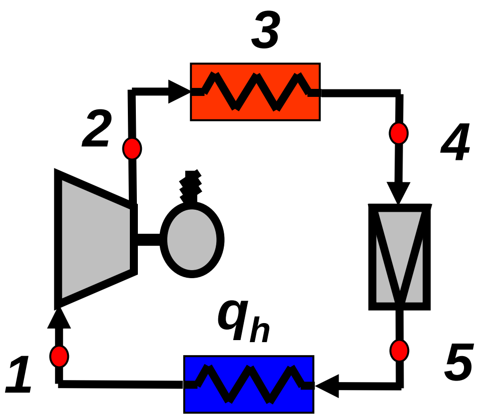
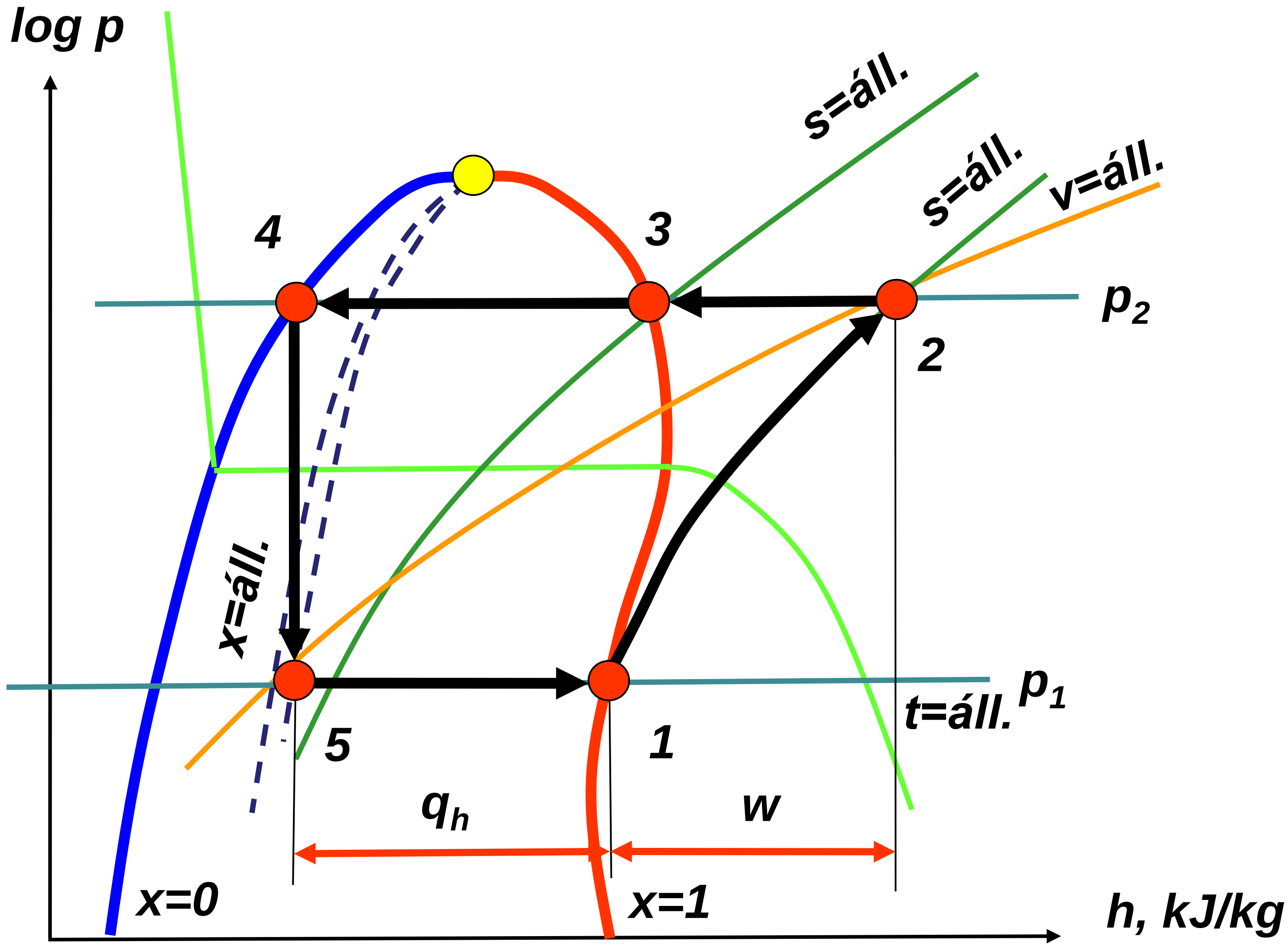
Refrigeration cycle

