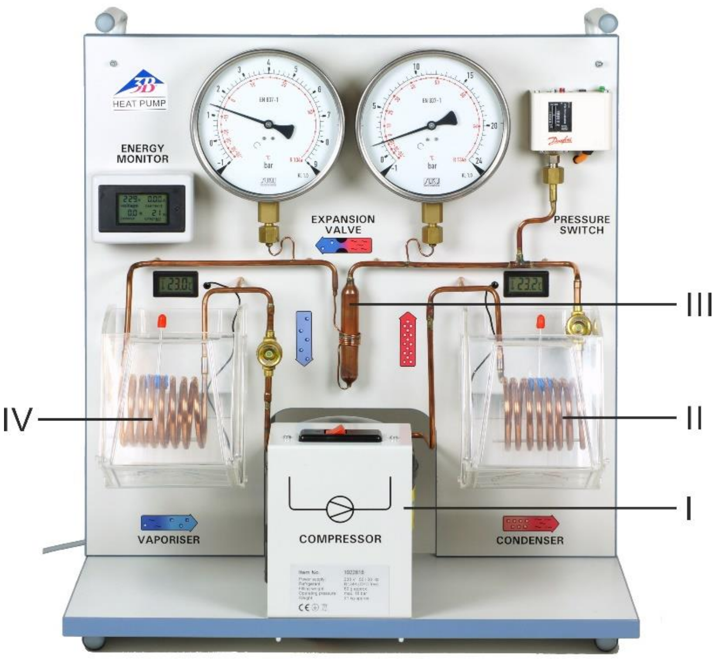
3B SCIENTIFIC® PHYSICS

Heat Pump D

230 V, 50/60 Hz   1022618
115 V, 50/60 Hz   1022619

Instruction sheet

03/20 JS/ALF/GH



I   Compressor
II   Condenser
III   Expansion valve
IV   Evaporator

1. Description

The Heat Pump D is a demonstration model for showing how refrigerators and electrical compression heat pumps work.

The components compressor, condenser, expansion valve and evaporator are mounted on a baseplate and are connected in a closed system by copper pipes. The clear layout makes it possible to directly relate the sequence of changes of state to the cyclic operation of the heat pump. Evaporator and condenser are constructed as copper tubing spirals and each of them is submerged in water filled containers serving as heat reservoirs for determining the heat absorbed or emitted. Two digital thermometers allow the necessary temperature measurements to be made in both water reservoirs.

Two observation windows are provided for observing the state of aggregation of the refrigerant after the evaporator and after the condenser. Two large manometers indicate the pressure before and after the safety valve. The mains connector incorporates a digital energy meter for determining the period of operation, the mains voltage, the current power consumption and the amount of electrical work done. A protective overpressure switch disconnects the compressor motor from the circuit when overpressure reaches 15 bars.

The heat pump D is available for two different mains voltages:

1022618	230V (±10 %), 50 Hz
1022619	115V (±10 %), 60 Hz .

2. Safety instructions

The Heat Pump D conforms to all safety regulations for electrical measuring, control, monitoring and laboratory equipment, as specified under DIN EN 61010, Section 1, and the equipment has been designed to meet protection class I. It is intended for operation in a dry environment, suitable for the operation of electrical equipment and systems.

Safe operation of the equipment is guaranteed, provided it is used correctly. However, there is no guarantee of safety if the equipment is used in an improper or careless manner.

If it may be assumed for any reason that non-hazardous operation will not be possible (e.g. visible damage), the equipment should be switched off immediately and secured against any unintended use.

In schools and other educational institutions, the operation of the power supply unit must be supervised by qualified personnel.

- Before using the heat pump for the first time, confirm that the specifications printed on the label are compatible with the local mains voltage.
- Before using the heat pump, check the device and the mains lead for any damage. In the event of any visible damage, switch off the unit immediately and secure it against unintended use.
- The device may only be connected to the mains via a socket that has an earth connection.

Risk of overheating: the heat pump's compressor can get very hot during operation.

- Do not hinder the free circulation of air around the compressor.
- Do not thermally insulate the compressor.
- After shut-down by the overpressure cut-out switch wait for 10 minutes to press the green reset button.

The fluid upon which the heat pump acts (the refrigerant) remains under pressure even if the compressor is switched off.

