S.I.A.E

THERMODYNAMIQUE APPLIQUEE

AUX MACHINES THERMIQUES

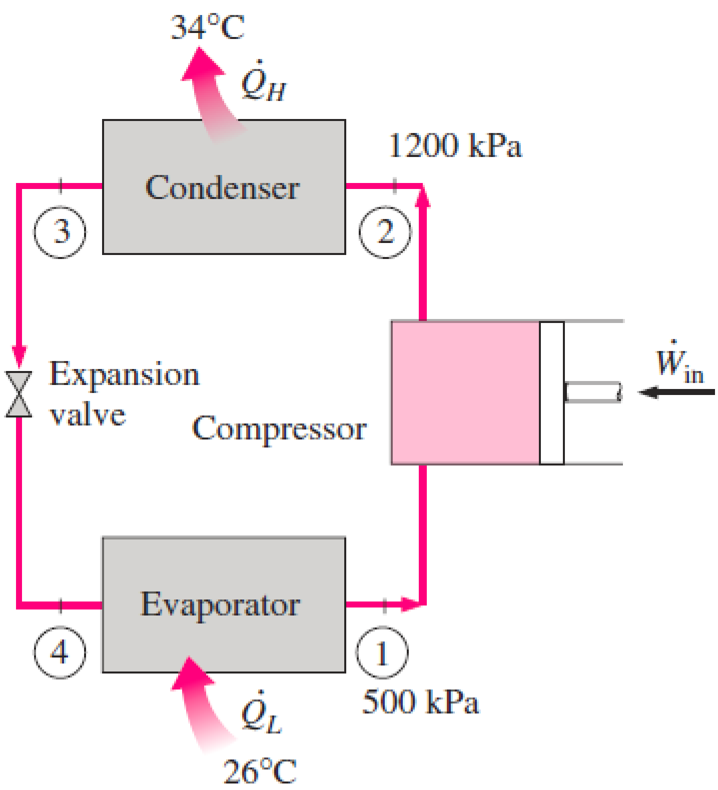
Examen du 28 Juin 2013

Durée : 2 heures

Documents non autorisés

PREMIERE PARTIE : THERMODYNAMIQUE DES MACHINES THERMIQUES

cycle de réfrigération



An air conditioner with refrigerant-134a as the working fluid is used to keep a room at 26℃ by rejecting the waste heat to the outside air at 34℃. The room is gaining heat through the walls and the windows at a rate of 250 kJ/min while the heat generated by the computer, TV, and lights amounts to 900 W. An unknown amount of heat is also generated by the people in the room. The condenser and evaporator pressures are1200 and 500 kPa, respectively. The refrigerant is saturated liquid at the condenser exit and saturated vapor at the compressor inlet. If the refrigerant enters the compressor at a rate of 100 L/min and the isentropic efficiency of the compressor is 75 percent, Please show the cycle on a p-h diagram and on a T-s diagram with respect to saturation lines. Determine ：

(a) the temperature of the refrigerant at the compressor exit ；

(b) the rate of heat generation by the people in the room ；

(c) the COP of the air conditioner ；

(d) the minimum volum flow rate of the refrigerant at the compressor inlet for the same compressor inlet and exit conditions.

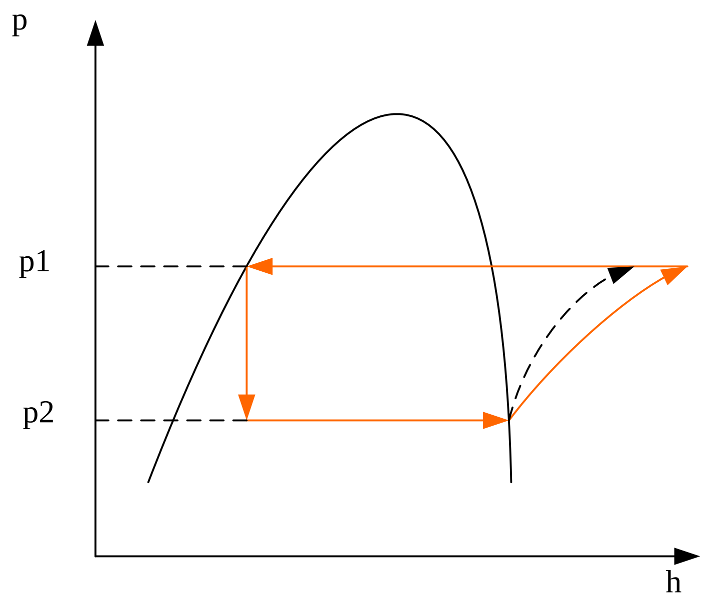
中文：一空调使用 R134a 作为冷却剂来保持室内温度为 26℃，同时将废热排到外面，外界大气温度为 34℃，屋内通过墙壁和玻璃会得到 250 kJ/min 的热量，同时电视、计算机和灯会产生 900W 的热量，人体产生的热量未知。冷凝室和蒸发室内的压力分别为 1200 kPa 和 500 kPa。冷却剂在冷凝室出口为饱和液体，在压气机进口为饱和蒸气，如果进入压气机的冷却剂流量为 100 L/min，同时压气机的等熵效率为 75%，请将循环在带有饱和线的 p-h 图和 T-s 图上表示出来，并确定：

