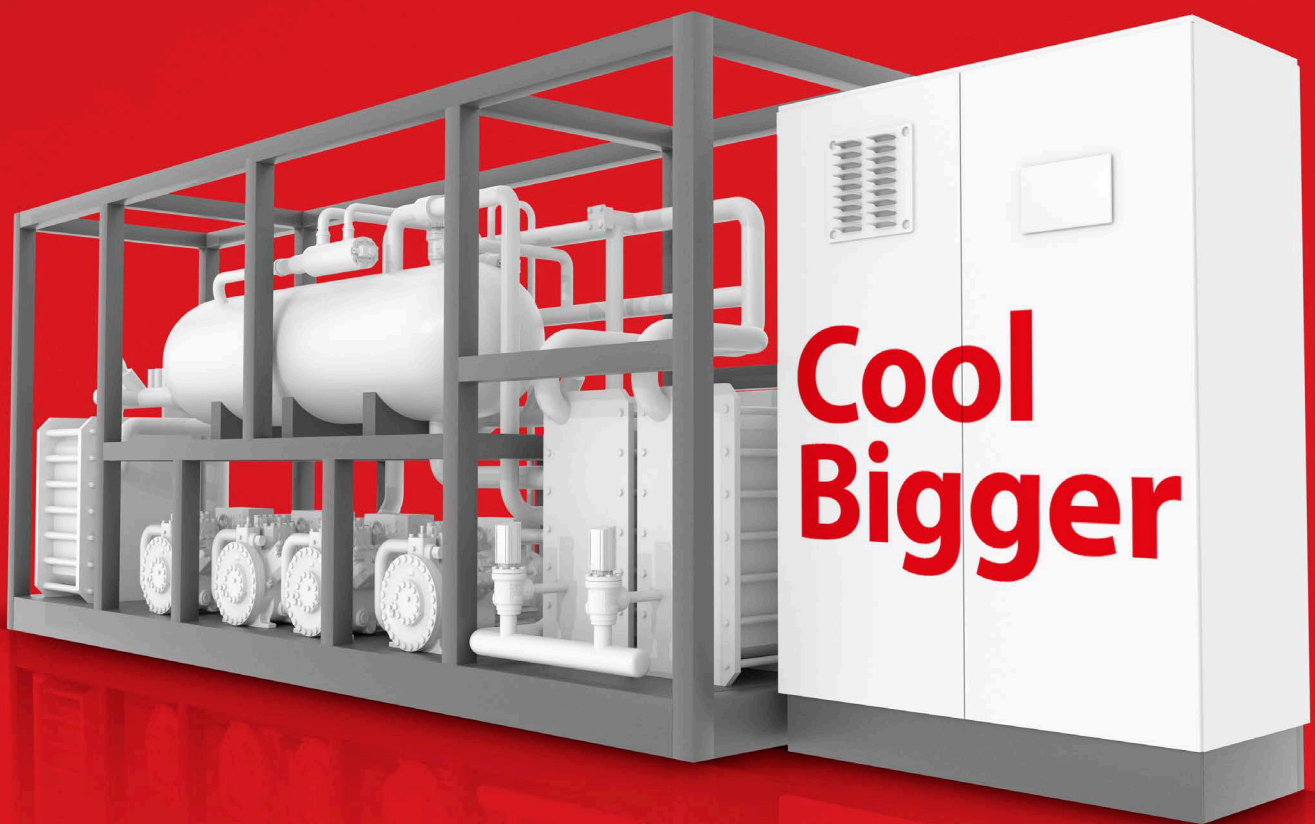


Designs of Large **Industrial** **Transcritical CO₂** Pump Circulating Systems

Paper based on a previous IP.com study. (IP.com Number: IPCOM000271079D)

This document describes how a transcritical CO₂ system, i.e., single or multiple transcritical CO₂ racks, can be connected to subcritical CO₂ pump circulated systems or a combination of pump circulating systems and DX systems. The transcritical CO₂ racks and pump circulating systems must be physically connected both hardware-wise (valves/pipes) and control-wise (sub/transcritical controls and overall system coordination).



FORWARD
CO₂ REFRIGERATION SOLUTIONS
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Abbreviations used in this document

MT:

Medium temperature level, referring to liquid supply temperatures between approximately -5 to -20 degrees Celsius.

LT:

Low-temperature level, referring to liquid supply temperatures lower than -20 degrees Celsius.

IT:

Intermediate temperature level, referring to liquid supply temperatures in the intermediate receiver, between approximately +8 to -5 degrees Celsius. These temperatures can be even lower in case it is only LT systems. Note that these temperature levels are indications and can differ.

VFD:

Variable Frequency Drive.

ICS+CVP-H. ICS is a Danfoss control pilot valve. The main valve ICS can perform several functions depending on the pilot valve function. CVP-H is a pilot function to control the inlet pressure. In case the inlet pressure of the ICS is lower than the CVP-H pilot valve pressure, the ICS main valve remains closed. If the inlet pressure of the ICS is higher than the CVP-H pilot valve, the ICS valve opens.

ICF + ICFD:

Danfoss liquid drain float module ICFD is used together with an ICF multi-purpose valve. ICFD works as a float module and is used in the condensate drain line. It ensures that only condensed liquid during defrost is returned to the separators and only a minimum of bypass gas. This reduces the power consumption of the refrigeration system.

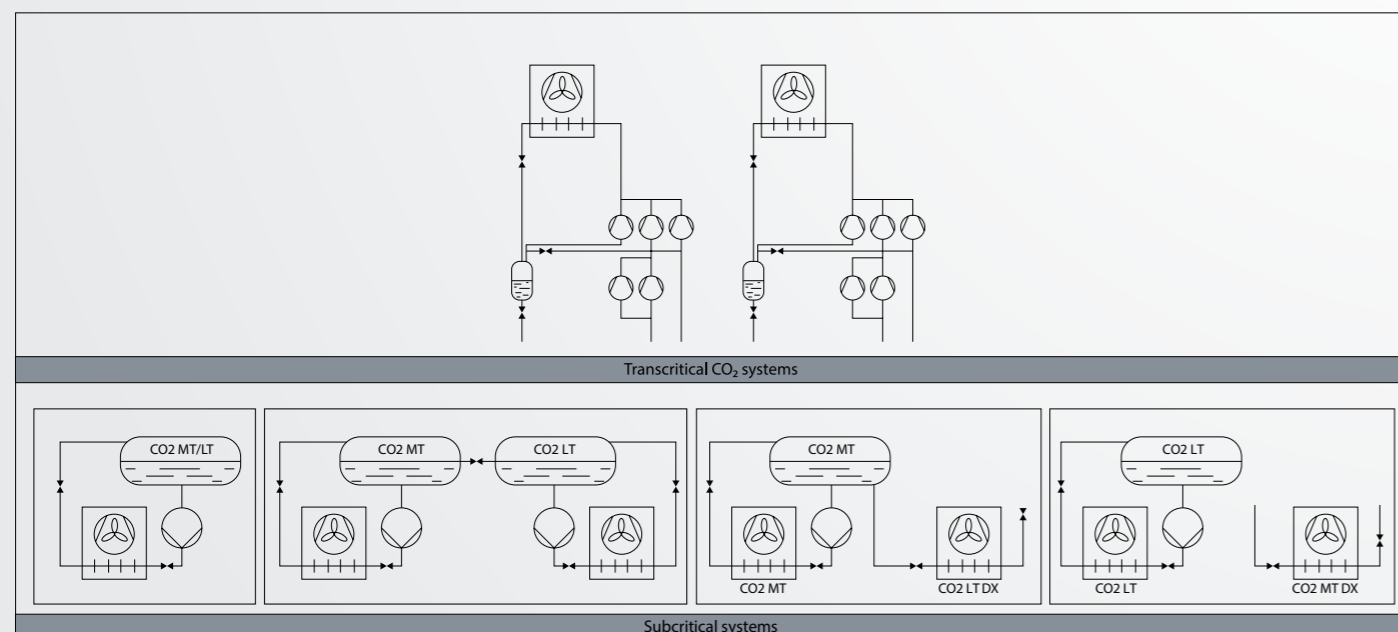
An Introduction to Industrial Refrigeration and Transcritical CO₂ Systems

The Industrial refrigeration segment is not well-defined, but compared to commercial refrigeration systems with direct expansion, there are some significant differences. Considerations like performance, lifetime, reliability, durability, efficiency, safety, and serviceability create different expectations.

