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1 Introduction

This guide describes the use of BITZER refrigerant ejectors in R744 systems and contains information and advice on transcritical applications and capacity control.

It is constantly developed and will in future cover the basics and special features of CO_2 applications for commercial and industrial refrigeration as well as heat pumps. As the individual topics are added successively, this guide does not claim to be complete at the moment.

Several information and notes in this technical information, such as compressor design, application limits and oil types used, refer to BITZER products, and cannot always be completely generalized.

2 Properties of R744 – general system and design criteria

Carbon dioxide – CO_2 – is a natural component of the air we breathe. The average concentration in the atmosphere is 400–420 ppm. Used as a refrigerant, carbon dioxide carries the ISO817/ASHRAE34 nomenclature **R744**.

Chemical properties:

R744 is highly soluble in water. At a temperature of 15°C and a pressure of 1 bar, 1 dm³ of water dissolves 1 dm³ of R744. When dissolved in water, it is called carbonic acid. As a gas, it is chemically and thermally stable enough for use as a refrigerant.

Physical properties:

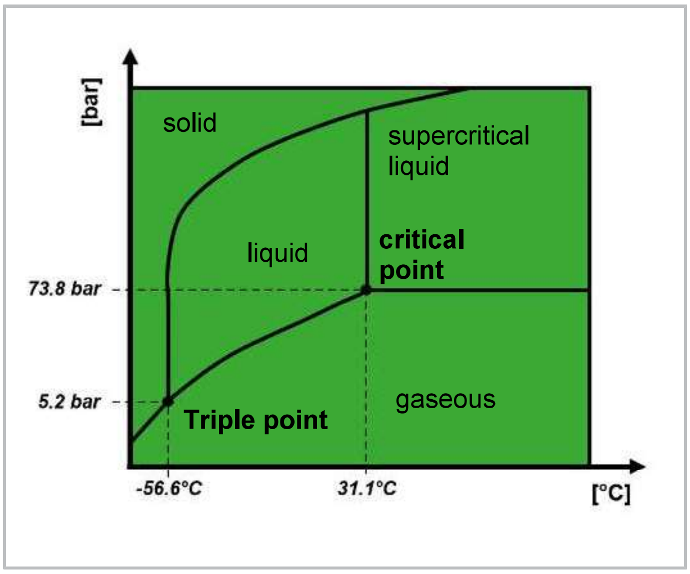
R744 is an odourless and colourless gas. The CO_2 molecule is not polar. R744 is non-toxic and non-flammable.

Molar mass	44.01 kg/kmol	Unit
Critical point	73.77 bar +30.98°C	bar °C
Triple point	5,20 -56,60	bar °C
Sublimation point	0,98 -78,90	bar °C

Saturation temperature	**-10°C**	**0°C**	**20°C**	**Unit**
Saturation pressure	26,49	34,85	57,29	bar
Liquid density	982,93	927,43	773,39	kg/m^3
Saturated vapor density	71,18	97,65	194,20	kg/m^3
Volumetric refrigerating capacity	18409,45	22546,12	29518,04	kg/m^3
Isentropic exponent	1,26	1,26	1,30	
Specific heat capacity, vapor c_p	1,51	1,86	4,56	kJ/kg K
Specific heat capacity, vapor c_v	0,81	0,87	1,07	kJ/kg K

Saturation temperature	-10°C	0°C	20°C	Unit
Heat conductivity, boiling curve	0,12	0,11	0,09	W/m K
Heat conductivity, condensation curve	0,02	0,02	0,04	W/m K

Phase diagram and phase transition for R744:



solid -> liquid	Melting
liquid -> solid	Freezing
liquid -> gaseous	Evaporation
gaseous -> liquid	Condensing
solid -> gaseous	Sublimation
gaseous -> solid	Resublimation

Safety-relevant properties:

- According to EN378-1, R744 is a refrigerant in safety class A1, i.e. toxicity class A "non-toxic" and flammability class 1 "non-flammable".
- R744 has a suffocating effect in higher concentrations. Higher concentrations of R744 in the air we breathe reduce the absorption of atmospheric oxygen in the lungs.
- Due to its high density, R744 displaces atmospheric oxygen in enclosed spaces or near the ground.
- R744 is odourless and colourless, not directly perceptible in case of emission.

Workplace exposure limits (WELs):	5000 ppm/volumetric
Short-term exposure limit:	10000 ppm/volumetric
Immediate Danger to Life or Health (IDLH):	50000 ppm/volumetric

Thermodynamic properties:

- The specific volume of the liquid phase of R744 increases with rising temperature, more so than with other common refrigerants.
- In closed-off areas of a system, this property can lead to a safety-relevant increase in pressure as soon as there is no more space/free volume available for the expansion of the liquid.

The following figure shows the pressure increase in an R744 refrigerant cylinder with increasing temperature for two filling ratios. At a temperature of 20°C, the saturation pressure is 57 bar (readable from the green boiling point curve). At 22.2°C, the cylinder is completely charged with a filling ratio of 0.75 kg/l. A further increase in temperature leads to an increase in pressure along the yellow function (isochoric change of state). R744 refrigerant cylinders are designed for a maximum pressure of 180 bar. This pressure is reached at a temperature of 50°C!

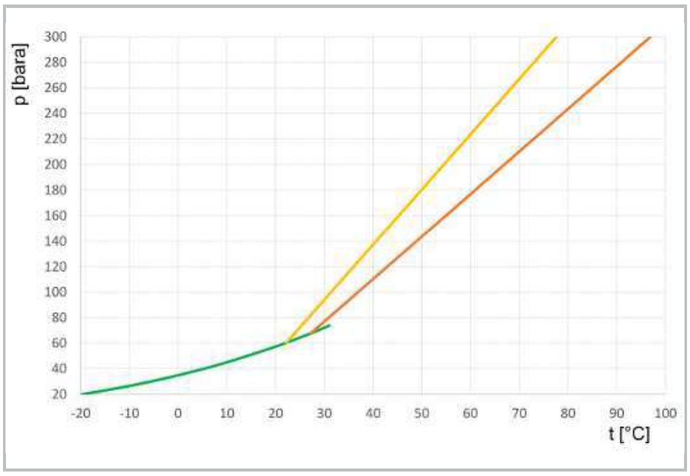


Fig. 1: Pressure in R744 refrigerant cylinders at rising temperature for two filling ratios

Green	Saturated liquid (boiling curve)
Yellow	Filling ratio 0.75 kg/l: 100% at 22.2°C = 59.3 bar
Red	Filling ratio 0.67 kg/l: 100% at 27°C = 65.5 bar

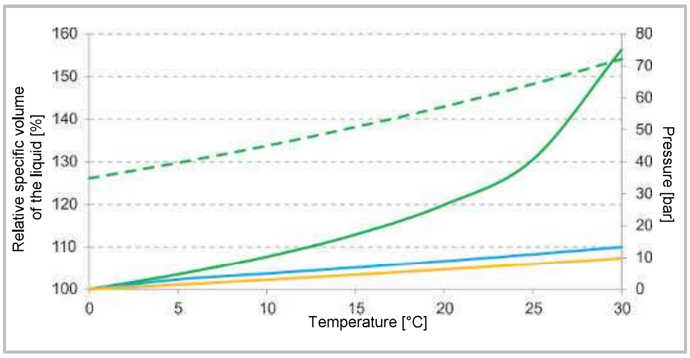


Fig. 2: Relative specific volume of the liquid and saturation pressure as a function of temperature

Green	Specific volume of the liquid R744	Green dashed	Saturation pressure of R744
Yellow	Specific volume of the liquid R717	Blue	Specific volume of the liquid R134a

Due to the low critical temperature of the refrigerant R744, heat dissipation occurs at high heat sink temperatures in the supercritical range, i.e. above the critical point. Heat absorption in the evaporators, on the other hand, continues to take place in the subcritical range. The fact that the process takes place both below and above the critical point means that the process is referred to as a transcritical process (see following figure).

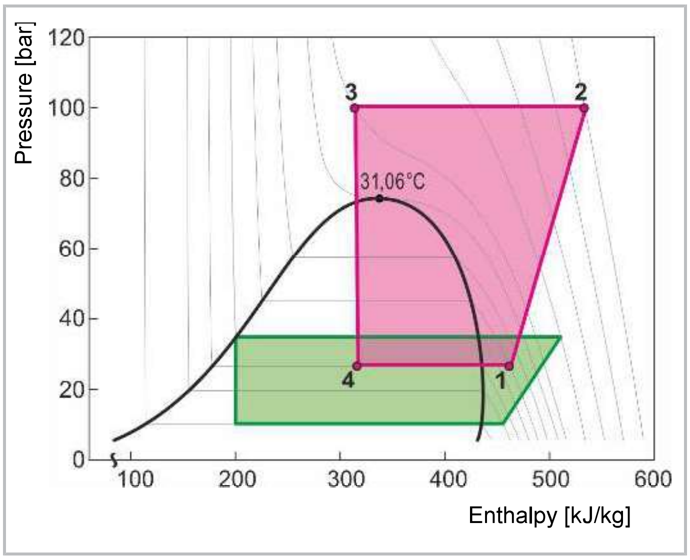


Fig. 3: Basic process: Single stage compression and expansion

Green	Subcritical process
Red	Transcritical process
2-3	Gas cooling supercritical, only sensible heat change
4-1	Subcritical heat absorption in the evaporator, latent and sensible heat change

Because pressure and temperature above the critical point are independent of each other (only sensible heat change), the efficiency, or Coefficient of Performance (COP), for a constant gas cooler outlet temperature is a function of pressure (see following figure).

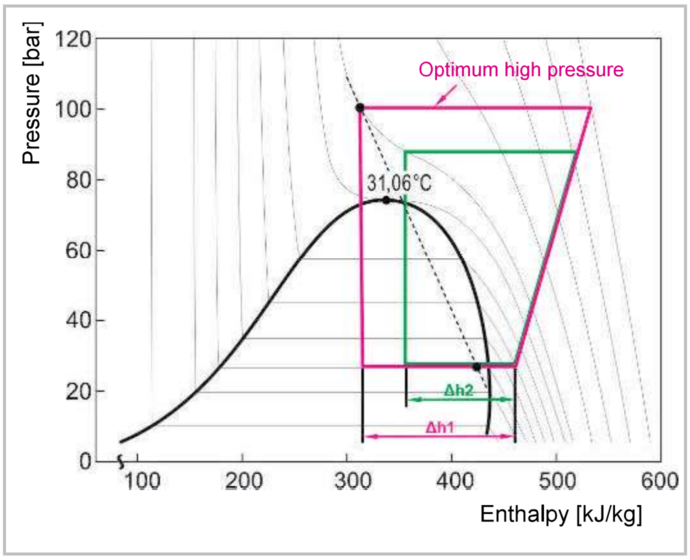


Fig. 4: Transcritical process: Optimum high pressure

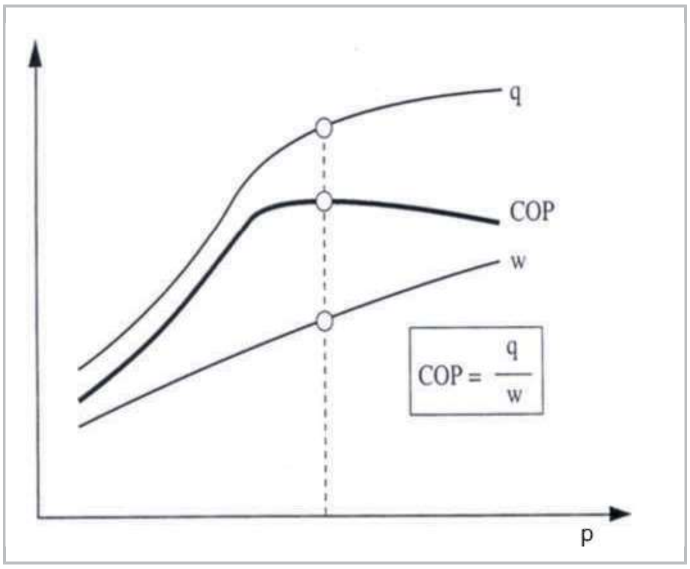


Fig. 5: Qualitative progression of the specific refrigerating capacity q, the specific power consumption w, and coefficient of performance COP above the high pressure for a constant gas cooler outlet temperature. Source: Sintef-NTNU

3 Safety

Authorized staff

All work done on the products and the systems in which they are or will be installed may only be performed by qualified and authorised staff who have been trained and instructed in all work. The qualification and competence of the qualified staff must correspond to the local regulations and guidelines.

Residual risks

The products, electronic accessories and further system components may present unavoidable residual risks. Therefore, any person working on it must carefully read this document! The following are mandatory:

- relevant safety regulations and standards
- generally accepted safety rules
- EU directives
- national regulations and safety standards

Depending on the country, different standards are applied when installing the product, for example: EN378, EN60204, EN60335, EN ISO14120, ISO5149, IEC60204, IEC60335, ASHRAE 15, NEC, UL standards.

Personal protective equipment

When working on systems and their components: Wear protective work shoes, protective clothing and safety goggles. In addition, wear cold-protective gloves when working on the open refrigeration circuit and on components that may contain refrigerant.

Fig. 6: Wear personal protective equipment!

Safety references

Safety references are instructions intended to prevent hazards. They must be stringently observed!

NOTICE
Safety reference to avoid situations which may result in damage to a device or its equipment.

CAUTION
Safety reference to avoid a potentially hazardous situation which may result in minor or moderate injury.

WARNING
Safety reference to avoid a potentially hazardous situation which could result in death or serious injury.

DANGER
Safety reference to avoid an imminently hazardous situation which may result in death or serious injury.

In addition to the safety references listed in this document, it is essential to observe the references and residual risks in the respective operating instructions!

3.1 General safety references

DANGER
R744 is an odourless and colourless gas and cannot be perceived directly in case of emission!
Lost of consciousness and danger of suffocation by inhaling higher concentrations!
Avoid R744 emission and uncontrolled deflating, particularly in closed rooms!
Aerate closed machine rooms!
Make sure that the safety regulations in accordance with EN378 are complied with!

DANGER
Observe the high pressure levels of the refrigerant R744!
At standstill the pressure in the system will rise and there is a risk of bursting!
Install pressure relief valves on the compressor and on the suction and high-pressure sides in system sections that are lockable from both sides.
Requirements and design according to EN378-2 and EN13136.

Critical temperature 30,98°C corresponds to 73.77 bar (*see chapter Pressure and saturated vapour temperature table for R744, page 130*) or see BITZER RefRuler App.

DANGER
Liquid R744 evaporates quickly, cools down at the same time and forms dry ice!
Danger of cold burns and frost bites!
Avoid uncontrolled deflating of R744!
When filling the system with R744, wear gloves and goggles!

NOTICE
Risk of insufficient lubrication due to high R744 solubility in the oil.
Operation at low pressure ratios and low suction gas superheat results in low discharge gas and oil temperature.
Continuous operation with frequencies > 60 Hz intensifies this effect and should therefore be avoided.
If necessary, consult with BITZER.

NOTICE
Oil foam formation and therefore insufficient lubrication!
Avoid strong pressure reduction in the crankcase during the compressor start and during operation!

3.2 Measures in case of unintentional emission of R744

DANGER
R744 is an odourless and colourless gas and cannot be perceived directly in case of emission!
Lost of consciousness and danger of suffocation by inhaling higher concentrations!
Avoid R744 emission and uncontrolled deflating, particularly in closed rooms!
Aerate closed machine rooms!
Make sure that the safety regulations in accordance with EN378 are complied with!

If uncontrolled emission of R744 occurs, take the following measures:

- Leave the room immediately, warn people, ensure sufficient ventilation.
- Only enter the area with self-contained breathing apparatus if the atmosphere has not been proven to be non-hazardousness.
- Stay outdoors on the side facing the wind. Close off the area.
- Replace the pressure relief valves of the compressors after venting, as the opening pressure may be reduced/ decreased after this kind of event.

- Check the system's pressure relief valves for tightness after venting and replace if necessary.

3.3 Pressure relief valves to atmosphere on compressor

BITZER compressors for R744 are equipped with pressure relief valves to the atmosphere on the low and/or on the high pressure side, depending on the compressor series (see table below).

Information
The pressure relief valves to atmosphere fitted to the compressor do not replace the system pressure relief valves required by EN378!
They only protect the compressor against impermissibly high pressures once it is shut off on both sides.
Any modification to the compressor is the responsibility of the customer/contractor.

Compressor:

- Ensure that these pressure relief valves can vent freely.
- In the case of compressors for subcritical applications (2NSL– 4NSL), the pressure relief valve is mounted on the suction gas shut-off valve. When operating the compressor, open the suction gas shut-off valve completely (pressure relief valve is then inactive).
- Do not connect any pipes to the outlet of the pressure relief valves.

When performing work or measurements on the maintenance connection of the discharge gas shut-off valve:

NOTICE
Pressures of up to 160 bar can occur at the maintenance connection of the discharge gas shut-off valve!
Standard components (e.g. pressure gauge bridges, hoses, etc.) can be damaged or destroyed.
Proceed carefully and only use components suitable for these high pressure levels!

Minimum opening pressure of the pressure relief valves to atmosphere

Compressor	Low pressure side in bar	High pressure side in bar
2MTE– 6CTE(U)	90 (*)	148
8FTE– 8CTE	80 (*)	140
2MME– 6PME	-	-
2NSL– 4NSL	30	-

(*) The pressure relief valve on the low pressure side is not part of the standard compressor design, but is available as an option.

3.4 Safety devices of the system in accordance with EN378

To protect the system against excess pressure, type-tested pressure relief devices must be installed. Which system sections are affected by this is determined by the requirements of EN378-2 and national legislation.

Generally speaking:

- Areas of the system that can be shut off from both sides must be secured against excess pressure, for example, because of the danger of trapped liquid!
- Lockable areas of the system that could be shut off, but cannot be shut off for operational reasons (according to EN378-2, e.g. secured shut-off valves, connection for pressure measurement) do not have to be protected against excess pressure.
- Always use type-tested pressure relief devices/pressure relief valves.
- When venting these pressure relief devices, it must be ensured that neither persons nor property are endangered by the released refrigerant.

- If possible, install the pressure relief devices on the outside wall.
- Design pressure relief device and venting lines in accordance with EN13136.
- All venting lines/pressure relief devices must be able to vent freely – be sure to protect them from blockages due to contamination and (dry) ice! In addition, it must be possible to perform a separate tightness test on these lines (e.g. for detecting a refrigerant leak).

3.5 Maximum allowable pressure of the compressor housing

See also name plate on the compressor.

Compressor	**Low pressure side in bar**	**High pressure side in bar**
from serial number: 16805187392 2MTE– 6CTE(U)	100	160
8FTE– 8CTE	80	150
2MME– 6PME	100	100
2NSL– 4NSL	30	53

3.6 Compressor with line start permanent magnet motor (LSPM)

WARNING
Strong magnetic field!
Keep magnetic and magnetizable objects away from compressor!
Persons with cardiac pacemakers, implanted heart defibrillators or metallic implants: maintain a clearance of at least 30 cm!

NOTICE
The PTC temperature sensor integrated in the stator as a standard protects the LSPM motor from overload when the temperature rises (e. g. in case of prolonged locked rotor conditions). It is recommended installing an additional overload protective device that reacts more quickly, since repeated locking conditions would damage the magnets.

4 Transcritical applications

Transcritical systems with R744 are the state of the art in commercial refrigeration. The systems are increasingly developing into complete integrated solutions with low and medium temperature applications, air conditioning and heating by means of heat recovery. In addition, measures are increasingly being taken to further improve efficiency while also reducing the cost of the systems. The optimal interaction, or the best possible control of the individual system components, forms the basis for year-round system efficiency, a long compressor lifetime and thus a high level of operational reliability.

The long-term, fault-free operation of a compressor can only be ensured if:

- The quality, design and suitability, as well as the perfect material condition and function of all components of the compressor are guaranteed.
- The permitted operating conditions are complied with.
- A control of the refrigerant mass flow is ensured which is not too dynamic.
- The oil supply/lubrication is ensured (pay attention to oil temperature and refrigerant concentration in the oil). This also includes a stable oil return from the system and a functioning oil management system (*see chapter Öl-management, page 93*), especially in compound systems with extended pipe works.
- Harmful foreign substances in the system, such as moisture, non condensable gas, dirt, chemical residue, metal oxides and swarf are minimised.

The following chapters provide information and instructions on how to classify system characteristics such as the quality of the control (control accuracy), the selected coverage of the minimum load, the type of desuperheating of the suction gas and the oil management – even in the case of conflicting requirements – and how to act accordingly.

4.1 System designs

The following sub-chapters list common system designs and describe important aspects of these.

The following applications are not listed in detail, as they always require individual coordination with BITZER:

- The use of the compressors 2MTE–8CTE, 4PTEU–6CTEU in systems with hot gas defrosting, systems with heat delivery to a chilled water network and in low-temperature applications.
- The use of the compressors with motor version 2 as parallel compressors.

4.1.1 Gustav Lorentzen process (single stage system)

- Single stage compression for a useful temperature level and single stage expansion for medium temperature applications. Without low-temperature compressor stage.
- Standard system design when using R744 in heat pumps.
- No overheating control at the outlet of the evaporator, but operation with flooded evaporator.
- A low-pressure separator must be installed in the suction gas line at the outlet of the evaporator.
- The oil return line must be connected to the bottom of this separator.
- The oil used must be BSG68K from BITZER (a polyalkylene glycol oil).
  When this PAG oil is mixed with liquid R744, the oil sinks to a saturation temperature of -32°C at the bottom of the low-pressure separator, where it can be removed. At temperatures below -32°C, however, the oil floats and makes oil return more difficult, especially in defrost mode!
- A liquid suction line heat exchanger must be installed so that the minimal amount of liquid R744 contained in the oil, which enters the suction gas line via the oil return line, can be re-evaporated.

This system design is recommended for systems with one evaporator. If several evaporators are to be operated, other system designs are more suitable (see *see chapter Booster system for medium and low temperature application with flash gas bypass, page 81*).

The following system diagram is a simplified representation, without the recommended shut-off valve and other control mechanisms recommended above in the oil return line at the low-pressure separator downstream of the evaporator.

