Example Exam

ChE 3172-01 **Final** **December 14, 1996**

Open Books and Notes

Name Solution

I. 30 points

Calculate the theoretical flame temperature for acetylene burned in a 10% stoichiometric excess of a synthetic air mixture consisting of 10 mole % O_2 in 90 mole % helium. For helium, use C_P=20.785 J/mol°K (constant with temperature).

II. 70 points

A conceptual design for a cascaded refrigeration system to reach low temperatures for the liquification of krypton is given in the figure on the next page. The heat of liquification of krypton is 2310 cal/mole, so we will design for $\dot{Q}_{E1}$ = 2310 cal/min load on the low temperature evaporator (EVAP #1) to give 1 mole/min of liquid krypton capacity. Krypton has a critical temperature of 209.4°K=-83°F, so we need to cool well below this temperature and therefore choose T_1=-120°F for the low temperature evaporator. Refrigerant R-503 is suitable for this low temperature. Assume that the condenser, COND #1, for this R-503 cycle operates with an exiting temperature of T_4=-10°F. Taking the R-503 as the system, and using reasonable assumptions for the operating conditions and equipment:

a) 10 points

Calculate the mass flowrate of R-503, $\dot{m}_1$, in lbm/min.

b) 10 points

Calculate the work requirement for compressor #1, $\dot{w}_{s1}$, in horsepower assuming the efficiency of the compressor is 0.8.

c) 10 points

Calculate the heat load on COND #1, $\dot{Q}_{C1}$ in Btu/min.

Refrigerant R-500 appears to be appropriate for operation of the second evaporator, EVAP #2, at T_5=-20°F (this is 10°F colder than COND #1 to provide for a temperature driving force), and the condensed liquid will leave COND #2 above ambient temperature at T_8=100°F. Now, taking the R-500 as the system and again, using reasonable assumptions for the operating conditions and equipment:

d) 10 points

Calculate the heat load on EVAP #2, $\dot{Q}_{E2}$, in Btu/min.

e) 10 points

Calculate the flowrate of R-500, $\dot{m}_2$, in lbm/min.