Transcritical in application

The well-known pump circulating systems utilized in NH₃ and NH₃/CO₂ plants can be effectively applied to transcritical CO₂ systems. This is partly attributed to the development and maturation of transcritical CO₂ racks in recent years and the availability of larger CO₂ compressors, which have opened the door for larger industrial transcritical CO₂ systems. By leveraging these factors, along with the utilization of pump circulating CO₂ systems, industrial requirements can be met in situations where ammonia is not viable or allowed.

Fig. 1.1 Principle Examples of Transcritical CO₂ Pump Circulating and DX Systems



Several Advantages of Pump Circulating Systems:

- Can handle high peak demands safely and reliably due to the two-phase state and liquid separation.
- Liquid overfeed ensures an optimal internal wetted surface of the evaporator and, thus, utilizes the heat transfer surface of the evaporator optimally, leading to better efficiency.
- Liquid overfeed also creates a better heat transfer coefficient for the evaporator.
- There is no superheat available, so evaporator control is simple.
- No superheat means a lower difference between evaporating temperature and ambient temperature. As the evaporating temperature rises, system efficiency will increase.
- Some evaporators, often very specialized, are not suited for DX operation; thus, pump circulation is necessary.
- Hot gas defrost is the most effective and energy efficient defrost method. It is relatively simple in a pump circulation system because the condensate drain can be easily and safely returned to the CO₂ liquid separators. And when using liquid drain control (i.e., Danfoss ICFD), the defrost efficiency even increases.
- Nevertheless, it is important to note that the initial costs associated with such a system may exceed those of DX systems. Oil must be rectified from the CO₂ separators and returned to the system. Additionally, effective coordination between the pump circulation system and the transcritical racks is essential.
- This document will go in-depth on the control of the hot gas supply pressure required for hot gas defrost and oil distribution, as well as oil management. Furthermore, the transcritical CO₂ design solutions presented in this document will center on the typical standards and requirements of the industrial refrigeration industry.

Technical Considerations

- The transcritical racks in this document can either be seen as mature, standalone readily-available (standard/modular) racks, or dedicated racks, custom-made per application/situation.
- These systems can operate at one, two, or more temperature levels.
- This document discusses two temperature levels, each with dedicated compressor groups. These temperature levels are called medium-temperature MT, low-temperature LT, and intermediate-temperature IT.
- Systems can be LT only, MT only, or both or more temperature levels. The principle of the system remains the same.
- For removing the flash gas from the intermediate temperature (IT) receiver, the racks can be equipped with dedicated intermediate temperature (IT) compressors (also known as parallel compressors) to enhance efficiency. However, for the function, it's not strictly necessary.
- We will look at the transcritical racks as "black boxes" with their own control system.
- CO₂ pump circulation systems are widely recognized and established as a proven technology commonly employed in industrial refrigeration applications. These systems are often integrated with cascade systems where NH₃ serves as the primary refrigerant, although other refrigerants can also be used. The principles underlying pump circulated systems are similar to those utilized in NH₃ systems, making them familiar and widely implemented.

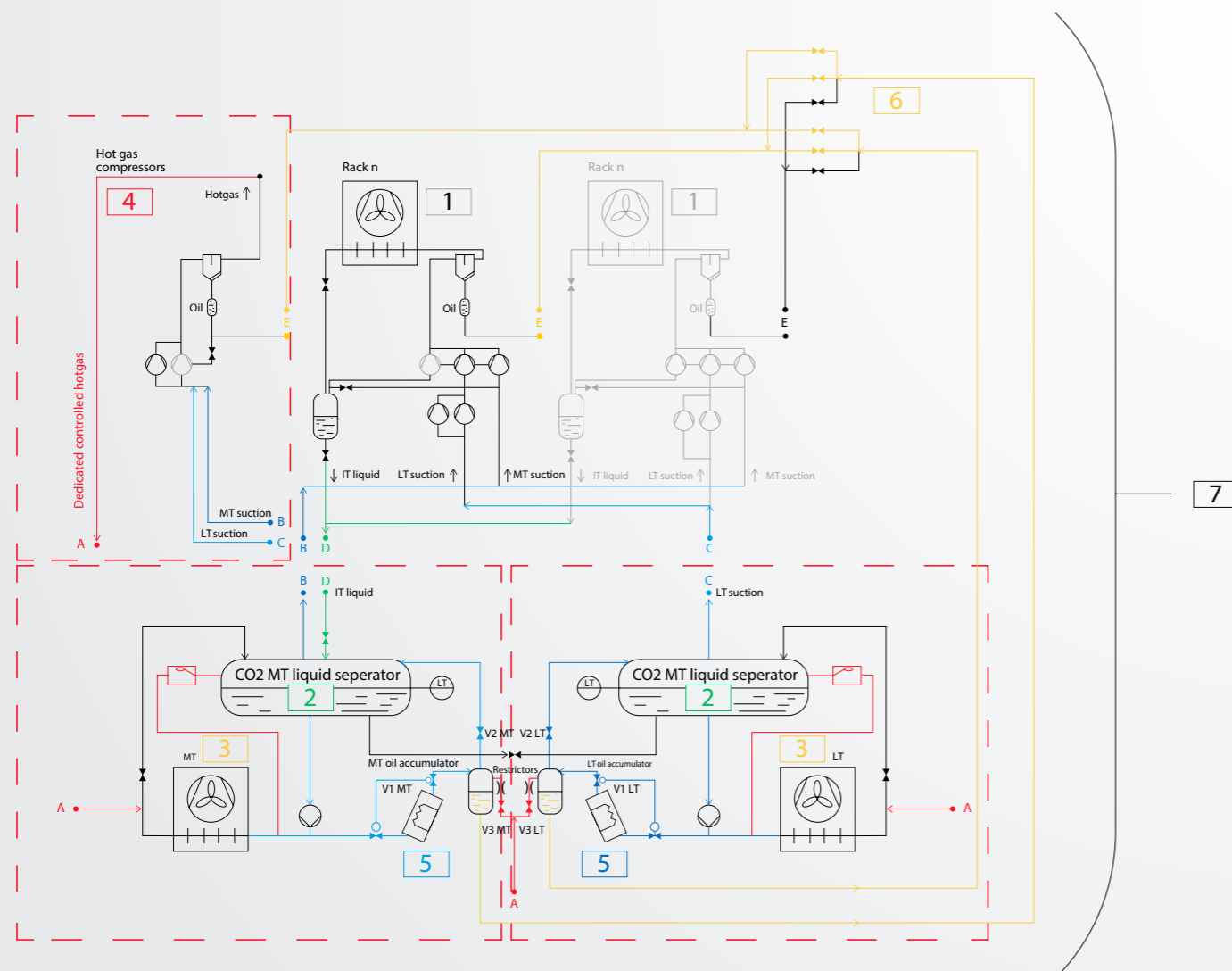
Chapter 2

Transcritical CO₂ Pump Circulating System – Key Elements and Design

This chapter provides a prime illustration of a CO₂ transcritical pump circulation system. With the advancement of large transcritical CO₂ compressors, a significant capacity can be achieved with a single rack (refer to Figure 2.1, Rack 1). However, it is possible to design the system with multiple parallel racks (refer to Figure 2.1, Rack n).

In this example, we focus on a single rack that encompasses transcritical rack control, LT and MT liquid separators, cold room control, oil rectification, oil accumulation and distribution, hot gas defrost, and system coordination. Moreover, it is worth noting that the number of temperature levels is not limited to MT and LT alone.

Fig. 2.1 Principle Drawing of an Industrial Transcritical CO₂ Pump Circulating System



Key System Elements:

1. Transcritical CO₂ operation, including heat recovery, i.e., with Danfoss AK-PC 782A/B pack controller
2. Recirculated CO₂ pump/vessel control, including liquid level and pump control (i.e., with Danfoss pump separator control)
3. Cold room control (i.e., Danfoss EKE 400), including DX, flooded, and several defrost operations
4. Dedicated hot gas supply pressure control
5. Oil rectification and accumulation from the liquid separators (i.e., Danfoss pump separator control)
6. Oil return and distribution to the racks that require oil
7. Coordination

In the following chapters, detailed descriptions will be provided regarding critical system elements, with a specific focus on the hot gas defrost pressure supply and oil management.