Calculation

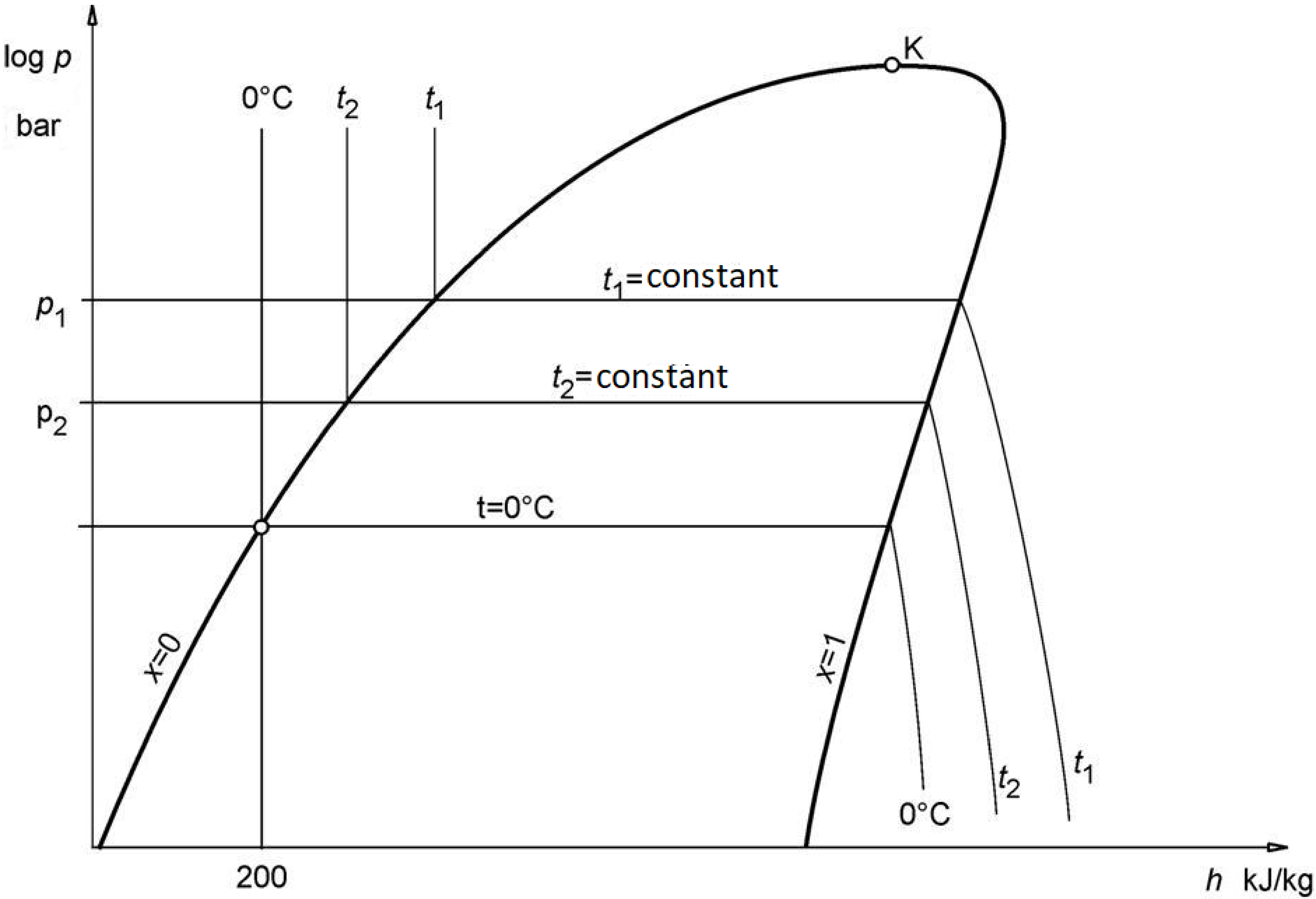
Vapor compression refrigeration process



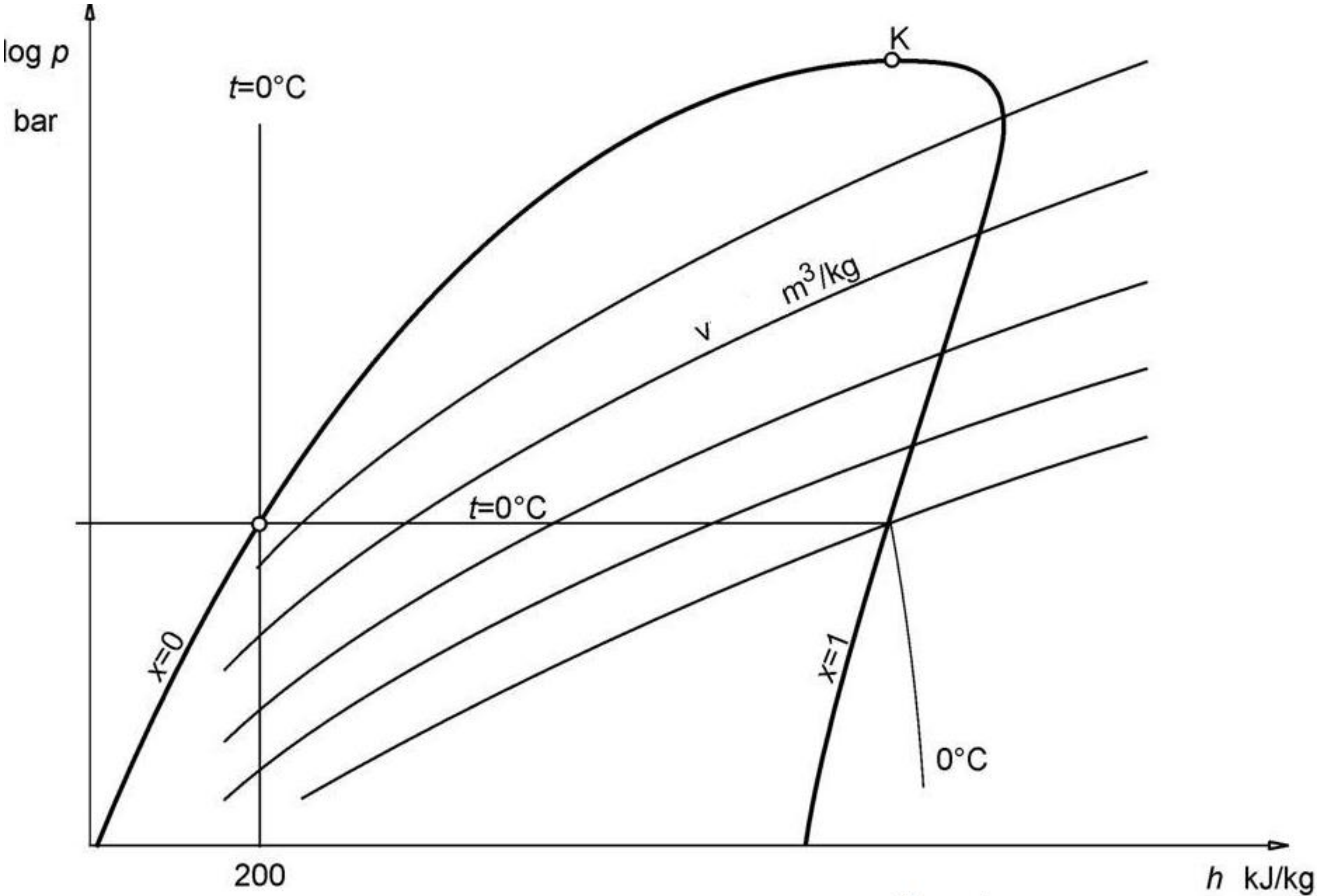


$$\varepsilon = \frac{q_h}{w}$$

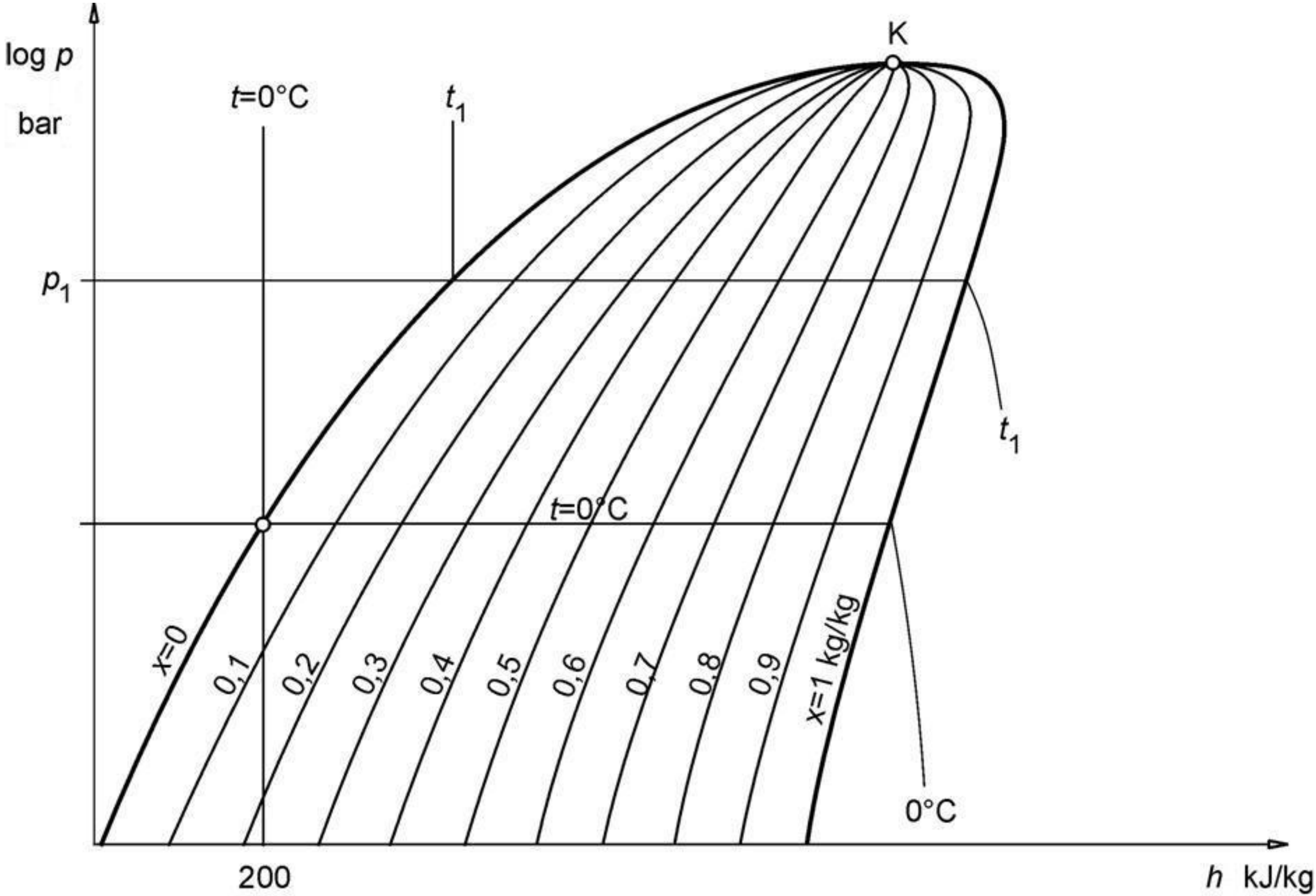
$$\varepsilon = 1,5 \ldots 3,5$$



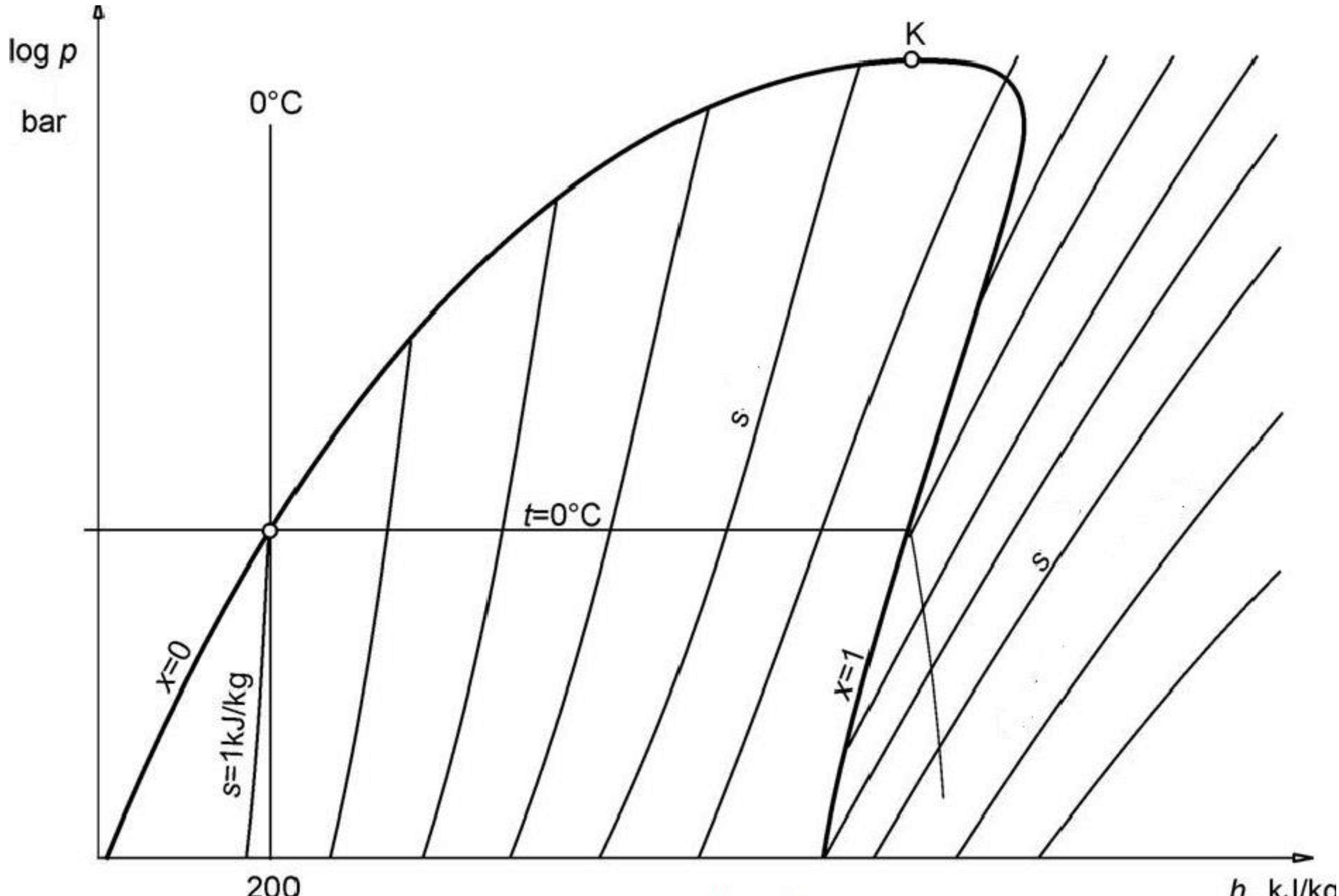
isotherm lines



constant specific volume
(or constant density)



