Related topics

Refrigerator, compressor, restrictor valve, cycle, vaporisation, condensation, vapour pressure, vaporisation enthalpy.

Principle and task

Pressures and temperatures in the circulation of the electrical compression heat pump are measured as a function of time when it is operated as a water-water heat pump.

The energy taken up and released is calculated from the heating and cooling of the two water baths.

When it is operated as an air-water heat pump, the coefficient of performance at different vaporiser temperatures is determined.

Equipment

Heat pump, compressor principle	04370.88	1
Lab thermometer, -10…+100C	38056.00	4
Lab thermometer, w. stem, -10…+110C	38060.00	2
Heat conductive paste, 50 g	03747.00	1
Hot-/Cold air blower, 1000 W	47540.93	1
Stopwatch, digital, 1/100 sec.	03071.01	1
Tripod base -PASS-	02002.55	1
Support rod -PASS-, square, l 250 mm	02025.55	1
Universal clamp with joint	37716.00	1
Glass beaker, tall, 2000 ml	36010.00	1
Glass rod, boro 3.3, l = 300 mm, d = 7 mm	40485.05	2

Option

Work and power meter	13715.93	1

Problems

1. Water heat pump:
   To measure pressure and temperature in the circuit and in the water reservoirs on the condenser side and the vaporiser side alternately. To calculate energy taken up and released, also the volume concentration in the circuit and the volumetric efficiency of the compressor.

2. Air-water heat pump:
   To measure vaporiser temperature and water bath temperature on the condenser side under different operating conditions on the vaporiser side,
   2.1 with stream of cold air
   2.2 with stream of hot air
   2.3 without blower.

   If a power meter is available, the electric power consumed by the compressor can be determined with it and the coefficient of performance calculated.

Fig. 1a: Experimental set-up for thermal conductivity.

Set-up and procedure

1. Water-water heat pump:
   Pour a measured quantity of water into both water reservoirs so that the heat exchanger is completely immersed. Care is to be taken to ensure that the water on the condenser side is not colder than that on the vaporiser side. Measure all pressures and temperatures before switching on the heat pump:

   Condenser side:
   p_1 = Pressure
   Θ_1 = Water temperature
   Θ_{C_i} = Temperature at the condenser inlet
   Θ_{C_o} = Temperature at the condenser outlet

   Vaporiser side:
   p_2 = Pressure
   Θ_2 = Water temperature
   Θ_{V_i} = Temperature at the vaporiser inlet
   Θ_{V_o} = Temperature at the vaporiser outlet

   Switch on heat pump and stop-clock and measure pressure and temperatures on condenser and vaporiser side alternately (e.g. every minute). Cease measurements after approx. 30 min.

2. Air-water heat pump:
   Remove water reservoir on the vaporiser side, carefully dry heat exchanger coils. Make three series of measurements with air-water heat pump. At the start of each series of measurements the water temperature is approx. 20°C, the volume of water is measured out (mark water level, drain off warm water and refill with cold water up to the mark). Set up a hot air blower approx. 30 cm away from the vaporiser coil and blow a stream of cold air on to the vaporiser. Switch on the heat pump and measure the temperature at the outlet of the vaporiser Θ_{V_o} and the water temperature Θ_1 as a function of time. Duration of a series of measurements approx. 20 min, until $\Theta_1 > 30°C$ and $\Theta_{V_o} \approx$ const.

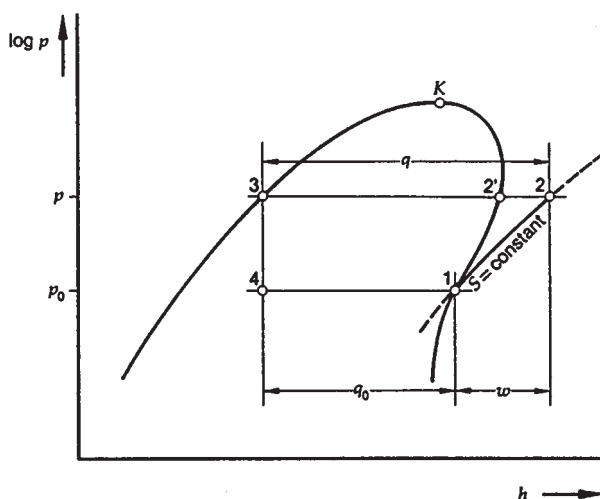   Repeat series of measurements with stream of hot air and then without stream of air.

Fig. 2: h, log p diagram of a heat pump, ideal curve.

Theory and evaluation

The Mollier (h, log p) diagram, in which p is the pressure and h the specific enthalpy of the working substance, is used to describe the cyclic process in heat technology. Fig. 2 shows an idealised representation of the heat pump circuit.