Chapter 3

The Transcritical CO₂ Operation

Pack controllers play a critical role in refrigeration and can be the difference between underperformance and optimal efficiency. Our AK-PC 782A/B pack controller is designed specifically to cover a multitude of operations and functions in a transcritical booster system. Providing a versatile and reliable solution that serves as a central control unit for your system.

The Complete Pack Controller Package

The Danfoss AK-PC 782A/B is a comprehensive regulating unit for capacity control of compressors (MT and LT) and fans on the gas cooler in transcritical booster systems with parallel compressors. Each compressor rack is equipped with a single AK-PC 782A/B controller. The controller encompasses oil management, heat recovery function, and CO₂ gas pressure control.

In addition to capacity control, the controllers can signal to other controllers regarding operating conditions, such as the forced closing of expansion valves, alarm signals, and alarm messages.

The Danfoss AK-PC 782A/B Features:

- Capacity control of up to 10 compressors on MT and 8 on IT
- Capacity control of up to 4 compressors on LT
- Up to 3 unloaders for each compressor
- Control of oil separator and oil receiver
- Speed control of 1 or 2 compressors in each group
- Up to 6 safety inputs for each compressor
- Option for capacity limitation to minimize consumption peaks
- If the compressor does not start, signals can be transmitted to other controllers to close the electronic expansion valves
- Regulation of liquid injection into suction line in case of high discharge temperature
- Safety monitoring of high pressure/low pressure/discharge temperature
- Capacity control of up to 8 fans
- Floating reference temperature out of the gas cooler regarding outside temperature

However, the controller's primary function is to regulate compressors and the gas cooler to ensure operation always occurs at the energy-optimum pressure conditions. Pressure transmitters provide signals for controlling both the suction pressure and the gas cooler pressure. Capacity control is performed based on the suction pressure P_o .

The P_o signal for the parallel compressor is supplied by the pressure transmitter Prec on the receiver.

- Heat recovery function
- CO₂ gas cooler control and receiver control
- Ejector regulation: High-Pressure lift (HP)/Low-Pressure lift (LP)/Liquid ejectors (LE)
- Safety monitoring of fans
- Alarm signals can be generated via data communication
- Alarms are depicted with text so that the cause of the alarm is easy to see
- Separate general-purpose functions that are completely independent of the regulation - such as alarm, thermostat, pressure, and PI-regulating functions

On the IT side

The (IT) receiver pressure can be controlled to keep it at the requested reference point. For this to occur, the receiver control coordinates the actions of the following actuators, if configured:

- Receiver/gas bypass valve Vrec
- IT compressor suction group (optional)
- Hot gas dump (optional)
- Additional Vrec valve (optional), operated simultaneously or in sequence with the previous one.

Receiver Pressure

CO₂ receiver pressure reference can have different operation modes:

- Fixed Setpoint - receiver control operates on a fixed set point defined by the user.
- External Offset - same reference as a fixed set point, but it can be offset with an analog input

- IT optimized - floating receiver pressure in the system with parallel IT compressors to achieve maximum system efficiency
- Delta P - keeping constant pressure difference between the receiver and suction MT compressors

It is also important to note that avoiding high receiver pressure is crucial for the system's safety. Drastic actions can compromise the functionality of other subsystems, and therefore AK-PC 782A provides different options:

Cancelling AC	always active
Limiting Heat recovery	always active
Increasing fan capacity	always active
Decreasing MT capacity (optional)	default on
Decreasing ejector and Vhp capacity (optional)	default off

Furthermore, avoiding low receiver pressure is essential for ensuring cooling. Aside from using the receiver actuators to raise the receiver pressure, the heat recovery is disabled, and the user can enable the option to increase the high-pressure expansion valve opening gradually.

Chapter 4

Pump circulated CO₂ and pump/vessel control

The liquid level in the liquid separators is dependent on the required capacity, requiring careful control. Additionally, the pumps must be controlled as well as protected to ensure proper functioning.

The recirculated CO₂ vessel systems can be controlled by the Danfoss pump vessel controller, based on an MCX-15B2 hardware or PLC, with the main features of the controller being liquid level control, pump control, and oil rectification.

A Pump Circulated CO₂ Solution

Liquid level control can be accomplished using digital inputs tied to float switches and digital outputs connected to solenoids. And can also be controlled via an analog input signal from an AKS4100 with a PID controlling one or two ICM+ICAD motorized valves for more precise level control.

The controller also manages up to three pumps.

Pump protection includes cavitation detection, low-level cutout, and over-amp alarm and shutdown. Automated pump control handles the start-up of additional pumps in the case of a pump failure and the ability for runtime leveling.

If only one compressor rack is connected to one vessel, the oil rectification can also be controlled by the pump vessel controller, with the oil being returned via the suction lines to the rack.

Chapter 5

CO₂ Cold Room Control

Precise control of evaporators in transcritical refrigeration systems is crucial for achieving efficient cooling, temperature management, product quality, energy efficiency, frost prevention, and heat transfer. All of which lead to the reliable and effective operation of the CO₂ system.

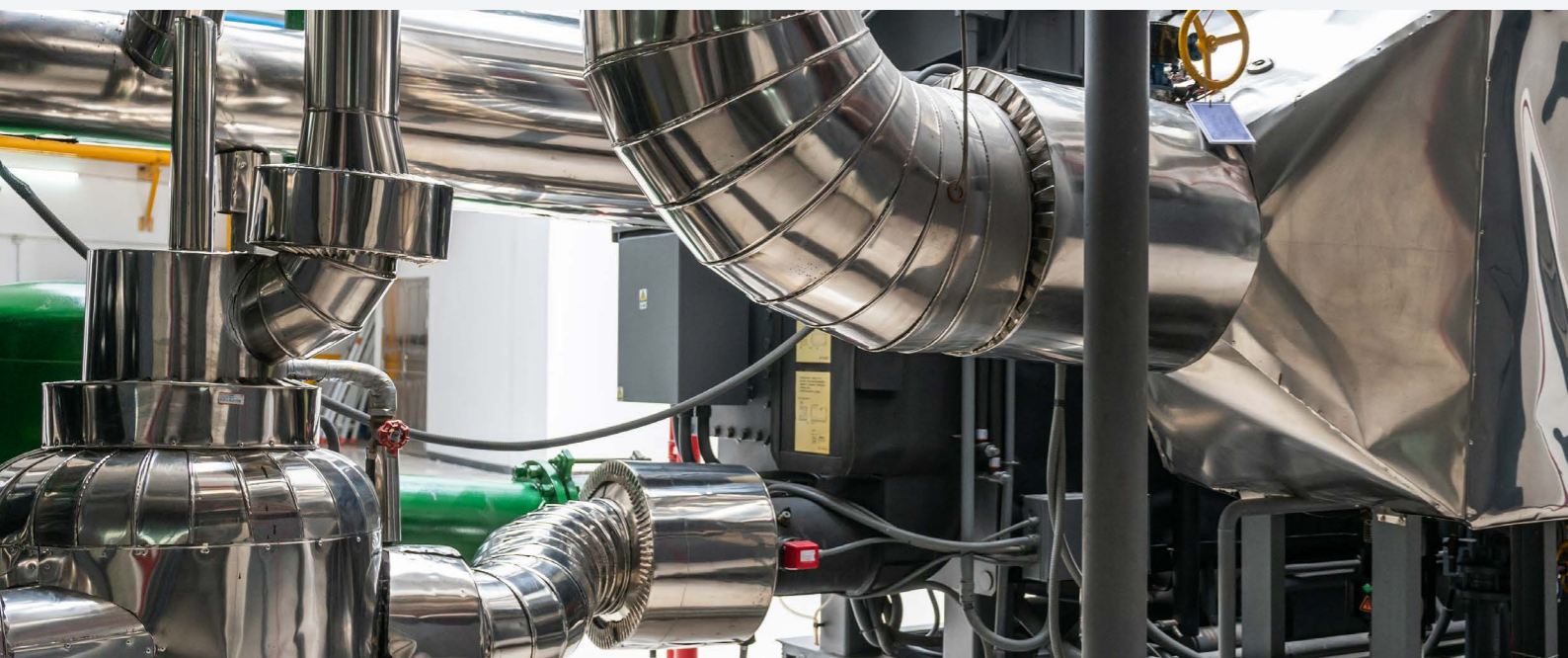
Complete Cold Room Control

The evaporators can be controlled by utilizing the Danfoss EKE 400 universal cold room controller. Communications to the supervisory PLC will be using MODBUS RTU. Multiple evaporators, each with an EKE-400 controller, will be supported. The number of evaporators will be limited by the total compressor rack capacities.