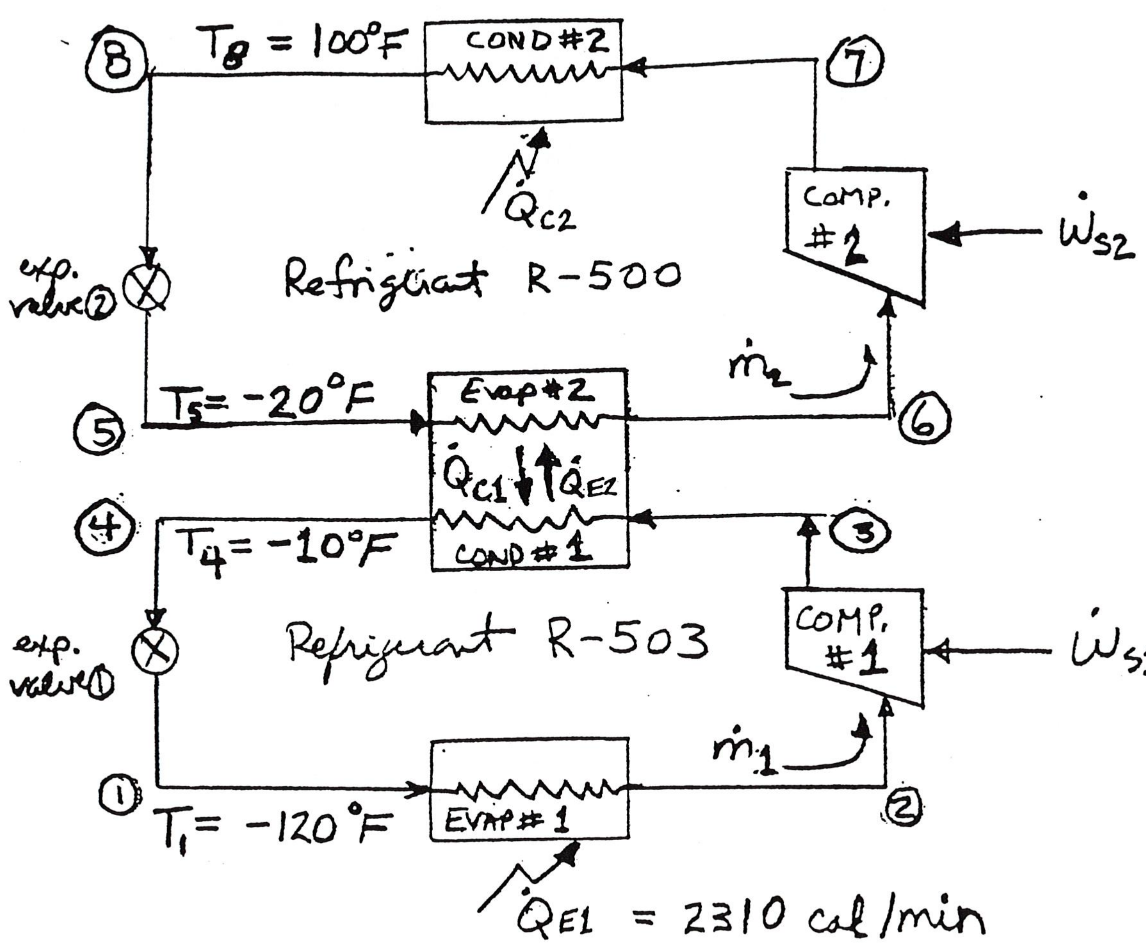
f) 10 points

Calculate the work requirement for compressor #2, $\dot{w}_{s2}$, in horsepower assuming the efficiency of the compressor is 0.8.

g) 10 points

Calculate the heat load on COND #2, $\dot{Q}_{C2}$, in BTU/min.

P-H diagrams for R-503 and R-500 are attached. Please be careful to maintain the formal sign convention that heat added to the system is positive and work done on the system is positive. Be sure to switch systems from R-503 in parts a-c to R-500 in parts d-g. Also, use the numbered points given in the diagram for subscripting your properties.



