BASIC KNOWLEDGE

THERMODYNAMICS OF THE REFRIGERATION CYCLE

Set-up and function of a compression refrigeration system

The refrigerant in a compression refrigeration system flows through a closed cycle with the following four stations:

- Evaporation ***A***
- Compression ***B***
- Condensation ***C***
- Expansion ***D***

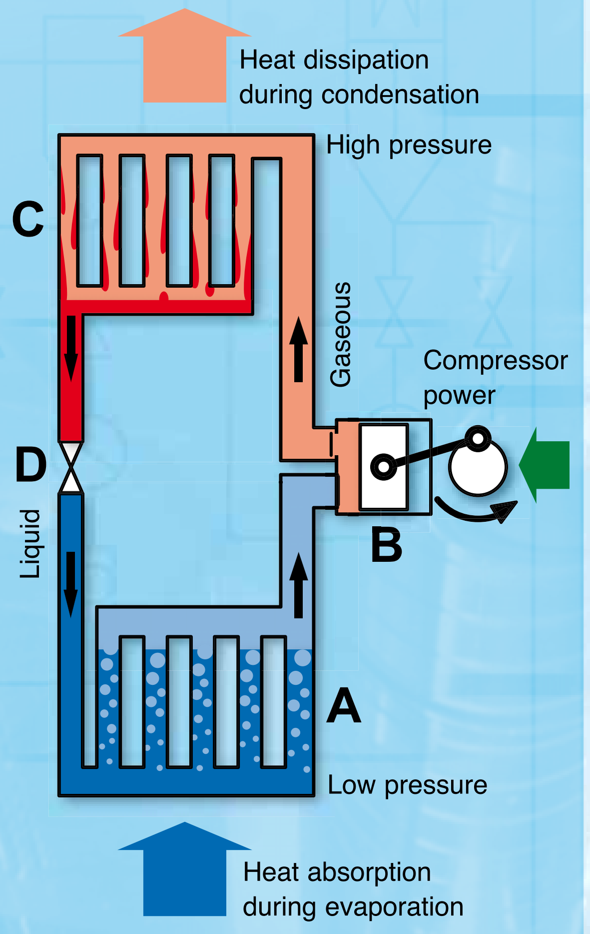
The cooling takes place in the evaporator *(A)*. The evaporation takes place at low pressures and temperatures. Here the refrigerant absorbs heat from the environment and thus cools it.

The still cold refrigerant steam is aspirated by a compressor *(B)* and subjected to higher pressure by using mechanical energy. The refrigerant steam heats up due to the compression.

The hot refrigerant steam is cooled down in a condenser *(C)* and condenses while discharging heat to the environment.

The liquid pressurised refrigerant is then expanded to the low evaporation pressure in an expansion element *(D)* and returned to the evaporator.

The refrigerant evaporates again and thus completes the circuit.



Cyclic process of a simple compression refrigeration system

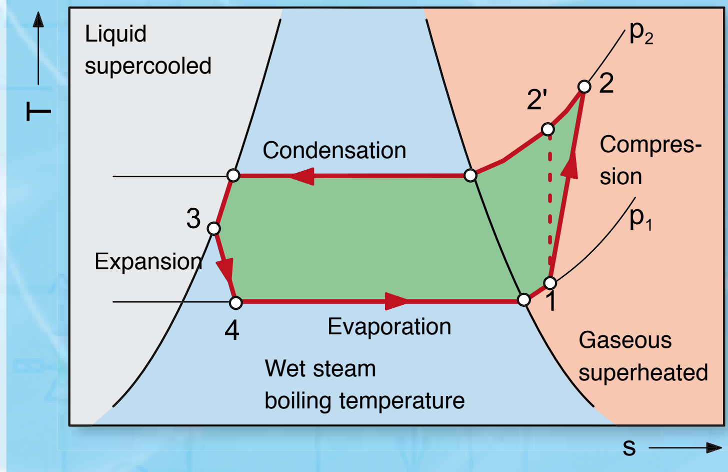
The refrigeration cycle

For operating media which can have different phases, such as water or refrigerant, the *T-s* diagram looks different.