Evaporators can reside on both LT and MT systems. The EKE-400 cold room controller will decide when a defrost cycle is required and relay this information to the hot gas controller. The Danfoss hot gas controller will respond to startup with a controlled hot gas supply pressure.

Features of the EKE 400 universal cold room controller:

- Pump circulated ammonia/CO₂/HCFC/HFC
- Direct expansion (DX) ammonia/CO₂/HCFC/HFC
- Superheat Control by:
 - Fixed Superheat reference
 - Load-defined reference (LoadAP)
 - Minimum Stable Superheat (MSS)
- Modulating Thermostat (MTR) or simple ON/OFF
- Media temperature control of the suction line
- Modulating Thermostat (MTR) by modulating the valve in the liquid line
- Support of Multiple Defrost methods:
 - Hot Gas defrost by pressure or by liquid drain
 - Defrost by water or brine
 - Individual defrost schedules by individual weekdays, Saturdays, and Sundays
- Defrost start by:
 - PLC via MODBUS
 - Digital Input
 - Time interval (time since last defrost start)
 - Accumulated cooling time
 - Defrost schedules and Real Time Clock (RTC)
 - Forced manual defrost via HMI
- Defrost stop is on a time duration or determined by temperature
- Separate Drip tray control (separate from main hot gas valve)
- Emergency cooling - failsafe operation
- Safe startup after power failure
- Product temperature alarm option



Controlled Hot Gas Pressure Supply for Defrost

In a transcritical CO₂ pump circulating system, a controlled hot gas pressure is required for two purposes:

1. Providing safe defrost pressures when defrosting the evaporators in the subcritical part of the system.
2. Providing a sufficient pressure to the oil accumulators to return the rectified oil to the transcritical system.

In this chapter, we will cover controlled hot gas supply pressure for defrost purposes, while in the subsequent chapter, we will go in depth on oil management in transcritical CO₂ refrigeration.

Defrost pressure in depth

From an efficiency point of view, it makes sense to use separate (dedicated) hot gas compressors to create the required hot gas for defrosting the evaporators. The benefit of doing so, is that the defrost cycle does not directly interfere with the main compressors for the refrigeration system, and that both flow and supply pressure can be controlled to the level required, independent of the cooling requirements.

The required hot gas capacity is depending on the size of the refrigeration system and the temperature of the evaporators. The more evaporators in the system, the more frequent defrost cycles are required. The dedicated hot gas compressors, operate from the central LT or MT/IT suction lines to produce sufficient hot gas. The discharge pressure must be controlled to ensure a safe and efficient hot gas supply to the air coolers/evaporators of the sub critical system. The sub critical system is typically designed for a lower pressure than the transcritical system.

In the principle drawings below, the controlled defrost pressure is represented as point "A" and the suction intake for the dedicated hot gas compressors are shown as point "B" at MT/IT level and C at LT level.

Fig. 6.1. Principle diagrams with 1 dedicated hot gas compressor

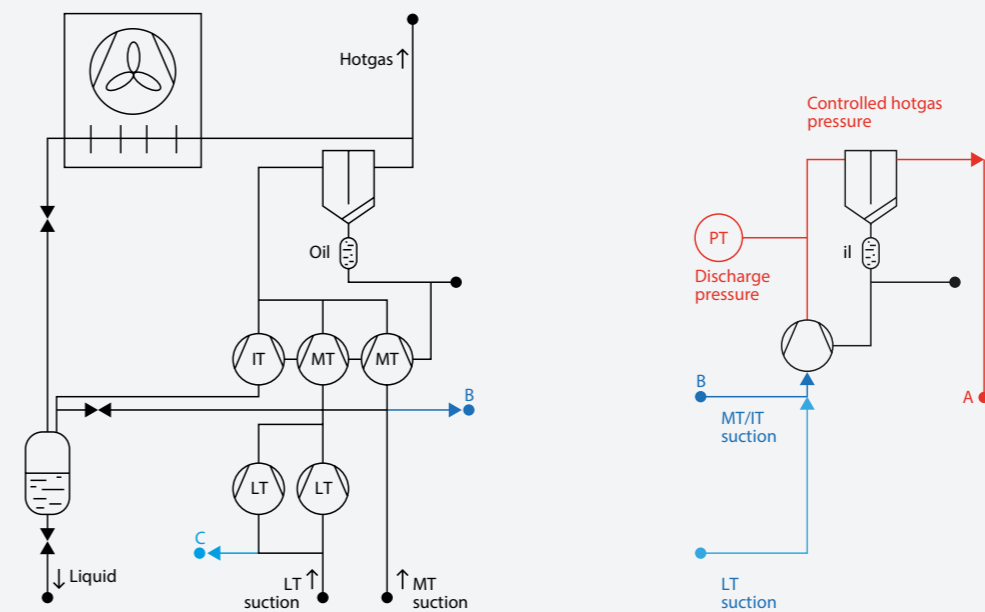
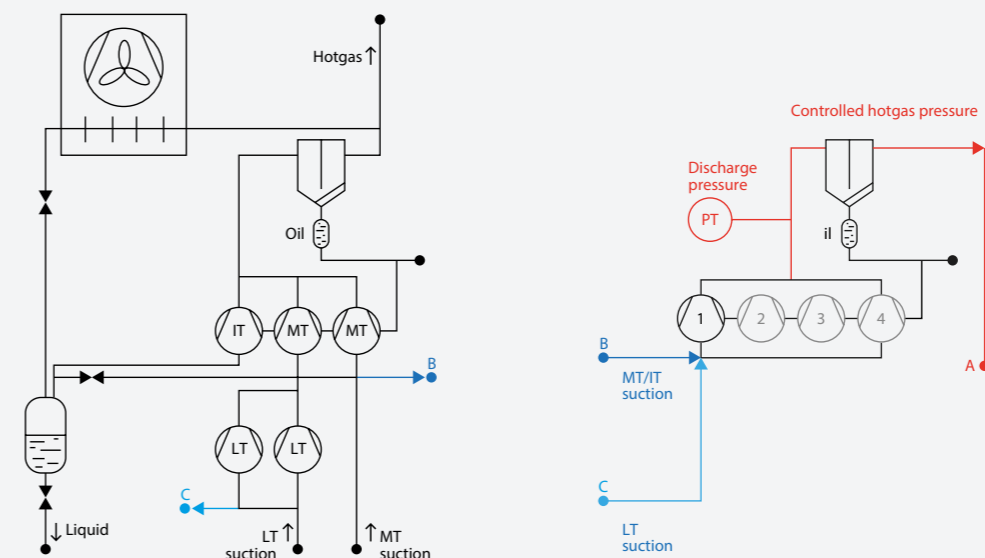


Fig 6.2. Principle diagrams with multiple dedicated hot gas compressors, in the example 4 compressors are shown.



The distance between the defrost compressors and the evaporators can be exceptionally long. Making it possible for the hot gas to condense in the long central discharge lines, especially when the compressors are at standstill.

When condensed liquid accumulates in these discharge lines, they can potentially be propelled further the next time the defrost compressors start. And due to the pressurized nature of these discharge lines, such a scenario could cause liquid hammer within the system. Creating a situation you would rather avoid.

A way to solve this, is to mount an expansion valve at the lowest point of the central discharge lines.

The outlet of the expansion valves is connected to the MT or LT liquid separators. Whenever defrost compressors are not in operation, these expansion valves bleed the accumulated liquid through the expansion valve, which then enters into the MT or LT separator. In addition, there are several ways for the control strategy. A repetitive controlled opening for a specific time slot is often enough to keep the central discharge line free from condensed liquid.

Depending on the required maximum working pressure, the Danfoss ICM(TS) series or CCM(T) series of expansion valves can be applied here. It is also important to note that systems should be designed so condensed liquid cannot flow back to the dedicated hot gas compressors.

