ES 3053 **Final** **December 12, 2019**

Open Books and Notes

Name: Solution

I. 50 points

A power plant operates on thermal gradients in the ocean. The schematic is exactly the same as a Rankine cycle which uses steam, but this cycle uses R134a as the working fluid since the temperatures are much lower. Warm seawater at 30°C on the top of the ocean is used in the boiler, and there needs to be a driving force of 5°C difference in temperature for the ocean's heat to flow into the R-134a in the boiler, so assume the boiler produces R134a at 25°C and 0.575 MPa. The condenser is placed in deep ocean water where the ocean's temperature is about 0°C, so assume the condenser operates at 5°C. Use good engineering practice and appropriate assumptions. $\eta_{turbine} = 0.75$ and $\eta_{pump} = 1.0$.

Use the attached PH diagram for R134a for all properties.

A. 30 points (each empty cell worth 2 points)

Fill in the following table:

Point	T (°C)	P (MPa)	h (kJ/kg)	s (kJ/kg-K)
1(sat. liquid)	5	0.37	57	
2	~5	0.575	57 + 0.164	
3	25	0.575	265	0.93
4' (isentropic base case)	10	0.37	255	0.93
4 (actual)	13	0.37	257.5	0.94

B. 5 points

Find the pump work assuming the pump (η_{pump}) has a thermal efficiency of 1.0 and that the specific volume liquid is constant at 0.0008 m^3/kg.

W_{pump} = 0.164 kJ/kg

C. 5 points

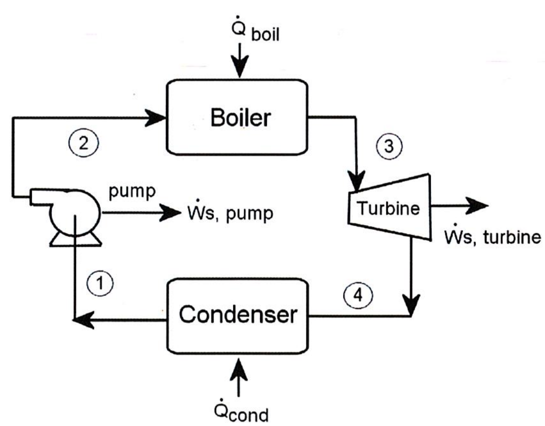
Find the turbine work assuming the turbine ($\eta_{turbine}$) has a thermal efficiency of 0.75

$W_{turbine}$ = 7.5 kJ/kg

D. 10 points

Find the flowrate of the R134a if the actual net power output is to be 1 MW.

$\dot{m}$ = 136.3 kg/s



II. 50 points

NASA plans to launch a probe to a planet where the atmospheric temperature is about 250°F. They are sending an experiment that will grow bacteria at 120°F inside a refrigerated box placed in the planet's atmosphere. Design a vapor-compression refrigeration cycle (see figure below) using Refrigerant-11 (PH diagram attached) to maintain the temperature of the refrigerated box at 120°F while rejecting heat to the planet's environment at 250°F. The evaporator needs to operate 20°F below the temperature maintained in the box, and the condenser needs to operate 20°F above the atmospheric temperature on the planet. These parameters are reflected in the table below. Assume the thermal efficiency of the compressor (η) is 1.0.

A. 24 points (each empty cell worth 2)

Fill in the table below using the Refrigerant-11 diagram. Use good engineering judgement in finding the appropriate values.

Point	T (°F)	P (psia)	h (Btu/lbm)	s (Btu/lbm-°R)
1	270	~~8~~ 230	65	
2	100	24	65	
3	100	24	104	0.197
4	290	230	125	0.197