- Carry the heat pump only at the carrying handles.
- Do not, under any circumstances, bend or damage the copper piping.

The refrigerant in its liquid phase must not get into the compressor. This would overload the compressor. It is imperative that no lubricant from the compressor enter into the cooling circuit.

- Always keep the heat pump in an upright position during storage, transport and operation.
- Make sure you let the equipment stand upright for at least 7 h before initial use if it was tipped over.
- Post heat pump in original box only standing upright on its one-way pallet.

3. Components

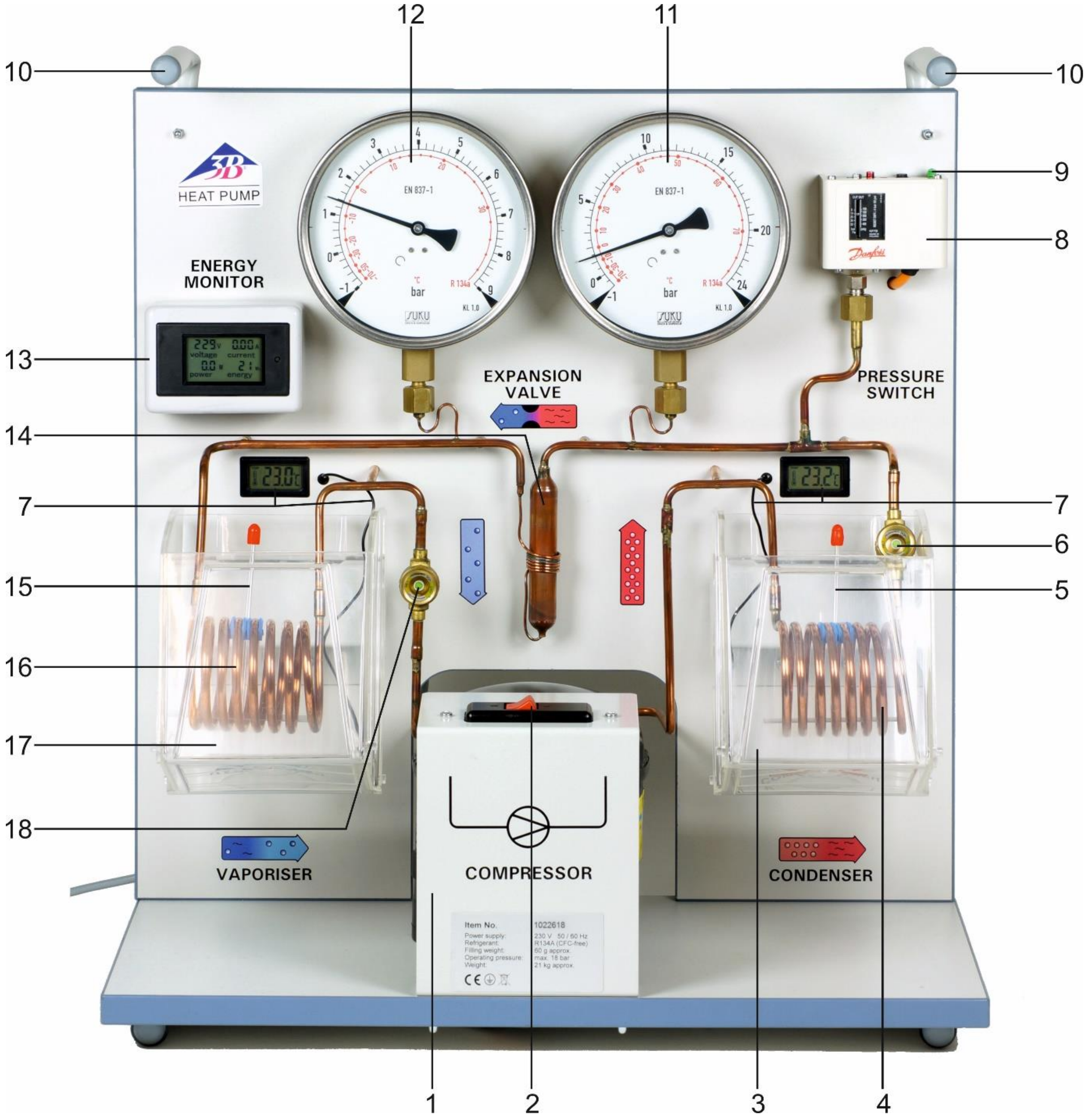


Fig. 1 Components of the heat pump

1 Compressor
2 On/off switch for compressor
3 Water reservoir around condenser
4 Condenser coil
5 Stirrer for condenser
6 Viewing window in condenser
7 Digital thermometer with temperature sensor
8 Overpressure cut-out switch
9 Reset switch
10 Carrying handles
11 Manometer for the high-pressure side
12 Manometer for the low-pressure side
13 Energy monitor
14 Expansion valve
15 Stirrer for evaporator
16 Evaporator coil
17 Water reservoir around evaporator
18 Viewing window in evaporator
Mains connection (on the backside)