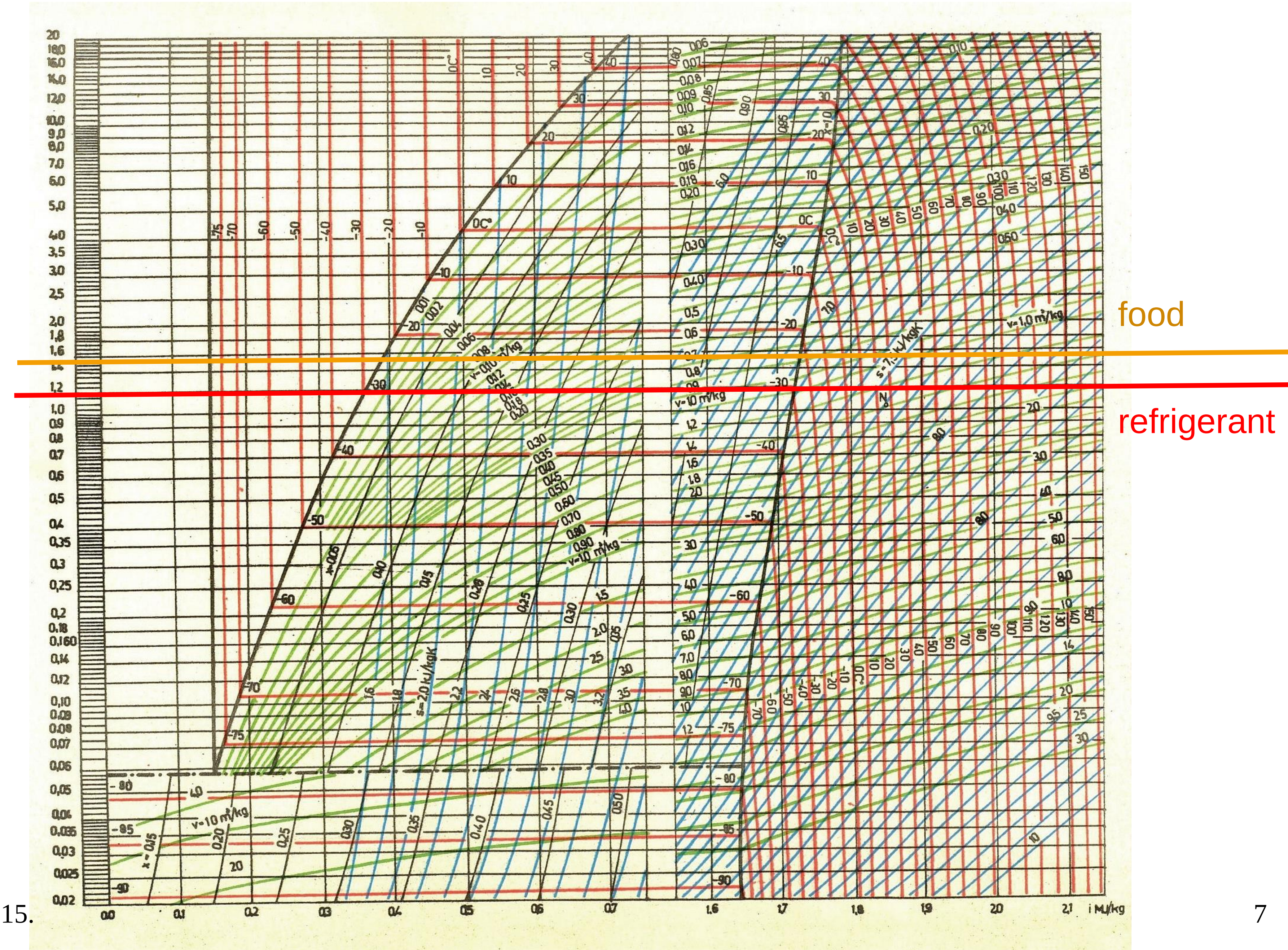
fraction of vapor



s isenthropic lines
(compression process)

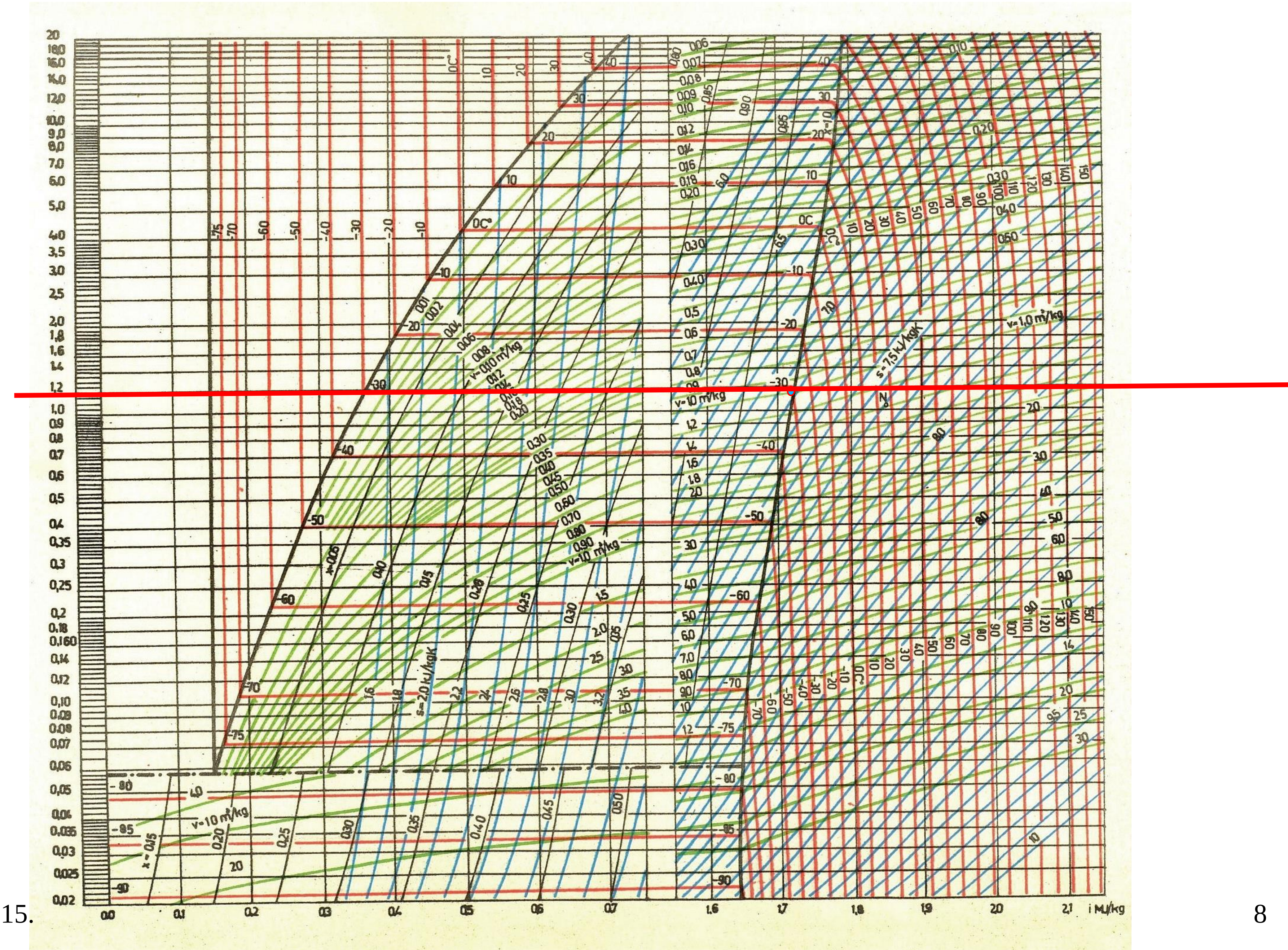
First step: calculating the pressure in the evaporator
The refrigerant must be cooler than the food
Example: -25°C food, -30°C refrigerant

Ammonia (R717)



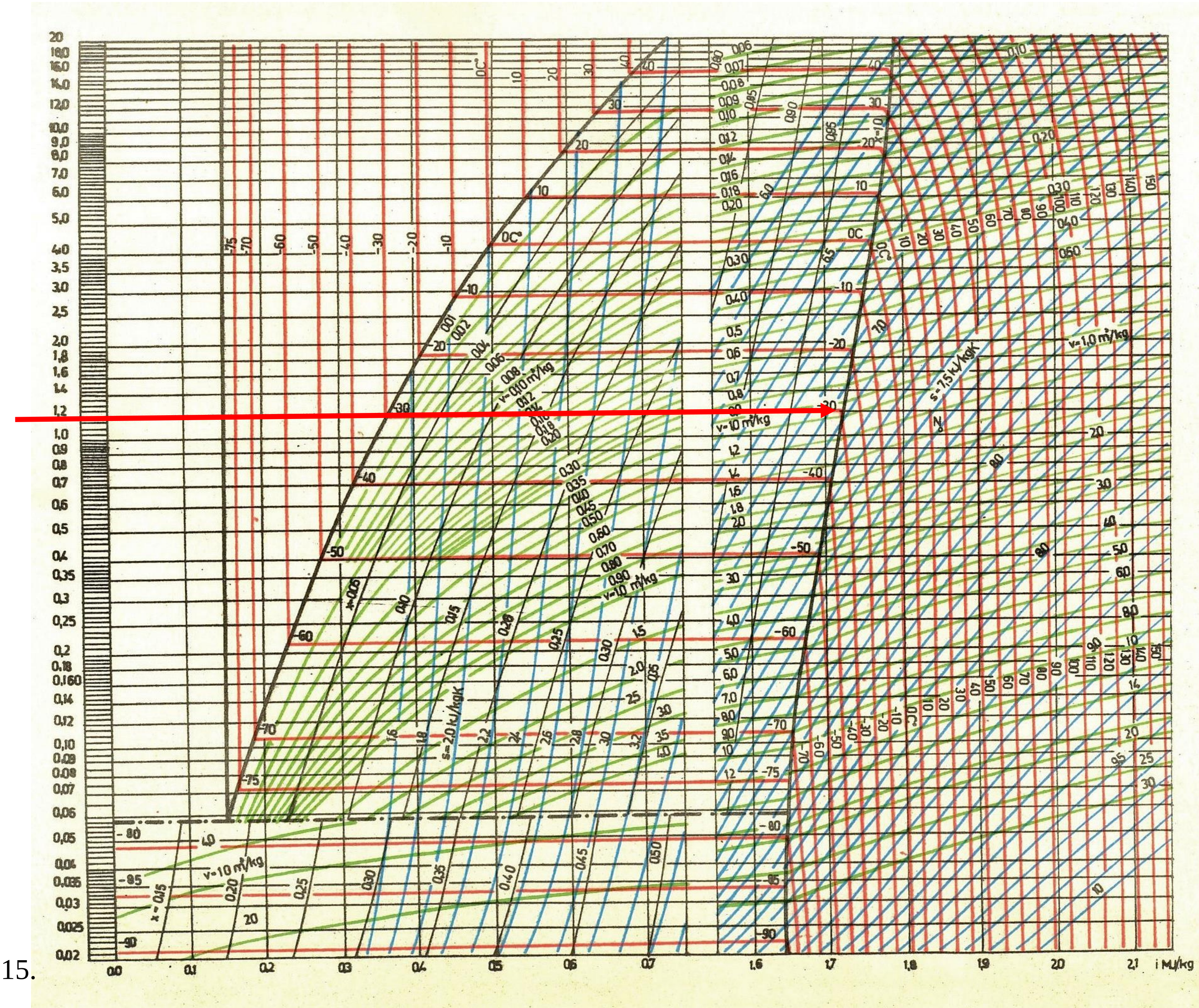
First step: calculating the pressure in the evaporator
looking up the pressure fitting to the temperature
Example: saturated vapor pressure 1.2 bar for-30C° refrigerant

