Basic knowledge

Refrigeration cycle

The refrigeration cycle can be described by a sequence of state changes of a refrigerant. This sequence runs periodically and always achieves the initial state (cyclic process). In refrigeration, the state variables such as pressure, temperature and density are important as is the dependence of these state variables on each other.

The thermodynamic processes in the refrigeration cycle are complex. Calculation using formulae and tables requires a considerable amount of effort due to the three different states of the refrigerant from liquid, boiling and gaseous. Therefore, for reasons of simplification, the log p-h diagram was introduced.

Using a log p-h diagram, the various state variables can be represented graphically according to their dependencies. The thermodynamic state variables can be read directly at each state point and are available for further calculations. Heat quantities, technical work or pressure differences of a change of state are shown as measurable lines. Using the log p-h diagram greatly simplifies thermodynamic calculations and is essential for understanding how refrigeration plants work.

On the basis of this knowledge, our software for refrigeration equipment displays the respective log p-h diagram in real time. Changes to operating parameters can be read directly in the diagram and allow a valuable insight into the formation of the thermodynamic states, which otherwise can only be appreciated statically.

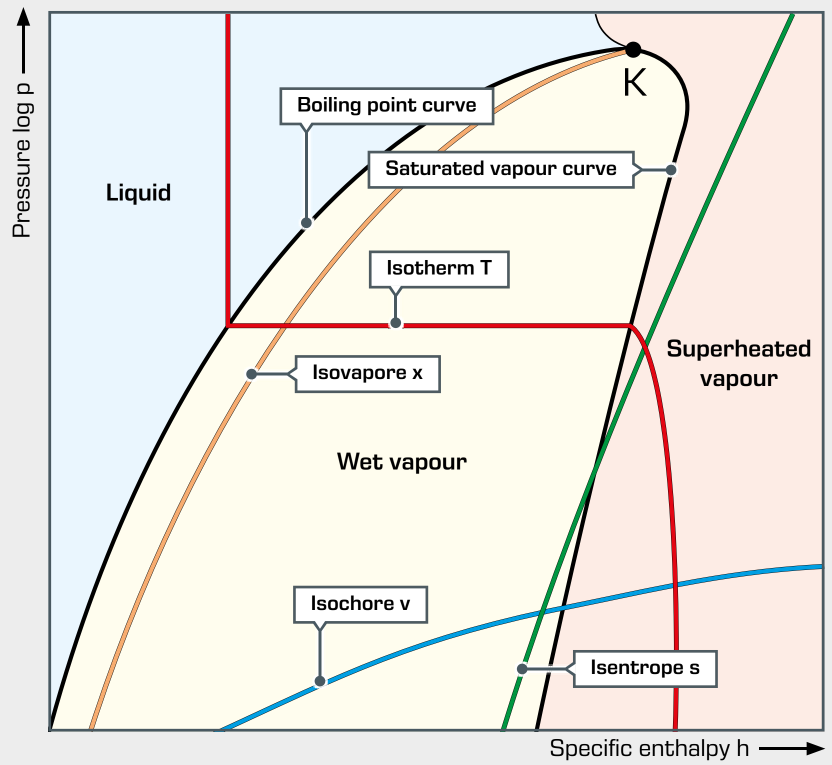
In general, a log p-h diagram shows the aggregate state of a substance, depending on pressure and heat. For refrigeration, the diagram is reduced to the relevant regions of **liquid** and **gaseous** as well as their **mixed form**.

The vertical axis shows the logarithmic pressure and the horizontal axis shows the specific enthalpy with linear scaling. Accordingly, the isobars are horizontal and the isenthalps are vertical. The logarithmic scaling makes it possible to represent processes with large pressure differences.

The saturated vapour curve and the boiling point curve meet at the critical point **K**.

The log p-h diagram shows the thermodynamic state variables in the respective phase.