6.1

Hot gas compressor control in detail

The Danfoss hot gas compressor controller can manage multiple dedicated hot gas defrost compressors. In this instance, control is based on maintaining a constant discharge pressure from the hot gas compressors, with a pressure transducer/transmitter mounted in the compressor rack discharge. From there, the controller modulates or steps compressors on/off to maintain the desired setpoint.

Different compressor configurations:

- Compressor without capacity steps and no VFD. The compressor is cycled on/off to maintain the desired discharge pressure.
- Compressor with capacity steps and no VFD. The compressor is turned on and stepped up/down in capacity to maintain the desired discharge pressure.
- Compressor without capacity steps but with VFD. The compressor is turned on, and the speed is varied to maintain the desired discharge pressure.
- Compressor with capacity steps and VFD. The compressors are turned on and both capacity steps, and speed are adjusted to maintain the desired discharge pressure.

The (multiple) dedicated hot gas compressor(s) could have any of the above attributes, where some are fixed capacity and controlled on/off. In contrast, other compressors may have capacity steps and others VFD. The compressors can be sequenced to maintain the desired discharge pressure, with the number of hot gas compressors ranging from one to five for a given plant design.

6.2

Hot gas defrost drain in transcritical CO₂ systems

It is important to note that even though a controlled hot gas supply pressure is required, it is also crucial that the condensate drain lines are controlled.

Danfoss cold room controller EKE 400 supports the two ways condensate drain lines are controlled:

- **Pressure control.** In this case, the defrost pressure in the evaporator is controlled during the defrost period. The pressure should be sufficiently higher than 0 degrees Celsius to enable ice/frost to melt from the evaporator. (An example of a defrost pressure control valve is Danfoss ICS+CVP-H6).
- **Liquid control.** In this case, mostly condensed hot gas (low enthalpy liquid) is returned to the system. It is more efficient than pressure control and reduces refrigeration power consumption. (An example of a liquid-controlled drain valve is Danfoss ICF + ICFD).

6.2.1

Hot gas defrost at pump circulated MT evaporators and DX LT evaporators

Fig. 6.3 MT pump circulation + LT DX hot gas defrost principle

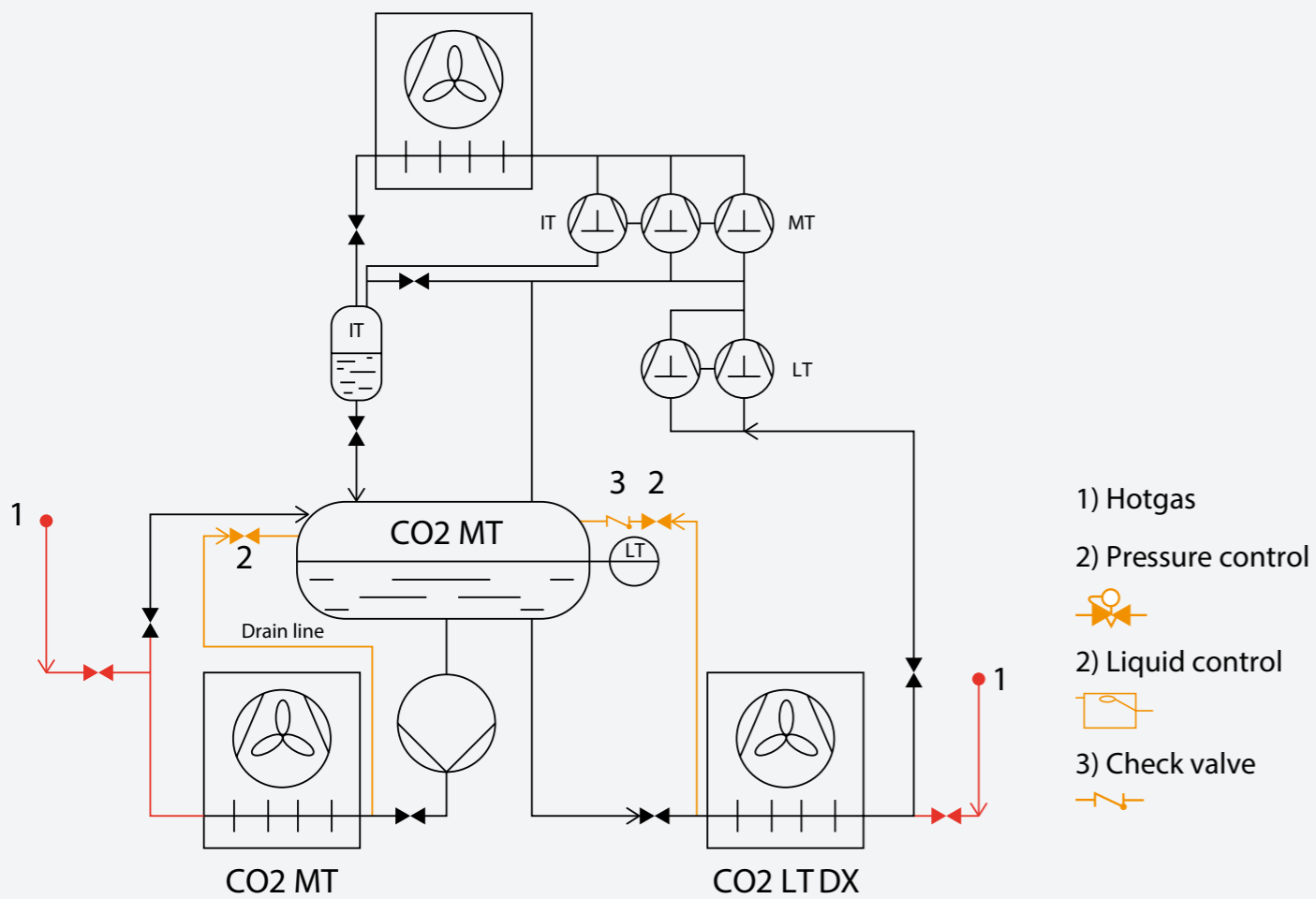


Fig 6.3 shows a principle drawing of an MT pump circulated system in combination with a DX system on LT with hot gas defrost. Controlled hot gas pressure from the dedicated hot gas compressor(s) (at point 1 in the drawing) is supplied to the evaporators. And the condensate drain line of both the MT and LT systems are connected to the MT liquid separator.

Valve 2 controls the drain line, which can either be liquid-controlled, i.e., with the Danfoss ICF+ICFD, or pressure controlled, i.e., with the Danfoss ICS+CVP-H. And the LT evaporators drain into the MT separator to increase efficiency.

Downstream, the drain control of the LT evaporator, a check valve 3, must be placed to prevent MT pressure from being drained into the LT evaporator.

Note: When a relatively small LT capacity is needed compared to the MT capacity. The LT evaporators can be DX controlled.

6.2.4

Hot gas defrost at pump circulated LT evaporators and MT DX evaporators

Fig 6.4 shows a principle drawing of an LT pump circulated system in combination with a DX system on MT with hot gas defrost.

Controlled hot gas pressure from the dedicated hot gas compressor(s) (point 1 in the drawing) is supplied to the evaporators. The condensate drain line of both the MT and LT systems is connected to the LT liquid separator.

Note: When relatively small MT capacity is needed compared to the LT capacity, the MT evaporators can be DX controlled.

Valve 2 controls the drain line, which can either be liquid-controlled with the Danfoss ICF+ICFD or pressure controlled with the Danfoss ICS+CVP-H.