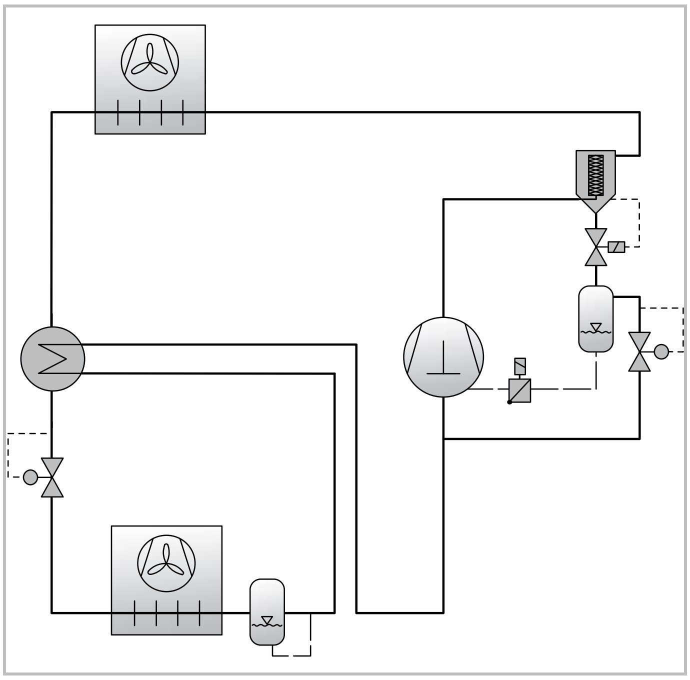


Fig. 7: System diagram Gustav Lorentzen Process (simplified representation)

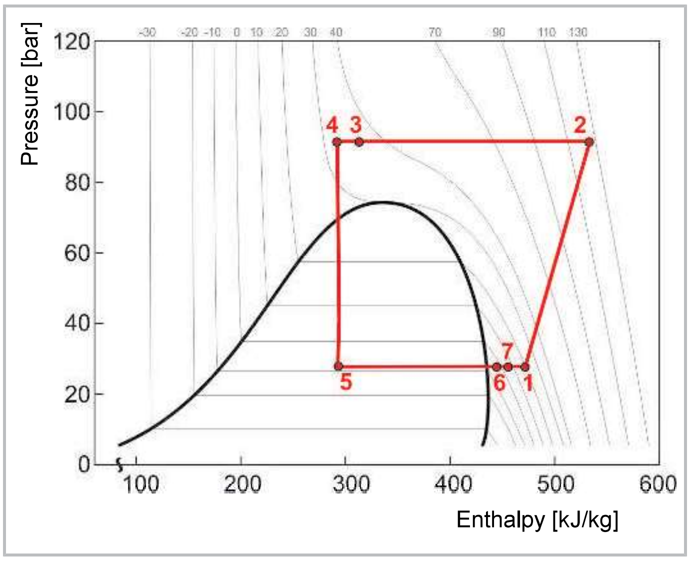


Fig. 8: Gustav Lorentzen process in the p-h-diagram

1	Compression
2-3	Gas cooling/condensation
3-4	Internal heat exchanger/subcooling
4-5	Expansion to evaporation temperature
5-6	Evaporation
6-7	Overheating in the suction gas line
7-1	Liquid suction line heat exchanger

4.1.2 Booster system for medium and low temperature application with flash gas bypass

In 2008, systems with "flash gas bypass (FGB)" also became standard R744 system designs due to their simple design.

- Systems with single stage compression, two-stage expansion and flash gas bypass for a useful temperature level e.g. medium temperature applications.
  - This system design provides for a separator in which liquid and gaseous R744 are separated from each other. This takes place at intermediate pressure and will be referred to in the description hereafter as an intermediate pressure vessel.
  - The pressure inside the intermediate pressure vessel is controlled by a flash gas bypass valve. The pressure level here is above the required evaporation pressure/above the suction pressure of the medium temperature compressors.
- However, the system is usually set up and used as a booster system for two different useful temperature levels, e.g. medium temperature application and low temperature application.

  It is composed of, among other things:
  - Two compressor stages (normal refrigeration and deep-freeze compressor stage)
  - with a common refrigerant and oil circuit
  - with two-stage expansion for each evaporator temperature level/evaporator pressure level
  - an intermediate pressure vessel and
  - a flash gas bypass.
- Two-stage compression is achieved by two single stage compressors connected in series.
- The operation of this standard system cools with the help of dry evaporators ("direct expansion").
- The refrigeration compressor stage in a booster system is a subcritical application.

Further features of a booster system with flash gas bypass

- After flowing through the gas cooler/condenser, the refrigerant is relaxed to intermediate pressure with the aid of a high-pressure control valve in the intermediate pressure vessel; gas and liquid phases are separated from each other:
  - The resulting flash gas is fed to the compressors of the medium temperature compressor stage via a flash gas bypass valve,
  - the liquid is led to the evaporators of the low and medium temperature application.
- This flash gas bypass can be used to lower the intermediate pressure to a defined set point (e.g. 35–40 bar). However, the mass flow from the intermediate pressure vessel to the evaporators is then also reduced. The increased available enthalpy difference during evaporation compensates for this.
- Unlike a simple refrigerating circuit or a cascade system, the temperature of the liquid refrigerant is higher than the saturation temperature on the high pressure side of the low temperature compressors. This means that less evaporation enthalpy is available to the evaporators, which must definitely be taken into account when selecting the compressors by means of a higher mass flow!
- Since the low temperature compressors feed the refrigerant directly into the suction header of the medium temperature compressor stage, the specific compression work is lower than in a cascade system due to the lower pressure ratio.

  The suction gas temperature of a compressor of the medium temperature compressor stage results from the three mass flows – low temperature mass flow, medium temperature mass flow and mass flow of the flash gas – which all have different temperatures.

Important points in system planning and system design

In addition to operational safety and efficiency, the influence of different **load conditions** during operation is decisive in the planning and design of R744 booster systems.

- The most extreme load conditions ("worst case conditions") must always be calculated and taken into account, i.e.:
  - Both the full load conditions at maximum ambient temperatures over several hours (simultaneous operation/ simultaneity factor 0.8–0.85), as well as the
  - Operating conditions at minimum load at low ambient temperatures and within/outside opening hours ("shop open" and "shop closed").

Based on these calculations, it is possible to answer the following questions:

- Is the capacity control of the compressors optimally set? (*see chapter Capacity control, page 103*).
  - For example, can a high control accuracy (CF) (*see page 88*) be achieved with minimal changes in performance when connecting and disconnecting follow-up compressors?
  - Can stable operation be guaranteed without frequent start-up and shut-off of the compressor(s) at minimum load conditions?
- Are the suction gas and discharge gas temperatures within the application limit(s) of the compressor(s)?

In order to optimise the operating conditions and avoid critical operating conditions, additional components such as liquid suction line heat exchangers, discharge gas desuperheaters, an increased number of compressors, or auxiliary systems such as refrigerant injection may have to be considered.

- Critical operating conditions caused by unfavourable load conditions include:
  - A low load on the evaporators of the medium temperature compressor stage and a simultaneous high load on the evaporators of the low temperature compressor stage:

    This leads to high suction gas temperatures in the medium temperature compressors and thus influences the engine cooling and discharge gas temperature and
  - The reverse case, i.e. a high load on the evaporators of the medium temperature compressor stage and a simultaneous low load on the evaporators of the low temperature compressor stage:

    This leads to low suction gas temperatures with low oil sump temperatures and possible wet operation due to too much liquid content in the flash gas.

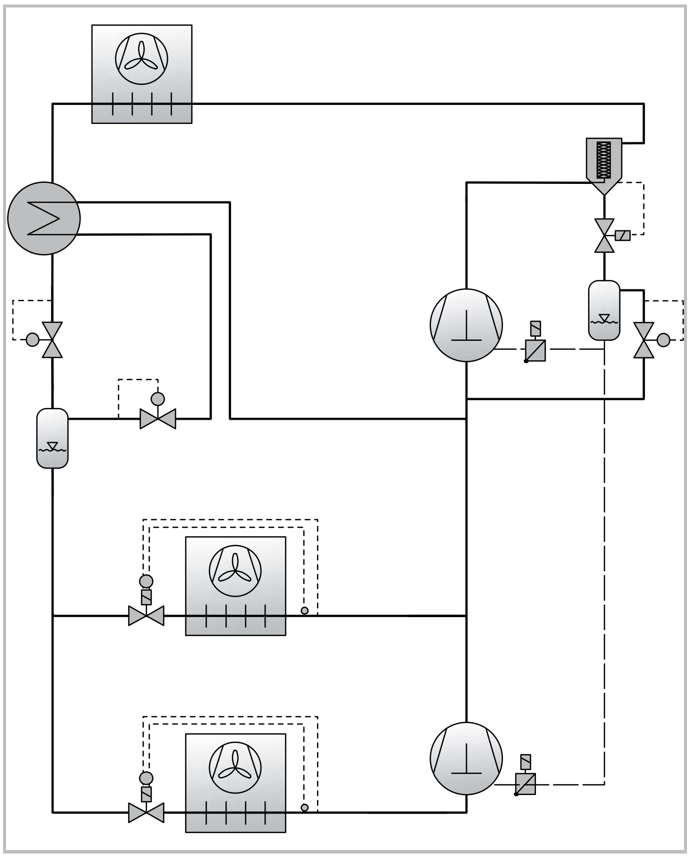


Fig. 9: System diagram: Booster system for medium and low temperature application with flash gas bypass (simplified representation)

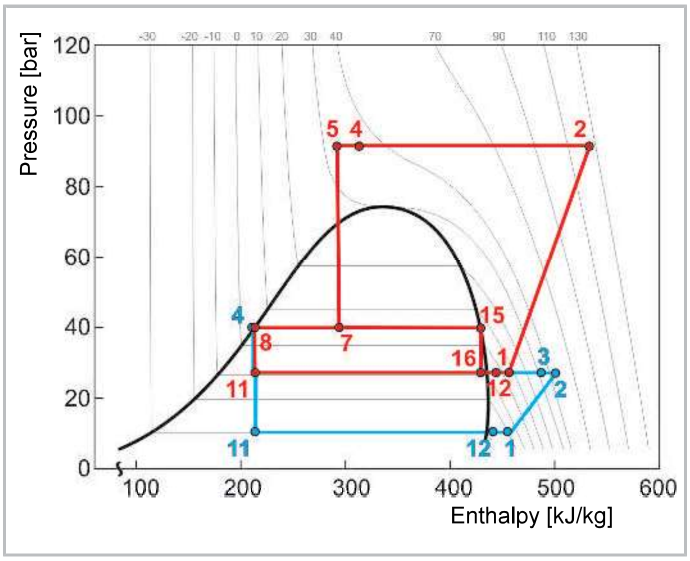


Fig. 10: Booster system for medium and low temperature application with flash gas bypass in the p-h-diagram

Low temperature compressor stage:

1-2	Compression
2-3	Desuperheating
4-11	Expansion
11-12	Evaporation

12-1	Overheating suction gas line

Medium temperature compressor stage:

1-2	Compression
2-4	Gas cooling/condensation
4-5	Internal heat exchanger/subcooling
5-7	Relaxation to intermediate pressure
7-8	Liquid outlet at the intermediate pressure vessel
8-11	Relaxation to evaporation pressure
11-12	Evaporation
12-1	Total overheating
7-15	Gas outlet at the intermediate pressure vessel
15-16	Expansion to evaporation pressure

4.1.3 Booster system for medium and low temperature application with parallel compression

- The principle of parallel compression reduces the pressure ratio required to recompress the flash gas to high pressure level. However, it does not reduce the amount of flash gas at intermediate pressure level, nor the losses during throttling.
- The flash gas is thus drawn in at a higher pressure level from a separate parallel compressor or parallel compressor stage which is directly connected to the intermediate pressure vessel.
- Gas and liquid are separated in the intermediate pressure vessel. The liquid is fed as usual to the evaporators of the low and medium temperature refrigeration compressor stages.
- After expansion and heat absorption in the evaporators, the mass flow of the evaporators of the low temperature compressor stage is absorbed by the low temperature compressor stage and compressed again to the suction pressure level of the medium temperature compressor stage.
- The higher efficiency of a booster system with parallel compression is therefore based on a smaller pressure ratio when compressing the flash gas and a higher density of the vapor to be compressed. This means that a lower geometric displacement is required for compressing the vapor drawn from the intermediate pressure vessel.
- Transcritical R744 booster systems with parallel compression typically have four different pressure levels and are composed of:
  - The low temperature suction pressure
  - the medium temperature suction pressure
  - the intermediate pressure
  - the gas cooler high pressure

  Each of these are in the respective compressor stages:
  - Low temperature compressor stage:
    Comprised of low temperature suction pressure and medium temperature suction pressure. The medium temperature suction pressure corresponds to the final compression pressure of the low temperature stage.
  - Medium temperature compressor stage:
    Comprising medium temperature suction pressure and gas cooler high pressure
  - Parallel compressor stage:
    Comprising intermediate pressure and gas cooler high pressure
- All compressor stages have a common refrigerating and oil circuit.

- For safety and control, systems with parallel compression need a flash gas bypass valve.
- To ensure a sufficiently high suction gas superheat (3– 5 K at full load in summer) of the flash gas sucked in by the parallel compressor, a liquid suction line heat exchanger should be installed between the gas cooler discharge line and the suction gas line of the parallel compressors.
- This increases the oil sump temperature while reducing the amount of refrigerant dissolved in the oil in the compressor crankcase. This is particularly advantageous when operating the system at low temperatures.

Important points in system planning and system design

- The following criteria may restrict the operation of a booster system with parallel compression:
  - The application limits of the parallel compressor(s) at higher suction pressure.
  - The minimum possible frequency of the parallel compressor(s) with capacity control (*see chapter Capacity control with frequency inverter, page 103*).
- The efficiency of the system is further improved by an optimised intermediate pressure – depending on the high pressure, the gas cooler outlet temperature or ambient temperature.
  An optimised intermediate pressure means that the set point for the intermediate pressure is variably controlled. Ideally, it should always be set as high as possible. This allows the parallel compressor(s) to be operated for longer without encountering either of the two limiting criteria mentioned above. At the same time, the efficiency/ COP of the system improves.
- The transition range from flash gas operation to parallel compression must be determined depending on different load conditions. For operation with heat recovery (HR), all expected operating scenarios or load conditions should be considered ("shop open", "shop closed", with heat recovery (HR), without heat recovery (HR), etc.).
- If parallel compression is not possible, e.g. at medium ambient temperatures, the medium temperature compressors must still be able to deliver the required refrigerating capacity!

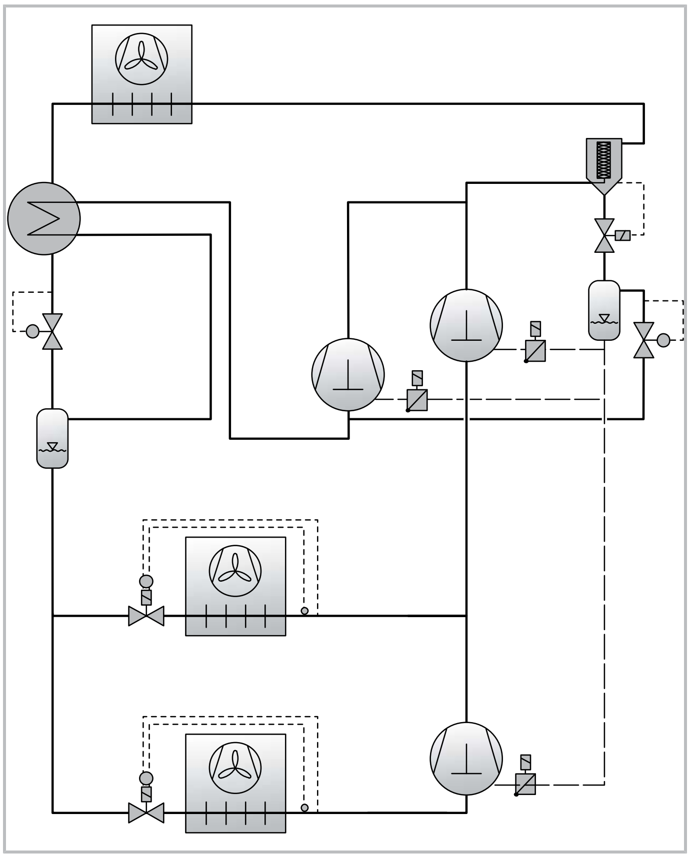


Fig. 11: System diagram: Booster system for medium and low temperature application with parallel compression (simplified representation)

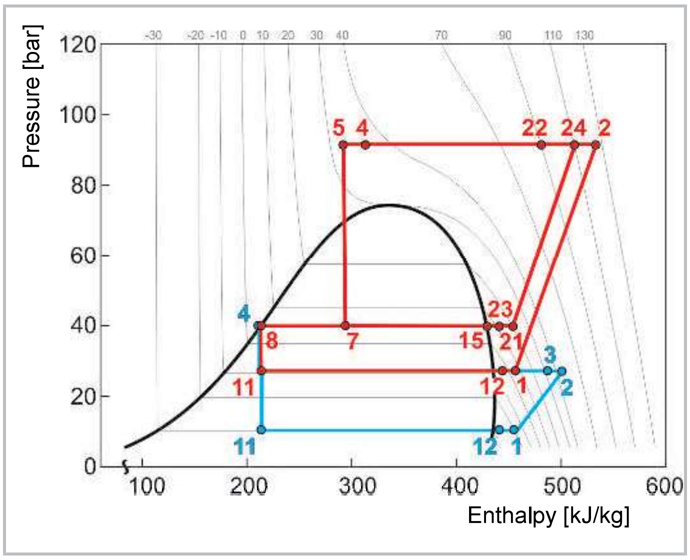


Fig. 12: Booster system for medium and low temperature application with parallel compression in the p-h-diagram

Low temperature compressor stage:

1-2	Compression
2-3	Desuperheating
4-11	Expansion
11-12	Evaporation
12-1	Overheating suction gas line

Medium temperature compressor stage:

1-2	Compression
2-4	Gas cooling/condensation
4-5	Internal heat exchanger/subcooling
5-7	Relaxation to intermediate pressure
7-8	Liquid outlet at the intermediate pressure vessel
8-11	Relaxation to evaporation pressure
11-12	Evaporation
12-1	Total overheating
7-15	Gas outlet at the intermediate pressure vessel

Parallel compressor stage:

21-22	Compression
23-21	Internal heat exchanger/overheating
24	Inlet temperature into the gas cooler

4.1.4 System components

Filter drier

NOTICE
Danger of blocked and clogged control valves due to dry ice!
The solubility of water in gaseous R744 is much lower than in other refrigerants. Therefore, especially in low temperature applications, even a relatively small amount of moisture can freeze out of the refrigerant.
Install a generously sized filter drier and a sight glass with a moisture indicator for R744!

- Use pure molecular sieve inserts. An additional filter with mesh size ≤ 25 µm is advantageous.
- Use R744 with low water content (< 5 ppm) and sight glasses with a moisture indicator (*see chapter Refrigerant requirements and filling process, page 96*).
- It is essential to follow the evacuation instructions (*see chapter Checklist for commissioning, point 4., page 97*)!
- Also: Observe the maximum allowable pressures of the filter drier and ask the manufacturer about suitability for use with added oils for wear protection!

Hydrate formation

- The solubility of water in gaseous R744 is lower than in other refrigerants and depends on temperature and pressure. For:
  - Gaseous R744: Water solubility decreases with increasing pressure and constant temperature.
  - Liquid R744: Water solubility increases with increasing pressure and constant temperature.
  - Gaseous and liquid R744: Water solubility decreases with decreasing temperature.
- The phase characteristic of the mixture of water and R744 shows in the p-t-diagram a large area in which hydrate can form (see figure below, blue area). Hydrate is corrosive, can dissolve metals and cannot be adsorbed by the molecular sieves on the filter driers. **Therefore, the filter driers should not be installed in plant areas where hydrate could be present.**
- To avoid not only the formation of hydrate, but also the formation of acid (hydrolysis), ice and to prevent corrosion, only generously sized and suitable filter driers and filter drier inserts should be used (see also safety note above).

Conclusion:
The use and effectiveness of filter driers in the system are limited to the suction side of the medium and low temperature compressor stages.

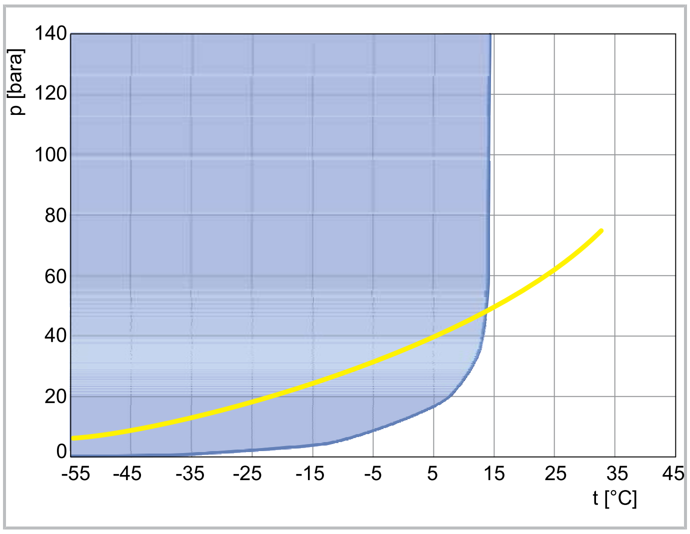


Fig. 13: Formation of hydrate in R744 systems
Blue: Hydrate
Yellow: R744 boiling point curve

4.2 Parameters and recommendations for optimal system efficiency and operational safety

The prerequisites for optimum system efficiency and operational safety are:

- **Optimisation of the control accuracy** thanks to compressor capacity control in the compressor stages (*see page 88*).
- Compressor capacity control in the compressor stages at **partial load or minimum load conditions, without frequent start-up and shut-off of the compressor(s)** (*see page 89*).
- Stable control of the **refrigerant mass flow** (*see page 89*).
- Compliance with the permitted **operating conditions** (*see page 90*).
- Guaranteed **oil circulation and lubrication** (*see page 91*).

Additionally: Avoid harmful foreign substances in the system such as moisture, non condensable gas, dirt, chemical residue, metal oxides and swarf!

Optimisation of the control accuracy (CF)

A wide control range of the capacity control ensures stable operation, even with load or power changes. However, this is only possible if the control range of the guide compressor can cover the capacity gaps caused by other compressors when switching on and off. The control accuracy (CF) is calculated from the difference between the power of the guide compressor at maximum and minimum frequency, divided by the power of the following compressor, multiplied by 100%.

The compressor capacity control in the compressor stages should ideally achieve values ≥ 100%. Values < 80% are not good and can cause unstable operating conditions.

See also Technical Information *KT-600*.

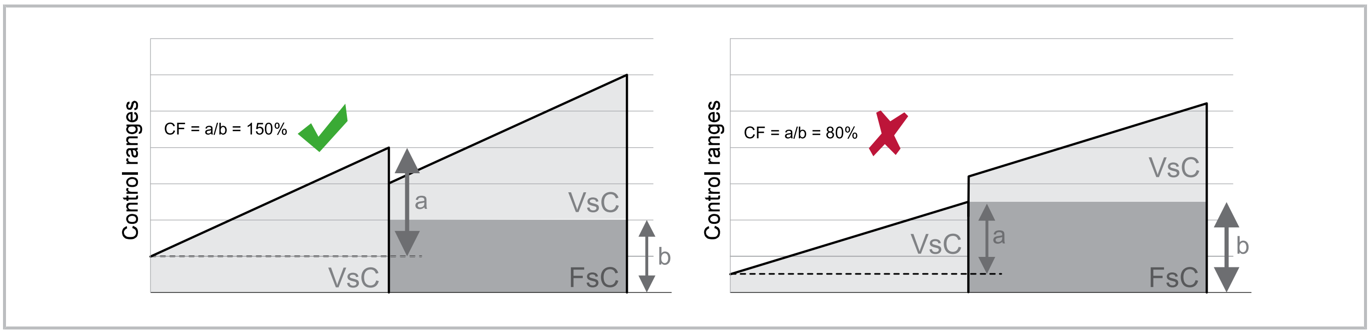


Fig. 14: Example of the control accuracy of parallel compounding with 2 compressors (source: ASERCOM)
VsC: Compressor with variable speed
FsC: Compressor with fixed speed
CF: Control accuracy in %

Covering part load/minimum load

Covering of partial load conditions down to minimum load, e.g. by the guide compressor, guarantees a continuous mass flow, stable suction and high pressures, and stable suction gas temperatures. This prevents poor efficiency of the system, possible wet operation, reduced oil return, fluctuating control loops and unfavourable operating conditions for the compressors.