4. Accessories

A temperature NTC sensor with measurement terminal (1021797) is ideal for measuring the temperature at various places along the copper piping, since it can be clamped directly to the copper and provides good thermal conduction between the pipe and the sensor. It can be used in conjunction with the “VinciLab” datalogger (1021477).

5. Technical data

Compressor power:	120 W, dependent on operating state
Refrigerant:	R 134A (tetrafluorethane $C_2H_2F_4$)
Boiling point:	-26°C at 1 bar
Water reservoirs:	2000 ml each
Manometer:	160 mm diam., up to 9 bars (low-pressure side, suction intake), up to 24 bars (high-pressure side, pressure pipe)
Excess pressure cut-off:	disconnects compressor from the mains at 15 bars
Thermometer:	
Measurable temperatures:	-20°C to 110°C
Resolution:	0.1°C
Accuracy:	±1°C
Measurement intervals:	10 s approx.
Powered by two LR44 button batteries	
Power supply:	115 V, 60 Hz or 230 V, 50 Hz
Dimensions:	750 x 350 x 540 mm³
Weight:	approx. 21 kg

6. Operation

6.1 Filling the water containers

- Fill up the water containers with water and move them with the low edge first under the evaporator and the condenser.
- Turn the beakers in such a way that the high edge points to the back wall.
- Lift up the beakers and mount them into the retaining plates.

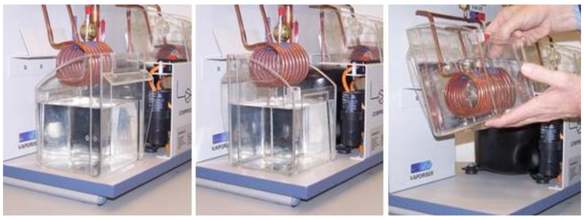


Fig. 3 Connection of the water reservoirs to the heat pump
Left: reservoir with its lower edge facing the pump
Centre: reservoir turned with its lower edge facing the front
Right: reservoir suspended in holding plate

6.2 Configuration

- Follow the safety instructions under point 2
- Allow the heat pump to stand upright for at least 7 h before using it if it was tipped over.
- To start the pump, fill the two water reservoirs and connect the pump to the mains.
- Turn on the compressor.

Note: the energy meter works even when the compressor is switched off.

7. Heat pump cycle

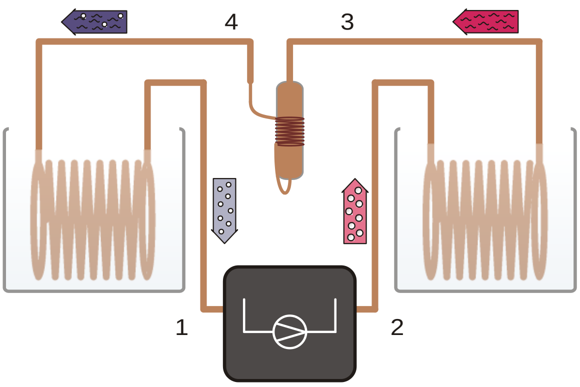


Fig. 4 Schematic diagram of the heat pump with compressor (1→2), condenser (2→3), expansion valve (3→4) and evaporator (4→1)