The cuve running through the critical point K delineates the wet vapour zone in which the liquid phase and gas phase co-exist. In this zone the isotherms run parallel to the h axis. Starting from point 1, the compressor compresses the working substance up to point 2; in the ideal case this action proceeds without an exchange of heat with the environment, i.e. isentropically (S = const.). On the way from point 3 useful heat is released and the working substance condenses. Then the working substance flows through the restrictor valve and reaches point 4. In an ideal restricting action the enthalpy remains constant. As it passes from point 4 to point 1, the working substance takes up energy from the environment and vaporises. The specific amounts of energy q_0 and q taken up and released per kg and the specific compressor work w required can be read off directly as line segments on the graph.

$$q_0 = h_1 - h_3$$
$$q = h_2 - h_3$$
$$w = h_2 - h_1$$

For evaluation purposes the data for the working substance R 134a in the wet vapour zone are set out in Table 1.

1. Water-water heat pump
   Fig. 3 shows the curve of the temperatures against time in the case of operation as a water-water heat pump. The temperature of the working substance does not change during vaporisation or during condensation. Superheating of the vapour occurs before the condenser (see Fig. 2; point 2 lies outside the wet vapour area). On the vaporiser side the restrictor valve thermostat ensures that the vapour is superheated so that liquid working substance does not enter the compressor. Point 1 (Fig. 2) therefore also lies outside the wet vapour zone in the actual heat pumping process.

   In Fig. 4 some of the measured pairs of pressure and temperature values are plotted and compared with the values from Table 1. It is to be borne in mind here that the pressure gauges in the circuit indicate pressure in excess of atmospheric pressure. It can be seen from the graph that supercooling of the liquid working substance also occurs in the actual heat pumping process, i.e. point 3 (Fig. 2) also lies outside the wet vapour zone.

The vaporisation and condensation of the working substance may be observed through the sight glasses of the heat pump. As the restrictor valve controlled by a thermostat lets through varying quantities of working substance, the scene is not always univorm. The energy flow Q on the condenser and vaporiser side is calcualed from the heating and cooling of the water bath.

$$\dot{Q} = c \cdot m_w \cdot \frac{\Delta \Theta}{\Delta t} \tag{1}$$

c = Specific heat capacity of water

m_w = Mass of the water

$\dfrac{\Delta \Theta}{\Delta t}$ = Temperature change per unit time

Fig. 3. Temperatures at the inlet and outlet of the vaporiser Θ_{V_i} (●), Θ_{V_o} (○) and condenser Θ_{C_i} (●), Θ_{C_o} (○) as a function of the operating time; continuous curves: temperature in water reservoirs.
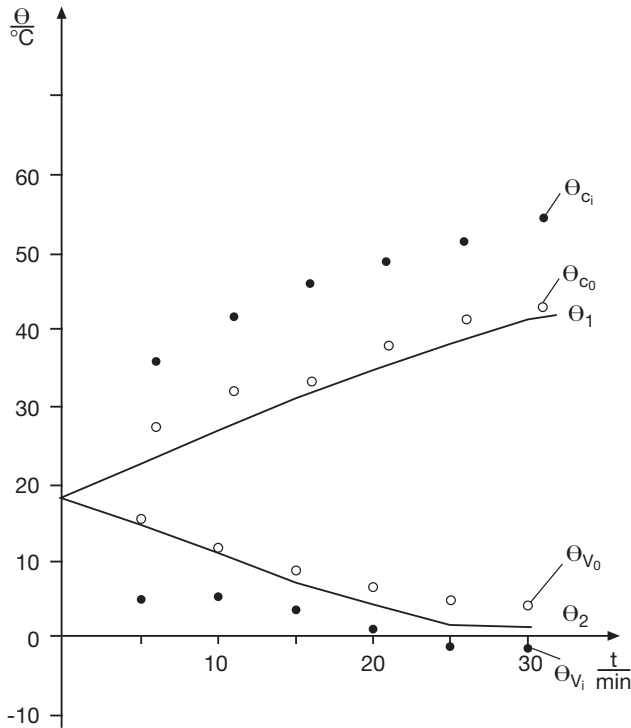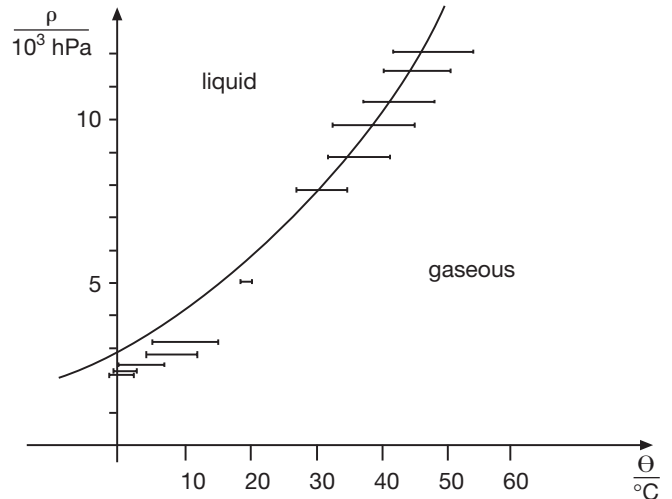

Fig. 4: Interdependence of (absolute) pressure and boiling temperature of the working substance (test value interval for vaporiser and condenser) when the heat pump is operating; continuous curve: in accordance with eqn. 1.

The energy flows are not constant but, apart from the operating condition of the heat pump (charge in the circuit, setting of the restrictor valve, instantaneous compressor power) are, above all, dependent upon the temperature difference between vaporiser and condenser.