B. 13 points

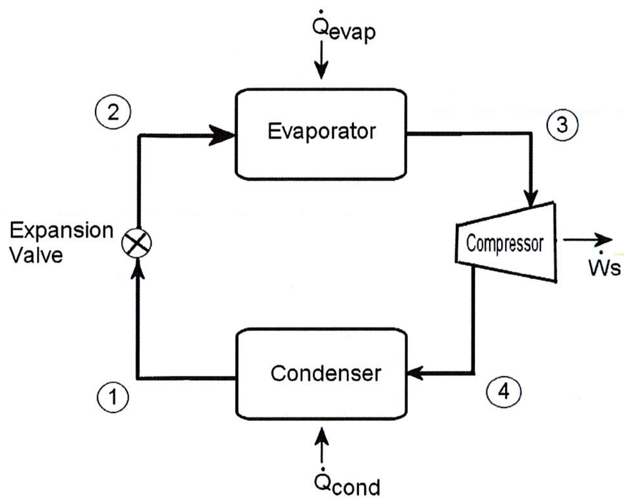
Find the flowrate of the R-11 if the refrigeration capacity is to be 100 Btu/min

$\dot{m}$ = 2.44 lbm/min

C. 13 points

Find the compressor work requirement in horsepower. 1 HP = 42.41 Btu/min

$\dot{W}_S$ = 1.21 HP



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I. Fill in table.