R-500

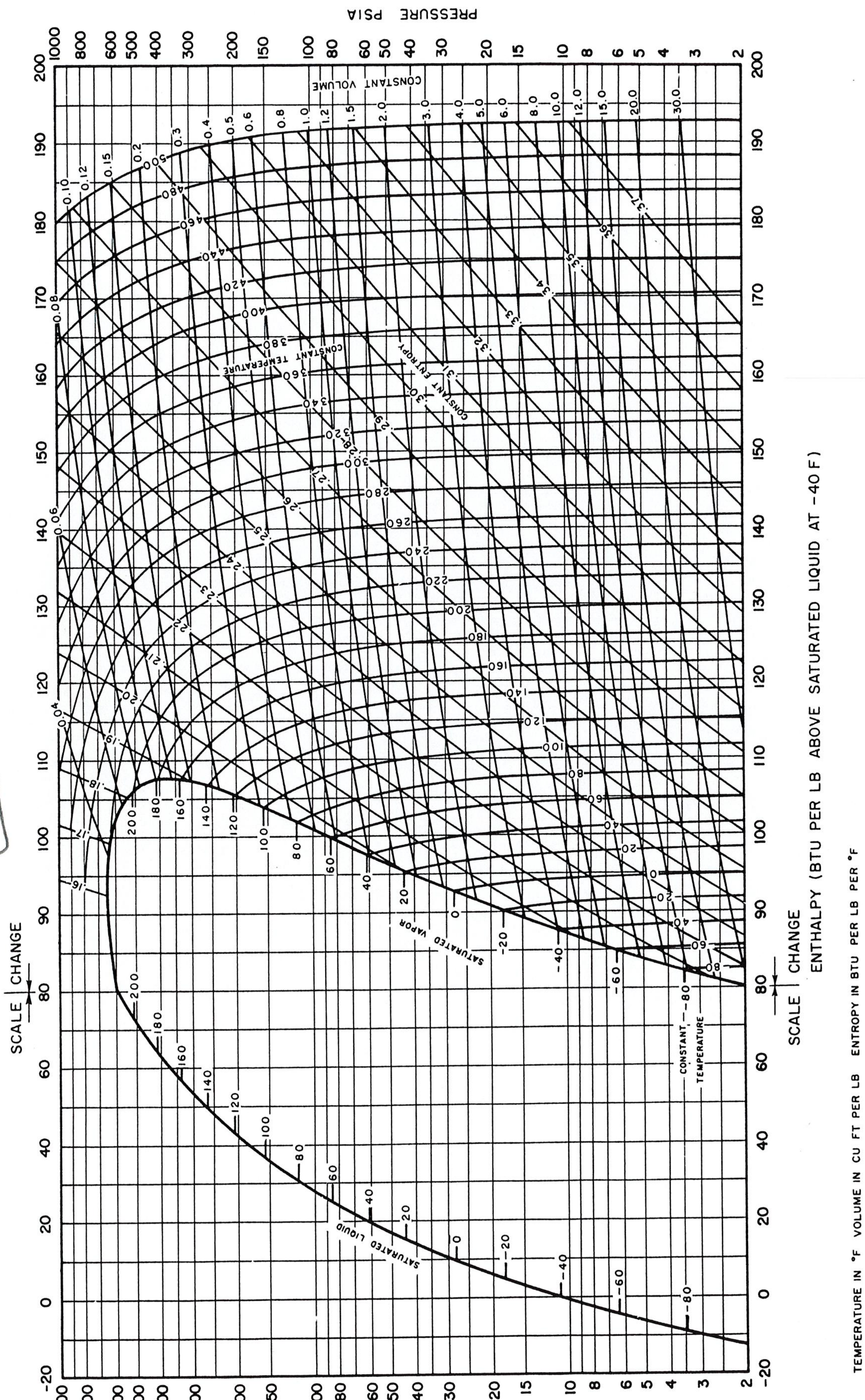


Fig. 9-11. Pressure-enthalpy diagram for refrigerant R-500. Note that 0 of enthalpy scale is taken at −40°F (−40°C). Also note that enthalpy scale changes at 80 Btu per lb. to help technician read superheat values.