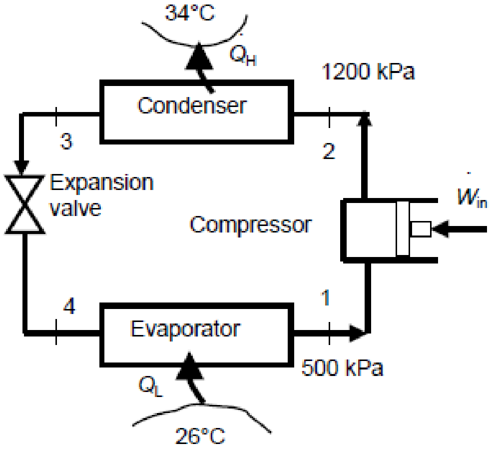
（a） 压气机出口冷却剂的温度；

（b） 室内人体产生的热量；

（c） 空调装置的性能系数；

（d） 在同样的压气机进口和出口条件下，压气机进口冷却剂的最小体积流量。 提示：此时循环为理想卡诺循环。





$$\left.\begin{array}{l} P_1 = 500\text{ kPa} \\ x_1 = 1 \end{array}\right\} \begin{array}{l} h_1 = 259.30\text{ kJ/kg} \\ v_1 = 0.04112\text{ kJ/kg} \\ s_1 = 0.9240\text{ kJ/kg} \end{array}$$

$$\left.\begin{array}{l} P_2 = 1200\text{ kPa} \\ s_2 = s_1 \end{array}\right\} h_{2s} = 277.39$$

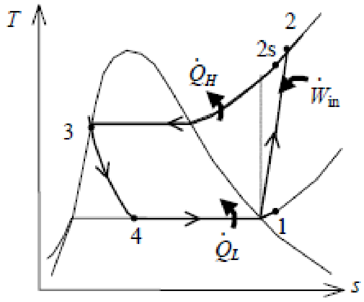
$$h_3 = h_{f@1200\text{ kPa}} = 117.77\text{ kJ/kg}$$

$$h_4 = h_3 = 117.77\text{ kJ/kg}$$

$$\eta_C = \frac{h_{2s} - h_1}{h_2 - h_1}$$

$$0.75 = \frac{277.39 - 259.30}{h_2 - 259.30} \longrightarrow h_2 = 283.42\text{ kJ/kg}$$

$$\left.\begin{array}{l} P_2 = 1200\text{ kPa} \\ h_2 = 283.42\text{ kJ/kg} \end{array}\right\} T_2 = \mathbf{54.5°C}$$



(*b*) The mass flow rate of the refrigerant is

$$\dot{m} = \frac{\dot{V}_1}{v_1} = \frac{(100\text{ L/min})\left(\dfrac{1\text{ m}^3}{1000\text{ L}}\right)\left(\dfrac{1\text{ min}}{60\text{ s}}\right)}{0.04112\text{ m}^3/\text{kg}} = 0.04053\text{ kg/s}$$

The refrigeration load is

$$\dot{Q}_L = \dot{m}(h_1 - h_4)$$
$$= (0.04053\text{ kg/s})(259.30 - 117.77)\text{kJ/kg} = 5.737\text{ kW}$$

which is the total heat removed from the room. Then, the rate of heat generated by the people in the room is determined from

$$\dot{Q}_{\text{people}} = \dot{Q}_L - \dot{Q}_{\text{heat}} - \dot{Q}_{\text{equip}} = (5.737 - 250/60 - 0.9)\text{ kW} = \mathbf{0.67\text{ kW}}$$