for point 4, $\eta = 0.75$

$\Delta H'_{3\to4} = 10$

$\Delta H_{ACTUAL} = 10 \cdot 0.75 = 7.5$

$H_{4,ACTUAL} = 265 - 7.5 = 257.5$

B. $-W_{PUMP} = (0.0008\ m^3/kg)(575 - 370)\ kPa$

$-W_{PUMP} = 0.164\ \frac{m^3 \cdot kPa}{kg} = 0.164\ kJ/kg$

C. $-W_s = -7.5\ kJ/kg = \Delta H_{ACTUAL,3\to4}$

D. $1000\ kJ/s = 1\ MW$

$\frac{1000\ kJ/s}{7.5\ kJ/kg - 0.164} = 136.3\ kg/s$

II. $\Delta H_{23} = 104 - 65 = 41\ BTU/lbm$

B. $\frac{100\ BTU/min}{41\ BTU/lbm} = 2.44\ lbm/min$

C. $\Delta H_{34} = -W_s = 125 - 104 = 21\ BTU/lbm$

$21\ BTU/lbm \cdot 2.44\ lbm/min = \dot{Q} = 51.24\ \frac{BTU}{min}$

$\frac{51.24\ BTU/min}{42.41\ \frac{BTU/min}{HP}} = 1.208\ HP$

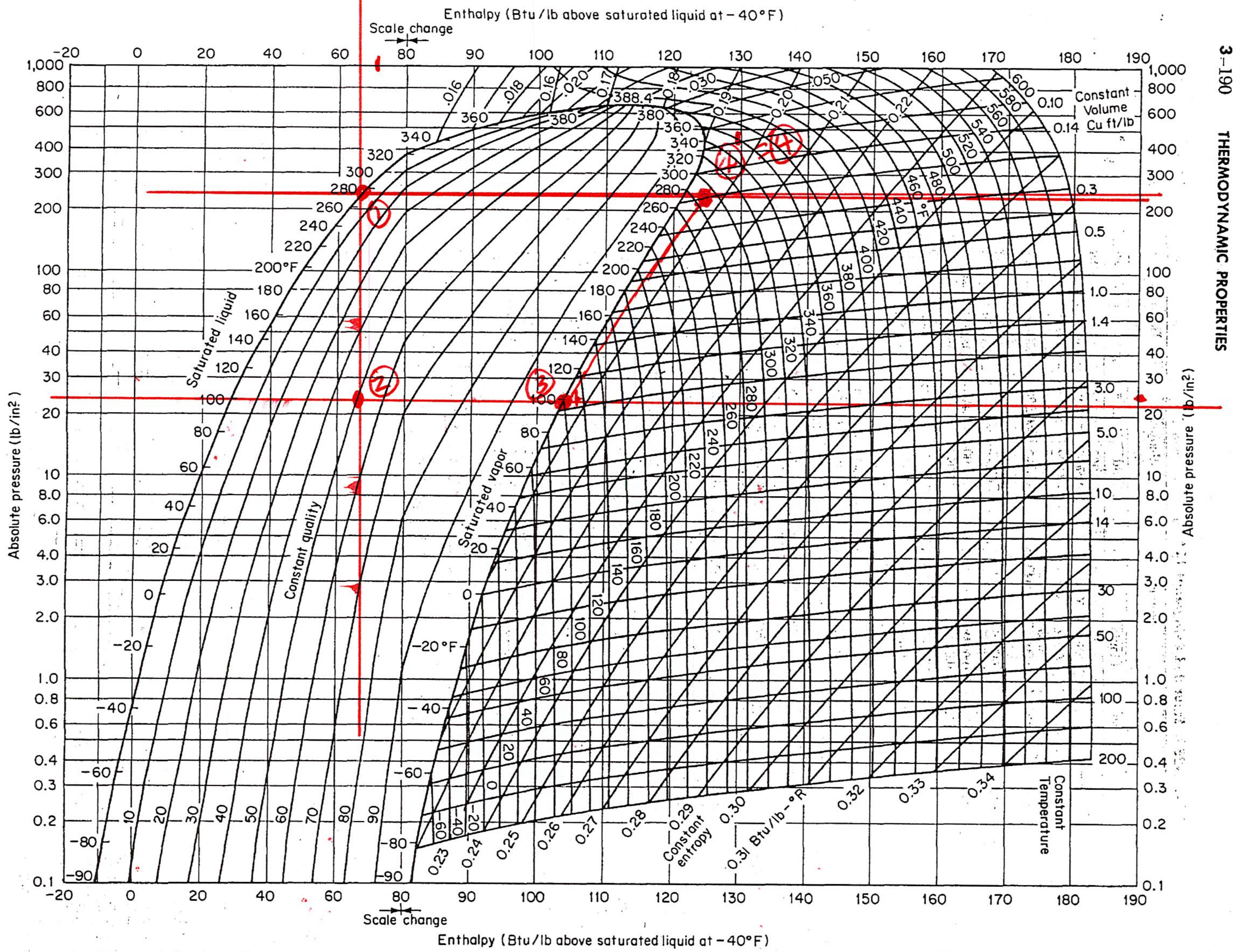

Fig. 3-36. Pressure-enthalpy for Refrigerant 11. Copyright E.I. du Pont de Nemours & Company. Reprinted with permission by the copyright owner. Rombusch and Giesen [*Kältetech.*, 18(2), 37 (1966)] describe the calculation of R11, R12, R13, and R21 properties. The Karlsruhe 1963 *H*-log *P* chart of this group extends from −50° to 320°C., 0.025 to 175 bars. D'Ans Lax "Taschenbuch" (1967) gives a saturation table from −70° to 70°C. The source used here also was selected for the 1967 A.S.H.R.A.E. "Fundamentals" volume, which also gives an enlarged section for pressures from 0.2 to 60 lb./sq. in. abs. Detailed tables for −161(1)388 and 388.40°F. for saturation conditions and from −70° to 570°F., 0.2 to 280 lb./sq. in. abs. for superheat conditions are contained in *du Pont Bulletin* T11 (1965) along with some other property information.