R-503

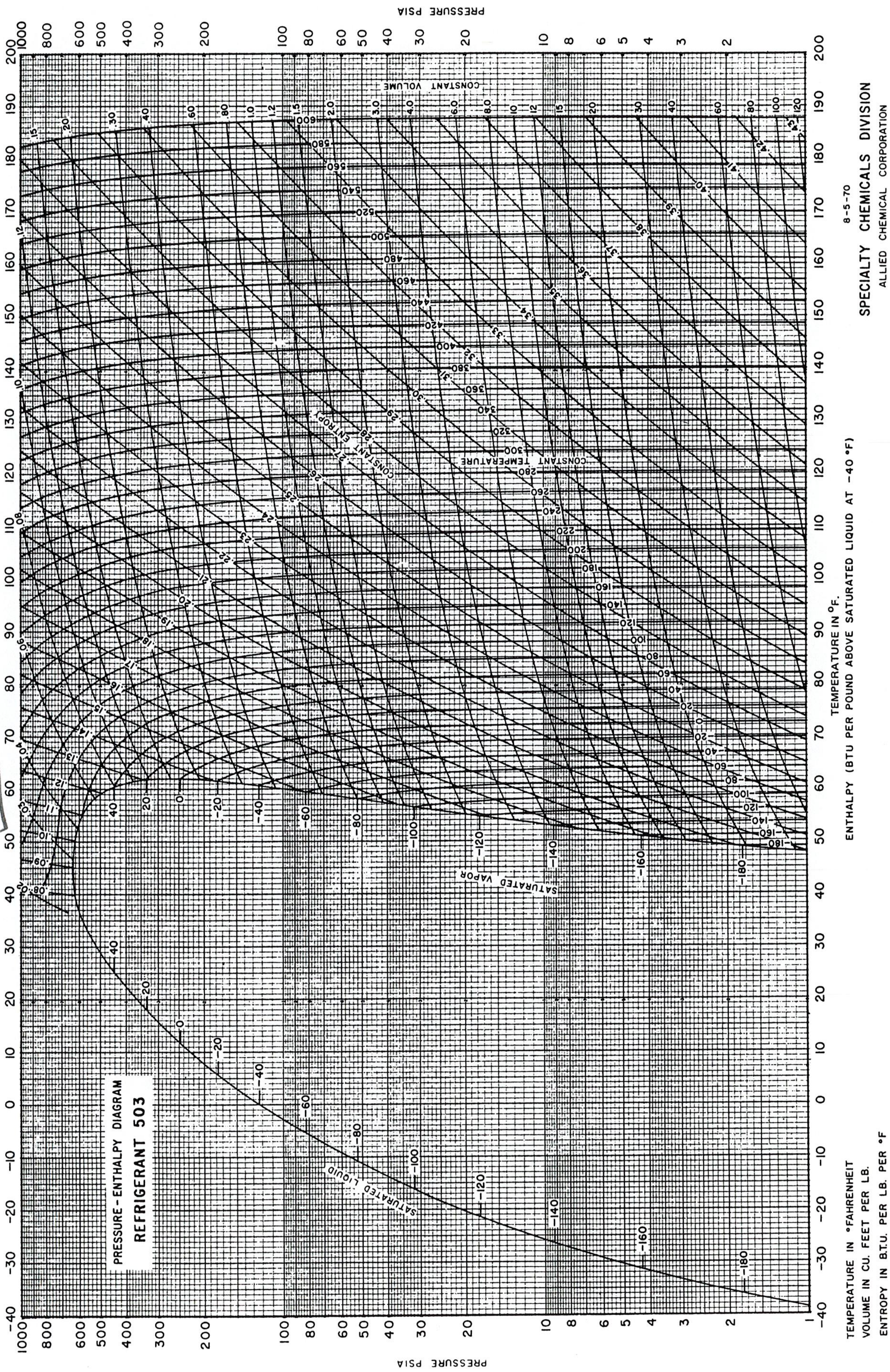


Fig. 9-15. Pressure-enthalpy diagram for refrigerant R-503. (Allied Chemical Corp.)

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Solution

I. $CH \equiv CH + 2\tfrac{1}{2} O_2 \rightarrow 2CO_2 + H_2O$

for 10% xcess O_2, synthetic air 10% O_2, 90% He

	Start	Final
$CH \equiv CH$	1	0
O_2	2.75	0.25
He	24.75	24.75
CO_2	0	2.0
H_2O	0	1.0

$$0 = \Delta H^{o}_{R,298} + \int_{298}^{T_{flame}} \sum_{prod} n_i C_{pi}\, dT$$

$$\Delta H^{o}_{R,298} = 2\Delta H^{o}_{f,CO_2,298} + \Delta H^{o}_{f,H_2O,298} - \Delta H^{o}_{f,298,CH\equiv CH}$$

$$\Delta H^{o}_{R298} = 2(-393,509) + (-241,818) - 1(227,480)$$

$$\Delta H^{o}_{R,298} = -1,256,316 \text{ J/mole}$$

leave out He from the other part of the calc

$\Sigma n_i a = 2(5.457) + (1)(3.470) + 0.25(3.639) = 15.294$

$\Sigma n_i b_i = 10^{-3}[2(1.045) + 1.450 + 0.25(0.506)] = 3.667 \times 10^{-3}$

$\Sigma n_i c_i = 0$

$\Sigma n_i d_i = 10^{5}[2(-1.157) + (0.121) + 0.25(-0.227)] = -2.250 \times 10^{5}$

$\cancel{C_p}$

$\cancel{\Sigma n_i \frac{C_{pi}}{R}}$

To add in He, add $\frac{20.785}{R} = \frac{20.785}{8.314} = 2.5$

multply by 24.75 moles ~~[illegible]~~ $\frac{n_{He} C_p}{R} = \cancel{[illegible]}\ 61.875$