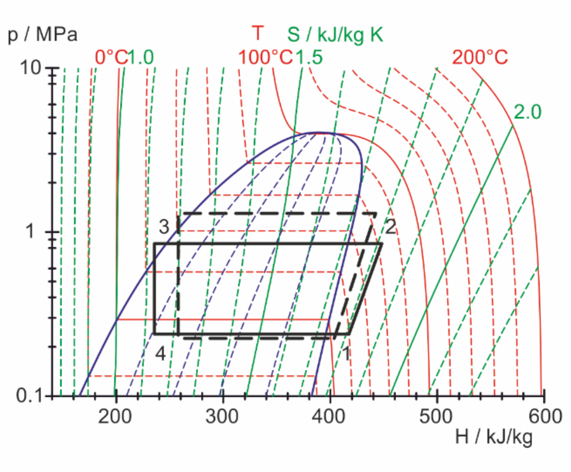


Fig. 5 Mollier diagram of ideal heat cycle (see section 8.2)

The idealised version of the heat pump cycle involves four steps: compression (1→2), liquefaction (2→3), controlled expansion (3→4) and vaporisation (4→1):

Compression:

The gaseous refrigerant is sucked in by the compressor without changing the entropy ($s_1 = s_2$). It is then compressed from pressure p_1 to p_2 which causes excess heat to be generated. The temperature rises from T_1 to T_2. The mechanical work done per unit mass is $\Delta w = h_2 - h_1$.

Liquefaction:

The fluid cools sharply inside the condenser causing it to liquefy. The heat emitted by this process (latent heat) heats up the surrounding reservoir to temperature T_2. The change in heat per unit mass is $\Delta q_2 = h_2 - h_3$.

Controlled expansion:

The condensed refrigerant reaches the expansion valve where it is allowed to expand to a lower pressure without any mechanical work being done. This results in a drop in temperature since work needs to be done against the force of attraction between refrigerant molecules (Joule-Thomson effect). Enthalpy remains constant ($h_4 = h_3$).

Vaporisation:

In the evaporator, the refrigerant absorbs heat and vaporises completely. This causes the surrounding reservoir to cool to a temperature T_1. The heat absorbed per unit mass is $\Delta q_1 = h_1 - h_4$.

The vaporised refrigerant is sucked back in again by the compressor to start the compression process anew.

Note:

The expanded refrigerant evaporates and withdraws heat from the left reservoir.

Under ideal conditions, the pipe system carries pure gaseous refrigerant from the evaporator via the sight glass to the compressor.

As the water temperature decreases, the heat absorption via the evaporator coil decreases. Therefore as a result drops of refrigerant can become visible in the left sight glass.

This has practically no influence on the function of the heat pump, but should be reduced to a minimum by constantly stirring the water.

For the determination of the coefficient of performance, a limited temperature window should be used:

Start temperature approx. 20°C to 25°C, termination temperature in the left reservoir approx. 10°C to 12°C.

8. Example experiments

8.1 Efficiency of the compressor

The efficiency of the compressor η_{co} is given by the ratio of the change in energy ΔQ_2 provided to the warm water reservoir per time interval Δt, to the power P supplied to the compressor to perform its work. It decreases as the temperature difference between the condenser and the evaporator increases.

$$\eta_{co} = \frac{\Delta Q_2}{P \cdot \Delta t} = \frac{c \cdot m \cdot \Delta T_2}{P \cdot \Delta t}$$

c = specific heat capacity of water and
m = mass of water.

Determining the efficiency:

- Connect the heat pump to the mains supply.
- Fill up the water containers with 2000 ml water and mount them into the retaining plates (see point 6.1). For the following measurement, keep at least 4 l of water at 20°C ready.
- Allow the compressor to run for about 10 minutes before starting the experiment until it reaches its operating temperature (the compressor should not heat up during the measurement).
- Empty the water container and fill it with water at a temperature of 20°C. Reset the energy meter (point 9)
- Switch on compressor and start timing (stop watch, smartphone, etc.).
- Stir the water in the containers thoroughly throughout the experiment.

- At equal time intervals, note the operating time, power consumption and water temperatures.
- Abort the measurement, at approx. 10°C in the left reservoir

From the measured values, an overall efficiency can be calculated for the course of the experiment and a partial efficiency for each time interval.

$$\eta_{co} = \frac{\Delta Q_2}{P \cdot \Delta t} = \frac{c \cdot m \cdot \Delta T_2}{P \cdot \Delta t}$$

c = specific heat capacity of water and
m = mass of water

8.2 Mollier diagram

An ideal cycle can be represented by a Mollier diagram by measuring pressures $p(3)$ and $p(4)$ before and after the expansion valve and the temperature $T(1)$ before the compressor:

$T(1)$ and $p(4)$ determine point 1 of the Mollier diagram (see Fig. 5). The intersection of the corresponding isentropes with the horizontal line $p(3)$ = constant defines point 2. The intersection of the horizontal with the line representing the boiling point gives point 3, then a perpendicular down to the horizontal $p(4)$ = const. provides point 4.