Avoid frequent start-up and shut-offs (cycling rate) of the compressors

High cycling rates lead to increased mechanical stress on the drive gear and thermomechanical stress on the compressor motor. Operating at low compressor frequency or repeatedly switching off risks a lack of oil!

For compressors without frequency inverter:

- Max. six starts per hour and min. 10 minutes between two starts.

For compressors with frequency inverter:

- Operation of the compressors in the starting phase with a frequency of ≥ 40 Hz for ≥ 10 s
  This ensures sufficient oil supply to the drive gear before the control is released.
- Note that frequent starts and shut offs usually occur at night or outside opening hours!
  - Cycling rates > 120 per day are critical. Check the control behaviour of the system!
  - Cycling rates > 160 per day reduce the service lifetime of the compressor!

If refrigerated display cabinets are retrofitted with glass doors, observe the following points:

- Most systems are ordered and delivered with a large power reserve. Subsequent installation of glass doors reduces the required cooling capacity by a further 40–50% depending on the temperature class and evaporation temperature. The deviation between installed and required cooling capacity thus increases considerably, with major effects on the part load behaviour of the system. Cycling rates, for example, will increase sharply.
- For systems with frequent start and shut-off of the guide compressor, check whether the additional installation of glass doors can be combined with a modification of the system.
  Appropriate measures would be:
  - Select a displacement stage smaller than the guide compressor and
  - design the downstream compressor with stepped capacity control.
  - Also: Observe the notes in the chapter on optimising the control accuracy! (*see page 88*)

Control refrigerant mass flow in a stable and carefully manner

Cautious control of all system components, adapted to the conditions of the system, leads to a stable refrigerant mass flow without oscillating control loops.

- Operation with frequency inverter:
  Speed ramps to be aimed for in standard operation: Increasing 1 Hz/s and decreasing 2.5 Hz/s, observe the timer involved (compound control, frequency inverter), set one timer to zero if necessary.
- Avoid unstable operating conditions:
  - Such as the "gas loop"/"rinse mode" – do not set any set points for the high pressure control in the critical point area in order to avoid fluctuating amounts of flash gas in the intermediate pressure vessel caused by pressure and temperature conditions between the boiling point line and the dew point at the gas cooler!
  - e.g. due to mutually influencing system components (e.g. gas cooler fan and high pressure control valve) on essential process control variables (e.g. the optimum high pressure).

Information
Notes on the control dynamics do not apply to the commissioning phase – here short reaction times of the control unit are often required!

Further recommendations:

- Reduce the start opening of the electronic expansion valves on evaporators with high refrigerating capacity in line with the total refrigerating capacity of the system.
- Design heat recovery systems with pressure boosting with buffer tank on the hot water side. This prevents constant changing of operating modes.

Adhere to the permitted operating conditions

- Maximum discharge gas temperature 160°C, measured inside the cylinder heads, or 140°C at the surface of the discharge gas line (see *Operating Instructions KB-130*).
- During continuous operation, the minimum discharge gas temperature must not drop below 50°C and the minimum oil temperature must not drop below 30°C.
- The minimum superheating of the suction gas is 10 K – this must not be undercut in systems with cooling by direct evaporation!
- Comply with the maximum operating currents of the compressors!

A standard compound control unit only monitors the variables: High pressure, discharge gas temperature, suction gas superheat, oil level and engine temperature independently and only provides a standard safety cut-out. However, the permitted discharge gas temperature depends on the pressure ratio, the suction gas superheat, the compressor frequency, the operating time and the dynamics of the operation.

A low compressor frequency and a higher suction gas superheat have an influence on the thermal load of the compressor and reduce its application limit. In the figure below, for example, the dashed line ③ indicates the maximum permitted discharge gas temperature ($t_{max.}$) for a compressor frequency of 25 Hz with a suction gas superheat of 30 K and thus the limitation of the application limit.

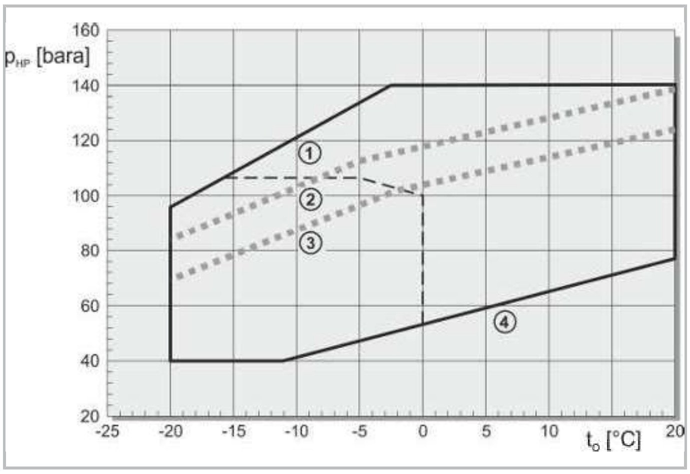


Fig. 15: Simplified representation of the thermal application limits of a compressor for transcritical applications

①	t_{max}, 10 K, 50 Hz	②	t_{max}, 10 K, 25 Hz
③	t_{max}, 30 K, 25 Hz	④	$t_{oil\ min}$, 10 K, 50 Hz

Ensure oil circulation and lubrication

Careful planning of the piping networks ensures the oil return from the system!
Oil migration and coating in the heat exchangers can thus be avoided.

- Observe minimum flow velocities, in rising lines for example, calculate using the equation according to Jacobs.
- Plan vertical rising lines with oil collection and oil breakaway bends.

The high gas solubility of the refrigerant in the oil can lead to strong degassing effects that negatively influence viscosity and tribology.

Continuous operation of the compressors without frequent starts and shut-offs aids good oil return from the system. This also prevents cold oil enriched with refrigerant from being returned abruptly from the evaporators to the compressors, e.g. after defrosting phases or at high refrigerating capacity.

Stable operating conditions also allow the oil level in the oil level controllers to be stabilised and the level to be aligned with the level in the drive gear.

Further information:

- *Technical information KT-600: Parallel compounding of BITZER reciprocating compressors*
- *Technische Information KT-420: Use of external frequency inverters with BITZER reciprocating compressors*

4.3 Recommendations for existing systems

Generally avoid unfavourable influences and operating conditions on the guide compressor, e.g:

- Daytime operation with frequent start-up and shut-off of the downstream compressors and unstable (fluctuating) operating conditions caused by poor control (*see page 88*),
- continuous operation at low compressor frequency, with simultaneous a high pressure ratio and high suction gas temperatures,
- Night operation with low compressor frequency and regular pump-down cycles, with a high pressure ratio and high suction gas temperatures.

Recommendations:

- **Increase of the control accuracy (control factor CF) in the medium temperature stage**

  - Use of a guide compressor with speed control. Here, first check whether the thermal load for the guide compressor is still permitted with the suction gas superheat and operating conditions that occur.
    If the frequency-controlled motor is star-connected, there must also be a sufficient motor current reserve.
  - Retrofitting of a downstream compressor with mechanical capacity control (CR 100% or CR 50%) (*see chapter CRII Mechanical capacity control for transcritical compressors, page 103*). For this purpose, the compound controller must be able to control another speed controlled compressor!
- **Suction gas superheating of the medium temperature stage**
  - Install an external desuperheater in the low temperature compressor stage. This reduces suction gas superheating in the medium temperature compressor stage in part load operation.
  - The use of a liquid injection can also be effective. Before doing so, check whether the capacity control of the system can cover the minimum load conditions without frequent pump-down and on-off cycles. If this is not the case, ensure that the liquid injection does not take place immediately before the pump-down set point is reached.
- **Control of the system components in a not too dynamic manner** (see *see page 89*).
- **Reduction of the maximum permitted high pressure in heat recovery mode**, standard value 80 bar.
- **Keep the system clean and dry.**
- **Eliminate causes of frequent oil alarms.**
- **Observe maintenance instructions** (see *KB-130 operating instructions*)

Further information:

- Technical information *KT-600: Parallel compounding of BITZER reciprocating compressors*
- Technische Information *KT-420: Use of external frequency inverters with BITZER reciprocating compressors*

4.3.1 Troubleshooting

Error	Possible cause	Fix
Strongly fluctuating operating conditions	High evaporator capacity in relation to compressor capacity + high degree of start opening of the electronic expansion valves.	Reduce the start opening.
	Control of the optimum high pressure.	Control of the gas cooler fans: In operation up to a minimum temperature, temperature sensor not close enough to the outlet (PT1 dead timer), or incorrect position (correct 5 or 7 o'clock).
	Parameters for controlling the suction pressure.	Assess neutral band and time delay, assess actual and required load, make small changes only incrementally and then reassess.
	Large change in capacity per stage of capacity control.	In the field: Check parameter settings for more stable operation, e.g. higher min. pressure in gas cooler. During planning: Increase the number of compressors, change the displacement of the guide compressor.
Application limit is not respected	Operation too close to the application limit and overshooting the control.	Adjust PID control (Proportional-Integral-Derivative controller) of the corresponding components and other parameters of the control system.
	The influence of the frequency inverter operation on the application limits was ignored.	Change minimum high pressure or minimum frequency.

Error	Possible cause	Fix
	Influence of part load operation on the suction gas temperature in booster systems.	Evaluate options for incremental change of parameters, use liquid injection, install desuperheater.
Liquid slugging	Compressor is flooded with liquid refrigerant.	Use fail-safe electronic expansion valves, check piping installation, check size of accumulator and refrigerant charge.
	Compressor flooded with oil.	Faulty oil management (*see chapter Ölmanagement, page 93*), too much oil in the system, check piping installation.
	Defrost mode.	Reduce the number of evaporators in defrost mode in parallel.
Moisture in the system	Inadequate evacuation.	Check vacuum pump and vacuum gauge connection. Open and check each area of the system.
	Leakage test carried out under vacuum.	Carry out leakage test under pressure.
Contaminants	Incorrect cutting of pipes to length.	Use a pipe cutter.
	Faulty soldering.	Use inert gas.

4.4 Oil management

NOTICE
Risk of insufficient lubrication due to high R744 solubility in the oil.
Operation at low pressure ratios and low suction gas superheat results in low discharge gas and oil temperature.
Continuous operation with frequencies > 60 Hz intensifies this effect and should therefore be avoided.
If necessary, consult with BITZER.

NOTICE
Oil foam formation and therefore insufficient lubrication!
Avoid strong pressure reduction in the crankcase during the compressor start and during operation!

Oil and compressed gas temperature

- Generally use oil heater, especially during standstill phases.
- Oil temperature: 30°C (20°C = absolute minimum value!).
- Recommended suction gas superheat 20 K – if necessary, provide heat exchanger to minimise refrigerant concentration in the oil.

  Lower suction gas superheat is possible, provided minimum oil and discharge gas temperatures are maintained. When cooling by direct evaporation, avoid values < 10 K!
- Minimum discharge gas temperature = condensing temperature $t(_{c})$ + 40 K.
- The discharge gas temperature during operation must be determined as a function of the peak pressures. During continuous operation, the temperature of the compressed gas should not fall below 50°C!
  Depending on the high and low pressure, very high discharge gas temperatures can occur even when operating with saturated suction gas!
- Maximum discharge gas temperature 140°C, measured at the discharge gas line at a distance of 10 cm from the compressor discharge gas connection.
- The influence of different load conditions (*see page 89*) and the use of different system concepts (e.g. flash gas bypass) on the operating conditions of the compressors must be taken into account and included in the calculations. If necessary, consultation with BITZER is recommended.

Oil separator and oil return

- Use oil separators with coalescence filter cartridges.
- Only use oil separators without a float valve. The (electronic/optical) oil level monitoring in the oil separator opens a solenoid valve in the line to the oil reservoir if required.
- Only use electronic oil level controllers that are suitable for the high maximum opening pressure differences (MOPD= Maximum Operating Pressure Difference).
  The permitted pressure figures for mechanical controllers are not sufficient for R744 systems, especially booster systems.
- The amount of oil in the oil reservoir should be at least as large as the amount of oil in all compressors. However, the oil reservoir itself may only be filled to maximum halfway with oil.
- It is not recommended to use a controlled intermittent oil return that feeds oil into the reservoir (low pressure oil reservoir) or the compressors (high pressure oil reservoir) regardless of the amount of oil in the oil separator.
- To ensure oil return to the compressors, the pressure in the oil reservoir must be higher than the highest suction pressure in the system.
  Degassing takes place in the corresponding suction gas line. In systems with parallel compression, degassing always takes place at the intermediate pressure level and not, for example, at the suction pressure level of the compressors in the medium temperature compressor stage.
- Differential pressure valves should be used in the degassing line. The required pressure difference depends on the boundary conditions. Pressure differences between 2.5 and 4.5 bar are usually used.

In addition, observe or coordinate the following parameters and variables:

- Nozzle cross-section of the oil level controllers used in the respective compressor stage.
- Opening time of the oil level controller when refilling oil.
- Amount of oil held in the oil reservoir.
- Nominal maximum pressure difference in the oil reservoir.
- Length and cross section of the oil lines from the oil reservoir to the oil level controllers.

Information
It is also recommended that the oil level be monitored by an oil level controller on all compressors, during operation and when the system is at a standstill.
In the event that oil is overfilled, an alarm/warning must be given and the cause rectified (excessive cycling rates, problems covering minimum load conditions, etc.).
It is not mandatory for the device to lock out and be switched off.

4.4.1 Oil charge for BITZER compressors

	BSE60K POE	BSE85K POE	BSG68K PAG
2NSL– 4NSL	Standard	Option	Option
2MME– 6PME	Standard	Option	Option
2MTE– 8CTE	-	Standard	Option

NOTICE
Use BSE85K: For booster units with POE oils and the compressors 2NSL– 4NSL and 2MME– 6PME.

NOTICE
Only use BSG68K for applications with suction pressure > 40 bar and/or high pressure > 120 bar (e.g. heat pumps).

Note when using PAG oil (BSG68K):

- PAG oil is only partially miscible with the liquid phase of R744.
- When PAG oil is mixed with liquid R744 in containers, the oil-rich phase sinks to the bottom of the vessel to a saturation temperature of -32°C. In applications with low-pressure separators, the oil can therefore be removed in the lower part of the separator. At temperatures lower than -32°C, however, the oil will float!
- To keep the proportion of liquid in the oil return line as low as possible, install an internal heat exchanger, e.g. between the gas cooler outlet and the oil return.
- Generally observe the flow velocities at the evaporator outlet. If the speeds are too low, there is a risk of oil migration back into the heat exchangers.

4.5 Commissioning

Information
Before the system is commissioned, check all safety and monitoring devices as well as control components in the system and in the machinery room for correct functioning! Calibrate sensors and pressure transducers, check signal tests and analogue/digital inputs and outputs.

Information
It is essential to observe the safety reference and information in chapters *see chapter "Sicherheit", page 75* and *see chapter "Ölmanagement", page 93*!

Commissioning compressors for applications with R744 requires a particularly careful approach:

- There is a risk of overstress due to high pressure levels and possibly strong pressure fluctuations after start-up as well as lack of oil due to high refrigerant solubility in the oil!
- Observe operating conditions carefully and shut off evaporators temporarily in case of unfavourable operating conditions. Rectify causes/errors (*see table , page 92*. In case of abnormal conditions, shut off compressors and evaporators.
- Monitor the system during the entire commissioning process!

In addition, the following information must be available:

- Design parameters
  - e.g. max. permitted pressures of compressors and components, at standstill and in operation

  - Temperature differences in heat exchangers, etc.
- Piping and instrumentation diagram
- Electrical schematic wiring diagram
- P&I diagram

4.5.1 Refrigerant requirements and filling process

DANGER
Liquid R744 evaporates quickly, cools down at the same time and forms dry ice!
Danger of cold burns and frost bites!
Avoid uncontrolled deflating of R744!
When filling the system with R744, wear gloves and goggles!

- Use a pressure reducer when removing R744 from cylinders without a riser tube! In general, even after maintenance work, always break vacuum with gaseous R744.
- For R744 cylinders with riser tube, high pressure liquid removal only! Do not use a pressure reducer! Membranes of the pressure reducers are not completely sealed against liquid.

  After filling the system with liquid, remove the filling pipe or hose and make sure that no liquid is trapped in it!

Permitted refrigerant

R744 or CO_2 of purity class N4.5 or comparable, or H_2O < 5 ppm.

The CO_2 purity class can contain a higher H_2O content if a generously sized filter drier is used and the system is filled via this. It is recommended to change the filter drier several times after commissioning (*see chapter chapter filter drier, page 87*).

Due to the high requirements for residual moisture, CO_2 of purity class N3.0 must always be filled via a filter drier!

Filling process

▸ Do not switch on the compressor.

▸ Switch on the oil heater.

▸ Do not start the filling process until the following oil temperature has been reached: min. $t_{oil} = t_{amb} + 20$ K. Ideally at 35–40°C.

▸ Open the valves of the filling connections and break the vacuum with R744 from the gas phase of the filling cylinder up to an excess pressure of approx. 10 bar. If the refrigerant cylinder cools down considerably, heat in a water bath (water max. 40°C)!

Information
From approx. 10 bar system pressure, ensure that the suction and discharge gas shut-off valves of the compressor(s) are closed.
For booster systems: Concerns the compressors of the medium and low temperature compressor stage.

Further filling and commissioning depend on the specific system design, see information in the chapters:

- *see chapter Commissioning booster systems for medium and low temperature applications, page 97*
- *see chapter Notes on commissioning for other system designs, page 100*

4.5.2 Commissioning booster systems for medium and low temperature applications

Be sure to observe the following:

- Always commission the medium temperature compressor stage before the low temperature stage.
- From a commissioning point of view, the parallel compressor stage is only an extension of the medium temperature compressor stage. Depending on the ambient temperatures, the number and capacity of the compressors, the parallel compressor stage should be ready to operate before the load is connected.
- If the parallel compressor stage is running, stable operating conditions should be achieved in the medium temperature compressor stage.
- When only the medium temperate compressor stage is in operation: Take the influence of the flash gas bypass into account!
- Observe the system configuration and adjust the commissioning procedure if necessary.

DANGER
Liquid R744 evaporates quickly, cools down at the same time and forms dry ice!
Danger of cold burns and frost bites!
Avoid uncontrolled deflating of R744!
When filling the system with R744, wear gloves and goggles!

NOTICE
Oil foam formation and therefore insufficient lubrication!
Avoid strong pressure reduction in the crankcase during the compressor start and during operation!

Checklist for the commissioning of R744 booster systems

1. Check pressure strength and tightness, mount pressure relief valves:

- Pressure and tightness test only with dehydrated nitrogen, not with air or oxygen!
- Compressor:
  - Was already subjected to a pressure strength test at the factory. A tightness test is therefore sufficient.
  - Test pressures must not exceed the maximum values on the compressor name plate! Distinguish between the high and low pressure sides!
- Piping:
  - Pressure strength according to EN 378-2: MOP x 1.43 or min. 1.1 (≥ category II) // subsequent EN12799 (brazed joints), EN12517 (welded joints).
- Decouple individual sections of the system, record (measure) pressure and temperature.
- Mount the pressure relief valves:
  - HP, MOP____________________ Serial number(s):__________________________
  - MP, MOP____________________ Serial number(s):__________________________
  - MT LP, MOP____________________ Serial number(s):__________________________
  - LT, LP, MOP____________________ Serial number(s):__________________________

2. Fill oil into oil separator and oil reservoir:

- Use BSE85K or BSG68K oil, do not mix POE and PAG oil!
- BSE60K oil is not permitted for compressors in the low temperature compressor stage in booster systems!
- Document the oil type and charge.

3. Install filter drier cartridges:

Checklist for the commissioning of R744 booster systems

- Model 48-DM

4. Evacuate:

It is difficult to dry systems merely by evacuating. Evaporating water by evacuation is time-consuming.

Therefore:

- Break the vacuum of 20 mbar 2–3 times with dehydrated nitrogen during the evacuation process.
- Avoid ice formation in the system (triple point) – no temperatures below 0°C!
- **Recommendation for "standing" vacuum: Approx. 0.7 mbar (500 microns).**

5. Break vacuum with gaseous R744:

- Connect R744 refrigerant cylinder with pressure reducer and suitable filling lines to the system.
- Evacuate filling lines or flush with gaseous R744.
- Open the filling connection and break the vacuum with gaseous R744 up to approx. 10 bar (-40°C).
- If the refrigerant cylinder cools down considerably, heat the cylinder in a water bath at max. 40°C!
- Close the discharge and suction gas shut-off valves of the compressors in the medium and low temperature compressor stages.

6. Check safety and control components:

- Connect laptop to compound controller (FRIGO DATA, Plant Visor, Service Tool, etc.).
- Switch the compound control digitally to "on". Load circuits of the compressors remain switched off (fuses removed).
- Calibrate pressure transducer and temperature sensor.
- Signal tests on the analogue and digital inputs and outputs.
- Check temperature sensor assignment (cold spray).
- If necessary, check arrangement of the wiring and electrical connections.
- Check correct mounting of the temperature sensor on the gas cooler.
- Check correct mounting of pressure transducers and temperature sensors on the evaporators.
- Check the rotation direction of the gas cooler fan.
- Check the rotation direction of the evaporator fan.
- Check the parameters of the superheat controller at the evaporators.
  - Activate protection function "Close expansion valves at MOP and minimum superheat".
  - Set/check parameters for MOP.
  - Set/check parameter for minimum superheat.
- Check the parameters of the suction pressure control on the compound regulator.
  - Allow for short time delays for the compressors during the initial commissioning phase.

7. Switch on the oil heater(s): (Do not switch on the compressor!)

- Oil sump temperature(s) should be at 35– 40°C, but at least 20 K above the ambient temperature.
- Check the oil level in the compressor.

8. Further charging with refrigerant (small to medium-sized systems)
➔ Not for systems with large capacities and long piping distances between evaporators and compressors.

- Set the evaporators digitally to "off".
- Close the shut-off valves at the outlet of the intermediate pressure vessel.