Ammonia (R 717)



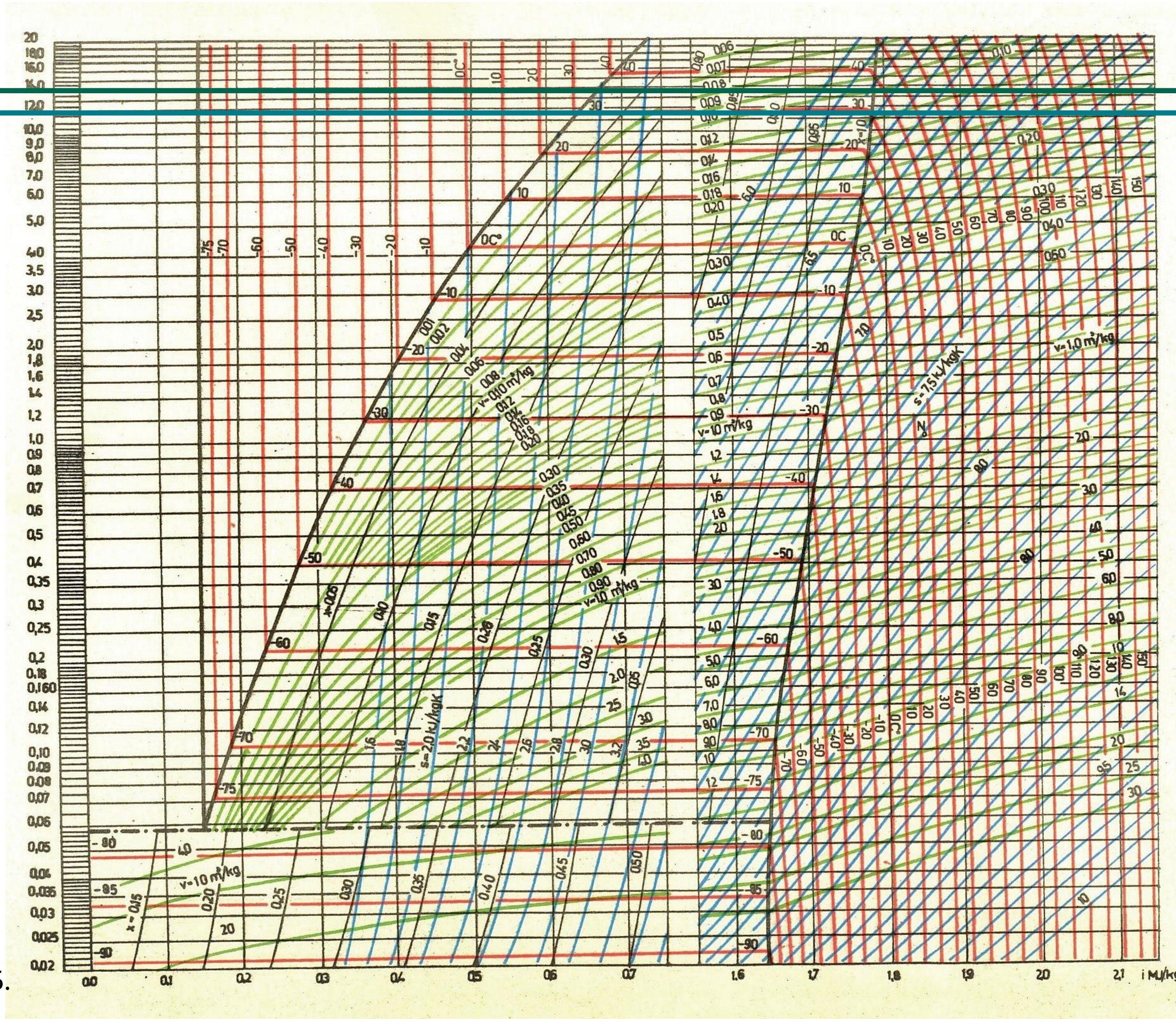
First step: calculating the pressure in the evaporator
Looking up the endpoint of the evaporation
Example: saturated vapor pressure 1.2 bar for-30C° refrigerant

Ammonia (R717)



Second step: looking up the pressure of the condenser
The temperature of surroundings must be warmer than the refrigerant
Example: heat transport from +35 refrigerant to +30 surroundings

Ammonia (R717)