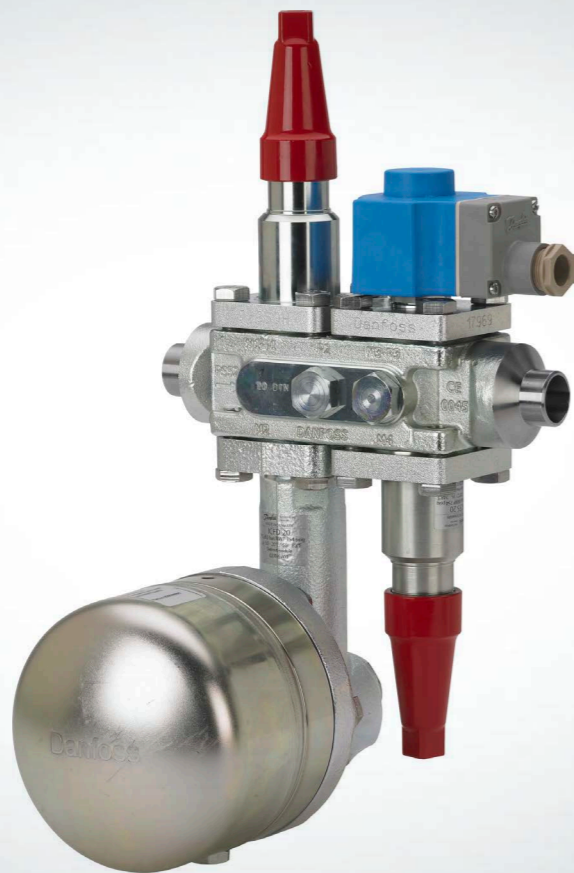
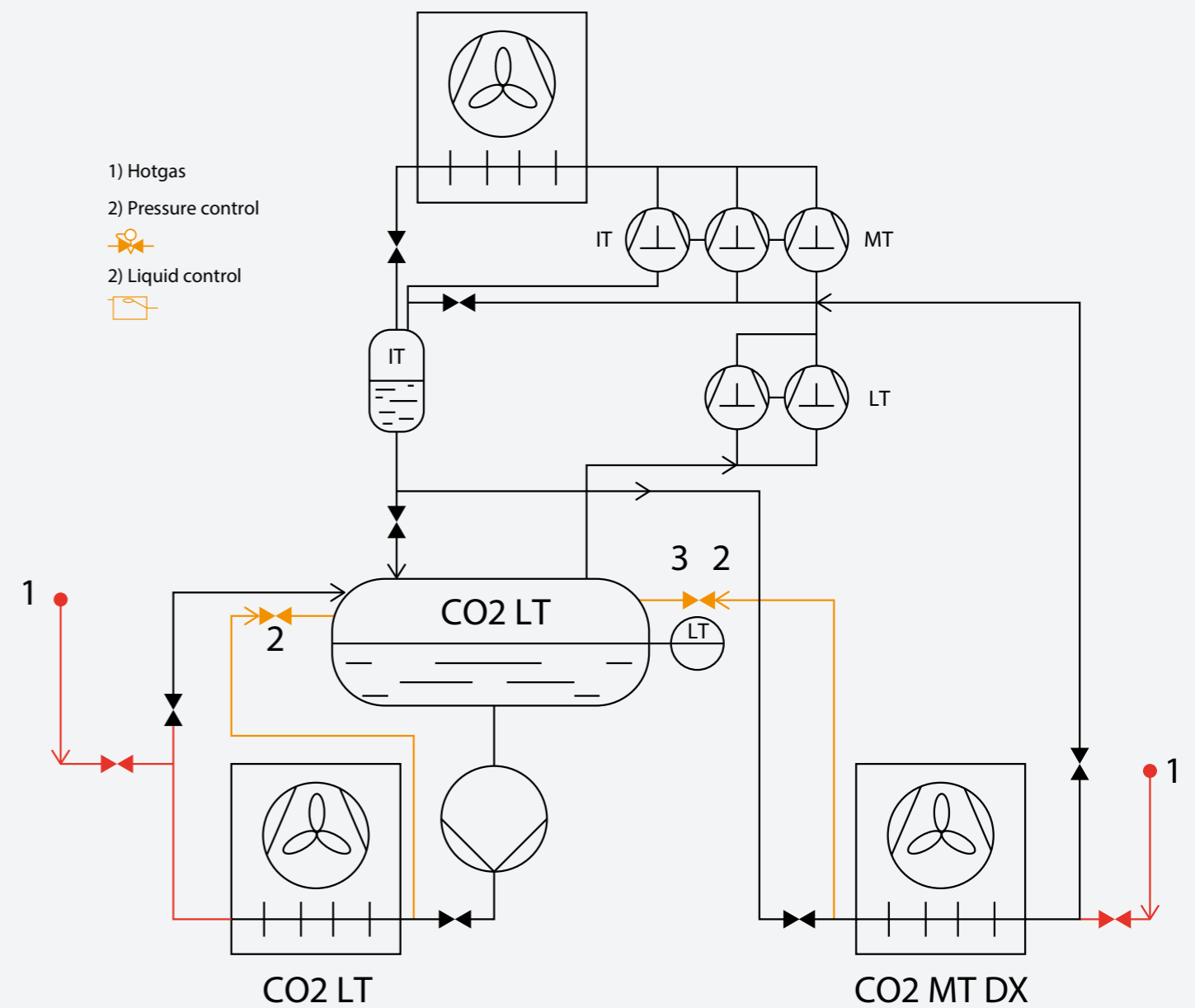


Fig. 6.4 LT pump circulation+ MT DX hot gas defrost principle



Chapter 7

The Interplay of Oil Management in **Transcritical Systems**

Reliable and efficient oil management in refrigeration is critical. As compressors in transcritical systems are subject to heavy load conditions, the correct lubricant is essential in keeping moving parts up and running and keeping your CO₂ system cooling.

Your choice of oil matters

Outlining and defining the oil specification for a transcritical system hinges on various conditions. Some of the most essential aspects to consider when choosing the proper lubricant are:

- Suction and discharge temperatures and pressures
- Refrigerant
- Compressor speed (RPM)
- Part or full load conditions
- Compressor type

Therefore, compressor manufacturers have clear oil type recommendations for each kind of compressor, refrigerant, and application.

7.1

Oil carryover—an unavoidable challenge

The sole purpose of compressor oil is lubrication, and in an ideal situation, that oil would only remain inside the compressor. However, this is not the case. The unavoidable truth is that compressor crankcase oil will mix with refrigerant, compress, and end up in the compressor discharge.

A phenomenon called oil carryover.

Oil carryover should be kept to a minimum because the oil ultimately ends up in the refrigeration system. However, this presents two challenges:

1. The oil will form a film inside the evaporators (fouling), resulting in a loss of heat transfer and decreased system efficiency.
2. The oil must be returned from the system back to the compressors.

Different oil management strategies must be followed and applied depending on the system type—direct expansion, or flooded systems.

How carryover plays out in CO₂ systems

The CO₂ booster system has compressors on both LT, MT, and IT levels, and, of course, oil carryover occurs on all levels. However, MT and IT compressors have a higher oil carryover rate in comparison with the LT compressors. This is caused by the higher suction vapor densities and mostly higher cooling loads on the MT level.

Here, oil separators can be situated on the LT and MT/IT compressor discharge lines, with oil separators always positioned in the MT compressor's discharge lines. Yet, these separators are not commonly seen in the



discharge lines of LT compressors. However, doing so would reduce the oil carryover to the MT compressor suction lines and, thus, reduce the absolute oil carryover of the MT compressors.

7.2

Oil return in DX systems

It is important to realize that the typical commercial systems are of the DX type, where in most cases, miscible oil is sent back to the suction lines.

Good miscibility of liquid CO₂ and POE oil, as well as high vapor densities on the suction side of the system, lead to an easy return of the lubricant to the

suction lines of the compressors, provided that similar velocities in suction lines, e.g., with HFC refrigerants, are applied.

At part load conditions, e.g., during a winter evening, mass flows and velocities inside the evaporators and suction lines are reduced, making the return of lubricant more challenging.

For a reliable oil distribution under all load conditions, the application of a suitable oil management system is essential. Based on the combination of CO₂ and miscible oils, the oil return in commercial DX systems has proven exceedingly reliable.



Oil management in DX systems

With oil management systems where oil returns into the suction lines, there is a possibility where the oil distribution between compressors does not match the amount lost, with the consequence that the level inside the crankcases of the LT compressors rises above the maximum.

Thus, the effectiveness of the oil separator must be high and in the range of the oil carryover rate of the MT/IT compressors to ensure a balanced condition.

This is an important fact and leads us to the conclusion that the effectiveness of any oil management

system starts with the oil carryover of the compressors (as low as possible) and the efficiency of the main oil separators (as high as possible).

7.3

Oil management in transcritical CO₂ pump circulating systems

In CO₂ pump circulation systems, the oil carried over to the system ultimately collects in the liquid separator(s) and does not depart with the suction gas. Consequently, this makes it necessary to collect the oil from the separator(s), with the amount of effort attributed to oil collection closely connected to its carryover. Confirming the substantial importance of a highly effective primary oil separation within the oil separators. And in cases where there is more than one liquid separator, oil will then be collected in each.