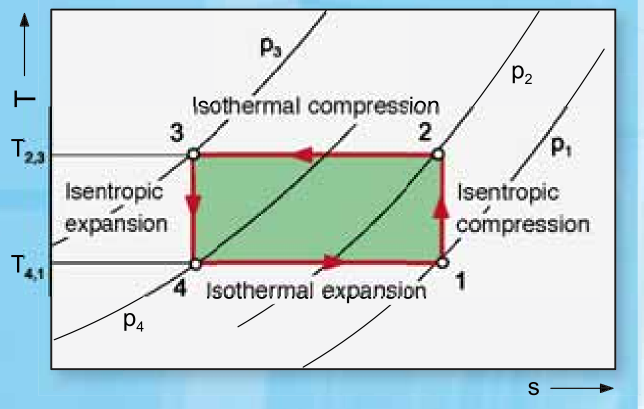
It has an area on the left *(grey)*, in which the operating medium is liquid and supercooled. In the centre *(blue)* there is a mixture of steam and liquid, the wet steam. On the right of it *(orange)* the operating medium is in pure steam form and superheated.

The real refrigeration cycle with its typical phase transitions can also be represented in this *T-s* diagram. The cycle has many similarities to the familiar steam power cycle. The processes of evaporation and condensation and expansion and compression (pumping) swap places.

The enclosed area *(green)* corresponds to the compressor work added to the cycle.



Refrigeration cycle in the T-s diagram



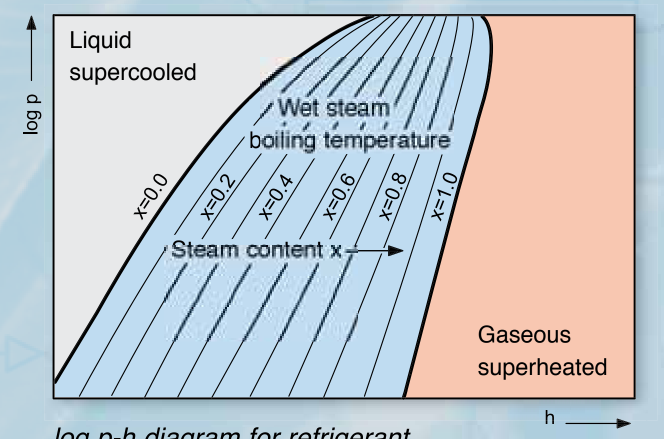
Ideal cyclic process (Carnot cycle) of a gaseous medium in the T-s diagram

The ideal cyclic process

A cyclic process can be represented very clearly in the *T-s* diagram. Here the temperature *T* of the operating medium is plotted above the entropy *s*. The area enclosed by the change of state of the operating medium corresponds to the work realised in the cyclic process.

The cyclic process with the highest possible efficiency is the Carnot cycle, here the enclosed area is a rectangle. This cycle is often used as a comparison cycle to describe the quality of the cyclic process.

The direction of the cyclic process in the *T-s* diagram determines whether this is a heat pump cycle (refrigeration cycle) or a work machine cycle (steam power cycle). Refrigeration cycles are anticlockwise and the work represented by the green area is added to the cycle.



log p-h diagram for refrigerant

The log p-h diagram for refrigerant

In the log p-h diagram the pressure *p* is plotted above the enthalpy h.

In the centre *(blue)* is the wet steam area. Here the temperature corresponds to the boiling temperature for the pressure. The wet steam area is surrounded by limit curves with the steam content x=0.0 and x=1.0.

To the left of it *(grey)* the refrigerant is liquid. The temperature is below the boiling temperature for the pressure; the refrigerant is supercooled.

On the right *(orange)* the refrigerant is gaseous and the temperature is above the boiling temperature. The refrigerant is superheated.

Every refrigerant has its own log p-h diagram.

The log p-h diagram is better suited to represent the refrigeration cycle than the T-s diagram and is therefore used predominantly.

Because energies exchanged with the refrigerant modify the enthalpy h of the refrigerant, energy flows can be read directly from the diagram as horizontal lines.

BASIC KNOWLEDGE

THERMODYNAMICS OF THE REFRIGERATION CYCLE

The refrigeration cycle in the log p-h diagram

The real refrigeration cycle consists of the following changes of state:

1 – 2	polytropic compression on the condensation pressure (for comparison 1 – 2' isentropic compression)
2 – 2''	isobaric cooling, deheating of the superheated steam
2'' – 3'	isobaric condensation
3' – 3	isobaric cooling, supercooling of the liquid
3 – 4	isenthalpic expansion to the evaporation pressure
4 – 1'	isobaric evaporation
1' – 1	isobaric heating, superheating of the steam

The refrigeration cycle in the log p-h diagram

In addition there are also pressure losses in the real refrigeration cycle, which means that evaporation and condensation are not exactly horizontal (isobaric).

The refrigerant

Every cyclic process requires an operating medium which in the refrigeration cycle is the refrigerant. In the refrigeration cycle the refrigerant has the purpose of transporting heat. Here the high absorption of energy during evaporation or discharge of energy during the condensation of a liquid is utilised. To achieve this at the temperatures prevailing in a refrigeration system at well manageable pressures, liquids with a low boiling point, such as different fluorocarbons (FC), ammonia (NH_3), carbon dioxide (CO_2) or hydrocarbons such as butane or propane, are used as operating medium.