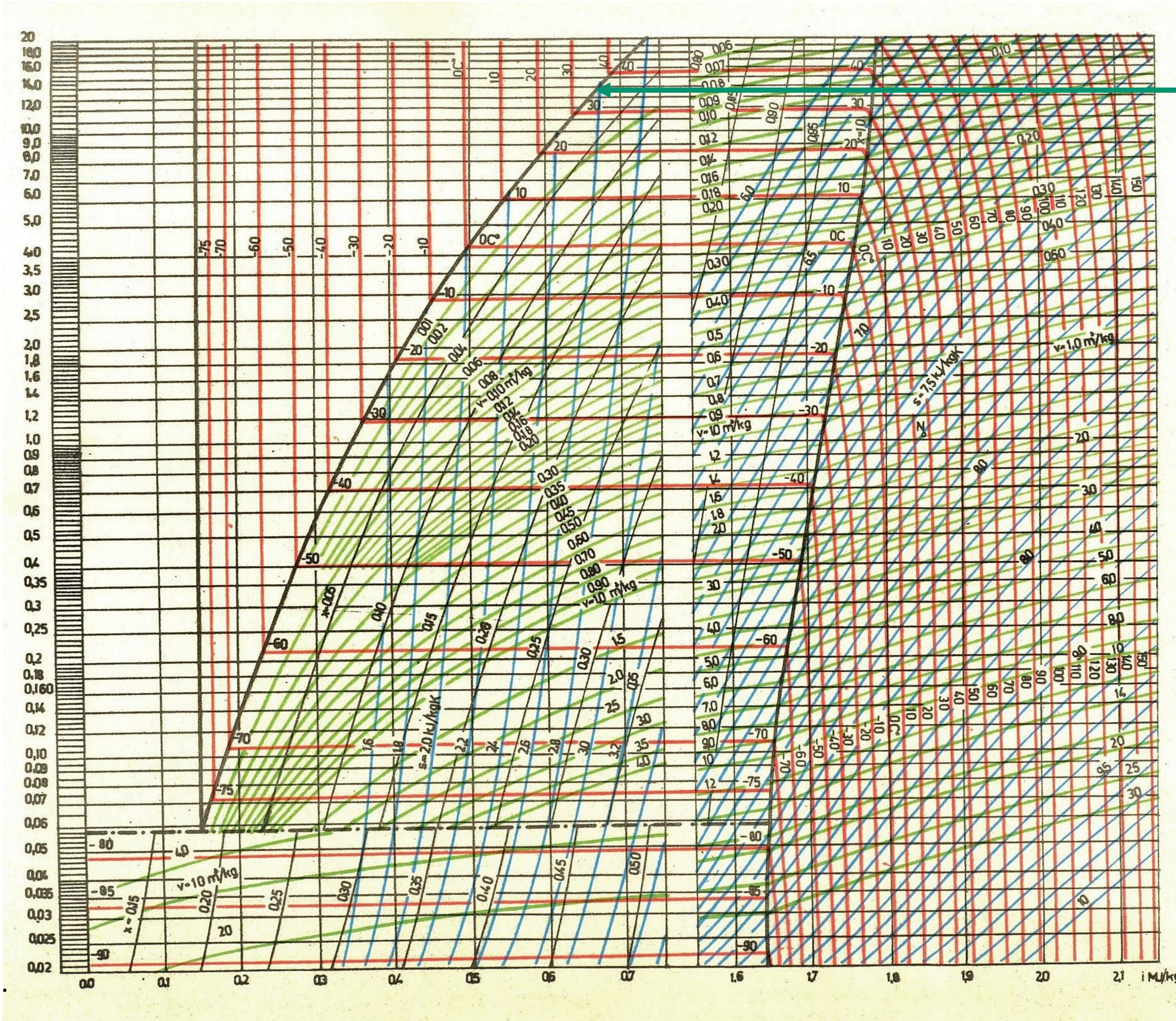


refrigerant

surroundings

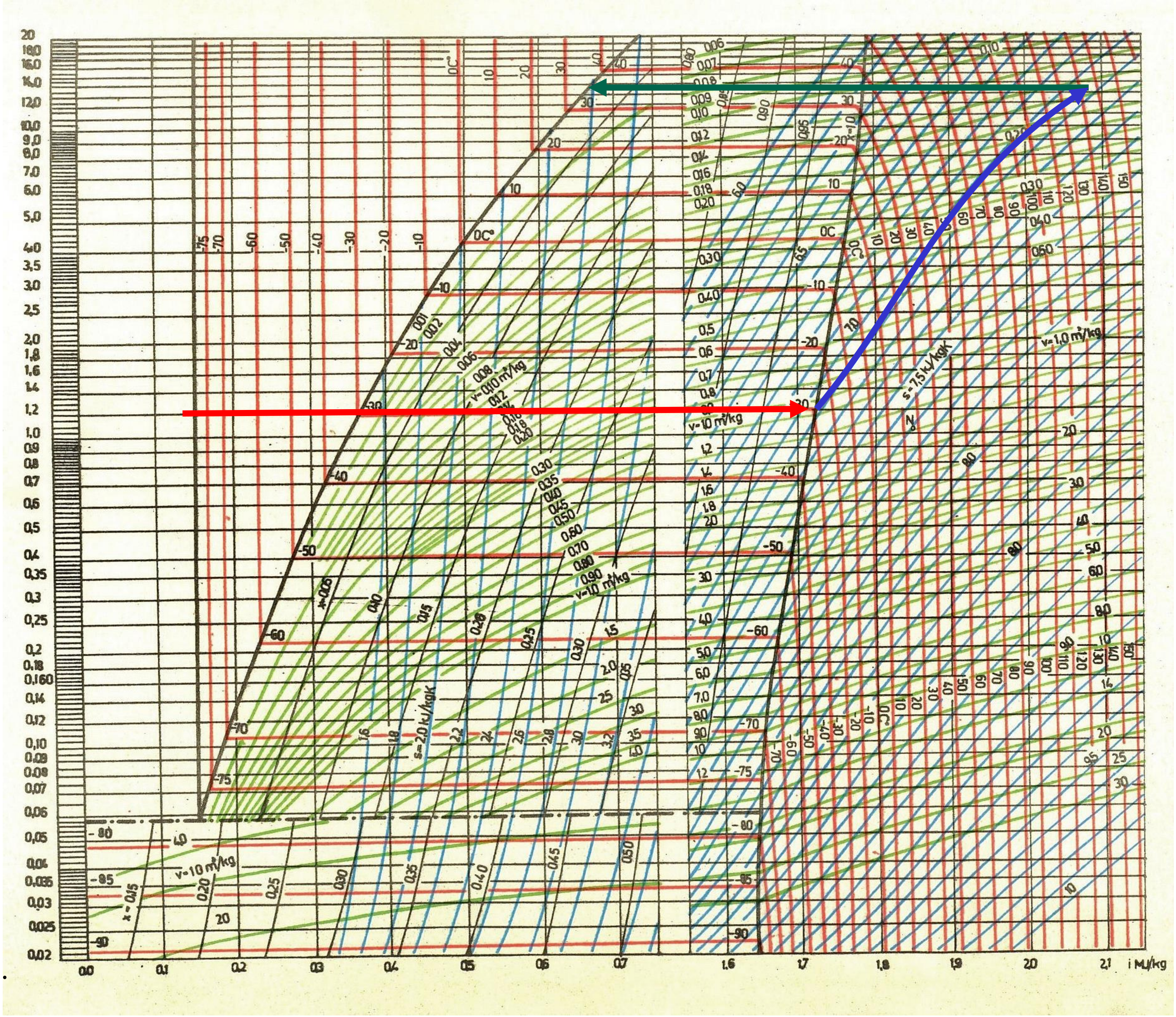
Second step: looking up the pressure of the condenser
At the end of condensation the refrigerant is liquid
Example: endpoint for liquid at 13,5 bar pressure

Ammonia (R717)



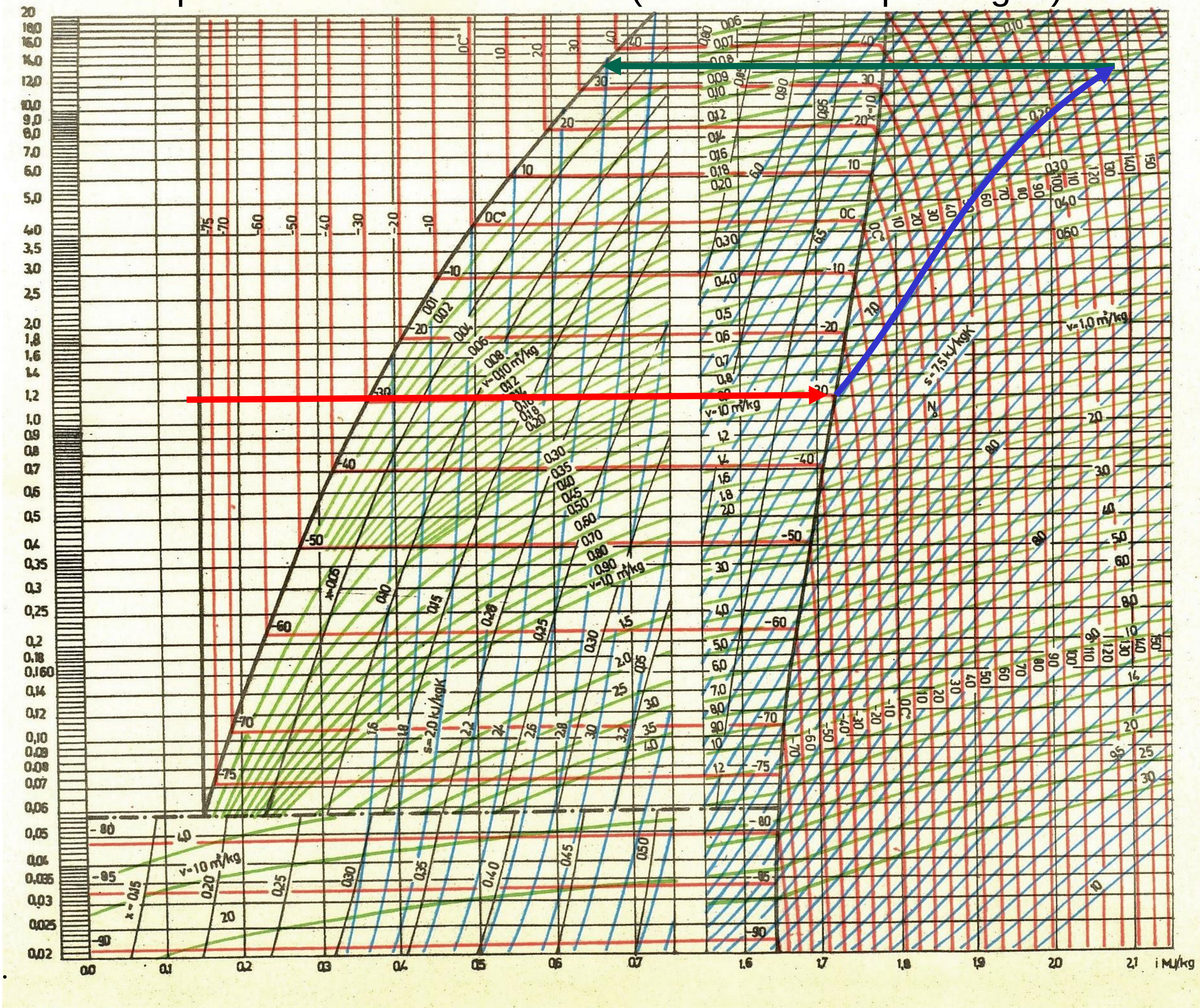
Third step: the compression process
Adiabatic compression from 1,2 bar to 13,5 bar
Example: the specific entropy is 7.05 kJ/(kg K) at 1,2 bar pressure

Ammonia (R717)



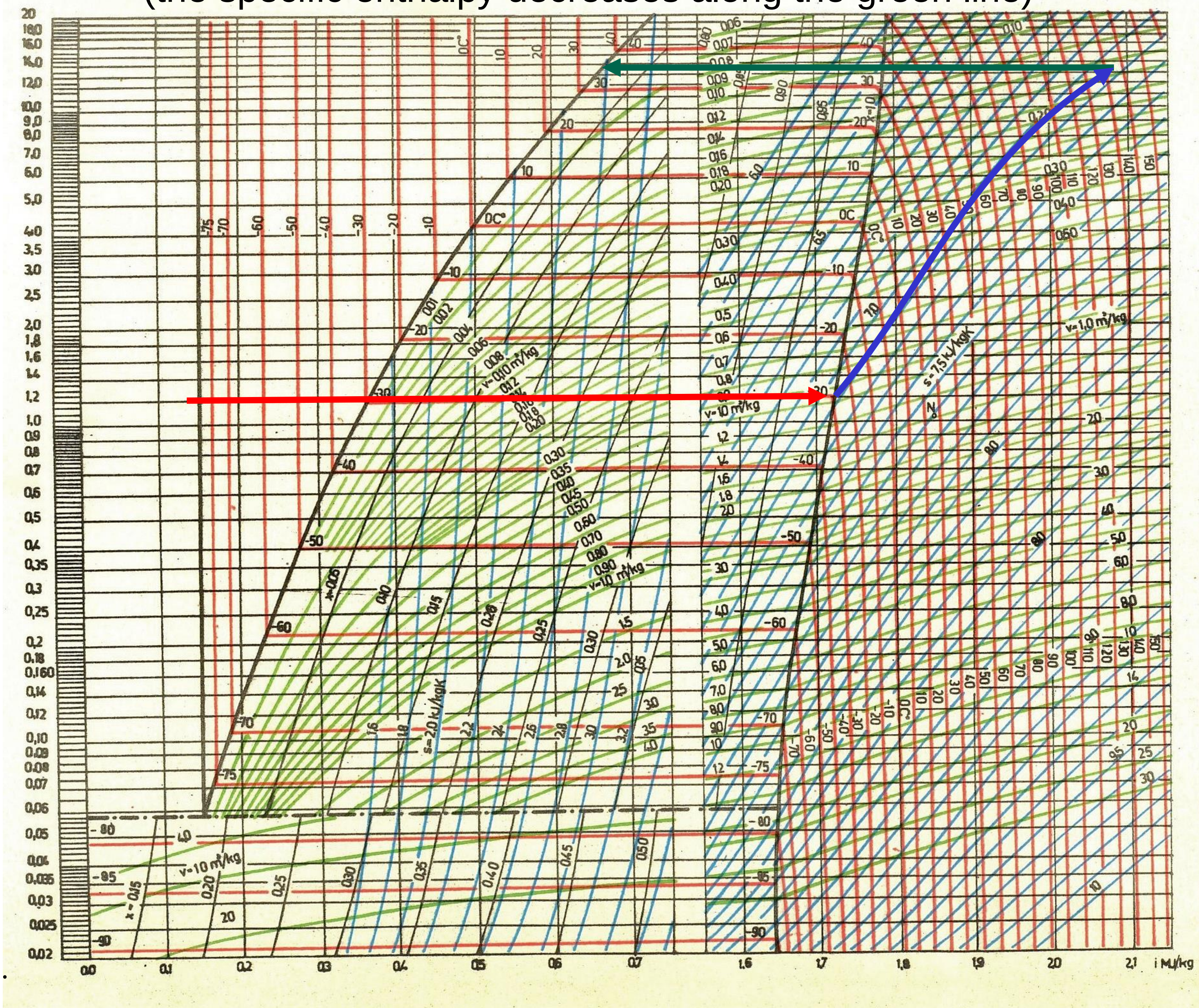
Third step: the compression process
Adiabatic compression from 1.2 bar to13.5 bar
Example: 7,05 kJ/(kg K) specific entropy at pressure of 13.5 bar means that the temperature ended at +140 °C (overheated vapor or gas)