$\Sigma n_i a_i = \cancel{42.794}\ 77.169$

$\Sigma n_i b_i = 3.667 \times 10^{-3}$

$\Sigma n_i c_i = 0$

$\Sigma n_i d_i = -2.250 \times 10^{5}$

$$\frac{1256316}{R} = \int_{298}^{T} \left[\cancel{42.794}\ 77.169 + 3.667 \times 10^{-3} T - \frac{2.25 \times 10^{5}}{T^2} \right] dT$$

$$\cancel{[illegible]}\ 151108.5 = \cancel{42.794}\ 77.169 (T - 298) + \frac{3.667 \times 10^{-3}}{2} (T^2 - 298^2) + 2.25 \times 10^{5} \left(\frac{1}{T} - \frac{1}{298} \right)$$

Guess	RHS
1000	55313
2000	137870
2200	154834
2100	146333
$\boxed{2156.2}$	$\boxed{151106.2}$ close enuf

$T_{FLAME} = 2156.2$ outside C_p range, but OK

II.

a) $T_1 = -120°F$

$T_2 = -120°F$ sat. vapor is assumed

$H_2 = 55$ BTU/lbm

$T_4 = -10°F$, take saturated liquid

$H_4 = 9$ BTU/lbm

$H_1 = H_4 = 9$ BTU/lbm

$\Delta H_{1\to 2} = Q_{E1} = 55 - 9 = 46$ BTU/lbm

$$\dot{m}_1 = \frac{2310 \text{ cal/min}}{46 \text{ BTU/lbm} \times \cancel{\frac{9.47831\times10^{-4}}{\text{BTU}}} \frac{1 \text{ J}}{9.47831\times10^{-4} \text{ BTU}} \times \frac{0.239 \text{ cal}}{\text{J}}}$$

$$\boxed{\dot{m}_1 = 0.199 \text{ lbm/min}}$$

b) for $\Delta S' = 0$

$H'_3 = 78$ BTU/lbm

$\Delta H'_{2\to3} = 78 - 55$ BTU/lbm $= 23$ BTU/lbm

$$\Delta H_{\text{ACTUAL}} = \dot{W}_{S2} = \frac{23}{0.8} = 28.75 \text{ BTU/lbm}$$

$\dot{W}_{S2} = (28.75 \times 0.199 \text{ lbm/min}) = 5.72$ BTU/min

$$\dot{W}_{S2} = (5.72 \text{ BTU/min}) \times \frac{\text{min}}{60 \text{ sec}} \times \frac{1 \text{ KW}}{0.947831 \text{ BTU/sec}} \times \frac{1.341 \text{ HP}}{\text{KW}}$$

$$\boxed{\dot{W}_{S2} = \cancel{0.09} \; 0.135 \text{ HP}}$$

c) heat load on COND#1

$H_{3,ACTUAL} = 55 + 28.75 = 83.75$

$H_{3\to4} = Q_{C1} = \cancel{8}\ 9 - 83.75 = -74.75$ BTU/lbm

$\boxed{\dot{Q}_{C1} = -74.75 \text{ BTU/min} \times 0.199 \text{ lbm/min} = -14.9 \text{ BTU/min}}$

heat leaves the R-503

d) $\boxed{\dot{Q}_{E2} = +14.9 \text{ BTU/min}}$ added to the system

e) $H_6 = 90$ BTU/lbm sat super @ -20°F

$H_5 = H_8 = 37$ BTU/lbm ⑧ at sat liq @ 100°F

$\Delta H_{5\to6} = Q_{E2} = 90 - 37 = 53$ BTU/lbm

$$\boxed{\dot{m}_2 = \cancel{83 \text{ BTU/lbm}}\ \frac{14.9 \text{ BTU/min}}{53 \text{ BTU/lbm}} = 0.281 \text{ lbm/min}}$$

