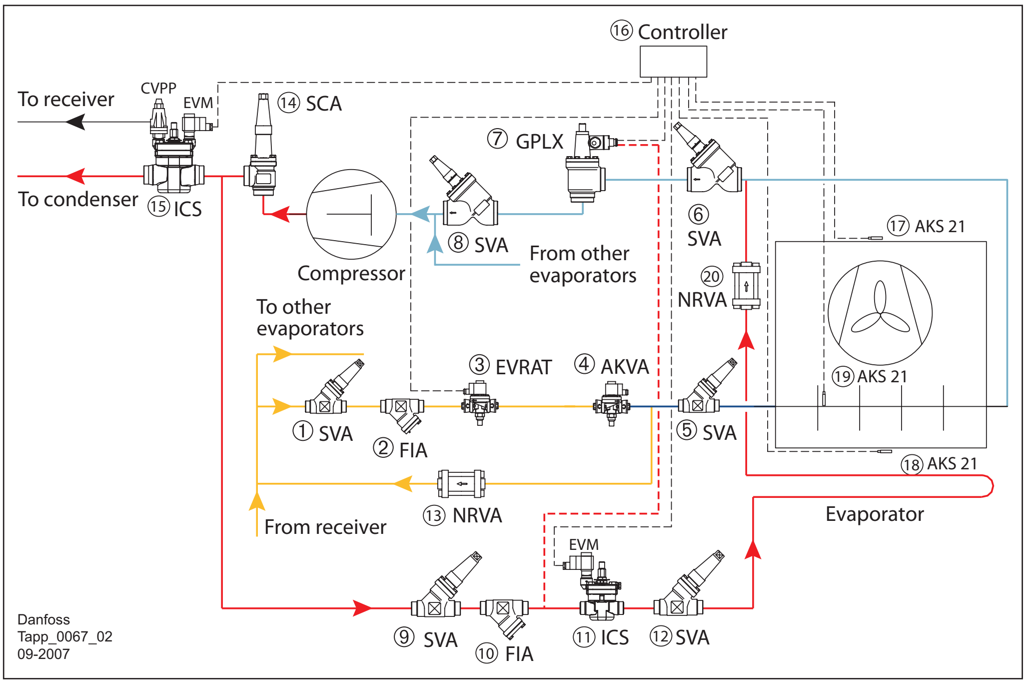
- Natural defrost
- Electric defrost
- Hot gas defrost

Natural defrost is achieved by stopping the refrigerant flow to the evaporator and keeping the fan running. This can only be used for room temperatures above 0°C. The resulting defrosting time is long.

Electric defrost is achieved by stopping the fan and the refrigerant flow to the evaporator and at the same time switching on an electric heater inside the evaporator fin block. With a timer function and/or a defrost termination thermostat, the defrosting can be terminated when the heat exchange surface is completely free of ice. Whilst this solution is easy to install and low in initial investment, the operating costs (electricity) are considerably higher than for other solutions.

For hot gas defrost systems, hot gas will be injected into the evaporator to defrost the surface. This solution requires more automatic controls than other systems, but has the lowest operating cost over time. A positive effect of hot gas injection into the evaporator is the removal and return of oil. To ensure enough hot gas capacity, this solution must only be used in refrigeration systems with three or more evaporators. Only a third of the total evaporator capacity can be under defrost at a given time.

Application example 5.3.1: DX evaporator, with hot gas defrost system



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🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟦 LP vapour refrigerant

Liquid Line
① Stop valve liquid inlet
② Filter
③ Solenoid valve
④ Expansion valve
⑤ Stop valve evaporator inlet

Suction Line
⑥ Stop valve evaporator inlet
⑦ Two step solenoid valve
⑧ Stop valve suction line

Hot gas line
⑨ Stop valve
⑩ Filter
⑪ Solenoid valve
⑫ Stop valve
⑬ Check valve

Discharge line
⑭ Stop check valve on the discharge line
⑮ Differential pressure regulator
⑯ Controller
⑰ Temperature sensors
⑱ Temperature sensors
⑲ Temperature sensors
⑳ Check valve

The application example illustrated above is a DX evaporator system with hot gas defrost. Whilst this method of defrosting is not common it is even less so for ammonia DX evaporator systems and more applicable to fluorinated systems.

Refrigeration Cycle
The servo valve ICS ③ in the liquid line is kept open by its solenoid valve pilot EVM. The liquid injection is controled by the electronic expansion valve AKVA ④.

The solenoid valve GPLX ⑦ in the suction line is kept open, and the defrosting solenoid valve ICS ⑪ is kept closed by its solenoid valve pilot EVM.

The check valve NRVA ⑳ prevents ice formation in the drain pan.

The servo valve ICS ⑮ is kept open by its solenoid valve pilot EVM.

Defrost Cycle
After initiation of the defrost cycle, the liquid supply solenoid valve ICS ③ is closed. The fan is kept running for 120 to 600 seconds depending on the evaporator size in order to pump down the evaporator of liquid.

The fans are stopped and the GPLX closed. The GPLX ⑦ valve is kept in its open position by hot gas.

The hot gas condenses in the cold valve and produces liquid on top of the servo piston. When the pilot valves change position to close the valve, the pressure on the piston equalises to the suction pressure.

This equalisation takes time because condensed liquid is present in the valve.The exact time taken from when the pilot valves change position to complete closing of the valve depends on the temperature, pressure, refrigerant and valve size. It is therefore not possible to state an exact closing time for the valves, but lower pressures generally result in longer closing times.

It is very important to take the closing times into consideration when hot gas defrost is used in evaporators.

A further delay of 10 to 20 seconds is required for the liquid in the evaporator to settle down in the bottom without vapour bubbles. The solenoid valve ICS ⑪ is then opened by its solenoid valve pilot EVM and supplies hot gas to the evaporator.

During the defrost cycle the solenoid valve pilot EVM for the servo valve ICS ⑮ is closed so that ICS ⑮ is controlled by the differential pressure pilot CVPP.
ICS ⑮ then creates a differential pressure Δp between hot gas pressure and the receiver pressure. This pressure drop ensures that the liquid which is condensed during defrosting is forced out into the liquid line through check valve NRVA ⑬.

When the temperature in the evaporator (measured by AKS 21 ⑲) reaches the set value, defrost is terminated, the solenoid valve ICS ⑪ is closed, the solenoid valve EVM for ICS ⑮ is opened and the solenoid valve GPLX ⑦ is opened.

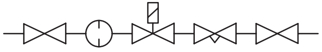
Because of the high differential pressure between the evaporator and the suction line, it is necessary to use a two step solenoid valve like the Danfoss GPLX or PMLX. GPLX/PMLX will have a capacity of only 10 % at high differential pressure, allowing the pressure to be equalized before opening fully to ensure smooth operation and avoid liquid slugging in the suction line.

After the GPLX fully opens, ICS ③ is opened to restart the refrigeration cycle. The fan is started after a delay in order to freeze remaining liquid droplets on the surface of the evaporator.

Application example 5.3.2: Liquid injection in an air cooler in a flooded system using pulse width modulation valve AKVA, with hot gas defrost.

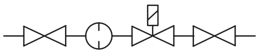
🟥 HP vapour refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟩 LP liquid refrigerant

① ICF control solution with:

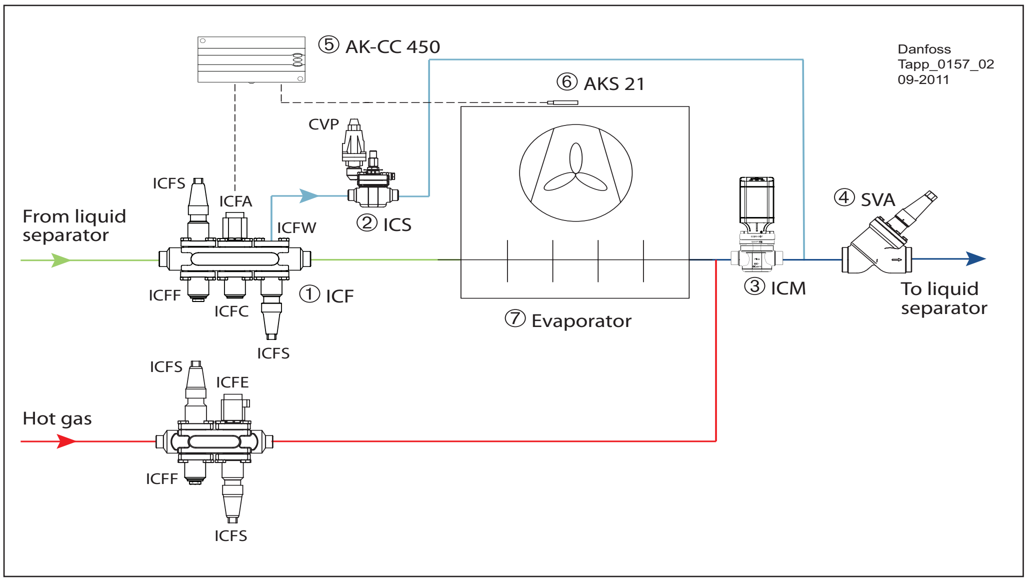


Stop valve
Filter
Electronic expansion valve
Check valve
Welding connection
Stop valve

② Pressure regulator
③ Pressure regulator
④ Suction line stop valve
⑤ Digital thermostat
⑥ Temperature sensor
⑦ Evaporator
⑧ ICF control solution with:



Stop valve
Filter
Electronic expansion valve
Stop valve



Application example 5.3.2 shows an installation for pumped liquid circulation evaporators with hot gas defrost using the ICF control solution. The ICF can accommodate up to six different modules in the same housing, easy to install control solution.

Refrigeration Cycle
The ICFA solenoid module of the ICF ① constantly adapts the liquid injection to the actual demand.
The motor valve ICM ③ in the suction line is kept open, and the defrosting solenoid valve ICFE in ICF ① is kept closed.

Defrost Cycle
After initiation of the defrost cycle, the liquid supply solenoid module ICFA of the ICF ① is closed. The fan is kept running for 120 to 600 seconds, depending on the evaporator size, to pump down the liquid in the evaporator.
The fans are stopped and the ICM valve closed. This is followed by a delay of 10 to 20 seconds for the liquid in the evaporator to settle down in the bottom without vapour bubbles. The solenoid valve ICFE in ICF ① is then opened and supplies hot gas to the evaporator.

During the defrost cycle, the condensed hot gas from the evaporator is injected into the low pressure side. The defrost pressure is controlled by the ICS and CVP. ②.

When the temperature in the evaporator reaches the set value or the defrost timer times out. defrost is terminated, the solenoid valve ICFE in ICF ① is closed, and after a small delay the motor valve ICM ③ is opened.

Because of the high differential pressure between the evaporator and the suction line, it is necessary to relieve the pressure slowly, allowing the pressure to be equalized before opening fully to ensure smooth operation and avoid liquid slugging in the suction line.

The advantage of using the motor valve ICM ③ is that the defrost pressure can be equalized by slowly opening the valve. A cost effective way to do this is to use the ICM on/off mode and select a very low speed. It can also be achieved by using the modulating mode, with the opening degree and speed controlled entirely by the PLC.

After the ICM fully opens, the liquid supply solenoid valve ICFA in ICF ① is opened to start the refrigeration cycle. The fan is started after a delay in order to freeze remaining liquid droplets on the surface of the evaporator.

Technical data

	Pilot operated servo valve - ICS
Material	Body: low temp. steel
Refrigerants	All common refrigerants, incl. R717 and R744
Media temp. range [°C]	–60 to 120
Max. working pressure [bar]	52
DN [mm]	20 to 150
Nominal capacity [kW]*	On hot gas line: 20 to 4000 On liquid line without phase change: 55 to 11,300

* Conditions: R717, T_{liq} = 30°C, $P_{disch.}$ = 12bar, ΔP = 0.2bar, $T_{disch.}$ = 80°C, T_e = –10°C, Recirculation Ratio = 4

	Gas powered two-step solenoid valve - GPLX	Gas powered two-step solenoid valve - PMLX
Material	Body: low temp. steel	Body: low temp. cast iron
Refrigerants	All common non-flammable refrigerants, incl. R717.	All common non-flammable refrigerants, incl. R717.
Media temp. range [°C]	–60 to 150	–60 to 120
Max. working pressure [bar]	40	28
DN [mm]	80 to 150	32 to 150
Nominal capacity [kW]*	On dry suction line: 442 to 1910 On wet suction line: 279 to 1205	On dry suction line: 76 to 1299 On wet suction line: 48 to 820

* Conditions R717, ΔP = 0.05 bar, T_e = –10°C, T_{liq} = 30°C, Recirculation Ratio = 4

	Check valve - NRVA
Material	Body: steel
Refrigerants	All common refrigerants, incl. R717
Media temp. range [°C]	–50 to 140
Max. working pressure [bar]	40
DN [mm]	15 to 65
Nominal capacity [kW]*	On liquid line without phase change: 160.7 to 2411

* Conditions: R717, ΔP = 0.2 bar, T_e = –10°C, Recirculation Ratio = 4

	Filter - FIA
Material	Body: steel
Refrigerants	All common refrigerants, incl. R717
Media temp. range [°C]	–60 to 150
Max. working pressure [bar]	40
DN [mm]	15 to 200
Filter insert	100/150/250/500μ stainless steel weave

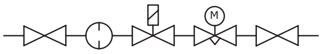
	Motor valve - ICM as control valve
Material	Body: low temp. steel
Refrigerants	All common refrigerants, incl. R717 and R744
Media temp. range [°C]	–60 to 120
Max. working pressure [bar]	52
DN [mm]	20 to 150
Nominal capacity [kW]*	On hot gas line: 2.3 to 4230 On wet suction line: 0.85 to 1570

* Conditions: R717, T_{liq} = 30°C, $P_{disch.}$ = 12bar, ΔP = 0.2bar, $T_{disch.}$ = 80°C, T_e = –10°C, Recirculation Ratio = 4

Application example 5.3.3: DX evaporator, hot gas defrost system with ICF control solution

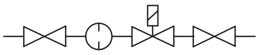
🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
▬ LP vapour refrigerant

① Liquid Line ICF with:



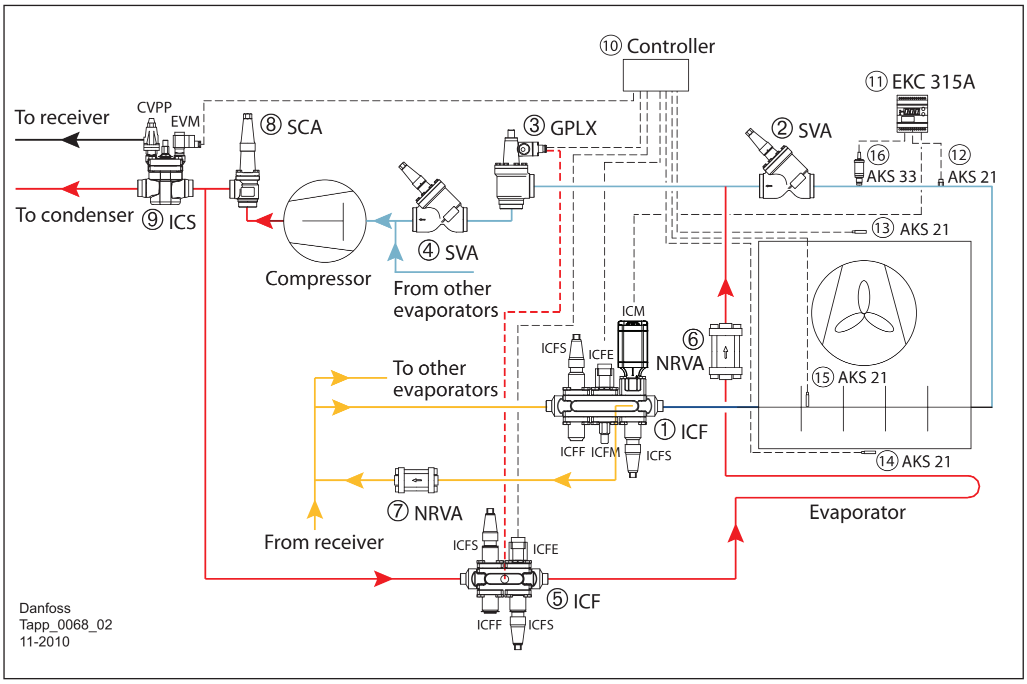
Stop valve liquid inlet
Filter
Solenoid valve
Manual opening
ICM expansion valve
Stop valve evaporator inlet

② Stop valve evaporator outlet
③ Two step solenoid valve
④ Stop valve suction line
⑤ Hot gas line ICF with:



Stop Valve
Filter
Solenoid valve
Stop valve

⑥ Check valve
⑦ Check valve
⑧ Stop check valve on the discharge line
⑨ Differential pressure regulator
⑩ Controller
⑪ Superheat controller
⑫ Temperature sensors
⑬ Temperature sensors
⑭ Temperature sensors
⑮ Temperature sensors
⑯ Pressure transmitter



Application example 5.3.3 shows an installation for DX evaporators with hot gas defrost using the new ICF control solution.

The ICF will accommodate up to six different modules assembled in the same housing offering a compact, easy to install control solution

Refrigeration Cycle
The solenoid valve ICFE in the ICF ① in the liquid line is kept open. The liquid injection is controled by the motor-valve ICM in the ICF ①.

The solenoid valve GPLX ③ on the suction line is kept open, and the defrosting solenoid valve ICFE in ICF ⑤ is kept closed.

The servo valve ICS ⑨ is kept open by its solenoid valve pilot EVM.

Defrost Cycle
After initiation of the defrost cycle, the liquid supply solenoid ICFE in ICF ① is closed. The fan is kept running for 120 to 600 seconds depending on the evaporator size in order to pump down the evaporator of liquid.

The fans are stopped and the GPLX closed. The GPLX valve ③ is kept in its open position by hot gas.

The hot gas condenses in the cold valve and produces liquid on top of the servo piston. When the pilot valves change position to close the valve, the pressure on the piston equalises to the suction pressure.

This equalisation takes time because condensed liquid is present in the valve.The exact time taken from when the pilot valves change position to complete closing of the valve depends on the temperature, pressure, refrigerant and valve size.

It is therefore not possible to state an exact closing time for the valves, but lower pressures generally result in longer closing times.

It is very important to take the closing times into consideration when hot gas defrost is used in evaporators.

A further delay of 10 to 20 seconds is required for the liquid in the evaporator to settle down in the bottom without vapour bubbles. The solenoid valve ICFE in ICF ⑤ is then opened and supplies hot gas to the evaporator.

During the defrost cycle the solenoid valve pilot EVM for the servo valve ICS ⑨ is closed so that ICS ⑨ is controlled by the differential pressure pilot CVPP. ICS ⑨ then creates a differential pressure Δp between hot gas pressure and the receiver pressure.
This pressure drop ensures that the liquid which is condensed during defrosting is forced out into the liquid line through check valve NRVA ⑦.

When the temperature in the evaporator (measured by AKS 21 ⑮) reaches the set value, defrost is terminated, the solenoid valve ICFE in ICF ⑤ is closed, the solenoid valve EVM pilot for ICS ⑨ is opened and the solenoid valve GPLX ③ is opened.

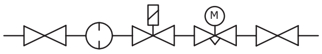
Because of the high differential pressure between the evaporator and the suction line, it is necessary to use a two step solenoid valve like the Danfoss GPLX ③ or PMLX. GPLX ③/PMLX will have a capacity of only 10 % at high differential pressure, allowing the pressure to be equalized before opening fully to ensure smooth operation and avoid liquid slugging in the suction line.

After the GPLX ③ fully opens, the liquid supply solenoid valve ICFE in ICF ① is opened to start the refrigeration cycle. The fan is started after a delay in order to freeze remaining liquid droplets on the surface of the evaporator.

Application example 5.3.4: DX evaporator, hot gas defrost system with ICF/ICM, fully welded

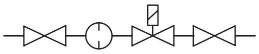
🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
▬ LP vapour refrigerant

① Liquid Line ICF with:



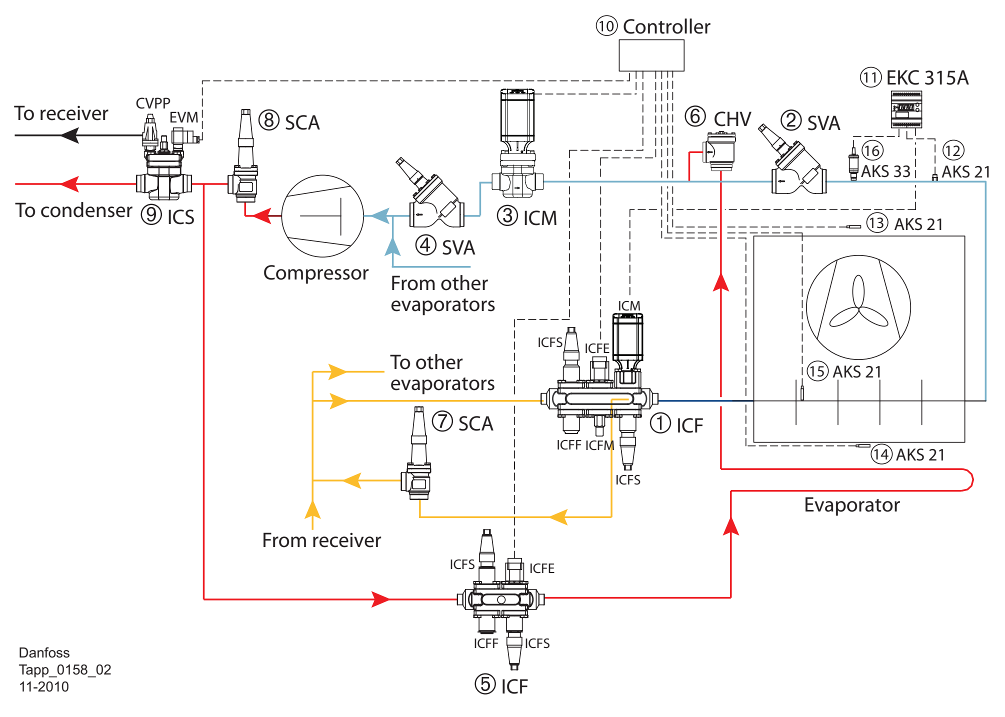
Stop valve liquid inlet
Filter
Solenoid valve
Manual opening
ICM expansion valve
Stop valve evaporator inlet

② Stop valve evaporator outlet
③ Pressure regulator (motor valve)
④ Stop valve suction line
⑤ Hot gas line ICF with:



Stop Valve
Filter
Solenoid valve
Stop valve

⑥ Check valve
⑦ Check valve
⑧ Stop check valve on the discharge line
⑨ Differential pressure regulator
⑩ Controller
⑪ Superheat controller
⑫ Temperature sensors
⑬ Temperature sensors
⑭ Temperature sensors
⑮ Temperature sensors
⑯ Pressure transmitter



Danfoss
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Application example 5.3.3 shows an installation for DX evaporators with hot gas defrost using the ICF control solution.

The ICF can accommodate up to six different modules in the same housing, easy to install control solution.

Refrigeration Cycle
The solenoid valve ICFE in the ICF ⑤ in the liquid line is kept open. Liquid injection is controlled by the motor valve ICM in the ICF ⑤.

The motor valve ICM ③ on the suction line is kept open, and the defrosting solenoid valve ICFE in ICF ⑤ is kept closed.

The servo valve ICS ⑨ is kept open by its solenoid valve pilot EVM.

Defrost Cycle
After initiation of the defrost cycle, the liquid supply solenoid ICFE in ICF ① is closed. The fan is kept running for 120 to 600 seconds, depending on the evaporator size, to pump down the liquid in the evaporator.

The fans are stopped and the motor valve ICM ③ closed.

A delay of 10 to 20 seconds is required for the liquid in the evaporator to settle down in the bottom without vapour bubbles. The solenoid valve ICFE in ICF ⑤ is then opened and supplies hot gas to the evaporator.

During the defrost cycle the solenoid valve pilot EVM for the servo valve ICS ⑨ is closed so that ICS ⑨ is controlled by the differential pressure pilot CVPP. ICS ⑨ then creates a differential pressure Δp between hot gas pressure and the receiver pressure.

This pressure drop ensures that the liquid which is condensed during defrosting is forced out into the liquid line through check valve SCA ⑦.

When the temperature in the evaporator (measured by AKS 21) reaches the set value, defrost is terminated, the solenoid valve ICFE in ICF ⑤ is closed, the solenoid valve EVM pilot for ICS ⑨ is opened and the motor valve ICM ③ is opened.

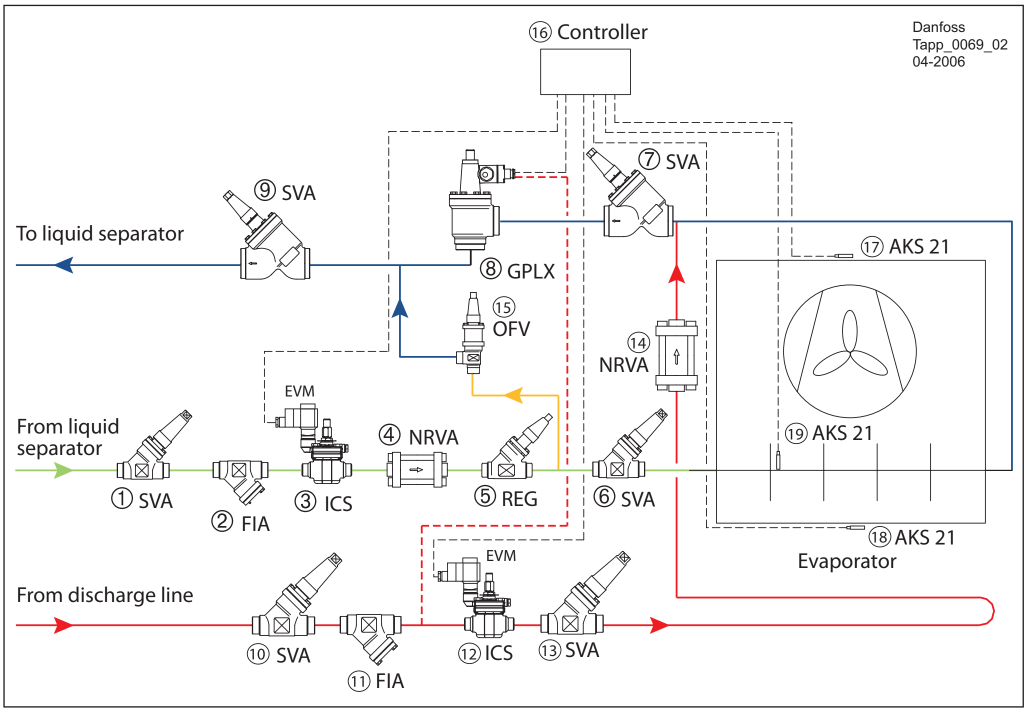
Because of the high differential pressure between the evaporator and the suction line, it is necessary to relieve the pressure slowly, allowing the pressure to be equalized before opening fully to ensure smooth operation and avoid liquid slugging in the suction line.

An advantage of using the motor valve ICM ③ , a benefit is that the defrost pressure can be equalized by slowly opening the valve. A cost effective way to do this is using the on/off mode on the ICM and selecting a very low speed, or it can be achieved by using the modulating mode, so the PLC totally controls the opening degree and speed.

After the motor valve ICM ③ fully opens, the liquid supply solenoid valve ICFE in ICF ① is opened to start the refrigeration cycle. The fan is started after a delay in order to freeze remaining liquid droplets on the surface of the evaporator

5.4
Hot Gas Defrost for Pumped Liquid Circulation Air Coolers

Application example 5.4.1: Pumped liquid circulation evaporator, with hot gas defrost system



🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟩 LP liquid refrigerant

Liquid Line
① Stop valve liquid inlet
② Filter
③ Solenoid valve
④ Check valve
⑤ Hand expansion valve
⑥ Stop valve evaporator inlet

Suction Line
⑦ Stop valve evaporator outlet
⑧ Two step solenoid valve
⑨ Stop valve suction line

Hot gas line
⑩ Stop valve
⑪ Filter
⑫ Solenoid valve
⑬ Stop valve
⑭ Check valve

Overflow line
⑮ Overflow valve

Controls
⑯ Controller
⑰ Controller
⑱ Controller
⑲ Controller

Application example 5.4.1 shows a typical installation for a pumped liquid circulation evaporator with hot gas defrost.

Refrigeration Cycle
The solenoid valve ICS ③ on the liquid line is kept open. The liquid injection is controled by the hand regulating valve REG ⑤.

The solenoid valve GPLX ⑧ in the suction line is kept open, and the defrosting solenoid valve ICS ⑫ is kept closed.

Defrost Cycle
After initiation of the defrost cycle, the liquid supply solenoid ICS ③ is closed. The fan is kept running for 120 to 600 seconds depending on the evaporator size in order to pump down the evaporator of liquid.

The fans are stopped and the GPLX closed. The GPLX valve ⑧ is kept in its open position by hot gas.

The hot gas condenses in the cold valve and produces liquid on top of the servo piston. When the pilot valves change position to close the valve, the pressure on the piston equalises to the suction pressure.

This equalisation takes time because condensed liquid is present in the valve.The exact time taken from when the pilot valves change position to complete closing of the valve depends on the temperature, pressure, refrigerant and valve size.

It is therefore not possible to state an exact closing time for the valves, but lower pressures generally result in longer closing times.

It is very important to take the closing times into consideration when hot gas defrost is used in evaporators.

A further delay of 10 to 20 seconds is required for the liquid in the evaporator to settle down in the bottom without vapour bubbles. The solenoid valve ICS ⑫ is then opened and supplies hot gas to the evaporator.

During the defrost cycle, the overflow valve OFV ⑭ opens automatically subject to the differential pressure. The overflow valve allows the condensed hot gas from the evaporator to be released into the wet suction line. The OFV could also be replaced with a pressure regulator ICS+CVP depending on the capacity, or a high pressure float valve SV1/3 which only drains liquid to the low pressure side.

When the temperature in the evaporator (measured by AKS 21 ⑲) reaches the set value, defrost is terminated, the solenoid valve ICS ⑫ is closed, and the two-step solenoid valve GPLX ⑧ is opened.

After the GPLX fully opens, the liquid supply solenoid valve ICS ③ is opened to start the refrigeration cycle. The fan is started after a delay in order to freeze remaining liquid droplets on the surface of the evaporator.

The PMLX valve has the same function (two step solenoid valve) as a GPLX. The GPLX/PMLX has a capacity of only 10% at high differential pressure, allowing the pressure to be equalized before opening fully to ensure smooth operation and avoid liquid slugging in the suction line

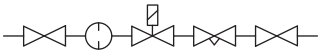
Technical data

	Overflow valve - OFV
Material	Body: steel
Refrigerants	All common refrigerants, incl. R717
Media temp. range [°C]	–50 to 150
Max. working pressure [bar]	40
DN [mm]	20/25
Opening differential pressure range [bar]	2 to 8

Application example 5.4.2: Pump circulated evaporator, with hot gas defrost system using ICF valve station and SV 1/3 float valve

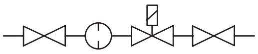
🟥 HP vapour refrigerant
🟧 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟩 LP liquid refrigerant

① Liquid Line ICF with:



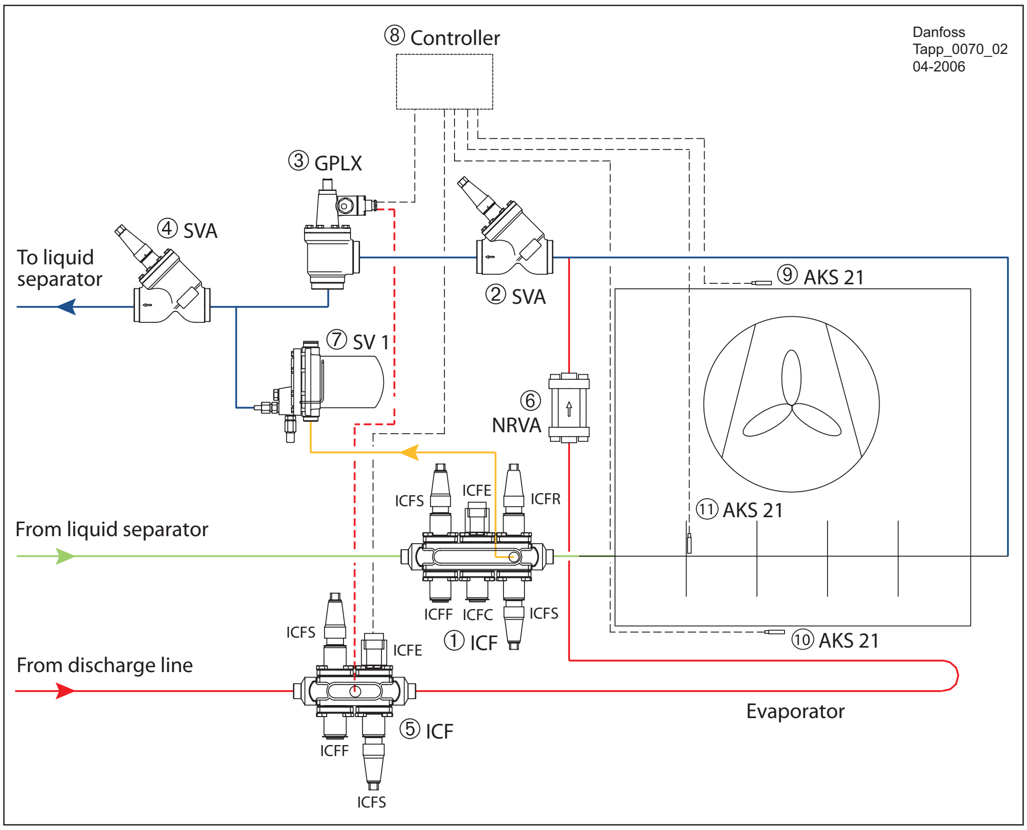
Stop valve liquid inlet
Filter
Solenoid valve
Check valve
Hand expansion valve
Stop valve evaporator inlet

② Stop valve evaporator outlet
③ Two step solenoid valve
④ Stop valve suction line
⑤ Hot gas line ICF with:



Stop Valve
Filter
Solenoid valve
Stop valve

⑥ Check valve
⑦ Float valve
⑧ Controller
⑨ Temperature sensors
⑩ Temperature sensors
⑪ Temperature sensors



Application example 5.4.2 shows an installation for pumped liquid circulation evaporators with hot gas defrost using the new ICF control solution and SV 1/3 float valve.

The ICF will accommodate up to six different modules assembled in the same housing offering a compact, easy to install control solution.

Refrigeration Cycle
The solenoid valve ICFE in ICF ① in the liquid line is kept open. The liquid injection is controled by the hand regulating valve ICFR in ICF ①.

The solenoid valve GPLX ③ in the suction line is kept open, and the defrosting solenoid valve ICFE in ICF ⑤ is kept closed.

Defrost Cycle
After initiation of the defrost cycle, the liquid supply solenoid module ICFE of the ICF ① is closed. The fan is kept running for 120 to 600 seconds depending on the evaporator size in order to pump down the evaporator of liquid.

The fans are stopped and the GPLX closed. The GPLX valve ③ is kept in its open position by hot gas.

The hot gas condenses in the cold valve and produces liquid on top of the servo piston. When the pilot valves change position to close the valve, the pressure on the piston equalises to the suction pressure.

This equalisation takes time because condensed liquid is present in the valve.The exact time taken from when the pilot valves change position to complete closing of the valve depends on the temperature, pressure, refrigerant and valve size.

It is therefore not possible to state an exact closing time for the valves, but lower pressures generally result in longer closing times.

It is very important to take the closing times into consideration when hot gas defrost is used in evaporators.

A further delay of 10 to 20 seconds for the liquid in the evaporator to settle down in the bottom without vapour bubbles. The solenoid valve ICFE in ICF ⑤ is then opened and supplies hot gas to the evaporator.

During the defrost cycle, the condensed hot gas from the evaporator is injected into the low pressure side. The injection is controlled by the high pressure float valve SV 1 or 3 ⑦ complete with special internal kit. Compared to the overflow valve OFV in the solution 5.4.1, this float valve controls the overflow according to the liquid level in the float chamber.

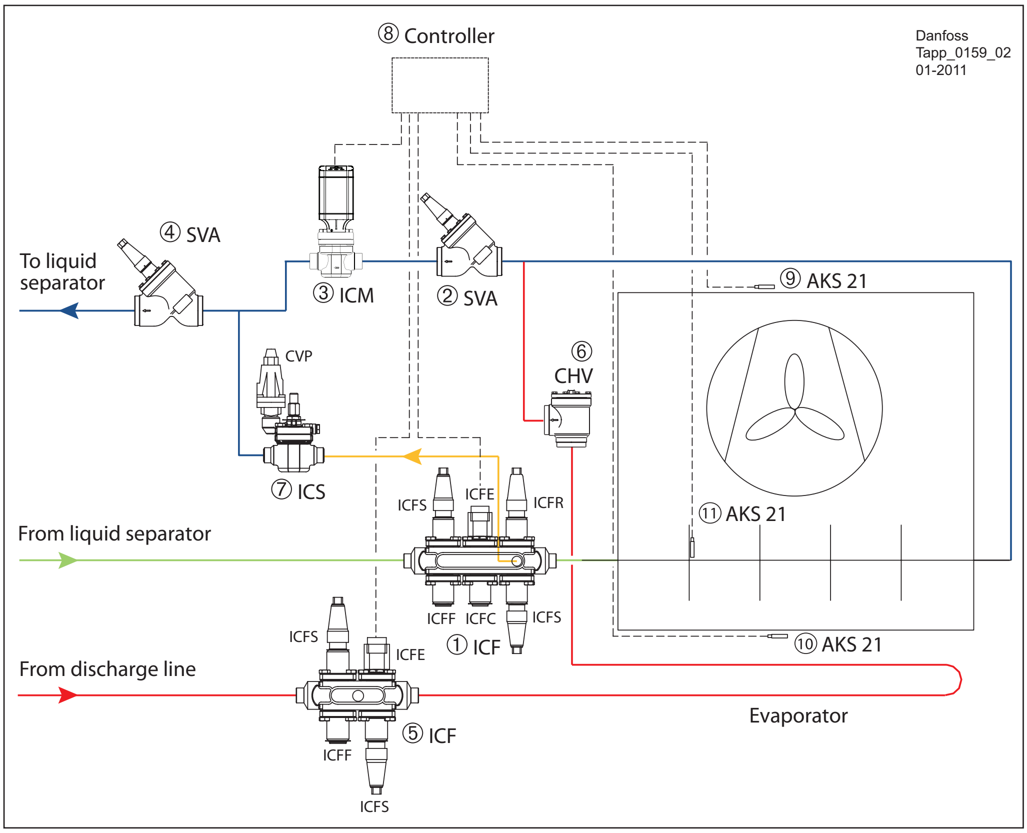
The use of a float valve ensures that the hot gas does not leave the evaporator until it is condensed into liquid, resulting in an increase in overall efficiency. Furthermore, the float valve is specifically designed for modulating control providing a very stable control solution.

When the temperature in the evaporator (measured by AKS 21 ⑪) reaches the set value, defrost is terminated, the solenoid valve ICFE in ICF ⑤ is closed, and after a small delay the solenoid valve GPLX ③ is opened.

After the GPLX fully opens, the liquid supply solenoid valve ICFE in ICF ① is opened to start the refrigeration cycle. The fan is started after a delay in order to freeze remaining liquid droplets on the surface of the evaporator.

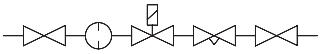
The PMLX valve has the same function (two step solenoid valve) as a GPLX. The GPLX/PMLX has a capacity of only 10% at high differential pressure, allowing the pressure to be equalized before opening fully to ensure smooth operation and avoid liquid slugging in the suction line

Application example 5.4.3: Pump circulated evaporator, with hot gas defrost system, fully welded, using ICF valve station and ICS with CVP



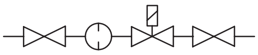
🟥 HP vapour refrigerant
🟧 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟩 LP liquid refrigerant

① Liquid Line ICF with:



Stop valve liquid inlet
Filter
Solenoid valve
Check valve
Hand expansion valve
Stop valve evaporator inlet

② Stop valve evaporator outlet
③ Pressure regulator (motor valve)
④ Stop valve suction line
⑤ Hot gas line ICF with:



Stop Valve
Filter
Solenoid valve
Stop valve

⑥ Check valve
⑦ Pressure regulator
⑧ Controller
⑨ Temperature sensors
⑩ Temperature sensors
⑪ Temperature sensors

Application example 5.4.3 shows an installation for pumped liquid circulation evaporators with hot gas defrost using the new ICF control solution.

The ICF can accommodate up to six different modules in the same housing, easy to install control solution.

Refrigeration Cycle
The solenoid valve ICFE in ICF ① in the liquid line is kept open. The liquid injection is controlled by the hand regulating valve ICFR in ICF ①.

The motor valve ICM ③ in the suction line is kept open, and the defrosting solenoid valve ICFE in ICF ⑤ is kept closed.

Defrost Cycle
After initiation of the defrost cycle, the liquid supply solenoid module ICFE of the ICF ① is closed. The fan is kept running for 120 to 600 seconds, depending on the evaporator size, to pump down the liquid in the evaporator.
The fans are stopped and the ICM valve closed. A delay of 10 to 20 seconds for the liquid in the evaporator to settle down in the bottom without vapour bubbles. The solenoid valve ICFE in ICF ⑤ is then opened and supplies hot gas to the evaporator.

During the defrost cycle, the condensed hot gas from the evaporator is injected into the low pressure side. The defrost pressure is controlled by the ICS+CVP ⑦.

When the temperature in the evaporator (measured by AKS 21) reaches the set value, defrost is terminated, the solenoid valve ICFE in ICF ⑤ is closed, and after a small delay the motor valve ICM ③ is opened.

Because of the high differential pressure between the evaporator and the suction line, it is necessary to relieve the pressure slowly, allowing the pressure to be equalized before opening fully to ensure smooth operation and avoid liquid slugging in the suction line.

The advantage of using the motor valve ICM ③ is that the defrost pressure can be equalized by slowly opening the valve. A cost effective way to do this is to use the ICM on/off mode and select a very low speed. It can also be achieved by using the modulating mode thus the PLC totally controls the opening degree and speed.

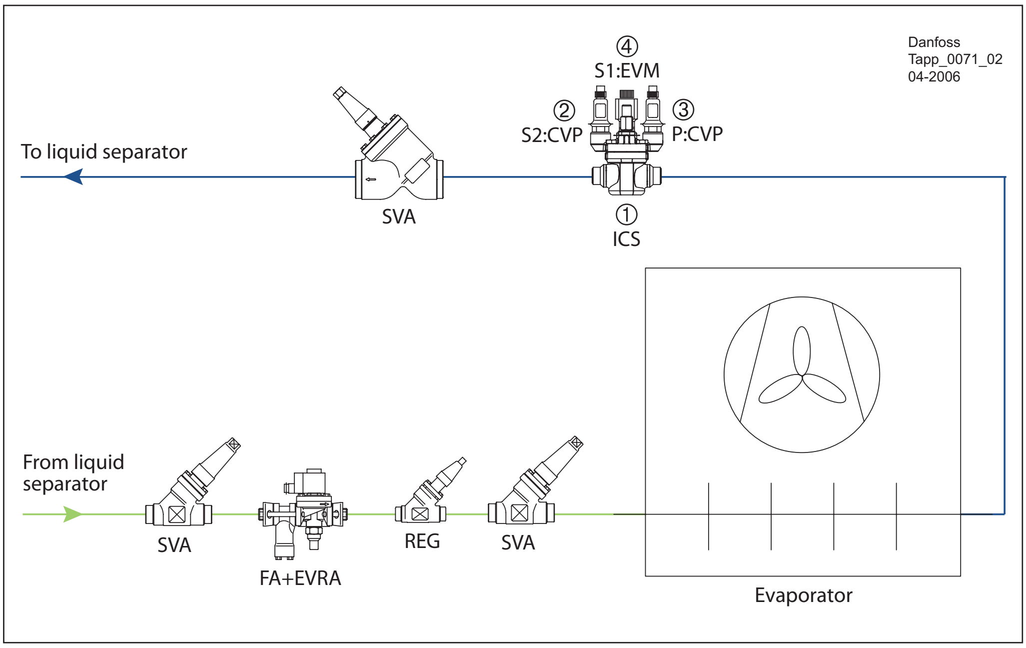
After the ICM fully opens, the liquid supply solenoid valve ICFE in ICF ① is opened to start the refrigeration cycle. The fan is started after a delay in order to freeze remaining liquid droplets on the surface of the evaporator.

5.5
Multi Temperature Changeover

In the process industry, it is very common to use an evaporator for different temperature settings.

When the operation of an evaporator is required at two different fixed evaporating pressures, this can be achieved by using one servo valve ICS with two constant pressure pilots.

Application example 5.5.1: Evaporating pressure control, changeover between two pressures



🟦 Liquid/vapour mixture of refrigerant
🟩 LP liquid refrigerant

① Pressure regulating valve
② Pressure regulating pilot valve
③ Pressure regulating pilot valve
④ Solenoid pilot valve

Application example 5.5.1 shows a solution for controlling two evaporating pressures in evaporators. This solution can be used for DX or pumped liquid circulation evaporators with any type of defrost system.

The servo valve ICS is equipped with one EVM (NC) solenoid valve pilot in the S1 port and two CVP constant pressure pilots in the ports S2 and P respectively.

The CVP in the S2 port is adjusted to the lower operating pressure and the CVP in the P port is adjusted to the higher operating pressure.

When the solenoid in S1 port is energised, the evaporator pressure will follow the setting of the CVP pilot in S1 port. When the solenoid is de-energised, the evaporator pressure will follow the setting of the CVP pilot in the P port.

Example:

	I	II
Outlet air temperature	+3°C	+8°C
Evaporating temperature	−2°C	+2°C
Temperature change	5K	6K
Refrigerant	R22	R22
Evaporating pressure	3.6 bar	4.4 bar

S2: CVP is preset to 3.6 bar, and
P: CVP is preset to 4.4 bar.

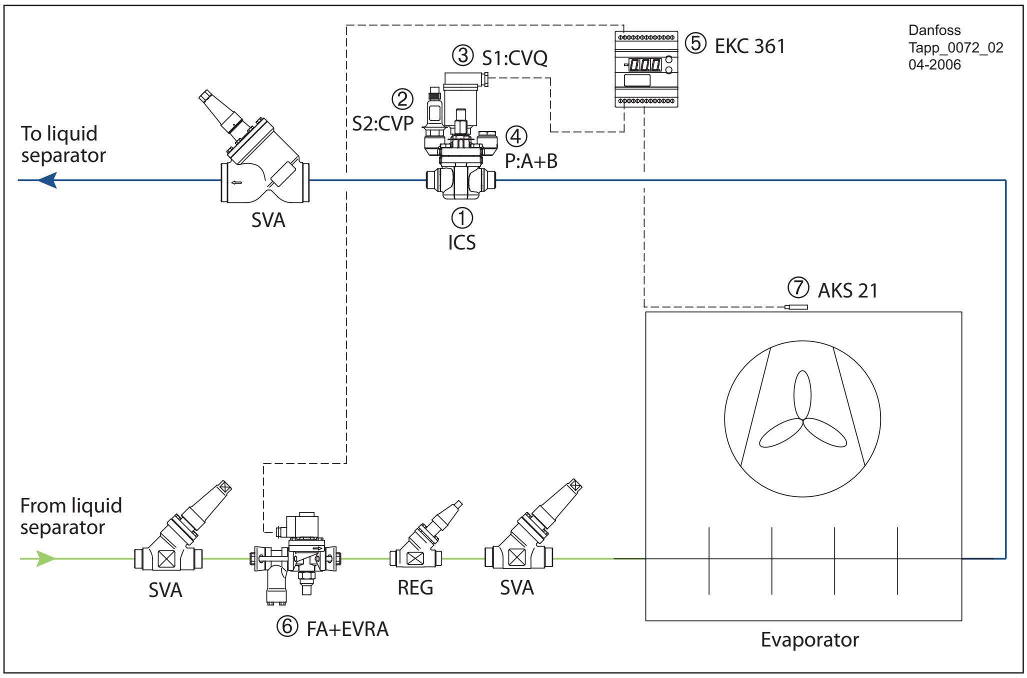
I: EVM pilot opens.
Hence the evaporating pressure is controlled by S2: CVP.
II: EVM pilot closes.
Hence the evaporating pressure is controlled by P: CVP.

