HEAT PUMPS

OBJECTIVE

Record and analyse the pressure-enthalpy diagram for a compression heat pump.

EXERCISES

- **Demonstrate how an electric compression heat pump works.**
- **Quantitatively investigate of the related cyclical process.**
- **Record and analyse the pressure-enthalpy diagram for a compression heat pump.**

SUMMARY

An electric compression heat pump consists of a compressor with a drive motor, a condenser, an expansion valve and an evaporator. Its functioning is based on a cyclical process with phase transition, through which the working medium in the pump passes; ideally, this process can be divided into the four steps comprising compression, liquefaction, depressurisation and evaporation. The theoretical performance coefficient of an ideal cyclical process can be calculated from the specific enthalpies h_1, h_2 and h_3 read from a Mollier diagram. Determining the enthalpies h_2 and h_3 of an ideal cyclical process and the quantity of heat ΔQ_2 supplied to the hot water reservoir per time interval Δt makes it possible to estimate the mass flow of the working medium.

REQUIRED APPARATUS

Quantity	Description	Number
1	Heat Pump D (230 V, 50/60 Hz)	**1000820 or**
	Heat Pump D (115 V, 50/60 Hz)	**1000819**
2	Temperature Sensor, Pt100 with Measurement Terminal	**1009922**
1	3B NET*log*™ (230 V, 50/60 Hz)	**1000540 or**
	3B NET*log*™ (115 V, 50/60 Hz)	**1000539**
Additionally recommended:		
1	3B NET*lab*™	**1000544**

GENERAL PRINCIPLES

An electric compression heat pump consists of a compressor with a drive motor, a condenser, an expansion valve and an evaporator. Its operation is based on a cyclical process with a phase transition, which the working medium inside the pump undergoes. Ideally, this process can be divided into four steps, comprising compression, liquefaction, depressurisation and evaporation.

For the compression part of the cycle, the gaseous working medium is drawn in by the compressor and compressed without any change in entropy ($s_1 = s_2$) from p_1 to p_2, during which process the medium heats up (see Figs. 1 and 2). The temperature accordingly rises from T_1 to T_2. The mechanical compression work performed per unit of mass is $\Delta w = h_2 - h_1$.

Inside the condenser, the working medium cools considerably and condenses. The heat released as a result (excess heat and latent heat of condensation) per unit of mass is $\Delta q_2 = h_2 - h_3$. It raises the temperature of the surrounding reservoir.

The condensed working medium reaches the release valve, where it is depressurised (without doing any mechanical work). In this process, the temperature also decreases due to the work which needs to be performed in opposition to the molecular forces of attraction inside the working medium (Joule-Thomson effect). The enthalpy remains constant ($h_4 = h_3$).

As it absorbs heat inside the evaporator, the working medium evaporates fully. This cools the surrounding reservoir. The heat absorbed per unit of mass is $\Delta q_1 = h_1 - h_4$.

A Mollier diagram of the working medium is often used to represent the cycle of a compression heat pump. This diagram plots the pressure p against the specific enthalpy h of the working medium (enthalpy is a measure of the working medium's heat content and generally rises with the pressure and gas content).

Also specified are the isotherms (T = constant) and isentropes (S = constant), as well as the relative proportion by mass of the working medium in the liquid phase. The working medium condenses fully to the left of the vaporisation phase boundary line. The medium is present as superheated steam to the right of the condensation phase boundary and as a mixture of liquid and gas between the two lines. The two lines make contact at the critical point.

To depict the system in a Mollier diagram, the ideal cycle described above can be determined by measuring the pressures p_1 und p_2 respectively before and after the expansion valve, as well as the temperatures T_1 and T_3 respectively before the compressor and expansion valve.

The components in this experiment are connected via a copper pipe to form a closed system, and mounted on a base board. Thanks to the clarity of the set-up, it is easy to associate them with the sequence of phase changes taking place in the heat pump cycle. The evaporator and condenser are designed as coiled copper tubes and they are each immersed in a separate water bath which serves as a reservoir for determining absorbed or emitted heat. Two large manometers indicate the pressures on the refrigerant in the two heat exchangers. Two analog thermometers allow you to measure temperature in the two water baths. Temperature sensors with specially designed measuring terminals are used to register the temperatures in the copper tube before the compressor and the expansion valve.