f) for $\Delta S' = 0$

$H_7 = 110.$ BTU/lbm

$\Delta H'_{6\to7} = 110 - 90 = 20$ BTU/lbm

$$\Delta H_{ACTUAL} = \frac{20}{0.8} = 25 \text{ BTU/lbm}$$

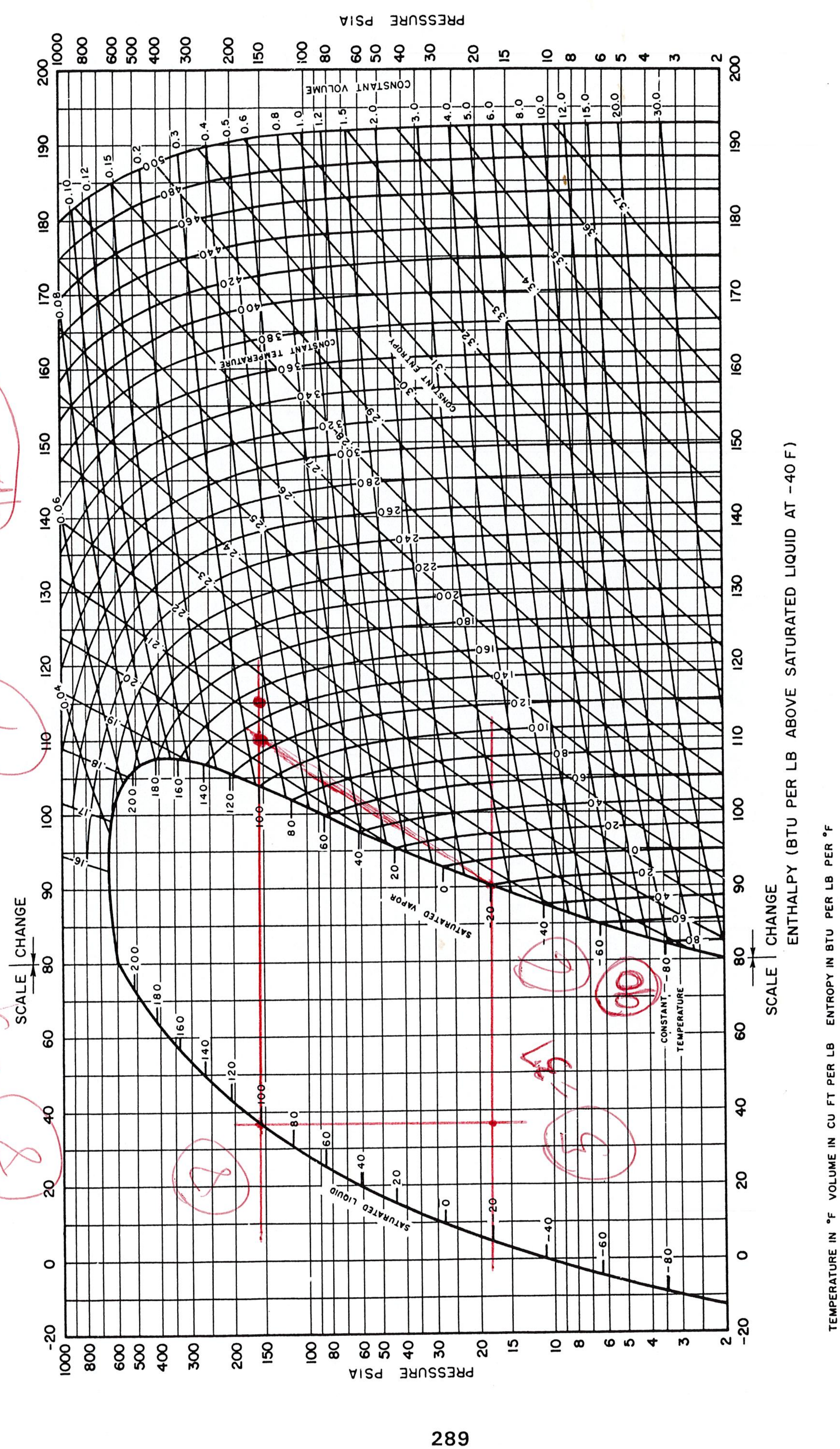
$\dot{W}_s = 25 \text{ BTU/lbm} \times 0.281 \text{ lbm/min} = 7.025$ BTU/min

$$\boxed{\dot{W}_s = 7.025 \frac{\text{BTU}}{\text{min}} \times \frac{1 \text{ min}}{60 \text{ sec}} \times \frac{1.341}{0.947831} = 0.166 \text{ HP}}$$

g) $H_{7,ACTUAL} = 90 + 25 = 115$

$\Delta H_{7\to8} = 115 - 37 = 78$ BTU/lbm

$\boxed{\dot{Q}_{C2} = 78 \text{ BTU/lbm} \times 0.281 \text{ lbm/min} = 21.9 \text{ BTU/min}}$