5.6
Media Temperature Control

Solutions are provided for where there are stringent requirements for accurate temperature control in connection with refrigeration. E.g.:

- Cold room for fruits and food products
- Work premises in the food industry
- Process cooling of liquids

Application example 5.6.1: Media temperature control using pilot operated valve ICS



🟦 Liquid/vapour mixture of refrigerant
🟩 LP liquid refrigerant

① Pressure regulating valve
② Pressure regulating pilot valve
③ Electronic pilot valve
④ Blind plug
⑤ Controller
⑥ Solenoid valve with filter
⑦ Temperature sensor

Application example 5.6.1 shows a solution for accurate media temperature control. Furthermore there is a need to protect the evaporator against a too low pressure to avoid freezing up of the products in the application.

This design can be applied for DX or pumped liquid circulation evaporators with any type of defrost system.

Control valve type ICS 3 with CVQ in S2 port, controlled by media temperature controller EKC 361 and CVP in the S1 port. The P port is isolated using the A+B blanking plug.

The CVP is adjusted according to the lowest pressure allowed for the application.

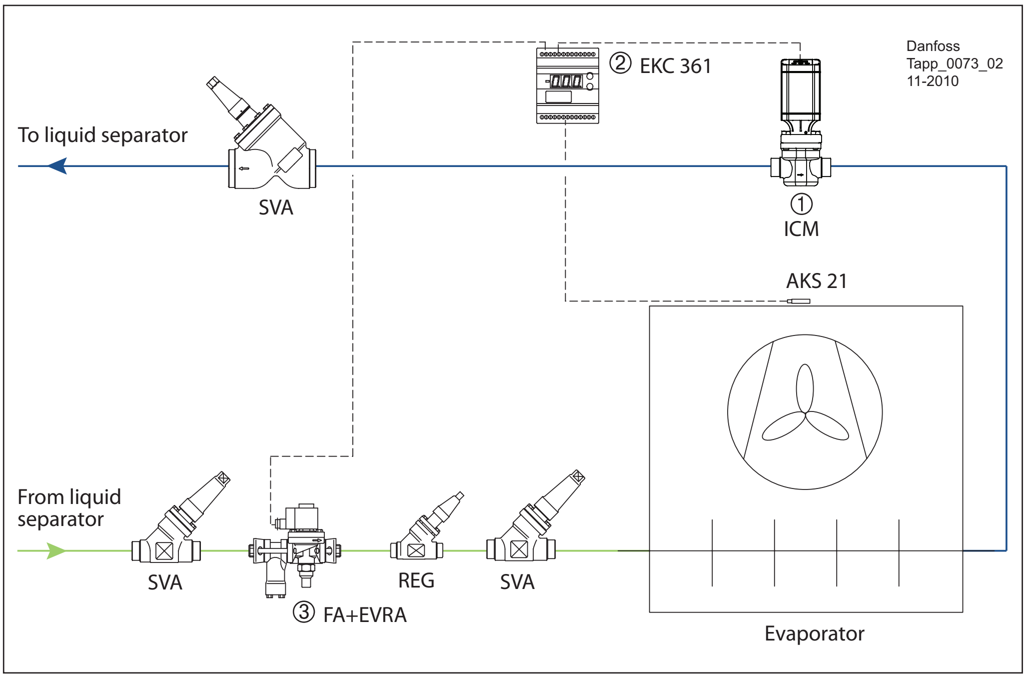
The media temperature controller EKC 361 will control the temperature in the application at the desired level, by controlling the opening of the CVQ pilot valve, and thereby controlling the evaporating pressure to match the required cooling load and temperature.

This solution will control the temperature with an accuracy of +/- 0.25°C. If the temperature falls below this range, the EKC controller can close the solenoid valve in the liquid line.

The media temperature controller EKC 361 will control all functions of the evaporator including thermostat and alarms.

For more details, please refer to the manual of the EKC 361 controller.

Application example 5.6.2: Media temperature control using direct operated valve



🟦 Liquid/vapour mixture of refrigerant
🟩 LP liquid refrigerant

① Pressure regulator (motor valve)
② Controller
③ Solenoid valve with filter

Application example 5.6.2 shows a solution for accurate media temperature control without start/stop control.

This design can be used for DX or pumped liquid circulation evaporators with any type of defrost system.

Motor valve type ICM controlled by media temperature controller EKC 361 is selected.

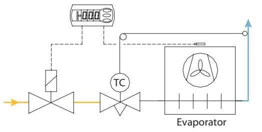
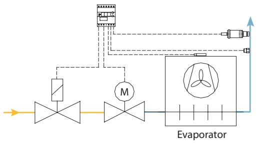
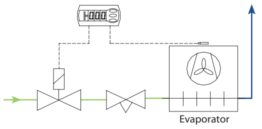
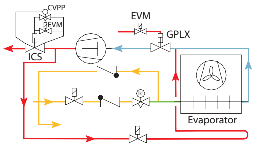
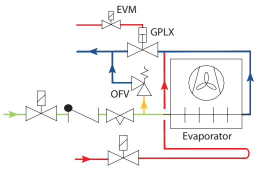
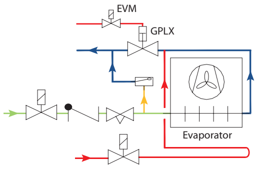
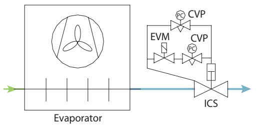
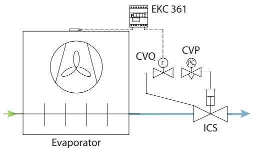
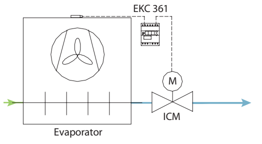
The media temperature controller EKC 361 will control the temperature in the application at the desired level, by controlling the opening degree of the ICM motor valve, and thereby controlling the evaporating pressure to match the required cooling load and temperature.

This solution will control the media temperature with an accuracy of +/- 0.25°C. If the temperature falls below this range, the EKC controller can close the solenoid valve in the liquid line.

The media temperature controller EKC 361 will control all functions of the evaporator including thermostat and alarms.

For more details, please refer to the separate manual of the EKC 361 controller.

5.7
Summary

Solution		**Application**	**Benefits**	**Limitations**
Direct Expansion Control				
DX evaporator, thermostatic expansion control with TEA, EVRA, and EKC 202		All DX systems	Simple installation without separator and pump system.	Lower capacity and efficiency than circulated systems; Not suitable for flammable refrigerants.
DX evaporator, electronic expansion control with ICM/ ICF, EVRA and EKC 315A		All DX systems	Optimised superheat; Quick response; Possible to control remotely; Wide capacity range.	Not suitable for flammable refrigerant.
Pumped Liquid Circulation Control				
Pumped liquid circulation evaporator, expansion control with REG, EVRA and EKC 202		Pump circulating systems	High capacity and efficient evaporator	Fluctuations, and high refrigerant charge
Hot Gas Defrost Control-DX Air Coolers				
DX Evaporator with hot gas defrost		All DX systems	Quick defrost; The hot gas can bring out the oil left in the low temperature evaporator.	Not capable for systems with less than 3 evaporators.
Hot Gas Defrost Control-Pumped Liquid Circulation Air Coolers				
Pumped liquid circulation evaporator with hot gas defrost		All pump circulated systems	Quick defrost; The hot gas can bring out the oil left in the low temperature evaporator.	Not suitable for systems with less than 3 evaporators.
Pumped liquid circulation evaporator with hot gas defrost controled by SV1/3		All pump circulated systems	Quick defrost; The hot gas can bring out the oil left in the low temperature evaporator; The float valve is efficient and stable in regulating the hot gas flow.	Not suitable for systems with less than 3 evaporators.
Multi-temperature Changeover				
Multi-temperature control with ICS and CVP		Evaporators that need to work at different temperature levels	The evaporator can change over between 2 different temperature levels.	Pressure drop in suction line.
Media Temperature Control				
Media temperature control with ICS, CVQ and CVP		Very precise temperature control combined with minimum pressure (frost) protection. Option of running at different temperatures.	The CVQ will precisely control the temperature; CVP can keep the pressure above the required lowest level.	Pressure drop in suction line
Media temperature control with motor valve ICM		Very precise temperature control. Option of running at different temperatures.	The ICM will control the temperature very accurate, by adjusting the opening degree	Maximum capacity is ICM 65.

5.8
Reference Documents

For an alphabetical overview of all reference documents please go to page 104

Technical Leaflet / Manual

Type	Literature no.
AKS 21	RK.0Y.G
AKS 32R	RD.5G.J
AKS 33	RD.5G.H
AKVA	PD.VA1.B
CVP	PD.HN0.A
CVQ	PD.HN0.A
EVM	PD.HN0.A
EKC 202	RS.8D.Z
EKC 315A	RS.8C.S
EKC 361	RS.8A.E
EVRA(T)	PD.BM0.B
FA	PD.FM0.A

Type	Literature no.
FIA	PD.FN0.A
GPLX	PD.BO0.A
ICF	PD.FT0.A
ICM	PD.HT0.B
ICS	PD.HS0.A
NRVA	RD.6H.A
OFV	PD.HQ0.A
PMLX	PD.BR0.A
REG	PD.KM0.A
SV 1-3	PD.GE0.B
SVA	PD.KD0.A
TEA	RD.1E.A

Product instruction

Type	Literature no.
AKS 21	RI.14.D
AKS 32R	PI.SB0.A
AKS 33	PI.SB0.A
AKVA	PI.VA1.C / PI.VA1.B
CVP	PI.HN0.C
CVQ	PI.VH1.A
EVM	RI.3X.H
EKC 202	RI.8J.V
EKC 315A	
EKC 361	RI.8B.F
EVRA(T)	RI.3D.A
FA	RI.6C.A

Type	Literature no.
FIA	PI.FN0.A
GPLX	RI.7C.A
ICF	PI.FT0.A
ICM 20-65	PI.HT0.A
ICM 100-150	PI.HT0.B
ICS 25-65	PI.HS0.A
ICS 100-150	PI.HS0.B
NRVA	RI.6H.B
OFV	PI.HX0.B
PMLX	RI.3F.D / RI.3F.C
REG	PI.KM0.A
SV 1-3	PI.GE0.C
SVA	PI.KD0.B
TEA	PI.AJ0.A

To download the latest version of the literature please visit the Danfoss internet site
http://www.danfoss.com/Products/Literature/RA_Documentation.htm

6. Oil Systems

Generally, industrial refrigeration compressors are lubricated with oil, which is forced by the oil pump or due to pressure difference between the high and the low pressure sides to the moving parts of the compressors (bearings, rotors, cylinder walls etc.). In order to guarantee reliable and efficient operation of the compressor the following oil parameters should be controlled:

- Oil temperature. This should be kept within the limits specified by manufacturer. The oil should have the correct viscosity and the temperature should be kept below the ignition point.
- Oil pressure. Oil pressure difference should be kept above the minimum acceptable level.

There are generally some supporting components and equipment within refrigeration systems for oil cleaning, oil separation from the refrigerant, oil return from the low pressure side, equalization of oil level in systems with several piston compressors and oil drain off points. Most of these are supplied by compressor manufacturer.

The oil system design of an industrial refrigeration plant depends on the type of the compressor (screw or piston) and on the refrigerant (ammonia, HFC/HCFC or CO2). Normally immiscible oil type is used for ammonia and miscible for Fluorinated refrigerants.
As oil systems are very compressor related, some of the above mentioned points have been described in compressor controls (section 2) and safety systems (section 7).

6.1
Oil cooling

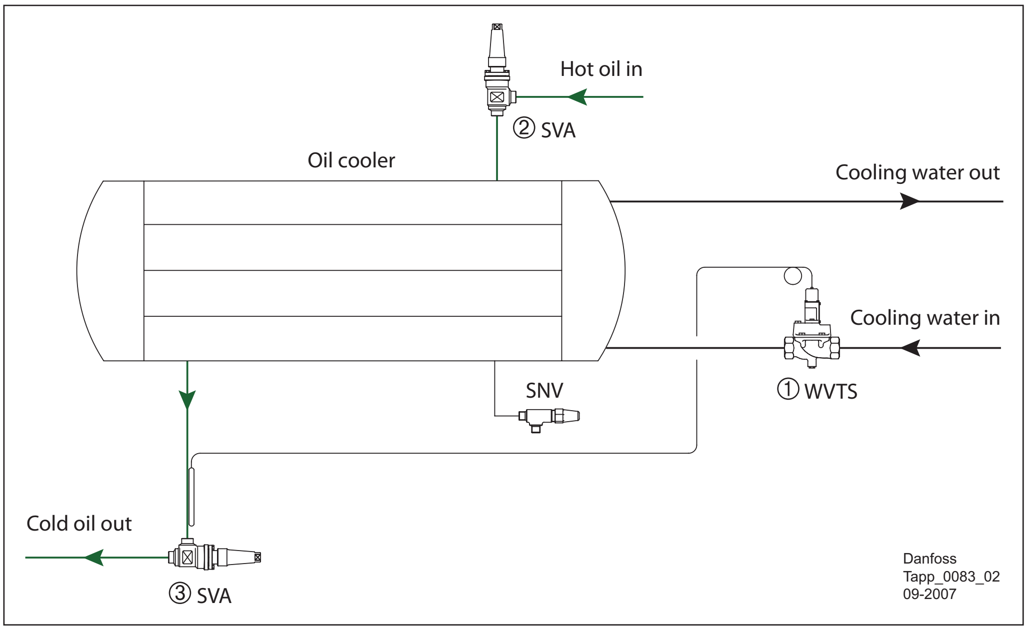
Refrigeration compressors (including all screw compressors and some piston compressors) generally require oil cooling. Too high discharge temperatures can destroy oil, which leads to the damage of the compressor. It is also important for the oil to have the right viscosity, which largely depends on the temperature level. It is not enough just to keep the temperature below critical limit, it is also necessary to control it. Normally, oil temperature is specified by the compressor manufacturer.

There are a few different types of oil cooling systems used in refrigeration. The most common types are:

- water cooling
- air cooling
- thermosyphon cooling

Oil can also be cooled by means of injection of the liquid refrigerant directly into the intermediate compressor port. For piston compressors, it is quite common not to have any special oil cooling systems at all, as temperature is less critical than for screw compressors, with the oil being cooled in the crankcase.

Application example 6.1.1:
Oil cooling with water



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▬ Water
▬ Oil

① Water valve
② Stop valve
③ Stop valve

These types of systems are normally used in plants where it is possible to get cheap water source. Otherwise, it is necessary to install a cooling tower to cool down the water. Water cooled oil coolers are quite common for marine refrigeration plants.

The water flow is controlled by the water valve type WVTS ①, which controls the water flow according to the oil temperature.

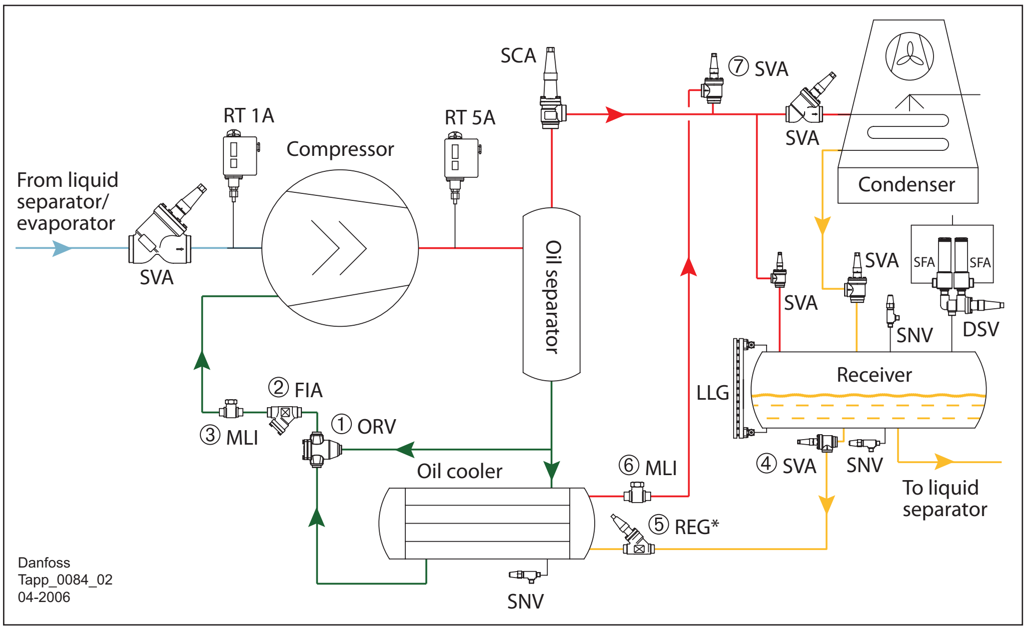
Please contact your local Danfoss sales company to check suitability of components to be used with sea water as the cooling medium.

Technical data

	Water valve - WVTS
Materials	Valve body: cast iron
Media	Fresh water, neutral brine
Max. working pressure [bar]	10
Operating temp. range [°C]	Bulb: 0 to 90 Liquid: –25 to 90
DN [mm]	32 to 100
Max. K_v value [m^3/h]	12.5 to 125

	Water valve - AVTA
Media	Fresh water, neutral brine
Max. working pressure [bar]	16
Operating temp. range [°C]	Bulb: 0 to 90 Liquid: –25 to 130
DN [mm]	10 to 25
Max. K_v value [m^3/h]	1.4 to 5.5

Application example 6.1.2:
Thermosyphon oil cooling



🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Oil regulating valve
② Filter
③ Sight glass
④ Stop valve
⑤ Hand regulating valve
⑥ Sight glass
⑦ Stop valve

These types of systems are very convenient, as oil gets cooled inside the system. It is only necessary to oversize the condenser for the amount of heat taken from the oil cooler. Conversely, thermosyphon oil cooling requires additional piping on site and sometimes it is also necessary to install an additional priority vessel (in cases when the HP liquid receiver is placed too low or not installed).

High pressure liquid refrigerant flows from the receiver due to gravity force into the oil cooler where it evaporates and cools the oil. Refrigerant vapour rises back to the receiver or, in certain cases, to the condenser inlet. It is critical that the pressure drop in the feed and the return pipes is minimal. Otherwise the refrigerant will not return from the oil cooler and the system will not function. Only minimal number of SVA stop valves should be installed. No pressure dependent solenoid valves are allowed. On the return pipe it is recommended to install a MLI ⑥ sight glass.

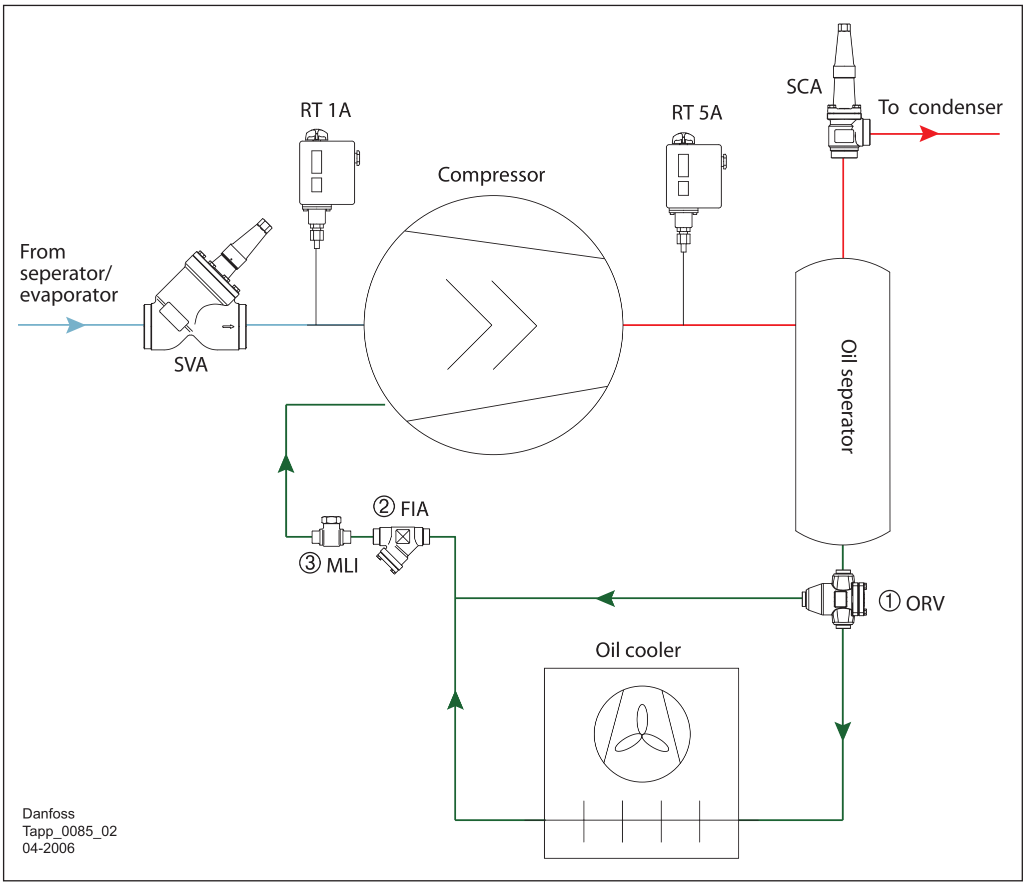
Oil temperature is maintained at the correct level by the ORV ① three-way valve. The ORV keeps the oil temperature within the limits defined by its thermostatic element. If the oil temperature rises too high then all the oil returns back to the oil cooler. If it is too low, then all the oil flow is bypassed around the oil cooler.

* REG regulating valve may be useful in case of largely oversized oil cooler.

Technical data

	Oil regulating valve - ORV
Materials	Valve body: cold resistant steel
Media	All common refrigeration oils and common refrigerants including R717
Max. working pressure [bar]	40
Temperature range [°C]	Continuous operation: –10 to 85 Short operation: –10 to 120
DN [mm]	25 to 80

Application example 6.1.3:
Oil cooling with air



🟥 HP vapour refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Oil regulating valve
② Strainer
③ Sight glass

It is quite common to use air cooled oil coolers on the compressor units with semi-hermetic screw compressor refrigeration packs.

The oil temperature valve is controlled by the oil regulating valve ORV ①.

In this case ORV divides the flow from the oil separator and controls according to the change of the oil discharge temperature.

6.2
Oil Differential Pressure Control

During normal running of the refrigeration compressor, oil is circulated by the oil pump and/ or pressure difference between the HP and LP sides. The most critical phase is during start-up.

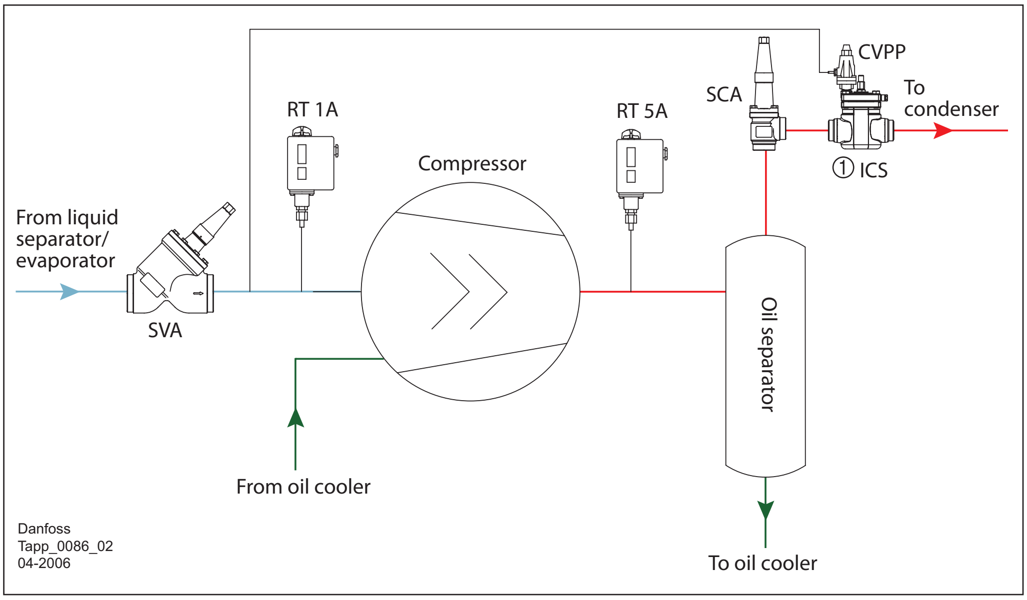
It is vital to have a quick build up of oil pressure otherwise the compressor may be damaged.

There are two basic ways to quickly build up oil differential pressure in the refrigeration compressor.

First is to use an external oil pump, and the second is to install a control valve on the compressor discharge line after the oil separator.

For the latter method it is necessary to check if the compressor manufacturer allows a few seconds of dry operation. Normally, this is possible for screw compressors with ball bearings but not possible for those with slide bearings

Application example 6.2.1: Oil differential pressure control with ICS and CVPP



🟥 HP vapour refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Differential pressure regulator

In this application, a servo operated ICS ① complete with differential pilot CVPP should be used. The pilot line from the CVPP valve is connected to the suction line before the compressor. ICS ① is closed at the moment the compressor is started up.

As the piping between the compressor and the valve is very short, the discharge pressure increases rapidly. It requires very little time before the valve fully opens and the compressor runs at normal conditions.

The main advantage of this solution is its flexibility, as differential pressure could be readjusted on site, and ICS can also serve for some other functions using other pilots.

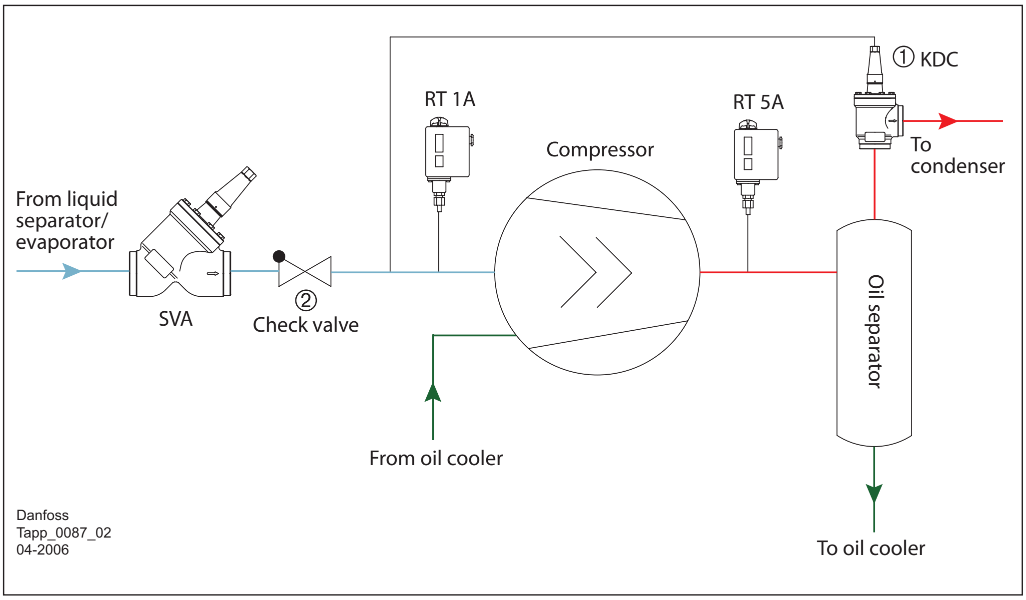
Technical data

	Pilot operated servo valve - ICS
Material	Body: low temp. steel
Refrigerants	All common refrigerants, incl. R717 and R744
Media temp. range [°C]	–60 to 120
Max. working pressure [bar]	52
DN [mm]	20 to 150
Nominal capacity [kW]*	20 to 4000

* Conditions: R717, hot gas line, T_{liq} = 30°C, $P_{disch.}$ = 12bar, ΔP = 0.2bar, $T_{disch.}$ = 80°C, T_e = –10°C

	Differential pressure pilot valve-CVPP
Material	Body: stainless steel
Refrigerants	All common non-flammable refrigerants incl. R717
Media temp. range [°C]	–50 to 120
Max. working pressure [bar]	CVPP (LP): 17 CVPP (HP): up to 40
Regulating range [bar]	CVPP (LP): 0 to 7 CVPP (HP): 0 to 22
K_v value m^3/h	0.4

Application example 6.2.2: Oil differential pressure control with KDC



🟥 HP vapour refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Differential pressure regulator
② Check valve (normally built into the compressor)

The principle of operation for this example is the same as for example 6.2.1. The multifunctional compressor valve KDC ① opens until the pressure difference between the oil separator and the suction line exceeds the setting value and at the same time the pressure in the oil separator is greater than the condensing pressure.

KDC ① valve has some advantages, as it can also function as a check valve (it can not be open by the back pressure), and it gives smaller pressure drop when open.

However, KDC ① also has some limitations. The valve is not adjustable and there are a limited number of differential pressure settings available, and it is necessary to have a check valve ② in the suction line.

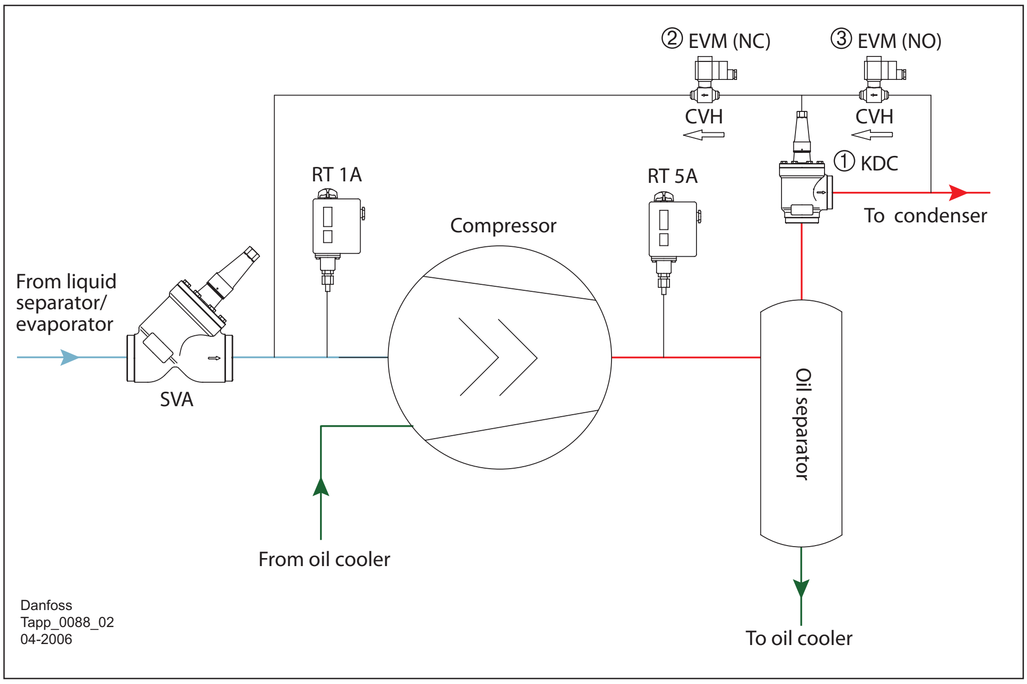
If this check valve is not present, there could be a very large reverse flow through the compressor from the oil separator. It is neither allowed to have a check valve between compressor and oil separator; otherwise it may require too long time for KDC to close.

Technical data

	Multifunctional compressor valve - KDC
Material	Low temp. steel
Refrigerants	All common refrigerants including R717
Media temp. range [°C]	–50 to 150
Max. working pressure [bar]	40
DN [mm]	65 to 200
Nominal capacity [kW]*	435 to 4207

* Conditions: R717, +35°C/–15°C, $\Delta P = 0.05$bar

Application example 6.2.3:
Oil differential pressure control with KDC and EVM pilots



🟥 HP vapour refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Multifunctional compressor valve
② Solenoid pilot (normally close)
③ Solenoid pilot (normally open)

When there is no possibility to install a check valve in the suction line or there is a check valve between the compressor and the oil separator, it is possible to use KDC ① equipped with EVM pilot valves.

These EVM pilots are installed in external lines using CVH bodies, as illustrated. During start up of the compressor the system works as in the previous example (6.2.2).

When the compressor stops, EVM NC ② should be closed and EVM NO ③ opens. That equalizes the pressure over the KDC spring and it closes.

Please note the installation direction of the CVH and EVM pilot valves.

6.3
Oil Recovery System

The compressors within industrial refrigeration ammonia systems are generally the only components that which require oil lubrication. Therefore the function of the compressor oil separator is to prevent any of the lubricating oil passing into the refrigeration system.

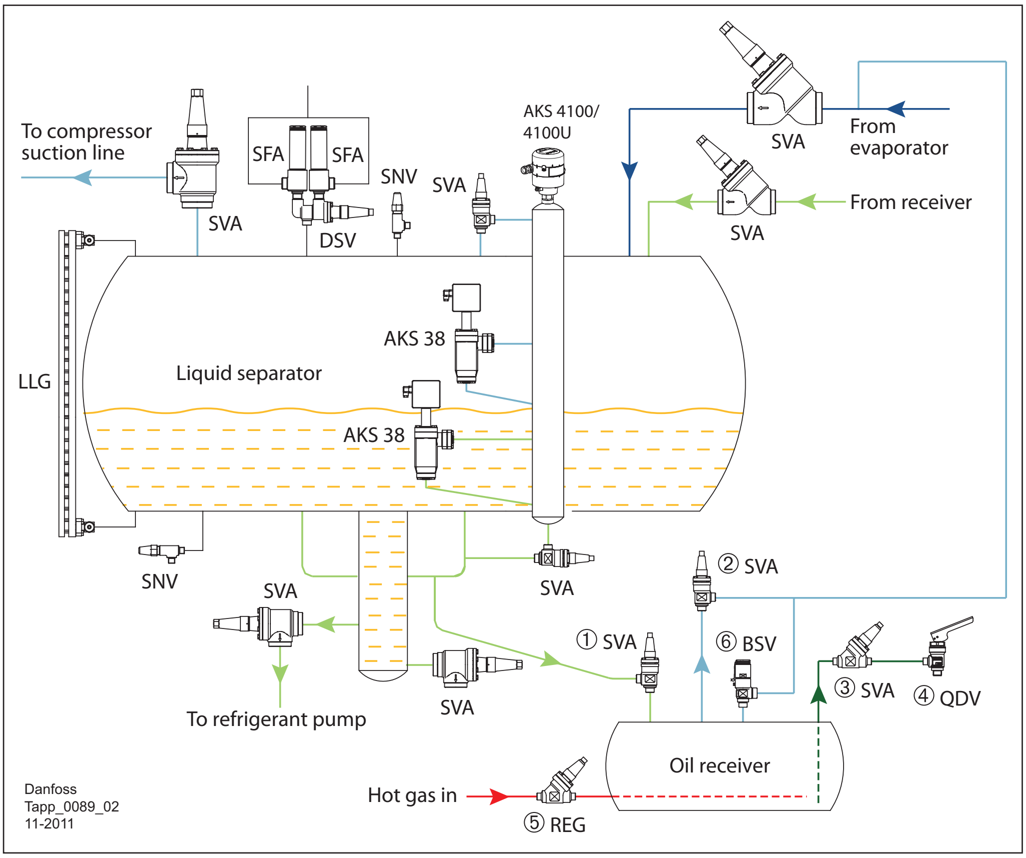
However, oil can carry over through the oil separator into the refrigeration system and often collects in the low pressure side in liquid separators and evaporators, decreasing their efficiency.

If too much oil carries over from the compressor into the system, the oil in the compressor will be reduced and there is then a risk of the oil level falling below the minimum limit set by the compressor manufacturer. Oil return systems are primarily used together with refrigerants that can be mixed with the oil e.g. HFC/HCFC systems. The oil return system can therefore have two functions:

- To remove oil from the low pressure side
- To feed the oil back to the compressor.

It is however extremely important to be aware that any oil removed from the low pressure side of the ammonia cooling system is usually unsuitable for further use with the compressor and it should be removed from the refrigeration system and discarded.

Application example 6.3.1: Oil drain from ammonia systems



🟥 HP vapour refrigerant
🟦 Liquid/vapour mixture of refrigerant
▬ LP vapour refrigerant
🟩 LP liquid refrigerant
▬ Oil

① Stop valve
② Stop valve
③ Stop valve
④ Quick closing oil drain valve
⑤ Regulating valve
⑥ Safety relief valve

In ammonia systems immiscible oil is used. As the oil is heavier than liquid ammonia, it stays in the bottom of the liquid separator and is unable to return to the compressor via the suction line.

Therefore, oil in ammonia systems is normally drained from the liquid separator into the oil receiver. It makes separation of oil from ammonia easier.

When draining the oil, close the stop valve ① and ②, and open the hot gas line, allowing the hot gas to increase the pressure and heat up the cold oil.

Then drain the oil using the quick closing oil drain valve QDV ④, which can be closed quickly after oil evacuation and when ammonia starts to come out.

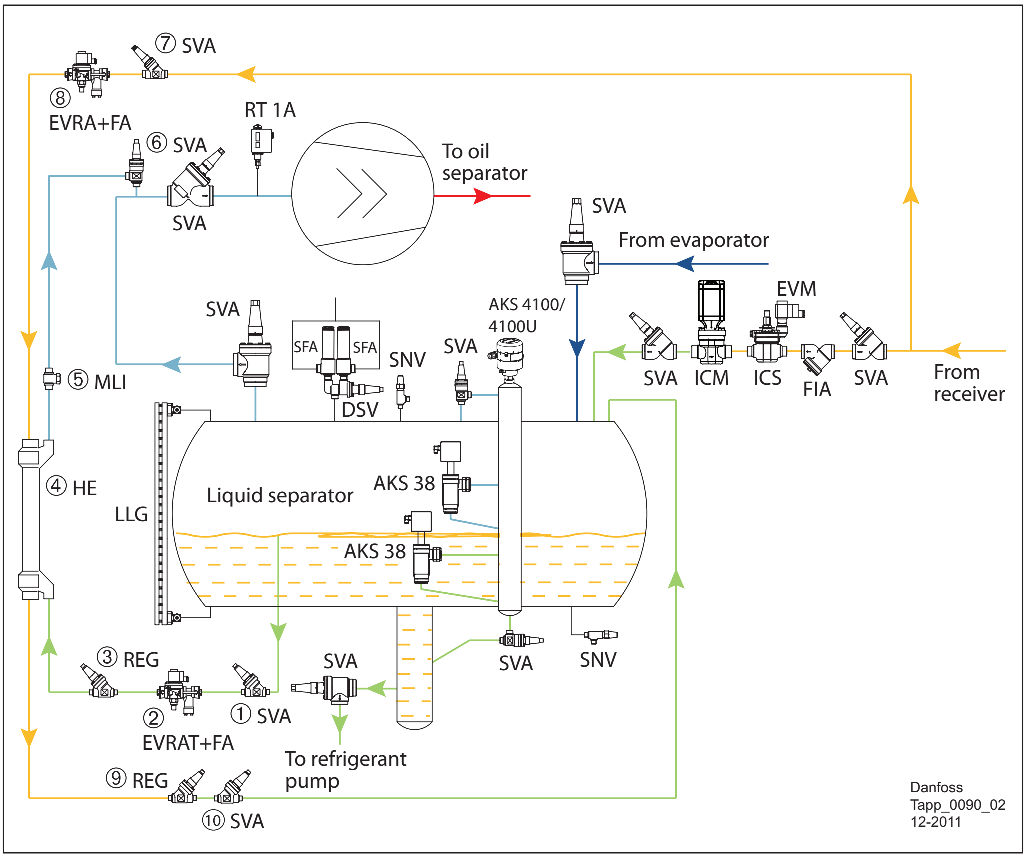
Stop valve SVA ③ between QDV and the receiver must be installed. This valve is opened before evacuation of oil and closed afterwards.

Necessary precautions during drain of oil from ammonia should be taken.

Technical data

	Quick closing drain valve - QDV
Material	Housing: steel
Refrigerants	Commonly used with R717; applicable to all common non-flammable refrigerants.
Media temp. range [°C]	–50 to 150
Max. working pressure [bar]	25
DN [mm]	15

Application example 6.3.2: Oil drain from fluorinated systems



🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant

① Stop valve
② Solenoid valve
③ Regulating valve
④ Heat exchanger
⑤ Sight glass
⑥ Stop valve
⑦ Stop valve
⑧ Solenoid valve
⑨ Regulating valve
⑩ Stop valve

In fluorinated systems miscible oil is predominantly used. In systems using good piping practice (slopes, oil loops etc.), it is not necessary to recover oil, as it returns with the refrigerant vapour.

However in low temperature plants oil may stay in the low pressure vessels. Oil is lighter than commonly used Fluorinated refrigerants, so it's impossible to drain it in a simple way as in ammonia systems.

Oil stays on top of the refrigerant, and the level fluctuates together with refrigerant level.

In this system the refrigerant moves from the liquid separator into the heat exchanger ④ due to gravity.

Low pressure refrigerant is heated up by high pressure liquid refrigerant and evaporates.

Refrigerant vapour mixed with oil returns to the suction line. Refrigerant from the liquid separator is taken from the working level.

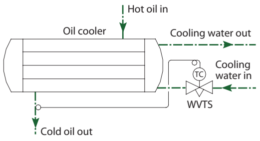
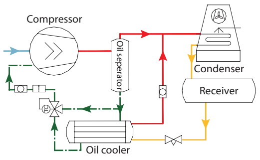
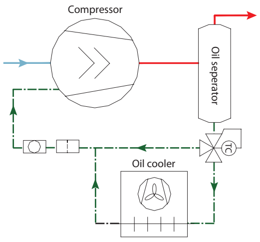
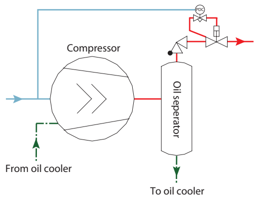
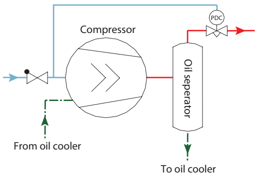
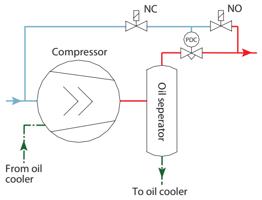
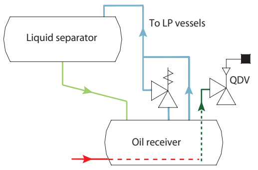
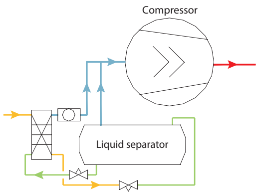
Regulating valve REG ⑤ is adjusted such a way that there are no drops of liquid refrigerant seen in the sight glass MLI ⑤. Danfoss heat exchange HE type could be used to recover the oil.

Refrigerant could also be taken from pump discharge lines. In this case it doesn't really matter if the refrigerant is taken from the working level or not.

Technical data

	Heat exchanger - HE
Refrigerants	All fluorinated refrigerants
Media temp. range [°C]	–60 to 120
Max. working pressure [bar]	HE0.5, 1.0, 1.5, 4.0: 28 HE8.0: 21.5
DN [mm]	Liquid line: 6 to 16 Suction line: 12 to 42

6.4
Summary

Solution		**Application**	**Benefits**	**Limitations**
Oil Cooling Systems				
Water cooling, WVTS water valve		Marine installations, plants where cheap cold water source is available	Simple and efficient	Could be expensive, requires separate water piping
Thermosyphon cooling, ORV		All types of refrigeration plants	Oil is cooled by refrigerant without loss of installation efficiency	Require extra piping and HP liquid receiver installed on defined height
Air cooling, ORV		“Heavy commercial” refrigeration systems with power packs.	Simple, no additional piping or water required	Big fluctuations in oil temperature in different seasons possible; Air cooler may be too big for large installations
Differential Oil Pressure Control				
ICS + CVPP		Screw compressors (should be confirmed by compressor manufacture)	Flexible, different settings possible	Requires installation of the check valve
KDC			Requires no discharge check valve, pressure drop lower than ICS solution.	It is necessary to install check valve in the suction line, no change of setting possible
KDC+EVM			As previous, but installation of the check valve in the suction line is not necessary.	Requires external piping, no change of setting possible
Oil Recovery Systems				
Oil recovery from ammonia systems, QDV		All ammonia plants	Simple and safe	Requires hand operating
Oil recovery from fluorinated systems, HE		Low temperature Fluorinated systems	Doesn’t require manual operation	Adjusting could be complicated

6.5
Reference Documents

For an alphabetical overview of all reference documents please go to page 104

Technical Leaflet / Manual

Type	Literature no.
BSV	RD.7F.B
CVPP	PD.HN0.A
EVM	PD.HN0.A
FIA	PD.FN0.A
HE	RD.6K.A
ICS	PD.HS0.A
KDC	PD.FQ0.A

Type	Literature no.
MLI	PD.GH0.A
ORV	PD.HP0.B
QDV	PD.KL0.A
REG	PD.KM0.A
SVA	PD.KD0.A

Product instruction

Type	Literature no.
BSV	RI.7F.A
CVPP	PI.HN0.C
EVM	RI.3X.H
FIA	PI.FN0.A
HE	RI.6K.A
ICS 25-65	PI.HS0.A
ICS 100-150	PI.HS0.B
KDC	PI.FQ0.A

Type	Literature no.
MLI	PI.GH0.A
ORV	PI.HP0.A
QDV	PI.KL0.A
REG	PI.KM0.A
SVA	PI.KD0.B

To download the latest version of the literature please visit the Danfoss internet site
http://www.danfoss.com/Products/Literature/RA_Documentation.htm

7. Safety systems

All industrial refrigeration systems are designed with different safety systems to protect them against unsafe conditions, like excessive pressure. Any foreseeable excessive internal pressure should be prevented or relieved with minimum risk for people, property and the environment.

Requirements on the safety systems are heavily controled by authorities, and it is therefore always necessary to verify the requirements in the local legislation in various countries.

Pressure relief device e.g. pressure relief valves are designed to relieve excessive pressure automatically at a pressure not exceeding the allowable limit and reseat after the pressure has fallen below the allowable limit.

Temperature limiting device or temperature limiter is a temperature actuated device that is designed to avoid unsafe temperatures so that the system can be stopped partly or completely in case of a defect or malfunction.

Pressure limiter is a device that protects against high or low pressure with automatic resetting.

Safety pressure cut out
Safety switches are designed for limiting the pressure with manual resetting.

Liquid level cut out is a liquid level actuated device designed to prevent against unsafe liquid levels.