The theoretical performance coefficient for an ideal cyclical process can be calculated from the specific enthalpies h_1, h_2 and h_3 read from a Mollier diagram:

$$\eta_{\mathrm{th}} = \frac{\Delta q_2}{\Delta w} = \frac{h_2 - h_3}{h_2 - h_1} \qquad (1)$$

Determining the enthalpies h_2 and h_3 of the ideal cyclical process and the quantity of heat ΔQ_2 supplied to the hot water reservoir per time interval Δt makes it possible to estimate the mass flow of the working medium.

$$\frac{\Delta m}{\Delta t} = \frac{\Delta Q_2}{\Delta t} \cdot \frac{1}{h_2 - h_3} \qquad (2)$$

EVALUATION

T_1 and p_1 determine point 1 in the Mollier diagram. The intersection where the relevant isentrope crosses the horizontal line p_2 = constant determines point 2. The intersection with the vaporisation boundary line determines point 3, while a perpendicular to the horizontal line p_4 = constant determines point 4.

Additional measurement of the temperature T_3 provides an advanced insight into the processes taking place in the heat pump. T_3 does not coincide with the temperature reading on the related manometer's temperature scale. This temperature scale is based on the vapour pressure curve for the working medium. The measurement therefore shows that the working medium before the expansion valve does not comprise a mixture of liquid and gas, but is entirely liquid.

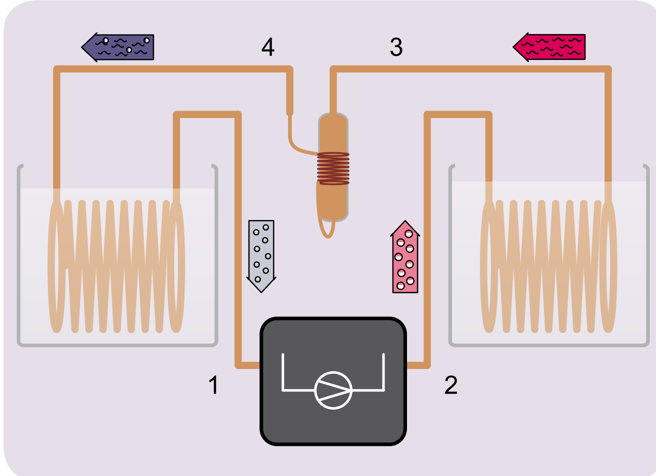

Fig. 1 Schematic representation of the heat pump with a compressor (1, 2), condenser (2, 3), expansion valve (3, 4) and evaporator (4, 1)

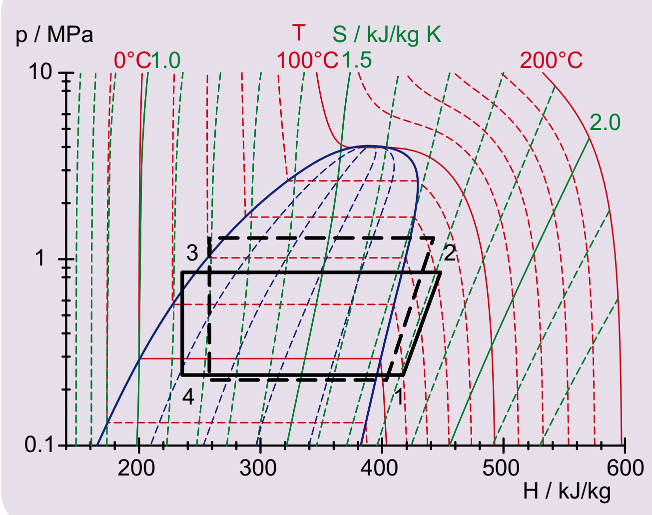

Fig. 2 Representation of ideal cyclical process for heat pump in a Mollier diagram.