The measured values from Figs. 3 and 4 are evaluated at the moment t = 10 min.

Mass of water in each water reservoir m_w = 4.8 kg

Condenser heat flow

$\dot{Q}$ = 269 W

Vaporiser heat flow

$\dot{Q}_0$ = 235 W

The compressor power fluctuates with time. On average it is P = 120 W.

The resulting performance figure is therefore

$$\varepsilon = \frac{\dot{Q}}{P} = 2.2.$$

The ratio of the actual stroke volume V to the geometrical stroke volume V_g of the compressor is called the volumetric efficientcy λ of the compressor:

$$\lambda = \frac{V}{V_g}.$$

Assuming an ideal heat pumping process, the actual volume flow $\dot{V}$ of the working substance in the circuit and the volumetric efficiency λ of the compressor can be calculated from the vaporiser heat flow with the aid of eqn. 1.

$$V = v \cdot \frac{\dot{Q}_0}{h_1 - h_3}$$

(v = specific volume of the vapour)

Pressure on the vaporiser side at

t = 10 min

p_0 = 3.1 · 10³ hPa

Condenser side

p = 8.6 · 10³ hPa

From Table 1:

h_1 = 399.84 kJ/kg

h_3 = 247.47 kJ/kg

v = 0.0647 m³/kg = 64.7 l/kg

Hence

$\dot{V}$ = 100 cm³/s.

From the geometrical stroke volume of the compressor

V_g = 5.08 cm³

and the frequency of rotation of the piston

f = 1450 min⁻¹

we obtain a geometrical volume flow of

$\dot{V}_g = V_g \cdot f = 123\ \text{cm}^3/\text{s}$

and therefore a volumetric efficiency of the compressor

$$\lambda = \frac{\dot{V}}{\dot{V}_g} = 81\ \%.$$

2. Air-water heat pump

The condenser heat flow of the heat pump is dependent upon the vaporiser temperature.

When operating as an air-water heat pump, the vaporiser temperature remains approximately constant after approx. 10 min since, because of the blower, a virtually infinite reservoir of air is available.

Without the blower the vaporiser ices up, as the result of which its temperature likewise remains almost constant.

To compare the different modes of operation, the condenser heat flow $\dot{Q}$ is calculated using equation (1) at a water temperature of $\Theta_1 = 30\ °C$.

The average vaporiser temperature Θ_{Vo}, the condenser heat flow $\dot{Q}$ and the performance figure ε (compressor power $P = 120\ W$) for the different modes of operation are shown in the following table.

Blower	$\dfrac{\Theta_{Vo}}{°C}$	$\dfrac{\dot{Q}}{W}$	ε
hot	12	276	2.1
cold	8	193	1.5
without	-10	117	0.9

A blower is therefore necessary for operation of an economically working airwater heat pump.

Table 1

Θ : temperature
p : pressure (absolute)
v : specific volume of the vapour
h' : specific enthalpy of the liquid (h_3)
h'' : specific enthalpy of the vapour (h_1)

$\dfrac{\Theta}{°C}$	$\dfrac{p}{\text{MPA}}$	$\dfrac{v}{\text{m}^3/\text{kg}}$	$\dfrac{h'}{\text{kJ/kg}}$	$\dfrac{h''}{\text{kJ/kg}}$
-30	0.08436	0.22596	161.10	380.45
-20	0.13268	0.14744	173.82	386.66
-10	0.20052	0.09963	186.78	392.75
-8	0.21684	0.09246	189.40	393.95
-6	0.23418	0.08591	192.03	395.15
-4	0.25257	0.07991	194.68	396.33
-2	0.27206	0.07440	197.33	397.51
0	0.29269	0.06935	200.00	398.68
2	0.31450	0.06470	202.68	399.84
4	0.33755	0.06042	205.37	401.00
6	0.36186	0.05648	208.08	402.14
8	0.38749	0.05238	210.80	403.27
10	0.41449	0.04948	213.53	404.40
12	0.44289	0.04636	216.27	405.51
14	0.47276	0.04348	219.03	406.61
16	0.50413	0.04081	221.80	407.70
18	0.53706	0.03833	224.59	408.78
20	0.57159	0.03603	227.40	409.84
22	0.60777	0.03388	230.21	410.89
24	0.64566	0.03189	233.05	411.93
26	0.68531	0.03003	235.90	412.95
28	0.72676	0.02829	238.77	413.95
30	0.77008	0.02667	241.65	414.94
32	0.81530	0.02516	244.55	415.90
34	0.86250	0.02374	247.47	416.85
36	0.91172	0.02241	250.41	417.78
38	0.96301	0.02116	253.37	418.69
40	1.0165	0.01999	256.35	419.58
42	1.0721	0.01890	259.35	420.44
44	1.1300	0.01786	262.38	421.28
46	1.1901	0.01689	265.42	422.09
48	1.2527	0.01598	268.49	422.88
50	1.3177	0.01511	271.59	423.63
60	1.6815	0.01146	287.49	426.86
70	2.1165	0.00867	304.29	428.89