Checklist for the commissioning of R744 booster systems

- Continue charging the system with liquid R744 into the intermediate pressure vessel. Use a pressure reducer when removing R744 from cylinders without a riser tube! If necessary, switch on standstill cooling.
- Before the first evaporator goes into operation, the minimum liquid level in the intermediate pressure vessel must be reached.
- Stop filling the intermediate pressure vessel at 30 bar (depending on the design (MOP) of the system at this pressure level) and ensure that the pressure remains below the set point for the flash gas bypass valve.

9. Commissioning

- Open the discharge, suction and oil shut-off valves of the compressors, switch on the compressor load circuit.
- Switch the compressor to "automatic mode" ready for operation.
- Slowly open the liquid line shut-off valve from the intermediate pressure vessel.
- Start up the evaporators of the medium temperature application one after the other in "automatic mode".
  - Note the capacity of the evaporator(s) in relation to the capacity of the compressor! Switch on the load in 3 to 5 steps in proportion to the nominal evaporator capacity.
  - After commissioning an evaporator, wait to see how the control parameters change and adjust.
    Observe the following parameters:
    High pressure
    Intermediate pressure
    Suction pressure medium temperature compressor stage
    Suction pressure low temperature compressor stage
    Suction gas temperature medium temperature compressor stage
    Discharge gas temperature medium temperature compressor stage
    Opening degree of high pressure control valve
    Opening degree of flash gas bypass valve
    Superheat and opening degree at the evaporators
  - Reduce the room/refrigerated display cabinet temperature to approx. 10° to 8°C before the next group of evaporators is switched on.
- Start up the low temperature application evaporators one after the other. Process is the same as that previously described.
  - Reduce the room/refrigerated display cabinet temperature to approx. -5°C° to -10°C° before the next group of evaporators is switched on.

➔ Adjust/supplement refrigerant charge as required.

10. After successful commissioning of the system, check the operating data and create a data protocol:

- Operating temperatures.
- Evaporation and condensing temperatures.
- Suction gas temperature.
- Discharge gas temperature > 50°C (40°C).
- Oil temperature > 30°C (20°C).
- Cycling rate
- Medium temperature compressor stage: Min. time for one start-up and shut-off: 10 min.
- Low temperature compressor stage: Min. Operating time: 2 min.
- Maximum number of compressor starts per hour:

Checklist for the commissioning of R744 booster systems	
– Medium temperature compressor stage: 6. – Low temperature compressor stage: 8. • Voltage and operating current in all three phases. • Filter change: – Suction gas filter and filter drier after max. 200 h. – Oil separator after 50 h.	

Checkliste als PDF zum Download

4.5.3 Notes on commissioning for other system designs

The following chapters point out differences in the commissioning of other system designs compared to booster units for medium and low temperature applications.

Single stage systems without intermediate pressure vessel (Gustav Lorentzen process)

These systems have a low-pressure separator on the suction side that collects excess liquid at the outlet of the evaporator to protect the compressor from liquid slugging. The superheat is not controlled by the high pressure expansion valve.

The following points facilitate stable operation of the compressor during commissioning:

- Breaking the vacuum with gaseous R744 in the entire system up to approx. 40 bar.
- For water cooled gas coolers:
  - Ensure water circulation.
  - Check flow temperature.
  - Set a constant high pressure set point on the gas cooler side, e.g. 80 bar.
- With water as the heat source on the evaporator side:
  - Ensure water circulation.
  - Check flow temperature.
- Switch compressors to "automatic mode" ready for operation and note that the controlled value for the capacity control of the compressors is temperature-controlled (hot water temperature), depending on the type of application.
- Further filling of the system, gaseous via the suction side.

Systems with large dimensions and high evaporator capacity

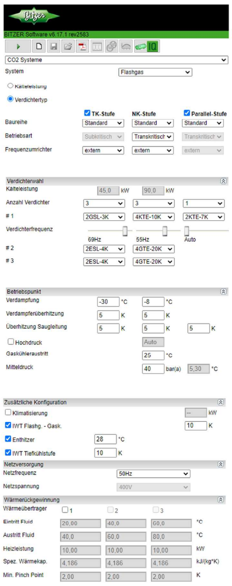
Commissioning of large cold stores or distribution centres often entails special requirements, such as partial commissioning of individual construction sections and compliance with temperature reduction curves for screeds and floors.

- Long pipe runs on the suction side can lead to low suction pressures after commissioning of the first evaporators and, in the worst case, to operation with high suction gas superheat and low compressor frequencies. Monitoring the thermal limits of the compressors is therefore mandatory. Note the position of the discharge gas temperature sensors and the thermal inertia of the measuring points!
- Large ambient temperature cold stores include the risk of overload conditions for compressors, especially if a lot of liquid refrigerant is injected into the evaporators when the first evaporators are commissioned. Carefully select, set and check the parameters for the evaporator and suction pressure controllers accordingly!

Recommendations:

- Fill the system on the suction side with more gaseous R744 (>10 bar) to avoid suction gas and discharge gas temperatures which are too high.
- Open the discharge and suction gas shut-off valves of the compressor, but keep the suction gas shut-off valve in the throttle position for the time being. After switching on the compressors to "automatic mode" and starting the first evaporators, observe the suction pressure and, if necessary, take the evaporators out of operation again if the suction pressure rises too quickly. After lowering the suction pressure, select a smaller evaporator capacity for start-up.

4.6 System design in the BITZER SOFTWARE


BITZER Software v6.17.1 rev2583

CO2 Systeme

System Flashgas

○ Kälteleistung
● Verdichtertyp

System selection (Gustav Lorentzen process/flash gas)

System design via "compressor type" or "refrigerating capacity"

	☑ TK-Stufe	NK-Stufe	☑ Parallel-Stufe
Baureihe	Standard	Standard	Standard
Betriebsart	Subkritisch	Transkritisch	Transkritisch
Frequenzumrichter	extern	extern	extern

Compressor stages selection (low temperature application (TK), medium temperature application (NK), parallel

Compressor series selection

Operation mode selection (subcritical or transcritical operation)

Capacity control selection (none/external frequency inverter (VARIPACK)/VARISPEED)

Verdichterwahl

	TK-Stufe	NK-Stufe	Parallel-Stufe
Kälteleistung	45,0 kW	90,0 kW	
Anzahl Verdichter	3	3	1
# 1	2GSL-3K	4KTE-10K	2KTE-7K
Verdichterfrequenz	69Hz	55Hz	Auto
# 2	2ESL-4K	4GTE-20K	
# 3	2ESL-4K	4GTE-20K	

Enter the required refrigerating capacity if "Refrigerating capacity" has been activated under point 2

Enter the number of compressors (Up to 10 compressors per stage, from 7 compressors, please follow these ins

Select compressors if "Compressor type" was activated under point 2

Enter the frequency of the guide compressor

Betriebspunkt

	TK-Stufe	NK-Stufe	Parallel-Stufe
Verdampfung	-30 °C	-8 °C	
Verdampferüberhitzung	5 K	5 K	
Überhitzung Saugleitung	5 K	5 K	5 K
☐ Hochdruck		Auto	
Gaskühleraustritt		25 °C	
Mitteldruck		40 bar(a)	5,30 °C

Automatic or manual setting of operating parameters such as: Evaporation temperatures,
superheat, condensing temperatures, gas cooler outlet temperatures, high pressure and intermediate pressure

Zusätzliche Konfiguration

☐ Klimatisierung -- kW
☑ IWT Flashg. - Gask. 10 K
☑ Enthitzer 28 °C
☑ IWT Tiefkühlstufe 10 K

Additional use of the medium pressure stage for a higher temperature level (air conditioning)

Heat exchanger options: For a more stable system operation

Netzversorgung

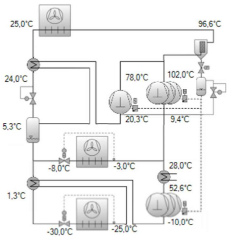
Netzfrequenz 50Hz
Netzspannung 400V

Selection of the supply frequency and supply voltage at the system location

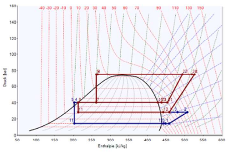
Wärmerückgewinnung

Wärmeübertrager	☐ 1	☐ 2	☐ 3	
Eintritt Fluid	20,00	40,0	60,0	°C
Austritt Fluid	40,0	60,0	80,0	°C
Heizleistung	10,00	10,00	10,00	kW
Spez. Wärmekap.	4,186	4,186	4,186	kJ/(kg*K)
Min. Pinch Point	2,00	2,00	2,00	K

Selection of heat exchangers for heat recovery



System flow diagram



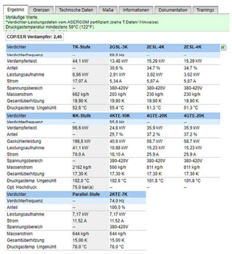
Representation of the process in the pressure-enthalpy diagram


TK-Stufe
- 1 - 2 Verdichtung
- 2 - 3 Enthitzung
- 4 - 5 Unterkühlung durch IWT
- 5 - 11 Expansion
- 11 - 12 Verdampfung
- 12 - 13 Überhitzung Saugleitung
- 13 - 1 Überhitzung IWT

Parallel-Stufe
- 21 - 22 Verdichtung
- 23 - 21 Überhitzung IWT

NK-Stufe
- 1 - 2 Verdichtung
- 2 - 4 Gaskühlung/Verflüssigung
- 4 - 5 Unterkühlung durch IWT
- 5 - 7 Expansion auf Mitteldruck
- 7 - 8 Mitteldruckflasche: Flüssigkeitsaustritt
- 8 - 11 Expansion auf Verdampfungsdruck
- 11 - 12 Verdampfung
- 12 - 1 Gesamtüberhitzung
- 7 - 15 Mitteldruckflasche: Gasaustritt

Legend/explanations for the pressure-enthalpy diagram



Menu tabs for further information such as: Application limits, technical data, dimensional drawings and CAD files

: Vorläufige Werte.
: *Verdichter-Leistungsdaten vom ASERCOM zertifiziert (siehe T.Daten/ Hinweise)
: Druckgastemperatur mindestens 50°C (122°F)

COP/EER Verdampfer: 2,46

Notes/warnings for critical operating conditions

Verdichter	TK-Stufe	2GSL-3K	2ESL-4K	2ESL-4K
Verdichterfrequenz	--	69,0 Hz	--	--
Verdampferleist.	44,1 kW	13,48 kW	15,29 kW	15,29 kW
Anteil	--	30,6 %	34,7 %	34,7 %
Leistungsaufnahme	8,96 kW	2,91 kW	3,02 kW	3,02 kW
Strom	17,07 A	5,34 A	5,87 A	5,87 A
Spannungsbereich	--	380-420V	380-420V	380-420V
Massenstrom	662 kg/h	203 kg/h	230 kg/h	230 kg/h
Gesamtüberhitzung	19,90 K	19,90 K	19,90 K	19,90 K
Druckgastemp. Ungekühlt	52,6 °C	55,4 °C	51,3 °C	51,3 °C

Tabular view of the operating parameters of the low temperature compressor stage

Verdichter	NK-Stufe	4KTE-10K	4GTE-20K	4GTE-20K
Verdichterfrequenz	--	55,0 Hz	--	--
Verdampferleist.	96,6 kW	24,8 kW	35,9 kW	35,9 kW
Anteil	--	25,7 %	37,2 %	37,2 %
Gaskühlerleistung	198,8 kW	40,6 kW	58,7 kW	58,7 kW
Leistungsaufnahme	41,1 kW	10,68 kW	15,23 kW	15,23 kW
Strom	70,0 A	18,10 A	25,9 A	25,9 A
Spannungsbereich	--	380-420V	380-420V	380-420V
Massenstrom	2182 kg/h	560 kg/h	811 kg/h	811 kg/h
Gesamtüberhitzung	17,30 K	17,30 K	17,30 K	17,30 K
Druckgastemp. Ungekühlt	102,0 °C	102,6 °C	101,8 °C	101,8 °C
Opt. Hochdruck	75,0 bar(a)	--	--	--

Tabular view of the operating parameters of the medium temperature compressor stage

Verdichter	Parallel-Stufe	2KTE-7K
Verdichterfrequenz	--	74,0 Hz
Anteil	--	100,0 %
Leistungsaufnahme	7,17 kW	7,17 kW
Strom	11,52 A	11,52 A
Spannungsbereich	--	380-420V
Massenstrom	644 kg/h	644 kg/h
Gesamtüberhitzung	15,00 K	15,00 K
Druckgastemp. Ungekühlt	78,0 °C	78,0 °C

Tabular view of the operating parameters of the parallel compressor stage

5 Capacity control

5.1 CRII Mechanical capacity control for transcritical compressors

The mechanical capacity control for the 4PTEU– 8CTEU compressors is specially designed for the high pressures and pressure differences in transcritical R744 applications. It enables quasi-stepless capacity control according to the capacity demand of a superior system controller with simple and effective activation by the CM-RC-01 compressor module. This CRII capacity control system is based on the principle of blocked suction. In this case, the gas flow on the suction side to individual cylinder banks is prevented by a control piston. The operating data and control parameters can be monitored and read out via BEST SOFTWARE.

The compressor is operated at constant speed, the speed of the motor correlates directly with the supply frequency. This results in nominal speeds for 4-pole asynchronous motors of

- 1450 min^{-1} at 50 Hz or
- 1750 min^{-1} at 60 Hz.

Information
For detailed information on operation with CRII mechanical capacity control, see *Technical Information KT-102*.

NOTICE
Compressor and motor damage!
Do not combine a frequency inverter with mechanical capacity control of the compressor! Especially at low speed, adequate motor cooling is not guaranteed because refrigerant mass flow is heavily reduced. Certain exceptions for screw compressors are possible in consultation with BITZER.

5.2 Capacity control with frequency inverter

NOTICE
Risk of insufficient lubrication due to high R744 solubility in the oil.
Operation at low pressure ratios and low suction gas superheat results in low discharge gas and oil temperature.
Continuous operation with frequencies > 60 Hz intensifies this effect and should therefore be avoided.
If necessary, consult with BITZER.

Information
For detailed information on operation with frequency inverter, see *Technical Information KT-420.*

The average torque at the compressor shaft depends mainly on the operating conditions and the refrigerant and therefore remains virtually constant over a wide speed/frequency range. The cooling capacity and power consumption therefore vary approximately proportionally to the speed (see figure below), and the cooling capacity can be continuously adjusted with the help of the speed. The permitted speeds for BITZER compressors are documented below.

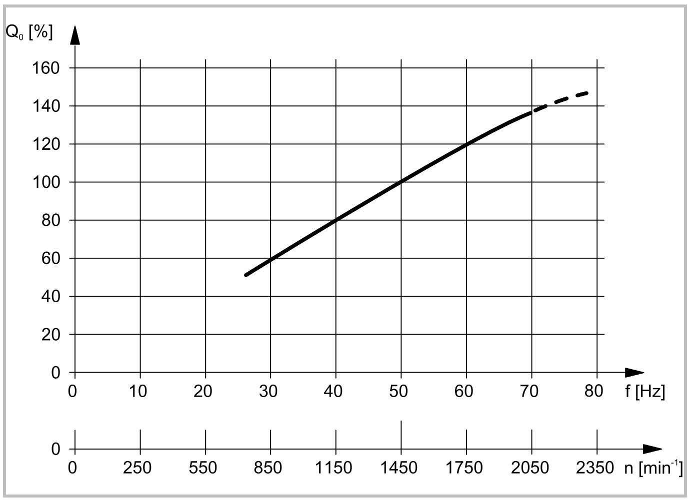


Fig. 16: Typical graph of the refrigerating capacity Q_0 depending on the speed and frequency of reciprocating compressors

For safe operation of the compressor with a frequency inverter, it is essential to consider the following limiting factors:

- Minimum and maximum frequency (see below)
- Maximum discharge gas temperature
- Maximum and minimum high pressure
- Maximum operating current of the compressor
- Maximum evaporation temperature

These limiting factors define the application limits for safe operation. However, they may vary depending on frequency ranges and operating conditions. See also chapter *see chapter Parameters and recommendations for optimal system efficiency and operational safety, page 88*.

Speed and frequency ranges

Compressor	Frequency range (Hz)	Speed range ($^{\text{min-1}}$)	Standard motor
2NSL–2FSL	30 .. 75	900 .. 2200	40S
2ESL–2CSL	30 .. 75	900 .. 2200	40S
4FSL–4CSL	25 .. 70	750 .. 2050	40S
4VSL–4NSL	25 .. 70	750 .. 2050	40P
ECOLINE ME R744 subcritical			
2MME–2FME	30 .. 75	900 .. 2200	40S
2EME–2DME	30 .. 75	900 .. 2200	40S
6TME–6PME	25 .. 70	750 .. 2050	40P
ECOLINE R744 transcritical			
2MTE–2KTE	30 .. 75	900 .. 2200	40S
4PTE–4KTE	25 .. 70	750 .. 2050	40S
4JTE–4CTE	25 .. 70	750 .. 2050	40P
6FTE–6CTE	25 .. 70	750 .. 2050	40P
8FTE–8CTE	30 .. 60	900 .. 1750	40D
ECOLINE+ R744 transcritical (LSPM)			
4PTEU–4KTEU	25 .. 70	750 .. 2100	40S
4JTEU–4CTEU	25 .. 70	750 .. 2100	40S

Compressor	Frequency range (Hz)	Speed range ($^{\text{min-1}}$)	Standard motor
6FTEU–6CTEU	25 .. 70	750 .. 2100	40S

Tab. 1: Permitted speed and frequency ranges of BITZER reciprocating compressors with external frequency inverters and standard motors (also observe the application limits and maximum current consumption of the motor)

Design for other supply voltages and frequencies

If the mains supply deviates from the previously defined standard conditions (400 V/3/50 Hz), special voltage motors and an adapted frequency inverter design may be required (*compressor motors*). Further information upon request.

Application limits

The following figure shows an example of the application limits of a reciprocating compressor for different frequencies and how they change with the evaporation and condensing temperature. Specific application limits for the respective compressors, motors and refrigerants are listed in the BITZER SOFTWARE.

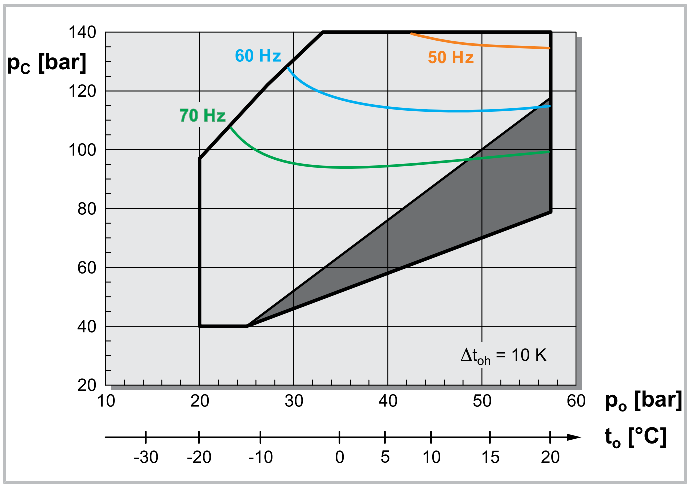


Fig. 17: Example for application limits for reciprocating compressor 4MTE-10 with refrigerant R744 (CO_2) and frequency inverter at 50, 60 and 70 Hz (limits due to motor temperature or maximum current). The compressor may only be operated **below** the indicated frequency lines (otherwise, select a larger inverter for a wider range of the application limit).
t_o: evaporation temperature, t_c: condensing temperature, Δt_{oh}: suction gas superheat
Dark grey area: mind operating conditions.

!

NOTICE
Compressor and motor damage!
Do not combine a frequency inverter with mechanical capacity control of the compressor! Especially at low speed, adequate motor cooling is not guaranteed because refrigerant mass flow is heavily reduced. Certain exceptions for screw compressors are possible in consultation with BITZER.

6 BITZER refrigerant ejectors

6.1 Safety

Authorized staff

All work done on the products and the systems in which they are or will be installed may only be performed by qualified and authorised staff who have been trained and instructed in all work. The qualification and competence of the qualified staff must correspond to the local regulations and guidelines.

Residual risks

The products, electronic accessories and further system components may present unavoidable residual risks. Therefore, any person working on it must carefully read this document! The following are mandatory:

- relevant safety regulations and standards
- generally accepted safety rules
- EU directives
- national regulations and safety standards

Depending on the country, different standards are applied when installing the product, for example: EN378, EN60204, EN60335, EN ISO14120, ISO5149, IEC60204, IEC60335, ASHRAE 15, NEC, UL standards.

Personal protective equipment

When working on systems and their components: Wear protective work shoes, protective clothing and safety goggles. In addition, wear cold-protective gloves when working on the open refrigeration circuit and on components that may contain refrigerant.

Fig. 18: Wear personal protective equipment!

Safety references

Safety references are instructions intended to prevent hazards. They must be stringently observed!

NOTICE
Safety reference to avoid situations which may result in damage to a device or its equipment.

CAUTION
Safety reference to avoid a potentially hazardous situation which may result in minor or moderate injury.

WARNING
Safety reference to avoid a potentially hazardous situation which could result in death or serious injury.

DANGER
Safety reference to avoid an imminently hazardous situation which may result in death or serious injury.

In addition to the safety references listed in this document, it is essential to observe the references and residual risks in the respective operating instructions!

6.1.1 General safety instructions

DANGER
Observe the high pressure levels of the refrigerant R744!
At standstill the pressure in the system will rise and there is a risk of bursting!
Install pressure relief valves on the compressor and on the suction and high-pressure sides in system sections that are lockable from both sides.
Requirements and design according to EN 378-2 and EN 13136.

Critical temperature 31.06°C corresponds to 73.84 bar.

DANGER
Liquid R744 evaporates quickly, cools down at the same time and forms dry ice!
Danger of cold burns and frost bites!
Avoid uncontrolled deflating of R744!
When filling the system with R744, wear gloves and goggles!

Information
All transcritical BITZER R744 compressors are equipped with an optional pressure relief valve to the atmosphere on the high-pressure side and on the low-pressure side as well.
However, they do not replace the safety valves of the system (EN 12693)!
Make sure that the pressure relief valves can freely vent to the atmosphere.
Do not mount any pipes near the outlet of the pressure relief valve!

DANGER
Risk of bursting of components and pipes due to excess hydraulic pressure.
Vessel and pipes may burst, small components may shoot out. The pressure wave may be lethal.
Never charge blocked components and pipes completely with liquid or leave them charged. Leave sufficient volume above the liquids.

Mounting

DANGER
Risk of bursting the pressure equipment due to mechanical stress.
Serious injuries are possible.
Connect the pipes to the pressure equipment without load and stress!

DANGER
Risk of bursting of components and pipes due to liquid overpressure.
Serious injuries are possible.
Make sure not to exceed maximum admissible pressures!

For work on the pressure equipment after having put the system into operation

CAUTION
Surface temperatures of more than 60°C or below 0°C.
Risk of burns or frostbite.
Close off accessible areas and mark them.
Before performing any work on the pressure equipment: switch off the system and let it cool down or warm up.

Before performing any work on the refrigerating circuit

WARNING
The pressure equipment is under pressure!
Serious injuries are possible!
Depressurise the pressure equipment!
Wear safety goggles!

