Heat pump.

In this laboratory exercise, you will study the performance of a commercial heat pump Leybold 389521.
The goal of the exercise

As a function of the increasing cost of energy, alternative methods of heating are being developed constantly. The heat pump technology plays a crucial part in many of these methods. In this laboratory exercise you will study the properties and performance of a small heat pump system, which illustrates a number of thermodynamic processes. You will determine the energy flows and the overall efficiency of this system.

Preparatory questions

Formulate the second law of thermodynamics
What is the relation between volume, pressure and temperature in a system where both vapor and fluid are present?
Define entropy and enthalpy.

Introduction

Heat transport with thermodynamic processes is widely used nowadays, for instance in heat pumps, refrigerators and air conditioners. The previously used ozone layer damaging freons are now being replaced by other coolants, like tetrafluoroethane (CH₂FCF₃), with the commercial name R134a. Since this freon does not contain chlorine nor bromine, it will not damage the ozone layer at all.
The Leybold 389521 heat pump

Fig. 1

Coolant: R134a (CFC-free)

1. Compressor 230 V; 50/60 Hz.
   Power consumption approx. 130 W at 50 Hz.
2. Hinged support for water vessel with red mark
3. Liquefier, internal diameter approx. 13 cm
4. Collector/purifier
5. Expansion valve, thermostatically controlled
6. Temperature sensor for expansion valve, thermally insulated
7. Vaporizer, internal diameter approx. 13 cm
8. Hinged support for water vessel with blue mark
9. Spiral tubing as elastic connection between compressor and heat exchanger
10. Pressure switch
11. Plastic holders (2x) for thermometer and temperature sensor for clamping to copper tubing, each consisting of two-sided clamp and copper tube.
12. Copper measuring lug (2x) with terminal screws and holes 2 mm dia. for inserting temperature sensors for temperature measurements at the copper tubes of the coolant circuit.
13. Manometer for the low-pressure side; inner scale for pressure measurement from -1...+10 bar, outer scale with corresponding dew-point temperature of R134a from -60 °C to +40 °C.
14. Manometer for high-pressure side; inner scale for pressure measurement from -1...+30 bar, outer scale with corresponding dew-point temperature of R134a from -60 °C to +65°C.

Note:
The two middle temperature scales of 13 and 14 apply for other coolants, and are thus irrelevant for this heat pump.
The components and the function of the heat pump

A heat pump withdraws heat from a reservoir with the temperature $T_1$ and transports it to a reservoir with the temperature $T_2$.

As a result, the temperature difference $(T_1 - T_2)$ between the two reservoirs increases. The heat is transported by the coolant R134a, which absorbs heat through evaporation and releases it when it condenses.

The heat reservoirs are vessels filled with water, in which the two "heat exchangers" 3 and 7 are immersed.

The gaseous coolant is compressed in the compressor 1, which heats it significantly. It is cooled in the spiral of copper tubing 3 of the liquefier and condenses, in the process transferring its heat of condensation to the water in the vessel.

The liquefied coolant still contains bubbles of gas, so it is filtered in the "purifier" 4. This simultaneously functions as a "collector": it accumulates a level of liquid which ensures that the expansion valve 5 always receives a bubble-free liquid supply.

The expansion valve is the counterpart of the compressor: it regulates the supply of coolant to the vaporizer 7, where the coolant expands and evaporates. In the process it cools down rapidly, and thus withdraws heat from the cold-water vessel. The coolant, once more in the gaseous state, is drawn into the compressor, and the cycle begins anew. The expansion valve 5 protects the compressor from "liquid shocks", i.e. suction of liquid coolant, which would otherwise destroy the compressor. The supply of coolant to the vaporizer is regulated by a temperature sensor 6 (thus the more precise designation "thermostatic expansion valve").

The temperature difference between the inlet and outlet tubes of the vaporizer serves as the controlled variable. If this value drops below a fixed value set at the expansion valve - e.g. because the supply of heat to the vaporizer is too low - the supply of coolant is reduced.

The pressure switch 10 shuts down the compressor when the pressure on the liquefier side exceeds 16 bar (setting on the left-hand scale). This can occur when the liquefier 3 is operated without a water reservoir and thus becomes too warm ($T_2 > 60$ °C). The compressor does not switch back on until the pressure drops below the shutoff pressure by the value set on the right side of the scale (9 bar).