(*c*) The power input and the COP are

$$\dot{W}_{\text{in}} = \dot{m}(h_2 - h_1) = (0.04053\text{ kg/s})(283.42 - 259.30)\text{kJ/kg} = 0.9774\text{ kW}$$

$$\text{COP} = \frac{\dot{Q}_L}{\dot{W}_{\text{in}}} = \frac{5.737}{0.9774} = \mathbf{5.87}$$

(*d*) The reversible COP of the cycle is

$$\text{COP}_{\text{rev}} = \frac{1}{T_H/T_L - 1} = \frac{1}{(34+273)/(26+273) - 1} = 37.38$$

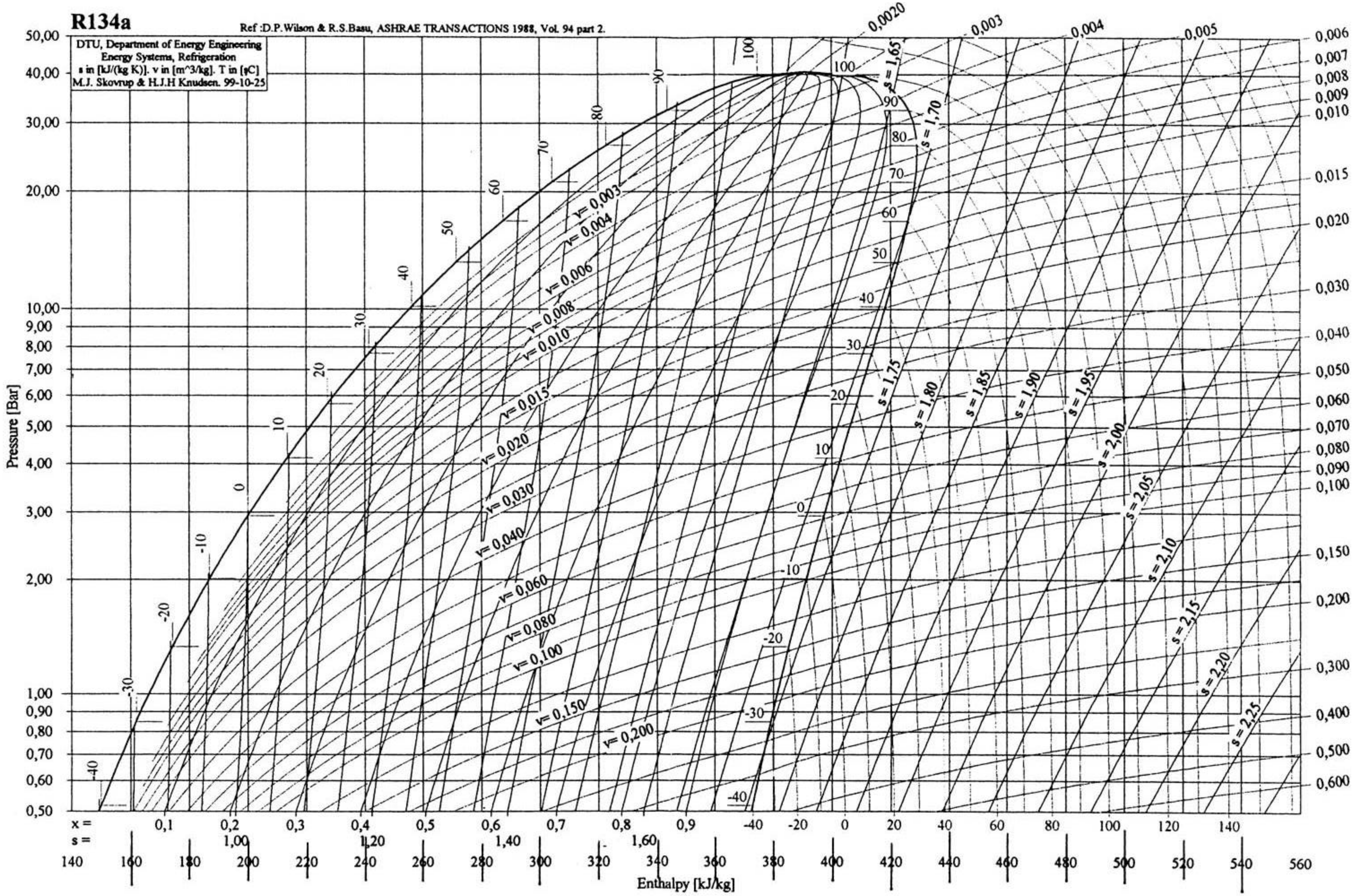
The corresponding minimum power input is

$$\dot{W}_{\text{in,min}} = \frac{\dot{Q}_L}{\text{COP}_{\text{rev}}} = \frac{5.737\text{ kW}}{37.38} = 0.1535\text{ kW}$$