CAUTION
Refrigerant can be very cold
Risk of severe frostbite.
Avoid any contact with the refrigerant. Wear cold-protective gloves.

6.1.2 Mind with the refrigerant R744

DANGER
R744 is an odourless and colourless gas and cannot be perceived directly in case of emission!
Lost of consciousness and danger of suffocation by inhaling higher concentrations!
Avoid R744 emission and uncontrolled deflating, particularly in closed rooms!
Aerate closed machine rooms!
Make sure that the safety regulations in accordance with EN378 are complied with!

6.1.3 Also observe the following technical documents

CB-300: Operationg instructions refrigerant ejectors

6.2 Introduction

Ejectors can relieve compressors in R744 systems or reduce the required displacement.

Without electrical operating energy, driven by the potential and kinetic energy of the motive mass flow, they cause a pressure lift for a partial mass or suction mass flow.

Characteristic values, possible system designs and design criteria for BITZER high pressure ejectors are presented below.

6.3 Operating principle

Ejectors are based on the functional principle of a jet pump and can be used in different arrangements in a system. They generate negative pressure according to the Venturi principle (see following figure). An ejector has a characteristic curve which is similar to that of a pump; as the pressure lift increases, the delivered mass flow drops sharply.

- At the inlet of the nozzle, a refrigerant mass flow under high pressure (high potential energy) – also called motive mass flow – is accelerated.
- The conversion of the potential energy into kinetic energy decreases the pressure of the motive mass flow while increasing its velocity (see figure below).
- The pressure reduction / acceleration continues until the pressure at the outlet of the nozzle has dropped so far that suction / negative pressure is created at an inlet located there.
- A secondary refrigerant mass flow − also called suction mass flow − is thus sucked in and carried along.

- The mass flows mix and the kinetic energy of the motive mass flow is converted into potential energy of the accumulated mass flow – also called outlet mass flow.
  This causes an increase in pressure above the pressure of the suction mass flow.

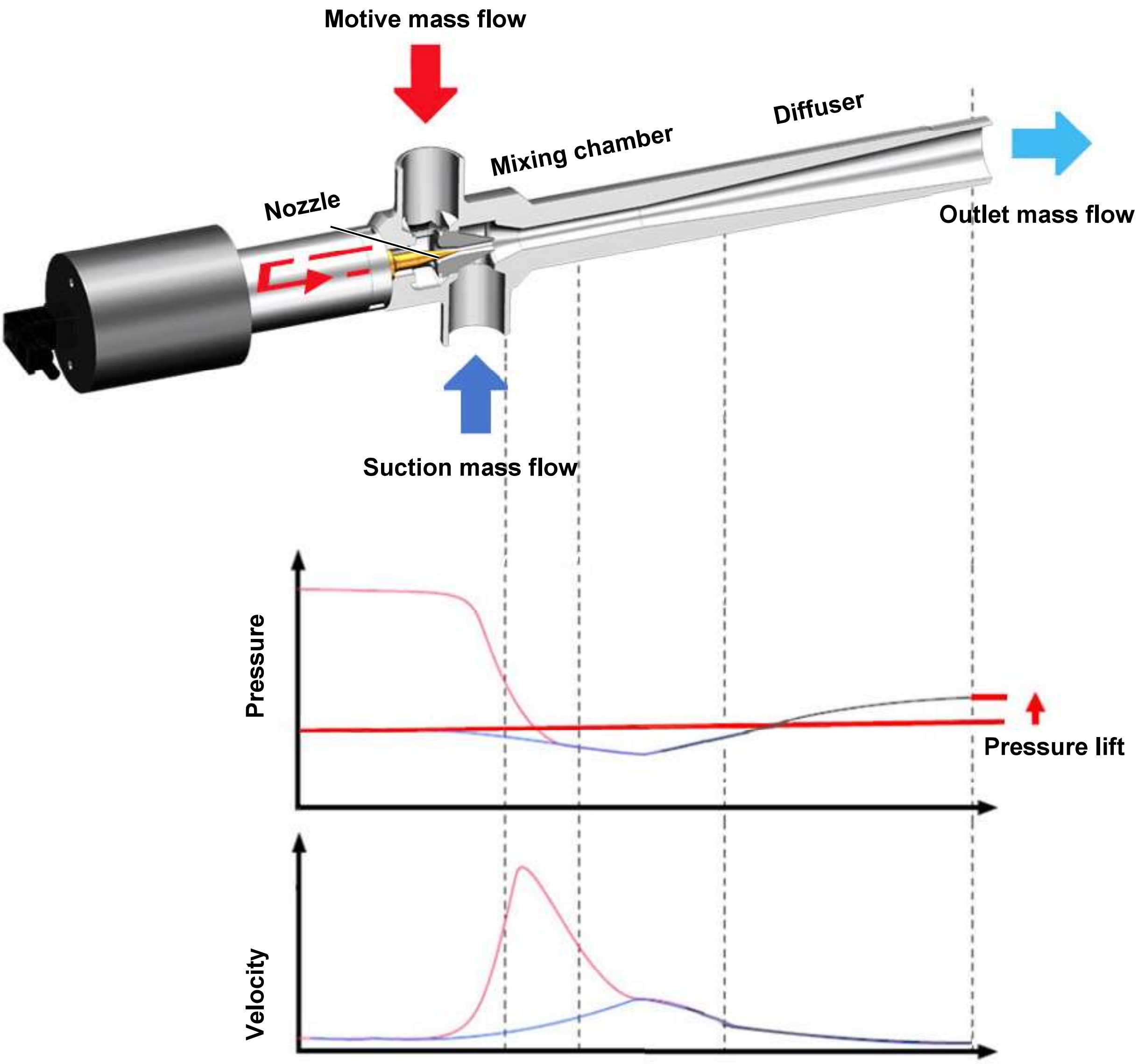


Fig. 19: Schematic representation of a controllable high pressure ejector with pressure and velocity curve of the mass flows

Applied to transcritical applications with R744, this means that the ejector uses the potential and kinetic energy present in the refrigerant at the gas cooler outlet to suck in another partial mass flow and bring it to a higher pressure level (see following figure).

- The R744 [2] leaving the compressor at high pressure level is accelerated in the ejector nozzle [3] after gas cooling / heat dissipation in the gas cooler [2].
- As a result, the static pressure drops and the pressure of the flow leaving the nozzle is lower than the suction gas pressure of the medium temperature compressor stage [4].
- This allows gas and/or liquid to be selectively extracted from a low pressure level [5].

- Both partial flows mix in the mixing chamber upstream of the diffuser [6].
- In the diffuser, the flow is decelerated again, thus increasing the pressure to intermediate pressure level [6].
- Downstream of the diffuser, the mixture is fed into the intermediate pressure vessel, the gas phase is separated [1] and compressed to a high pressure level [2].

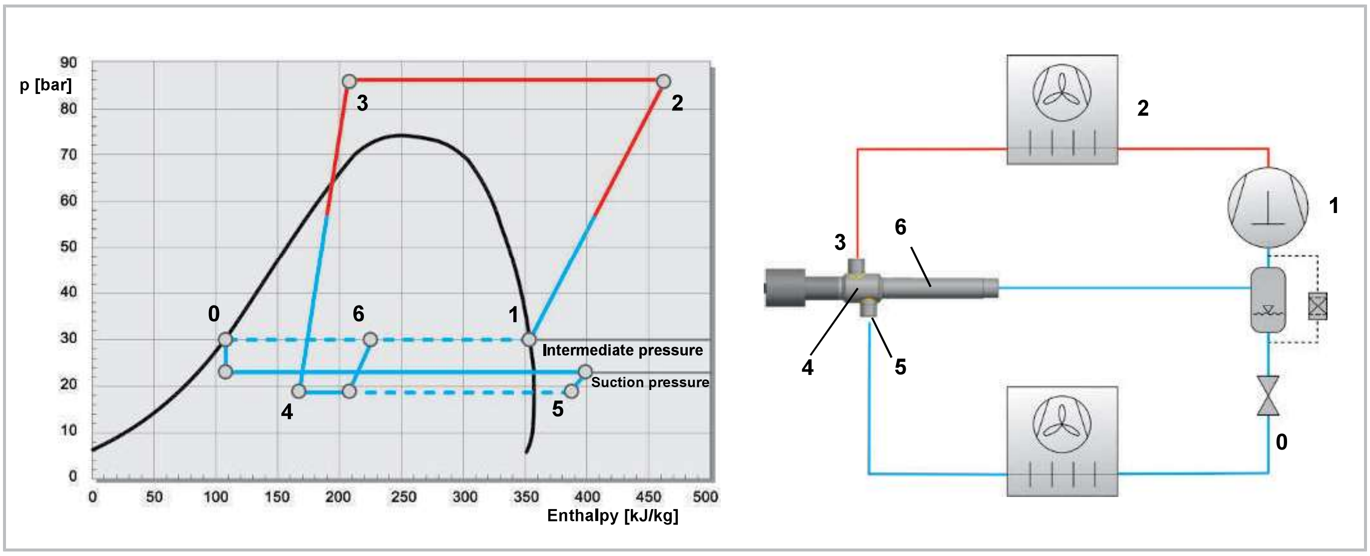


Fig. 20: Simplified, schematic ejector circuit, on the left in the pressure enthalpy diagram

0	Throttling from intermediate pressure to evaporator pressure	4	Expansion under suction pressure
1	Compressor outlet / compression	5	Suction of the suction mass flow
2	Gas cooling / condensation	6	Mixing and pressure increase of the motive mass flow / suction mass flow
3	Gas cooler / condenser outlet / entry into the ejector		

6.3.1 Ejector in low lift applications

Ejectors in low lift applications should deliver the highest possible mass flow. They are usually used to extract the entire mass flow that is evaporated in the system and deliver it back to the intermediate pressure vessel. The limiting factor here is the mass flow which determines how much the ejector can raise the pressure or how high the intermediate pressure may be so that the refrigerant can be fed back.

Liquid phase and gas phase are separated in the intermediate pressure vessel. The gas phase is extracted by the compressor and represents the motive mass flow. The liquid phase is still available to supply the evaporator and represents the suction mass flow.

Ejectors in low lift applications are used as robust "refrigerant pumps", as they can also pump a gas-liquid mixture. This allows operation with a flooded evaporator. The evaporator surface can be used without a superheat section and the evaporating temperature can be raised without endangering the compressor.

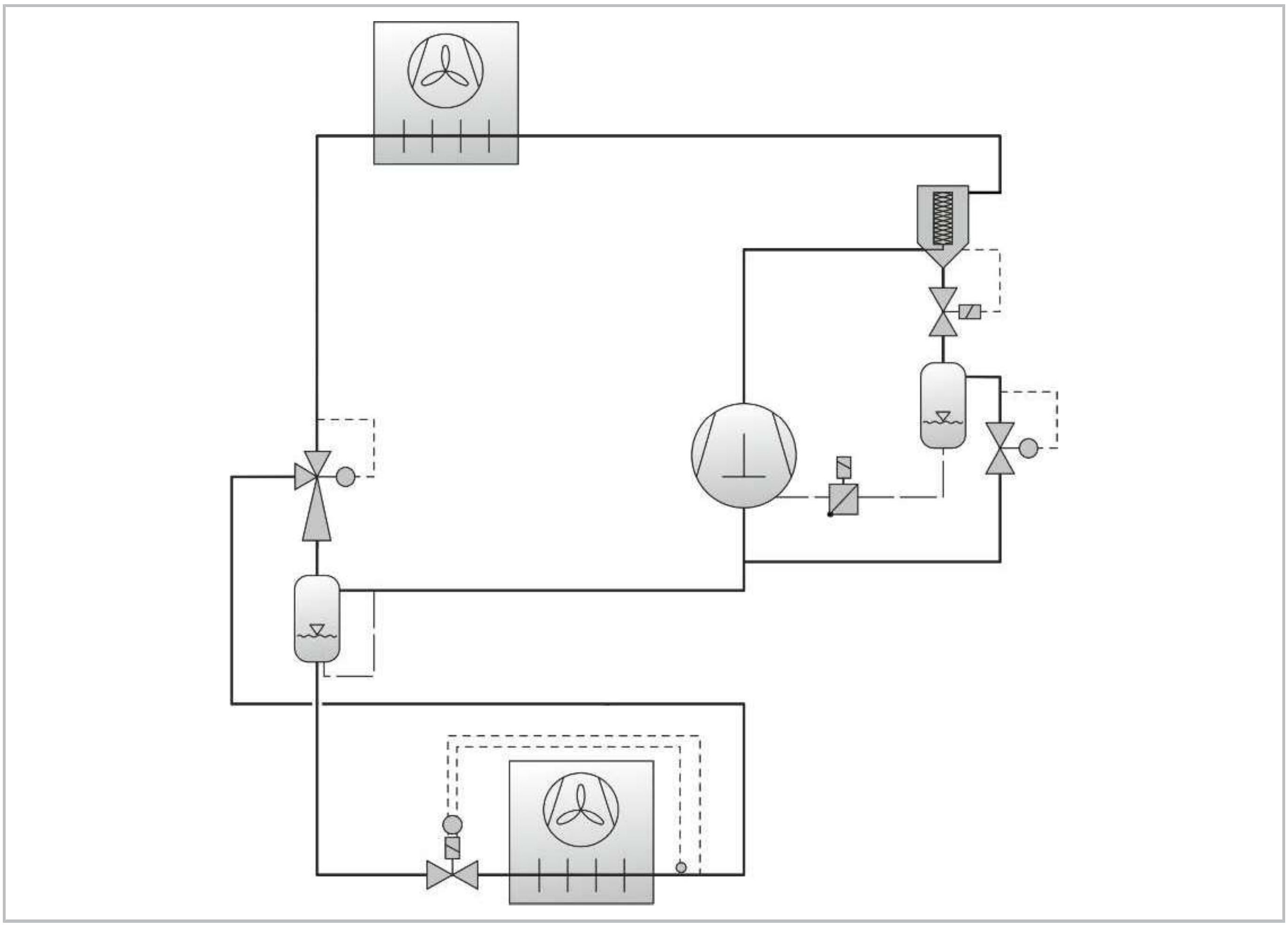


Fig. 21: System diagram: Ejector in low lift application (simplified representation)

Design example of a low lift ejector created with the help of BITZER SOFTWARE *see chapter see here, page 121*.

6.3.2 Ejector in high lift applications

Ejectors in high lift applications are used to achieve the highest possible pressure lift at a lower delivery rate. The pressure lift and the suction mass flow to be delivered are the limiting factors and must be balanced in the system such that the highest possible efficiency is achieved.

Ejectors in high lift applications are usually used to transport superheated gas, as they do not transport the entire mass flow from the evaporator and a partial mass flow must continue to be extracted by the medium temperature compressors. The partial mass flow transported by the ejector is returned to the intermediate pressure vessel of the system which is kept here at a higher pressure level than in a low lift version. The gas is extracted there by the parallel compressors.

The advantage lies here in the pre-compression of part of the evaporated refrigerant and the resulting load shift to the parallel compressors which operate at a lower pressure ratio and thus more efficiently.

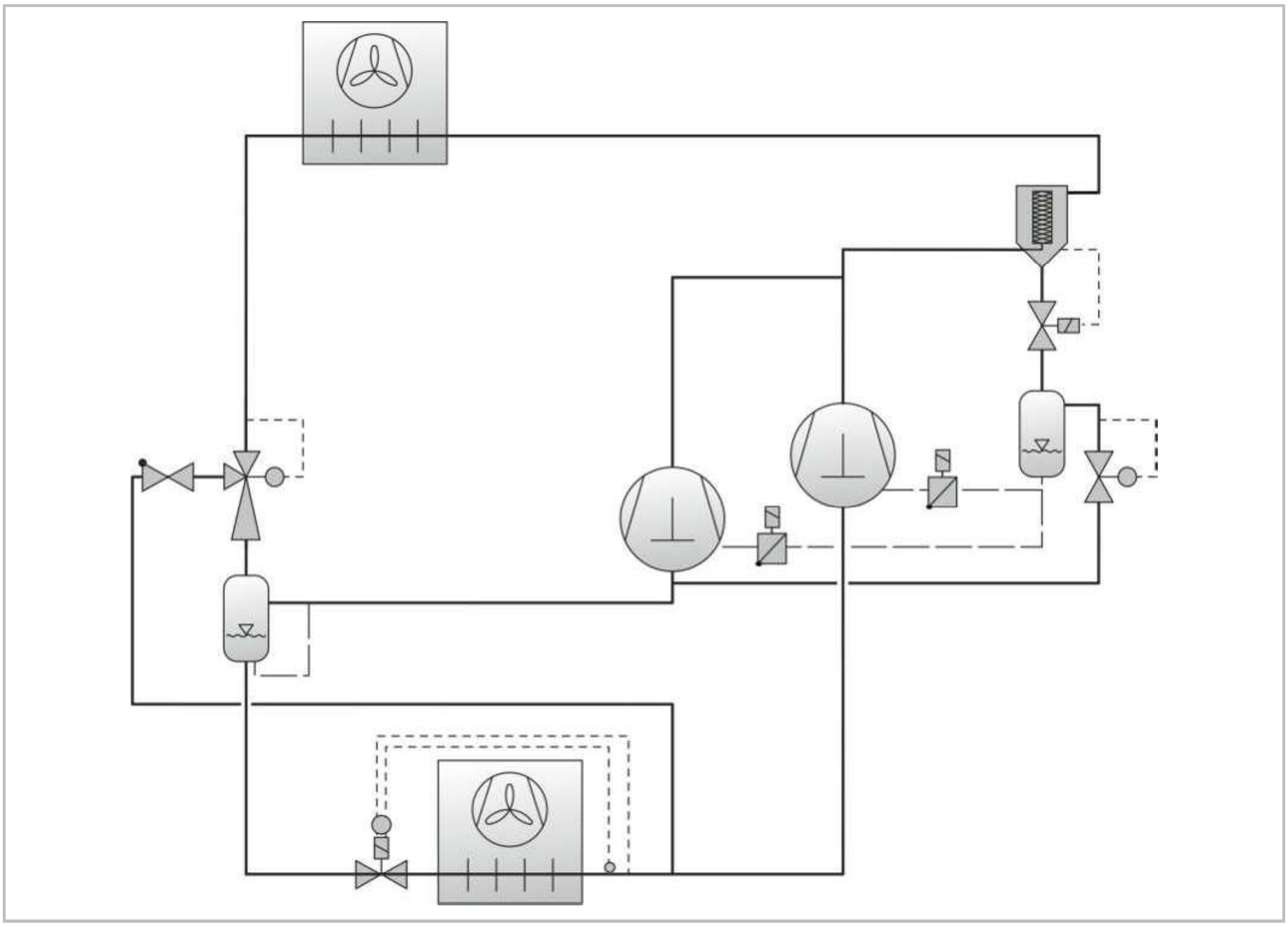


Fig. 22: System diagram: Ejector in high lift application (simplified representation)

Design example of a high lift ejector created with the help of BITZER SOFTWARE *see chapter see here, page 123*.

6.4 Characteristic values

The following characteristic values can be used to describe the behaviour of an ejector and to design a system:

Pressure ratio

The pressure ratio indicates the ratio of the pressure at the outlet of the ejector to the suction pressure.

$\Pi = p_{\text{diffuser, off}} / p_{\text{suction pressure}}$

Pressure lift

The pressure lift indicates how much the pressure of the suction mass flow has been raised to the outlet level (see *see figure 19, page 109* and figure below).

$\Delta p = p_{\text{diffuser, off}} - p_{\text{suction mass flow, on}}$

Mass flow ratio

The mass flow ratio is the quotient of suction mass flow to motive mass flow.

$\varnothing = \dot{m}_{\text{suction}} / \dot{m}_{\text{motive}}$

Ejector efficiency

The ejector efficiency is the ratio of the energy that can be gained by expanding the ejector's motive mass flow to the work done by the pressure lift of the motive mass flow and suction mass flow at the ejector outlet. In simplified form, ejector efficiency is defined as follows:

Assumption: Isentropic expansion and isentropic compression, superheated / dry saturated

$$\eta_{Ejektor} = \frac{\dot{m}_{suction}}{\dot{m}_{motive}} \times \frac{\Delta h_{compression}}{\Delta h_{expansion}}$$

Elbel, S., 2011. Historical and present developments
of ejector refrigeration systems with emphasis on transcritical
carbon dioxide air-conditioning applications.
International Journal of Refrigeration 34 (2011) 1545 - 1561

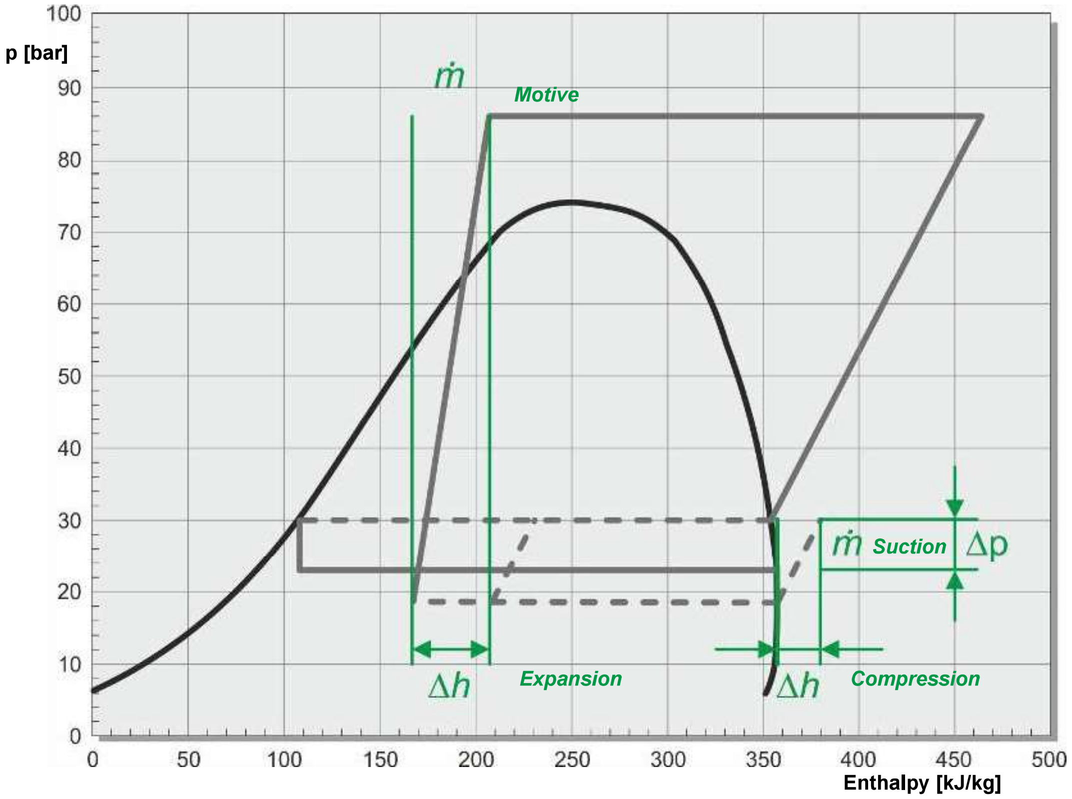


Fig. 23: Representation and definition of ejector efficiency

Design example of a low lift ejector created with the help of BITZER SOFTWARE *see chapter see here, page 121*.