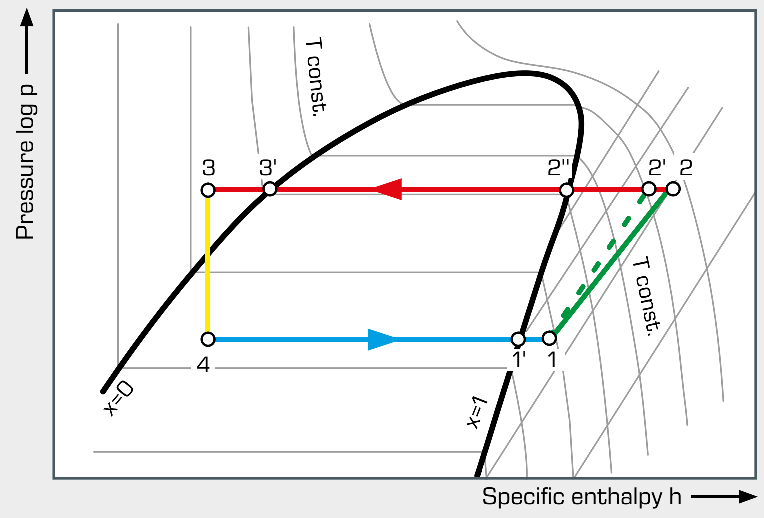
- pressure **p**
- specific enthalpy **h**
- temperature **T**
- specific volume **v**
- specific entropy **s**
- gas content **x**



The refrigeration cycle in the log p-h diagram

The distinctive feature of the refrigeration cycle is that it runs counter-clockwise, i.e. opposite to the joule or steam cycle. A change of state occurs when the refrigerant flows through one of the four main components of the refrigeration plant. The actual refrigeration cycle consists of the following changes of state:

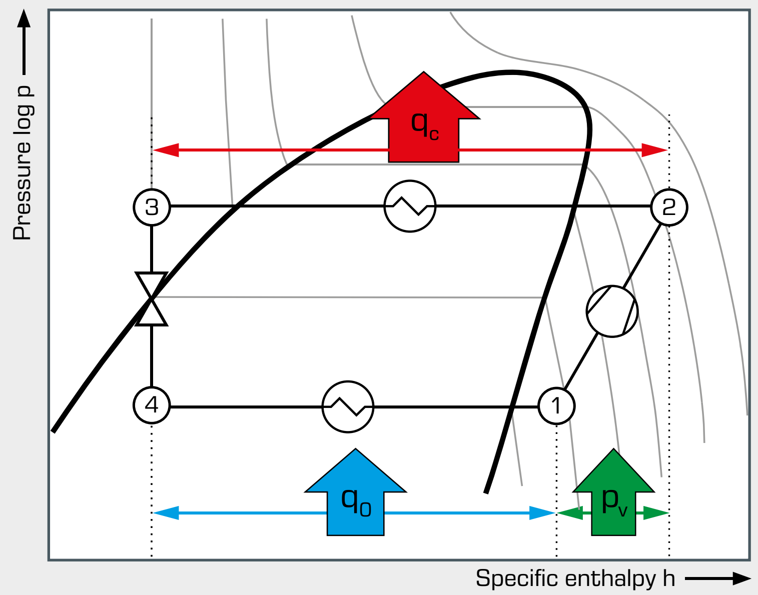
1 – 2	polytropic compression to the condensing pressure (for comparison 1 – 2' isentropic compression)
2 – 2''	isobaric cooling, deheating of the superheated vapour
2'' – 3'	isobaric condensation
3' – 3	isobaric cooling, supercooling of the liquid
3 – 4	isenthalpic expansion to the evaporation pressure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



Refrigeration cycle in the log p-h diagram

compressor, condenser, expansion valve, evaporator

In addition, pressure losses also occur in the actual refrigeration cycle, so that evaporation and condensation do not take place exactly horizontally (isobarically).



The **specific amounts of energy** that can be absorbed and released to reach the state points are marked as lines in the log p-h diagram. The specific enthalpy **h** can be read for each separate state point directly from the log p-h diagram.

If the mass flow rate of the refrigerant is known, the associated **thermal output** can be calculated by means of the specific enthalpy at the respective state point.

- the line $h_1 – h_4 = q_0$ corresponds to the cooling and results in the **refrigeration capacity** by multiplication with the the mass flow rate.
- the line $h_2 – h_1 = p_v$ corresponds to the technical work of the compressor, which is actually transferred to the refrigerant.
- the line $h_2 – h_3 = q_c$ corresponds to the emitted heat and results in the **condenser capacity** by multiplication with the the mass flow rate. It is the waste heat from a refrigeration plant.