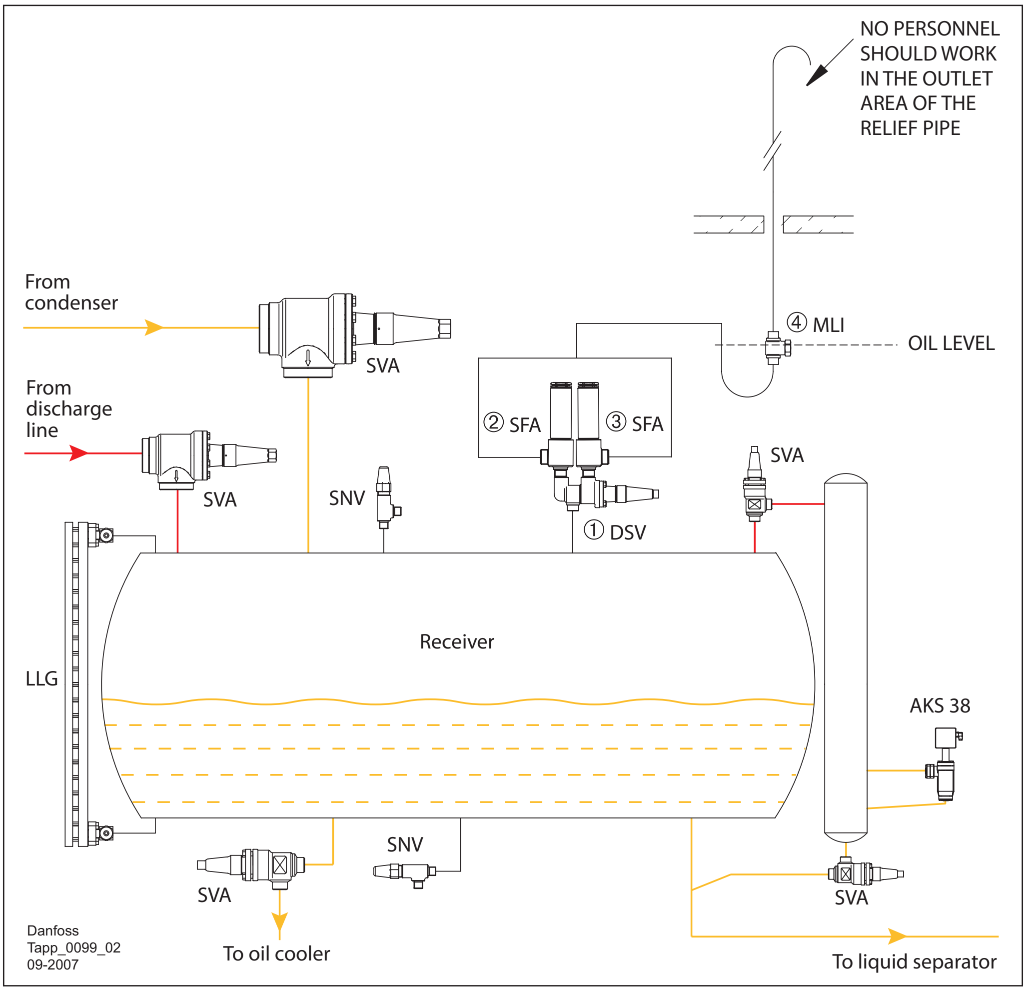
Refrigerant detector is a sensing device which responds to a pre-set concentration of refrigerant gas in the environment. Danfoss produces refrigerant detectors type GD, please see specific application guide for more information.

7.1
Pressure Relief Devices

Safety valves are installed in order to prevent the pressure in the system from rising above the maximum allowable pressure of any component and the system as a whole. In case of excessive pressure, safety valves relieve refrigerant from the refrigeration system.

Main parameters for safety valves are the relief pressure and reseating pressure. Normally the relief pressure should not exceed more than 10% of the set pressures. Furthermore, if the valve does not reseat or reseats at too low a pressure, there can be significant loss of system refrigerant.

Application example 7.1.1:
Safety valve SFA + DSV



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🟥 HP vapour refrigerant
🟨 HP liquid refrigerant

① Double stop valve
② Safety relief valve
③ Safety relief valve
④ Sight glass

Pressure relief devices should be installed on all vessels in the systems, as well as on compressors.

Generally, back pressure dependent safety relief valves (SFA) are normally used. Safety valves should be installed with a changeover valve DSV ①, to enable the servicing of one valve whilst the other is still in operation.

Pressure relief devices should be mounted close to the part of the system they are protecting. In order to check if the relief valve has discharged to the atmosphere a u-trap filled with oil and with a sight glass MLI ④ mounted can be installed after the valve.

Please note: Some countries do not allow installation of u-trap.

Outlet pipe from the safety valve should be designed in such a way that people are not endangered in the event that refrigerant is relieved.

Pressure drop in the outlet pipe to the safety valves is important for the function of the valves. It is recommended to check the relative standards for recommendations on how to size these pipes.

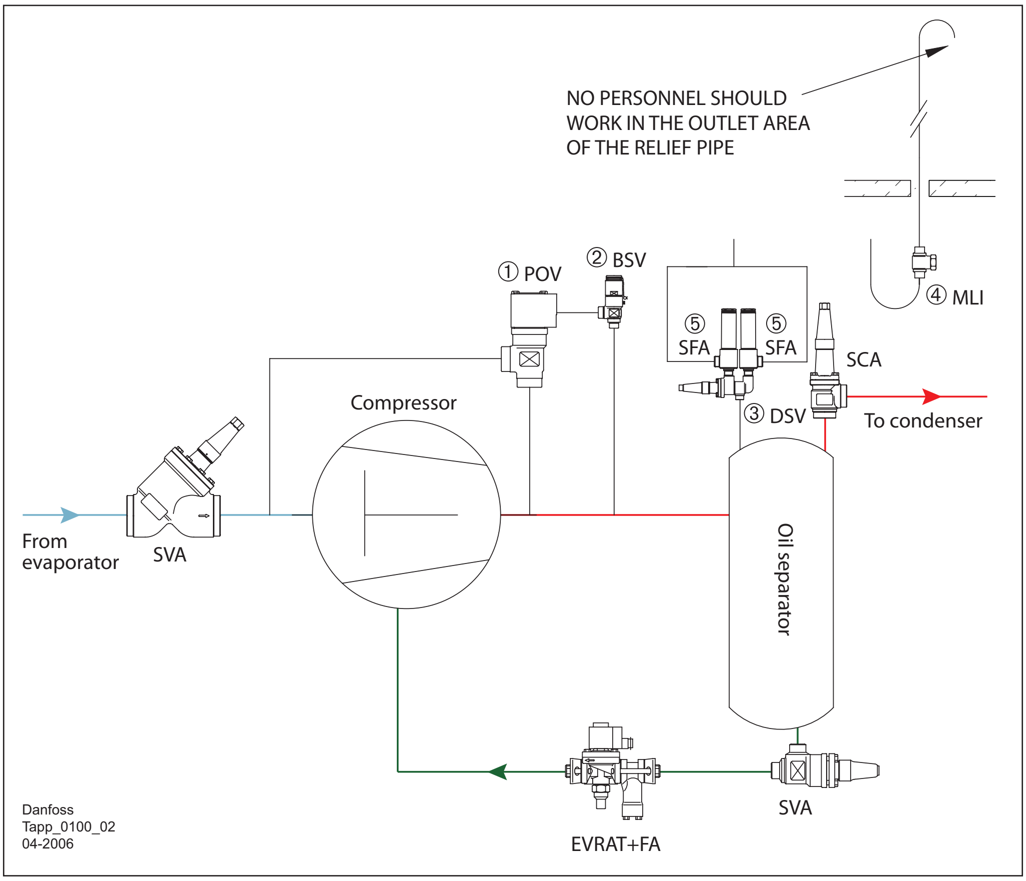
Technical data

	Safety relief valve - SFA 15 (Back pressure dependent)
Material	Housing: special steel approved for low temperature operation
Refrigerants	R717, R744 ,HFC, HCFC, other refrigerants (depending on the sealing material compatibility)
Media temp. range [°C]	–30 to 100
Flow area [mm²]	133
Set pressure [bar]	10 to 40

	Safety relief valve - SFV 20-25 (Back pressure dependent)
Material	Housing: special steel approved for low temperature operation
Refrigerants	R717, R744 ,HFC, HCFC, other refrigerants (depending on compatibility with gasket material)
Media temp. range [°C]	–30 to 100
Flow area [mm²]	SFV 20 : 254 / SFV 25 : 415
Set pressure [bar]	10 to 25

	Double stop valve - DSV 1/2
Material	Housing: special steel approved for low temp. operation
Refrigerants	All common non-flammable refrigerants incl. R717
Media temp. range [°C]	–50 to 100
Max. operation pressure [bar]	40
K_v value [m^3/h]	DSV1: 17.5 DSV2: 30

Application example 7.1.2: Internal safety valves-BSV and POV



🟥 HP vapour refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Pilot-operated internal safety valve
② Internal safety valve
③ Double stop valve
④ Sight glass
⑤ Safety relief valve

To relieve refrigerant from high pressure side to low pressure side only back pressure independent relief valves should be used (BSV/ POV).

BSV ② can act either as a direct relief valve with low capacity or as a pilot valve for POV ① main valve. When the discharge pressure exceeds the set pressure, BSV will open the POV to relieve high pressure vapour into the low pressure side.

The back pressure independent relief valves are installed without change over valve. In case it is necessary to replace or readjust the valves, the compressor has to be stopped.

If a stop valve is mounted in the discharge line from the oil separator, it is necessary to protect the oil separator and the compressor against excessive pressure caused by external heat or compression heat.

This protection can be achieved with standard safety relief valves SFA ⑤ combined with a change over valve DSV ③.

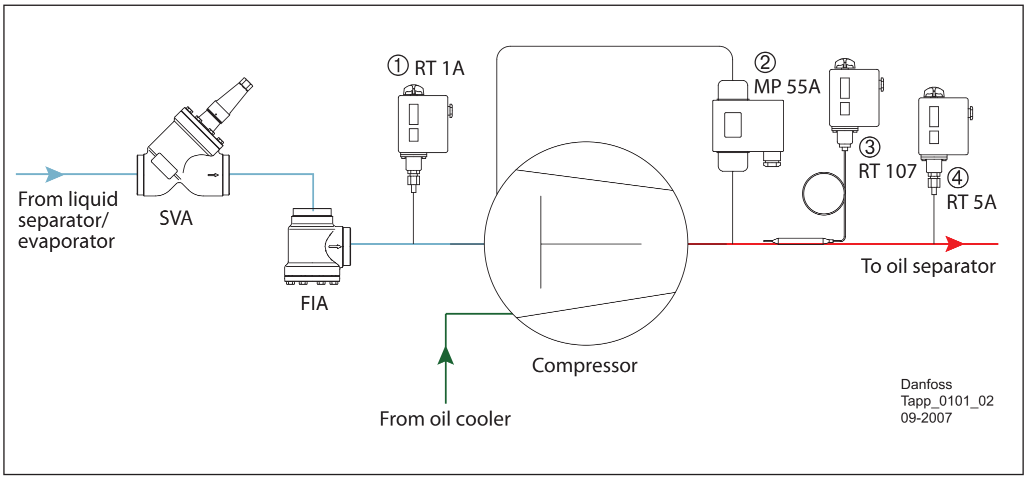
Technical data

	Safety relief valve - BSV (Back pressure independent)
Material	Housing: special steel approved for low temperature operation
Refrigerants	R717, R744, HFC, HCFC and other refrigerants (depending on the sealing material compatibility)
Media temp. range [°C]	–30 to 100 as an external safety relief valve –50 to 100 as a pilot valve for POV
Set pressure [bar]	10 to 25
Flow area [mm^2]	50

	Pilot-operated internal safety valve - POV
Material	Housing: steel
Refrigerants	R717, HFC, HCFC and other refrigerants (depending on the sealing material compatibility)
Media temp. range [°C]	–50 to 150 as a pilot valve for POV
Set pressure [bar]	15 to 25
Flow area [mm^2]	POV 600: 835 POV 1050:1244 POV 2150: 2734
DN [mm]	40/50/80

7.2
Pressure and Temperature Limiting Devices

Application example 7.2.1: Pressure /temperature cut-out for compressors



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🟥 HP vapour refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Low pressure cut-out
② Low differential pressure cut-out
③ High temperature cut-out
④ High pressure cut-out

To protect the compressor from too high discharge pressure and temperature, or too low suction pressure, switches KP/RT are used. RT1A ① is a low pressure control, RT 5A ④ is a high pressure control, and RT 107 ③ is a thermostat.

Setting of the high pressure controls should be below setting of the safety valves settings on the high pressure side. Setting on the low pressure switch is specified by the compressor manufacture.

For piston compressors oil differential switch MP 54/55 ② is used to stop the compressors in case of too low oil pressure.

The oil differential switch cuts out the compressor, if it does not build up enough differential pressure during start up after defined period of time (0-120 s).

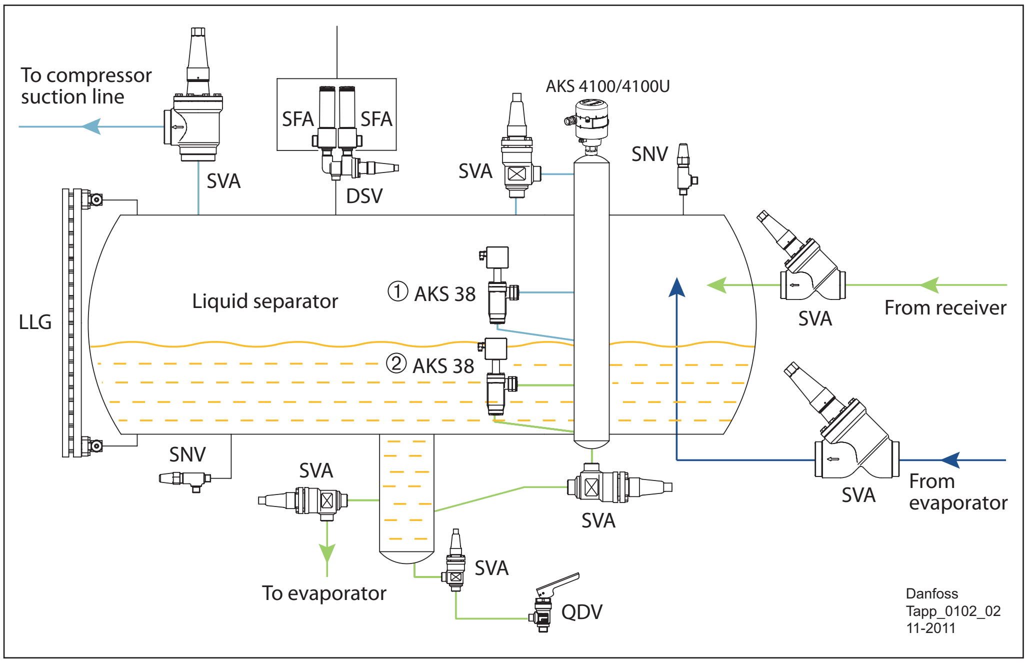
Technical data

	Thermostat - RT
Refrigerants	R717 and fluorinated refrigerants
Enclosure	IP 66/54
Max. bulb temperature [°C]	65 to 300
Ambient temperature [°C]	–50 to 70
Regulating range [°C]	–60 to 150
Differential Δt [°C]	1.0 to 25.0

	Differential pressure control - MP 54/55/55A
Refrigerants	MP 54/55: fluorinated refrigerants MP 55A: R717
Enclosure	IP 20
Regulating range ΔP [bar]	MP 54: 0.65/0.9 MP 55/55A: 0.3 to 4.5
Max. working pressure [bar]	17
Max. test pressure [bar]	22
Operation range on LP side [bar]	–1 to 12

7.3
Liquid Level Devices

Application example 7.3.1:
Low / high level controls for liquid separator



▬ Liquid/vapour mixture of refrigerant
▬ LP vapour refrigerant
▬ LP liquid refrigerant

① High level switch
② Low level switch

Vessels on the high pressure side and low pressure side have different liquid level switches.

High pressure receivers only need to have low level switch (AKS 38) in order to guarantee minimum refrigerant level to feed expansion devices.

Sight glass LLG for visual monitoring of the liquid level can also be installed.

Low pressure vessels normally have both low and high level switches. The low level switch is installed to make sure that there is sufficient head of refrigerant to avoid cavitation of pumps.

A high level switch is installed to protect compressors against liquid hammering.

Liquid level sight glass LLG for visual level indication should also be installed.

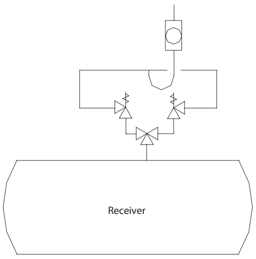
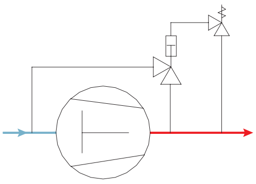
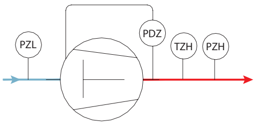
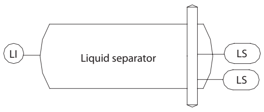
LLG liquid level indicators for low pressure vessels may require that a sight adapter is mounted which makes it possible to observe the level, even though there may be a certain amount of frost on the liquid level indicator.

Technical data

	Level switch - AKS 38
Material	Housing: zinc chromate cast iron
Refrigerants	All common non-flammable refrigerants, including R717.
Media temp. range [°C]	–50 to +65
Max. working pressure [bar]	28
Measuring range [mm]	12.5 to 50

	Sight glass - LLG
Refrigerants	All common non-flammable refrigerants, including R717.
Media temp. range [°C]	–10 to 100 or –50 to 30
Max. working pressure [bar]	25
Length [mm]	185 to 1550

7.4 Summary

Solution		**Application**
Safety Valves		
Safety valves SFA + change over valve DSV		Protection of vessels, compressors, and heat exchangers against excessive pressure
Overflow valve BSV + pilot operated overflow valve POV		Protection of compressors and pumps against excessive pressure
Pressure Cut Out Controls		
Pressure cut out: RT		Protection of compressors against too high discharge and too low suction pressure
Differential pressure cut out MP 55		Protection of reciprocating compressors against too low oil pressure
Thermostat RT		Protection of compressors against too high discharge temperature
Liquid level Devices		
Liquid level switch AKS 38		Protection of the system against too high/too low refrigerant level in the vessels
Liquid level glass LLG		Visual monitoring of liquid refrigerant level in the vessels

7.5 Reference Documents

For an alphabetical overview of all reference documents please go to page 104

Technical Leaflet / Manual

Type	Literature no.
AKS 38	PD.GD0.A
BSV	RD.7F.B
DSV	PD.IE0.A
LLG	PD.GG0.A
MLI	PD.GH0.A
MP 55 A	RD.5C.B

Type	Literature no.
POV	PD.ID0.A
RT 1A	PD.CB0.A
RT 107	RD.5E.A
RT 5A	PD.CB0.A
SFA	PD.IF0.A

Product instruction

Type	Literature no.
AKS 38	RI.5M.A
BSV	RI.7F.A
DSV	PI.IE0.A / RI.7D.A
LLG	RI.6D.D
MLI	PI.GH0.A
MP 55 A	RI.5C.E

Type	Literature no.
POV	PI.ID0.A
RT 1A	RI.5B.C
RT 107	
RT 5A	RI.5B.C
SFA	PI.IB0.A

To download the latest version of the literature please visit the Danfoss internet site
http://www.danfoss.com/Products/Literature/RA_Documentation.htm

8.
Refrigerant Pump Controls

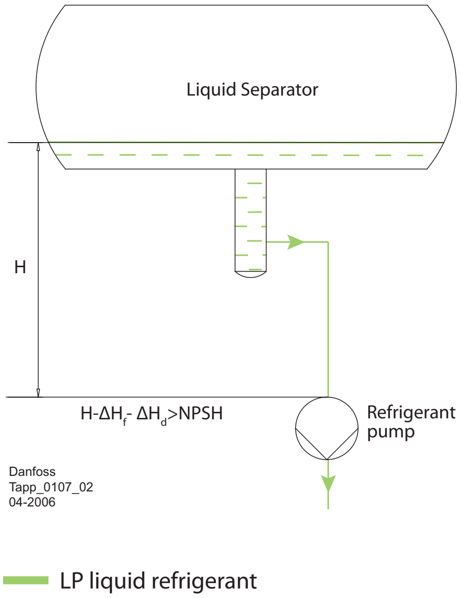
Generally, industrial refrigeration systems have pump circulation of liquid refrigerant. There are a few advantages of pump circulation compared with DX type systems:

- Pumps provide efficient distribution of liquid refrigerant to evaporators and return of vapour-liquid mixture back to the pump separator;
- It is possible to decrease the superheat to almost 0 K, thereby increase efficiency of the evaporators, without risk of liquid hammer in the compressor.

When installing the pump, care must be taken to prevent cavitation. Cavition can occur only if the static refrigerant liquid pressure at the pump inlet is lower than the saturation pressure corresponding to the liquid temperature at this point.

Therefore the liquid height H above the pump should at least be able to compensate the pressure loss of friction ΔH_f through the pipe and valves, the pipe inlet loss ΔH_d, and the acceleration of the liquid into the pump impellor ΔH_p (pump net positive suction head, or NPSH), as shown in fig. 8.1.

Fig. 8.1
Placing of the pump



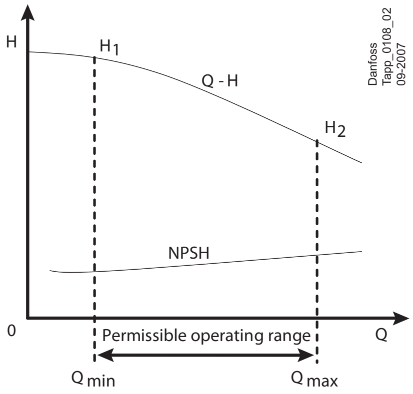
In order to keep the refrigerant pump in trouble-free operation, the flow through the pump should be maintained within the permissible operating range, fig. 8.2.

If the flow is too low, the motor heat may evaporate some of the refrigerant and result in dry running or cavitation of the pump.

When the flow is too high, the NPSH (Net Positive Suction Head) characteristic of the pump deteriorates to an extent that the available positive suction head becomes too low to prevent cavitation.

Therefore, systems should be designed for the refrigerant pump to keep this flow within the operating range.

Fig. 8.2
A typical Q-H curve for pumps



8.1
Pump Protection with Differential Pressure Control

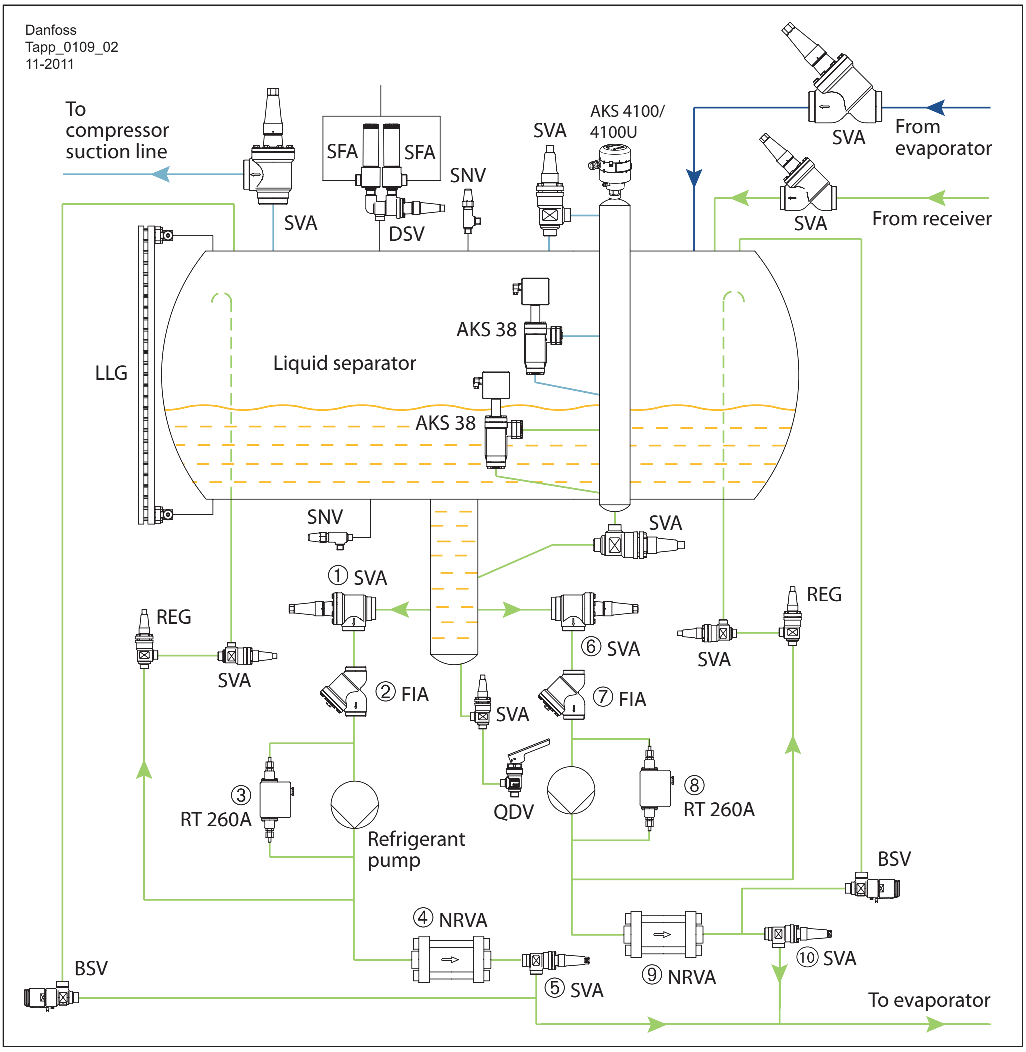
Pumps are easily damaged by cavitation. To avoid cavitation, it is important to maintain sufficient positive suction head for the pump. To achieve enough suction head, low level switch AKS 38 is installed on the liquid separator.

However, even if the low level switch is installed on the liquid separator is kept above the minimum acceptable level, cavitation can still occur.

For example, incorrect operations on the evaporators may cause increased flow through the pump, the low level switch may fail, and the filter before the pump may be blocked, etc.

All these may lead to cavitation. Therefore, it is necessary to shut down the pump for protection when the differential pressure drops below H_2 in fig. 8.2 (equivalent to Q_{max}).

Application example 8.1.1: Pump protection with differential pressure control RT 260A



▬ Liquid/vapour mixture of refrigerant
▬ LP vapour refrigerant
▬ LP liquid refrigerant

① Stop valve
② Filter
③ Differential pressure switch
④ Check valve
⑤ Stop valve
⑥ Stop valve
⑦ Filter
⑧ Differential pressure switch
⑨ Check valve
⑩ Stop valve

Differential pressure controls are used for protection against too low pressure difference. RT 260A ③ and ⑧ are supplied without a timing relay and cause a momentary cut-out when the differential pressure drops below the pressure controls setting.

The filters FIA ② and ⑦ are installed on the pump line to remove particles and protect automatic control valves and pumps from damage, blockage, and general wear and tear. The filter can be installed in either suction line or discharge line of the pump.

If the filter is installed in the suction line before the pump, it will primarily protect the pump against particles. This is particularly important during initial clean-up during commissioning.

Since pressure drop can lead to cavitation, it is recommended to install a 500μ mesh. Finer meshes could be used during the cleaning up, but be sure to take into account the pressure drop when designing the piping. Additionally, it is necessary to replace the mesh after a period of time.

If a filter is installed in the discharge line, pressure drop is not as crucial and a 150-200μ filter can be used. It is important to note that in this installation, particles can still enter the pump before being removed from the system.

The check valves NRVA ④ and ⑨ are installed on the discharge lines of the pumps to protect the pumps against reverse flow (pressure) during standstill. The stop check valve SCA can also be used for this purpose (NRVA and SVA are replaced with the SCA, see application example 8.1.2).

Technical data

	Differential pressure control - RT 260A/252A/265A/260AL
Refrigerants	R717 and fluorinated refrigerants
Enclosure	IP 66/54
Ambient temperature [°C]	–50 to 70
Regulating range [bar]	0.1 to 11
Max. working pressure [bar]	22/42

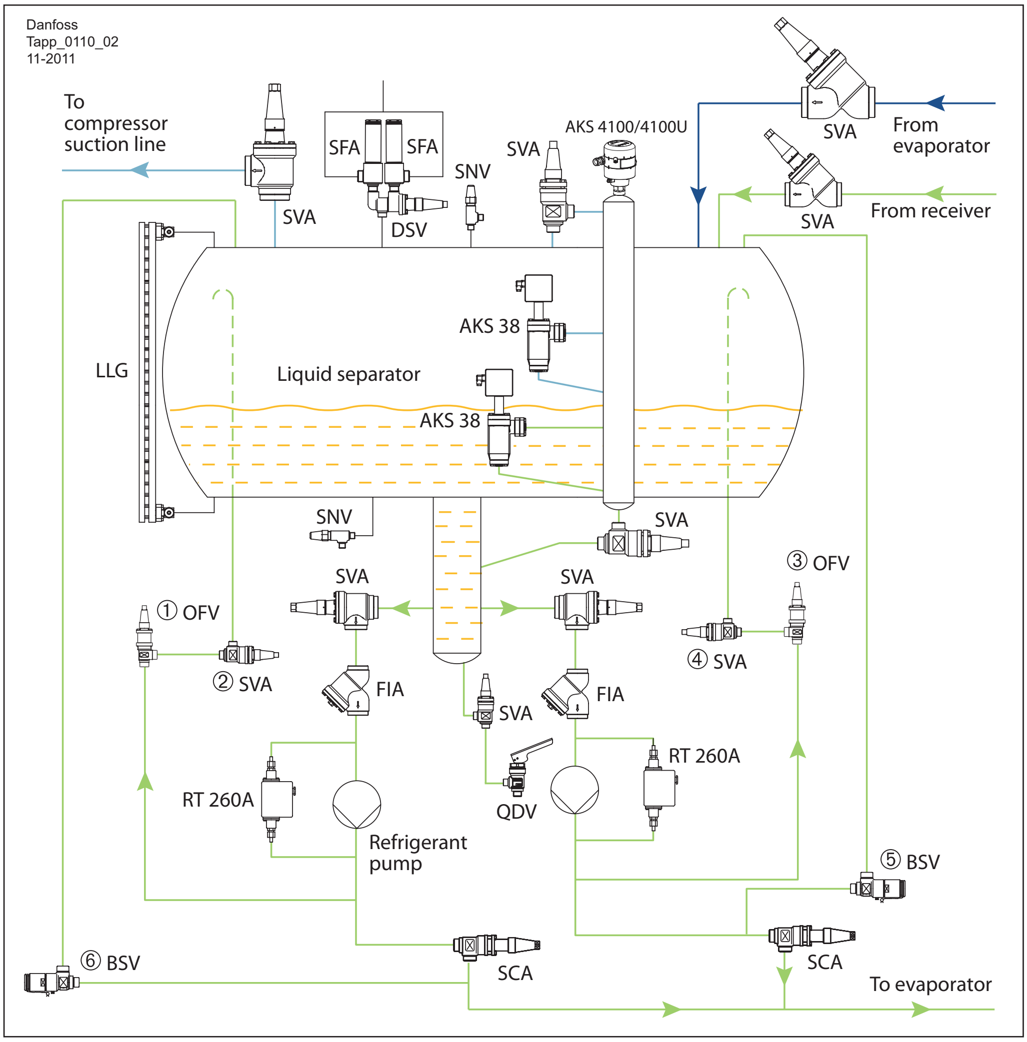
8.2
Pump Bypass Flow Control

The most common way to keep the flow through the pump above the minimum permissible value (Q_{min} in fig. 8.2) is to design a bypass flow for the pump.

The bypass line can be designed with regulating valve REG, differential pressure overflow valve OFV, or even just an orifice.

Even if the liquid supply to all evaporators in the system is stopped, the bypass line can still keep a minimum flow through the pump.

Application example 8.2.1: Pump bypass flow control with OFV



- 🟦 Liquid/vapour mixture of refrigerant
- 🟦 LP vapour refrigerant
- 🟩 LP liquid refrigerant

① Overflow valve
② Stop valve
③ Overflow valve
④ Stop valve
⑤ Internal safety relief valve
⑥ Internal safety relief valve

The bypass line is designed for each pump with overflow valve OFV.
The internal overflow valve BSV is designed for safety relief when there is excessive pressure. For example, when the stop valves are closed, the liquid refrigerant trapped in the pipes may be heated to excessive high pressure.

Technical data

	Overflow valve - OFV
Material	Body: steel
Refrigerants	All common refrigerants, incl. R717
Media temp. range [°C]	–50 to 150
Max. working pressure [bar]	40
DN [mm]	20/25
Opening differential pressure range [bar]	2 to 8

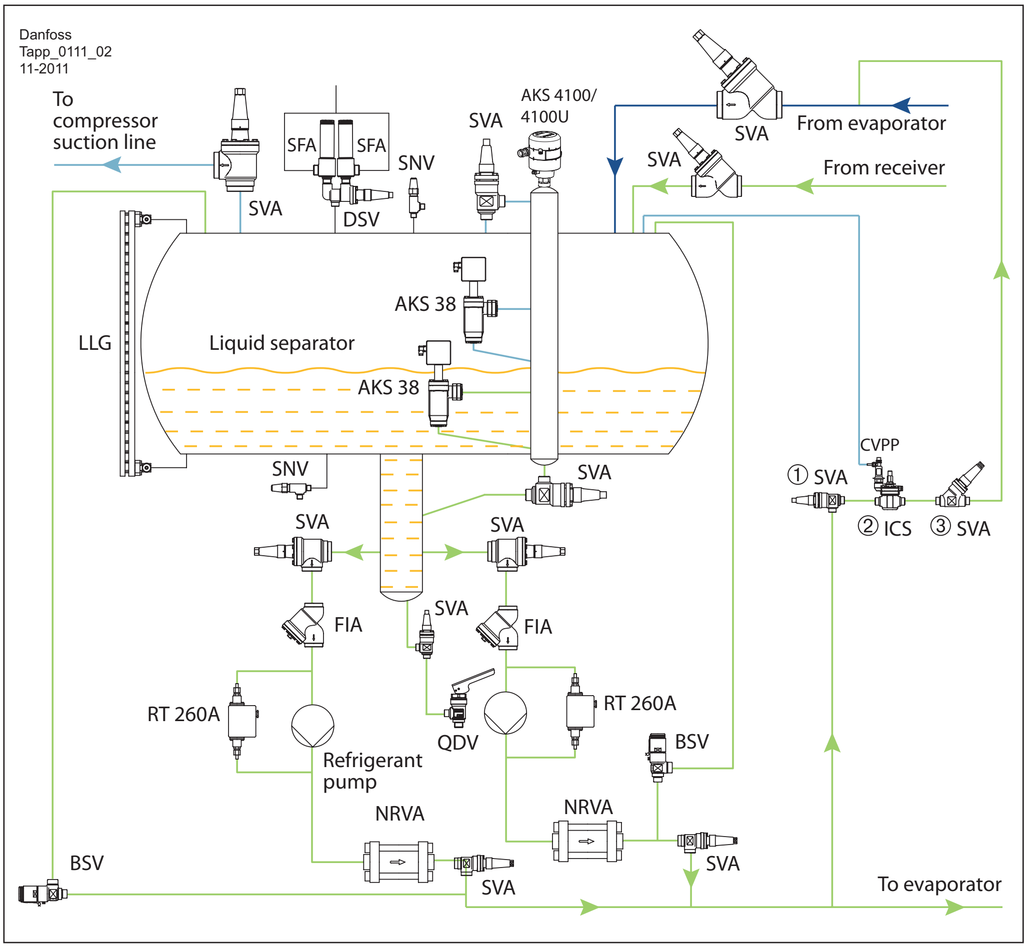
	Safety relief valve - BSV (Back pressure independent)
Material	Housing: special steel approved for low temperature operation
Refrigerants	R717, R744, HFC, HCFC and other refrigerants (depending on the sealing material compatibility)
Media temp. range [°C]	–30 to 100 as an external safety relief valve –50 to 100 as a pilot valve for POV
Set pressure [bar]	10 to 25
Flow area [mm²]	50

8.3 Pump Pressure Control

It is of great importance to some types of pump circulation systems that a constant differential pressure can be maintained across the permanently set throttle valve before the evaporator.

By using pilot controlled servo valve ICS and pilot valve CVPP, it is possible to maintain a constant differential pressure across the pump, and therefore a constant differential pressure across the throttle valve.

Application example 8.3.1: Pump differential pressure control with ICS and CVPP



▬ Liquid/vapour mixture of refrigerant
▬ LP vapour refrigerant
▬ LP liquid refrigerant

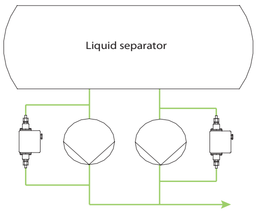
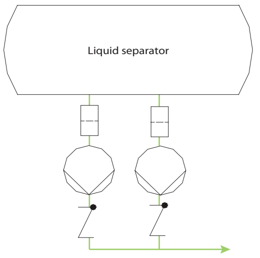
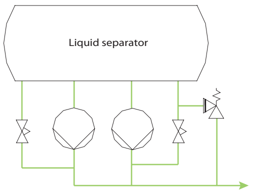
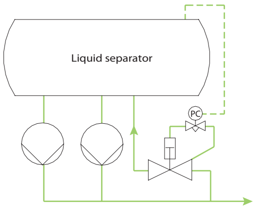
① Stop valve
② Differential pressure regulator
③ Stop valve

Technical data

	Pilot-operated servo valve - ICS
Material	Body: low temp. steel
Refrigerants	All common refrigerants, incl. R717 and R744
Media temperature range [°C]	–60 to 120
Max. working pressure [bar]	52
DN [mm]	20 to 150

	Differential pressure pilot valve-CVPP
Refrigerants	All common non-flammable refrigerants incl. R717
Media temp. range [°C]	–50 to 120
Max. working pressure [bar]	CVPP (LP): 17 CVPP (HP): up to 40
Regulating range [bar]	CVPP (LP): 0 to 7 CVPP (HP): 0 to 22
K_v value m^3/h	0.4

8.4
Summary

Solution		**Application**	**Benefits**	**Limitations**
Pump Protection with Differential Pressure Control				
Pump protection with differential pressure control RT 260A		Applicable to all pump circulation systems.	Simple. Effective in protecting the pump against low differential pressure (corresponding to high flow).	Not applicable to flammable refrigerants.
Filter and Check Valve				
Filter FIA and check valve NRVA on the pump line		Applicable to all pump circulation systems.	Simple. Effective in protecting the pump against back flow and particles.	Filter on the suction line may lead to cavitation when blocked. Filter on the discharge line still allows particles to enter the pump.
Pump Bypass Flow Control				
Pump bypass flow control with REG and protection with safety relief valve BSV		Applicable to all pump circulation systems.	Simple. Effective and reliable in keeping the minimum flow for the pump. Safety valve can effectively prevent excessive pressure.	Part of pump power wasted.
Pump Pressure Control				
Pump pressure control with ICS and CVPP		Applicable to pump circulation systems that require constant differential pressure across the regulating valves before evaporators.	Provides a constant differential pressure and circulation ratio for the evaporators.	Part of pump power wasted.

8.5
Reference Documents

For an alphabetical overview of all reference documents please go to page 104

Technical Leaflet / Manual

Type	Literature no.
BSV	RD.7F.B
CVPP	PD.HN0.A
FIA	PD.FM0.A
ICS	PD.HS0.A

Type	Literature no.
NRVA	RD.6H.A
REG	PD.KM0.A
RT 260A	PD.CB0.A
SVA	PD.KD0.A

Product instruction

Type	Literature no.
BSV	RI.7F.A
CVPP	PI.HN0.C
FIA	PI.FN0.A
ICS 25-65	PI.HS0.A
ICS 100-150	PI.HS0.B

Type	Literature no.
NRVA	RI.6H.B
REG	PI.KM0.A
RT 260A	RI.5B.B
SVA	PI.KD0.B

To download the latest version of the literature please visit the Danfoss internet site
http://www.danfoss.com/Products/Literature/RA_Documentation.htm

9. Others

9.1 Filter Driers in Fluorinated Systems

Water, acids and particles appear naturally in fluorinated refrigeration systems. Water may enter the system as a result of installation, service, leakage, etc..

Acid is formed as a result of the breakdown of the refrigerant and oil.

Particles usually result from soldering and welding residue, the reaction between refrigerant and oil, etc.

Failure to keep the contents of acids, water and particles within acceptable limits will significantly shorten the lifetime of the refrigeration system and even burn out the compressor.

Too much moisture in systems with evaporating temperatures below 0°C could form ice which may block control valves, solenoid valves, filters, and so on. Particles increase the wear-and-tear of the compressor and valves, as well as the possibility of creating a blockage. Acids are not corrosive if there is no water. But in water solution, acids can corrode the pipe work and plate the hot bearing surfaces in the compressor.

This plating builds up on to the hot bearing surfaces including the oil pump, crankshaft, con rods, piston rings, suction and discharge valve reeds etc. This plating causes the bearings to run hotter as the lubrication gap in the bearings reduces as the plating gets thicker.

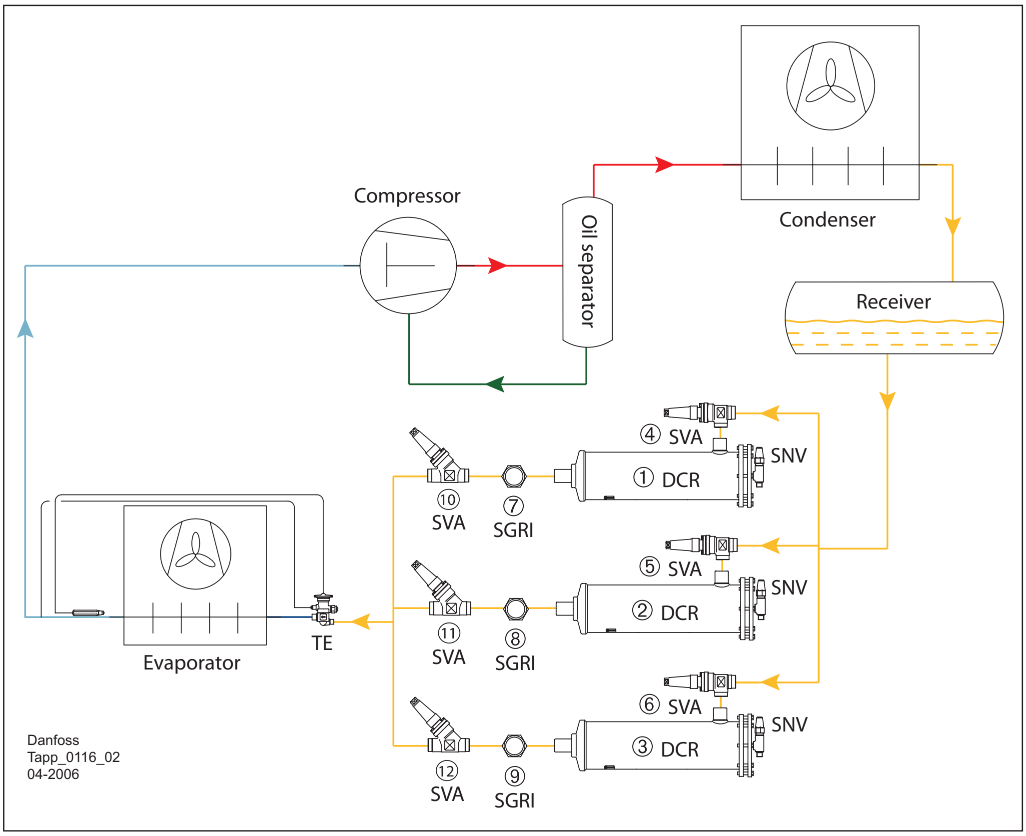
Cooling of the bearings is reduced due to less oil circulating through the bearing gap. This causes these components to get hotter and hotter. Valve plates start to leak by causing higher discharge superheating effect. As the problems escalate the compressor failure is imminent.

Filter driers are designed to prevent all the above circumstances. Filter driers serve two functions: drying function and filtering function.

The drying function constitutes the chemical protection and includes the adsorption of water and acids. The purpose is to prevent corrosion of the metal surface, decomposition of the oil and refrigerant and avoid burn-out of motors.

The filter function constitutes the physical protection and includes retention of particles and impurities of any kind. This minimizes the wear and tear of the compressor, protects it against damage and significantly prolongs its life.

Application example 9.1.1: Filter drier in fluorinated systems



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🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Filter drier
② Filter drier
③ Filter drier
④ Stop valve
⑤ Stop valve
⑥ Stop valve
⑦ Sight glass
⑧ Sight glass
⑨ Sight glass
⑩ Stop valve
⑪ Stop valve
⑫ Stop valve

For fluorinated systems, filter driers are normally installed in the liquid line before the expansion valve. In this line, there is only pure liquid flow through the filter drier (unlike the two-phase flow after the expansion valve).

The pressure drop across the filter drier is small, and the pressure drop in this line has little influence on the performance of the system. The installation of filter drier could also prevent ice formation in the expansion valve.

In industrial installations the capacity of one filter drier is not normally sufficient to dry the whole system, therefore several filter driers could be installed in parallel.

DCR is a filter drier with interchangeable solid cores. There are three types of solid cores: DM, DC and DA.

- **DM** - 100% molecular sieve solid core suitable for HFC refrigerants and CO_2;
- **DC** - 80% molecular sieve and 20% activated alumina solid core suitable for CFC & HCFC refrigerants and compatible with HFC refrigerants;
- **DA** - 30% molecular sieve and 70% activated alumina solid core suitable for clean up after compressor burn-out and compatible with CFC / HCFC / HFC refrigerants.

In addition to the above normal solid cores, Danfoss also provide other customer-tailored solid cores. And Danfoss also provide filter driers with fixed solid cores. For more information, please refer to the product catalogue or contact your local sales companies.

The sight glass with indicator for HCFC/CFC, type SGRI, is installed after the filter drier to indicate the water content after drying. Sight glasses with indicator for other types of refrigerants can also be provided. For more information, please refer to Danfoss product catalogue.

Technical data

	Filter drier - DCR
Refrigerants	CFC/HFC/HCFC/R744
Material	Housing: steel
Max. working pressure [bar]	HP: 46
Operating temp. range [°C]	–40 to 70
Solid cores	DM/DC/DA

9.2 Water Removal for Ammonia Systems

The issue of water in ammonia systems is unique compared with fluorinated systems and CO_2 systems:
The molecular structure of ammonia and water are similar, both small and polar and as a result both ammonia and water are completely soluble.

As a result of the similarity of ammonia and water molecular, there has been no efficient filter drier for ammonia. Furthermore, because of the high solubility of water in ammonia, free water is difficult to extract from the solution.

Water and ammonia will co-exist and act as a kind of zeotropic refrigerant, whose saturated P-T relationship is no longer the same as anhydrous ammonia.

These are factors as to why ammonia systems are seldom designed as DX systems: on one hand, the liquid ammonia is hard to completely vaporize when water is present, which will lead to liquid hammer; on the other hand, how can a thermostatic expansion valve function correctly when the saturated P-T relationship changes?

Pumped liquid circulation systems could well avoid the potential damages of water to the compressors. With only vapour entering in the suction line, liquid hammer is avoided; and so long as there is not too much water in the liquid, the vapour will contain nearly no water (< the recommended max. of 0.3%), which could effectively avoid the oil pollution by water.

While pumped liquid circulation systems effectively avoid damage to the compressors, it also keeps the other penalties of water unnoticed:

- **COP of the system is reduced**
  When there is water content, the saturated P-T relationship of the refrigerant will be different from pure ammonia. Specifically, the refrigerant will evaporate at a higher temperature for a given pressure. This will decrease the refrigeration capacity of the system and increase power consumption.
- **Corrosion**
  Ammonia becomes corrosive with water present and start to corrode the pipe work, valves, vessels, etc.
- **Compressor problems**
  If water is taken into the compressors, e.g. due to inefficient liquid separators, it will also lead to oil and corrosion problems to the compressors.

Therefore, to keep the system in efficient and trouble-free mode, it’s recommended to detect water regularly, and employ some water removal method when the water content is found to be above the acceptable level.

Basically, there are three ways to deal with water contamination:

- **Change the charge**
  This is suitable for systems with small charges (e.g. chillers with plate type evaporators), and it should comply with local legislation.
- **Purging from some evaporators**
  This is suitable for some gravity driven systems without hot gas defrost. In these systems, water remains in the liquid when ammonia vaporizes, and accumulates in the evaporators.
- **Water rectifier**
  Part of contaminated ammonia is drained into the rectifier, where it is heated, with the ammonia vaporising and the water drained. This is the only way of removing water for pumped liquid circulation systems.