The minimum mass and volume flow rates are

$$\dot{m}_{\text{min}} = \frac{\dot{W}_{\text{in,min}}}{h_2 - h_1} = \frac{0.1535\text{ kW}}{(283.42 - 259.30)\text{kJ/kg}} = 0.006366\text{ kg/s}$$

$$\dot{V}_{1,\text{min}} = \dot{m}_{\text{min}} v_1 = (0.006366\text{ kg/s})(0.04112\text{ m}^3/\text{kg}) = (0.0002617\text{ m}^3/\text{s}) = \mathbf{15.7\text{ L/min}}$$



R134a
Ref :D.P.Wilson & R.S.Basu, ASHRAE TRANSACTIONS 1988, Vol. 94 part 2.
DTU, Department of Energy Engineering
Energy Systems, Refrigeration
s in [kJ/(kg K)]. v in [m^3/kg]. T in [°C]
M.J. Skovrup & H.J.H Knudsen. 99-10-25
Pressure [Bar]
50,00
40,00
30,00
20,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,90
0,80
0,70
0,60
0,50
x =
s =
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,00
1,20
1,40
1,60
Enthalpy [kJ/kg]
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
520
540
560
v= 0,003
v= 0,004
v= 0,006
v= 0,008
v= 0,010
v= 0,015
v= 0,020
v= 0,030
v= 0,040
v= 0,060
v= 0,080
v= 0,100
v= 0,150
v= 0,200
s = 1,65
s = 1,70
s = 1,75
s = 1,80
s = 1,85
s = 1,90
s = 1,95
s = 2,00
s = 2,05
s = 2,10
s = 2,15
s = 2,20
s = 2,25
0,0020
0,003
0,004
0,005
0,006
0,007
0,008
0,009
0,010
0,015
0,020
0,030
0,040
0,050
0,060
0,070
0,080
0,090
0,100
0,150
0,200
0,300
0,400
0,500
0,600

DEUXIEME PARTIE : THERMOCHIMIE

Une des solutions permettant de réduire les émissions polluantes dans les produits de combustion, est d'avoir recours à des mélanges pauvres. Toutefois, ce choix peut aboutir à la formation de NOx. C'est pourquoi des études sont actuellement menées sur des moteurs fonctionnant au gaz naturel. La composante majeure de ce combustible est le méthane qui sera donc l'objet de ce problème. On considèrera ici un mélange de cet hydrocarbure dans l'air selon la composition :

$$CH_4 + z_i\,(0.21\,O_2 + 0.79\,N_2)$$

On fixera la richesse r=0.8.

1）Enthalpies de formation H^*_{Fi} (à $T = T^*$) des divers constituants)

i	CH_4	C_2H_4	C_3H_8	CO_2	CO	$H_2O(g)$
$H^*_{F\,i}$（kcal/mole）	-17.9	12.5	-24.8	-94.05	-26.42	-57.8

2）Enthalpie de vaporisation de l'eau à T^* :

$H_{v,H2O}$=10.5kcal/mole.

A : On considère le mélange frais et les gaz brûlés à la température T*

1) Calculer z_{ist}.
2) Calculer la composition des gaz brûlés à T* pour la richesse considérée.
3) En déduire l'enthalpie de réaction $\Delta_R H^*$ à T*.

B : On porte les gaz brûlés à la température T=2500 K.