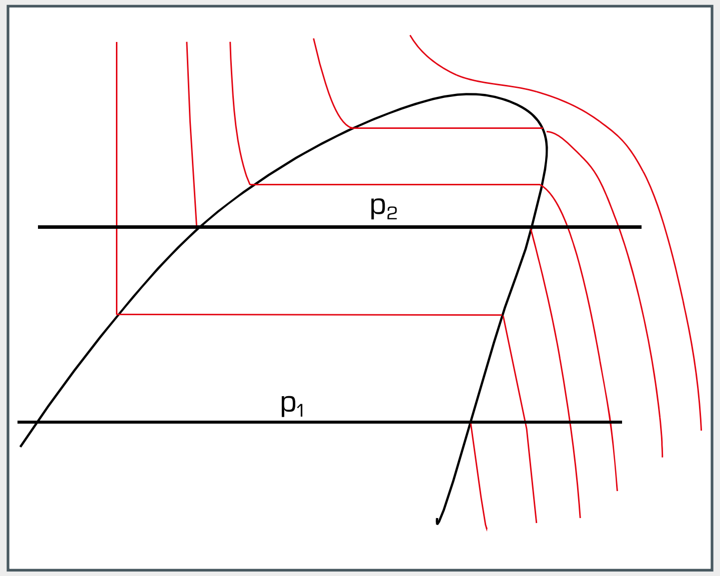
Basic knowledge

Representation of a refrigeration cycle in the log p-h diagram

This digression is designed to help you understand the functional relationship between the components of the refrigeration plant and the thermodynamic processes. The following state variables are required to display a refrigeration cycle in the log p-h diagram:

- **p_1** evaporation pressure
- **p_2** condensing pressure
- **T_1** temperature at the compressor inlet
- **T_2** temperature at the condenser inlet
- **T_3** temperature at the condenser outlet

Step 1: plot limiting isobars

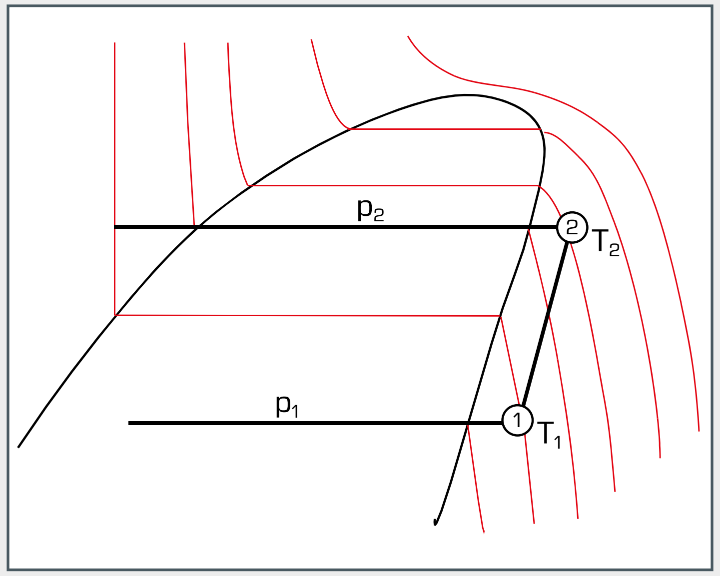


First of all the isobaric changes of state have to be plotted in the diagram.

- **p_1** evaporation pressure
- **p_2** condensing pressure

In doing so it is important that absolute pressures are plotted in the diagram.