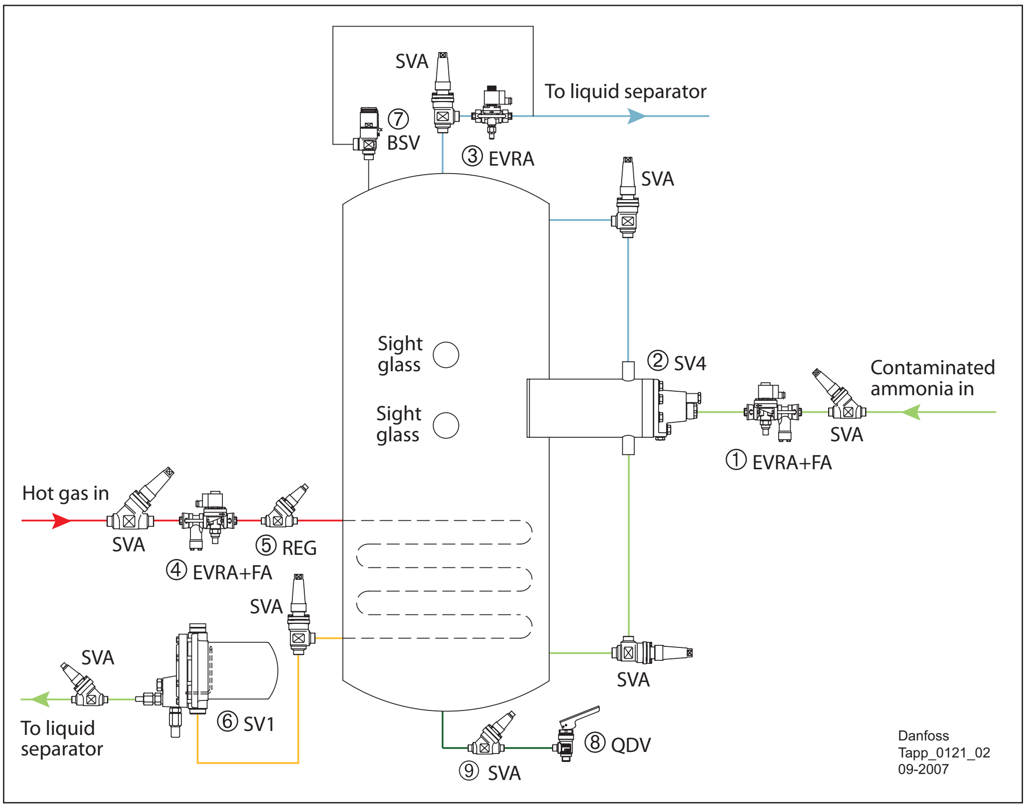
For more information on water contamination and water removal in ammonia refrigeration systems, please refer to IIAR bulletin 108.

It is necessary to mention that there is a down side to too low water content - the possibility of a special kind of steel corrosion. However it is not likely in a real plant.

Application example 9.2.1:
Water rectifier heated by hot gas controled by float valves

🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant
■ Oil

① Solenoid valve
② Low pressure float valve
③ Solenoid valve
④ Solenoid valve
⑤ Hand regulating valve
⑥ High pressure float valve
⑦ Internal safety relief valve
⑧ Quick drain valve
⑨ Stop valve



Procedure for removing water:

1. Energise the solenoid valve EVRA ① and ③. Contaminated ammonia is drained into the rectifying vessel. The float valve SV4 ② will close when the liquid level in the vessel reaches the set level.

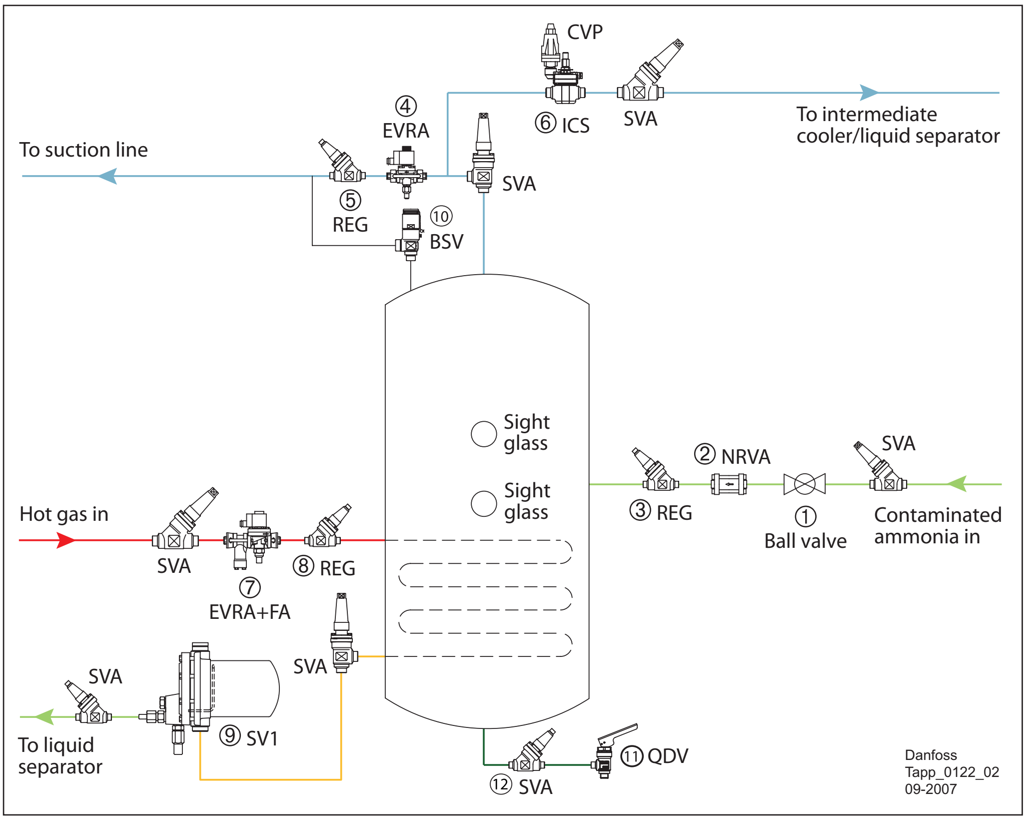
2. Energise the solenoid valve EVRA ④. Hot gas is fed to the coil inside the vessel and starts to heat the contaminated ammonia. Ammonia starts to evaporate, and water remains in the liquid. The float valve SV1/3 ⑥ complete with a special kit inside (shown in dot line) controls the flow of hot gas according to the heating load and maintains the heating temperature at the condensing temperature of the hot gas. When ammonia evaporates in the vessel and the liquid level drops, the float valve SV4 ② will open and drain more contaminated ammonia into the vessel.

3. When the rectifying is completed the levels in both the vessel and the coil will stop changing, and the float valve ② and ⑥ will close. De-energise the solenoid valve ① and ④, then open the stop valve SVA and drain valve QDV ⑧, and drain off the water remaining in the vessel.

4. Close the drain valve QDV ⑧ and stop valve SVA ⑨. Then de-energise the solenoid valve ③ to stop the water removal process, or if necessary, repeat step 1 to continue the process.

For safety considerations, safety relief valve BSV ⑦ is installed on the vessel to avoid excessive pressure build up.

Application example 9.2.2: Water rectifier heated by hot gas, equipped with float valve and ball valve



🟥 HP vapour refrigerant
🟧 HP liquid refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant
■ Oil

① Ball valve
② Check valve
③ Hand regulating valve
④ Solenoid valve
⑤ Hand regulating valve
⑥ Pressure regulating valve
⑦ Solenoid valve
⑧ Hand regulating valve
⑨ High pressure float valve
⑩ Internal safety relief valve
⑪ Quick drain valve
⑫ Stop valve

This is a manual water removal process.

Steps for removing water:

1. Energise the solenoid valve EVRA ④, then open the ball valve ①. Contaminated ammonia from the low pressure side is drained into the water rectifier. When the ammonia in the vessel reaches the required level (monitor through the sight glasses), close the ball valve ① and de-energise the solenoid valve EVRA ④.

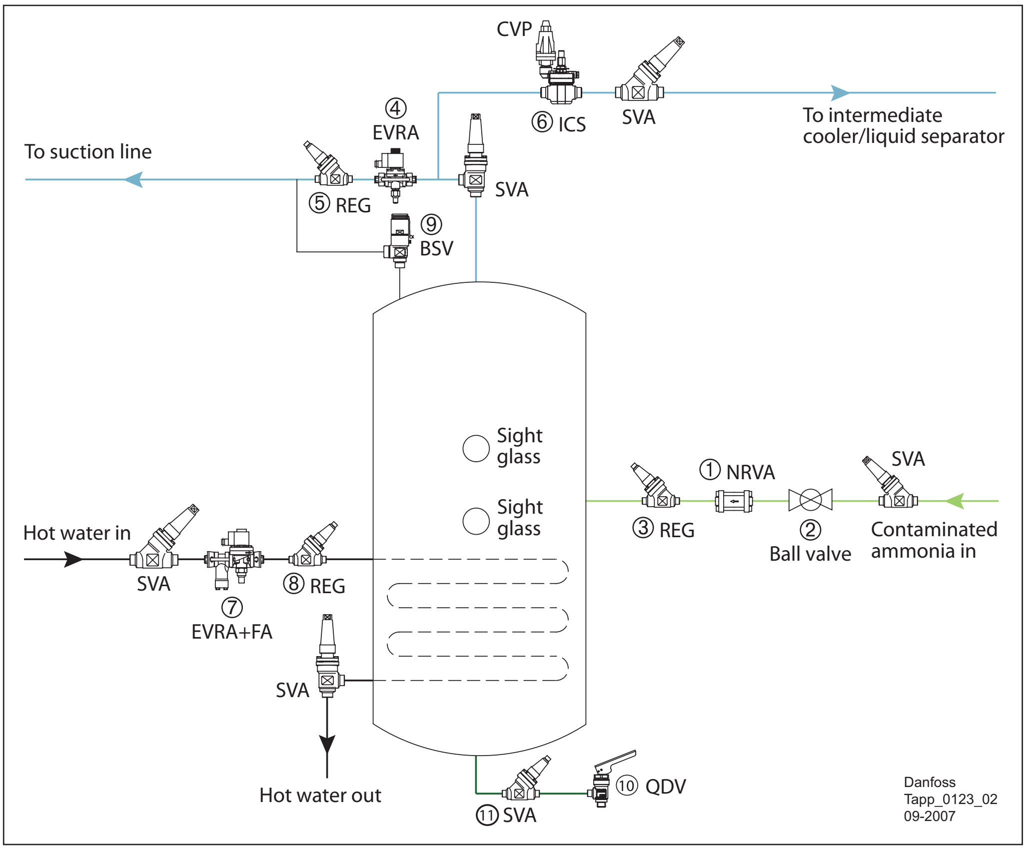
2. Energise the solenoid valve EVRA ⑦. Hot gas is fed to the coil inside the vessel and starts to heat the contaminated ammonia, with the ammonia evaporating and the water remaining in the liquid. The float valve SV1/3 ⑨ with a special kit inside (shown in dot line) controls the flow of hot gas according to the heating load, and maintains the heating temperature at the condensing temperature of the hot gas.

3. When the boiling in the vessel stops (monitor through the sight glasses), de-energise the solenoid valve EVRA ⑦, open the stop valve SVA ⑫. Use the drain valve QDV ⑪ to drain the water/ammonia mixture from the vessel.

During the distillation, it is important to maintain the proper pressure and temperature in the vessel. The temperature should not be too high, otherwise water will evaporate. Additionally the temperature should not be too low; otherwise too much ammonia will remain in the vessel as liquid and be wasted when draining. This is ensured by the servo valve ICS ⑥ with the constant pressure pilot valve CVP, which keeps the pressure in the vessel at an optimal level.

For safety considerations, safety relief valve BSV ⑩ is installed on the vessel to avoid excessive pressure build up.

Application example 9.2.3:
Water rectifier heated by hot water



🟥 HP vapour refrigerant
🟧 HP liquid refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant
🟩 Oil
⬛ Water

① Ball valve
② Check valve
③ Hand regulating valve
④ Solenoid valve
⑤ Hand regulating valve
⑥ Pressure regulating valve
⑦ Solenoid valve
⑧ Hand regulating valve
⑨ Internal safety relief valve
⑩ Quick drain valve
⑪ Stop valve

This is a manual water removal process with hot water as the heating source. The hot water supplied via heat reclaim.

Steps for removing water:

1. Energise the solenoid valve EVRA ④, then open the ball valve ①. Contaminated ammonia from the low pressure side is drained into the water rectifier. When the ammonia in the vessel reaches the required level (monitor through the sight glasses), close the ball valve ① and de-energise the solenoid valve EVRA ④.

2. Open the solenoid valve EVRA ⑦. Hot water is fed to the coil inside the vessel and starts to heat the contaminated ammonia, with the ammonia evaporating and the water remaining in the liquid.

3. When the boiling in the vessel stops (monitor through the sight glasses), de-energise the solenoid valve EVRA ⑦, open the stop valve ⑪. Use the drain valve QDV ⑩ to drain the water from the vessel.

During the distillation, it is important to maintain the proper pressure and temperature in the vessel. The temperature should not be too high, otherwise water will evaporate. Additionally the temperature should not be too low; otherwise too much ammonia will remain in the vessel as liquid and be wasted when draining. This is ensured by the servo valve ICS ⑥ with constant pressure pilot valve CVP, which keeps the pressure in the vessel at an optimal level.

For safety considerations, safety relief valve BSV ⑨ is installed on the vessel to avoid excessive pressure build up.

9.3
Air purging systems

Presence of Non Condensable Gases

Non-condensable gases are present in refrigeration systems at the outset of the installation process, with pipes and fittings being full of air. Therefore, if a good vacuum process is not undertaken air can remain within the system.

Additionally, air can enter the system as a result of the system leaking, when the system is open for maintenance, penetration through the system components, leaking at welded connections where the pressure of the ammonia is lower than atmospheric pressure (below -34°C evaporating temperature), when adding oil, etc.

Moreover, impurities in the refrigerant and / or decomposition of the refrigerant or the lubricating oil due to high discharge temperatures may generate non-condensable gases (e.g. Ammonia decomposes into nitrogen and hydrogen).

Location & Detection

Non-condensable gases are contained within the high pressure side of the refrigeration system, mainly in the coldest and less agitated points in the condenser.

A simple way to check for the presence of non-condensable gases in the system, is to compare the pressure difference between the actual condensing pressure, read at the pressure gauge of the receiver and the saturated pressure corresponding to the temperature measured at the condenser outlet.

For example if 30°C is measured at the outlet of the condenser in an ammonia system, the related saturated temperature is 10.7 bar g and if the pressure gauge reading is 11.7 bar g then there is 1 bar difference and this is due to the presence of non-condensable gases.

Problems generated

The air tends to form a film over the condenser pipes isolating the heat transfer surface from the refrigerant in the condenser. The result is a reduction of the condenser capacity and thus an increase in the condensing pressure. The energy efficiency will then decline and depending on the condensing pressure, the potential for oil related problems would increase.

The capacity reduced in the condenser is a fact but is very hard to determine. Air purger manufacturers have provided some data, which indicates a 9-10 % capacity reduction for every bar of increased condensing pressure. If a more accurate calculation is required, ASHRAE gives some guidelines on how to estimate it as well as some examples of research undertaken with the results achieved. (HVAC Systems & Equipment Manual, Non-Condensable Gases).

Other manufacturers estimate the risks and the associated costs rising from the compressor side. As the condensing pressure and discharge temperature increase, there will be higher risks to the bearings due to oil problems, as well as an increase in the running cost of a compressor. The cost estimation is related to the compressor type and size in the plant.

All in all the presence of non-condensable gases is as undesirable as unavoidable and air purging equipment is often used.

Air purging systems

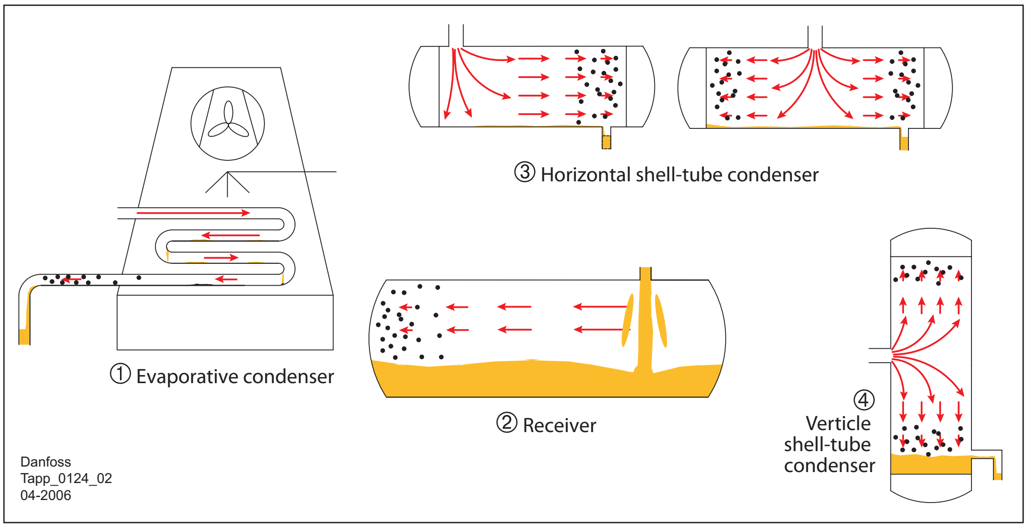
The air or non-condensable gases can be purged out of the system manually. This is performed by maintenance personnel and may lead to excessive refrigerant losses.

Another way of purging is called refrigerated purging: gases coming from the sampling points are cooled down inside a chamber with a cooling coil in order to condense the refrigerant and return it back to the system. The gases then left in the chamber should be purged out to the atmosphere. The idea of cooling down and condensation is to reduce the amount of refrigerant released.

The refrigerant used for the cooling coil could be the same as the refrigeration plant; it can also be another different refrigerant.

Location for purge connection is quite difficult and depends on the system and condenser type. Below are some examples of purge points. In the picture, the arrows in the condenser coils and the vessels represent the flow velocities. The length of arrow decreases as the velocity decreases.

The air accumulation is shown by the black dots. These places with high content of air are where samples for purging should be taken.



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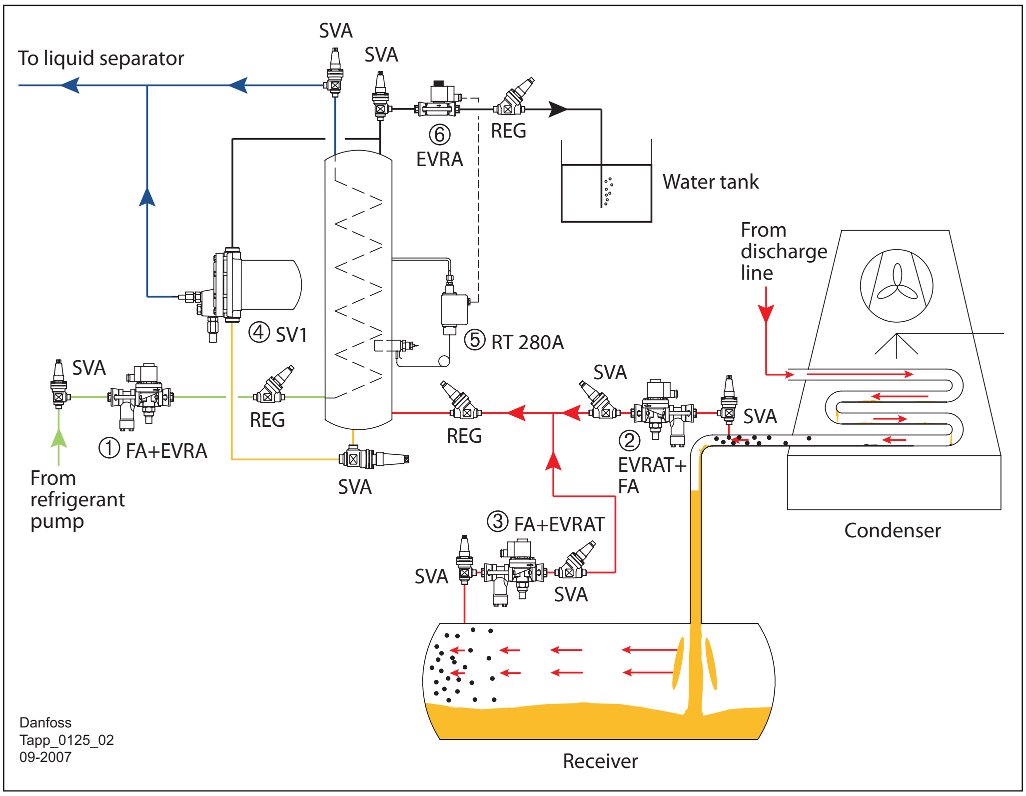
Application example 9.3.1: Automatic air purging system using the refrigerant from the plant



🟥 HP vapour refrigerant
🟧 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟩 LP liquid refrigerant
⬛ Air

① Solenoid valve
② Solenoid valve
③ Solenoid valve
④ Float valve
⑤ Pressure switch
⑥ Solenoid valve

Steps for air purging:

1. Energise the solenoid valve EVRA ①, so that low pressure liquid refrigerant enters the coil and cools down the refrigerant contained in the vessel.

2. Energise the solenoid valve EVRAT ② or ③. Gas refrigerant with accumulated air is drawn into the vessel, inside which refrigerant vapour condenses and air rises to the top of the vessel. The float valve SV1 ④ drains the condensed liquid refrigerant automatically.

3. With the air that accumulates in the top of the vessel, the total pressure inside the vessel compared with the saturated pressure of the liquid refrigerant increases. When this pressure reaches the setting on the pressure switch RT 280A ⑤ opens the solenoid valve EVRA ⑥ and purges some air from the vessel.

9.4
Heat Recovery System

The free heat from de-superheating and/or condensing in the condenser can be reclaimed if there are requirements for heating in the plant. These include heating of air in offices or shops, heating water for washing or processing, preheating boiler feed water, etc.

To make heat recovery an economic solution, it is important to ensure that the free heat and the heating requirements match in terms of timing, temperature level and heat flow. For example, for production of hot water, i.e. when heat at high temperature level is required, the de-superheating heat could be recovered; whilst for office heating, usually the recovery of all the condenser heat could be considered.

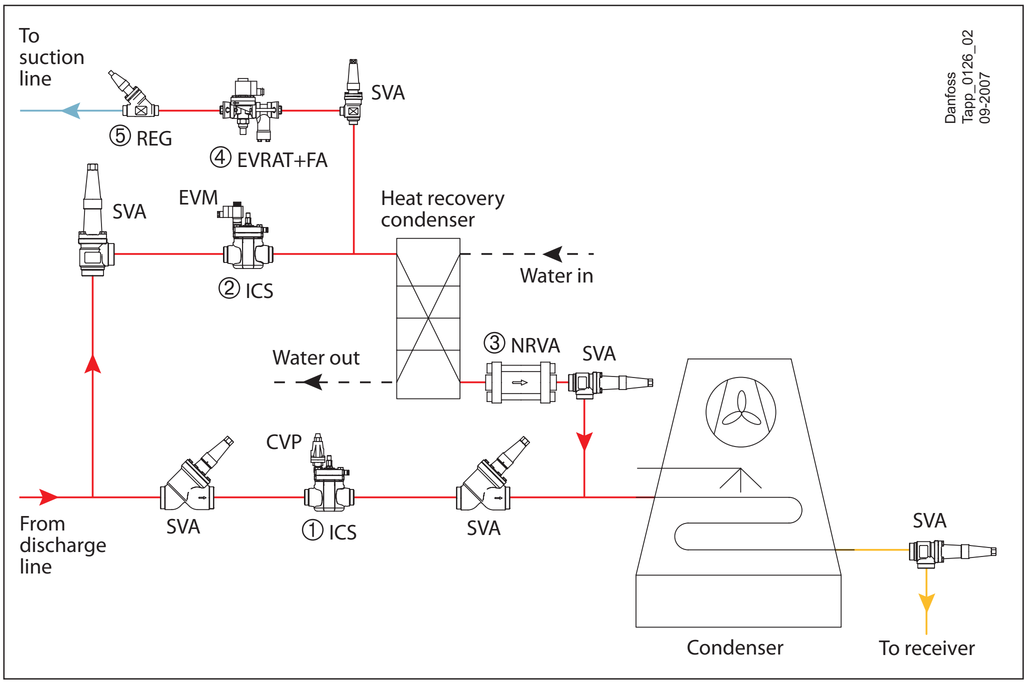
A well designed control system is crucial for trouble free and efficient operation of refrigeration systems with heat recovery.

The purpose of control is to coordinate heat recovery and refrigeration:

1. The basic function of refrigeration should be ensured whether the heat recovery is running or not. The condensing pressure should not be too high when heat recovery stops. Furthermore for DX systems, the condensing pressure should not be too low either (See section 3).
2. The requirements for heat recovery, e.g. the temperature and the heat flow, should be fulfilled.
3. Trouble free on/off control of the heat recovery loop according to the demand.

Heat recovery control needs very sophisticated design, which may vary from plant to plant. The following are some examples:

Application example 9.4.1: Control for series arrangement of recovery heat exchanger and condenser



🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 LP vapour refrigerant
⬛ Water

① Pressure regulator
② Solenoid valve
③ Check valve
④ Solenoid valve
⑤ Hand regulating valve

This heat recovery system is applicable to air as well as water.

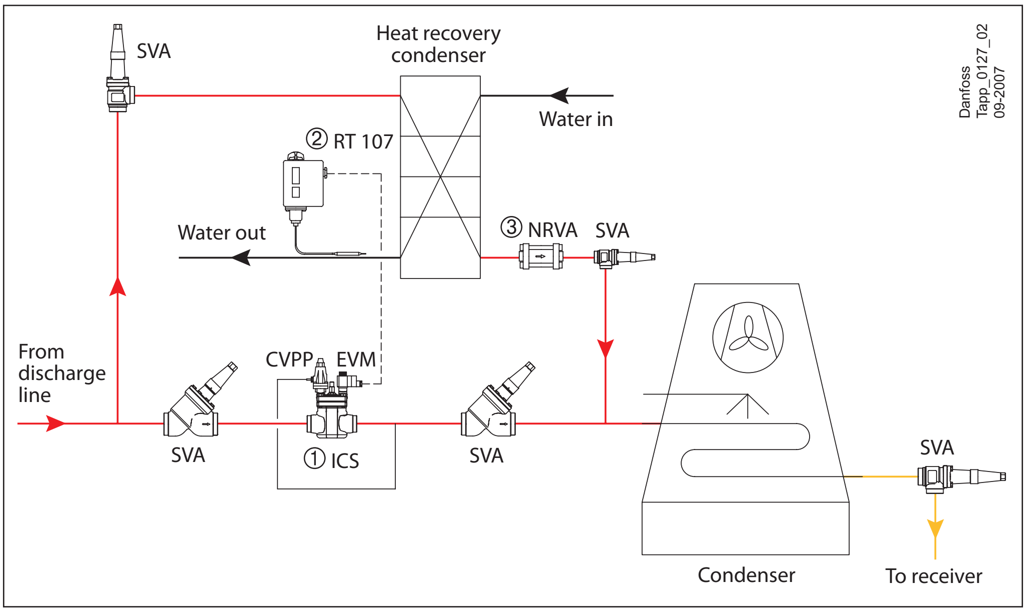
Refrigerating cycle without heat recovery
Hot gas from the discharge line is led directly to the main condenser through the pilot-operated servo valve ICS ① with constant pressure pilot CVP (HP). The check valve NRVA ③ prevents the flow back towards the heat recovery condenser.

Heat recovery cycle
The pilot operated servo valve ICS ② is controlled by the on/off switching of the pilot solenoid valve EVM, through a time clock, thermostat etc. Hot gas enters the recovery condenser.

ICS ① will normally close because of the increased condensing capacity and decreased discharge pressure. If the discharge pressure increases, constant pressure pilot CVP (HP) will open the servo valve ICS ① so that part of the hot gas can flow towards the main condenser.

In summertime the heat recovery condenser is idle for extended periods of time. To avoid the risk of accumulation of liquid in this condenser, a solenoid valve EVRA ④ and a regulating valve REG ⑤ ensure periodic evaporation of any condensate in the recovery condenser.

Application example 9.4.2: Control for series arrangement of recovery heat exchanger and condenser



🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
⬛ Water

① Differential pressure regulator
② Thermostat
③ Check valve

This heat recovery system is applicable to central refrigeration plant with several compressors.

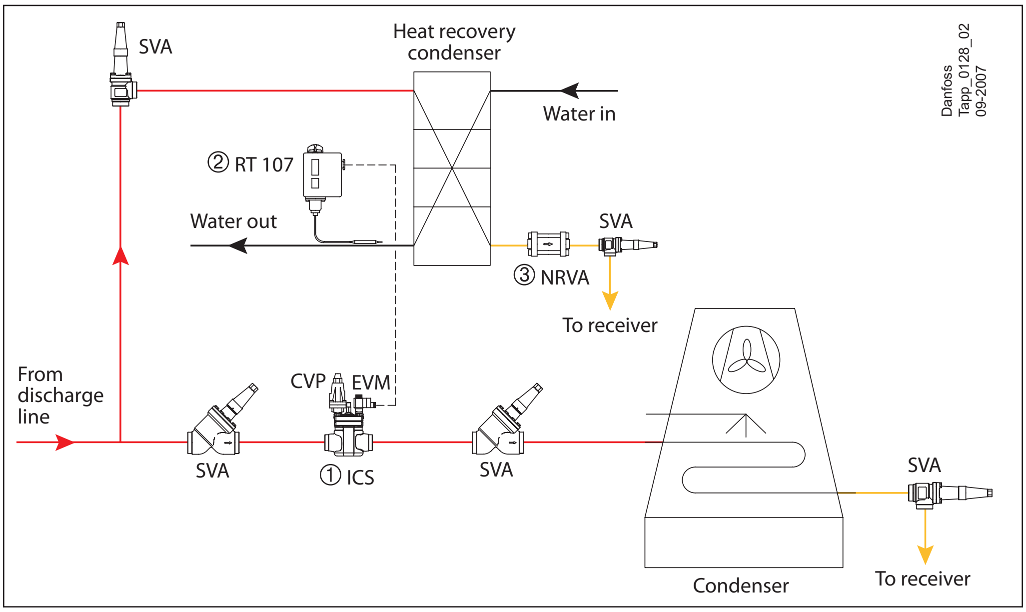
Provided only a small proportion of compressor capacity is used, all the discharge gas will pass through the recovery condenser and then to the main condenser.

The greater the amount of compressor capacity used, the higher becomes the pressure drop in the recovery condenser.

When this pressure drop exceeds the setting of differential pressure pilot CVPP(HP) on the servo valve ICS ① partially opens and excess pressure gas is led direct into the main condenser.

When the desired water or air temperature has been achieved by means of the heat recovery condenser, the thermostat RT 107 ② activates the on/off pilot EVM, and the servo valve ICS ① will open fully.

Application example 9.4.3: Control for parallel arrangement of recovery heat exchanger and condenser



🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
⬛ Water

① Pressure regulator and solenoid valve
② Thermostat
③ Check valve

This heat recovery system is applicable to systems with several compressors - e.g. for the heating of central heating water.

In normal operation the servo valve ICS ① is kept open by the on/off switching of the solenoid valve pilot EVM, activated by an external control connected to the thermostat RT 107.

In wintertime, when the heating demand necessitates heat recovery, the solenoid valve pilot EVM is closed, which in turn causes the servo valve ICS ① to close. If the condensing pressure exceeds the setting of the constant pressure pilot CVP (HP), the servo valve ICS 3 will open and excess pressure gas will be led to the main condenser.

The check valve NRVA prevents flow back of refrigerant to the recovery condenser.

9.5
Reference Documents

For an alphabetical overview of all reference documents please go to page 104

Technical Leaflet / Manual

Type	Literature no.
BSV	RD.7F.B
CVP	PD.HN0.A
DCR	PD.EJ0.A
EVM	PD.HN0.A
EVRA(T)	PD.BM0.B
ICS	PD.HS0.A
NRVA	RD.6H.A

Type	Literature no.
REG	PD.KM0.A
RT 107	RD.5E.A
SGR	PD.EK0.A
SNV	PD.KB0.A
SVA	PD.KD0.A
SV 1-3	PD.GE0.B
SV 4-6	PD.GE0.D

Product instruction

Type	Literature no.
BSV	RI.7F.A
CVP	PI.HN0.C
DCR	PI.EJ0.B
EVM	RI.3X.H
EVRA(T)	RI.3D.A
ICS 25-65	PI.HS0.A
ICS 100-150	PI.HS0.B
NRVA	RI.6H.B

Type	Literature no.
REG	PI.KM0.A
RT 107	
SGR	PI.EK0.A
SNV	PI.KB0.A
SVA	PI.KD0.B
SV 1-3	PI.GE0.C
SV 4-6	RI.2B.B

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10.

Using CO$_2$ in refrigeration systems

The use of carbon dioxide (CO$_2$) in refrigeration systems is not new. Carbon dioxide was first proposed as a refrigerant by Alexander Twining (ref. [1]), who mentioned it in his British patent in 1850. Thaddeus S.C. Lowe experimented with CO$_2$ for mililtary balloons, but he also designed an ice machine with CO$_2$ in 1867. Lowe also developed a machine onboard a ship for transportation of frozen meat.

From the literature it can be seen that CO$_2$ refrigerant systems were developed during the following years and they were at their peak in the 1920's and early 1930's. CO$_2$ was generally the preferred choice for use in the shipping industry because it was neither toxic nor flammable, whilst ammonia (NH$_3$ or R717) was more common in industrial applications (ref. [2]). CO$_2$ disappeared from the market, mainly because the new "miracle refrigerant" Freon had become avaialble and was marketed very successfully.

Ammonia has continued to be the dominant refrigerant for industrial refrigeration applications over the years. In the 1990's there was renewed interest in the advantages of using CO$_2$, due to ODP (Ozone Depletion Potential) and GWP (Global Warming Potential), which has restricted the use of CFCs and HFCs and imposed limits on refrigerant charges in large ammonia systems.

CO$_2$ is classified as a natural refrigerant, along iwth ammonia, hydrocarbons such as propane and butane, and water. All of these refrigerants have their respective disadvantages. Ammonia is toxic, hydrocarbons are flammable, and water has limited application potential. By contrast, CO$_2$ is non-toxic and non-flammable.

CO$_2$ differs from other common refrigerants in many aspects and has some unique properties. Technical developments since 1920 have removed many of the barriers to using CO$_2$, but users must still be highly aware of its unique properties, and take the necessary precautions to avoid problems in their refrigeration systems.

The chart in figure 1 shows the pressure/temperature curves of CO$_2$, R134a and ammonia. Highlights of CO$_2$'s properties relative to the other refrigerants include:

- Higher operating pressure for a given temperature
- Narrower range of operating temperatures
- Triple point at a much higher pressure
- Critical point at a very low temperature.

While the triple point and critical point are normally not important for common refrigerants, CO$_2$ is different. The triple point is relatively high at 5.2 bar [75.1 psi], but more importantly, higher than normal atmospheric pressure.
This can create problems unless suitable precautions are taken. Also, CO$_2$'s critical point is very low: 31.1°C [88.0°F], which strongly affects design requirements.

In the table below. various properties of CO$_2$ are compared with those of R134a and ammonia.

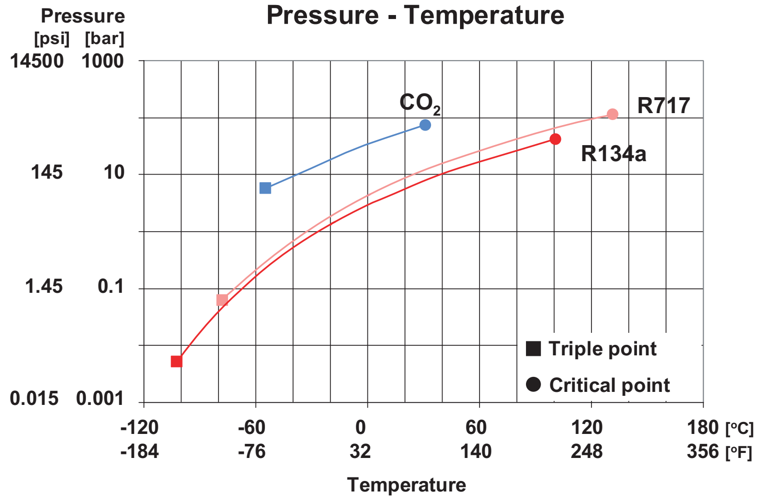


Figure 10.1

Refrigerant			R 134a		NH$_3$		CO$_2$	
Natural substance			NO		YES		YES	
Ozone Depletion Potential (ODP)*			0		0		0	
Global Warming Potential (GWP)*			1300		-		1	
Critical point	bar	[psi]	40.7	[590]	113	[1640]	73.6	[1067]
	°C	[°F]	101.2	[214]	132.4	[270]	31.1	[87.9]
Triple point	bar	[psi]	0.004	[0.06]	0.06	[0.87]	5.18	[75.1]
	°C	[°F]	–103	[–153]	–77.7	[–108]	–56.6	[–69.9]
Flammable or explosive			NO		(YES)		NO	
Toxic			NO		YES		NO	

10.1
CO_2 as a refrigerant

CO_2 may be employed as a refrigerant in a number of different system types, including both subcritical and supercritical. For any type of CO_2 system, both the critical point and the triple point must be considered.

The classic refrigeration cycle we are all familiar with is subcritical, i.e., the entire range of temperatures and pressures are below the critical point and above the triple point.
A single-stage subcritical CO_2 system is simple, but it also has disadvantages because of its limited temperature range and high pressure (figure 10.1.2).

Transcritical CO_2 systems are at presently only of interest for small and commercial applications, e.g., mobile air conditioning, small heat pumps, and supermarket refrigeration, but not for industrial systems (figure 10.1.3). Transcritical systems are not described in this handbook.

Operating pressures for subcritical cycles are usually in the range 5.7 to 35 bar [83 to 507 psi], corresponding to –55 to 0°C [–67 to 32°F]. If the evaporators are defrosted using hot gas, then the operating pressure is approximately 10 bar [145 psi] higher.

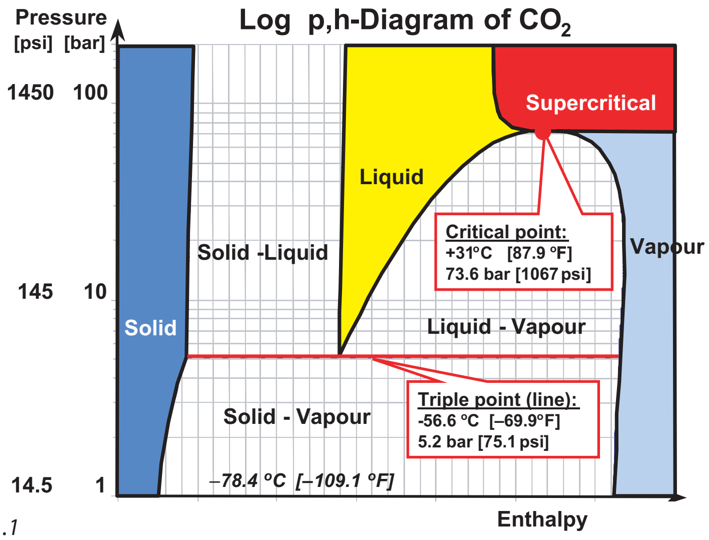


Figure 10.1.1

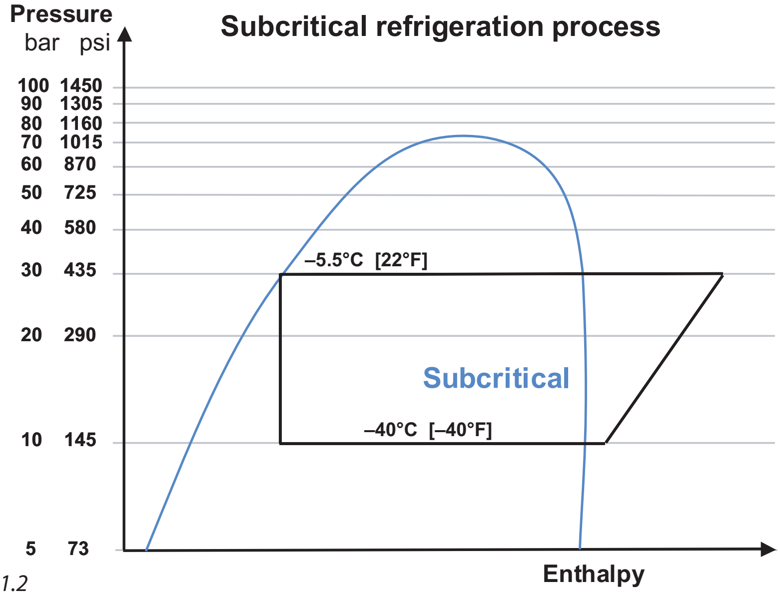


Figure 10.1.2

10.1
CO_2 as a refrigerant
(Continued)

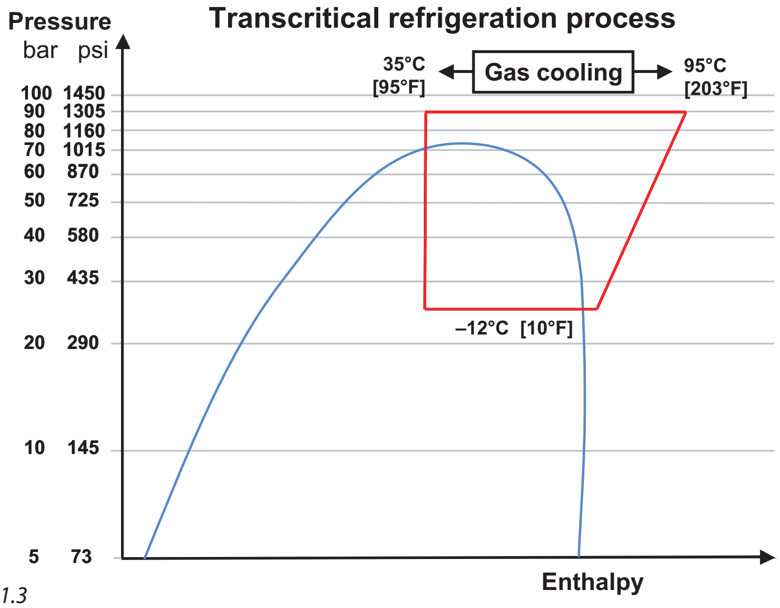


Figure 10.1.3

CO_2 is most commonly used in cascade or hybrid system designs in industrial refrigeration, because its pressure can be limited to such extent that commercially available components like compressors, controls and valves can be used.

CO_2 cascade systems can be designed in different ways, e.g., direct expansion systems, pump circulating systems, CO_2 in volatile secondary “brine” systems, or combinations of these.

10.2
CO_2 as a refrigerant in industrial systems

Figure 10.2.1 shows a low temperature refrigerating system –40°C [–40°F] using CO_2 as a phase change refrigerant in a cascade system with ammonia on the high-pressure side.

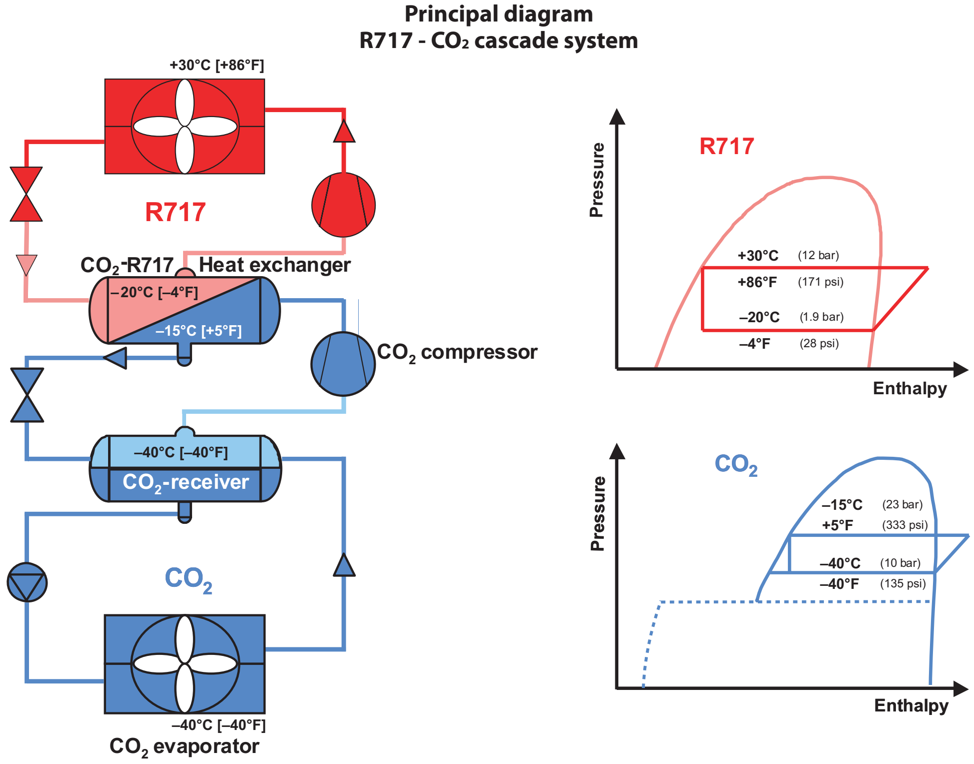


Figure 10.2.1

10.2
CO_2 as a refrigerant in industrial systems
(Continued)

Principal diagram
R717 - CO_2 cascade system with CO_2 hot gas defrosting

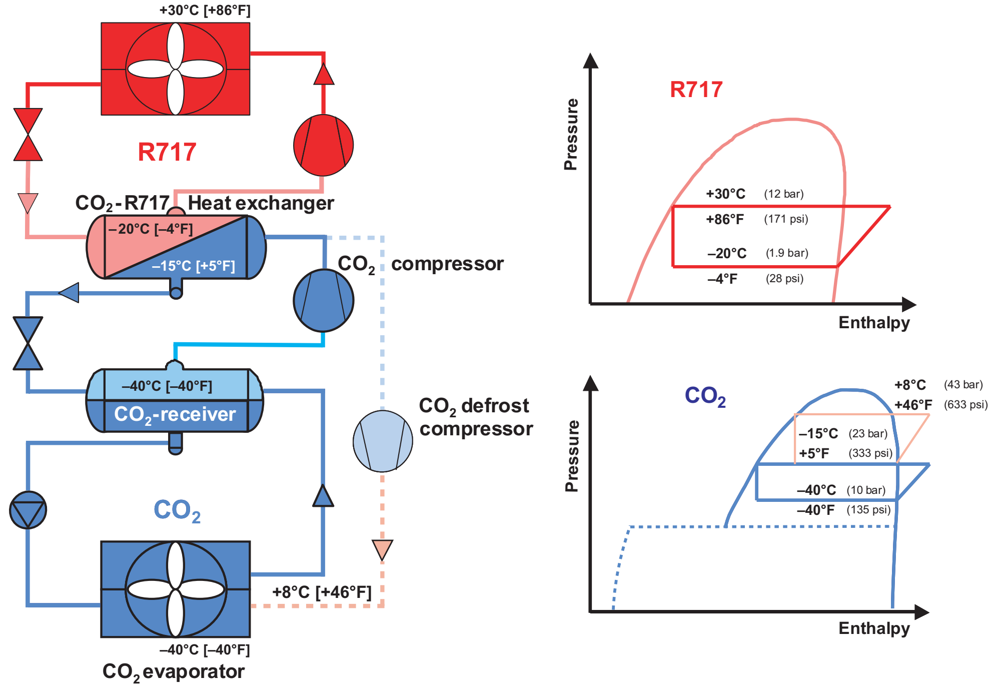


Figure 10.2.2

The CO_2 system is a pump circulating system where the liquid CO_2 is pumped from the receiver to the evaporator, where it is partly evaporated, before it returns to the receiver. The evaporated CO_2 is then compressed in a CO_2 compressor, and condensed in the CO_2-NH_3 heat exchanger. The heat exchanger acts as an evaporator in the NH_3 system. Compared to a traditional ammonia system, the ammonia charge in the above mentioned cascade system can be reduced by a factor of approximately 10.

Figure. 10.2.2 shows the same system as in figure 10.2.1, but includes a CO_2 hot gas defrosting system.