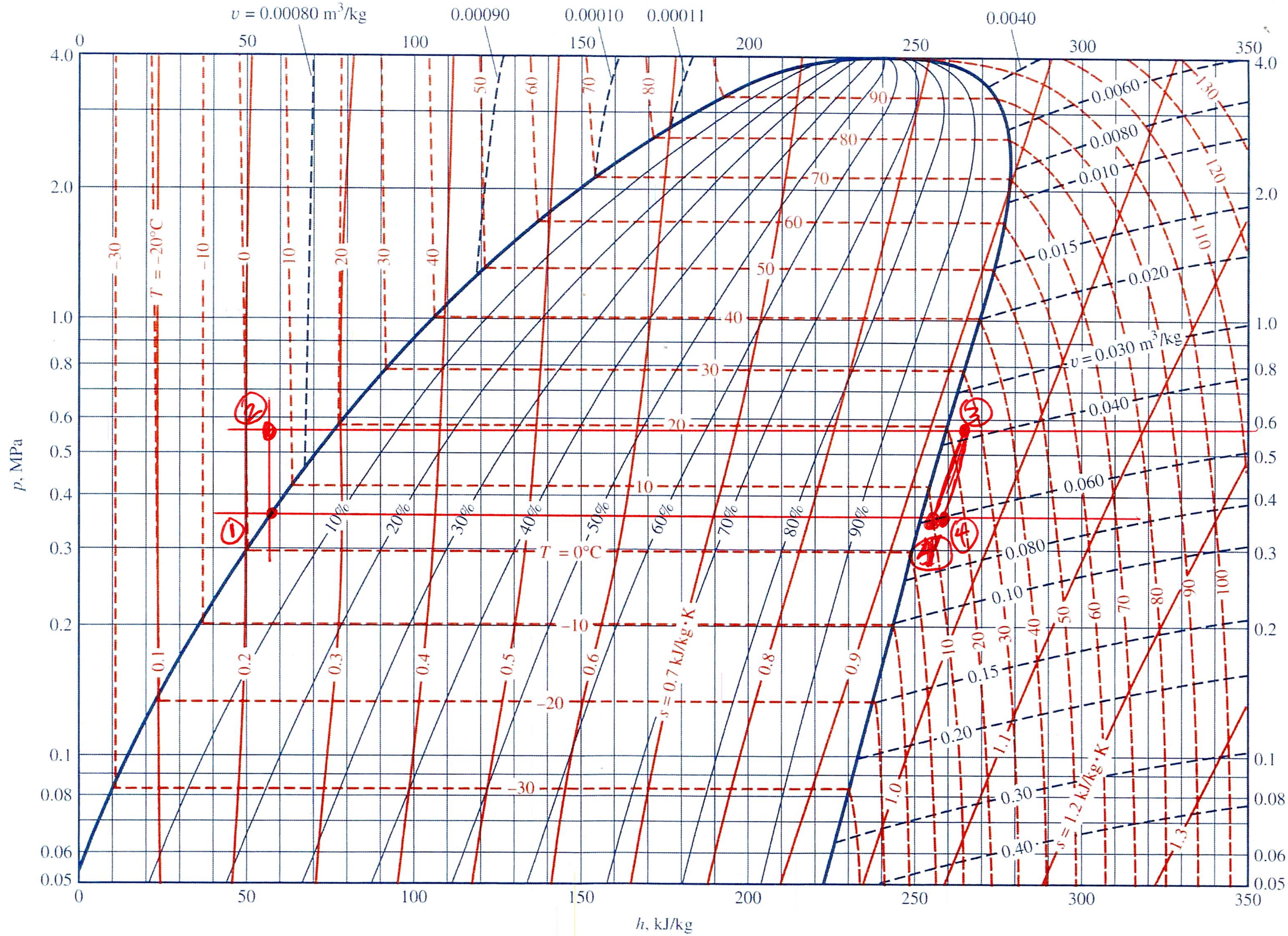

Chart A·11 R134a *ph* diagram. (*Source:* Based on *Thermodynamic Properties of HFC-134a (1,1,1, 2-tetrafluoroethane)*, DuPont Company, Wilmington, Delaware, 1993, with permission.)