The spiral tubing sections 9 at the compressor inlet and outlet prevent the vibrations of the compressor from being transmitted to the entire apparatus.
Figure 3 shows the different processes involved in the thermodynamic cycle of the heat pump, including the $TS$ and $ph$ diagrams.
Measurements

After the heat pump has been in function for about 10 minutes, and the pressures and temperatures appear to have stabilized, you can start measuring. You can measure either energy or power. When the power is constant, the measurements become simple. In order to obtain the released heat, you need to measure the temperature rise of a known amount of water on the condensor (liquefier) side. The measurement of the absorbed heat on the vaporizer side is carried out analogously. The temperatures $T_1$ and $T_2$ in the heat pump are measured using thermoelements on both sides of the expansion valve (points 3 and 4 of the scheme in Fig. 3). The temperature in point 2 immediately after compression is also measured, as well as the pressures. You will need all these data in order to draw the process in a Mollier-diagram. Observe that in the Mollier $ph$-diagram, the absolute pressures are used.

The coefficient of performance

The coefficient of performance $\varepsilon_v$ for the heating of water is defined as

$$\varepsilon_v = \frac{Q_1}{W}$$

where $Q_1$ is the released heat.

The coefficient of performance $\varepsilon$ of the heat pump can be written as

$$\varepsilon = \frac{Q_2 + W}{W}$$

where $\varepsilon$ is the coefficient of performance, $Q_2$ is the supplied heat and $W$ is the supplied work. If there were no energy losses, $\varepsilon_v$ and $\varepsilon$ would be equal.
The coefficient of performance $\varepsilon_C$ of the Carnot-process is defined as

\[ \varepsilon_C = \frac{T_1}{T_1 - T_2}, \]

where $\varepsilon_C$ is the coefficient of performance of the Carnot-process, $T_1$ is the condensation temperature and $T_2$ is the vaporization temperature.

The efficiency of the heat pump is obtained through division of $\varepsilon$ by $\varepsilon_C$, while the efficiency of water heating is obtained correspondingly through division of $\varepsilon_v$ by $\varepsilon_C$.

**The Mollier-diagram**

In the Mollier-diagram on the last page of the instruction you will draw a curve, corresponding to the data you have obtained during the lab exercise. The diagram shows the pressure as a function of the enthalpy. In the diagram, there are also curves for constant temperature (isotherms), constant volume (isochors) and constant entropy (isentropes).

Start by looking for the pressure and temperature, corresponding to the measurements after the compressor. Then, go to the left in the diagram until you reach the phase border between liquid and mixed phase. The pressure should coincide with the measured pressure in the condensor (liquefier). Continue thereafter vertically downwards (the enthalpy is constant during expansion) until you reach the pressure in the vaporizer. Thereafter, go to the right to the pressure and temperature of the gas before the compressor.
Report

In the report, give a short description of the heat pump.
Write a table of measured temperatures, energies and pressures.
Calculate the coefficients of performance of the heat pump.
Calculate the Carnot coefficient of performance.
Calculate the two efficiencies of the heat pump.
Estimate the accuracy of your results.
Draw the process in the Mollier-diagram.
Control questions

Five of the following questions will be given in the beginning of the lab exercise. In order to perform the exercise, correct answers must be given to at least three of these, in addition to the preparatory questions.

1. Describe the difference between a heat pump and a refrigerator.
2. Describe the Carnot-process. Draw a diagram.
3. Give the coefficient of performance of the Carnot process.
5. Describe what happens in the vaporizer.
6. What is happening in the expansion valve?
7. How do you calculate the heat supplied to the water by the heat pump?
8. How is the heat supplied to the heat pump calculated?
9. How is the work supplied to the process calculated?
10. How is the heat supplied to the heat pump?
11. How are the temperatures measured? Two answers must be given.
12. How are the pressures measured?
13. How is the coefficient of performance $\varepsilon$ calculated?
14. How is the enthalpy defined?
15. How is the temperature in the condensor (liquefier) measured?
16. How can you obtain the efficiency of the process? Give two methods.
17. What are the quantities and dimensions on the axes of the Mollier-diagram?