Principal diagram
R717 - CO_2 brine system

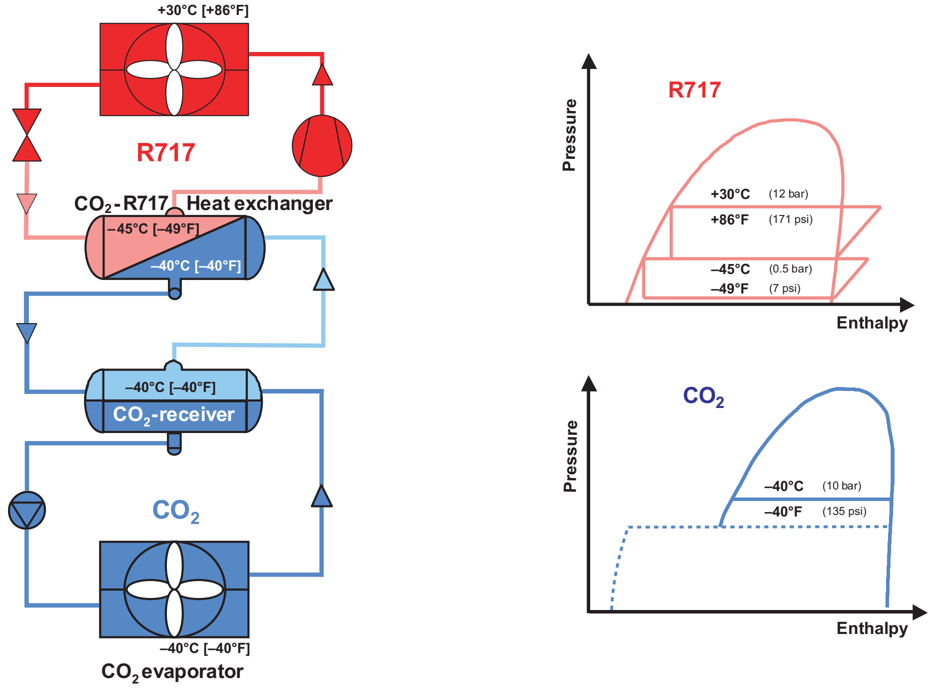


Figure 10.2.3

10.2
CO_2 as a refrigerant in industrial systems
(Continued)

Principal diagram
CO_2 cascade system with 2 temperature levels
(e.g. supermarket refrigeration)

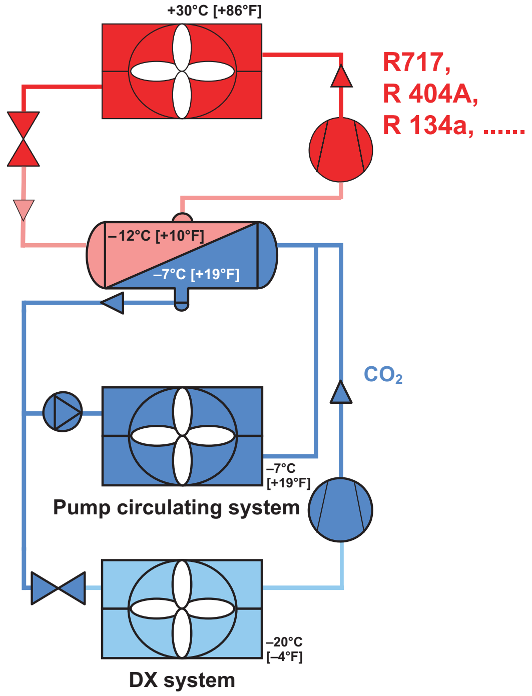


Figure 10.2.4

Figure 10.2.3 shows a low temperature refrigerating system –40°C [–40°F] using CO_2 as a "brine" system with ammonia on the high-pressure side.
The CO_2 system is a pump circulating system, where the liquid CO_2 is pumped from the receiver to the evaporator. Here it is partly evaporated, before it returns to the receiver.

The evaporated CO_2 is then condensed in the CO_2- NH_3 heat exchanger. The heat exchanger acts as an evaporator in the NH_3 system.
Figure 10.2.4 shows a mixed system with flooded and DX-system, e.g. for a refrigeration system in a supermarket, where 2 temperature levels are required

10.3
Design pressure

When determining the design pressure for CO_2 systems, the two most important factors to consider are:

- Pressure during *stand still*
- Pressure required during defrosting

Importantly, without any pressure control, at *stand still*, i.e., when the system is turned off, the system pressure will increase due to heat gain from the ambient air. If the temperature were to reach 0°C [32°F], the pressure would be 34.9 bar [505 psi] or 57.2 bar [830 psi] @ 20°C [68°F]. For industrial refrigeration systems, it would be quite expensive to design a system that can withstand the equalizing pressure (i.e., saturation pressure corresponding to the ambient temperature) during *stand still*. Therefore, installing a small auxiliary condensing unit is a common way to limit the maximum pressure during *stand still* to a reasonable level, e.g., 30 bar [435 psi].

With CO_2, many different ways of defrosting can be applied (e.g., natural, water, electrical, hot gas). Hot gas defrosting is the most efficient, especially at low temperatures, but also demands the highest pressure. With a design pressure of 52 bar-g [754 psig], it is possible to reach a defrosting temperature of approx. 10°C [50°F].

The saturated pressure at 10°C [50°F] is 45 bar [652 psi]. By adding 10% for the safety valves and approximately 5% for pressure peaks, the indicated maximum allowable working pressure would be ~ 52 barg [~754 psig] (figure 10.3.2 & 10.3.3).

10.3

Design pressure

(Continued)

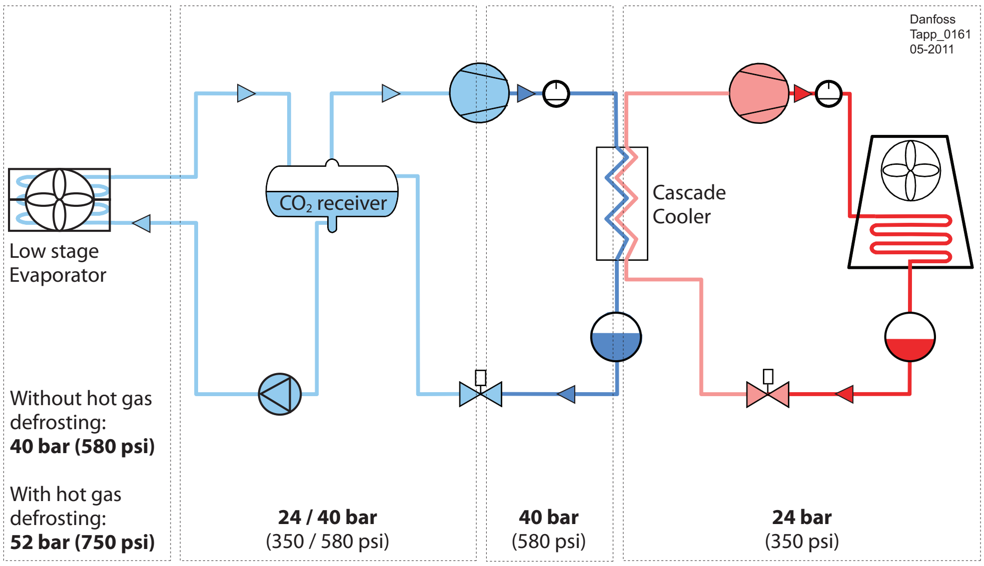


Figure 10.3.1 - CO_2/NH_3 cascade system - Typically used design pressures

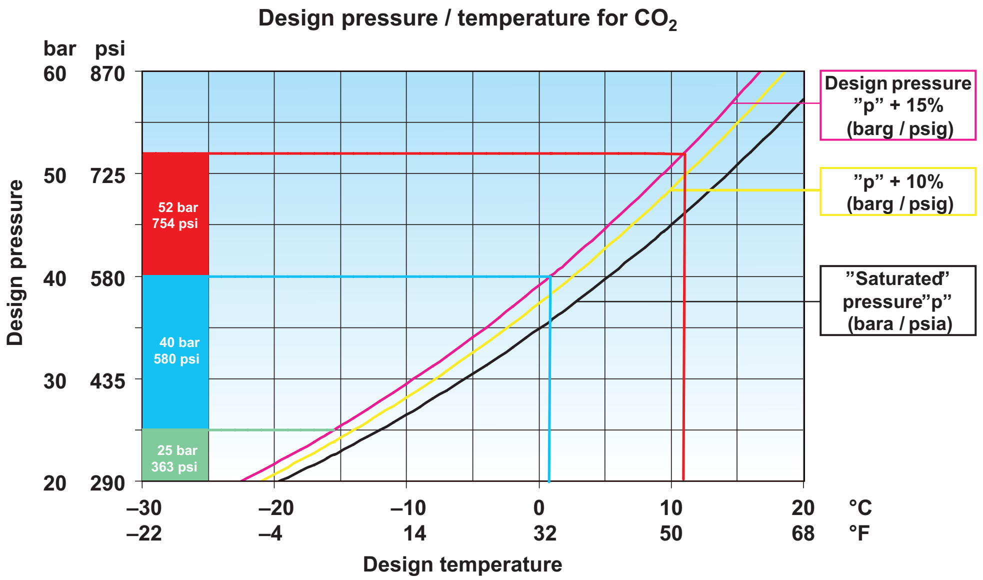


Figure 10.3.2

Practical limit: $PS \geq P_{saturated} + 15\%$

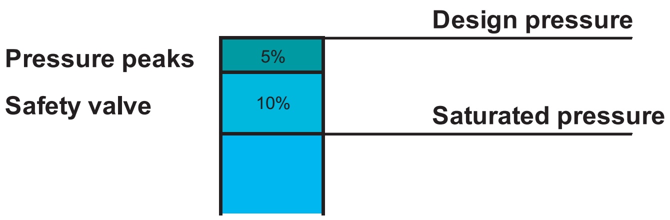


Figure 10.3.3

10.4 Safety

CO_2 is an odourless, colourless substance classified as a non-flammable and non-toxic refrigerant, but even though all the properties seem very positive, CO_2 also has some disadvantages.

Due to the fact that CO_2 is odourless, it is not self-alarming if leaks occur (ref. [6]).

CO_2 is heavier than air, so it sinks to the ground or floor level. This can create dangerous situations, especially in pits or confined spaces. CO_2 can displace oxygen so much that the resulting mixture is lethal. The relative density of CO_2 is 1.529 (air=1 @ 0°C [32°F]). This risk requires special attention during design and operation. Leak detection and / or emergency ventilation are always necessary.
Compared to ammonia, CO_2 is a safer refrigerant. The TLV (threshold limit value) is the maximum concentration of vapour CO_2 in air, which can be tolerated over an eight-hour shift for 40 hours a week. The TLV safety limit is 25 ppm for ammonia and 5000 ppm (0.5%) for CO_2.

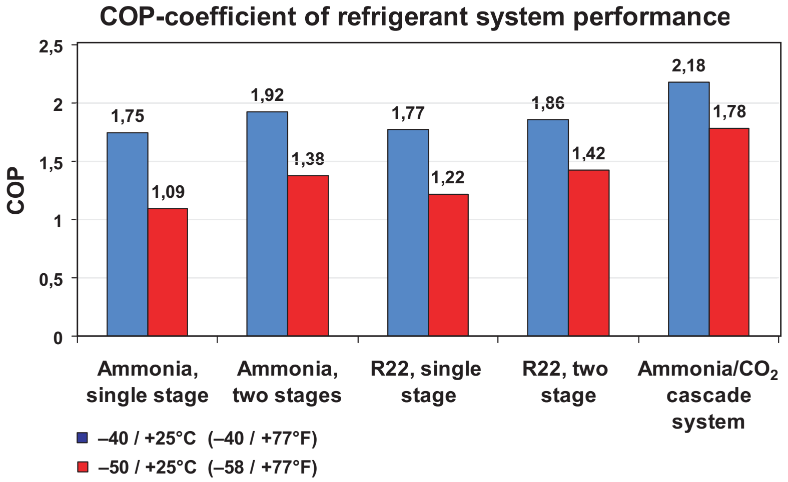
Approx. 0.04% CO_2 is present in the air.
With higher concentration, some adverse reactions are reported:

2%	50% increase in breath rate
3%	100% increase in breath rate
5%	300% increase in breath rate
8-10%	Natural respiration is disrupted and breathing becomes almost impossible. Headache, dizziness, sweating and disorientation.
> 10%	Can lead to loss of consciousness and death.
> 30%	Quickly leads to death.

10.5 Efficiency

In CO_2- NH_3 cascade systems it is necessary to use a heat exchanger. Using heat exchangers reduces system efficiency, due to the necessity of having a temperature difference between the fluids. However, compressors running with CO_2 have a better efficiency and heat transfer is greater. The overall efficiency of a CO_2- NH_3 cascade system is not reduced when compared to a traditional NH_3 system (figure 10.5.1 & ref. [3]).

Example:



Source: IIAR - Albuquerque, New Mexico 2003, P.S Nielsen & T.Lund
Introducing a New Ammonia/CO_2 Cascade Concept for Large Fishing Vessels

Figure 10.5.1

10.6 Oil in CO_2 systems

In CO_2 systems with traditional refrigeration compressors, both miscible and immiscible oil types are used (see the table below).

For immiscible lubricants, such as polyalphaolefin (PAO), the lubricant management system is relatively complicated. The density of PAO is lower than the density of the liquid CO_2. The lubricant therefore floats on top of the refrigerant, making it more difficult to remove than in ammonia systems. Also, to avoid fouling evaporators, compressor oil separation with non- miscible oils must be highly effective; basically, a virtually oil-free system is desirable.

With miscible lubricants, such as polyol ester (POE), the oil management system can be much simpler. POE oils have high affinity with water, so the challenge when using POE is to ensure the stability of the lubricant.

In *volatile brine* systems using CO_2 as a secondary refrigerant, and in recirculating systems with oil free compressors, no oil is present in the circulated CO_2. From an efficiency point of view, this is optimum because it results in good heat transfer coefficients in the evaporators. However, it requires that all valves, controls and other components can operate *dry*.

CO_2 and oil

Oil type	**PAO** **Poly-alpha-olefin oil** *(synthetic oil)*	**POE** **Polyol ester oil** *(ester oil)*
Solubility	Low (immiscible)	High (miscible)
Hydrolysis	Low	High affinity to water
Oil separation system	**Special requirements:** ● High filtration performance ● Multistage coalescing filters ● Active carbon filter	**No special requirements** (System requirements like HCFC/HFC)
Oil return system	**Special requirement:** ● Oil drain from low temperature receiver (oil density lower than CO_2 - opposite of NH_3)	**Simple** (System requirements like HCFC/HFC)
Challenge	● Oil separation and return system ● Long term oil accumulation in e.g. evaporators	● High affinity to water ● Long term stability of oil ● "Clean" refrigerant system required

10.6
Oil in CO_2 systems
(Continued)

The oil concentration in the pump separator increases gradually because the oil cannot be directly sucked back to the compressor with the gas. If the oil concentration in the evaporator becomes too high, the adhesive forces will make the oil "stick" to the heat transferring surfaces. This reduces the capacity of the plant.

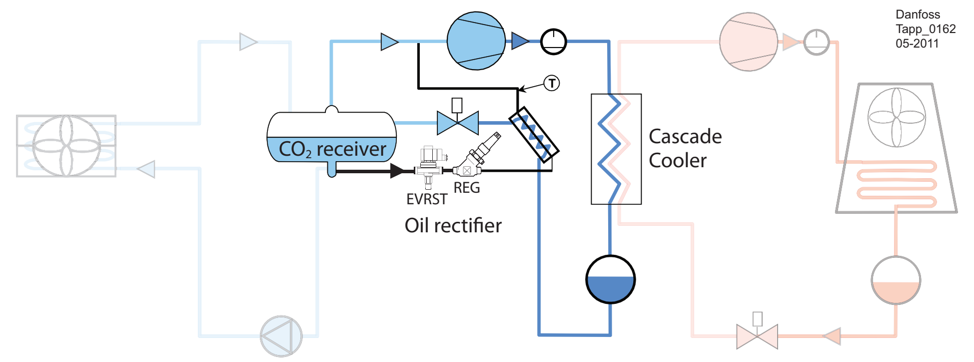
By constantly boiling of part of the oil/CO_2 liquid from the pump separator, the oil concentration in the plant remains low. During the boiling process in the oil rectifier, the CO_2 liquid is sub-cooled and the oil/CO_2 liquid mixture from the CO_2 separator is boiled off and sucked back to the CO_2 compressor.

Pure CO_2 liquid must never be returned back to compressor as this will damaged the compressor, therefor it is imperative that the CO_2 at the heat exchanger outlet is superheated.

The superheat can be controlled by a REG valve fitted down streams of the solenoid valve.

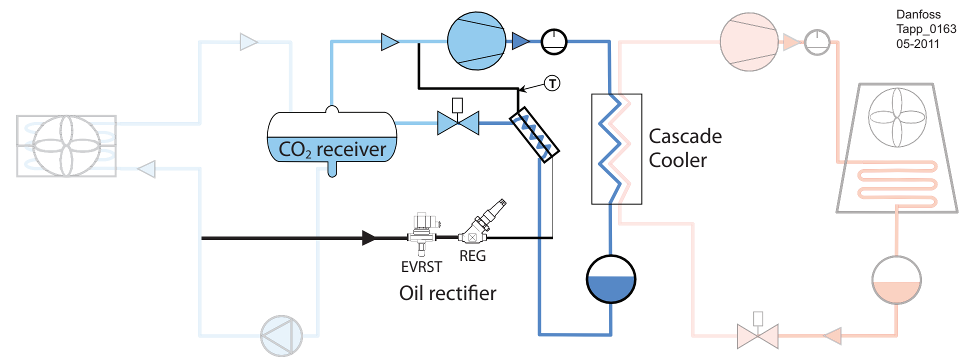
Example 10.6.1
Oil management system for systems with soluble (miscible) oils

Oil recovery system connected to the stand pipe of the CO_2 separator



Example 10.6.2
Oil management system for systems with soluble (miscible) oils

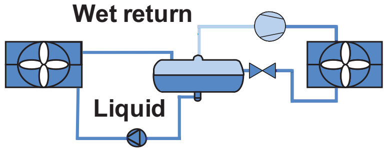
Oil recovery system connected downstream of the liquid pump



10.7
Comparison of component requirements in CO_2, ammonia and R134a systems

Compared to ammonia and R134a, CO_2 differs in many respects. The following comparison illustrates this fact; to allow an "true" comparison, operating conditions such as evaporating temperature, condensing temperature, are kept constant.

Comparison of pipe cross section area
Wet return / Liquid lines

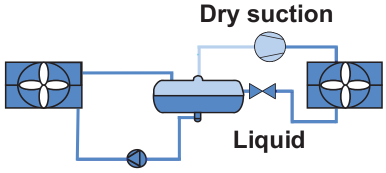


	Refrigerant			R 134a		R 717		CO_2	
	Capacity	kW	[TR]	250	[71]	250	[71]	250	[71]
"Wet return" line	ΔT	K	[F]	0.8	[1.4]	0.8	[1.4]	0.8	[1.4]
	Δp	bar	[psi]	0.0212	[0.308]	0.0303	[0.439]	0.2930	[4.249]
	Velocity	m/s	[ft/s]	11.0	[36.2]	20.2	[66.2]	8.2	[26.9]
				●		●		●	
	Diameter	mm	[inch]	215	[8.5]	133	[5.2]	69	[2.7]
	"Wet return" area	mm^2	[$inch^2$]	36385	[56.40]	13894	[21.54]	3774	[5.85]
"Liquid" line	Velocity	m/s	[ft/s]	0.8	[2.6]	0.8	[2.6]	0.8	[2.6]
				●		●		●	
	Diameter	mm	[inch]	61	[2.4]	36	[1.4]	58	[2.3]
	"Liquid" area	mm^2	[$inch^2$]	2968	[4.6]	998	[1.55]	2609	[4.04]
Total pipe cross section area	"Wet return" area	mm^2	[$inch^2$]	39353	[61.0]	14892	[23.08]	6382	[9.89]
Liquid cross section area			%	8		7		41	

L_{eqv} = 50 [m] / 194 [ft] - Pump circ.: n_{circ} = 3 - Evaporating temp.: TE = –40[°C] / –40[°F]

Table 1

Comparison of pipe cross section area
Dry suction / Liquid lines



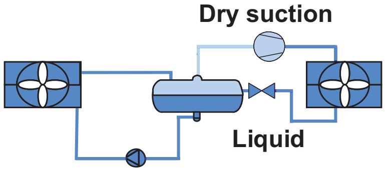
	Refrigerant			R 134a		R 717		CO_2	
	Capacity	kW	[TR]	250	[71]	250	[71]	250	[71]
"Dry suction" line	ΔT	K	[F]	0.8	[1.4]	0.8	[1.4]	0.8	[1.4]
	Δp	bar	[psi]	0.0212	[0.308]	0.0303	[0.439]	0.2930	[4.249]
	Velocity	m/s	[ft/s]	20.4	[67]	37.5	[123]	15.4	[51]
				●		●		●	
	Diameter	mm	[inch]	168	[6.6]	102	[4.0]	53	[2.1]
	"Dry suction" area	mm^2	[$inch^2$]	22134	[34.31]	8097	[12.55]	2242	[3.48]
"Liquid" line	Velocity	m/s	[ft/s]	0.8	[2.6]	0.8	[2.6]	0.8	[2.6]
				●		●		●	
	Diameter	mm	[inch]	37	[1.5]	21	[0.8]	35	[1.4]
	"Liquid" area	mm^2	[$inch^2$]	1089	[1.69]	353	[0.55]	975	[1.51]
Total pipe cross section area	"Dry suction + liquid" area	mm^2	[$inch^2$]	23223	[36.00]	8450	[13.10]	3217	[4.99]
Liquid cross section area			%	5		4		30	

L_{eqv} = 50 [m] / 194 [ft] - Evaporating temp.: TE = –40[°C] / –40[°F] - Condensing temp.: TE = –15[°C] / –5[°F]

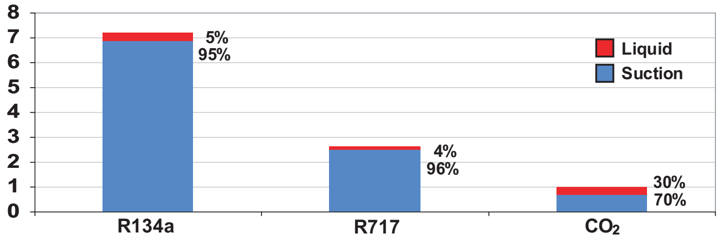
Table 2

10.7 Comparison of component requirements in CO_2, ammonia and R134a systems *(Continued)*

Comparison of pipe cross section area Dry suction / Liquid lines



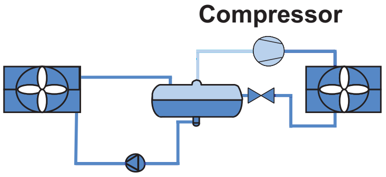
	Refrigerant			R 134a		R 717		CO_2	
	Capacity	kW	[TR]	250	[71]	250	[71]	250	[71]
"Dry suction" line	"Dry suction" area	mm²	[inch²]	22134	[34.31]	8097	[12.55]	2242	[3.48]
"Liquid" line	"Liquid" area	mm²	[inch²]	1089	[1.69]	353	[0.55]	975	[1.51]
Total pipe cross section area	"Dry suction + liquid" area	mm²	[inch²]	23223	[36.00]	8450	[13.10]	3217	[4.99]
Relative cross section area		-		7.2		2.6		1.0	
Liquid cross section area		%		5		4		30	
Vapour cross section area		%		95		96		70	



L_{eqv} = 50 [m] / 194 [ft] - Evaporating temp.: TE = –40[°C] / –40[°F] - Condensing temp.: TE = –15[°C] / –5[°F]

Table 3

Comparison of compressor displacement

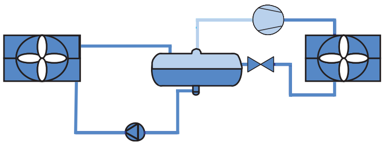


Refrigerant			R 134a		R 717		CO_2	
Refrigerant capacity	kW	[TR]	250	[71]	250	[71]	250	[71]
Required compressor displacement	m³/h	[ft³/h]	1628	[57489]	1092	[38578]	124	[4387]
Relative displacement	-	-	13.1		8.8		1.0	

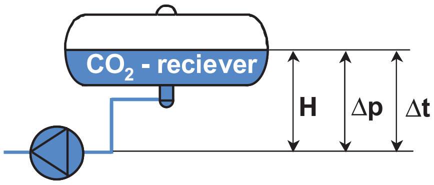
Evaporating temp.: TE = –40[°C] / –40[°F] - Condensing temp.: TE = –15[°C] / –5[°F]

Table 4

Comparison of pressure / subcooling produced in liquid risers



Refrigerant			R 134a		R 717		CO_2	
Hight of liquid riser "H"	m	[ft]	3	[9.8]	3	[9.8]	3	[9.8]
Pressure produced in liquid riser "Δp"	bar	[psi]	0.418	[6.06]	0.213	[2.95]	0.329	[4.77]
Subcooling produced in liquid riser "Δt"	K	[°F]	14.91	[26.8]	5.21	[9.4]	0.88	[1.6]



Evaporating temp.: TE = –40[°C] / –40[°F]

Table 5

Wet return lines in recirculation systems:

A comparison of pump circulating systems shows that for "wet return" lines, CO_2 systems require much smaller pipes than ammonia or R134a (table 3). In CO_2 "wet return" lines, the allowable pressure drop for an equivalent temperature drop is approximately 10 times higher than for ammonia or R134a wet return lines. This phenomenon is a result of the relatively high density of the CO_2 vapor. The above comparison is based on a circulating rate of 3. The results are slightly different if the circulating rate is optimized for each refrigerant.

Suction lines in dry expansion systems:

In the comparison of "dry suction" lines, the results are very nearly the same as in the previous comparison, in terms of both pressure drop and line size (table 2).

Liquid lines:

For both recirculating and dry expansion systems, calculated sizes for CO_2 liquid lines are much larger than those for ammonia, but only slightly larger than those for R134a (table 1 and 2). This can be explained by ammonia's much larger latent heat relative to CO_2 and R134a.
With reference to the table showing the relative liquid and vapor cross-sectional areas for the three refrigerants (table 1), the total cross-section area for the CO_2 system is approximately 2.5 times smaller than that of an ammonia system and approximately seven times smaller than that of R134a. This result has interesting implications for the relative installation costs for the three refrigerants.
Due to the relative small vapor volume of the CO_2 system and large volumetric refrigeration capacity, the CO_2 system is relatively sensitive to capacity fluctuations. It is therefore important to design the liquid separator with sufficient volume to compensate for the small vapor volume in the pipes.

The required compressor capacity for identical refrigeration loads is calculated for the three refrigerants (table 4). As can be seen, the CO_2 system requires a much smaller compressor than the ammonia or R134a systems.

For compressors of identical displacement, the capacity of the compressor capacity for CO_2 is 8.8 times greater than for ammonia and 13 times greater than for R134a.

The subcooling produced in a liquid riser of a given height "H" is calculated for the three refrigerants (table 5). The subcooling for the CO_2 liquid riser is much smaller than that for ammonia and R134a. This characteristic must be noted when designing CO_2 systems in order to prevent cavitation and other problems with liquid CO_2 pumps.

10.8
Water in CO_2 Systems

In ammonia systems, the oil is changed regularly and non-condensibles are purged frequently to minimise the accumulation of oil, water and solid contaminants that can cause problems.

Compared to ammonia systems, CO_2 is less sensitive, but if water is present, problems may occur. Some early CO_2 installations reported problems with control equipment, among other components. Investigations revealed that many of these problems were caused by water freezing in the system. Modern systems use filter driers to maintain the water content in the system at an acceptable level.

The acceptable level of water in CO_2 systems is much lower than with other common refrigerants. The diagram in figure 10.8.1 shows the solubility of water in both the liquid and vapor phases of the CO_2 liquid and vapor as a function of temperature. The solubility in the liquid phase is much higher than in the vapor phase. The solubility in the vapor phase is also known as the *dew point*.

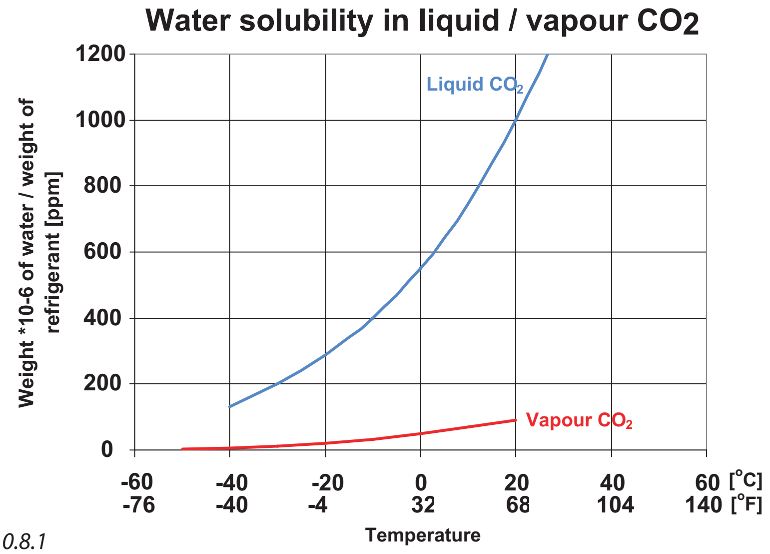


Figure 10.8.1

10.8
Water in CO_2 Systems
(Continued)

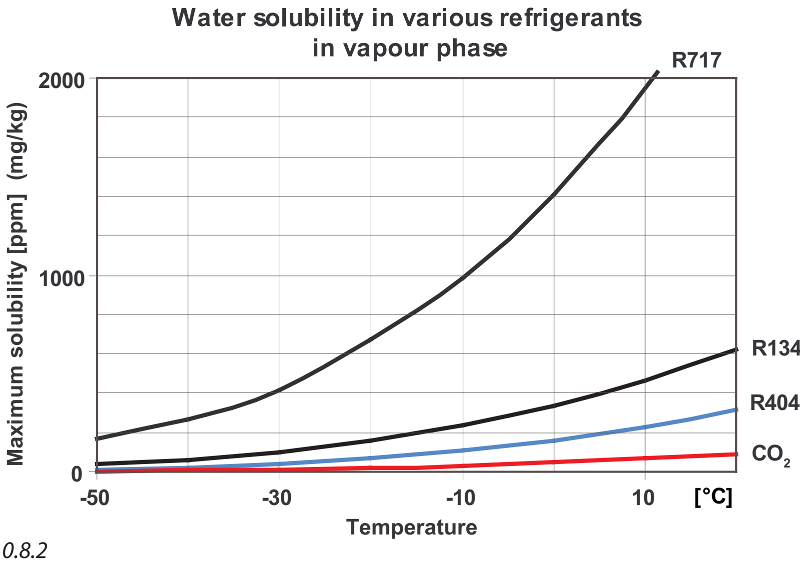


Figure 10.8.2

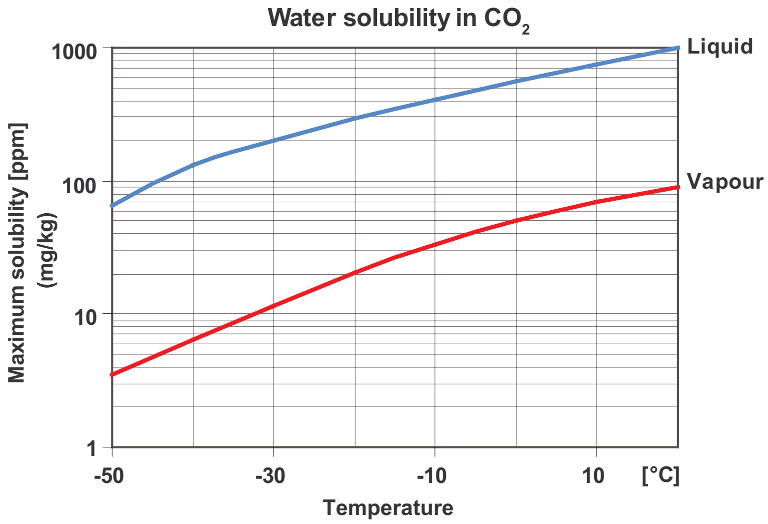


Figure 10.8.3

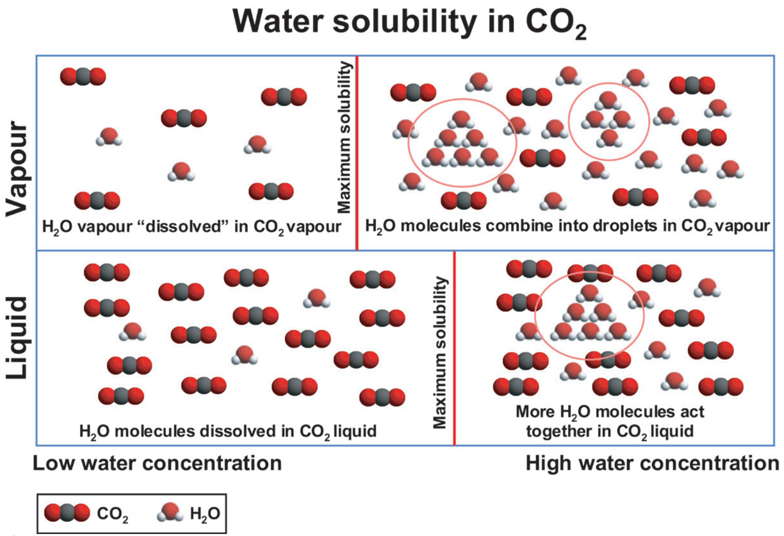


Figure 10.8.4

10.8
Water in CO_2 Systems
(Continued)

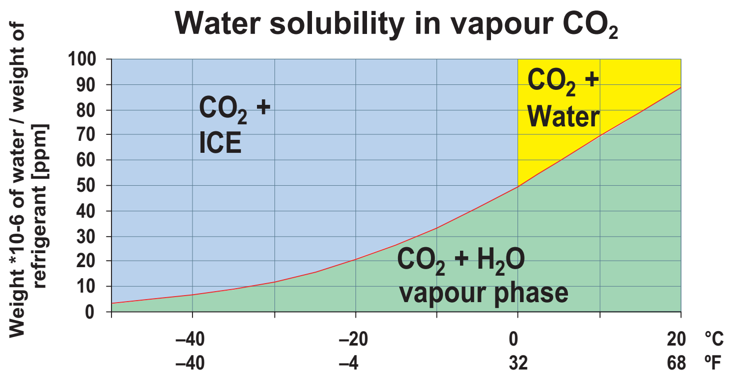


Figure 10.8.5

The diagram in figure 10.8.1 shows that the water solubility in CO_2 is much lower than for R134a or ammonia. At –20°C [–4°F], water solubility in the liquid phase is:

- 20.8 ppm for CO_2
- 158 ppm for R134a
- 672 ppm for ammonia

Below these levels, water remains dissolved in the refrigerant and does not harm the system. As illustrated in figure 10.8.4, water (H2O) molecules are dissolved if the concentration is lower than the maximum solubility limit, but they precipitate out of solution into droplets if the water concentration is higher than the maximum solubility limit.

If the water is allowed to exceed this limit in a CO_2 system, problems may occur, especially if the temperature is below 0°C. In this case, the water will freeze, and the ice crystals can block control valves, solenoid valves, filters and other equipment (figure 10.8.5). This problem is especially significant in flooded and direct expansion CO_2 systems, but less so in volatile secondary systems because less sensitive equipment is used.

Chemical reactions

It should be noted that the reactions described below do not occur in a well-maintained CO_2 system, where the water content is below the maximum solubility limit.

In a closed system such as a refrigeration system, CO_2 can react with oil, oxygen, and water, especially at elevated temperatures and pressures. For example, if the water content is allowed to rise above the maximum solubility limit, CO_2 can form carbonic acid, as follows (ref. [4] and [5]):

$CO_2 + H_2O \rightarrow H_2CO_3$

(CO_2 + water → carbonic acid)

In CO_2 production systems, where water concentrations can rise to high levels, it is well known that carbonic acid can be quite corrosive to several kinds of metals, but this reaction does not take place in a well-maintained CO_2 system, because the water content in the system is kept below the maximum solubility limit.

Water in vapor phase

If the water concentration is relatively high, CO_2 and water in vapor phase can react to form a CO_2 gas hydrate:

$CO_2 + 8\,H_20 \rightarrow CO_2(H_20)_8$

(CO_2 + water → hydrated CO_2)

The CO_2 gas hydrate is a large molecule and can exist above 0°C [32°F]. It can create problems in control equipment and filters, similar to the problems due to ice.

POE lubricant

Generally, esters such as POE react with water as follows:

$RCOOR' + H_2O \rightarrow R'OH + RCOOH$

(ester + water → alcohol + organic acid)

As shown, if water is present POE will react with water to form alcohol and an organic acid (carboxylic acid), which is relatively strong and may corrode the metals in the system. It is therefore essential to limit the water concentration in CO_2 systems if POE lubricants are used.

PAO lubricant

$2RCH_3 + 3\,O_2 \rightarrow 2\,H_20_2 + 2RCOOH$

(oil + oxygen → water + acid)

PAO lubricant is also called synthetic oil. Ordinarily, PAO is very stable. However, if sufficient free oxygen is present, such as might be available from corrosion in pipes, the oxygen will react with the lubricant to form carboxylic acid.

10.9 Removing water

Controlling the water content in a refrigeration system is a very effective way to prevent the above-mentioned chemical reactions.

In Freon systems, filter driers are commonly used to remove water, usually the type with a zeolite core. The zeolite has extremely small pores, and acts like a molecular sieve (figure 10.9.1).

Water molecules are small enough to pass through the sieve, and being very polar, are adsorbed on the zeolite molecules. R134a molecules are too large to penetrate the sieve. When the replaceable core is removed, the water goes with it.

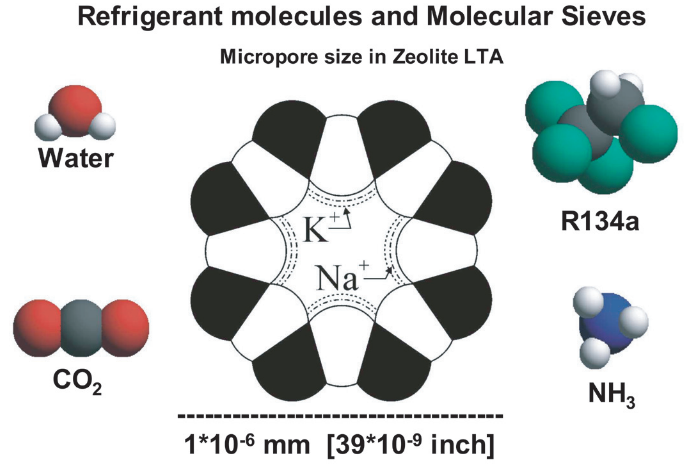


Figure 10.9.1

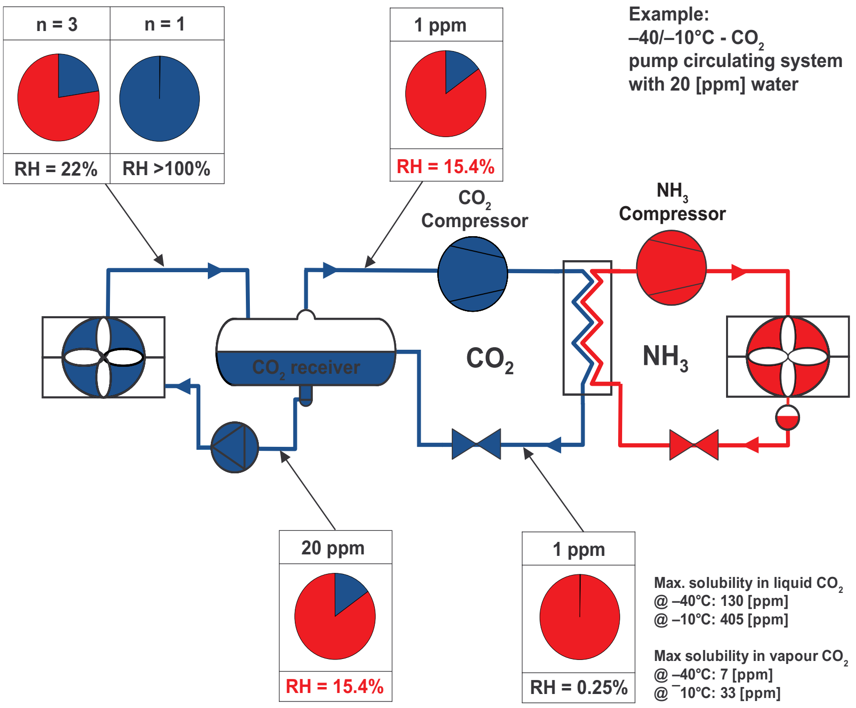


Figure 10.9.2

10.9
Removing water
(Continued)

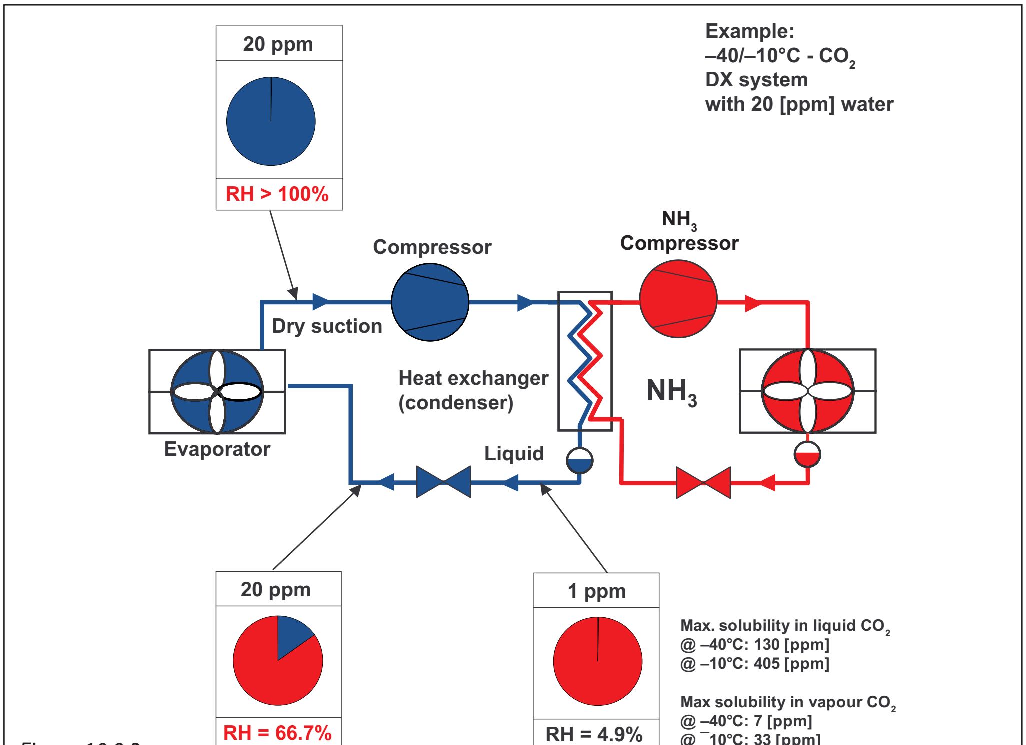


Figure 10.9.3

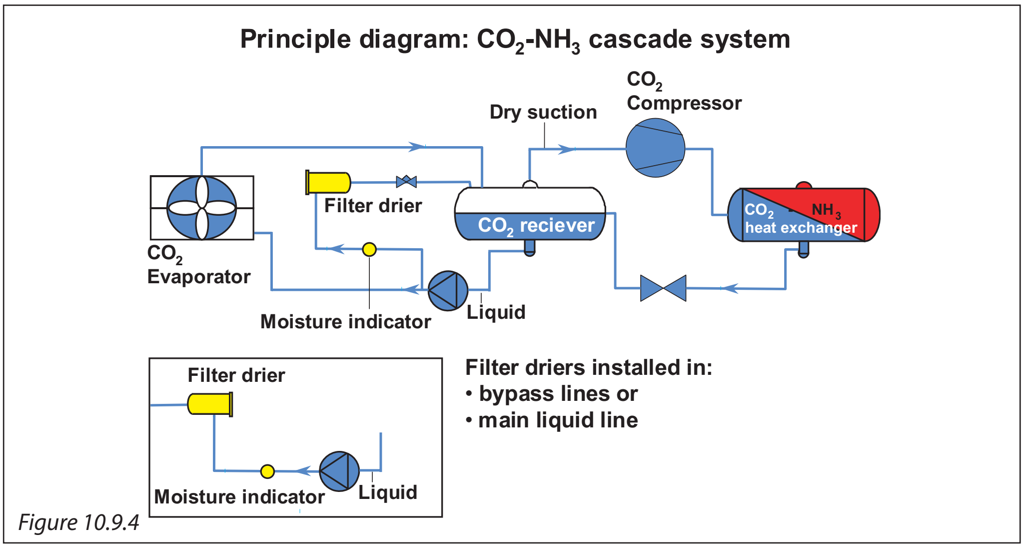


Figure 10.9.4

CO_2 is a non-polar molecule, so the removal process is different. Like water molecules, CO_2 molecules are small enough to pass through the molecular sieve. However, the water molecules adsorbed on the molecular sieve tend to displace the CO_2 molecules, due to the difference in polarity. Zeolite filter driers cannot be used in ammonia systems, because both water and ammonia are very polar. Even though the driers function differently in this respect in CO_2 systems, the efficiency is fairly good. The water retention capacity is approximately the same as in R134a systems.

The most effective location to detect and remove water is where the concentration is high. The solubility of water in CO_2 is much lower in the vapor phase than in the liquid phase, so more water can be transported in liquid lines.

Fig. 10.9.2 illustrates the variation of the relative humidity in a pump circulation system operating at –40°C. The illustration shows that the relative humidity is highest in the wet return line, and that it depends on the circulating rate. In a DX system the variation of the relative humidity differs, but also in this case the highest concentration is located in the suction line (fig. 10.9.3).

Taking advantage of this principle, moisture indicators and filter driers are typically installed in a liquid line or liquid bypass line from the receiver (figure 10.9.4). The moisture level indicated by these devices varies according to temperature and also by type of indicator. In figure 10.9.5, the indication level of a Danfoss SGN indicator is shown for liquid CO_2.

10.9
Removing water
(Continued)

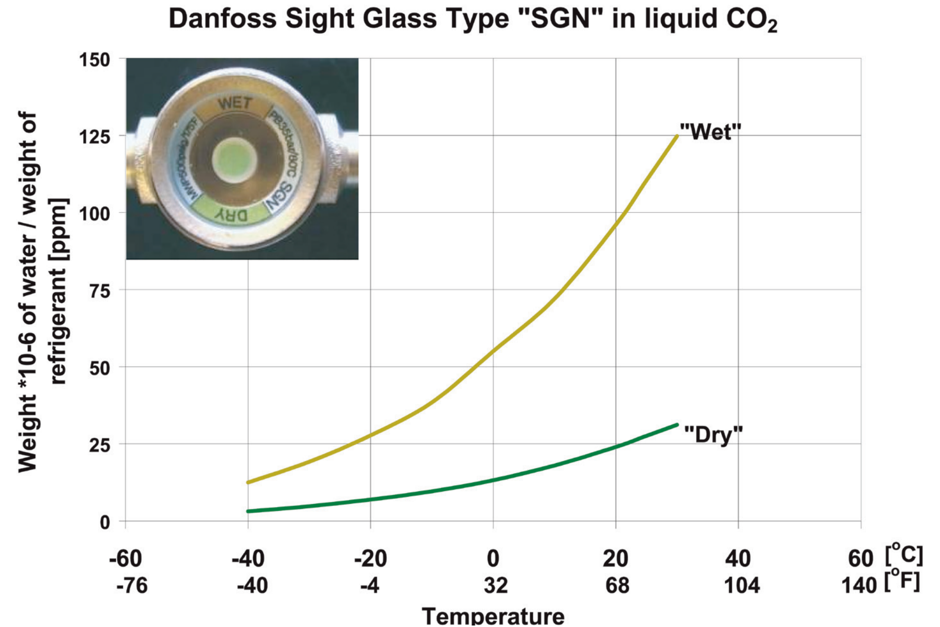


Figure 10.9.5

10.10
How does water enter a CO_2 system?

Unlike some ammonia systems, the pressure in CO_2 systems is always above atmospheric. However, water can still find its way into CO_2 systems.