Ammonia (R717)



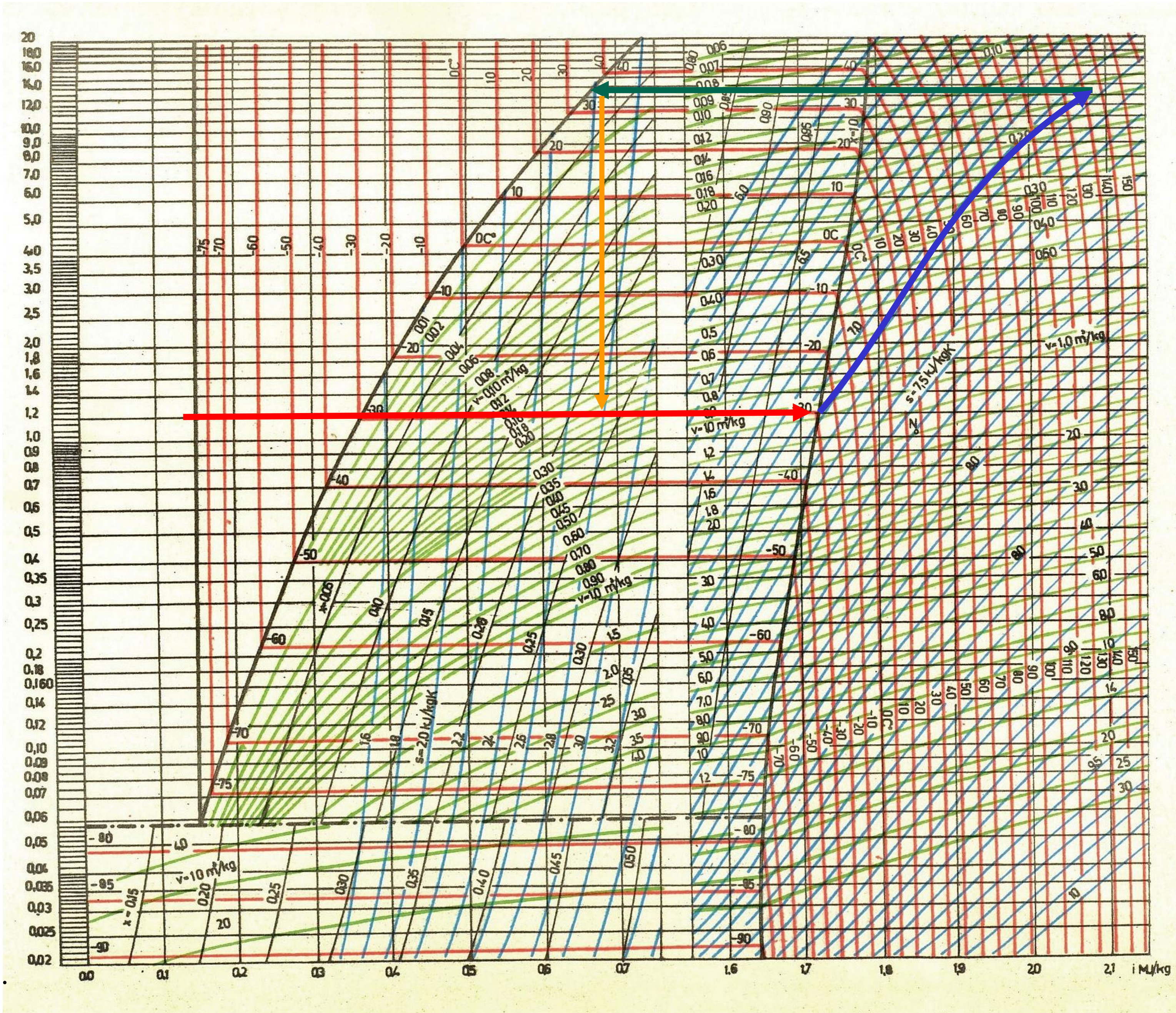
Fourth step: calculating the process of condensation
Isobaric condensation at 13.5 bar pressure to reach the liquid state
Example: 13,5 bar isobaric heat transfer: both overheating and condensation heat
(the specific enthalpy decreases along the green line)

Ammonia (R717)



Fifth step: isenthalpic expansion by expansion valve
The isenthalpic process is vertical line here (orange)
Example: 0.68 MJ/kg

Ammonia (R717)



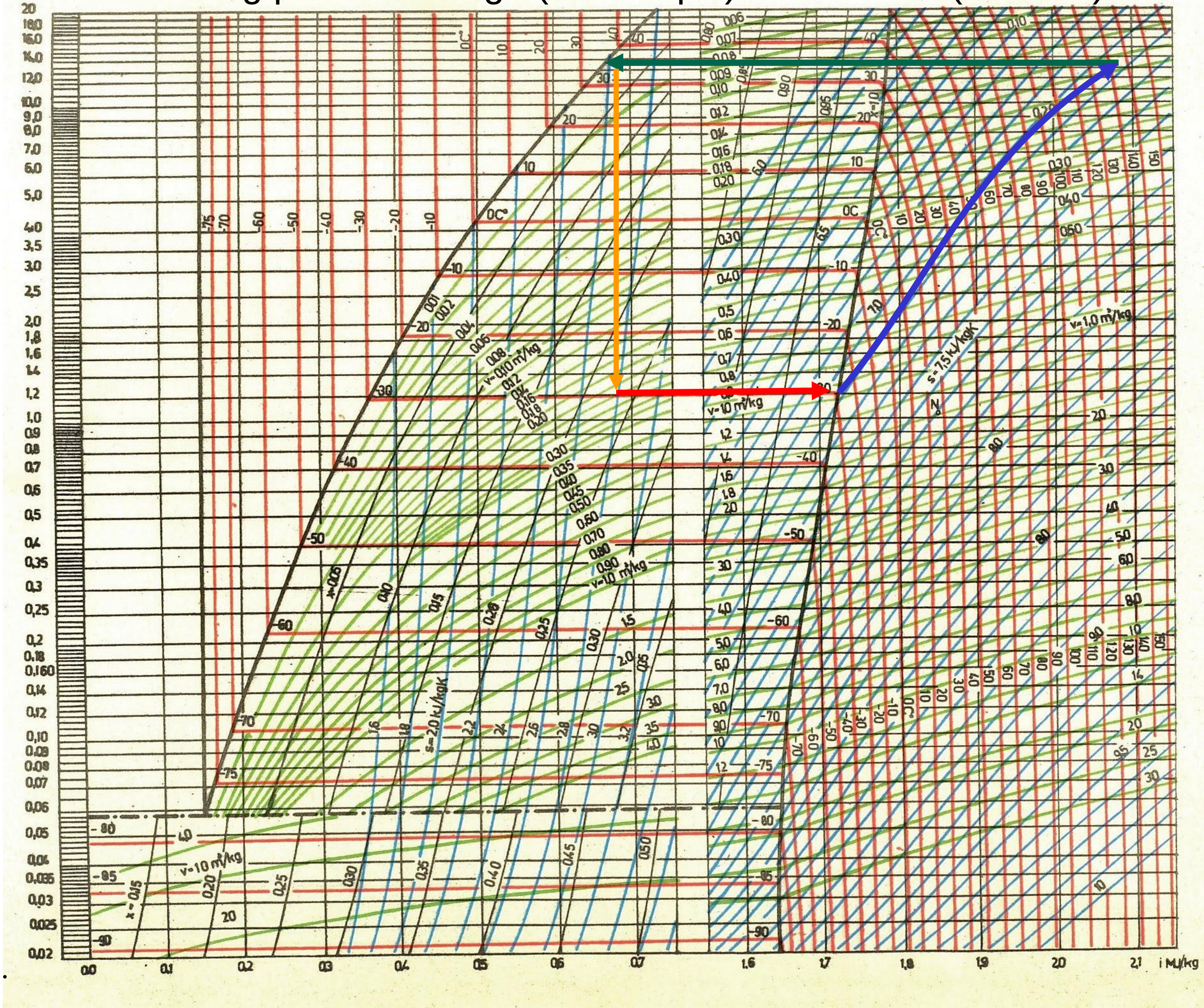
Fifth step: isenthalpic expansion by expansion valve

The isenthalpic expansion (orange) determines the start point of the evaporation

Expample: the vapor fraction is 0.23 kg/kg (a part of liquid evaporated)

see the crossing point of orange (isentkalpic) and the red (isobaric) lines

Ammonia (R717)