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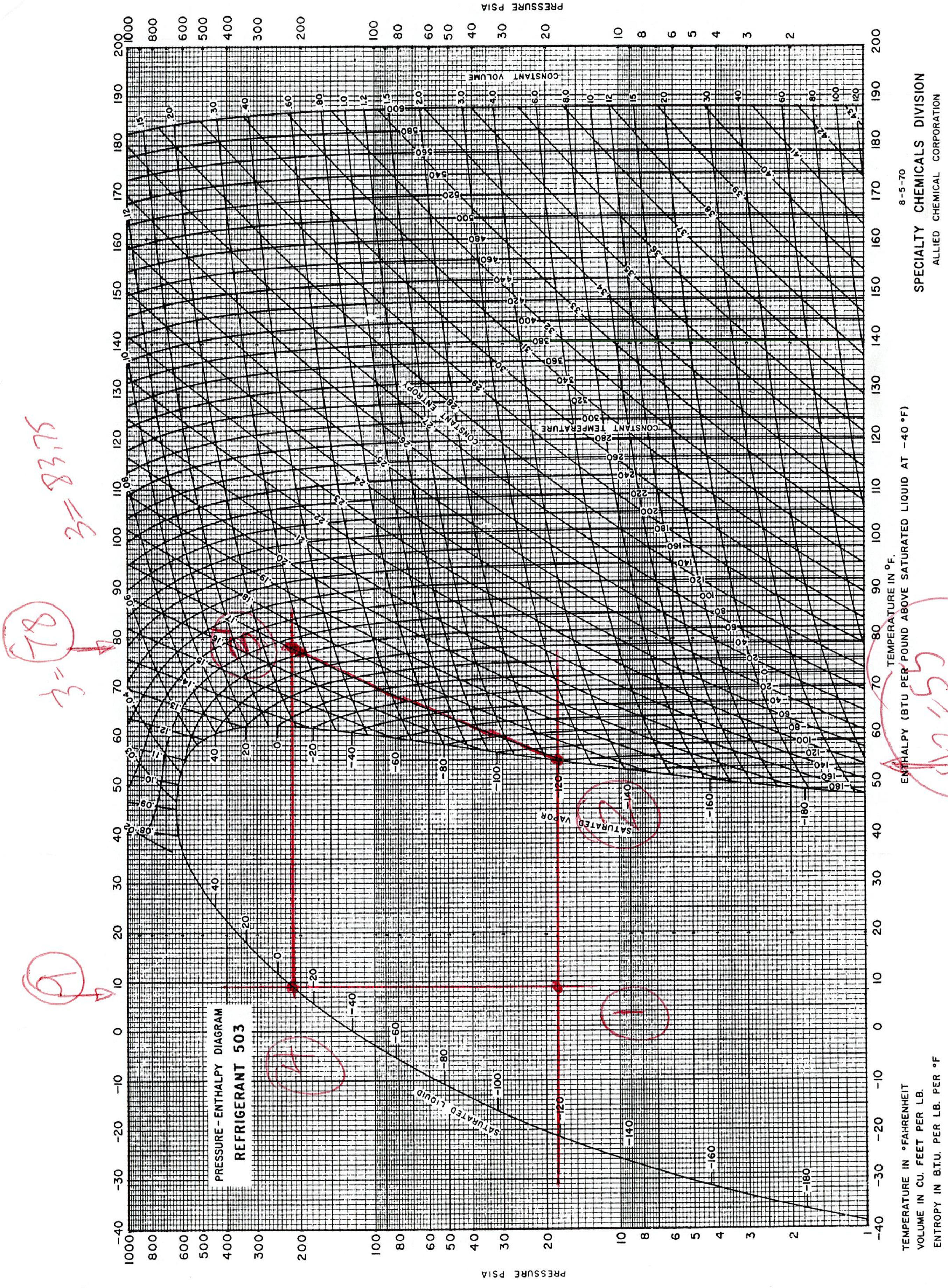

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