Water may contaminate a CO_2 system through five different mechanisms:

1. Diffusion
2. Maintenance and repair activities
3. Incomplete water removal during installation/ commissioning
4. Water-contaminated lubricant charged into the system
5. Water-contaminated CO_2 charged into the system

Obviously, all these mechanisms should be avoided or minimized.

To illustrate a scenario in which water may contaminate a system, think of a contractor, who, believing CO_2 is a very safe refrigerant, thinks that it may be handled without following the normal ammonia safety requirements. He might open up the system to perform a repair. Once the system is opened up, air enters, and the moisture in the air condenses inside the piping. If the contractor does not evacuate the system very thoroughly, some water may be left in the system.

In another scenario, the contractor forgets that the lubricant used in the system, POE, has a high affinity for water, and leaves the cap off the container. After the POE is charged into the system, the water may start to cause problems in the system.

10.11
Miscellaneous features to be taken into consideration in CO_2 refrigeration systems

Safety valve

CO_2's particularly high triple point can cause solid CO_2 to form under certain conditions. Figure 22 shows the expansion processes occurring in pressure relief valves starting at three different conditions. If the set pressure of a pressure relief valve in the vapor phase is 35 bar [507 psi] or less, e.g., the rightmost line, the pressure in the relief line will pass through the triple point at 5.2 bar [75.1 psi]. Once below the triple point, the CO_2 will be pure vapor.

CO_2 expansion - phase changes
Safety valves

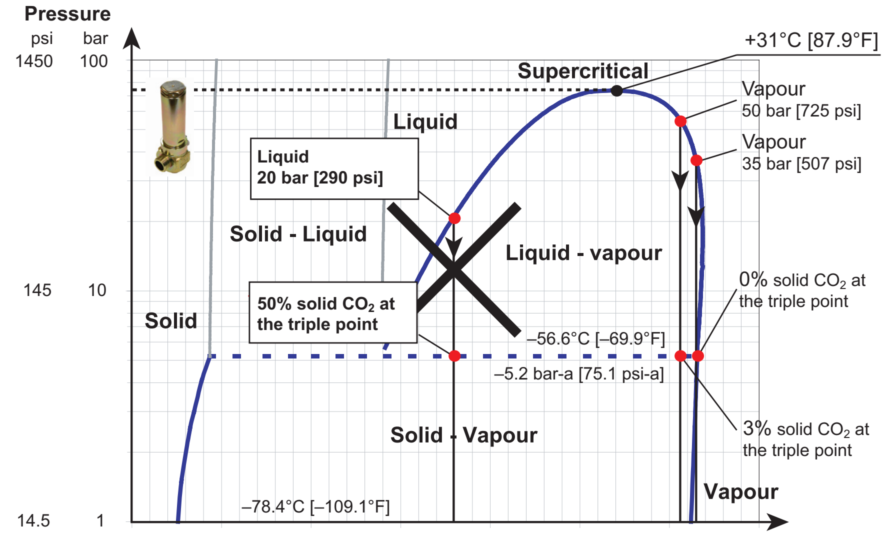


Figure 10.11.1

CO_2 expansion - phase changes
Cleaning filters / charging CO_2

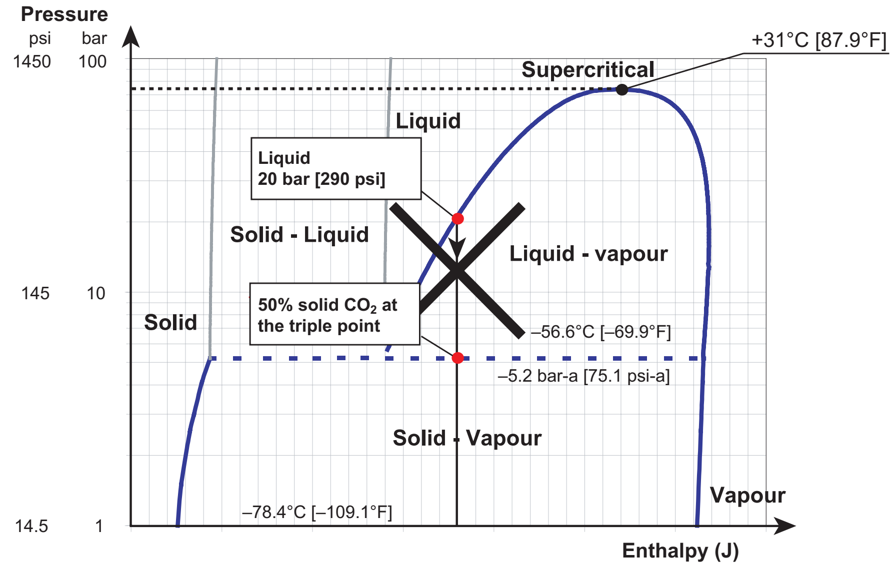


Figure 10.11.2

If the set pressure of a safety valve in the vapor phase is 50 bar [725 psi], e.g., the middle line, the relief line pressure will pass the triple point and 3% of the CO_2 will change into solid during relief. In a worst-case scenario (e.g., a long relief line with many bends), solid CO_2 may block this line. The most effective solution to this problem would be to mount the safety valve without an outlet line, and relieve the system directly to the atmosphere. The phase change of the CO_2 does not take place in the valve, but just after the valve, in this case, in the atmosphere.

If a pressure relief valve is set to relieve liquid at 20 bar [290 psi], the relief products would pass through the triple point, whereupon 50% of the CO_2 would change into solid upon further relief, subjecting the relief line to a high risk of blockage. Thus, to safely protect liquid lines against formation of dry ice, connect safety relief valves to a point in the system at a pressure higher than the triple point pressure of 5.2 bar [75.1 psi].

Charging CO_2

It is important to start up with CO_2 in the vapor phase, and continue until the pressure has reached 5.2 bar [75.1 psi]. It is therefore strongly recommended to write a procedure for charging a CO_2 system. One must be aware when charging a refrigerant system that until the pressure reaches the triple point, the CO_2 can only exist as a solid or vapor inside the refrigeration system. Also, the system will exhibit very low temperatures until the pressure is sufficiently raised (figure 10.11.2). For example, at 1 bar [14.5 psi], the sublimation temperature will be –78.4°C [–109°F].

Filter cleaning

The same considerations apply to cleaning liquid strainers or filters. Even though CO_2 is non-toxic, one cannot just drain the liquid outside the system. Once the liquid CO_2 contacts the atmosphere, the liquid phase will partly change into the solid phase, and the temperature will drop dramatically, as in the example described above. This sudden temperature drop is a thermal shock to the system materials, and can cause mechanical damage to the materials. Such a procedure would be considered to be a code violation because this equipment is not normally designed for such low temperatures.

Trapped liquid

Trapped liquid is a potential safety risk in refrigerant systems, and must always be avoided. This risk is even higher for CO_2 systems than for ammonia or R134a systems. The diagram in figure 10.11.1 shows the relative liquid volume change for the three refrigerants. As shown, liquid CO_2 expands much more than ammonia and R134a, especially when the temperature approaches CO_2's critical point.

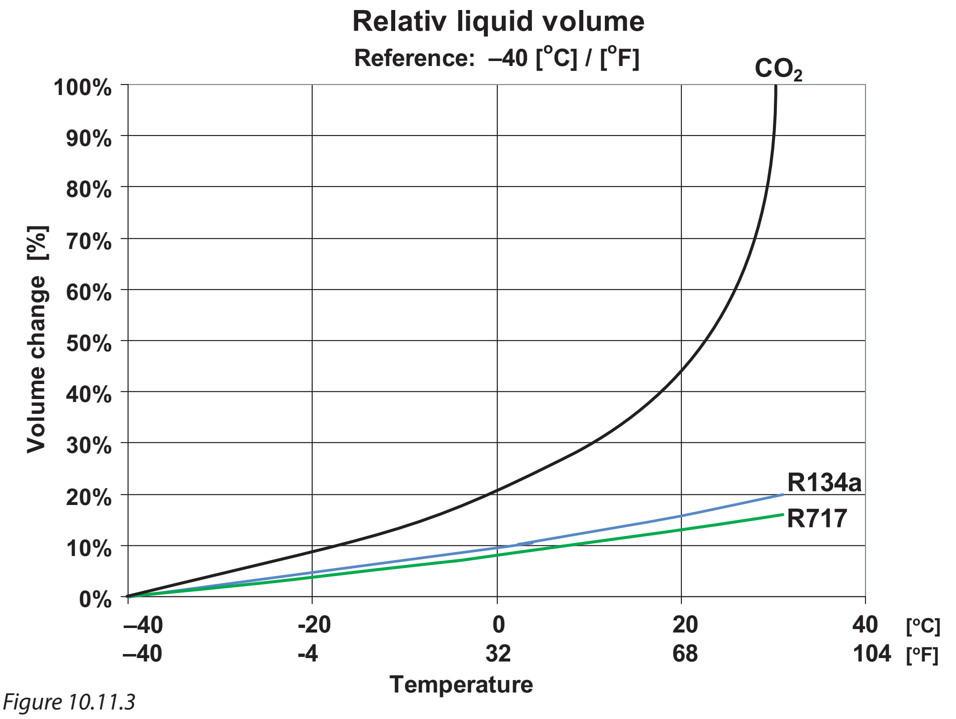


Figure 10.11.3

Leaks in CO_2- NH_3 cascade systems

The most critical leak in a CO_2- NH_3 cascade system is in the heat exchangers between CO_2 and NH_3. The pressure of the CO_2 will be higher than the NH_3, so the leak will occur into the NH_3 system, which will become contaminated.

The solid substance ammonium carbamate is formed immediately when CO_2 is in contact with NH_3. Ammonium carbamate is corrosive (ref. [5]).

CO_2 +	$2\,NH_3$	→	$H_2NCOONH_4$
CO_2	ammonia		ammonium carbamate

Material compatibility

CO_2 is compatible with almost all common metallic materials, unlike NH_3. There are no restrictions from a compatibility point of view, when using copper or brass.
The compatibility of CO_2 and polymers is much more complex. Because CO_2 is a very inert and stable substance critical, chemical reactions with polymers are not a problem. The main concern with CO_2 is the physiochemical effects, such as permeation, swelling and the generation of cavities and internal fractures. These effects are connected with the solubility and diffusivity of CO_2 in the material concerned.

Danfoss has carried out a number of tests to ensure that components released for use with CO_2 can withstand the impact of CO_2 in all aspects.

These tests have shown that CO_2 is different, and modifications have to be made on some products. The large amount of CO_2 that can dissolve in polymers must be taken into consideration. Some commonly used polymers are not compatible with CO_2, and others require different fixing methods e.g. sealing materials. When the pressure is close to the critical pressure and the temperature is high, the impact on polymers is much more extreme. However, these conditions are not important for industrial refrigeration, as pressure and temperatures are lower in these systems.

Conclusion

CO_2 has good properties, in particular at low temperature, but it is not a substitute for ammonia. The most common industrial CO_2 refrigeration systems are hybrid systems with ammonia on the high temperature side of the system.

CO_2 is in many aspects a very uncomplicated refrigerant, but it is important to realize that CO_2 has some unique features compared with other common refrigerants. Knowing the differences, and taking these into account during design, installation, commissioning and operation, will help avoid problems.

The availability of components for industrial CO_2 refrigeration systems with pressures up to approximately 40 bar is good. Several manufacturers of equipment for traditional refrigerants can also supply some components for CO_2 systems. The availability of components for high-pressure industrial CO_2 refrigeration systems is limited, and the availability of critical components is an important factor in the growth rate of CO_2 use.

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11.
Pumped CO$_2$ in Industrial Refrigeration Systems

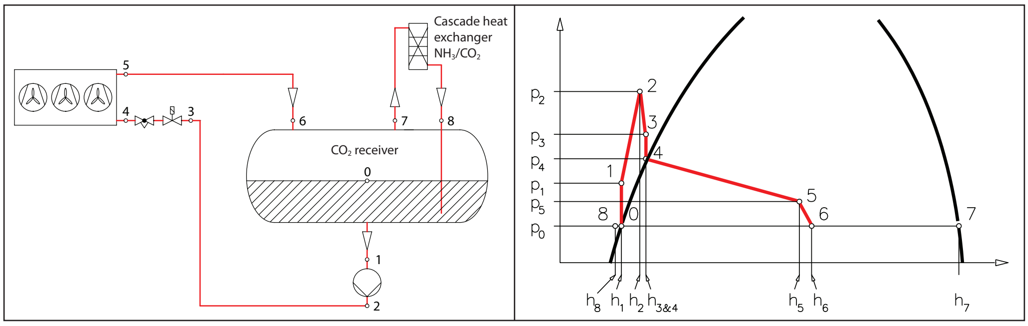


Figure 11.1 - General diagram of CO$_2$ pumped system.

General description of the systems

A typical schema of a low/medium temperature NH_3/CO_2 system (fig. 11.1) consisting of

- a standard NH_3 refrigeration system with a cascade heat exchanger acting as evaporator
- CO_2 acts as a volatile fluid in the evaporators (flooded system (1-6))

CO_2 is circulated by gravity in the cascade heat exchanger, which gives good control of the CO_2 temperature in the receiver.

The CO_2 gas flows up (7) into the cascade heat exchanger, where it is cooled by NH_3, condenses and flows back down into the CO_2 receiver as liquid CO_2 (8). On the ammonia side the refrigeration cycle can be controlled using a high pressure float valve (HFI) or by direct expansion into the evaporator (e.g. with an electronic expansion valve type ICM, and a cascade controller type EKC 313).

Differences to traditional NH_3/brine systems

System performance:
NH_3/CO_2 fluid systems have significantly lower energy consumption compared to traditional systems with NH_3 and water based brines. COP of the system is higher due to the following:

- *Evaporation temperature and PHE efficiency*
  Typically the high side NH_3 system evaporation temperature is a few degrees higher. The reason for this is the better CO_2 heat transfer coefficient in the air coolers and the PHE, resulting in a lower temperature difference in the heat exchangers. This directly reduces the energy consumption of the NH_3 compressors. Some figures indicate that the COP of NH_3/CO_2 systems is close to that of pure NH_3 systems.
- *Pump energy*
  The pump energy needed to circulate the CO_2 through the air coolers is significantly lower, due to the fact that less CO_2 needs to circulate, but also thanks to the lower density of CO_2. The pump recirculation rate for CO_2 is relatively low as well (typically between 1.1 and 2), and this also makes it possible to use a smaller pump.

Line and component sizes in a flooded system:
Due to the high specific heat content of CO_2 and its lower density, smaller components and line sizes can be used compared to a traditional brine system, for both the outward and the return lines.

The smaller volume of circulating CO_2 to circulate means that smaller pumps can be used which yields lower energy consumption for the circulated cooling capacity.

The smaller CO_2 pipes have a smaller surface and therefore lower heat loss compared to larger brine/glycol pipes.

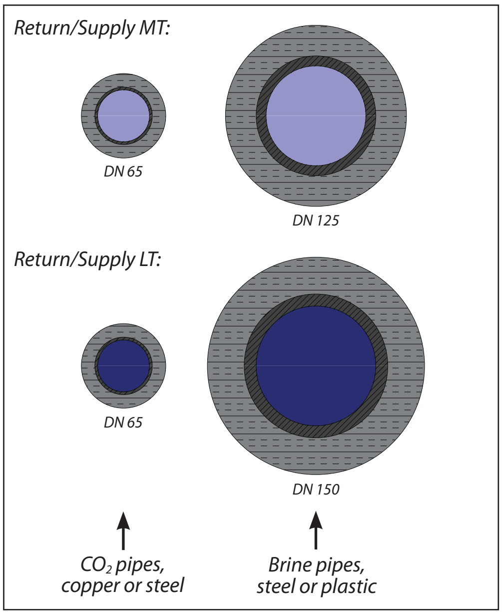


Figure 11.2 - Comparative pipe size

Differences to traditional NH_3/brine systems. (Continued)

Optimising energy management:
Further reduction of energy consumption by NH_3/CO_2 systems is possible using smart control algorithms. A good way to improve the efficiency (COP) of the system is to reduce the pressure ratio in the NH_3 compressor. There are two ways to do this:

- Keep the condenser at the lowest possible pressure.
- Keep evaporation at the highest possible pressure

The condenser control is similar to that of traditional systems, where fans can be controlled by an AKD102 variable frequency drive, and the condensing pressure can vary depending on the ambient temperature. That can be done using the Danfoss pack controller AK-PC 730/840.

Mangement of the suction pressure is another area where there are differences between CO_2 cascade systems and brine/glycol systems. Assuming a system design as shown in fig. 11.3, a pressure signal from the CO_2 receiver can be used to control the capacity of the cascade compressors (the NH_3 system).
If the pressure in the CO_2 receiver decreases, then the speed of the cascade compressors also decreases in order to maintain the CO_2 pressure. This function can be provided by the AK-PC 730 / 840 Pack Controller.

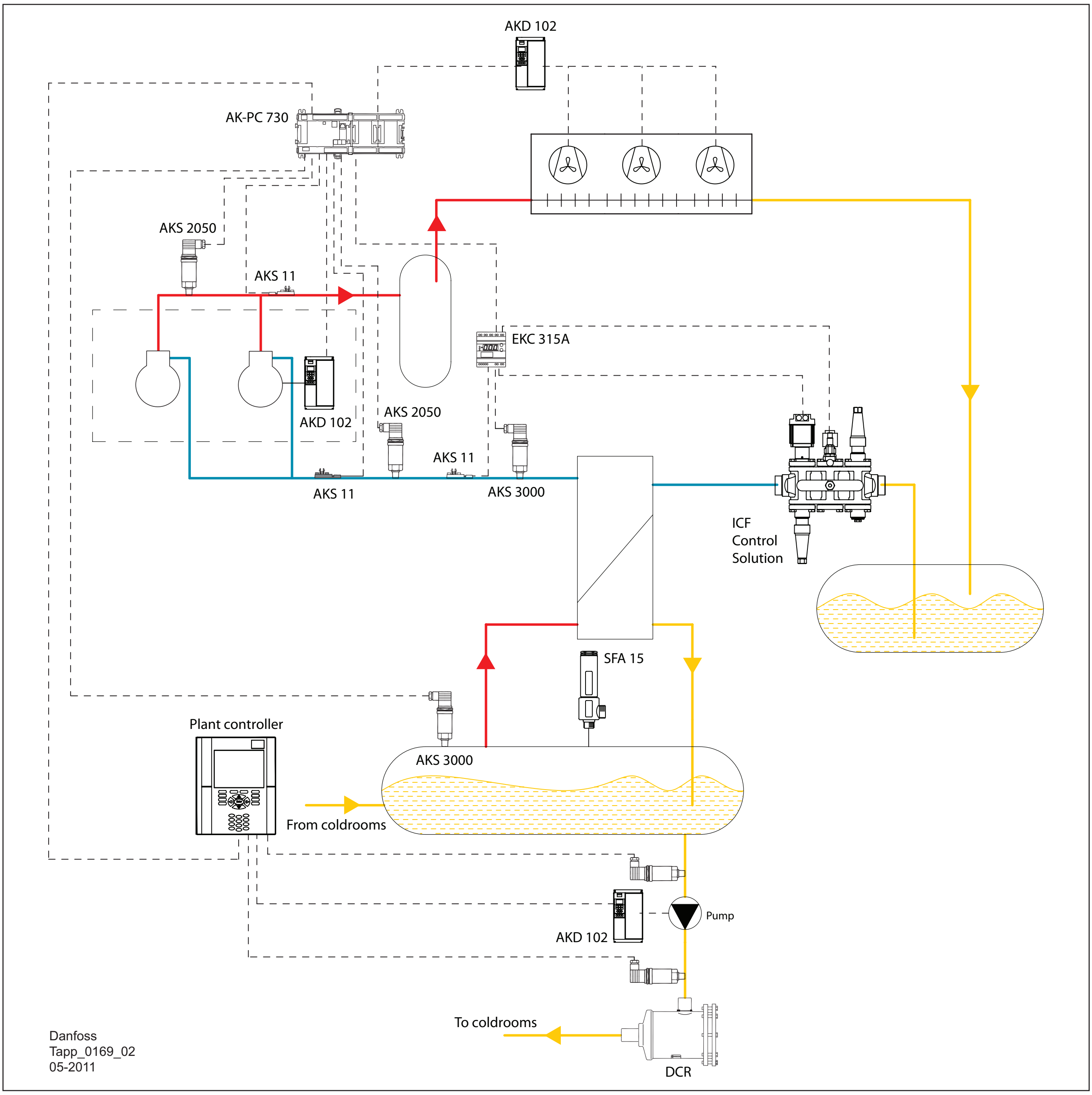


Figure 11.3 - Integrated control of pump-circulated CO_2 systems

Frequency control of the CO_2 pumps

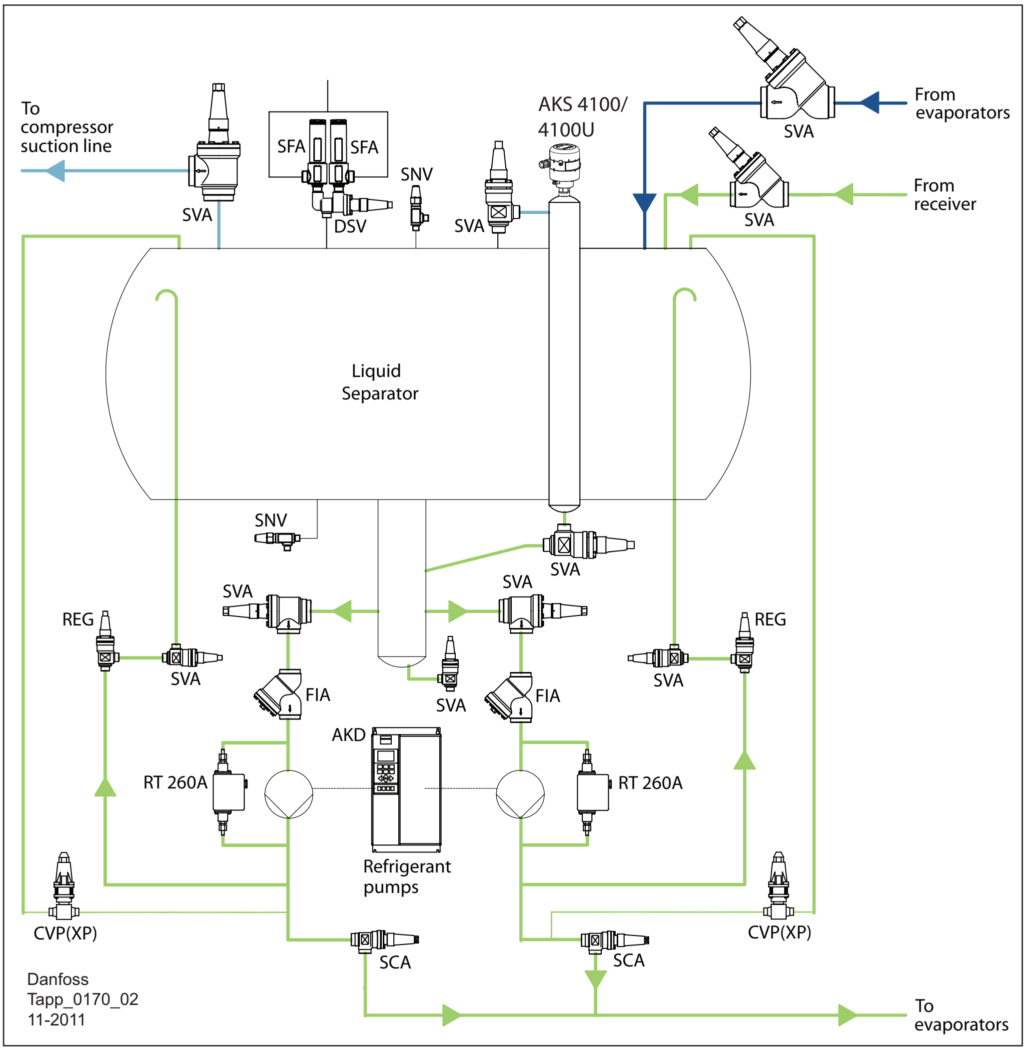


Figure 11.4 - CO_2 pump stations with AKD and the necessary valves and controls

There are two ways to control the liquid CO_2 pumps: using a simple on/off step control or using a frequency converter (type AKD). Frequency converter operation is becoming increasingly popular for two reasons: energy savings and better liquid distribution in the evaporator coils.

Energy savings
CO_2 pumps are typically controlled by a constant pressure difference. Under standard conditions the energy consumption is the same as or slightly higher than that of a fixed-speed pump. When running under partial load conditions, a fixed-speed pump would still consume the same energy due to the increased pressure difference. A liquid CO_2 pump using a frequency converter will run at a lower speed and consume less energy.

The savings will vary depending on the running time and the actual running conditions. Savings can, however, be up to 50% compared to pumps operating on/off at full speed.

Better liquid distribution in the evaporators
A requirement for good performance of the evaporators / air coolers is a good distribution of the refrigerant liquid in the system.

A precondition for good distribution of refrigerant liquid is having a stable pressure differential across the evaporators.

Pumps controlled by frequency converters can ensure that the pressure is kept at a stable level under all load conditions. At low capacity the energy consumption will be low and at high capacity there will be sufficient flow of CO_2.

A typical piping layout with CO_2 pumps controlled by frequency converters (AKD 102 type) is shown in figure 11.4. Another benefit of pumps driven by frequency converters is that the Q-max orifices can be omitted.

Defrosting pumped CO_2 systems

There are several ways to defrost pumped CO_2 systems

- **Electrical defrosting.** This is the simplest and least energy efficient method of defrosting. The additional power consumption for defrosting can be quite significant in some cases.
- **Hot gas defrosting.** CO_2 hot gas defrosting can be used if a compressor is built into the system to support defrosting. This compressor runs only when defrosting is needed. This method is more economical than electrical defrosting.

The process is similar to a traditional NH_3 defrosting system.

- **Brine defrosting.** By using brine it is possible to utilize the heat from the cascade system to defrost CO_2 evaporators. This method is especially attractive if the ammonia condenser is water cooled.
- **Water defrosting.** In some cases (especially in rooms with temperatures above zero) evaporators can be defrosted using sprayed water.

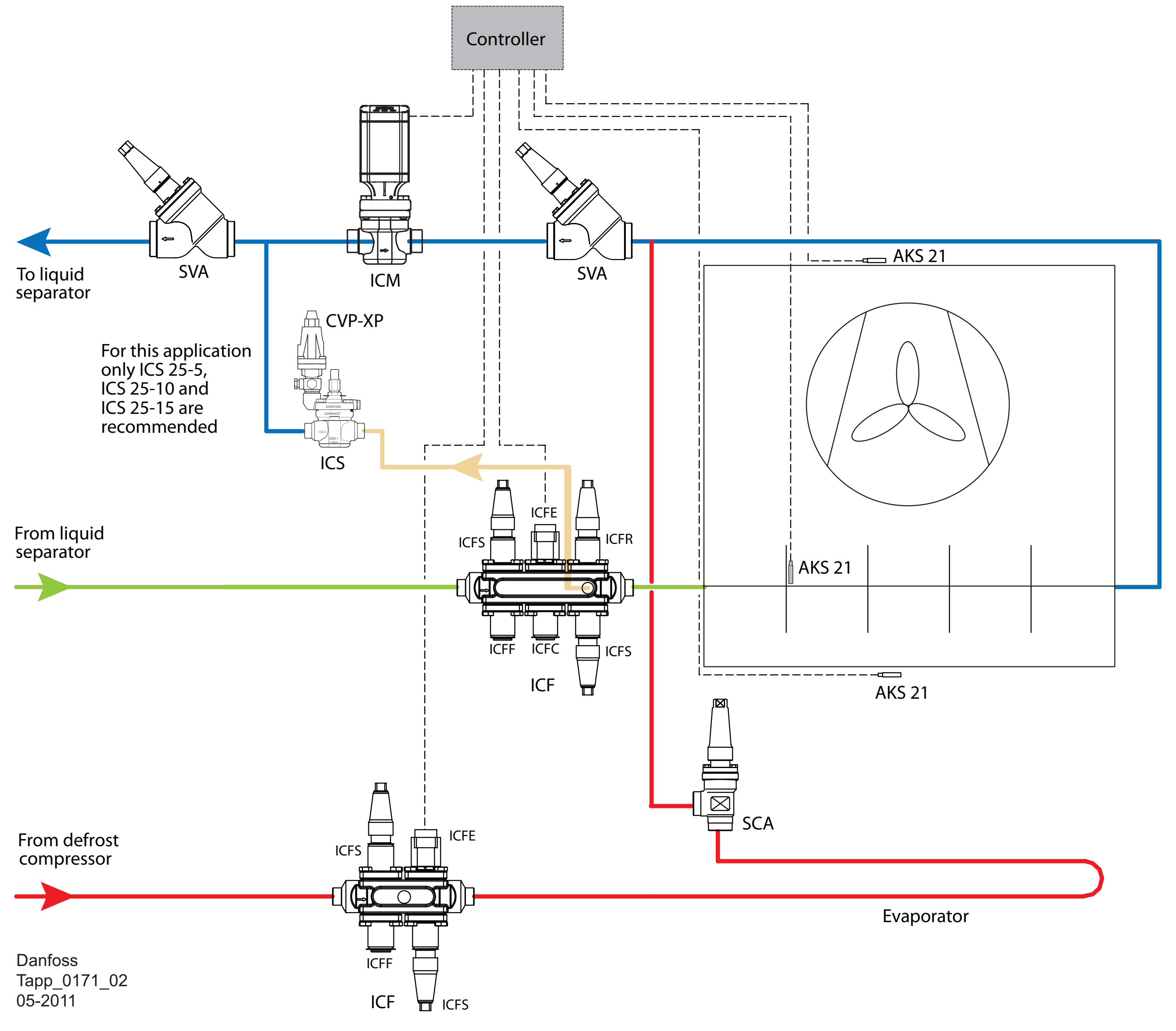


Figure 11.5 - CO_2 hot gas defrosting

Defrosting pumped CO_2 systems (continued)

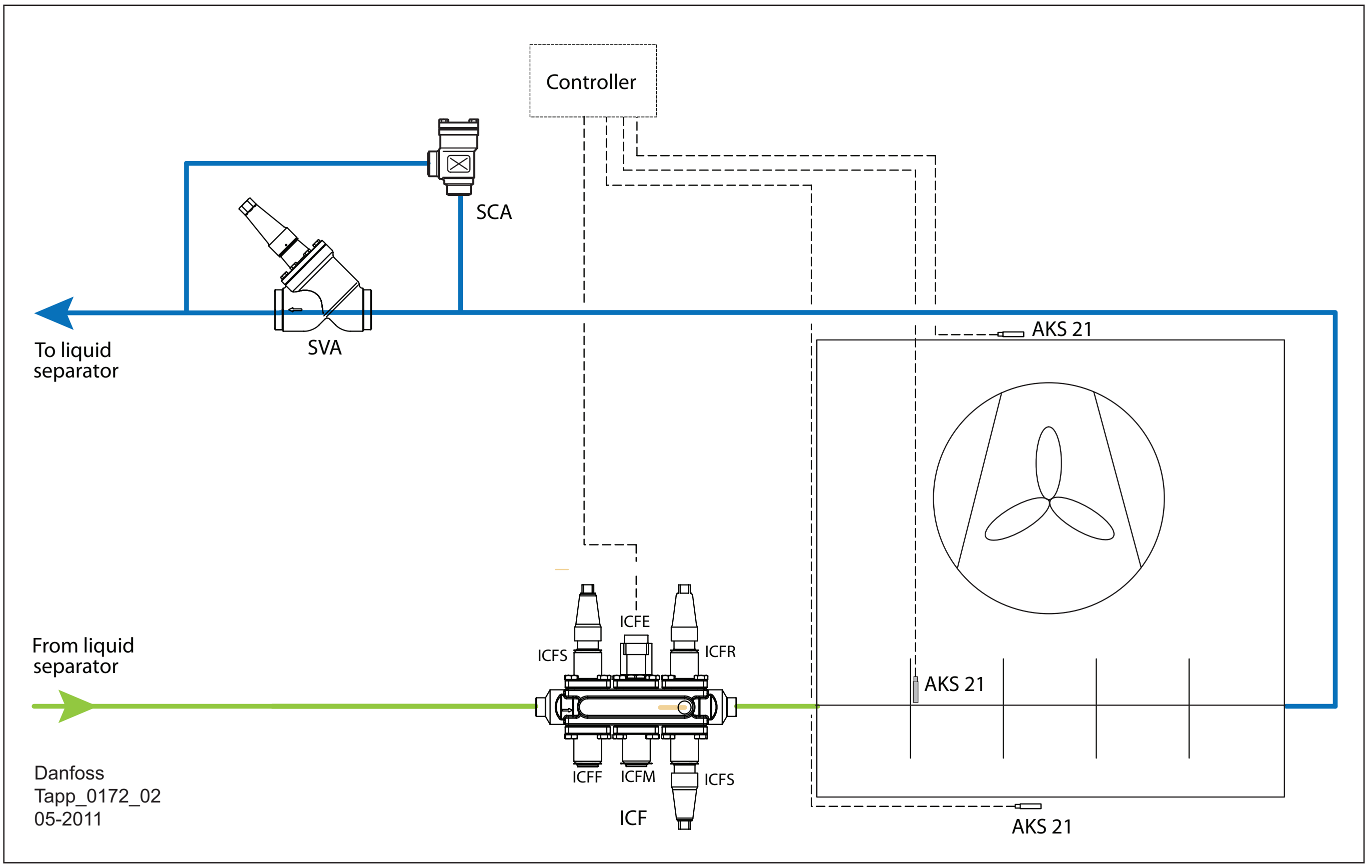


Figure 11.6 - CO_2 electrical or brine defrosting

Evaporator control in pumped CO_2 systems

Traditional industrial refrigeration systems are flooded (pumped) systems. In a flooded system, the evaporators are injected with more liquid then needed for full evaporation. The amount of liquid supplied to the evaporators is defined by the "circulation rate".

The circulation rate is 1 when exactly enough liquid is supplied to be fully evaporated in the cooler. If, however, twice as much liquid is injected, the circulation rate is 2. See the table below.

Circulation rate n	**Gas mass flow created**	**Liquid mass flow supplied**	**Liquid mass flow out**
1	x	x	0

The benefit of liquid overfeed is increased efficiency of the coolers, due to better utilization of evaporator surface area, and better heat transfer, due to a higher heat transfer coefficient. In addition, flooded systems are relatively easy to control.

The injected liquid at the correct temperature is pumped from a separator to the evaporators.

When liquid is needed, a solenoid valve in front of the evaporator is opened. A manual regulating valve is usually fitted after the soleniod valve to allow the required circulation rate to be set and hydraulic balance to be achieved in the system.

Evaporator control in pumped CO_2 systems (continued)

Temperature control in evaporators can be managed as follows:

- Regulating valve for distribution control + ON-OFF solenoid valve for temperature control
- Regulating valve for distribution control + pulse-width modulated solenoid valve for temperature control
- AKV valves for both distribution control (orifice size) and PWM temperature control

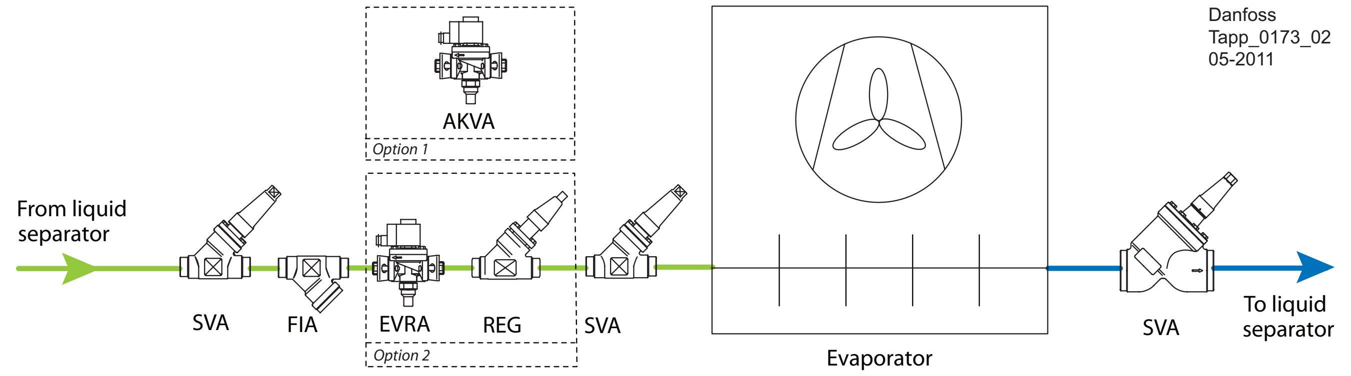


Figure 11.7

Traditional injection valves in pumped CO_2 systems

In a traditional flooded system, liquid injection is controlled by a thermostat which constantly measures the air temperature.

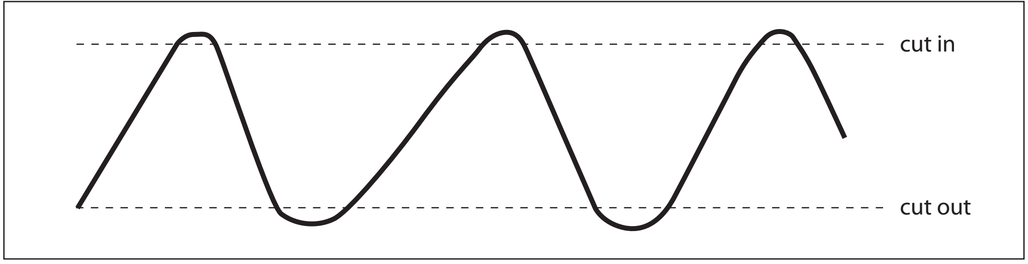
The solenoid valve is opened for several minutes or longer until the air temperature has reached the set point. During injection the mass of the refrigerant flow is constant.

This is a very simple way to control the air temperature, however, the temperature fluctuation caused by the differential of the thermostat may cause unwanted side effects in some applications, like dehumidification and inaccurate control.

Air cooler capacity
The capacity of an air cooler is described by the following equations:

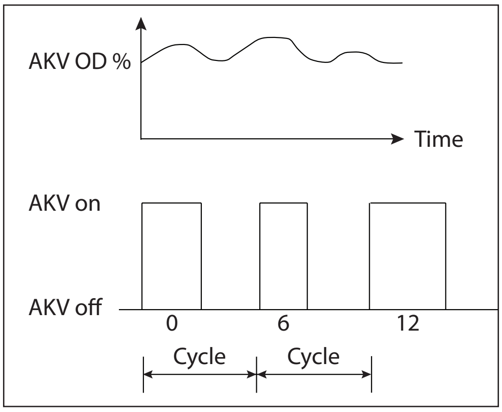
Refrigerant side:
Q cooler = mass flow × Δh (1)
Mass flow [kg/s evaporated liquid]
Δh [kJ/K]

Refrigerant/Air side:
Q cooler = k × A × ΔT (2)
K [W/(m2.K] : the total heat transfer coefficient, (depending on the heat transfer coefficient of the air and refrigerant, which depend on air/refrigerant flow) and the heat conductivity of the materials used in the coolers.
A [m2]: cooler surface
ΔT [K]: the difference between the evaporation and air temperatures.



Injection into an air cooler using a pulse width modulation AKV(A) valve

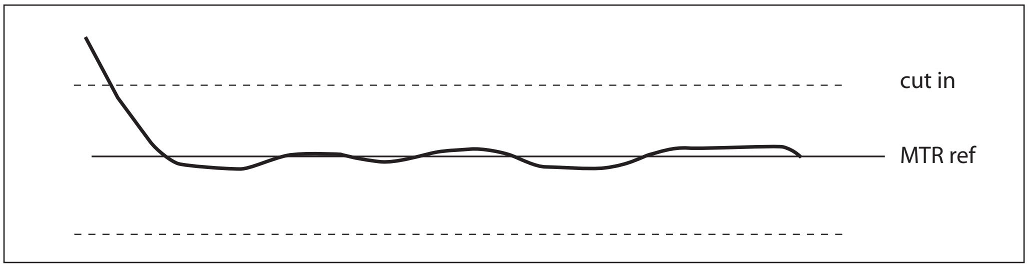
Instead of injecting periodically, as described above, one can also constantly adapt the liquid injection to the actual need. This can be done by means of a PWM AKV(A) valve.



The air temperature is constantly measured and compared to the reference temperature. When the air temperature reaches the set point, the opening of the AKV(S) is reduced, giving it a smaller opening angle during a cycle, resulting in less capacity and vice versa. The duration of a cycle is usually 3 to 6 seconds.

In a flooded system this means that the average refrigerant flow is constantly controlled and adapted to the demand, with circulation rate decreasing when less refrigeratant is injected.

The result of this is that more refrigerant will be evaporated, creating a certain amount of superheated gas in the air cooler. A direct effect of this is a cooler average surface temperature, resulting in a smaller ΔT between the refrigerant and the air.



Looking at the equations (1) and (2), it can be concluded that reducing injection results in:

- a decreasing ΔT (evaporating temperature comes nearer to ambient temperature)
- a decreasing k value
- a decreasing heat transfer surface on the air cooler (less “wetted” surface)

All resulting in smaller cooler capacity.

This approach to liquid injection in a flooded system yields a high degree of operational flexiblity. The amount of injected liquid can be controlled exactly, which increases the accuracy and the energy efficiency of the system.

Typical applications are cool stores for fruit/vegetables, where adaptation to the actual load is frequently needed. A chilling cycle (AKV valve fully open) needs much more capacity then a storage cycle (AKV valves in PWM mode).
Also these types of cool rooms are often used for different amounts and types of fruit, so load adaptation is a must.

How to select an AKV(A) valve in a flooded CO_2 application?

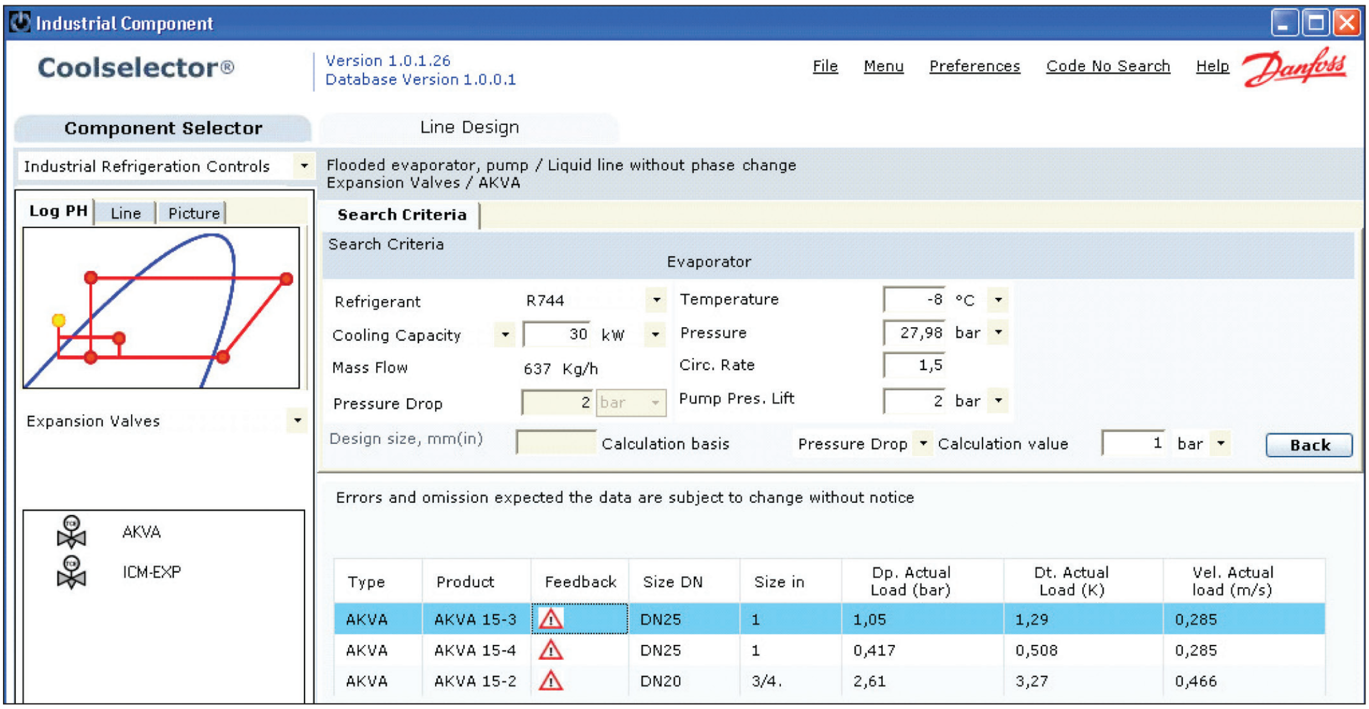
When selecting a valve for a flooded system, we need to know the maximum cooler capacity required, given the highest circulation rate, which basically means the maximum amount of liquid to be injected. Secondly, we must define the net available pressure drop across the AKV(A) valve. The selection can made easily using CoolSelector.

Please be aware that the total pump pressure required depends on several factors, such as system pressure drop (distributors/nozzles of the air coolers, components, lines, bends, static height and so on)

The minimum pressure drop in pressure needed in practice for an AKV(A) alone in a flooded system to operate satisfactorily has been shown to be 1 bar (or more if enough pump pressure is available).

Example:

- Refrigerant: CO_2
- N = 1.5
- $T_o = -8°C$
- Available drop in pressure across valve: 1 bar
- Cooler capacity: 30 kW



Version 1.0.1.26
Database Version 1.0.0.1

Industrial Refrigeration Controls

Flooded evaporator, pump / Liquid line without phase change
Expansion Valves / AKVA

Expansion Valves

Search Criteria
Evaporator

Refrigerant R744
Cooling Capacity 30 kW
Mass Flow 637 Kg/h
Pressure Drop 2 bar
Design size, mm(in)
Temperature -8 °C
Pressure 27,98 bar
Circ. Rate 1,5
Pump Pres. Lift 2 bar
Calculation basis Pressure Drop
Calculation value 1 bar

Errors and omission expected the data are subject to change without notice

Type	Product	Feedback	Size DN	Size in	Dp. Actual Load (bar)	Dt. Actual Load (K)	Vel. Actual load (m/s)
AKVA	AKVA 15-3	⚠	DN25	1	1,05	1,29	0,285
AKVA	AKVA 15-4	⚠	DN25	1	0,417	0,508	0,285
AKVA	AKVA 15-2	⚠	DN20	3/4.	2,61	3,27	0,466

CoolSelector recommends an AKVA 15-3, (kV = 0.63 m^3/h) which yields 30 kW at a circulation rate of 1.5 and a pressure drop across the valve of 1 bar. If more capacity is needed, a bigger valve or higher pressure drop in pressure across the valve should be provided.

Please keep in mind that all AKVA versions have a PS of 42 bar, AKV versions only have a PS of 42 bar in the AKV10 series and AKV15-1,2,3

Pumped systems with ICF

The example in fig. 6 is implemented with a standard AKVA valve. A multi-modular valve of type ICF would also be a good choice for this application.

If the coolers are defrosted using CO_2, a version with a check valve is needed.