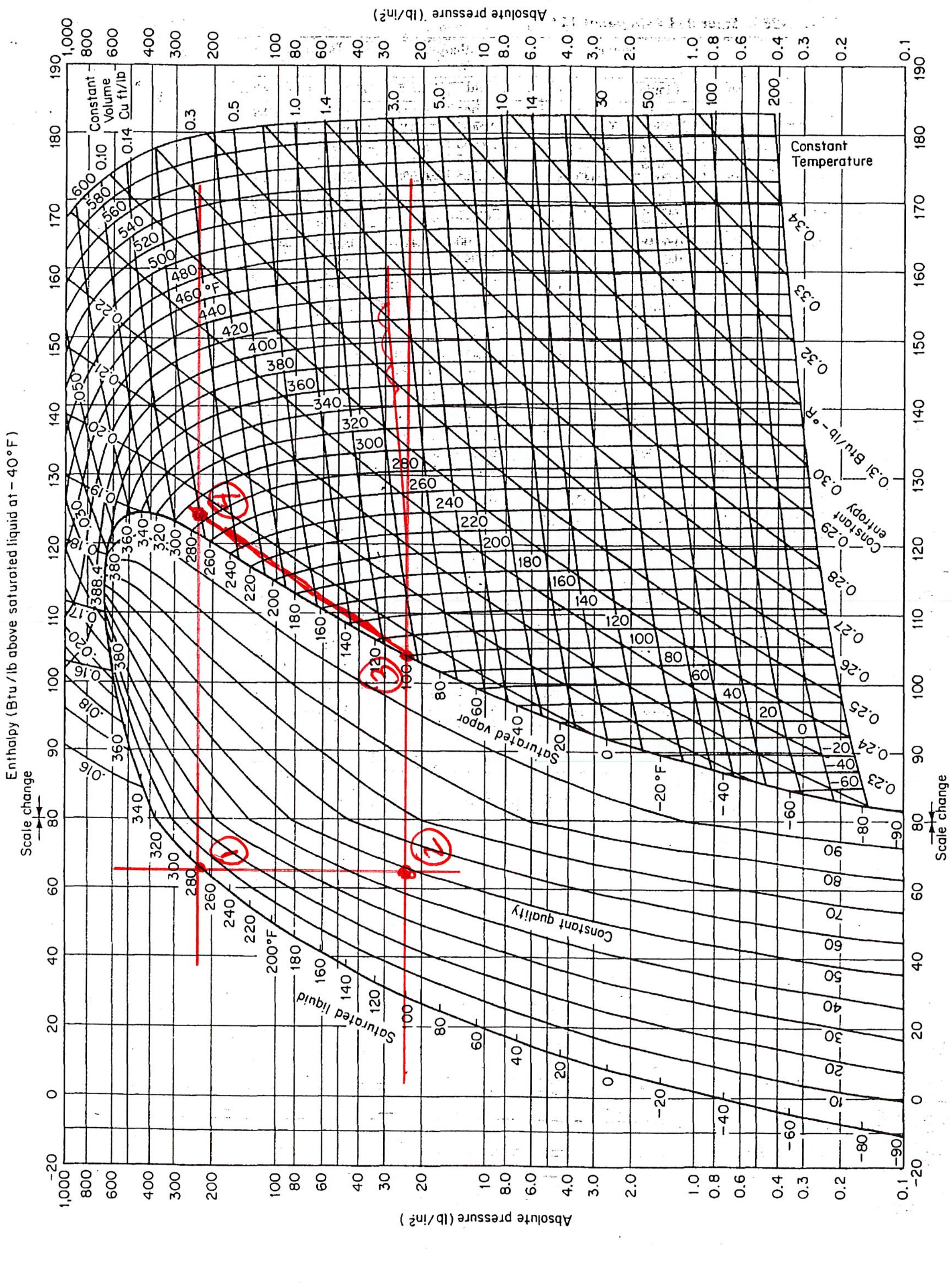

FIG. 3-36. Pressure-enthalpy for Refrigerant 11. Copyright E.I. du Pont de Nemours & Company. Reprinted with permission by the copyright owner. Rombusch and Giesen [*Kältetech.*, 18(2), 37 (1966)] describe the calculation of R11, R12, R13, and R21 properties. The Karlsruhe 1963 *H*-log *P* chart of this group extends from −50° to 320°C., 0.025 to 175 bars. D'Ans Lax "Taschenbuch" (1967) gives a saturation table from −70° to 70°C. The source used here also was selected for the 1967 A.S.H.R.A.E. "Fundamentals" volume, which also gives an enlarged section for pressures from 0.2 to 60 lb./sq. in. abs. Detailed tables for −161(1)388 and 388.4°F. for saturation conditions and from −70° to 570°F., 0.2 to 280 lb./sq. in. abs. for superheat conditions are contained in *du Pont Bulletin* T11 (1965) along with some other property information.