Collection, rectification, and return

Collected oil from the separator must be rectified and then sent back to the compressors. Here, the system oil can either be miscible or immiscible. If miscible oil is used, the liquid CO₂/oil mixture can be rectified from the liquid separator relatively easily.

However, if immiscible oil is used, depending on the oil type and system conditions where the oil-rich layer is situated within the liquid separator(s), several collection points can be used to skim from the correct location. Regardless of the oil type, collection and rectification is a must. This process is accomplished using oil rectifiers, a well-known principle for many years in both freon- and CO₂ subcritical pump circulated systems.

The oil return to the system can be accomplished in many ways. Electronic expansion valves control the oil rectification process—the oil/CO₂ mixture leaving the oil rectifier can, in principle, be sent back directly to the suction lines of the compressors connected to the liquid separator where the rectification occurs.

In any case, a suction accumulator is recommended. However, no system is similar, and many parameters could influence the balance of oil carried over into the system and rectified from the system.

Major parameters to consider:

- Does the system have one LT liquid separator or one MT liquid separator, or does the system have both?
- Does the system have multiple LT and MT liquid separators?
- Is the LT refrigeration capacity the same as the MT capacity? And is it higher or lower?
- What is the oil separator capacity?
- Is it in balance with the system? Is part load considered?

Therefore, the oil management described in this document uses oil collection accumulators per liquid separator where rectified oil is stored. In case racks need oil, the rectified oil collected into the oil receivers is sent back to the oil receiver of the specific rack requiring oil. With dedicated oil accumulators, the system becomes independent of many parameters and guarantees a safe and efficient oil return to the racks.

The oil management in transcritical CO₂ pump circulated systems in this document follows the following procedures:

- Oil rectifying and oil collection
- Oil return and distribution

7.4

Oil rectifier and oil accumulation control of miscible oil in transcritical CO₂ pump circulating systems

Fig. 7.1 Oil rectifying and oil accumulation with miscible oil

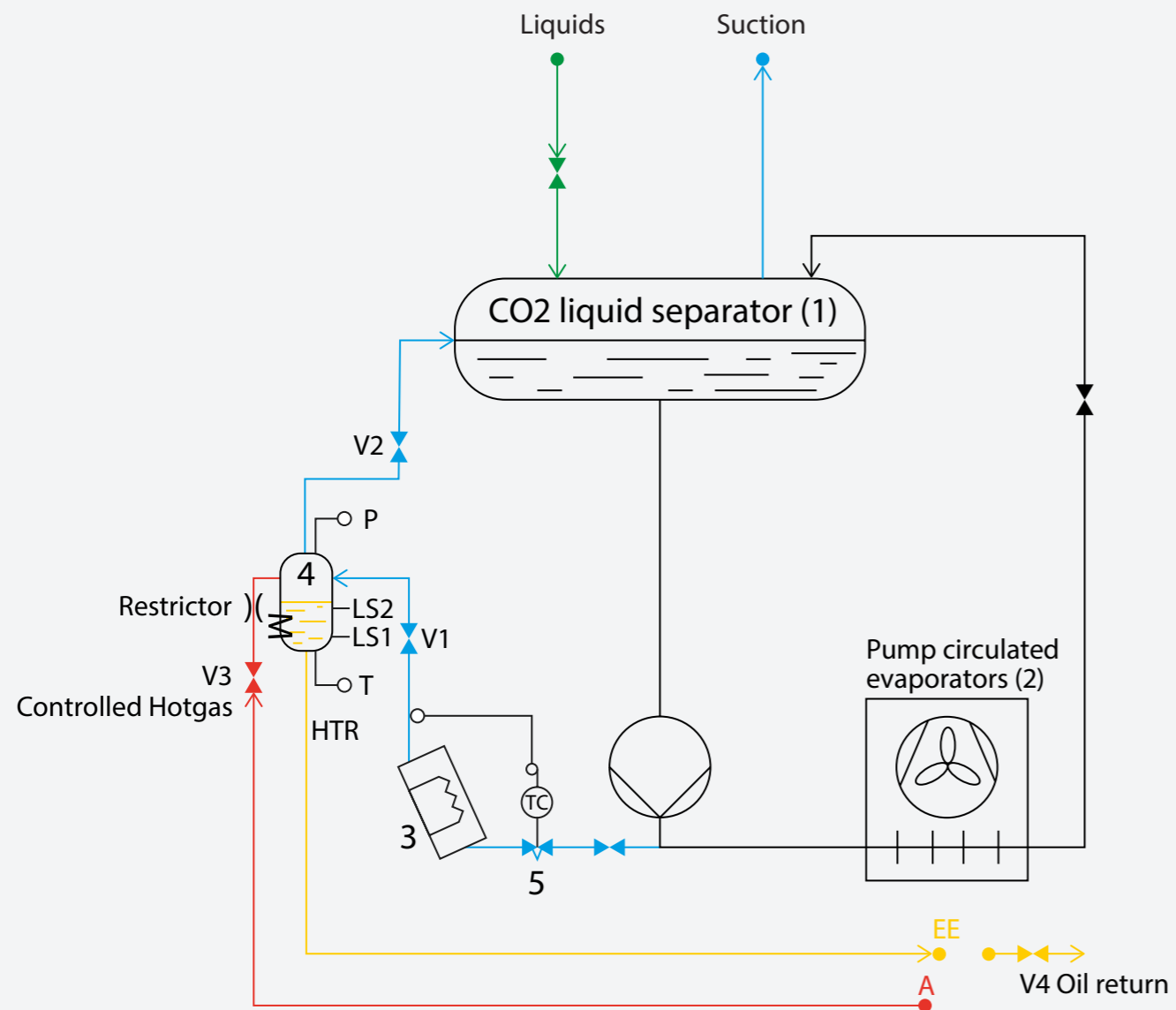


Figure 7.1 illustrates a basic configuration for a CO₂ oil management system and describes the oil rectifying process for MT, LT, or more liquid separators.

- If the liquid separator is on MT level (point 1), the evaporators (point 2) are MT evaporators, the liquid supply comes from the IT receiver and the suction lines of the evaporators return to the MT liquid separator.
- If the liquid separator is on LT level (point 1), the evaporator (point 2) are LT evaporators, the liquid supply comes from the MT liquid separator and the suction lines of the evaporators return to the LT separator

- It is recommended to superheat the suction gas back to the compressors. Please refer to the compressor manufacturer's recommendations.

The Accumulation and Rectifying Process

The oil in the separator must be rectified, accumulated, and returned to the compressor rack(s). The oil rectifier (3) essentially is a heat exchanger and boils off the oil-rich liquid CO₂ into CO₂ vapor and oil. The rectified oil is captured in the oil accumulator (4). The boiled-off CO₂ vapor returns, via valve V2, back to the liquid separator.

During the oil rectifying process in this example, liquid is injected into the oil rectifier through an electronic expansion valve (point 5), with superheat controlled. And depending on the required maximum working pressure, this valve can be Danfoss CCM, CCMT, ICM, or ICMTS type. The pump pressure enables the needed pressure drop across the expansion valve.

Running the oil rectifier with the thermosyphon operation is possible if a pump is unavailable.

Control functions during oil rectifying and oil accumulation in Fig 7.1

- Oil rectifying: V1 & V2 are in the open position, the expansion valve (at point 5) is enabled when the refrigerant pumps are running, the level in the oil accumulator is below "LS2," and when no oil requests from the racks are signaled. This operation continues until the oil level reaches "LS2." At this point, V1 & V2 are closed, liquid injection stops, and sufficient oil is rectified and accumulated.
- The heater (HTR) operates when the temperature in the oil accumulator drops to or below saturation temperature. The pressure sensor (P) and temperature sensor (T) are used to calculate the saturated temperature for CO₂.
- Anytime the oil accumulator level drops below "LS1", the heater (HTR) is locked off.
- When the oil level reaches "LS2," the oil accumulator LS2 sensor signals that sufficient oil is rectified.

7.5

Return and distribution of miscible oil in transcritical CO₂ pump circulating systems

The oil accumulator(s) send the oil back to the rack's oil receiver(s) that require oil. The oil return process can be accomplished by pressurizing the oil accumulator with controlled hot gas pressure generated from the dedicated hot gas supply compressor(s). The flow is regulated with a hand-regulating valve or a fixed orifice (restrictor). The oil receiver(s) on the rack(s) must be equipped with low- and high-level switches.