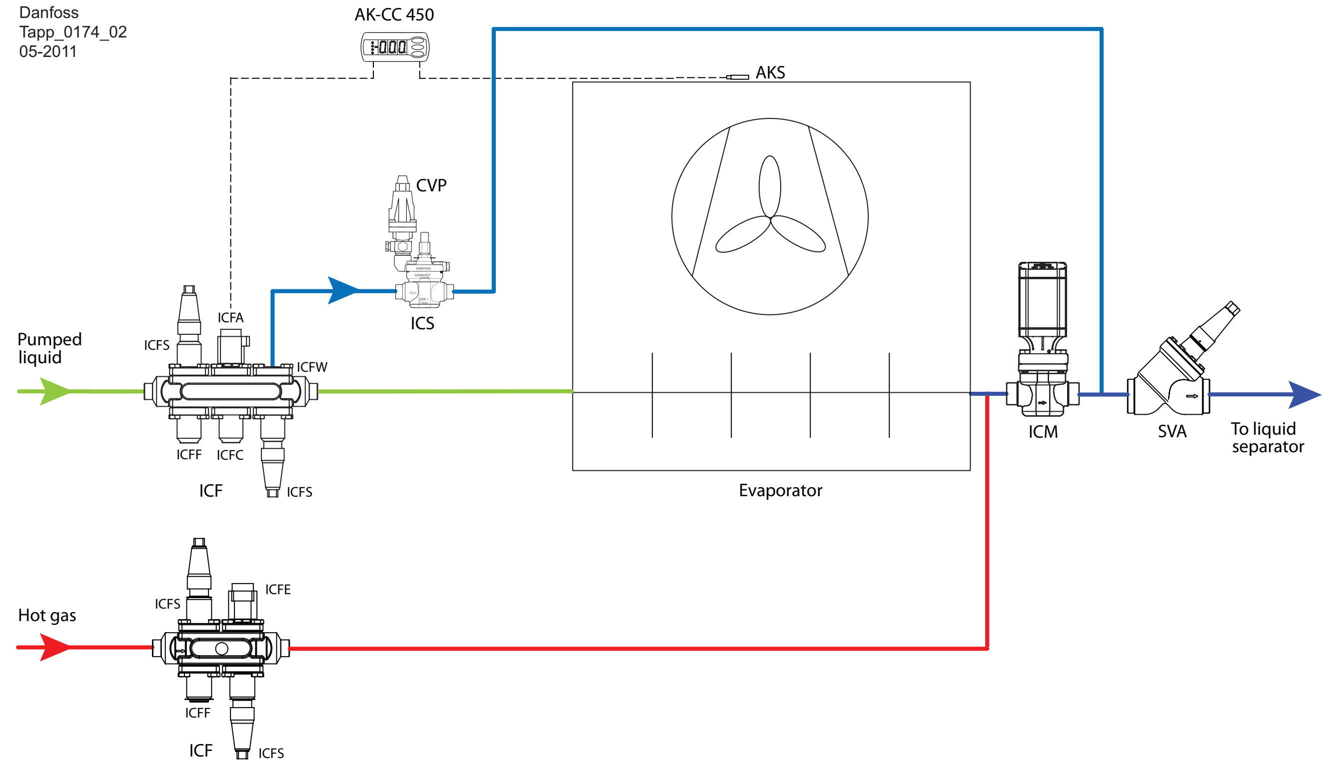


Figure 11.8 - CO_2 hot gas defrosting with ICF, ICM and ICS+CVP

Special care should be taken with the solenoid valve in the wet suction line. A commonly used defrost temperature is around 9-10°C, corresponding to a pressure of 44-45 bar (a) upstream of this solenoid valve.

Depending on the separator pressure, the MOPD of this valve could be too small to open. It is good practice to use a small bypass valve like EVRST (PS = 50 bar) to equalise the pressure first, before opening the main valve. The MOPD of the ICM 20-32 is 52 bar, so it is always able to open after a defrost cycle, even when the separator pressure is near the triple point of 5.2 bar a.

A benefit of using ICM is that the defrost pressure can be equalised by slowly opening the valve. A cost-effective way to do this is using the on/off mode on the ICM and selecting a very low speed (I04), or it can be achieved by using the modulating mode, so the PLC totally controls the opening degree and speed.

Reference documents - aphabetical list

Type	Title	Technical brochure / Manual	Product instructions
AK-CC 450	Appliance Controller	RS8EU	
AKD 102	Variable speed drive	PD.R1.B	MG11L
AK-PC 730	Capacity controller	RS8EG	
AKS 21	Temperature sensor	ED.SA0.A	RI14D
AKS 32R	Pressure transmitter	RD5GJ	PI.SB0.A
AKS 33	Pressure transmitter	RD5GH	PI.SB0.A
AKS 4100/4100U	Liquid level sensor	PD.SC0.C	PI.SC0.D / PI.SC0.E
AKVA	Electrically operated expansion valve	PD.VA1.B	PI.VA1.B (AKVA 10) PI.VA1.C (AKVA 15)
CVC	Pilot valves for servo-operated main valve	PD.HN0.A	RI4XL
CVP	Pilot valves for servo-operated main valve	PD.HN0.A	PI.HN0.B
CVPP	Pilot valves for servo-operated main valve	PD.HN0.A	PI.HN0.C
DCR	Filter drier	PD.EJ0.A	
EKC 315A	Controller for industrial evaporator	RS8CS	
EKC 347	Liquid level controller	RS8AX	
EVM	Pilot valves for servo-operated main valve	PD.HN0.A	RI3XH
EVRA / EVRAT	Solenoid valve	PD.BM0.B	RI3XE
FIA	Filter	PD.FN0.A	PI.FN0.A
ICF	Control solution	PD.FT0.A	PI.FT0.A
ICM / ICAD	Motor operated valve	PD.HT0.B	PI.HT0 (ICM) PI.HV0 (ICAD)
ICS	Servo operated valve	PD.HS0.A	PI.HS0
NRV	Check valves	PD.FE0.A	PI.FE0.A
OFV	Overflow valve	PD.HQ0.A	PI.HX0.B
REG	Manual regulating valve	PD.KM0.A	PI.KM0.A
RT 260A	Pressure control, differential pressure control	PD.CB0.A	RI5BB
SCA	Stop check valve / check valve	PD.FL0.A	PI.FL0.A
SGR	Sight glass	PD.EK0.A	PI.EK0.A
SNV	Stop needle valve	PD.KB0.A	PI.KB0.A
SVA	Stop valve	PD.KD0.A	PI.KD0.B

To download literature for other Danfoss products, please visit the Danfoss internet site
http://www.danfoss.com/Products/Literature/RA_Documentation.htm

12.
Control methods for CO_2 systems

-1 Bypass valve
2 Auxillary refrigeration system / stand still unit (cooling)
3 Solenoid valve
4 Safety valve

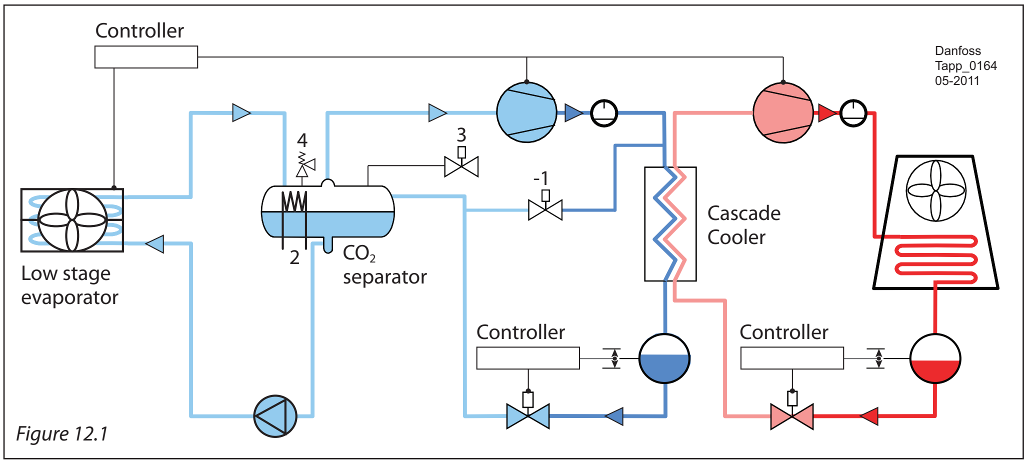


Figure 12.1

Compressor control

There is no difference in the way the compressors can be controlled in CO_2 systems compared to a normal industrial refrigeration installation, but as they are cascade systems, it must be ensured that the NH_3 compressor is started / ready to start before the start signal is given to the CO_2 compressor (see the section regarding compressor control).

Liquid level control

There is no difference in the way the liquid level can be controlled in CO_2 systems compared to a normal industrial refrigeration installation (see the section regarding liquid level control).

Possible control devices in case of high pressure in the CO_2 separator

If the pressure in the CO_2 separator rises above the normal range, the following steps can be taken in order to minimize the escape of CO_2:

1. The CO_2 compressor can be forced to start and the CO_2 liquid pump forced to stop to prevent relatively warm liquid returning to the CO_2 separator.
2. If there is a fault preventing the CO_2 compressor from starting, the pressure will continue to increase. This will force the stand-still unit to start.
3. If the pressure continues to rise, a solenoid valve can be forced open to provide a controlled release of the CO_2 pressure down to a defined pressure.
4. The last device is the safety valve, which operates at its set pressure.

Possible control devices in case of low pressure in the CO_2 separator

If the pressure in the CO_2 separator drops below the normal operating range, the following steps can be taken to minimize the risk of formation of dry ice:

1. Opening a bypass valve enables the system to maintain a sufficient high suction pressure in the CO_2 separator. This also prevents stopping of the compressor to stop if there is a sudden drop in cooling load, e.g. if there is a freezing process with variations in the cooling load. This ensures that the compressor keeps running and maintains the system ready for a sudden increase in the cooling load.
2. The CO_2 compressor can be forced to stop, and thus avoid the forming of dry ice.

13.
Design of a CO_2 sub-critical installation

In general the design and selection of valves for a CO_2 sub-critical installation are no different than for a traditional HN_3 installation, except for the higher working pressures and the oil recovery system.

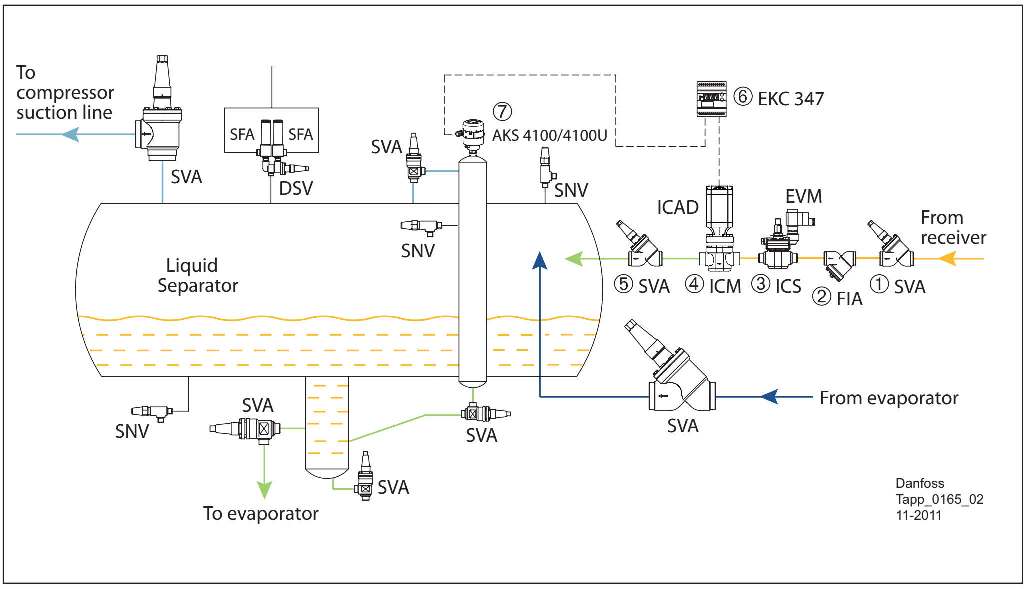
Therefore, the examples given in the previous sections of this handbook are also valid for CO_2. However, generally speaking it is recommended to avoid flange connections in CO_2 systems where possible.

13.1
Electronic solution for liquid level control

Application example 13.1.1: Electronic solution for LP liquid level control

▬ HP liquid refrigerant
▬ Liquid/vapour mixture of refrigerant
▬ LP vapour refrigerant
▬ LP liquid refrigerant

① Stop valve
② Filter
③ Solenoid valve
④ Motor valve
⑤ Stop valve
⑥ Controller
⑦ Level transmitter



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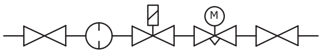
The level transmitter AKS 4100/4100U ⑦, monitors the liquid level in the separator and sends a level signal to the liquid level controller EKC 347 ⑥, which sends a modulating signal to the actuator of the motor valve ICM ④. The ICM motor valve acts as an expansion valve.

The liquid level controller EKC 347 ⑥ also provides relay outputs for upper and lower limits and for alarm level.

Application example 13.1.2: Electronic solution for LP liquid level control

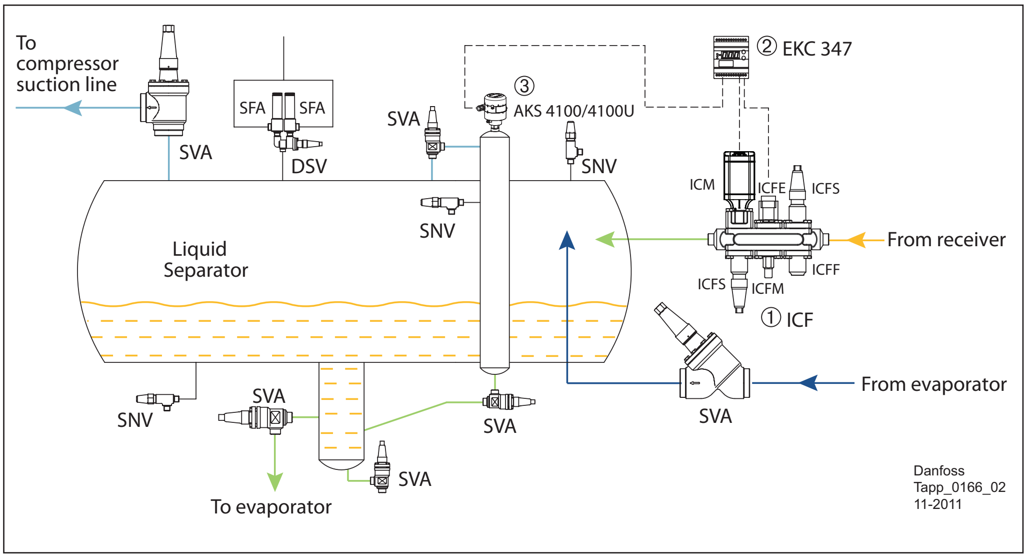
▬ HP liquid refrigerant
▬ Liquid/vapour mixture of refrigerant
▬ LP vapour refrigerant
▬ LP liquid refrigerant

① ICF valve station including:



Stop valve
Filter
Solenoid valve
Manual opener
Motor valve
Stop valve

② Controller
③ Level transmitter



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Danfoss can supply a very compact valve solution ICF ①. Up to six different modules can be fitted in the same housing, which is easy to install.
The module ICM acts as an expansion valve and the module ICFE is a solenoid valve.

This solution operates in the same way as example 4.2.3. An ICF solution similar to example 4.2.4 is also available. Please refer to ICF literature for further information.

13.2
Hot Gas Defrost for Pumped Liquid Circulation Air Coolers

Application example 13.2.1: Pumped liquid circulation evaporator, with hot gas defrost system

🟥 HP vapour refrigerant
🟧 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟩 LP liquid refrigerant

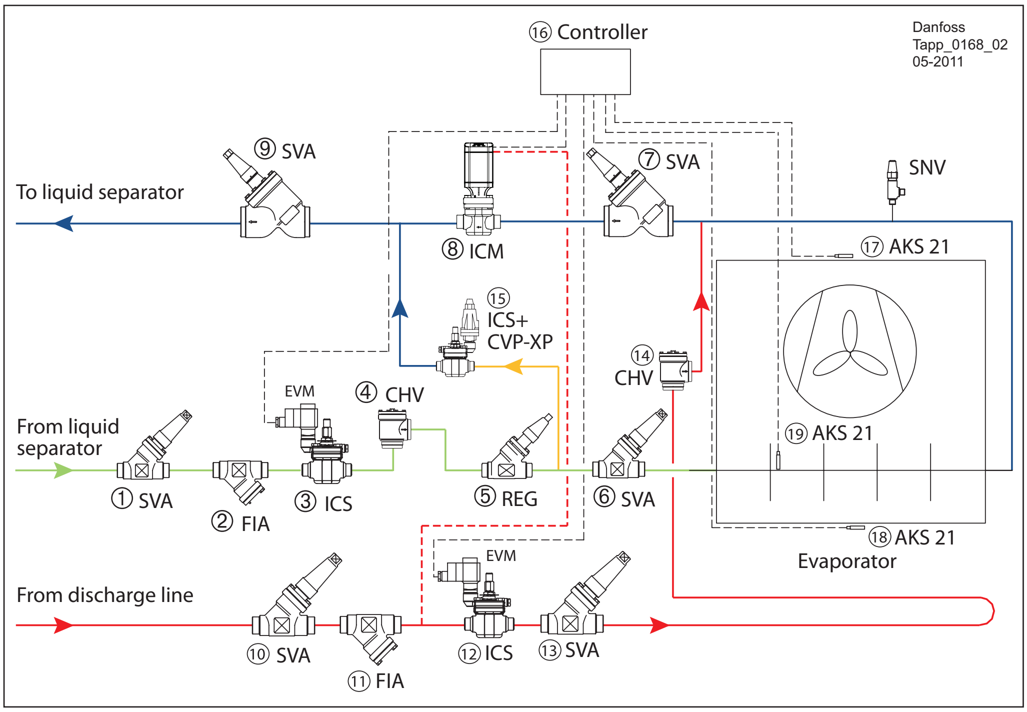
Liquid Line
① Liquid inlet stop valve
② Filter
③ Solenoid valve
④ Check valve
⑤ Manual expansion valve
⑥ Evaporator inlet stop valve

Suction Line
⑦ Evaporator outlet stop valve
⑧ Motor valve
⑨ Suction line stop valve

Hot gas line
⑩ Stop valve
⑪ Filter
⑫ Solenoid valve
⑬ Stop valve
⑭ Check valve

Overflow line
⑮ Overflow valve

Controls
⑯ Controller
⑰ Controller
⑱ Controller
⑲ Controller



Application example 13.2.1 shows an installation for pumped liquid circulation evaporators with hot gas defrost using the ICV valves.

Refrigeration Cycle
The solenoid valve ICS ③ in the liquid line is kept open. Liquid injection is controlled by the manual regulating valve REG ⑤.
The motor valve ICM ⑧ in the suction line is kept open, and the defrosting solenoid valve ICS ⑫ is kept closed.

Defrost Cycle
After initiation of the defrost cycle, the liquid supply solenoid module ICFE of the ICS ③ is closed. The fan is kept running for 120 to 600 seconds depending on the evaporator size in order to pump down the liquid in the evaporator.

The fans are stopped and the ICM valve ⑧ closed.

A delay of 10 to 20 seconds is provided to allow the liquid in the evaporator to settle down in the bottom without vapour bubbles. The motor valve ICM ⑫ is then opened and supplies hot gas to the evaporator.

Because of the high differential pressure between the hot gas line and the evaporator, it is recommended to increase the pressure slowly, allowing the pressure to be equalized before opening fully to ensure smooth operation and avoid liquid slugging in the evaporator.

A benefit of using the motor valve ICM ⑫ ,
a benefit is that the defrost pressure can be equalized by slowly opening the valve. A cost effective way to do this is using the on/off mode on the ICM and selecting a very low speed, or it can be achieved by using the modulating mode, so the PLC totally controls the opening degree and speed.

During the defrost cycle, the condensed hot gas from the evaporator is injected into the low pressure side. The defrost pressure is controlled by the ICS+CVP ⑮.

When the temperature in the evaporator (measured by AKS 21) reaches the set value, defrost is terminated, the motor valve ICM ⑫ is closed, and after a small delay the motor valve ICM ⑧ is opened.

Because of the high differential pressure between the evaporator and the suction line, it is necessary to relieve the pressure slowly, allowing the pressure to be equalized before opening fully to ensure smooth operation and avoid liquid slugging in the suction line.

A benefit of using the motor valve ICM ⑧ a benefit is that the defrost pressure can be equalized by slowly opening the valve. A cost effective way to do this is using the on/off mode on the ICM and selecting a very low speed, or it can be achieved by using the modulating mode, so the PLC totally controls the opening degree and speed.

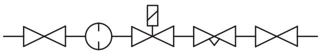
After the ICM fully opens, the liquid supply solenoid valve ICS③ is opened to start the refrigeration cycle. The fan is started after a delay in order to freeze remaining liquid droplets on the surface of the evaporator.

13.2
Hot Gas Defrost for Pumped Liquid Circulation Air Coolers

Application example 13.2.2: Pump circulated evaporator, with hot gas defrost system, fully welded, using ICF Valve station for evaporator with hot gas defrost

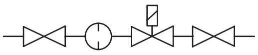
🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟩 LP liquid refrigerant

① Liquid Line ICF with:



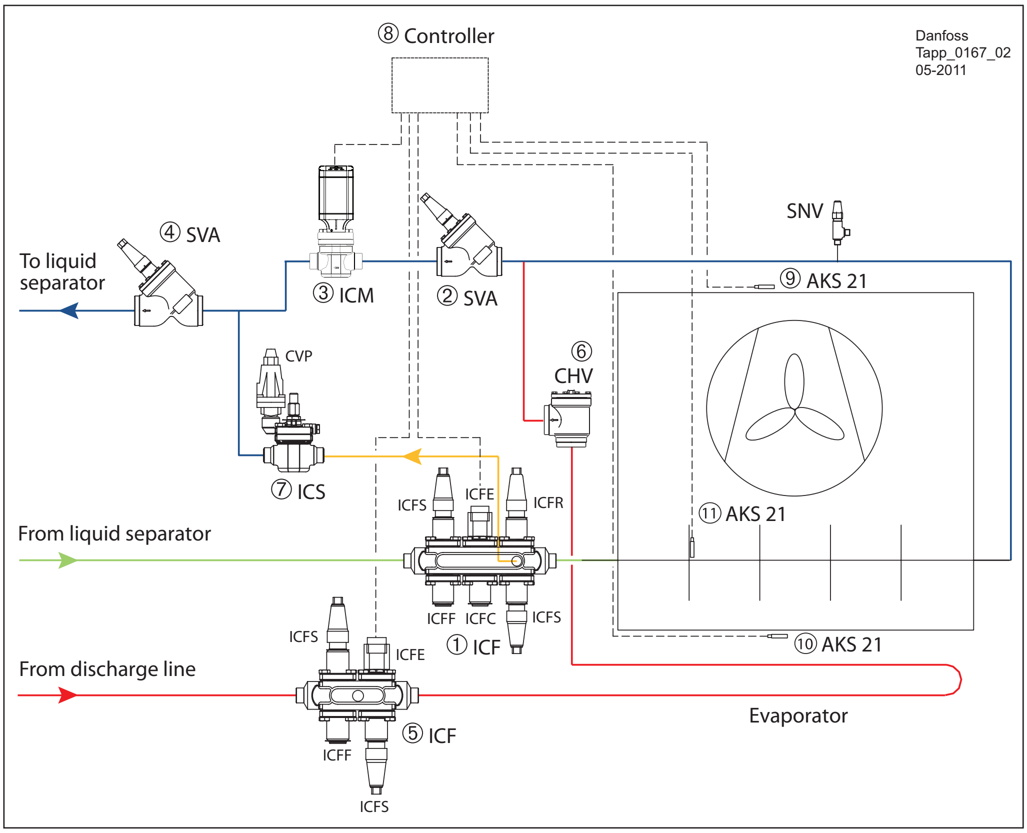
Stop valve
Filter
Solenoid valve
Check valve
Manual expansion valve
Evaporator inlet stop valve

② Evaporator outlet stop valve
③ Pressure regulator (motor valve)
④ Suction line stop valve
⑤ Hot gas line ICF with:



Stop Valve
Filter
Solenoid valve
Stop valve

⑥ Check valve
⑦ Pressure regulator
⑧ Controller
⑨ Temperature sensors
⑩ Temperature sensors
⑪ Temperature sensors



Application example 13.2.2 shows an installation for pumped liquid circulation evaporators with hot gas defrost using the new ICF control solution.

The ICF will accommodates up to six different modules fitted in the same housing, offering a compact, easy to install control solution.

Refrigeration Cycle
The solenoid valve ICFE in ICF ① in the liquid line is kept open. The liquid injection is controlled by the hand regulating valve ICFR in ICF ①.

The motor valve ICM ③ in the suction line is kept open, and the defrosting solenoid valve ICFE in ICF ⑤ is kept closed.

Defrost Cycle
After initiation of the defrost cycle, the liquid supply solenoid module ICFE of the ICF ① is closed. The fan is kept running for 120 to 600 seconds depending on the evaporator size in order to pump down the liquid in the evaporator. The fans are stopped and the ICM valve closed. A delay of 10 to 20 seconds is provided to allow the liquid in the evaporator to settle down in the bottom without vapour bubbles. The solenoid valve ICFE in ICF ⑤ is then opened and supplies hot gas to the evaporator.

During the defrost cycle, the condensed hot gas from the evaporator is injected into the low pressure side. The defrost pressure is controlled by the ICS+CVP ⑦.

When the temperature in the evaporator (measured by AKS 21) reaches the set value, defrost is terminated, the solenoid valve ICFE in ICF ⑤ is closed, and after a small delay the motor valve ICM ③ is opened.

Because of the high differential pressure between the evaporator and the suction line, it is necessary to relieve the pressure slowly, allowing the pressure to be equalized before opening fully to ensure smooth operation and avoid liquid slugging in the suction line.

A benefit of using the motor valve ICM ③ is that the defrost pressure can be equalized by slowly opening the valve. A cost effective way to do this is to use the ICM on/off mode and select a very low speed. It can also be achieved by using the modulating mode, so that the PLC fully controls the opening degree and speed.

After the ICM fully opens, the liquid supply solenoid valve ICFE in ICF ① is opened to start the refrigeration cycle. The fan is started after a delay in order to freeze remaining liquid droplets on the surface of the evaporator.

14.
Filter Driers in CO_2 Systems

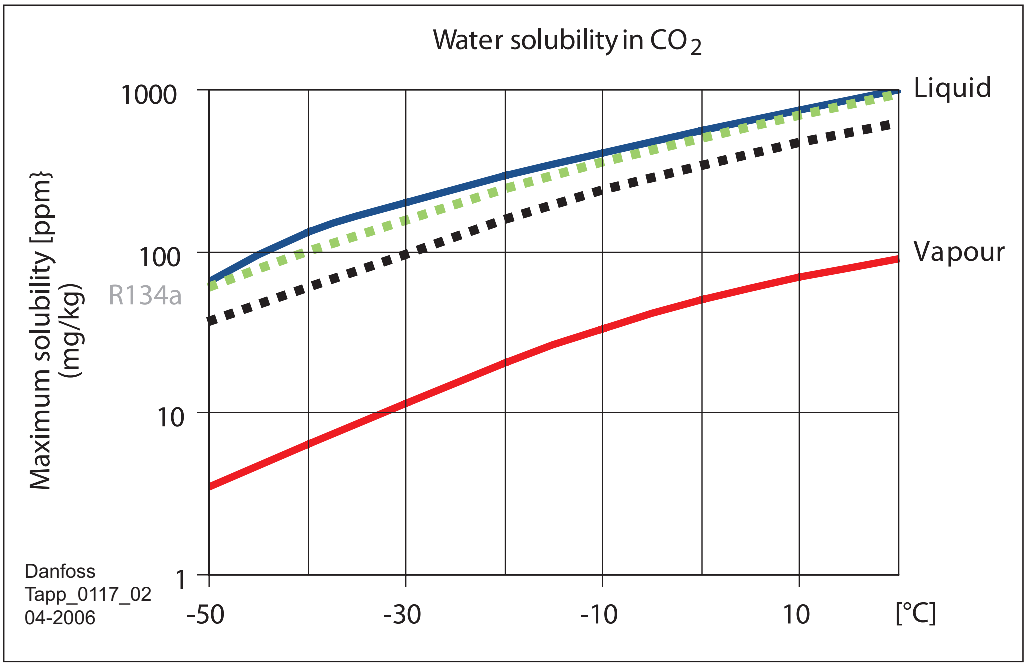
In many respects CO_2 is a far less complicated refrigerant, but it does have some unique features compared with other common refrigerants. One such feature is the water solubility in CO_2. As shown in the figure below, there is little difference between the solubility in both the liquid and vapour phases of R134a. However, with CO_2 this difference is quite significant.

What happens in fluorinated system will also happen in CO_2 systems when water, acids and particles are present in the system, e.g. blockage by particles and corrosion by acids.

Furthermore the unique water solubility of CO_2 will increase the risk of freezing in CO_2 systems.

In the evaporator, when the liquid CO_2 vaporizes, the water solubility in the refrigerant decreases significantly especially when the circulation ratio is near to one. This brings a risk of creating free water. If this happens and the temperature is below 0°C, the free water will freeze, and the ice crystals may block control valves, solenoid valves, filters and other equipment.

Installing filter driers is still the most efficient method to avoid the above mentioned freezing, blockages and chemical reactions. And the zeolite type filter drier commonly used in fluorinated systems has proven to be effective for CO_2 systems. To install filter driers in a CO_2 system, the unique water solubility should also be taken into consideration.



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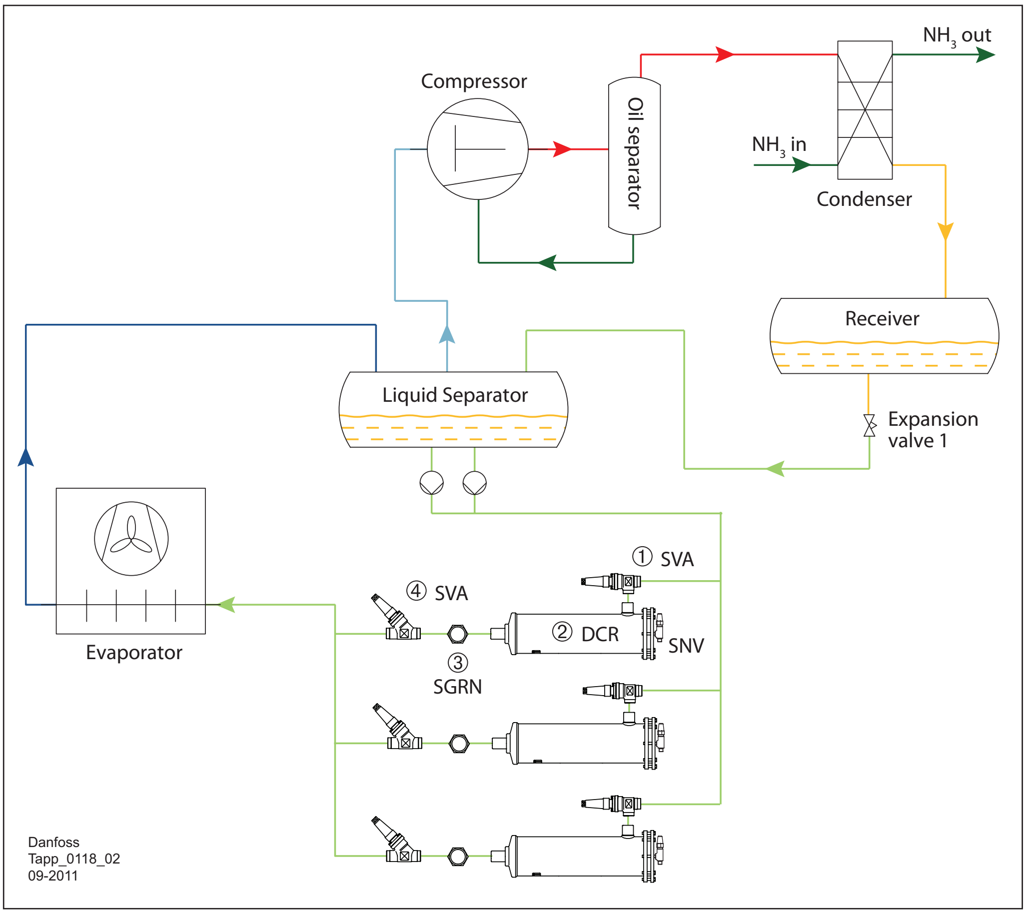
Application example 14.1: Filter driers in CO_2 pumped liquid circulation systems



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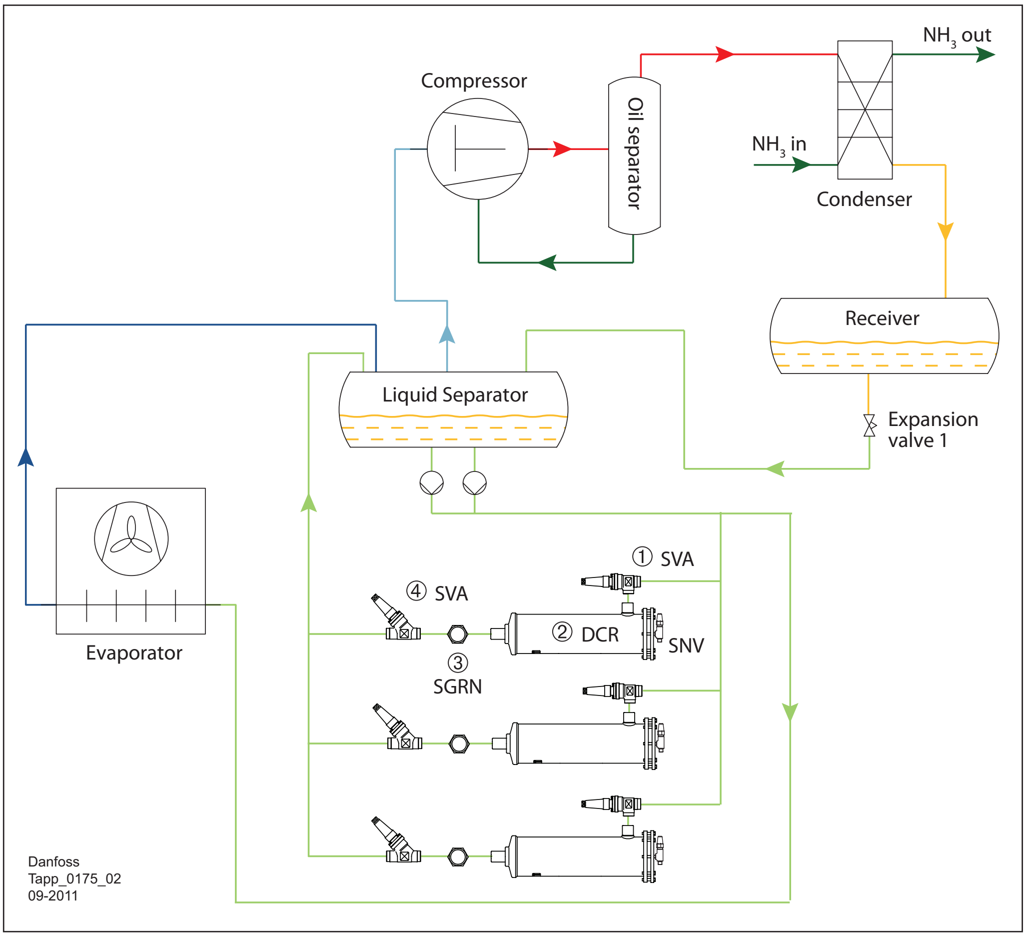
- 🟥 HP vapour refrigerant
- 🟨 HP liquid refrigerant
- 🟦 Liquid/vapour mixture of refrigerant
- 🟦 LP vapour refrigerant
- 🟩 LP liquid refrigerant
- 🟩 Oil

① Stop valve
② Filter drier
③ Sight glass
④ Stop valve



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- 🟥 HP vapour refrigerant
- 🟨 HP liquid refrigerant
- 🟦 Liquid/vapour mixture of refrigerant
- 🟦 LP vapour refrigerant
- 🟩 LP liquid refrigerant
- 🟩 Oil

① Stop valve
② Filter drier
③ Sight glass
④ Stop valve

Application example 14.1: Filter driers in CO_2 pumped liquid circulation systems (Continued)

To install a filter drier in a CO_2 system, the following criteria should be considered:

- **Relative Humidity**
  The relatively humidity should be high.
- **Pressure Drop**
  The pressure drop across the filter drier should be small. And the system performance should not be sensitive to this pressure drop.
- **Two Phase Flow**
  Two phase flow through the filter drier should be avoided, which brings risk of freezing and blocking because of the unique water solubility characteristics.

In a CO_2 pumped liquid circulation systems, filter driers are recommended to be installed on the liquid lines before evaporators. On these lines, RH is high, there is no two phase flow, and it's not sensitive to pressure drop.

Installation in other positions is not recommended for the following reasons:

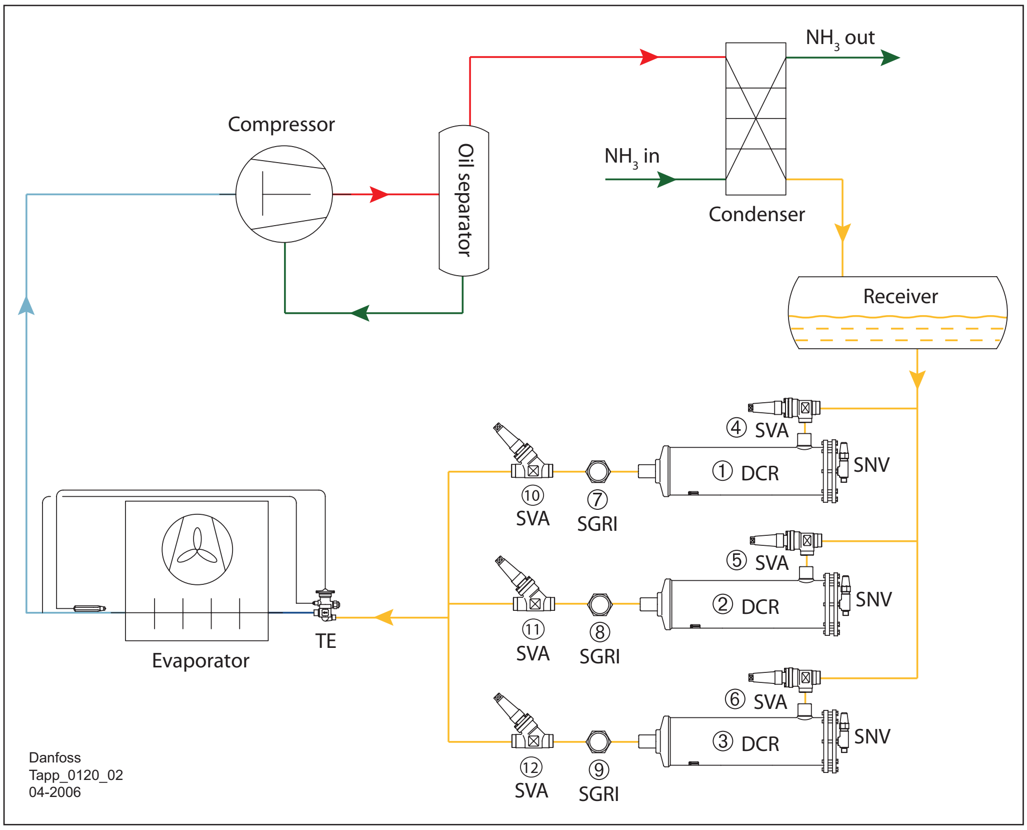
1. In the compressor-condenser-expansion valve loop the RH is low. In the liquid separator, more than 90% water exists in the liquid phase because of the much lower solubility of vapour CO_2 compared with liquid. Therefore, little water is brought into the compressor loop by the suction vapour. If filter driers are installed in this loop, the drier will have too little capacity.
2. In the wet suction line there is a risk of "freezing" because of the two phase flow as mentioned.
3. In the liquid line before the refrigerant pumps, pressure drop increases the risk of cavitation to the pumps.

If the capacity of one filter drier is not enough, several filters driers in parallel could be considered.

Application example 14.2: Filter driers in CO_2 DX systems

🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Filter drier
② Filter drier
③ Filter drier
④ Stop valve
⑤ Stop valve
⑥ Stop valve
⑦ Sight glass
⑧ Sight glass
⑨ Sight glass
⑩ Stop valve
⑪ Stop valve
⑫ Stop valve



In a CO_2 DX system, the water concentration is the same throughout the system, so the RH is only up to the water solubility of the refrigerant.

Although the RH in the liquid line before the expansion valve is relatively small because of the high water solubility of the high temperature liquid CO_2, it's still recommended that filter driers be installed on this line (same position as in fluorinated system) for the following reasons:

1. In the suction line and discharge line, it is sensitive to the pressure drop, as well as the high risk of freezing in the suction line. Filter driers are not recommended to be installed here although the RHs are high.
2. In the liquid line after the expansion valve, installation of filter drier should also be avoided because of the two phase flow.

15.
Danfoss sub-critical CO_2 components

Today, Danfoss now offers a broad range of industrial components suitable for CO_2.

The majority of the components listed below have been evaluated and upgraded, and are therefore applicable for CO_2 within the pressure and temperature ranges stated in the technical documentation. In particular the pressure is the limiting factor for this group of components.

Special components for high-pressure CO_2 applications have been developed. The most common types of valves are listed on the following pages.

Please note that special high-pressure versions are generally only available on special order and extended deliivery times should be taken into account.

Pressure Equipment Directive (PED)
The Industrial Refrigeration valves are approved in accordance with the European standards specified in the Pressure Equipment Directive and are CE marked.

Industrial Refrigeration products

Danfoss Sub Critical CO_2 - components **Industrial Refrigeration products**			DN	**PS 40bar [580 psi]**	**PS 52 bar [754 psi]**
Main Valves, Solenoid Valves	ICS 1 ICS 3	all	20-150	▨	▨
Motor Valves	ICM	all	20-150	▨	▨
Multifunction valve	ICF	all	20-40	▨	▨
Pilots for ICS Valves	CVC-XP			▨	▨
	CVP-HP			▨	
	CVPP-HP			▨	
	EVM-NC			▨	🟦 **65 bar**
	EVM-NO			▨	▨
Stop Valves - SVA ST,HS	SVA	all	10-65	▨	🟦
	SVA	all	80-200	▨	🟦 **50 bar**
Regulating Valves - REG	REG	all	15 - 65	▨	🟦
Stop Check Valves SCA	SCA	all	15-65	▨	🟦
	SCA	all	80-125	▨	🟦 **50 bar**
Filters FIA	FIA	all	15-65	▨	🟦
	FIA	all	80-200	▨	🟦 **50 bar**
Check Valves	CHV	all	15- 40	▨	🟦
	CHV	all	80-125	▨	🟦 **50 bar**
Solenoid Valves	EVRS/EVRST	all	10-25	▨	🟦
	EVRA/EVRAT	all	10-40	▨	
Electrically operated expansion valve	AKVA	all	10-40	▨	
Safety Valves and Change Over Valves SFV - DSV	SFA	15	-	▨	
	DSV	1, 2	20-32	▨	
	POV	40, 50, 80	40-80	▨	
Filter drier	DCRH	High pressure version		▨	▨ **46 bar**
Liquid level transmitter	AKS 4100/4100U	-	-	▨	▨
Gas detectors	GD				

▨ The product can be used in standard version.
All products are CE approved

🟦 The product must be manufactured in a special version (higher test pressure, marking and documentation). All products are CE approved

15.1
Danfoss sub-critical CO_2 components
(Continued)

Commercial Refrigeration products

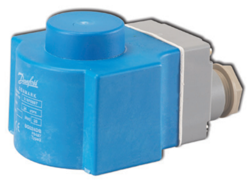
Danfoss Sub Critical CO_2 - components **Commercial Refrigeration products**		**PS 35 bar [508 psi]**	**PS 42bar [609 psi]**	**PS 46 bar [667 psi]**
Solenoid Valves	EVR 2, EVR 3	▨	▨	▨
	EVRH 6 - EVRH 15	▨	▨	▨
Thermostatic expansion valves	TU	▨ **34 bar**		
Shutoff Valves (Ball Valves)	GBC	▨	▨	▨ **45 bar**
Check Valves	NRV	▨	▨	▨
	NRVH	▨	▨	▨
Electrically operated expansion valve	AKV 10 - AKV 15 (type A, B, C)	▨	▨	
Filter drier	DCRH	▨	▨	▨
	DCR	▨		
	DML	▨	▨	
Moisture indicator	SGN	▨		
Pressure controls	KP6	▨	▨	
Pressure transmitters	AKS 3000	▨	▨	▨

Controllers for CO_2 systems:

Case controllers	AKC 114A, AKC 115A, AKC 116A
	EKC 414A, EKC 414A1, AK-CC 550
	AK-CC 750
Evaporator controllers	EKC 315A, EKC 316, EKD 316, EKC 312
Pack controllers	EKC 331T, AK-PC 530, AK-PC 420, AK-PC 730, AK-PC 840, AK-CH 650

▨ The product can be used in standard version.
All products are CE approved

Coils for solenoid valves



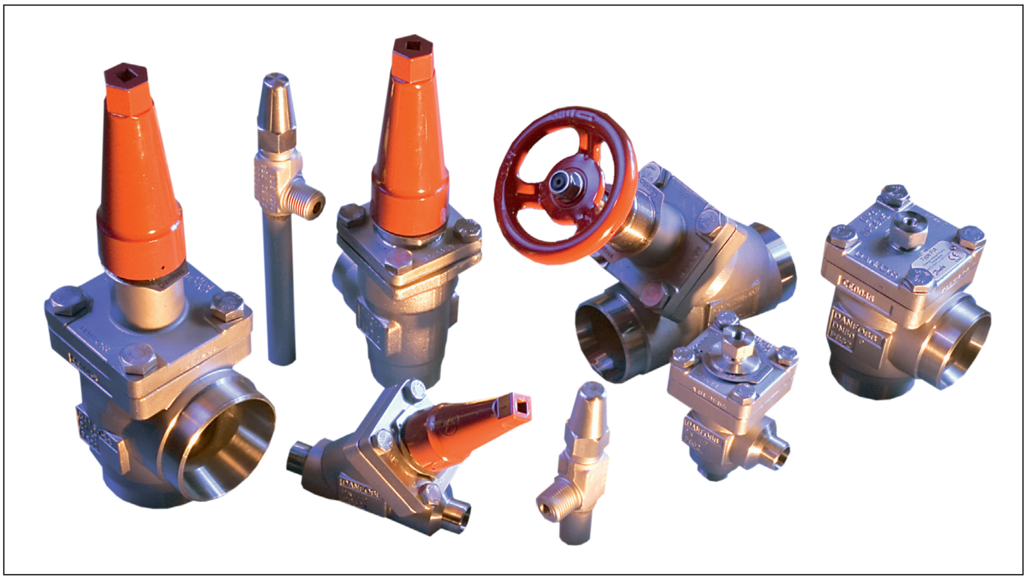
Due to the high pressure difference between the condenser and evaporator, the Maximum Opening Pressure Differential (MOPD) requirement for the solenoid valve in some applications may exceed the standard coil capabilities.

Examples of typical applications are:

- Liquid injection for cooling the compressor
- Hot gas defrost
- Shutoff valve before expansion valve

Therefore Danfoss offers a 20 W coil that covers a MOPD range up to 40 bar.
The 20 W coil range includes coils for 24, 110 and 230 V a.c. 50 Hz supply voltages.

16.
Full range of stainless steel products



Surface protection is becoming increasingly important, especially for refrigeration systems in the food industry, where cleaning with strong cleaning agents is common.

Therefore Danfoss offers both angle flow and straight flow versions of stainless steel valves in the sizes DN 15 mm ($^{1}/_{2}$") to DN 125 mm (5") .

■ Stop Valves	SVA-SS
■ Manual regulating valves	REG-SS
■ Stop Check Valves	SCA-SS (only angleway)
■ Check Valves	CHV-SS (only angleway)
■ Filters	FIA-SS
■ Overflow Valves	OFV-SS (only angleway)
■ Needle valves	SNV-SS

This range of valves meets more stringent requirements resulting from:

1. The need for higher protection of external surfaces on valves and fittings
2. The need to accommodate current trends in plant design.

In certain specific areas such as outdoor applications and corrosive atmospheres, such as coastal installations, there is a need for high surface protection to prevent failure due to corrosion.

Today's food safety standards often call for daily cleaning with detergents to protect against bacteria growth, again producing a need for high surface protection.