Additionally, measuring temperatures $T(2)$, $T(3)$ and $T(4)$ provides an extra insight into the processes taking place inside the heat pump:

The temperature $T(4)$ measured externally is in agreement with the overall temperature read from the temperature scales of the corresponding manometer to within the precision of the equipment. This temperature scale is based on the curve representing work done by the refrigerant. The measurement therefore shows that the refrigerant beyond the expansion valve is in a mixture of liquid and gaseous states.

The externally measured temperature $T(3)$, however, differs from the temperature read from the manometer on the high-pressure side. The refrigerant at this point contains no gas content. It is entirely liquid.

The following equipment is recommended for taking external measurements (see section 4. accessories):

Temperature sensor NTC with measurement terminal	1021797
VinciLab	1021477
Coach 7 License	

8.3 Theoretical efficiency

The theoretical efficiency of the ideal cycle can be calculated from specific enthalpies h_1, h_2 and h_3, which can be read directly from the Mollier diagram:

$$\eta_{th} = \frac{\Delta q_2}{\Delta w} = \frac{h_2 - h_3}{h_2 - h_1}$$

8.4 Mass flow rate of refrigerant

Once the enthalpies h_2 and h_3 for the ideal cycle are known as well as the amount of heat ΔQ_2 supplied to the water reservoir in a time interval Δt, then it is possible to estimate the mass flow rate of the refrigerant.

$$\frac{\Delta m}{\Delta t} = \frac{\Delta Q_2}{\Delta t} \cdot \frac{1}{h_2 - h_3}$$

9. Energy monitor

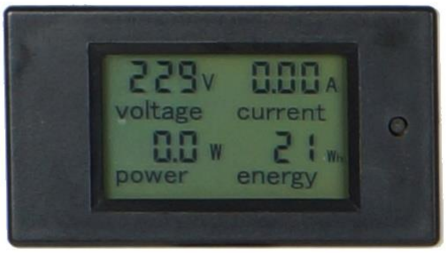


Fig. 6 Energy monitor

The following values can be read on the display of the energy meter:

Electrical voltage	Unit: Volt
Electrical current	Unit: Ampere
Electrical power	Unit: Watt
Electrical energy	Unit: watt-hour

To reset the electrical energy to zero, press the small button to the right of the display with a pointed object as follows:

- Hold it for about 4 seconds until the electrical energy value flashes, then press it again briefly.

The display can be tilted to make it easier to read.

10. Mollier diagram

Mollier diagrams for a refrigerant are often use to demonstrate the operating cycle for a compression heat pump. They plot the pressure p against the specific enthalpy h for the refrigerant (enthalpy is a measure of heat content in the refrigerant and always increases with increasing pressure and gas content).

In addition the isotherms (T = const.) and isentropes (S = const) are given as well as the relative mass content of the liquid phase. Left of the so-called boiling line, the refrigerant is fully liquefied. To the right of the so-called saturated vapour line, the refrigerant will exist as overheated vapour. Between the lines the refrigerant will be in a mixture of liquid and gas states. Both lines intersect at the critical point.

See Fig.7 on page 8.

11. Changing the battery

- Remove the cover at the rear of the thermometer and take out the flat batteries.
- Insert new batteries, making sure that their polarity is correct.
- Close the cover again afterwards.
- During prolonged periods of disuse, remove the batteries.
- Do not dispose of the batteries in the regular household garbage. Follow the applicable legal regulations (UK: Waste Batteries and Accumulators Regulations, EU: 2006/66/EC).

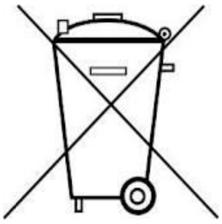
12. Storage, care and maintenance

The heat pump is maintenance-free.

- Keep the heat pump in a clean, dry and dust-free place.
- Before cleaning the equipment, disconnect it from its power supply.
- Use a soft, damp cloth to clean it.