Design example of a high lift ejector created with the help of BITZER SOFTWARE *see chapter see here, page 123*.

6.5 Installation in the system

- Install the ejector(s) preferably above the compressors, ensuring that they are accessible from the outside.
- Installation: horizontal (a) or vertical (outlet downwards, b).

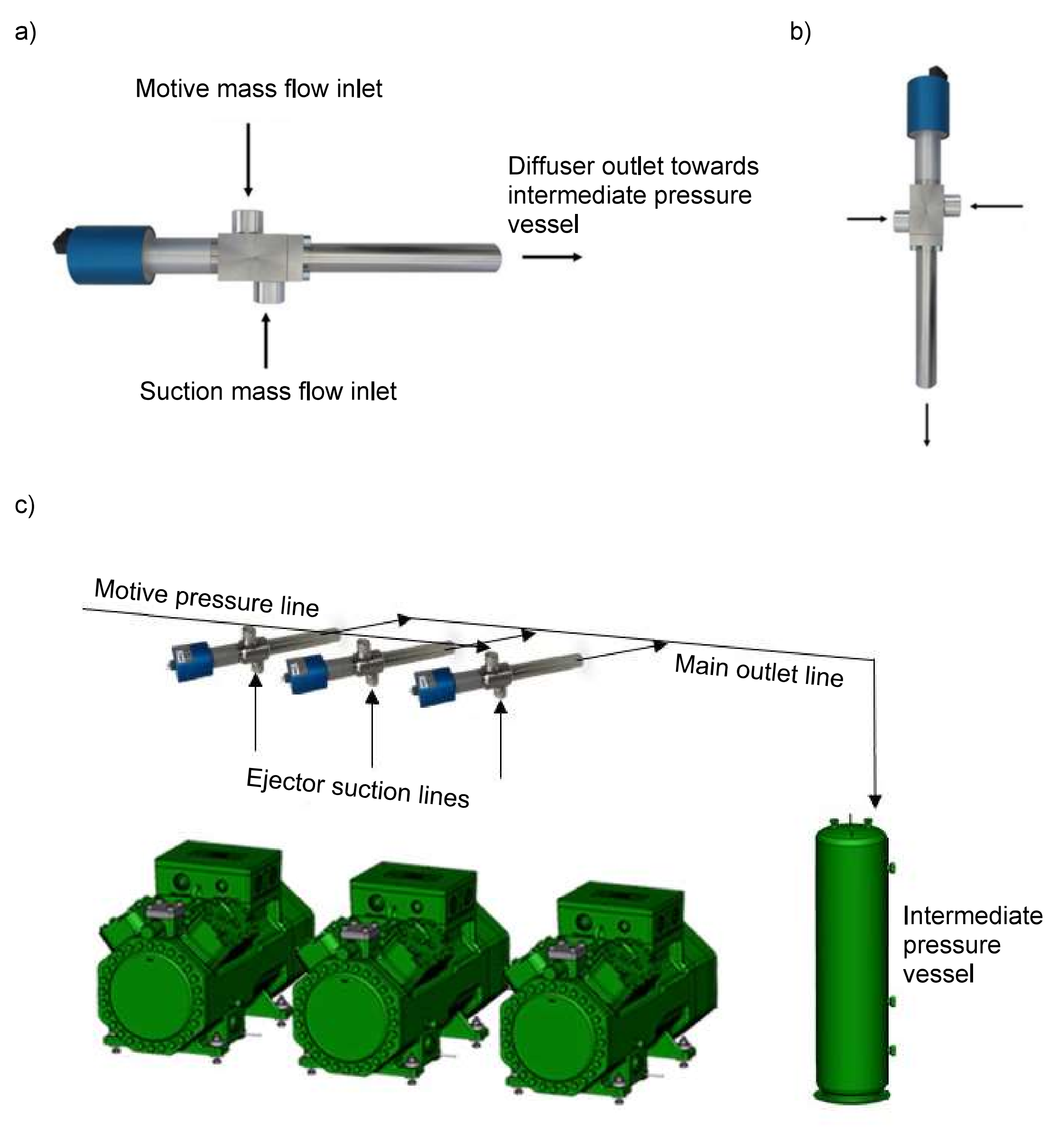


Fig. 24: Installation positions of an ejector in the system

a) horizontal

b) vertical with outlet downwards

c) system with ejectors connected in parallel (simplified representation)

- A mechanical high-pressure control valve for emergency operation can be installed parallel to the ejector (*see chapter System design B with ejector, parallel compression and mechanical high-pressure control valve for emergency operation, page 118*).
- Install a filter in the motive pressure line upstream of the ejector inlet and the parallel-connected high-pressure control valve.

- Only use pipes with bent pipe sections. This reduces turbulence and avoids pressure drops. Do not use 90° pipe bends (e.g. T-pieces)!
- Install shut-off valves for maintenance purposes in the lines to and from the ejector.
- Install an additional check valve in the suction line of the ejector in order to prevent possible re-expansion of the suction mass flow from the intermediate pressure vessel. This may happen if the suction effect created by the motive mass flow is too low to suck in the suction mass flow.
- As an alternative to the check valve, a motor-controlled valve can be installed in the suction line to prevent possible re-expansion. The control is based on a minimum pressure difference between the suction connection of the ejector and the suction gas pressure (in the flow direction upstream of the motor-controlled valve). As soon as the pressure drops below a minimum pressure difference, the valve closes.
- A settling section aligned with the diffuser must be installed on the outlet side. This section must be at least 1.5 x as long as the ejector ($l_{settling}$ = 1.5 x $l_{ejector}$).
- The main outlet line at the diffuser must not rise towards the intermediate pressure vessel! This is the only way to ensure unhindered entry into the vessel without having to overcome any hydrostatic pressure.
- The flow cross section of the main outlet line corresponds, to put it simply, to the sum of the cross sections of the motive pressure line and suction line.

Additional installation instructions for systems with ejectors connected in parallel

- Make outlets from the main lines to the connections of the ejectors on the motive pressure side and suction side without T-pieces; this reduces turbulence and avoids pressure drops.
- The connections from the main lines to the individual lines should preferably be made at an angle of 45°.
- Join the individual outlet lines in the collector without T-pieces and preferably at an inlet angle of 45°.
- Dimension the flow cross section of the outlet line such that a flow velocity of 0.3..1.0 m/s is not exceeded at full load at the defined design point.

6.6 System designs

System design	**A** ***see chapter System design A standard ejector system, page 116***	**B** ***see chapter System design B with ejector, parallel compression and mechanical high-pressure control valve for emergency operation, page 118***
Ejector static	Applicable	Non-applicable
Ejector adjustable ①	Applicable	Applicable
Ejector motive mass flow	High pressure refrigerant mass flow	High pressure refrigerant mass flow
Ejector suction mass flow	Liquid	Liquid/gas
Ejector suction pressure	$p_{o\ MT}$	$p_{o\ MT}$
Pressure level outlet mass flow	Intermediate pressure (IP)	Intermediate pressure (IP)
Ejector pressure lift	Low	High
System with intermediate pressure vessel	Yes	Yes
Evaporator operation	Flooded or dry	Flooded or dry

System design	A see chapter System design A standard ejector system, page 116	B see chapter System design B with ejector, parallel compression and mechanical high-pressure control valve for emergency operation, page 118
System with separator	No	Yes
System with parallel compression stage	No	Yes

Tab. 2: Overview: System designs A and B for ejector operation

① Adjustable either by modulating static ejectors connected in parallel or by changing the opening degree of the ejector nozzle or by connecting ejectors in parallel with adjustable opening degree of the ejector nozzles.

6.6.1 System design A standard ejector system

Standard system design when using R744 in heat pump systems and refrigeration systems with single-stage compression and expansion. Typically with only one evaporator.

Further features of this system design:

- The separator is at intermediate pressure and is referred to as the intermediate pressure vessel in the further description, see figure below.
- In the ejector, a polytropic expansion of the motive mass flow *see page 117* to a pressure level below the evaporation pressure occurs in the nozzle.
- The suction mass flow is sucked in via the ejector and combined with the motive mass flow in the mixing chamber (*see chapter Operating principle, page 108*).
- The pressure is increased to intermediate pressure in the diffuser (*see chapter Operating principle, page 108*).
- The outlet mass flow then flows into the intermediate pressure vessel. Liquid and gas are separated from each other.
- The liquid mass flow expands to evaporation pressure upstream of the evaporator and corresponds to the suction mass flow of the ejector.
- Depending on the system design, a superheat control or operation with a flooded evaporator can be used.
- The flash gas mass flow, which corresponds to the motive mass flow of the ejector, is sucked in as saturated vapour by the compressor and compressed to a high pressure level.
- To keep the refrigerant liquid share in the oil return line as low as possible, an oil return line must be connected to the intermediate pressure vessel and the polyalkylene glycol oil BSG68K from BITZER must be used.
  Apart from that: Install a heat exchanger in the oil return line!
- Depending on the system design, an adjustable or a non-adjustable ejector can be used. The adjustable ejector can also be used to optimise the high pressure.

Information

① The available pressure difference in air-cooled systems depends on the gas cooler outlet temperature and the pressure in the intermediate pressure vessel.

The gas cooler outlet temperature in turn depends on the ambient temperature and gas cooler-specific criteria such as heat dissipation, surface and air volume flow. At high gas cooler outlet temperatures, the potential and kinetic energy available to the ejector is higher than at lower temperatures. The lower application limit of the ejector(s) is defined by a minimum temperature at the outlet of the gas cooler. Below this temperature or the corresponding pressure difference, the ejector no longer works satisfactorily, as the energy of the motive mass flow available at the nozzle is no longer sufficient to enable an increase in pressure of the suction mass flow.

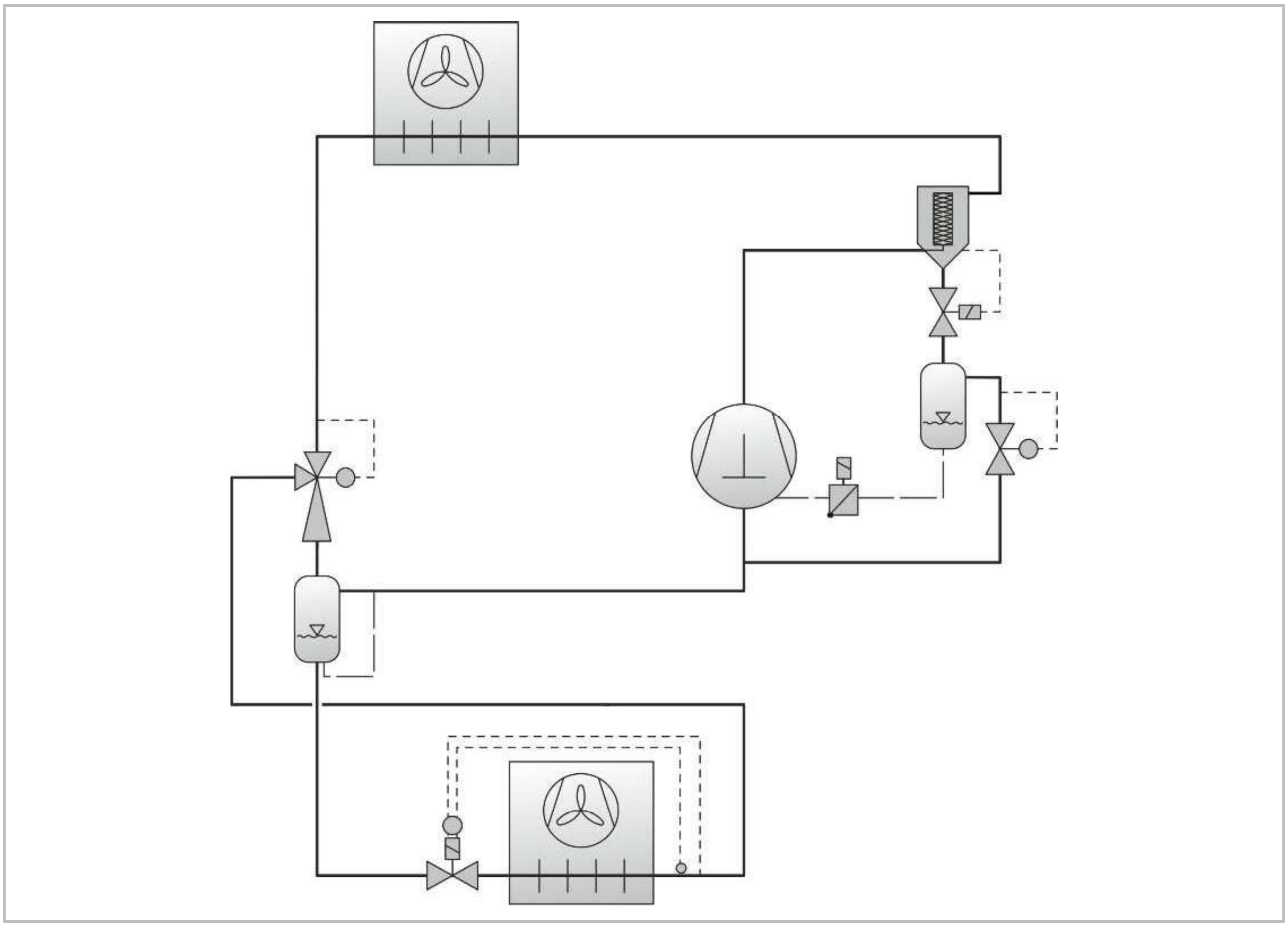


Fig. 25: System design A: Standard ejector system (simplified representation)

6.6.2 System design B with ejector, parallel compression and mechanical high-pressure control valve for emergency operation

- The parallel compression concept reduces the pressure ratio required to re-compress the flash gas to high pressure level.
- The flash gas is sucked in at a higher pressure level by a separate compressor or compressor stage that is directly connected to the intermediate pressure vessel.
- Transcritical R744 booster systems with parallel compression typically have four different pressure levels and consist of:
  - a low temperature compressor stage
  - a medium temperature compressor stage
  - a parallel compressor stage
- The high pressure ejector(s) is (are) installed upstream of the intermediate pressure vessel at the outlet of the gas cooler and use the compressor mass flow with the largest possible pressure difference in the system.
- Parallel to the ejector, a mechanical high-pressure control valve can optionally be installed for emergency operation.
- In the intermediate pressure vessel, the gas and liquid phases are separated *see page 117*. The liquid from the intermediate pressure vessel is fed as usual to the evaporators of the low temperature and medium temperature compressor stages.
  After expansion and heat absorption in the evaporators, the mass flow of the evaporators of the low temperature compressor stage is absorbed by the low temperature compressor stage and re-compressed to the suction pressure level of the medium temperature compressor stage.
- On the suction side of the medium temperature compressor stage, either:
  - a superheat control is used and the suction mass flow of the ejector can be sucked in directly in gaseous form or
  - a separator is used for operation with a semi flooded evaporator, which enables operation of the medium temperature cooling points at low superheat.
    In this case, the ejector is a liquid ejector that delivers the share of the excess liquid from the evaporators of the medium temperature compressor stage back into the intermediate pressure vessel. An oil return line must be connected to the separator!

During operation, also ensure that:

- the ejector controls the optimum high pressure via a control characteristic even during part load operation with very low load and at low outside temperatures.
- the mass flow ratio (entrainment) is influenced by this high pressure control. This can result in no suction mass flow being delivered by the ejector during part load operation!

Two different operating modes of the system are possible:

1. **Operation with high pressure ejector(s) with high load requirements and gas cooler outlet temperatures > 25°C:**
   - The evaporator mass flow of the medium temperature compressor stage is absorbed by the ejector(s) after expansion and heat absorption in the evaporators and forms the suction mass flow. This flow is then compressed from medium temperature suction pressure to intermediate pressure.
   - The flash gas bypass valve between the intermediate pressure vessel and the medium temperature suction side is closed, which relieves the medium temperature compressor stage.
   - The pressure lift generated by the ejector compression stage reduces the pressure ratio for the compression of the mass flow (in terms of thermodynamics, this is referred to as a "temperature lift"). At the same time, the

suction gas density increases, allowing the energetic advantage of parallel compression to take effect. The pressure in the intermediate pressure vessel is controlled by the parallel compressor stage.

- In systems with semi flooded evaporators and a separator, the ejector only has to transport the excess liquid back to the intermediate pressure vessel. The energetic advantage here lies mainly in the increased evaporation temperature due to the full utilisation of the heat transfer surface. A superheat control is not necessary in this case.

2. **Standard operation without high pressure ejector(s) with low load requirements and gas cooler outlet temperatures < 25°C:**

- During standard flash gas bypass operation, the control valve (e.g. solenoid valve or motor valve) is closed upstream of the ejector's suction connection.
- The parallel compressor stage is out of operation and the flash gas bypass valve controls the pressure in the intermediate pressure vessel by expanding the flash gas to medium temperature suction pressure.
- The mass flow of the medium temperature evaporator and the flash gas mass flow are picked up and compressed by the medium temperature compressor stage.
- To enable operation of the medium temperature compressor stage at low loads and low ambient temperatures at lower high pressures, it may be advantageous to install a high-pressure control valve in parallel with ejector(s) (see the following simplified diagram).

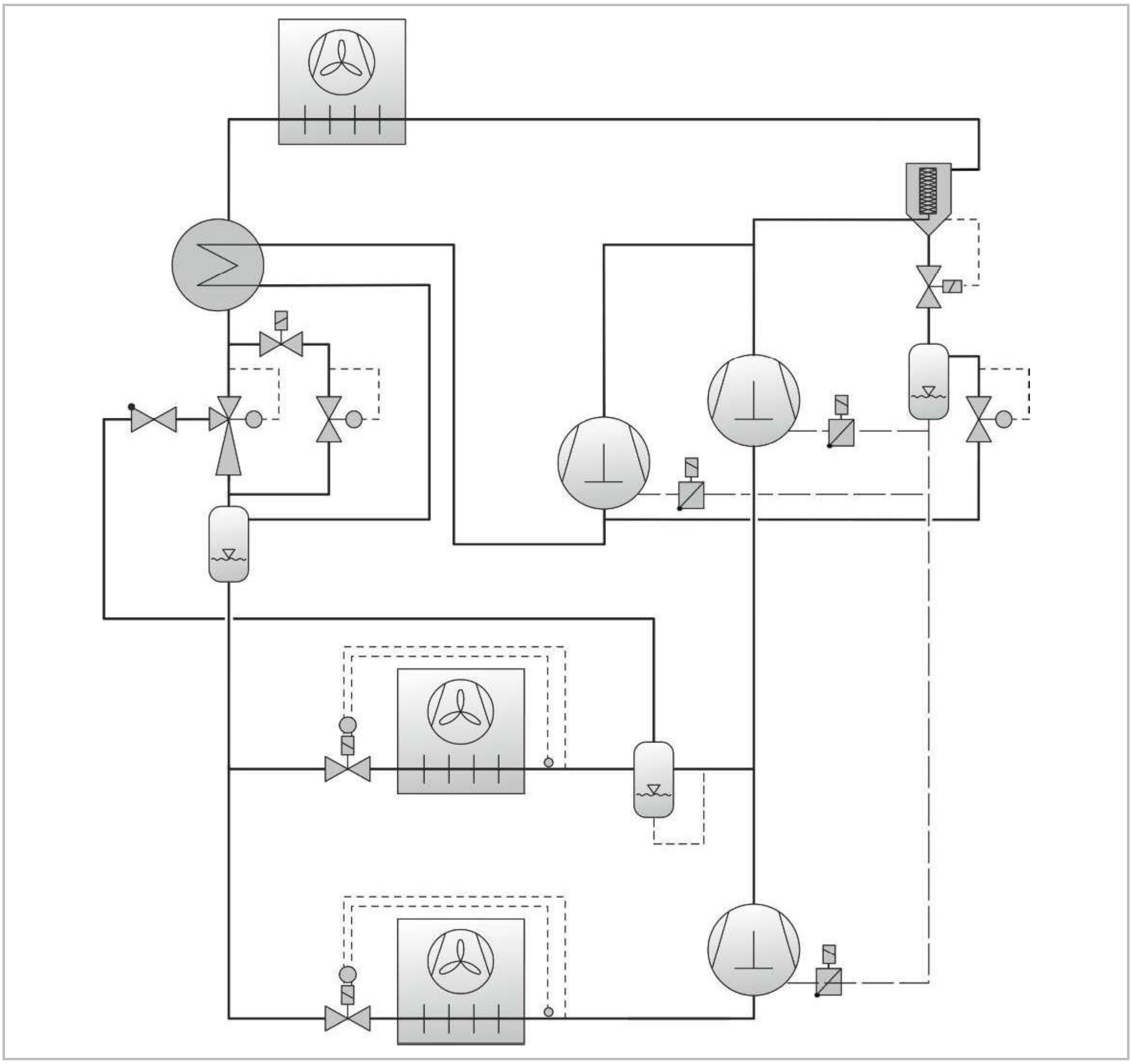


Fig. 26: System design B: with ejector, parallel compression and mechanical high-pressure control valve for emergency operation (simplified representation)

6.7 Design criteria and selection

6.7.1 Design example of an ejector in a low lift application

In a low lift application, the mass flow ratio is the essential selection criterion. The ejectors circulate the refrigerant in a similar way to a refrigerant pump. The goal is to increase the pressure only to the extent allowed by the mass flow ratio of the pumping operation.

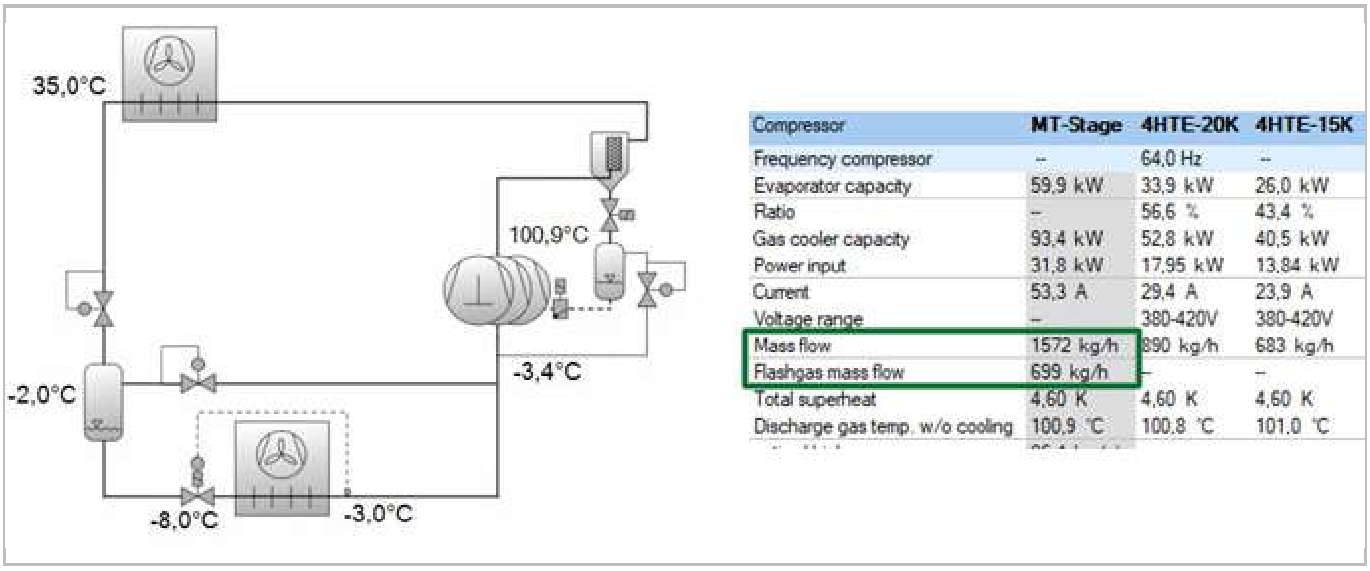
From the characteristics of the selected ejector results the suction mass flow at the given high pressure, motive mass flow rate and intermediate pressure. The intermediate pressure is determined by the suction pressure control of the compressor.