- Compatible with all common non flammable refrigerants including R717 and non-corrosive gases/liquids dependent on sealing material.
- Optional accessories:

	Vented cap	Handwheel
SVA-SS	X	X
REG-SS	X	
SCA-SS	X	
CHV-SS		
FIA-SS		
OFV-SS	X	

- Designed to give favourable flow conditions.
- Internal backseating enables replacement of the spindle seal while the valve is in service, i.e. under pressure (SVA-SS, REG-SS, SCA-SS, OFV-SS).
- Housing is made of special cold resistant stainless steel approved for low temperature operation.
- Easy to disassemble for inspection and service.
- SVA-SS Stop Valves can accept flow in either direction.
- Butt-weld DIN connections.
- Max. operating pressure:
  52 bar g (754 psig)
- Temperature range:
  -60 to +150°C (-76 to 3020°F).
- Compact and light valves for easy handling and installation.
- Classification: contact your Danfoss sales company for a current product certification list.

17. Appendix

17.1 Typical Refrigeration Systems

Refrigeration systems are basically characterized by the refrigeration cycle and the way of supplying refrigerant to the evaporator. By the refrigeration cycle, industrial refrigeration systems are categorized into three types:

Single-stage system
This is the most basic cycle: compression-condensation-expansion-evaporation.

Two-stage system
In this kind of system, compression is undertaken in two stages, typically by two compressors. Intermediate cooling is often used for optimizing the performance of the system.

Cascade system
This system is actually two basic cycles in cascade. The evaporator in the high temperature cycle acts also as the condenser of the low temperature cycle.

By the way of supplying refrigerant to evaporators, the systems could be categorized into two basic types:

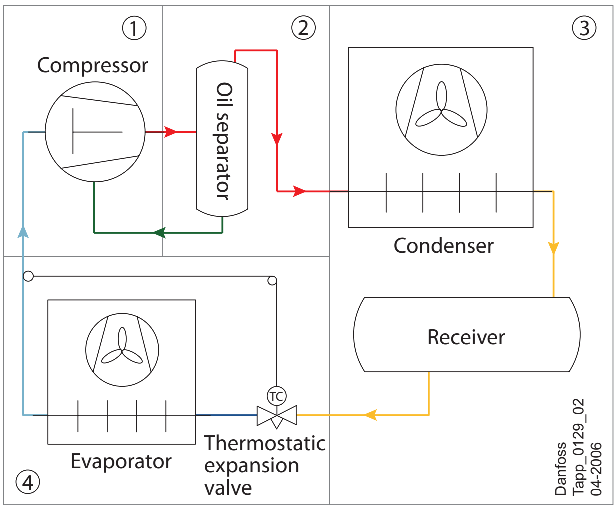
Direct expansion system
The liquid/vapour mixture of refrigerant after expansion is directly fed into evaporators.

Circulated system
The liquid and vapour of refrigerant after expansion are separated in a liquid separator and only the liquid is fed into evaporators. The liquid circulation could be either gravity circulation or pump circulation.

These types of refrigeration systems will be illustrated by some examples:

Single-stage system with direct expansion (DX)

Fig.17.1.1 Single-stage Refrigeration System with Direct Expansion



🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟦 LP vapour refrigerant
🟩 Oil

① Compressor control zone
② Oil control zone
③ Condenser control zone
④ Evaporator control zone

Single-stage refrigeration system with direct expansion is the most basic refrigeration system, which is very popular in air conditioning and small refrigeration systems, fig.17.1.1. The refrigeration cycle is: low pressure vapour refrigerant is compressed by the compressor into the condenser, where the high-pressure vapour condensates into high pressure liquid. The high-pressure liquid then expands through the thermal expansion valve into the evaporator, where the low pressure liquid evaporates into low-pressure vapour, and will be drawn into the compressor again.

The oil separator and the receiver have nothing to do with the refrigeration cycle, but they are important to the control:
The oil separator separates and collects the oil from the refrigerant, then sends the oil back to the compressor. This oil loop is important to secure safe and efficient running of the compressor, e.g. good lubrication. And oil control (Section 6) is essential for keeping the oil temperature and pressure at an acceptable level.

The receiver could absorb/release refrigerant when the refrigerant contents in different components vary with the load, or some components shut off for service. The receiver could also maintain a supply of liquid refrigerant at constant pressure to the expansion valve.

The thermostatic expansion valve is controlled by the superheat. This is of great importance for the functions of both the evaporator and the compressor:

- By keeping a constant superheat at the outlet of the evaporator, the thermostatic expansion valve supplies the right flow of liquid refrigerant to the evaporator according to the load.
- A certain superheat could ensure that only vapour enters the compressor suction. Liquid droplet in the suction will cause liquid hammering, which is equivalent to knocking in a motor.

Please notice that thermostatic expansion valve can only keep a constant superheat, instead of a constant evaporating temperature. Specifically, if no other controls happen, the evaporating temperature will rise with a load increase and drop with a load decrease. Since a constant evaporating temperature is the aim of refrigeration, some other controls are also necessary, e.g. compressor control and evaporator control. The **compressor control** could adjust the refrigeration capacity of the system, and the **evaporator control** could secure a right flow of refrigerant to the evaporator. Details of these two kinds of controls can be seen in Section 2 and Section 5, respectively.

Theoretically, the lower the condensing temperature, the higher the refrigeration efficiency is. But in a direct expansion system, if the pressure in the receiver is too low, the pressure difference across the expansion valve will be too low to provide enough flow of refrigerant. Therefore, controls should be designed to prevent a too low condensing pressure, if the condensing capacity of a direct expansion system is possible to vary too much. This is discussed in **Condenser Controls** (Section 3).

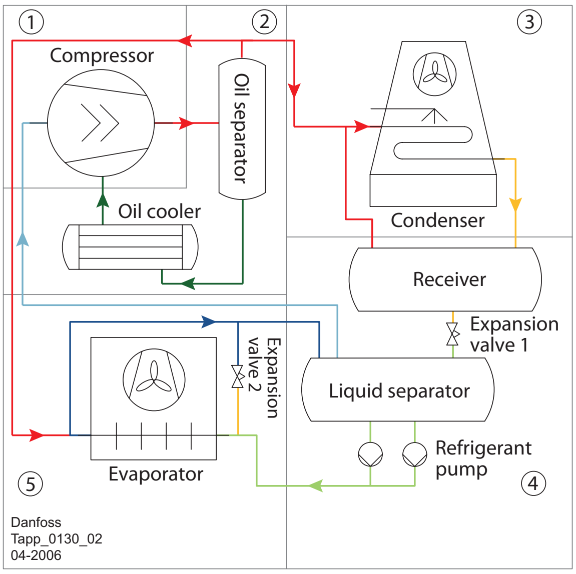
The main drawback of direct expansion is the low efficiency. Since a certain superheat has to be maintained:

- Part of the heat transfer area in the evaporator is occupied by vapour, and the heat transfer efficiency is lower.
- The compressor consumes more power to compress the superheated vapour than the saturated vapour.

This drawback becomes especially terrible in a low-temperature refrigeration plant or a large refrigeration plant. In these refrigeration systems, circulated system with pump circulation or natural circulation is designed in order to save energy.

Single-stage system with pump circulation of refrigerant

Fig.17.1.2 Single-stage Refrigeration System with Pump Circulation and Hot Gas Defrost



Danfoss
Tapp_0130_02
04-2006

🟥 HP vapour refrigerant
🟨 HP liquid refrigerant
🟦 Liquid/vapour mixture of refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant
🟩 Oil

① Compressor control zone
② Oil control zone
③ Condenser control zone
④ Liquid level control zone
⑤ Evaporator control zone

The circuit for a single-stage refrigeration system as shown in figure 17.1.2 has many similarities to the DX system shown in figure 17.1.1. The main difference is that in this system the refrigerant vapour entering the compressor suction is saturated vapour instead of superheated vapour.

This is caused by the installation of a liquid separator between the evaporator and the compressor. In the liquid separator the liquid from the liquid/vapour mix comes partly from the evaporator and partly from expansion valve 1. Only saturated vapour will pass to the compressor suction whilst only liquid is fed by the refrigerant pumps to the evaporator.

As the suction vapour is not superheated, the evaporation temperature will be lower than in a DX system. Due to the lower evaporation temperature the compressor will work more efficiently. The evaporator will provide more capacity as its surface area is used totally for cooling and not partially to superheat the refrigerant. Therefore a circulation system is more efficient than a corresponding DX system.

The line between the condenser inlet and the receiver is intended for pressure equalisation to ensure that the condensing liquid from the condenser can run to the receiver without problems.

In pump circulation systems it is important to keep the pump running, i.e. that the pump operation is not unintentionally interrupted. Therefore pump control is important to ensure that the pump has the correct pressure difference, that a constant supply of liquid is ensured and that the condition of the pump is not compromised. This subject is discussed in Section 7.

In circulation systems there is no superheating which can be used as a control variable for a thermostatically controlled expansion valve operation.

Expansion Valve 1 is usually controlled by the level in the liquid separator or sometimes by the level in the receiver/condenser. This is also called liquid level control, which is discussed in Section 4.

If the evaporators are of a fin and tube design and used with air and if the evaporation temperature is below 0°C, a layer of frost/ice builds up on the evaporator surface which originates from the water/moisture present in the air. This layer must be removed regularly as otherwise it will restrict the evaporator airflow and reduce the evaporator capacity.

Possible defrosting methods are hot gas, electrical heat, air and water. In figure 18.1.2 hot gas is used for defrosting. Part of the hot gas from the compressor is led to the evaporator for defrosting.

The hot gas warms up the evaporator and melts the ice layer on the evaporator and simultaneously the hot gas condenses and becomes high-pressure liquid. Using an overflow valve, this high-pressure liquid can be returned to the liquid separator in the suction pipe.

Hot gas defrosting can only be used in systems that contain at least three parallel evaporators.

During defrosting, at least two of the evaporators (by capacity) must be cooling and a maximum of one evaporator should be defrosting – otherwise there is insufficient hot-gas available for the defrosting process.

The method for switching between refrigeration and defrosting cycles is discussed in the section on evaporator control (Section 5).

Two-stage system

A typical two-stage system is shown in fig 17.1.3. Part of the liquid refrigerant from the receiver first expands into the intermediate pressure, and evaporates to cool the other part of liquid refrigerant in the intermediate cooler.

The intermediate-pressure vapour is then directed into the discharge line of the low-stage pressure, cools the low-stage discharge vapour, and enters the high-stage compressor.

The power used to compress this part of vapour from the suction pressure into the intermediate pressure is saved and the discharge temperature of the high-stage compressor is lower.

So the two-stage system is especially suitable for low-temperature refrigeration system, for the high efficiency and low discharge temperature.

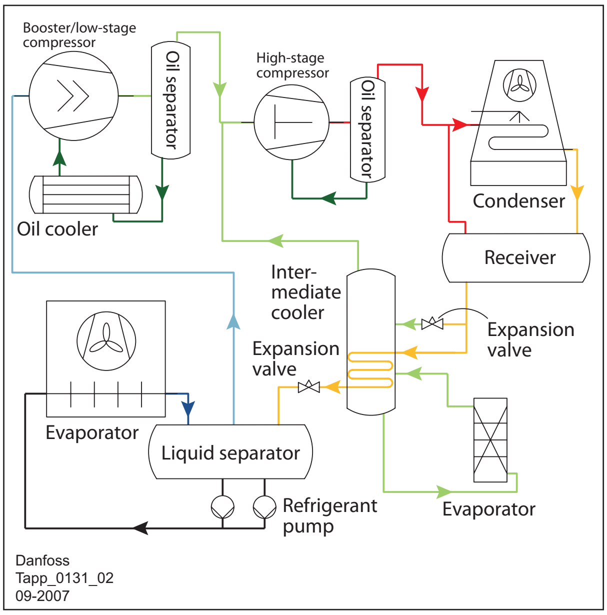
The intermediate cooler could also supply refrigerant to intermediate-temperature evaporators. In fig. 17.1.3, the intermediate supply refrigerant to the plate type evaporator by gravity circulation.

Compared with pump circulation, gravity circulation is driven by the thermosyphon effect in the evaporator, instead of the pump. Natural circulation is simpler and more reliable (on pump failure), but the heat transfer is generally not as good as the pump circulation.

Two-stage system could be theoretically effective. However, it difficult to find a kind of refrigerant that is suited for both the high temperature and the low temperature in low-temperature refrigeration systems.

At high temperatures, the refrigerant pressure will be very high, posing high requirement on the compressor. At low temperatures, the refrigerant pressure may be vacuum, which leads to more leakage of air into the system (the air in the system will reduce heat transfer of the condenser, see Section 9.3). Therefore, cascade system may be a better choice for low refrigeration system.

Fig.17.1.3 Two-stage Refrigeration System



- 🟥 HP vapour refrigerant
- 🟨 HP liquid refrigerant
- 🟦 Liquid/vapour mixture of refrigerant
- 🟦 LP vapour refrigerant
- ⬛ LP liquid refrigerant
- 🟩 Intermediate pressure liquid refrigerant
- 🟩 Intermediate pressure vapour refrigerant
- 🟩 Other media (oil, water, etc.)

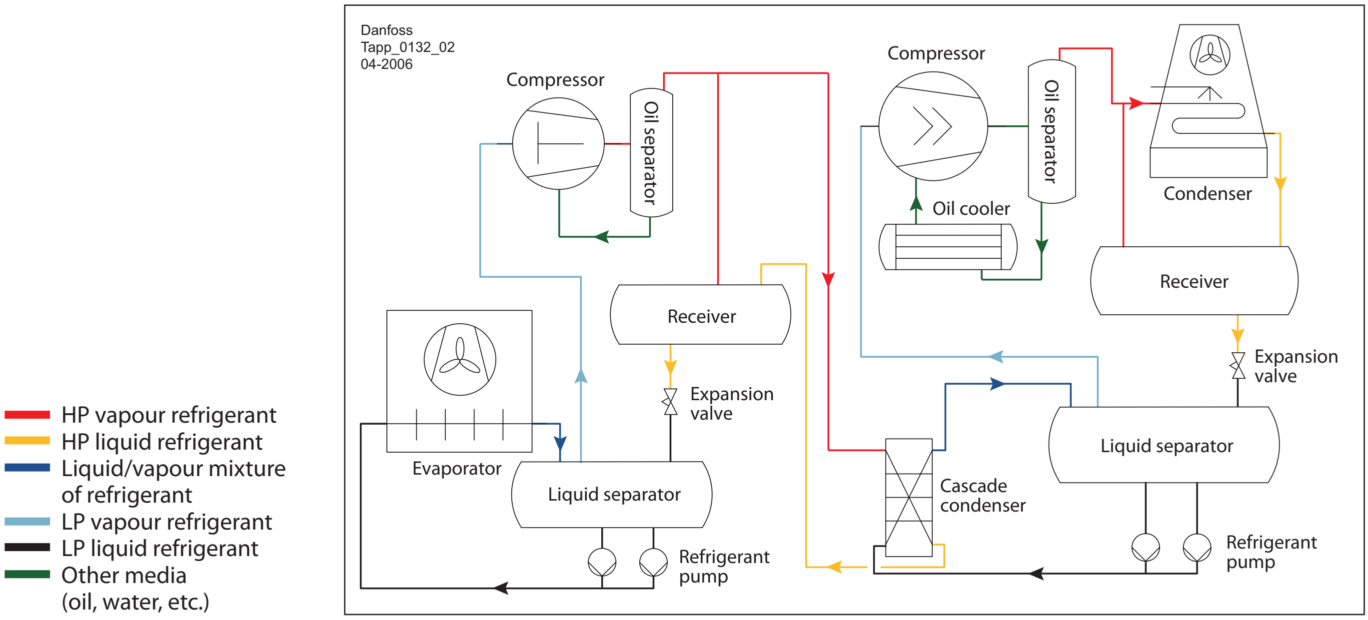
Cascade system

A cascade system consists of two separate refrigeration circuits, as shown in fig. 17.1.4. A cascade condenser interconnected the two circuits by acting as both the condenser of the high temperature circuit and the evaporator of the low temperature circuit.

The refrigerant for the two circuits could be different, and optimized for each circuit. For example, the refrigerant could be NH_3 for the high temperature circuit and CO_2 for the low temperature circuit.

This CO_2/NH_3 system needs less charge of ammonia and proves to be more efficient in low temperature refrigeration than a similar two-stage ammonia system.

Fig.17.1.4 Cascade Refrigeration System



18. ON/OFF and modulating controls

Detailed below is the basic theory for ON/OFF and modulating control. The intension is to provide a basci understanding of control theory and the technical terms used. Furthermore some practical advice will also be given.

Abbreviations and definitions

P	Proportional
I	Integration
D	Derivative
PB	Proportional Band [%] in a P, PI or PID controller. Number in percent, that Process variable (PV),has to change, in order for the controller to change the output (y) from 0 to 100 %
K_p	Amplification factor in a P, PI or PID controller
T_i	Integration time [s] in a PI or PID controller
T_d	Differential time [s] in a PID controller
PID	A typical controller that includes both P, I and D functions
SP	Set point
PV	Process Variable (the controlled parameter: temperature, pressure, liquid level, etc)
offset (x)	Difference between Set point (SP) and Process Variable (PV)
y	Calculated output of a controller.
dead time	If Process Variable (PV) measurement is physically mounted thus the signal is always has a time delay , compared to if Process Variable (PV) measurement was installed locally without time delay.

References

[1] Reguleringsteknik, Thomas Heilmann / L. Alfred Hansen

18.1
ON/OFF control

In some cases a control application in practice can be achived with ON/OFF control. This means that the regulating device (valve, thermostat) only has two positions:,contacts closed or open This control principle is called ON/OFF control. Historically ON/OFF was employed widely within refrigeration, particularly in refrigerators equipped with thermostats.

However ON/OFF principles can also be used in advanced systems where PID principles are used. E.g. is an ON/OFF valve (i.e. Danfoss type AKV/A) used to control superheat with PID available parameters on the dedicated electronic controller. (Danfoss type EKC 315A)

An ON/OFF controller will only react within some given limit values, like e.g. Max and Min. Outside these limit values an ON/OFF controller can not carry out any action.

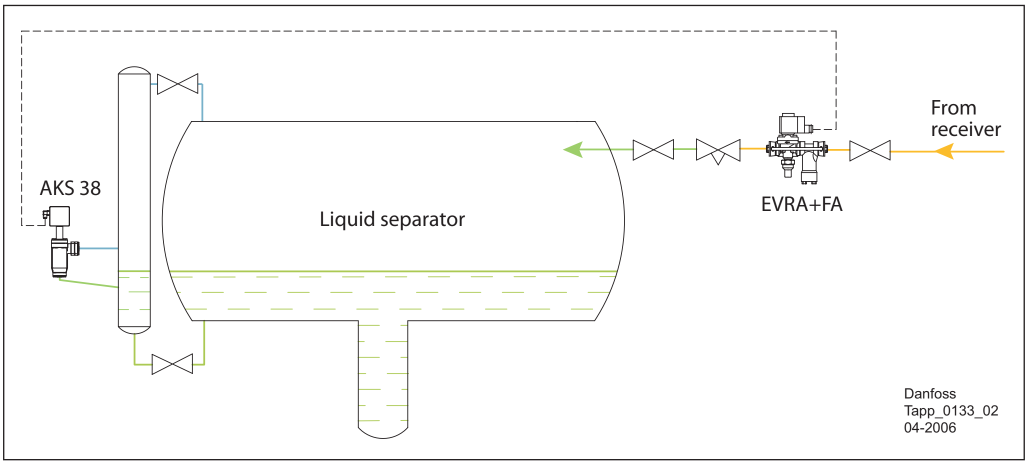
Normally ON/OFF is used because:

- Low price, less complicated system, no feedback loop.
- It can be accepted that PV varies a little from SP, along with that the ON/OFF device is operating.
- The process has so big capacity that the ON/OFF operation does not have any influence on PV
- In systems with dead time, ON/OFF control can be advantageous

In ON/OFF systems you will have a feed back, as for modulating systems, but, characteristic of ON/OFF systems is that PV varies and the system is not able to eliminate any offset.

Application example 18.1.1
ON/OFF control

To control liquid level between a minimum and a maximum level an ON/OFF device can be used like Danfoss type AKS 38. AKS 38 is a float switch that can control the switching of ON/OFF solenoid valves.



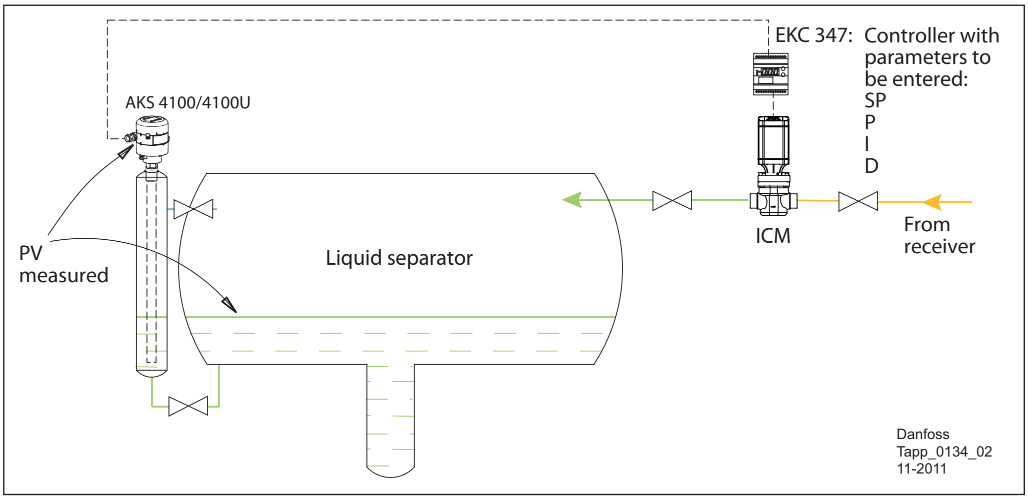
🟨 HP liquid refrigerant
🟦 LP vapour refrigerant
🟩 LP liquid refrigerant

18.2 Modulating control

The main difference between modulating controls and ON/OFF systems is that modulating systems will constantly react when there is a change of PV.

Furthermore electronic controller provide the flexibility to change different control parameters, like P, I and D. This gives a high degree of flexibility which again is very useful because the controller can then be adjusted to suit different applications.

Application example 18.2.1
ON/OFF control

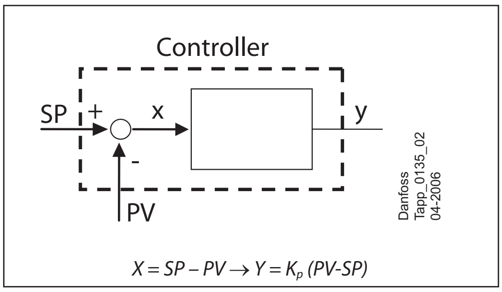


🟨 HP liquid refrigerant
🟩 LP liquid refrigerant

Basic P, I and D principles
Generally, in most common controllers there is the facility to adjust parameters for P, PI, or PID settings

- In a P controller it is possible to adjust: PB or K_p;
- In a PI controller it is possible to adjust: PB or K_p and T_i;
- In a PID controller it is possible to adjust: PB or K_p and T_i and T_d.

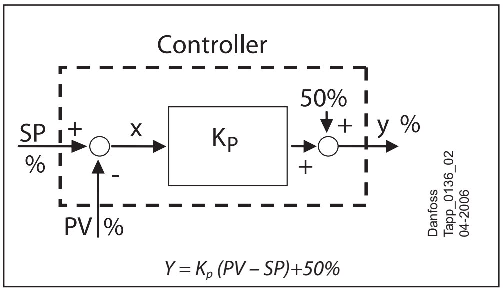
P-controller
In every controller a P component exists. In a P-controller there is a linear relation between input and output.



$X = SP - PV \rightarrow Y = K_p\ (PV\text{-}SP)$

Practical P-controllers are designed so when SP=PV the controller must give an output that corresponds to the normal load of the system.

Normally this means that the output will be 50 % of max output. E.g. a motorized valve will over time run in 50 % opening degree in order to maintain SP.



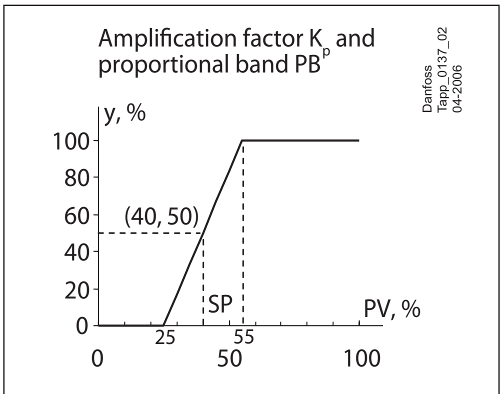
$Y = K_p\ (PV - SP) + 50\%$

Some controllers do not use PB, but K_p.
The relation between PB and K_p is:
$PB[\%] = 100/K_p$

Please observe that PB can be bigger than 100%, corresponding to that K_p is less than 1.

18.2
Modulating control
(continued)

P-controller (continued)



SP = 40%, PB = 30% (K_p = 3.33)

When PV = SP = 40% the regulator gives an output (y) of 50%. (This means that the valve has an opening degree of 50%).

If PV increases to 46%, there is a deviation between PV and SP of 6%. As Kp is assumed to be 3.33, a deviation of 6% means that output increases by 6% x 3.33 = 20%, i.e. if PV rises to 46%, the output increases to 50% + 20% = 70%.

The deviation of the 6% is a deviation that a P regulator cannot overcome. The resulting deviation stems from the basic function of a P regulator.

In order to achieve a minimum deviation it is important that the regulation device (the valve) is shaped so that the output (y) from the regulator can control the process so that it is equal to the standard average load. Then the deviation will always be as small as possible and will in time approach zero.

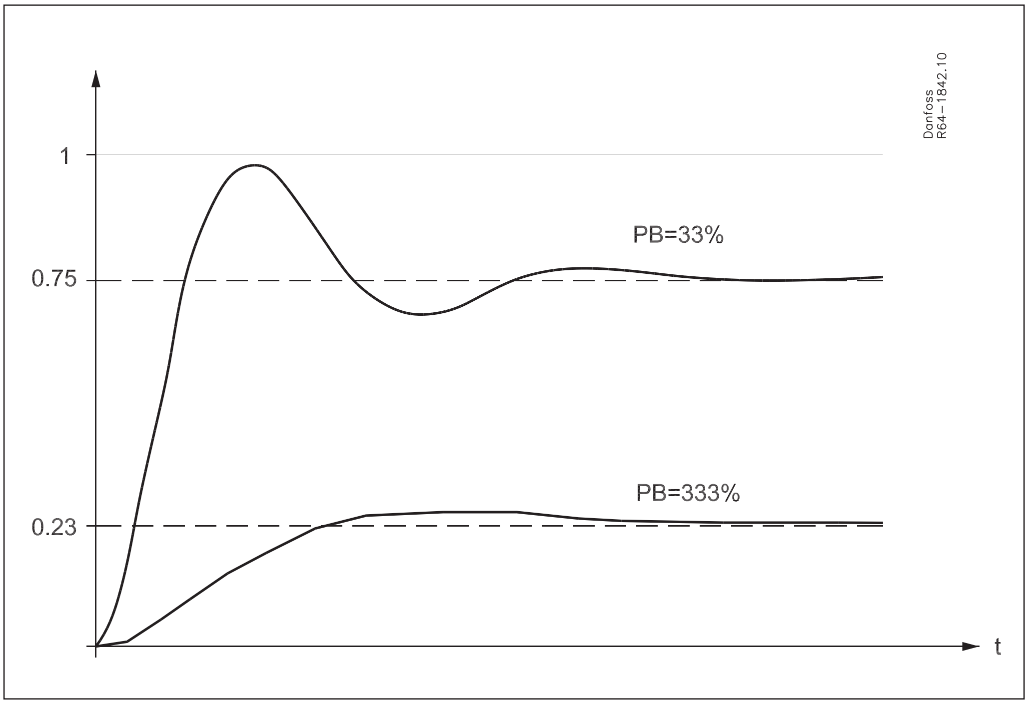
P-controller adjustment characteristics
P is the primary control component. In most cases, P will create a permanent offset that can be insignificant small, but also unacceptable big. However a P control is better than none (no feedback, no closed loop).

Change of PB has two important effects:

- Smaller PB (bigger amplification) gives less offset, i.e. better effect against load changes, but also increased tendency to fluctuations.
- Bigger P-band (smaller amplification) gives more offset, but less tendency to fluctuations.
- Smaller PB means that theoretically the control is approaching ON/OFF operation.

Below drawing is of universal validity for straight forward P controlled loop.

It shows the different responses by a loop having PB = 33% and PB = 333% when the P controlled loop is influenced by SP is changed by +1 unit.



18.2
Modulating control
(continued)

I-controller
The most important characteristic for an I-controller is that it eliminates offset, and that is why it is used. I-controller continues to change its output as long as offset exists. However the ability to fully remove offset is linked to that it in practice, is proportioned correctly.

I-controller's good property to remove offset has also a negative action: It will increase the tendency to fluctuations in a control loop.

Basically the tendency to fluctuations is worse for an I-controller than a P-controller.

The ability to counteract on load changes is slower for an I-controller than a P-controller.

PI controller
The combination of advantages and disadvantages for both P and I makes it advantageous to combine P and I into a PI-controller.

In a PI controller it would be possible to adjust: PB and T_i. T_i is normally entered in seconds or minutes.

When T_i has to be entered, it has to be compromise between stability and elimination of offset.

Decreased T_i (bigger integration influence) means faster elimination of offset, but also increased tendency to fluctuations.

D-controller
The most important characteristic for a D-controller (derivative) is that it can react on changes. This also means that if a constant offset is present, a D-controller will not be able to do any action to remove the offset. D-component makes the system fast respond on load changes.

D effect improves stability and makes the system faster. It does not have any significance for offset, but it works to make tendency to fluctuations smaller. D reacts on changes in the error and the loop reacts faster against load changes than without D. The fast reaction on changes means a damping of all fluctuations.

In controllers with D influence the T_d can be adjusted. T_d is normally entered in seconds or minutes.

It has to be observed not to make T_d too big, as then the influence, when e.g. changing SP, will be too dramatic. During start-up of plants it may be advantageous simply to remove the D influence. (T_d=0)

The above means that a D-controller will never be used alone. Its typical use is in combination as PD or PID with its ability to damp fluctuations.

PID-controller
The combination of all three components into a PID controller has become of general use.

The general guidelines / properties for a PID controller are:

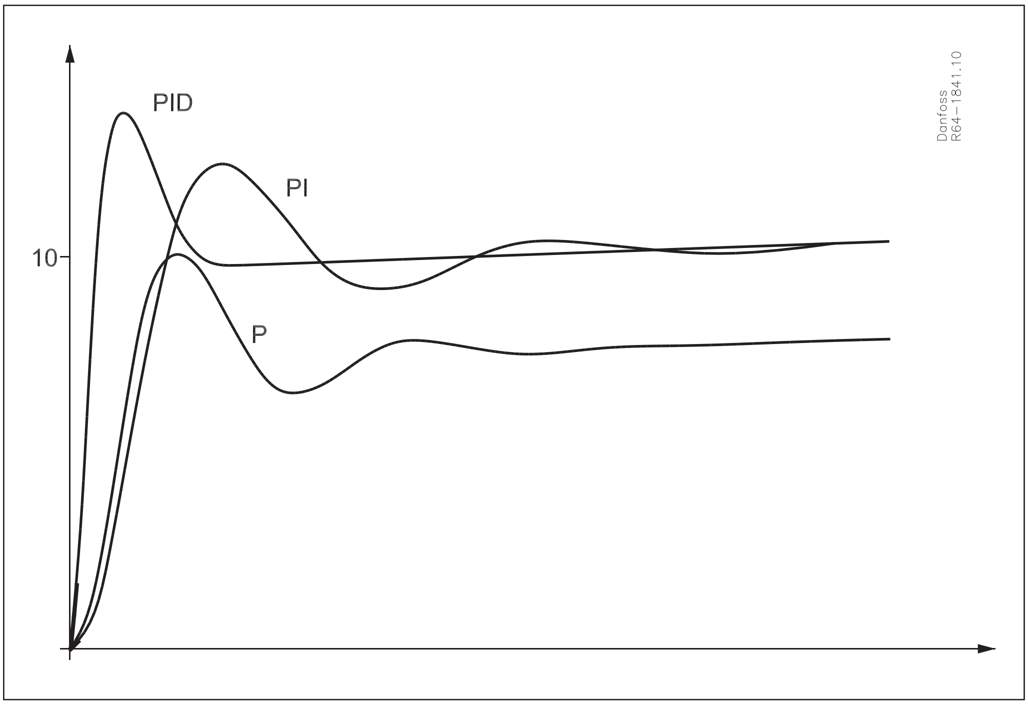
- Decreased PB improves offset (less offset), but the stability is worse;
- I component eliminates offset. Bigger I (less T_i) makes faster elimination of offset.
- I component increases the tendency to fluctuations.
- D component damps the tendency to fluctuations and makes the control faster. Bigger D (bigger T_d) the stronger influence on above, however until a specific limit. A too big T_d will mean that it reacts too strong on sudden changes, and the control loop becomes unstable.

18.2 Modulating control
(continued)

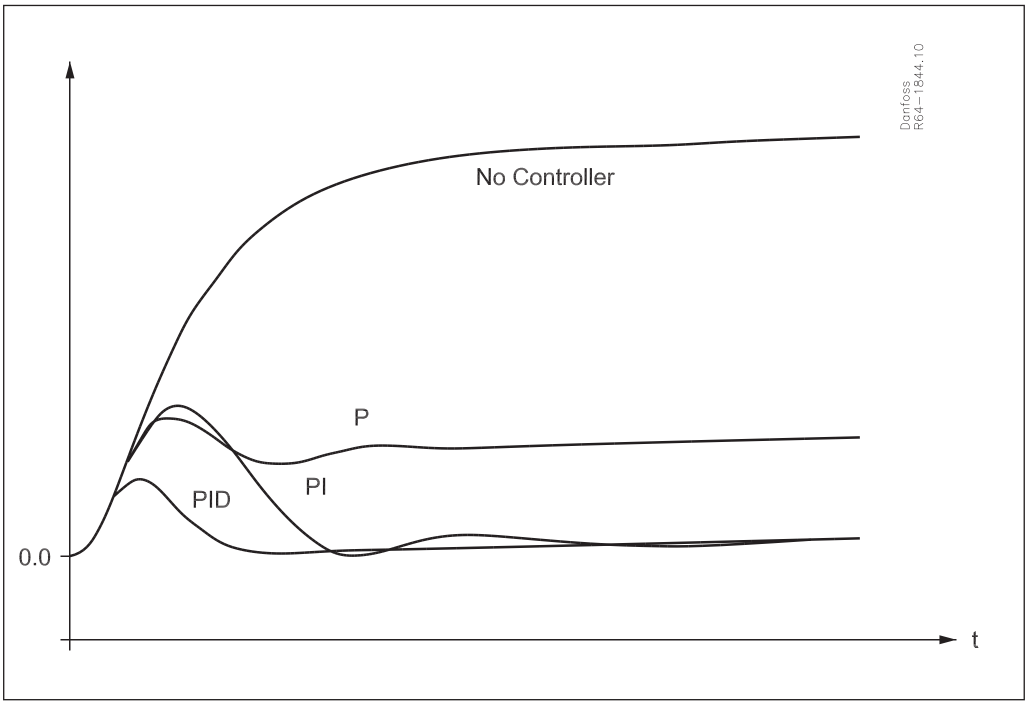
Typical PID transient state curves 1: optimal PID settings

The settings:

	PB	T_i	T_d
P	66.7 %	-	-
PI	100 %	60 s	-
PID	41.7 %	40 s	12 s



Above displays the different controls principles, when is influenced by SP is changed by +1 unit.



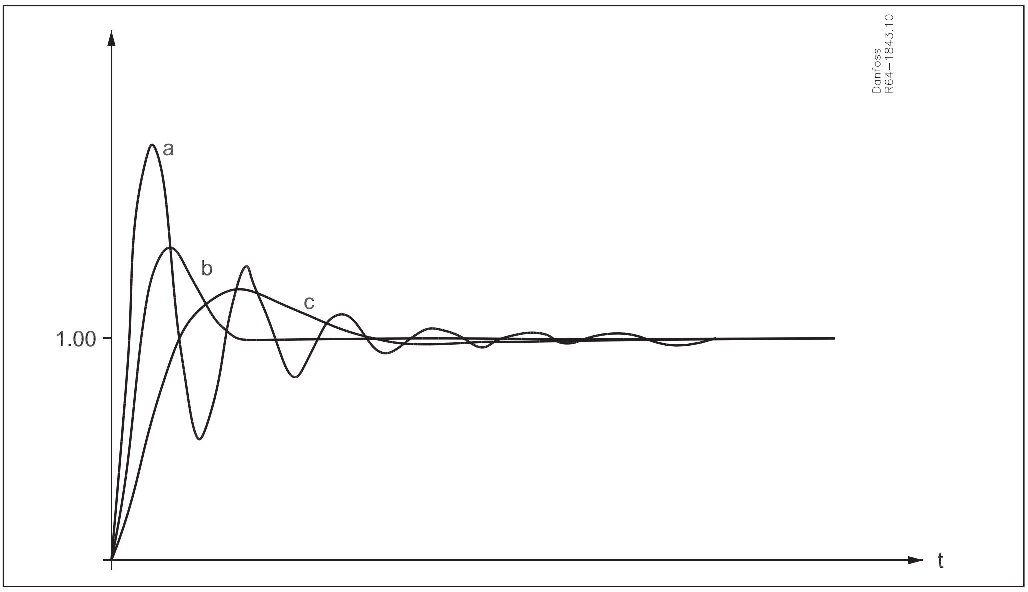
Same settings as above. Exposed to a load change of 1.

18.2
Modulating control
(continued)

Typical PID transient state curves 2: change of PB

The settings:

	PB	T_i	T_d
PID-a	25.0 %	40 s	12 s
PID-b	41.7 %	40 s	12 s
PID-c	83.3 %	40 s	12 s

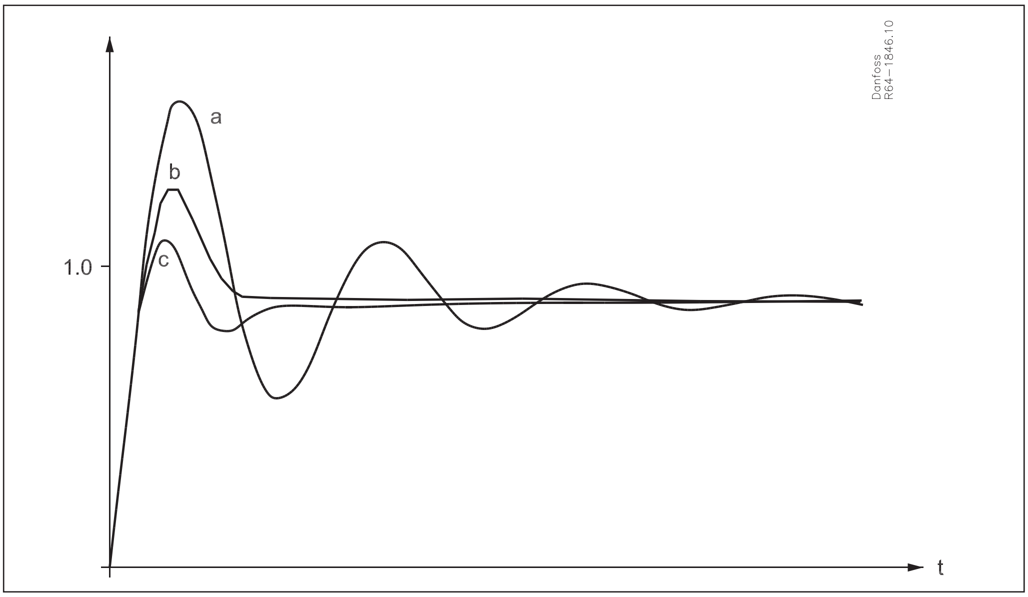


Above shows variation of PB for PID control when is influenced by SP is changed by +1 unit. From above it is clear when PB is too small the systems becomes more unstable (oscillatory). When PB is too big it becomes too slow.

Typical PID transient state curves 3: change of T_i

The settings:

	PB	T_i	T_d
PID-a	41.7 %	20 s	12 s
PID-b	41.7 %	40 s	12 s
PID-c	41.7 %	120 s	12 s



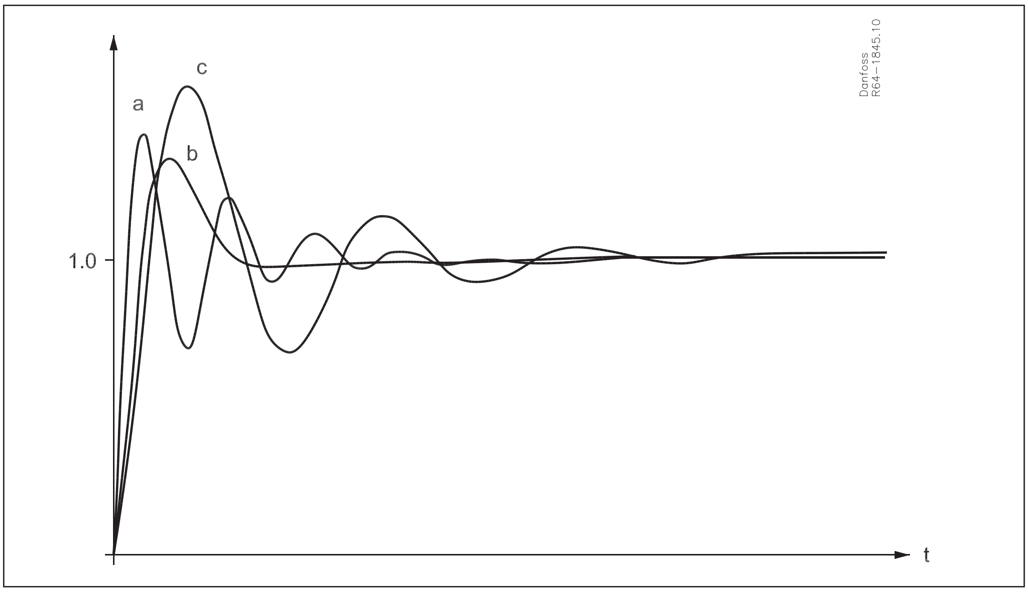
Above shows variation of T_i for PID control when is influenced by SP is changed by +1 unit. From above it is clear when T_i is too small the systems becomes more unstable (oscillatory). When Ti is too big it takes a very long time to eliminate the last offset.

18.2
Modulating control
(continued)

Typical PID transient state curves 4: change of T_i

The settings:

	PB	T_i	T_d
PID-a	41.7 %	40 s	24 s
PID-b	41.7 %	40 s	12 s
PID-c	41.7 %	40 s	6 s



Above shows variation of T_d for PID control when is influenced by SP is changed by +1 unit. From above it is clear when T_d is either too small or too big compared to the optimal (T_d=12) the systems become more unstable (oscillatory).

Reference Documents - Alphabetical overview

Type	Title	Technical leaflet / Manual	Product instruction	
AKD 102	Variable speed drive	PD.R1.B	MG.11.L	
AKS 21	Temperature sensor	RK.0Y.G	RI.14.D	
AKS 32R	Pressure transmitter	RD.5G.J	PI.SB0.A	
AKS 33	Pressure transmitter	RD.5G.H	PI.SB0.A	
AKS 38	Float switch	PD.GD0.A	RI.5M.A	
AKS 4100/4100U	Liquid level sensor	PD.SC0.C	PI.SC0.D	PI.SC0.E
AKVA	Electrically operated expansion valve	PD.VA1.B	PI.VA1.C	PI.VA1.B
AMV 20	Three point controlled actuator	ED.95.N	EI.96.A	
BSV	Safety relief valve	RD.7F.B	RI.7F.A	
CVC	Pilot valves for servo operated main valve	PD.HN0.A	RI.4X.L	
CVP	Pilot valves for servo operated main valve	PD.HN0.A	PI.HN0.C	
CVPP	Pilot valves for servo operated main valve	PD.HN0.A	PI.HN0.C	
CVQ	Pilot valves for servo operated main valve	PD.HN0.A	PI.VH1.A	
DCR	Filter drier	PD.EJ0.A	PI.EJ0.B	
DSV	Double stop valve (for safety valve)	PD.IE0.A	PI.IE0.A	RI.7D.A
EKC 202	Controller for temperature control	RS.8D.Z	RI.8J.V	
EKC 315A	Controller for control of industrial evaporator	RS.8C.S		
EKC 331	Capacity controller	RS.8A.G	RI.8B.E	
EKC 347	Liquid level controller	RS.8A.X	RI.8B.Y	
EKC 361	Controller for control of media temp.	RS.8A.E	RI.8B.F	
EVM	Pilot valves for servo operated main valve	PD.HN0.A	RI.3X.H	
EVRA / EVRAT	Solenoid valve	PD.BM0.B	RI.3D.A	
FA	Strainer	PD.FM0.A	RI.6C.A	
FIA	Filter	PD.FN0.A	PI.FN0.A	
GPLX	Gas powered stop valve	PD.BO0.A	RI.7C.A	
HE	Heat exchanger	RD.6K.A	RI.6K.A	
ICF	Control solution	PD.FT0.A	PI.FT0.A	
ICM / ICAD	Motor operated valve	PD.HT0.B	PI.HT0.A	PI.HT0.B
ICS	Servo operated valve	PD.HS0.A	PI.HS0.A	PI.HS0.B
KDC	Compressor discharge valve	PD.FQ0.A	PI.FQ0.A	
LLG	Liquid level glass	PD.GG0.A	RI.6D.D	
MLI	Sight glass	PD.GH0.A	PI.GH0.A	
MP 55 A	Differential pressure control	RD.5C.B	RI.5C.E	
NRVA	Check valve for ammonia	RD.6H.A	RI.6H.B	
OFV	Overflow valve	PD.HQ0.A	PI.HX0.B	
ORV	Oil regulating valve	PD.HP0.B	PI.HP0.A	
PMFL / PMFH	Modulating liquid level regulator	PD.GE0.C	RI.2C.F	PI.GE0.A
PMLX	Solenoid valve, two-step on/off	PD.BR0.A	RI.3F.D	RI.3F.C
POV	Pilot operated internal safety valve	PD.ID0.A	PI.ID0.A	
QDV	Quick oil drain valve	PD.KL0.A	PI.KL0.A	
REG	Hand regulating valve	PD.KM0.A	PI.KM0.A	
RT 107	Differential thermostat	RD.5E.A		
RT 1A	Pressure control, differential pressure control	PD.CB0.A	RI.5B.C	
RT 260A	Pressure control, differential pressure control	PD.CB0.A	RI.5B.B	
RT 5A	Pressure control, differential pressure control	PD.CB0.A	RI.5B.C	
SCA	Stop check valve / check valve	PD.FL0.A	PI.FL0.A	
SFA	Safety relief valve	PD.IF0.A	PI.IB0.A	
SGR	Sight glass	PD.EK0.A	PI.EK0.A	
SNV	Stop needle valve	PD.KB0.A	PI.KB0.A	
SV 1-3	Modulating liquid level regulator	PD.GE0.B	PI.GE0.C	
SV 4-6		PD.GE0.D	RI.2B.B	
SVA	Stop valve	PD.KD0.A	PI.KD0.B	
TEA	Thermostatic expansion valve	RD.1E.A	PI.AJ0.A	
TEAT		RD.1F.A	PI.AU0.A	
VM 2	Pressure balanced valve	ED.97.K	VI.HB.C	
WVS	Water valve	PD.DA0.A	PI.DA0.A	

To download the latest version of the literature please visit the Danfoss internet site
http://www.danfoss.com/Products/Literature/RA_Documentation.htm

Notes

Notes


HTRS AMMONIA
HTRL AMMONIA
GPV
AU7-04
ICS 25-15
027H2203
Function module
ICF 20-6-2
RD&S

The Danfoss components for the refrigeration and air conditioning industry

Danfoss Refrigeration & Air Conditioning is a worldwide manufacturer with a leading position in industrial, commercial and supermarket refrigeration as well as air conditioning and climate solutions.

We focus on our core business of making quality products, components and systems that enhance performance and reduce total life cycle costs – the key to major savings.

We are offering a single source for one of the widest ranges of innovative refrigeration and air conditioning components and systems in the world. And, we back technical solutions with business solution to help your company reduce costs, streamline processes and achieve your business goals.

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