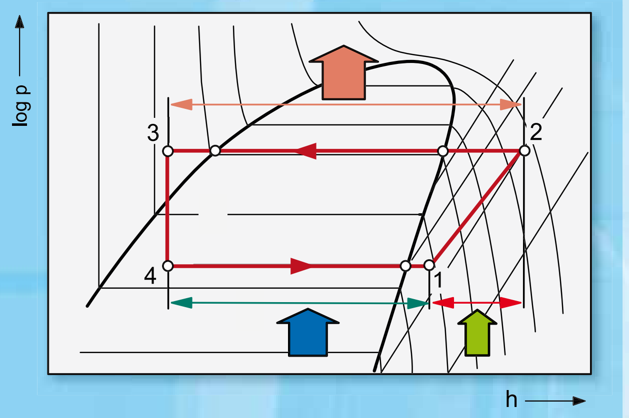
The different refrigerants are marked with an *R* followed by a number.

The water often used in technical cycles is not suitable for the refrigeration cycle. At the low temperatures prevailing in a refrigeration system the evaporation pressure is extremely low and there is a risk of the water freezing.

The use of CO_2 is technically demanding. Due to its low boiling temperature a very high pressure level results. This means that common components from refrigeration technology, such as valves, compressors or heat exchangers, cannot be used.

For NH_3 there are also special components, because materials containing copper are not resistant against ammonia.

Name		Boiling temperature
FC R134a	Pure substance	Ts = -26°C
FC R404a	Mixture	Ts = -47°C
FC R407a	Mixture	Ts = -39...-45°C
NH_3 R717	Pure substance	Ts = -33°C
Isobutane R600a	Pure substance	Ts = -12°C
CO_2 R744	Pure substance	Ts = -78°C



Energy flows in the refrigeration cycle
cooling capacity absorbed
compressor drive power
heat capacity discharged

Energy considerations in the log p-h diagram

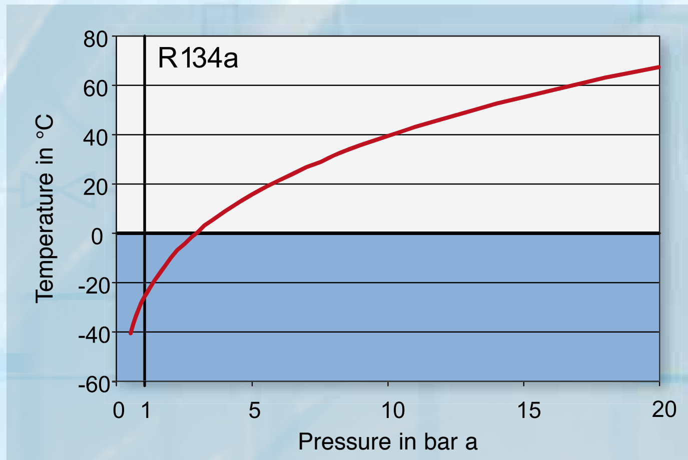
The horizontal distances of the key cycle points in the log p-h diagram correspond to the enthalpy differences. In the simple refrigeration cycle without branched off mass flows these result in the energy flows or capacities of the ideal system when multiplied with the refrigerant mass flow. The distances in the log p-h diagram are therefore a direct measure for the energy flows exchanged.

The distance 4 – 1 corresponds to the cooling capacity and is the net capacity of the refrigeration system. The distance 1 – 2 is the drive power exerted via the compressor. The distance 2 – 3 corresponds to the heat capacity discharged via the condenser. This is the waste heat of the refrigeration system.

From the ratio of the net capacity and the drive power the coefficient of performance COP can be calculated.

$$COP = \frac{h_1 - h_4}{h_2 - h_1}$$

The coefficient of performance can be compared to the efficiency in a work machine.



Steam pressure curve of FC R134a

Important for a good operation is the steam pressure curve of the operating medium. It should be gaseous at low pressures and at the desired cooling temperatures and liquid at high pressures and temperatures. The pressure levels should also be easy to manage technically.

The diagram shows the steam pressure curve of the well suited FC R134a. Typical freezing temperatures of -26°C in the evaporator can be implemented with pressures around 1bar while for condensing only a pressure of 17bar at 60°C is required.

While in pure substances, such as NH_3, propane and CO_2,, the steam pressure curve is fixed, it can be adapted in FC within wide boundaries to meet requirements by mixing different base grades.