When the oil in any available oil receiver(s) drops under the necessary level of the low-level switch, the oil return process starts. If the oil receiver(s) on the rack(s) reach the proper level again, a high-level switch will detect this, and the oil return process will stop.

Control functions: (See Fig. 7.1)

- V1 & V2 remain closed and liquid injection has stopped.
- Heater (HTR) may be on or off based on saturated temperature.
- The hot gas for pressurizing the oil accumulator originates from the regulated dedicated hot gas compressors represented by point A in Fig. 7.1. The controlled pressure must be higher than the pressure in the oil receivers on the racks to create flow. Introducing a large flow of high-pressure CO₂ gas to the oil accumulator is unsafe and unnecessary. Therefore, the hot-gas supply lines should be well-designed and flow-restricted, e.g., with a fixed orifice or a manual hand-regulating valve. When the oil rectifying and oil return process is well balanced, it becomes a continuous repetitive process. So, the oil flow and simultaneously the hot-gas flow are of less importance if the timing of the oil return is well controlled and safe.

- When any of the oil receiver(s) on the rack(s) require oil, the hot gas supply valve (V3) is opened. The restrictor ensures a restriction, so the pressurization is completed slowly and safely. Furthermore, when the oil return valve (V4) is opened, oil is returned to the oil receiver of the rack that is requires oil.
- When the oil level of the respective oil accumulator drops below "LS1," or if the level of the oil receiver(s) on the rack(s) reaches the correct level, the heater (HTR) is turned off, and the oil transfer is terminated. The hot gas supply valve (V3) and the oil return valve (V4) are closed. As such, the dedicated hot gas compressor stops and goes either into a disabled mode or hot gas defrost mode if hot gas defrost is required.
- V2 is slowly opened first to relieve the oil accumulator pressure, then V1 to start the oil rectifying cycle again. V1 will only open when the oil accumulator pressure is reduced to the liquid separator pressure. The oil rectifying cycle repeats as described above.
- When applying "Controlled Hot Gas" to the oil accumulator, and if the oil accumulator pressure reaches a "Max pressure" setpoint, the hot gas valve (V3) is shut off. The hot gas valve (V3) can be cycled to maintain the oil accumulator pressure but not allow over-pressure.
- Pressure build-up in the system due to defective or non-responding valves, trapped liquid, power cuts, or any other factor should be safeguarded against using pressure cut-out switches and pressure relief valves.

7.6 Oil management of miscible oil in transcritical CO₂ pump circulating systems with multiple liquid separators

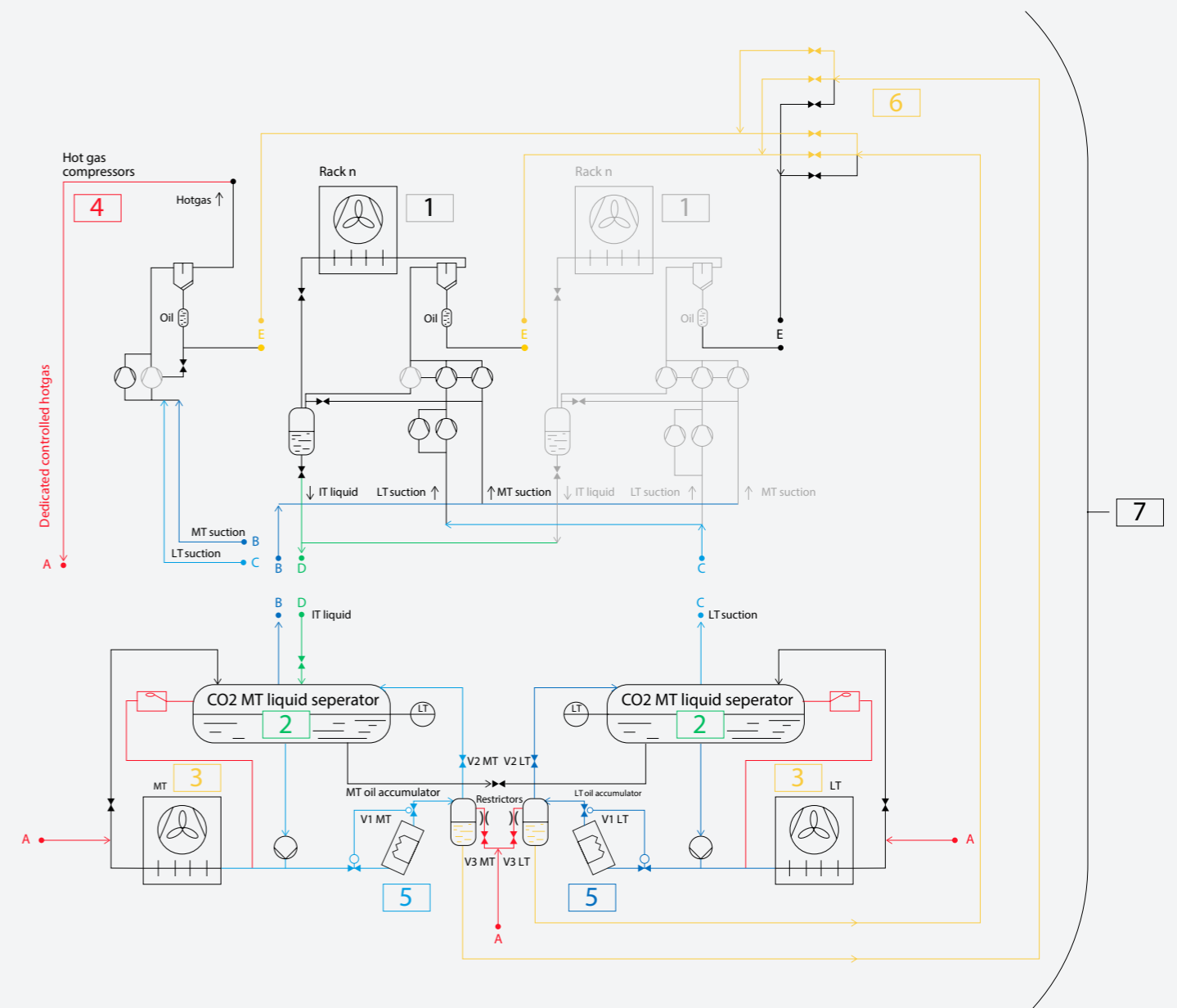
When multiple liquid separators are available, each should have its own oil rectifying and accumulation process for preventing unbalanced oil management. This means the system would work as depicted in section 7.4 and 7.5, but with multiple oil accumulators returning oil to the oil receiver(s) on the rack(s).

In Fig. 7.2 below, two liquid separators on MT and LT levels are shown. Each with its own oil rectifying, accumulation, return, and distribution system.

- Oil return valves (V4MT) supply accumulated oil from the MT liquid separator back to the oil receiver(s) on the rack(s) that requires oil.
- Oil return valves (V4LT) supply accumulated oil from the LT liquid separator back to the oil receiver(s) on the rack(s) that require oil.
- If these valves are ON/OFF solenoid valves, they must be equipped with check valves downstream. Otherwise, oil can be pushed back from one oil accumulator to another and backwards through the other oil supply valves.

For oil rectifier and oil collection control of immiscible oil in transcritical CO₂ pump circulating systems see the full study on www.IP.com

Fig. 7.2 Oil management of a transcritical CO₂ pump circulating system with miscible oil and multiple liquid separators





About **Danfoss**

Danfoss is focused on engineering a better tomorrow. From one of the world's first radiator thermostats and mass-produced frequency converters to the many solutions and technologies that push the boundaries of what's possible today, we have always kept an eye on building a better future. Our journey began in 1933 when Mads Clausen founded Danfoss in his parent's farmhouse in Nordborg, Denmark. Since then, the business has grown from a solo enterprise into one of the world's leading innovative and energy-efficient solutions suppliers.

The passion for technology and our customers has led to a legacy of rising to increasingly complex challenges and delivering exceptional results. With the promise of quality, reliability, and innovation deeply rooted in our DNA, we deliver an extensive range of products and solutions across a multitude of business segments. Our focus on meeting ESG ambitions sets us apart, and we believe it allows us to pioneer decarbonization solutions, best-in-class circular products, transparency, and a better customer experience. Partner with us, and let's engineer the future together.