In the following example, a single-stage system with one ejector is to be calculated:

Boundary conditions:

- Gas cooler outlet temperature (t_{gc}) at the design point: 35°C
- High pressure, absolute (p_{HP}): 89 bar
- Evaporation temperature in the medium temperature compressor stage ($t_{o\ MT}$): -8°C
- Cooling capacity of the medium temperature compressor stage ($Q_{o\ MT}$): 60 kW
- Medium pressure, absolute (estimated): 33 bar

First, a system without ejector with a standard superheat control is calculated in BITZER SOFTWARE under "R744 booster selection" (see following figure). The intermediate pressure is selected approx. 5 bar above the evaporation pressure. According to a first estimate, this corresponds to the pressure lift of the system with ejector.



Compressor	MT-Stage	4HTE-20K	4HTE-15K
Frequency compressor	--	64,0 Hz	--
Evaporator capacity	59,9 kW	33,9 kW	26,0 kW
Ratio	--	56,6 %	43,4 %
Gas cooler capacity	93,4 kW	52,8 kW	40,5 kW
Power input	31,8 kW	17,95 kW	13,84 kW
Current	53,3 A	29,4 A	23,9 A
Voltage range	--	380-420V	380-420V
Mass flow	1572 kg/h	890 kg/h	683 kg/h
Flashgas mass flow	699 kg/h	--	--
Total superheat	4,60 K	4,60 K	4,60 K
Discharge gas temp. w/o cooling	100,9 °C	100,8 °C	101,0 °C

With these assumptions, the first step is to calculate the ejector's mass flow to be delivered to achieve the cooling capacity of 60 kW. Due to the separation in the intermediate pressure vessel, the **net mass flow** that flows through the evaporator and is sucked in again by the ejector is the total mass flow minus the flash gas mass flow; in this example, this is 1572 kg/h - 699 kg/h = **873 kg/h**.

Based on the mass flow that must flow through the evaporator to achieve the cooling capacity of 60 kW, the necessary delivery rate of the compressors can be determined via the mass flow ratio of the ejector. The HDV-E23 ejector pre-selected in the BITZER calculation tool has a **mass flow ratio of 0.56 and a pressure stroke of 4 bar** at a high pressure of 89 bar and a motive mass flow of 1572 kg/h.

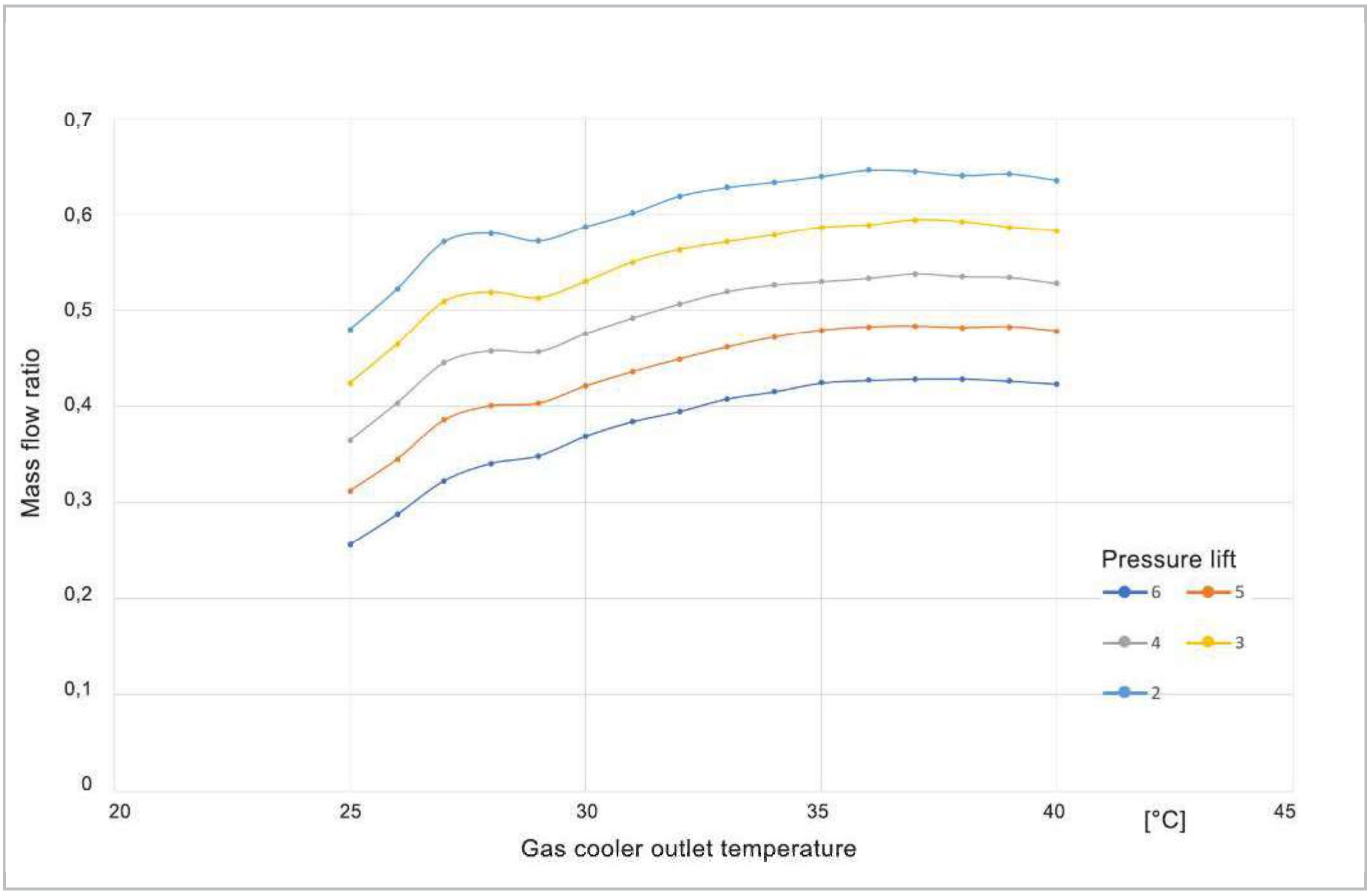
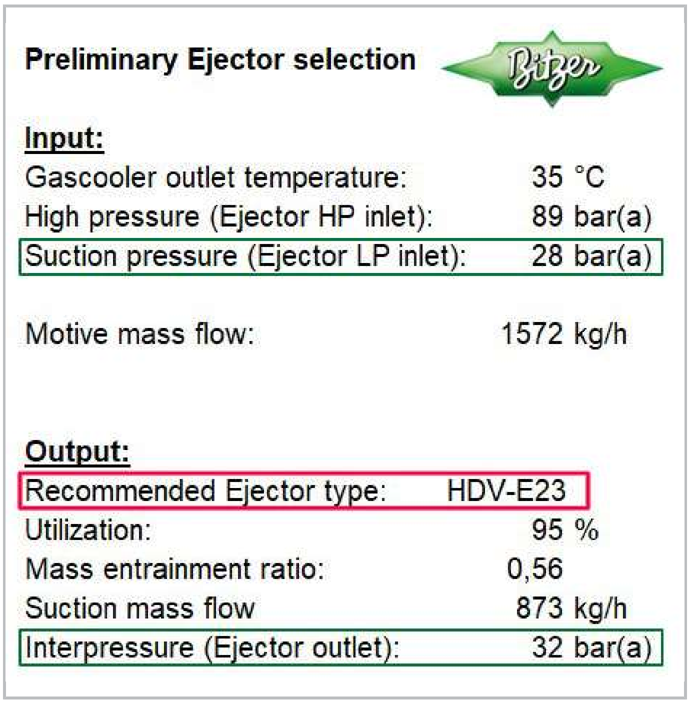


Fig. 27: Entrainment rate of the HDV-E23 ejector as a function of gas cooler outlet temperature for selected pressure lifts

The recommended ejector HDV-E23 can therefore suck in 873 kg/h and deliver to an intermediate pressure that is 4 bar higher.



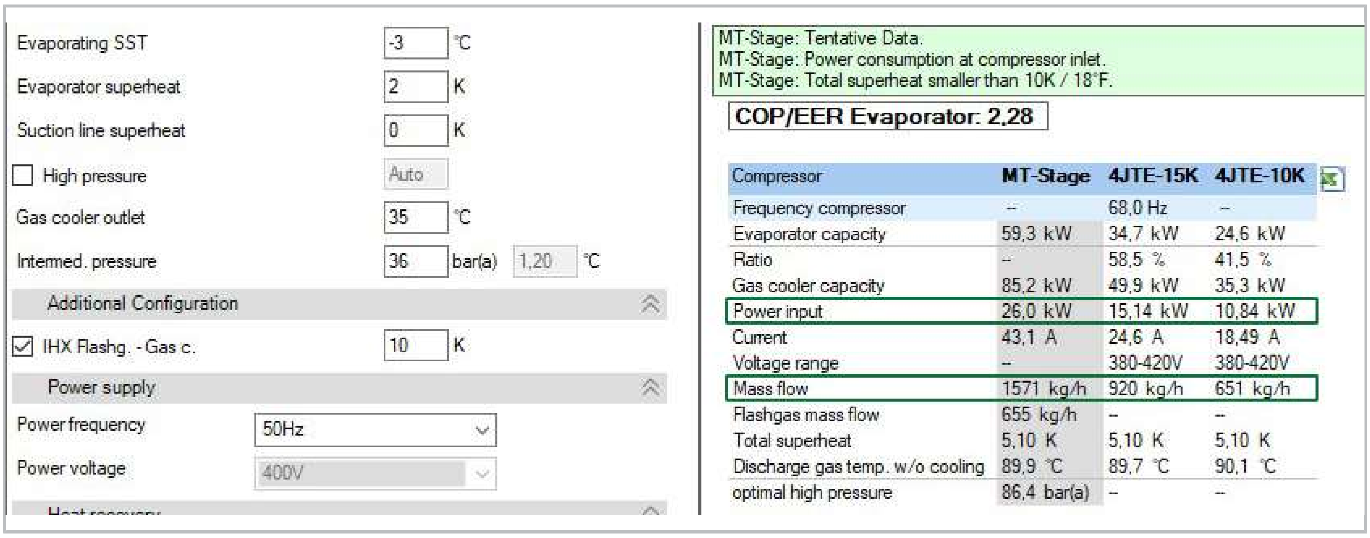
Preliminary Ejector selection

Input:
Gascooler outlet temperature: 35 °C
High pressure (Ejector HP inlet): 89 bar(a)
Suction pressure (Ejector LP inlet): 28 bar(a)

Motive mass flow: 1572 kg/h

Output:
Recommended Ejector type: HDV-E23
Utilization: 95 %
Mass entrainment ratio: 0,56
Suction mass flow 873 kg/h
Interpressure (Ejector outlet): 32 bar(a)

Smaller compressors can now be selected due to the increased suction pressure. The cooling capacity shown in the new selection is irrelevant. The calculation is only used for the new compressor configuration based on the motive mass flow for the ejector at the higher pressure level and to determine the power consumption. The compressors would now have to deliver a mass flow of 1572 kg/h from the intermediate pressure vessel at 32 bar suction pressure (-3°C) (see figure below). The corresponding power consumption is the new compressor power consumption of the system with ejector.



Evaporating SST: -3 °C
Evaporator superheat: 2 K
Suction line superheat: 0 K
☐ High pressure: Auto
Gas cooler outlet: 35 °C
Intermed. pressure: 36 bar(a) 1,20 °C

Additional Configuration

☑ IHX Flashg. - Gas c.: 10 K

Power supply

Power frequency: 50Hz
Power voltage: 400V

MT-Stage: Tentative Data.
MT-Stage: Power consumption at compressor inlet.
MT-Stage: Total superheat smaller than 10K / 18°F.

COP/EER Evaporator: 2,28

Compressor	MT-Stage	4JTE-15K	4JTE-10K
Frequency compressor	--	68,0 Hz	--
Evaporator capacity	59,3 kW	34,7 kW	24,6 kW
Ratio	--	58,5 %	41,5 %
Gas cooler capacity	85,2 kW	49,9 kW	35,3 kW
Power input	26,0 kW	15,14 kW	10,84 kW
Current	43,1 A	24,6 A	18,49 A
Voltage range	--	380-420V	380-420V
Mass flow	1571 kg/h	920 kg/h	651 kg/h
Flashgas mass flow	655 kg/h	--	--
Total superheat	5,10 K	5,10 K	5,10 K
Discharge gas temp. w/o cooling	89,9 °C	89,7 °C	90,1 °C
optimal high pressure	86,4 bar(a)	--	--

COP

The **COP of the flash gas bypass system** is Q_o / P_e = 59.9 kW / 31.8 kW = **1.9**

The **COP of the system with ejector** is Q_o / P_e = 59.9 kW / 26 kW = **2.3**

It must be kept in mind that the advantage of the approx. 3 K higher evaporation temperature due to operation with flooded evaporator has not yet been taken into account.

6.7.2 Design example of an ejector in a high lift application

The mass flow ratio as a function of the high pressure and the pressure lift is decisive for the design of an ejector in a high lift application. The pressure stroke itself is a variable that can be freely selected within certain limits and has a major influence on the selection of compressors in the individual compressor stages.

When selecting an ejector, the control strategy must first be determined.
Either:

- the intermediate pressure is varied depending on the high pressure so that parallel compressors and ejectors are operated within the optimum range.
  Although this promises the highest efficiency of the system, it also means increased control effort.

Or:

- the intermediate pressure is kept constant. This is easier to implement.

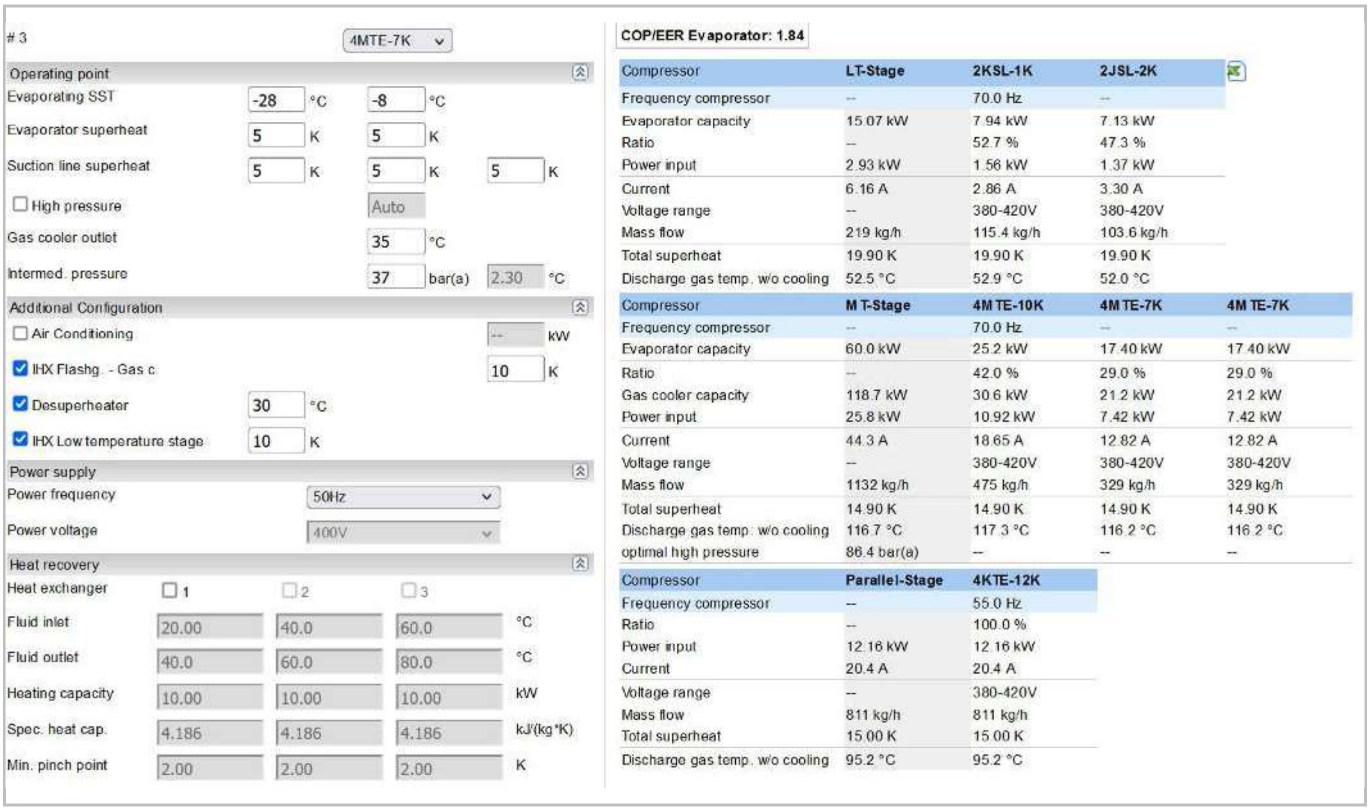
In the following example, an ejector is to be selected for a low temperature/medium temperature booster system with parallel compression:

Boundary conditions:

- Gas cooler outlet temperature (t_{gc}) at the design point: 35°C
- Evaporation temperature in the medium temperature compressor stage ($t_{o\,MT}$): -8°C
- Evaporation temperature in the low temperature compressor stage ($t_{o\,LT}$): -28°C
- Cooling capacity of the medium temperature compressor stage ($Q_{o\,MT}$): 60 kW

- Cooling capacity of the low temperature compressor stage ($Q_{o\,LT}$): 15 kW
- Intermediate pressure, absolute (p_{IP}): 37 bar

First, a system without ejector with a standard superheat is calculated in the BITZER SOFTWARE under R744 booster, see following figure:



3 — 4MTE-7K

Operating point

Evaporating SST: -28 °C; -8 °C
Evaporator superheat: 5 K; 5 K
Suction line superheat: 5 K; 5 K; 5 K
☐ High pressure: Auto
Gas cooler outlet: 35 °C
Intermed. pressure: 37 bar(a); 2.30 °C

Additional Configuration

☐ Air Conditioning: -- kW
☑ IHX Flashg. - Gas c: 10 K
☑ Desuperheater: 30 °C
☑ IHX Low temperature stage: 10 K

Power supply

Power frequency: 50Hz
Power voltage: 400V

Heat recovery

Heat exchanger	☐ 1	☐ 2	☐ 3	
Fluid inlet	20.00	40.0	60.0	°C
Fluid outlet	40.0	60.0	80.0	°C
Heating capacity	10.00	10.00	10.00	kW
Spec. heat cap.	4.186	4.186	4.186	kJ/(kg*K)
Min. pinch point	2.00	2.00	2.00	K

COP/EER Evaporator: 1.84

Compressor	LT-Stage	2KSL-1K	2JSL-2K
Frequency compressor	--	70.0 Hz	--
Evaporator capacity	15.07 kW	7.94 kW	7.13 kW
Ratio	--	52.7 %	47.3 %
Power input	2.93 kW	1.56 kW	1.37 kW
Current	6.16 A	2.86 A	3.30 A
Voltage range	--	380-420V	380-420V
Mass flow	219 kg/h	115.4 kg/h	103.6 kg/h
Total superheat	19.90 K	19.90 K	19.90 K
Discharge gas temp. w/o cooling	52.5 °C	52.9 °C	52.0 °C

Compressor	MT-Stage	4MTE-10K	4MTE-7K	4MTE-7K
Frequency compressor	--	70.0 Hz	--	--
Evaporator capacity	60.0 kW	25.2 kW	17.40 kW	17.40 kW
Ratio	--	42.0 %	29.0 %	29.0 %
Gas cooler capacity	118.7 kW	30.6 kW	21.2 kW	21.2 kW
Power input	25.8 kW	10.92 kW	7.42 kW	7.42 kW
Current	44.3 A	18.65 A	12.82 A	12.82 A
Voltage range	--	380-420V	380-420V	380-420V
Mass flow	1132 kg/h	475 kg/h	329 kg/h	329 kg/h
Total superheat	14.90 K	14.90 K	14.90 K	14.90 K
Discharge gas temp. w/o cooling	116.7 °C	117.3 °C	116.2 °C	116.2 °C
optimal high pressure	86.4 bar(a)	--	--	--

Compressor	Parallel-Stage	4KTE-12K
Frequency compressor	--	55.0 Hz
Ratio	--	100.0 %
Power input	12.16 kW	12.16 kW
Current	20.4 A	20.4 A
Voltage range	--	380-420V
Mass flow	811 kg/h	811 kg/h
Total superheat	15.00 K	15.00 K
Discharge gas temp. w/o cooling	95.2 °C	95.2 °C

At the gas cooler outlet there is a **motive mass flow** of 1132 kg/h (MT) + 811 kg/h (parallel) = **1943**. The pressure lift that the ejector must carry out from medium temperature level to intermediate pressure level is 9 bar (see figure below).
Based on the motive mass flow (mass flow of the medium temperature and parallel compressors) of 1943 kg/h, the high pressure and the pressure stroke, one ejector or several ejectors can be selected.

Two HDV-E16 ejectors are suitable for this design variant to fully utilise the motive mass flow. In this case, both ejectors operate at 100% opening degree. The ejectors should be designed and controlled such that the operating point is as close as possible to 100% opening degree. Individual ejectors can be deactivated in order to make greater use of the still activated ejectors working at part load. This must be done at the latest when their opening degree falls below 30%, as no significant mass flow can be sucked in and compressed below this point. The ejector would then only work as a pure expansion device with isenthalpic throttling.