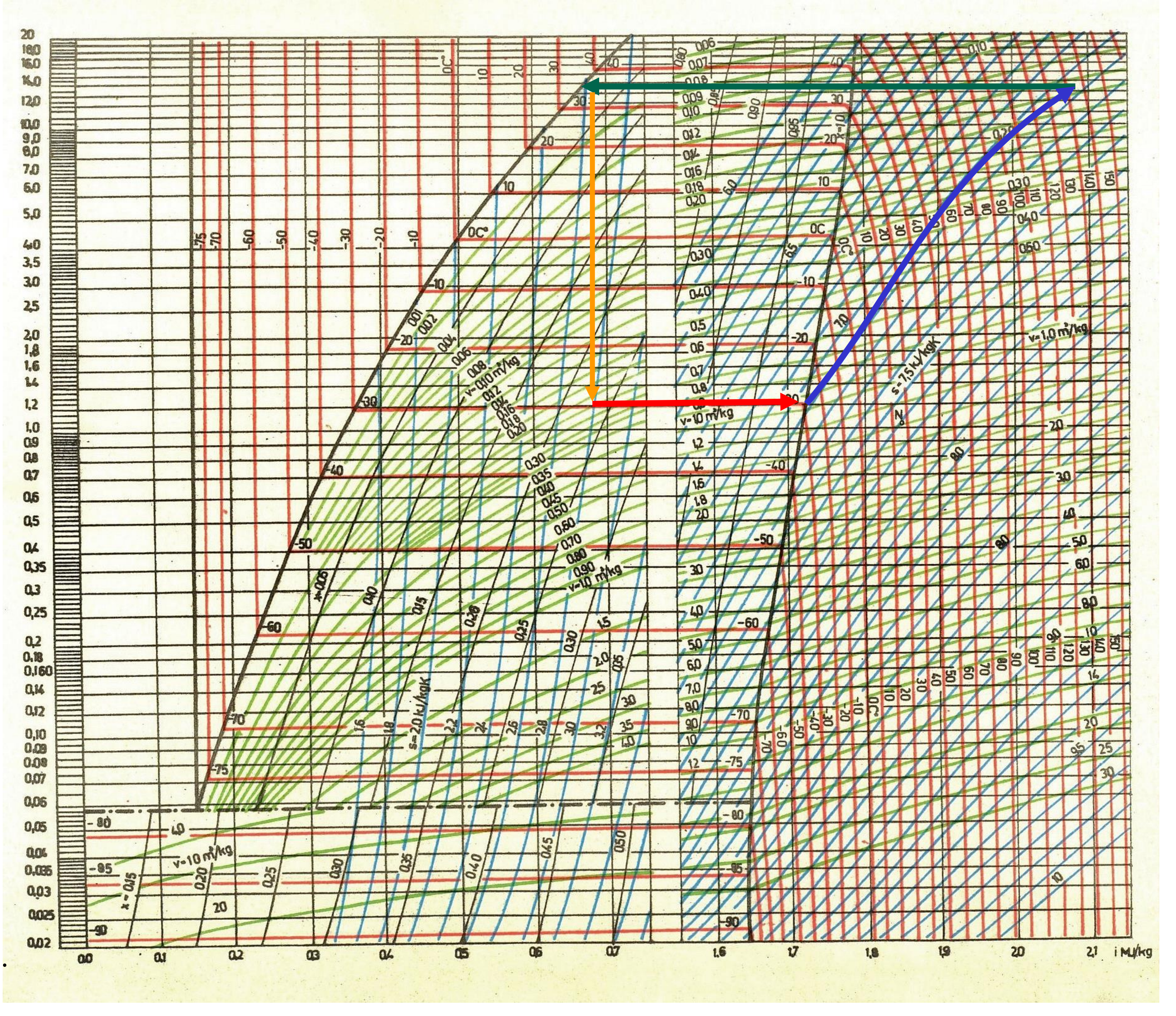


Fifth step: isenthalpic expansion by expansion valve

The isenthalpic expansion (orange) determines the start point of the evaporation

Example: as a result of evaporation the specific volume increases from 0.001 to 0.280 m^3/kg

Ammonia (R717)

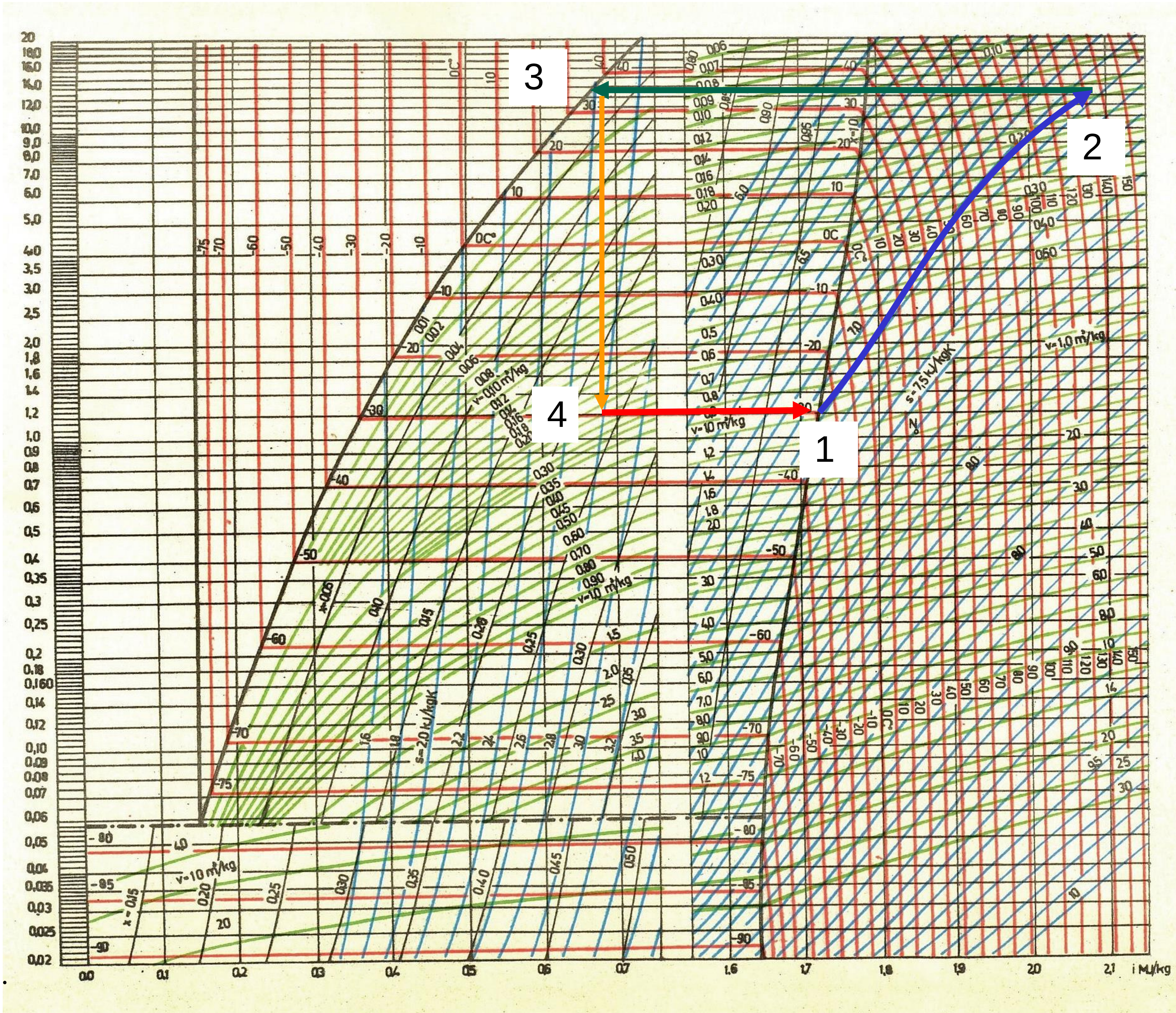


Sixth step: reading the results

1 h = 1.72 MJ/kg, **2**: h = 2.1 MJ/kg, both **3** and **4**: h = 0.67 MJ/kg

Heat entered in the evaporator: h_1-h_4= (1.72 – 0.67) MJ/kg = 1.05 MJ/kg

Ammonia (R717)