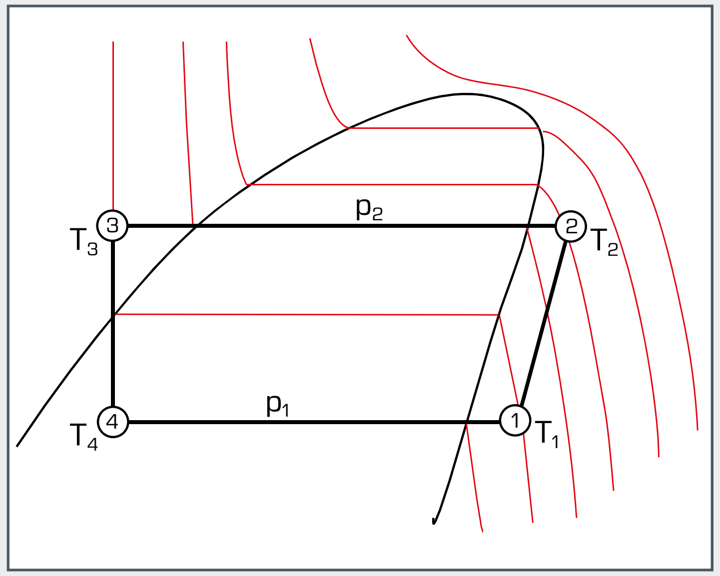
Step 2: plot compression process



After the limiting isobars have been plotted in the diagram, the compression process can now be plotted.

- identifying the point of intersection of the isobars **p_1** with the temperature at the compressor inlet **T_1** gives the state point **1**.
- identifying the point of intersection of the isobars **p_2** with the temperature at the condenser inlet **T_2** gives the state point **2**.
- the connection between the two state points **1** and **2** describes the compression process.

Step 3: plot the isenthalpic expansion

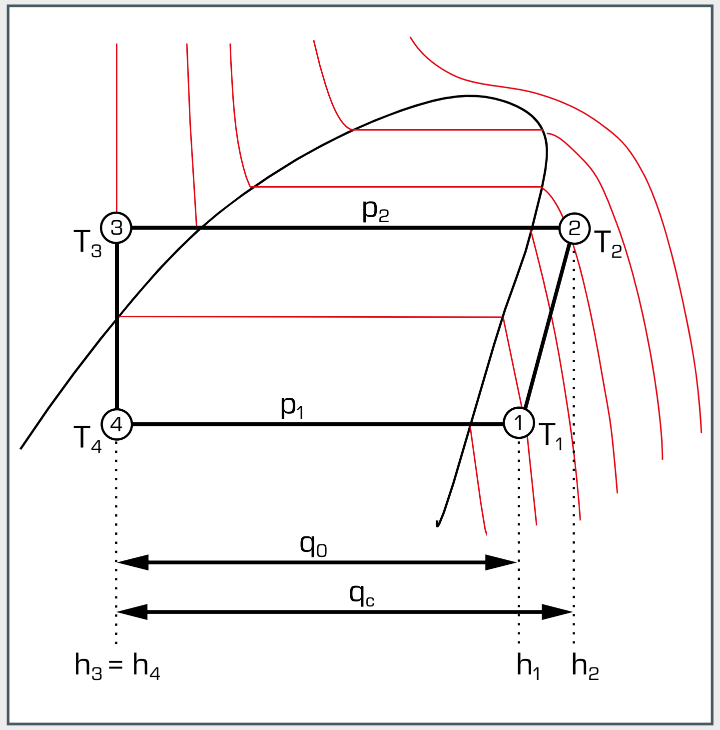


The expansion process is plotted in the diagram as follows:

- identifying the point of intersection of the isobars **p_2** with the temperature **T_3** at the condenser outlet gives the state point **3**.

The expansion is an isenthalpic process. Therefore, the previously marked intersection point can be connected to the isobars **p_1** by a vertical line.
This results in the last state point **4** with the evaporation temperature **T_4**.

Step 4: reveal the specific enthalpy values



When calculating operating states of a refrigeration plant, it is necessary to determine the specific enthalpies of the individual changes of state.
The procedure is as follows:

The specific enthalpy can be read off using a vertical connection of the state points and the x-axis.

- **h_1** spec. enthalpy after evaporator
- **h_2** spec. enthalpy after compressor
- **h_3** spec. enthalpy after condenser
- **h_4** spec. enthalpy after expansion valve

The specific refrigeration capacity **q_0** and the specific condensation capacity **q_c** can be read directly from the log p-h diagram.

specific refrigeration capacity $\mathbf{q_0 = h_1 - h_4}$

specific condensation capacity $\mathbf{q_c = h_2 - h_3}$