13. Disposal

- For any necessary repairs, returns etc., the heat pump needs to be packaged in its original box standing upright on its one-way pallet. For this reason you should not dispose of the original box or pallet.
- Should you need to dispose of the heat pump itself, never throw it away in normal domestic waste. Local regulations for the disposal of electrical equipment will apply.



- Do not dispose of the batteries in the regular household garbage. Follow the applicable legal regulations (UK: Waste Batteries and Accumulators Regulations, EU: 2006/66/EC).

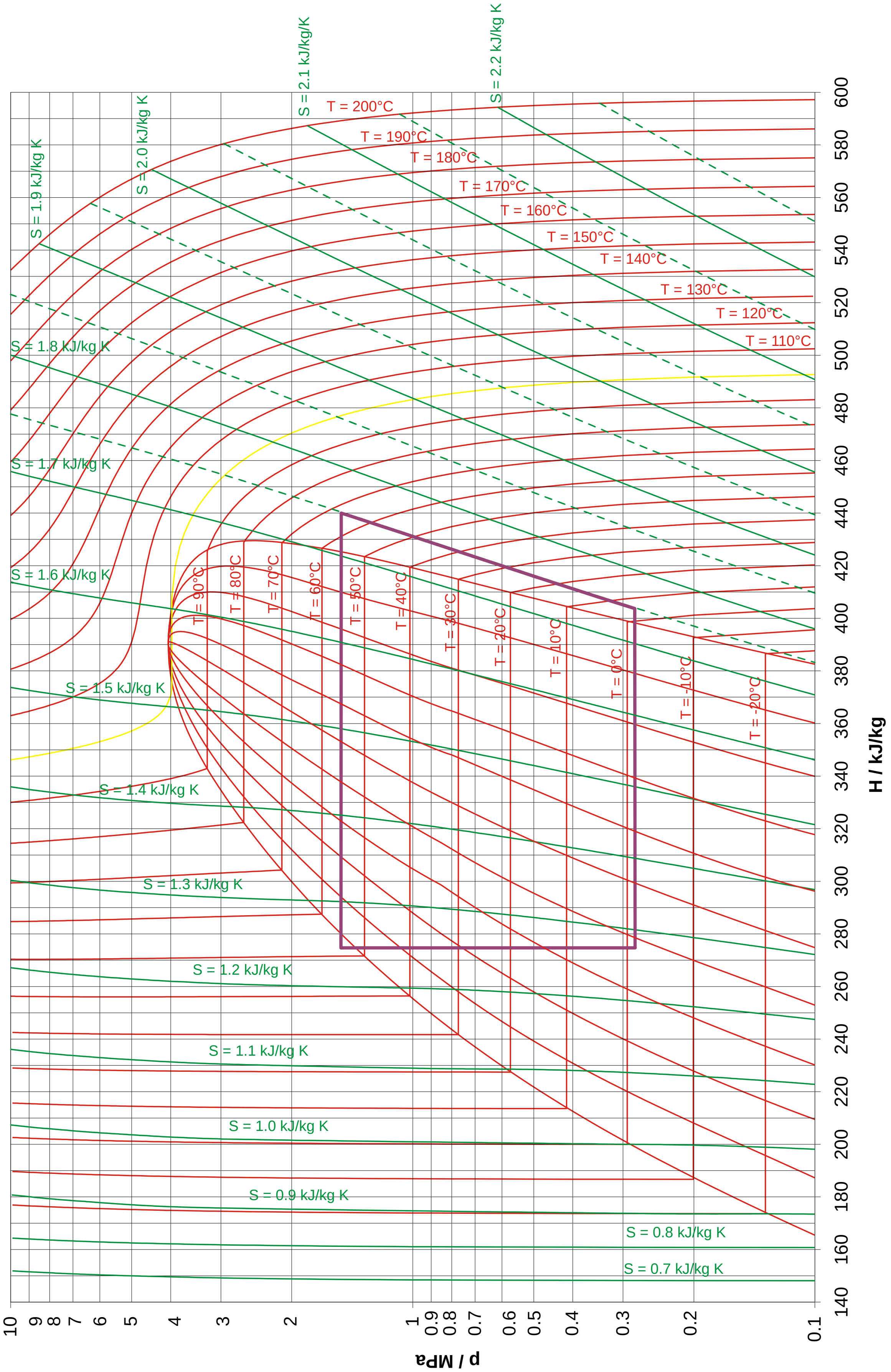


Fig. 7 Mollier diagram