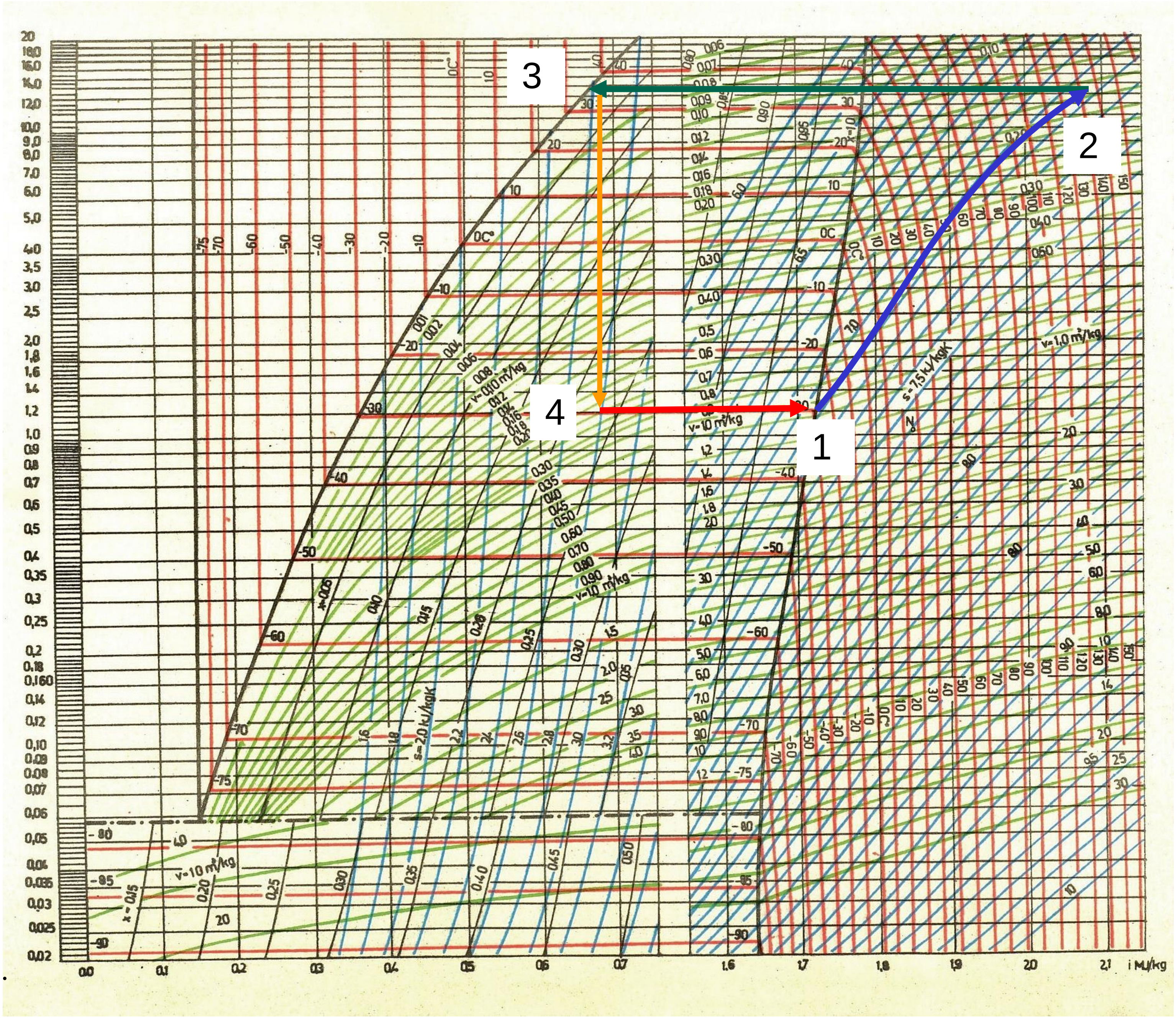


Sixth step: reading the results

1 h = 1.72 MJ/kg, **2**: h = 2.1 MJ/kg, both **3** and **4**: h = 0.67 MJ/kg

The work needed by the compressor: $h_2 - h_1 = (2.1 - 1.72)$ MJ/kg = 0.38 MJ/kg

Ammonia (R717)



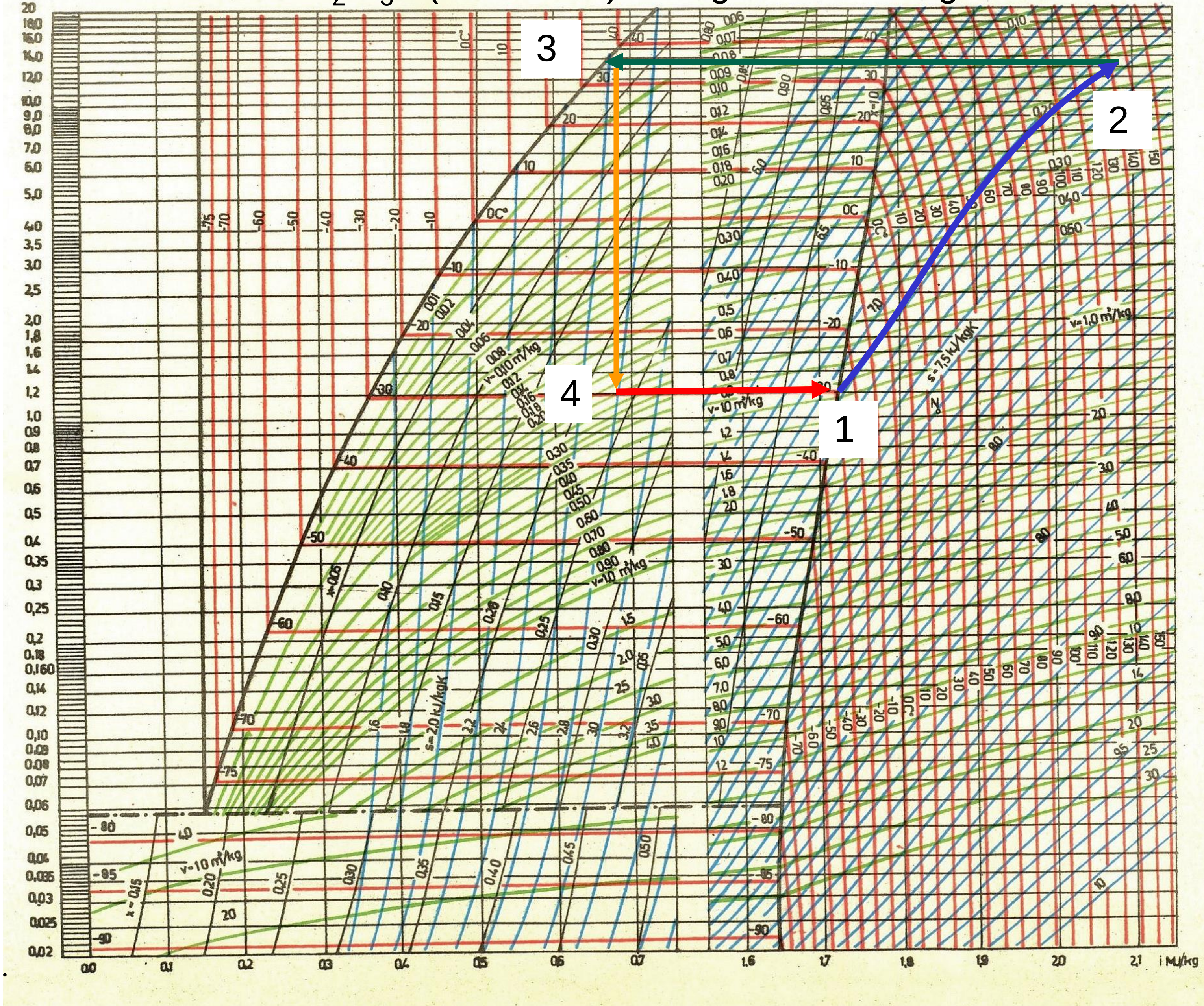
Sixth step: reading the results

1 h = 1.72 MJ/kg, **2**: h = 2.1 MJ/kg, both **3** and **4**: h = 0.67 MJ/kg

Heat transfer sent to the surroundings:

h_2-h_3= (2.1 – 0.67) MJ/kg = 1.43 MJ/kg

Ammonia (R717)



Calculations

Coefficient of performance: quotient of the heat transfer in the evaporator and the work of compression

$$\varepsilon = \frac{1.05\mathrm{MJ/kg}}{0.38\mathrm{MJ/kg}} = 2.76$$

The real cycle calculated including wastage. Example: friction loss of mechanics, flow friction loss (liquid and vapor), the power consumption of lubricant pump, etc.

Try to calculate it on the theoretical base!

$$\varepsilon = \frac{T_0}{T - T_0} = \frac{(273.15 - 30)\mathrm{K}}{(273.15 + 35)\mathrm{K} - (273.15 - 30)\mathrm{K}} = \frac{243.15}{65} = 3.74$$

Huge difference. The equation below related to proper gases, while the equation above related to the real material, values originated from the chart of real refrigerant

calculations

Let's calculate a refrigerator with J_m=0.1 kg/s flow rate of the refrigerant!

The work needed by the compressor

$$P = w_k J_m = 380 \mathrm{kJ/kg} \cdot 0.1 \mathrm{kg}/s = 38 \mathrm{kJ}/s = 38 \mathrm{kW}$$

Heat flow in the evaporator

$$\Phi = q_0 J_m = 1050 \mathrm{kJ/kg} \cdot 0.1 \mathrm{kg}/s = 105 \mathrm{kJ}/s = 105 \mathrm{kW}$$

Usually the heat flow calculated a more practical unit:

$$\Phi = 105 \mathrm{kW} = 105 \frac{\mathrm{kJ}}{\mathrm{s}} \cdot 3600 \frac{\mathrm{s}}{\mathrm{h}} = 378000 \frac{\mathrm{kJ}}{\mathrm{h}} = 378 \frac{\mathrm{MW}}{\mathrm{h}}$$

Calculations

To gain the size of the refrigerator we need to know the flow ratio!

Specific volume of the vapor at temperature -30°C v_g=0,963 m^3/kg,
and the liquid at +35 °C v_l=0,0017m^3/kg

Vapor flow rate at the inlet of the compressor:

$$J_{Vg} = J_m \cdot v_\mathrm{g} = 0{,}1\,\frac{\mathrm{kg}}{\mathrm{s}} \cdot 0{,}963\,\frac{\mathrm{m}^3}{\mathrm{kg}} = 0{,}0963\,\frac{\mathrm{m}^3}{\mathrm{s}} = 96{,}3\,\frac{\mathrm{l}}{\mathrm{s}}$$

Liquid flow rate at the outlet of the condenser:

$$J_{Vl} = J_m v_\mathrm{l} = 0{,}1\,\frac{\mathrm{kg}}{\mathrm{s}} \cdot 0{,}0017\,\frac{\mathrm{m}^3}{\mathrm{kg}} = 0{,}00017\,\frac{\mathrm{m}^3}{\mathrm{s}} = 0{,}17\,\frac{\mathrm{l}}{\mathrm{s}}$$

Saturated Ammonia --Temperature Table						http://energ
		Spec, Volume		Enthalpy		http://www.
deg-C	kPa	m^3/kg		kJ/kg		
temperatur	saturated	saturated	saturated	saturated	saturated	
		liquid	vapor	liquid	vapor	
T °C	p_sat@T	vf	vg	hf	hg	
-40	71,7	0,00145	1,55256	0	1388,8	
-35	93,2	0,001463	1,21613	22,06	1396,5	
-30	119,5	0,001476	0,96339	44,26	1404	
-25	151,6	0,00149	0,77119	66,58	1411,2	
-20	190,2	0,001504	0,62334	89,05	1418	
-15	236,3	0,001519	0,50838	111,66	1424,6	
-10	290,9	0,001534	0,41808	134,41	1430,8	
-5	354,9	0,00155	0,34648	157,31	1436,7	
0	429,6	0,001566	0,2892	180,36	1442,2	
5	515,9	0,001583	0,24299	203,58	1447,3	
10	615,2	0,0016	0,20541	226,97	1452	
15	728,6	0,001619	0,17462	250,54	1456,3	
20	857,5	0,001638	0,14922	274,3	1460,2	
25	1003,2	0,001658	0,12813	298,25	1463,5	
30	1167	0,00168	0,11049	322,42	1466,3	
35	1350,4	0,001702	0,09567	346,8	1468,6	
40	1554,9	0,001725	0,08313	371,43	1470,2	

Start point of this table: of the liquid at -40 °C temperature: h=0 kJ/kg
This is why the enthalpy difference between the liquid and vapor is -40 °C: 1388,8 kJ/kg

The end