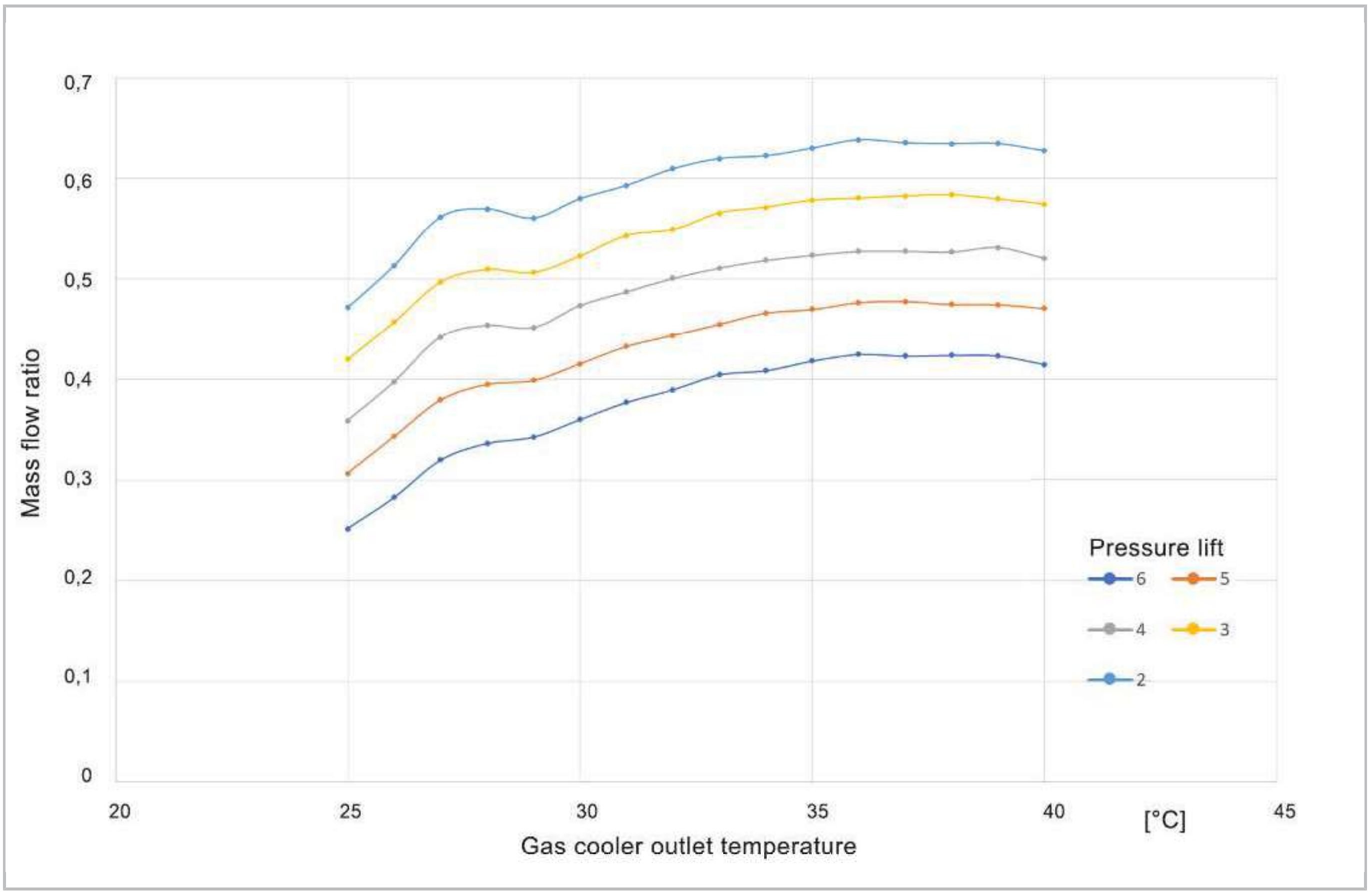
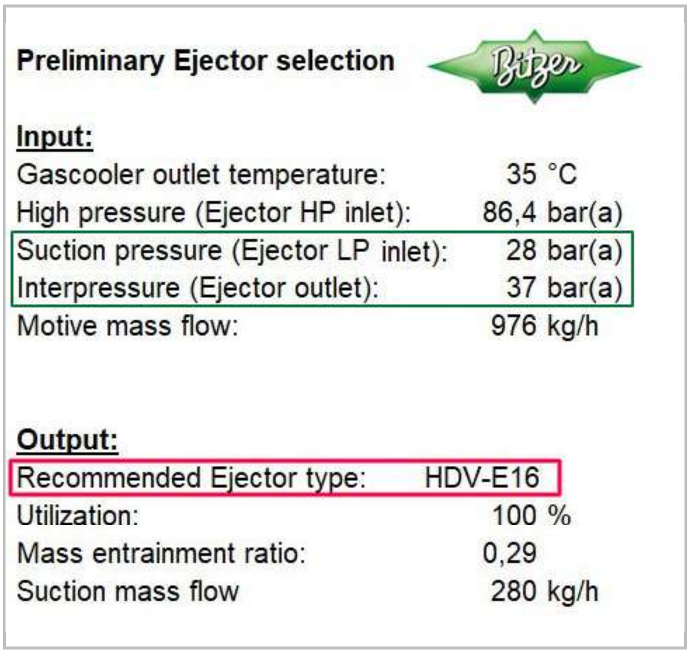


Fig. 28: Entrainment rate of the HDV-E16 ejector as a function of gas cooler outlet temperature for selected pressure lifts

The two ejectors proposed by the BITZER calculation tool have a **mass flow ratio of 0.29** at a **high pressure of 86.4 bar** and at a **pressure lift of 9 bar**. **The total mass flow sucked in and delivered to intermediate pressure is 560 kg/h (2x 280 kg/h)**.



Preliminary Ejector selection

Input:

Gascooler outlet temperature:	35 °C
High pressure (Ejector HP inlet):	86,4 bar(a)
Suction pressure (Ejector LP inlet):	28 bar(a)
Interpressure (Ejector outlet):	37 bar(a)
Motive mass flow:	976 kg/h

Output:

Recommended Ejector type:	HDV-E16
Utilization:	100 %
Mass entrainment ratio:	0,29
Suction mass flow	280 kg/h

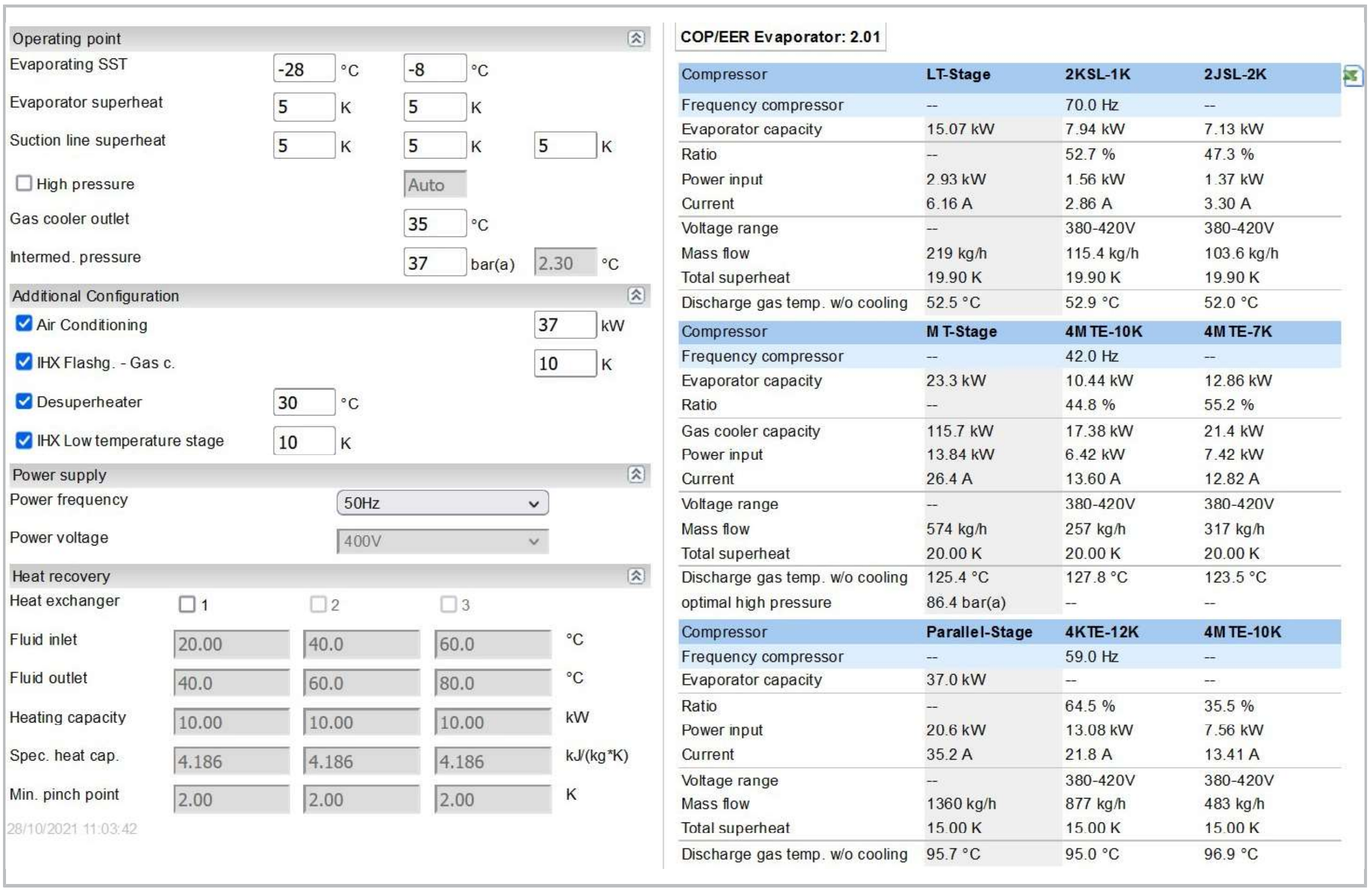
These results will be included in the further steps of the design. The **medium temperature compressors are relieved by 560 kg/h** and the parallel compressors are loaded accordingly. Since BITZER SOFTWARE always ideally adapts the parallel compressors to the mass flows of the medium temperature and low temperature compressors, the additional load shift introduced by the ejector must be specified as "high temperature load" (in this case approx. 37 kW). This increases the delivered mass flow of the parallel compressors by 560 kg/h.

The new conditions are:

- Medium temperature compressor: 572 kg/h
- Parallel compressor: 1371 kg/h
- Of which high temperature load for ejector simulation: approx. 37 kW (corresponds to the mass flow of 560 kg/h)

The shift in mass flows has significantly changed the compressor selection (see following figure). The 4MTE-10K compressor, originally used in the medium temperature compressor stage, now appears in the parallel compressor stage.

However, it should be kept in mind that the elimination of the mass flow from the evaporator at the mixing point with the discharge gas of the low temperature compressor stage has greatly increased the mixing temperature and thus the suction gas temperature. This results in a sharp increase of the discharge gas temperature and must be considered in extreme cases. Additional suction gas cooling may be necessary!



Operating point
Evaporating SST: -28 °C; -8 °C
Evaporator superheat: 5 K; 5 K
Suction line superheat: 5 K; 5 K; 5 K
☐ High pressure: Auto
Gas cooler outlet: 35 °C
Intermed. pressure: 37 bar(a); 2.30 °C

Additional Configuration
☑ Air Conditioning: 37 kW
☑ IHX Flashg. - Gas c.: 10 K
☑ Desuperheater: 30 °C
☑ IHX Low temperature stage: 10 K

Power supply
Power frequency: 50Hz
Power voltage: 400V

Heat recovery

Heat exchanger	☐ 1	☐ 2	☐ 3	
Fluid inlet	20.00	40.0	60.0	°C
Fluid outlet	40.0	60.0	80.0	°C
Heating capacity	10.00	10.00	10.00	kW
Spec. heat cap.	4.186	4.186	4.186	kJ/(kg*K)
Min. pinch point	2.00	2.00	2.00	K

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COP/EER Evaporator: 2.01

Compressor	LT-Stage	2KSL-1K	2JSL-2K
Frequency compressor	--	70.0 Hz	--
Evaporator capacity	15.07 kW	7.94 kW	7.13 kW
Ratio	--	52.7 %	47.3 %
Power input	2.93 kW	1.56 kW	1.37 kW
Current	6.16 A	2.86 A	3.30 A
Voltage range	--	380-420V	380-420V
Mass flow	219 kg/h	115.4 kg/h	103.6 kg/h
Total superheat	19.90 K	19.90 K	19.90 K
Discharge gas temp. w/o cooling	52.5 °C	52.9 °C	52.0 °C
Compressor	**MT-Stage**	**4MTE-10K**	**4MTE-7K**
Frequency compressor	--	42.0 Hz	--
Evaporator capacity	23.3 kW	10.44 kW	12.86 kW
Ratio	--	44.8 %	55.2 %
Gas cooler capacity	115.7 kW	17.38 kW	21.4 kW
Power input	13.84 kW	6.42 kW	7.42 kW
Current	26.4 A	13.60 A	12.82 A
Voltage range	--	380-420V	380-420V
Mass flow	574 kg/h	257 kg/h	317 kg/h
Total superheat	20.00 K	20.00 K	20.00 K
Discharge gas temp. w/o cooling	125.4 °C	127.8 °C	123.5 °C
optimal high pressure	86.4 bar(a)	--	--
Compressor	**Parallel-Stage**	**4KTE-12K**	**4MTE-10K**
Frequency compressor	--	59.0 Hz	--
Evaporator capacity	37.0 kW	--	--
Ratio	--	64.5 %	35.5 %
Power input	20.6 kW	13.08 kW	7.56 kW
Current	35.2 A	21.8 A	13.41 A
Voltage range	--	380-420V	380-420V
Mass flow	1360 kg/h	877 kg/h	483 kg/h
Total superheat	15.00 K	15.00 K	15.00 K
Discharge gas temp. w/o cooling	95.7 °C	95.0 °C	96.9 °C

The cooling capacity of the compressor stages shown in the new selection has no meaning. Only the compressor selection was adapted to the new mass flow ratios to determine the compressor sizes and power consumption. Thus, with the originally calculated cooling capacity and the new power consumption due to the use of the ejector, the following COP can be calculated:

COP

The total COP of the parallel system is:
Q_o / P_e = (15.07 kW + 60 kW) / (2.93 kW + 25.8 kW + 12.16 kW) = **1.84**

The total COP of the parallel + ejector system is:
Q_o / P_e = (15.07 kW + 60 kW) / (2.93 kW + 13.84 kW + 20.6 kW) = **2.01**

6.8 Control

- Adjustable ejectors (e.g. HDV-**E**30) have a bipolar servomotor by means of which the position of a throttle element and thus the cross-sectional area of the nozzle in the ejector can be changed.
- To control the valve, the following is needed:
  - an analogue control signal (0..10 V) from the superior controller (independent of the manufacturer)
  - the control device SVD1A1
  - the activation of the bipolar servomotor (via the control device)

Control device SVD1A1

Connect cables to the ejector only with a seal (included in delivery). Tightening torque for the connector: 0,5 Nm.

For any work performed on the electrical system: Observe the protection objectives of the EU Low Voltage Directive , EN60204-1, the IEC60364 series of safety standards and national safety regulations.

NOTICE
Malfunctions due to electromagnetic interference!
When connecting ejectors with a cable length > 5 m, use shielded connection cables.
Connect the shield to terminal 35 and the earth to terminal 34.

Information
The SVD1A1 is inactive when the combination 0/0 is set on the rotary switches!

Setting the ejector group and ejector type:

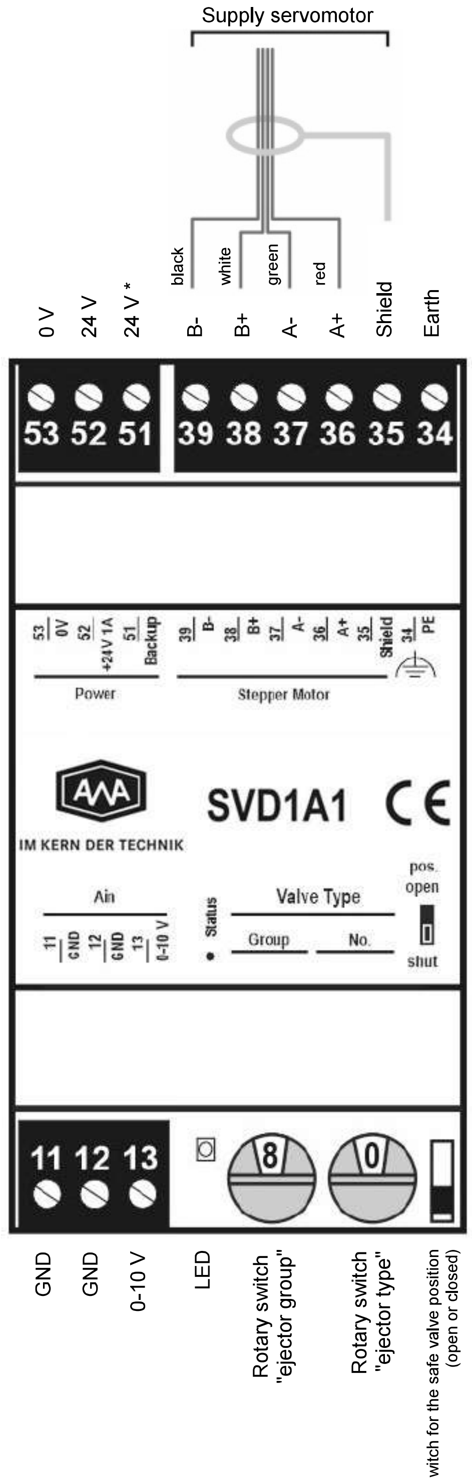
- Set ejector group "**8**" (left-hand rotary switch) and ejector type "**0**" or "**1**" (right-hand rotary switch) on the rotary switches of the control device (see figure below).

Ejectorgroup "**8**"	HDV-E23/HDV-E30
Type "**0**"	100% of the Kv value
Type "**1**"	100% of the Kv value at cascade operation

Tab. 3: Settings on the control device SVD1A1

Cable lengths and cross sections:

- < 5 m -> 0.5 mm^2
- 5-30 m -> 0.5 mm^2 shielded
- 30-50 m -> 0.75 mm^2 shielded



* Second supply input with switch function

Fig. 29: Control device SVD1A1

Settings for emergency operation / in case of voltage supply interruption:

- The ejector position (open or closed) is preset directly on the switch for the safe valve position (safe pos.) of the SVD1A1 (see figure above, switch to the right of the rotary switches).
- SVD1A1 has an integrated emergency closing function for emergency operation / in case of voltage supply interruption.

Control characteristic

In the applications described in this Technical Information, the ejector controls the optimum high pressure via a control characteristic (depending on the manufacturer of the superior controller). For control, the measured high pressure for the temperature at the gas cooler outlet, which is also measured, is compared with the target high pressure using the control characteristic.

- Depending on the control deviation between the measured high pressure and the target high pressure, an analogue control signal is output by the superior controller. The control device is used to activate the bipolar servomotor and thus change the cross-sectional area of the nozzle.
- The mass flow ratio (entrainment) is influenced by controlling the cross-sectional area of the nozzle and thus the high pressure. When using the ejector as a low lift / liquid ejector, this dependency must be taken into account when planning and designing the system.
- The height of the pressure lift may only be selected such that no stall effect occurs in the ejector even at low high pressure and motive mass flow.
- For some ejector applications, a distinction can be made between different operating conditions, for example with an open or closed suction line for the ejector.
- One criterion for activating the various operating conditions is the gas cooler outlet temperature or the inlet temperature of the motive mass flow into the ejector. However, the gas cooler outlet temperature alone does not provide information on the load requirements at the cooling points.
- Depending on the manufacturer and type of the superior controller, further criteria are taken into account, for example opening degree of the flash gas bypass valve, opening degree of the high-pressure control valve, operation feedback of the compressors, superheat and alarm messages.

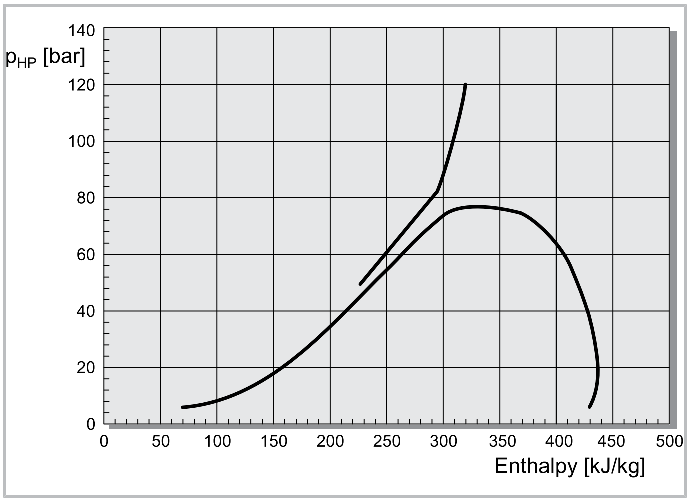


Fig. 30: Ejector control characteristic in the p,h diagram

6.9 Document as PDF

Open document as PDF

Related documents

AT-744-1.pdf (Resources/pdf/522229387.pdf)

7 Pressure and saturated vapour temperature table for R744

Saturated vapour temperature **t_{sat} (°C)**	**Absolute pressure** **p (bar)**
31.06** ①	73.84
31	73.74
30	72.05
29	70.42
28	68.82
27	67.27
26	65.74
25	64.25
24	62.79
23	61.36
22	59.95
21	58.57
20	57.22
19	55.89
18	54.58
17	53.30
16	52.05
15	50.81
14	49.60
13	48.41
12	47.24
11	46.10
10	44.57
9	43.87
8	42.78
7	41.70
6	40.67
5	39.65
4	38.64
3	37.66
2	36.69
1	35.74
0	34.81
-1	33.90
-2	33.00
-3	32.12
-4	31.26
-5	30.42
-6	29.59
-7	28.78
-8	27.99

Saturated vapour temperature **t_{sat} (°C)**	**Absolute pressure** **p (bar)**
-9	27.21
-10	26.45
-11	25.71
-12	24.98
-13	24.26
-14	23.56
-15	22.88
-16	22.21
-17	21.55
-18	20.91
-19	20.28
-20	19.67
-21	19.07
-22	18.49
-23	17.91
-24	17.35
-25	16.81
-26	16.27
-27	15.75
-28	15.25
-29	14.75
-30	14.26
-31	13.79
-32	13.33
-33	12.88
-34	12.44
-35	12.02
-36	11.60
-37	11.19
-38	10.80
-39	10.42
-40	10.04
-41	9.68
-42	9.32
-43	8.98
-44	8.64
-45	8.32
-46	8.00
-47	7.70
-48	7.40
-49	7.11
-50	6.83
-51	6.55

Saturated vapour temperature t_{sat} (°C)	Absolute pressure p (bar)
-52	6.29
-53	6.03
-54	5.78
-55	5.54
-56	5.31

① Critical point

8 Checklists for commissioning

Related documents

AT-744 Checklist Booster Systems.pdf (Resources/pdf/713114379__en.pdf)

9 Document as PDF

Dokument als PDF öffnen

Related documents

AT-744-2.pdf (Resources/pdf/718074891.pdf)