Les gaz brûlés peuvent maintenant être le siège de réactions de dissociation. Parmi celles qui sont proposées ci-après, on indiquera les réactions de dissociation susceptibles d'être prises en compte :

	Kp
$CO_2 + H_2 = CO + H2O$	0,1645
$H_2 = 2H$	6,256.10E-04
$N_2 = 2N$	8,452.10E-14
$O_2 = 2O$	2,067.10E-04
$N_2 + O_2 = 2NO$	0,0035
$H_2 + O_2 = 2OH$	0,7573

Déterminer la composition de gaz brûlés à T=2500 K

A : On considère le mélange frais et les gaz brûlés à la température T*

1) Calculer z_{ist}.
   9.524
2) Calculer la composition des gaz brûlés à T* pour la richesse considérée.

   $$CH_4 + 11.9(0.21O_2 + 0.79N_2) \rightarrow CO_2 + 2H_2O(g) + 0.499O_2 + 9.4N_2$$

3) En déduire l'enthalpie de réaction $\Delta_R H^*$ à T*.

   $$\Delta_R H^* = H_{F,CO_2} + 2H_{F,H_2O} - H_{F,CH_4}$$

   -191.75kcal/mol,CH_4 or -212.75kcal/mol,CH_4

B : On porte les gaz brûlés à la température T=2500 K.

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Déterminer la composition de gaz brûlés à T=2500 K

N_2+O_2 = 2NO major reaction

$x_{CO_2} = 1$ $x_{H_2O} = 2$ $x_{N_2} = 9.34$ $x_{O_2} = 0.44$ $x_{NO} = 0.12$

C : Décrit comment obtenir température de flamme isobare adiabatique.

1. Qualification of the mixture: stoichiometric or ?
2. Composition of the products @ room temperature
3. Calculation of the heat of reaction
4. Guess of expected composition @ high temperature and identification of unknowns
5. Identification of available equilibrium reactions that involve the unknowns
6. Expressions of degree of advancement of these reactions and equilibrium constants
7. Set of equations that include both the mass balance and equilibrium constants of the reactions
8. Solving this set of equations

9. Calculation of enthalpy of the non dissociated products
10. Calculation of enthalpy of the dissociated products
11. Final enthalpy = summation of both values
8. Plot of final enthalpy vs. temperature (two data points only)
9. Linear interpolation of temperature that fit the heat of reaction (graphical solution)

TROISIEME PARTIE : THERMODYNAMIQUE

Determine the specific volume of refrigerant-134a at 1 Mpa and 50℃, using the generalized compressibility chart.

中文：使用通用压缩因子图确定冷却剂 R-134a 在 1 Mpa，50℃时的比体积。

TABLE A-1 Atomic or Molecular Weights and Critical Properties of Selected Elements and Compounds

Substance	Chemical Formula	M (kg/kmol)	T_c (K)	p_c (bar)	$Z_c = \frac{p_c v_c}{RT_c}$
Acetylene	C_2H_2	26.04	309	62.8	0.274
Air (equivalent)	—	28.97	133	37.7	0.284
Ammonia	NH_3	17.03	406	112.8	0.242
Argon	Ar	39.94	151	48.6	0.290
Benzene	C_6H_6	78.11	563	49.3	0.274
Butane	C_4H_{10}	58.12	425	38.0	0.274
Carbon	C	12.01	—	—	—
Carbon dioxide	CO_2	44.01	304	73.9	0.276
Carbon monoxide	CO	28.01	133	35.0	0.294
Copper	Cu	63.54	—	—	—
Ethane	C_2H_6	30.07	305	48.8	0.285
Ethyl alcohol	C_2H_5OH	46.07	516	63.8	0.249
Ethylene	C_2H_4	28.05	283	51.2	0.270
Helium	He	4.003	5.2	2.3	0.300
Hydrogen	H_2	2.016	33.2	13.0	0.304
Methane	CH_4	16.04	191	46.4	0.290
Methyl alcohol	CH_3OH	32.04	513	79.5	0.220
Nitrogen	N_2	28.01	126	33.9	0.291
Octane	C_8H_{18}	114.22	569	24.9	0.258
Oxygen	O_2	32.00	154	50.5	0.290
Propane	C_3H_8	44.09	370	42.7	0.276
Propylene	C_3H_6	42.08	365	46.2	0.276
Refrigerant 12	CCl_2F_2	120.92	385	41.2	0.278
Refrigerant 22	$CHClF_2$	86.48	369	49.8	0.267
Refrigerant 134a	CF_3CH_2F	102.03	374	40.7	0.260
Sulfur dioxide	SO_2	64.06	431	78.7	0.268
Water	H_2O	18.02	647.3	220.9	0.233

Sources: Adapted from *International Critical Tables* and L. C. Nelson and E. F. Obert, Generalized Compressibility Charts, *Chem. Eng.*, *61:* 203 (1954).

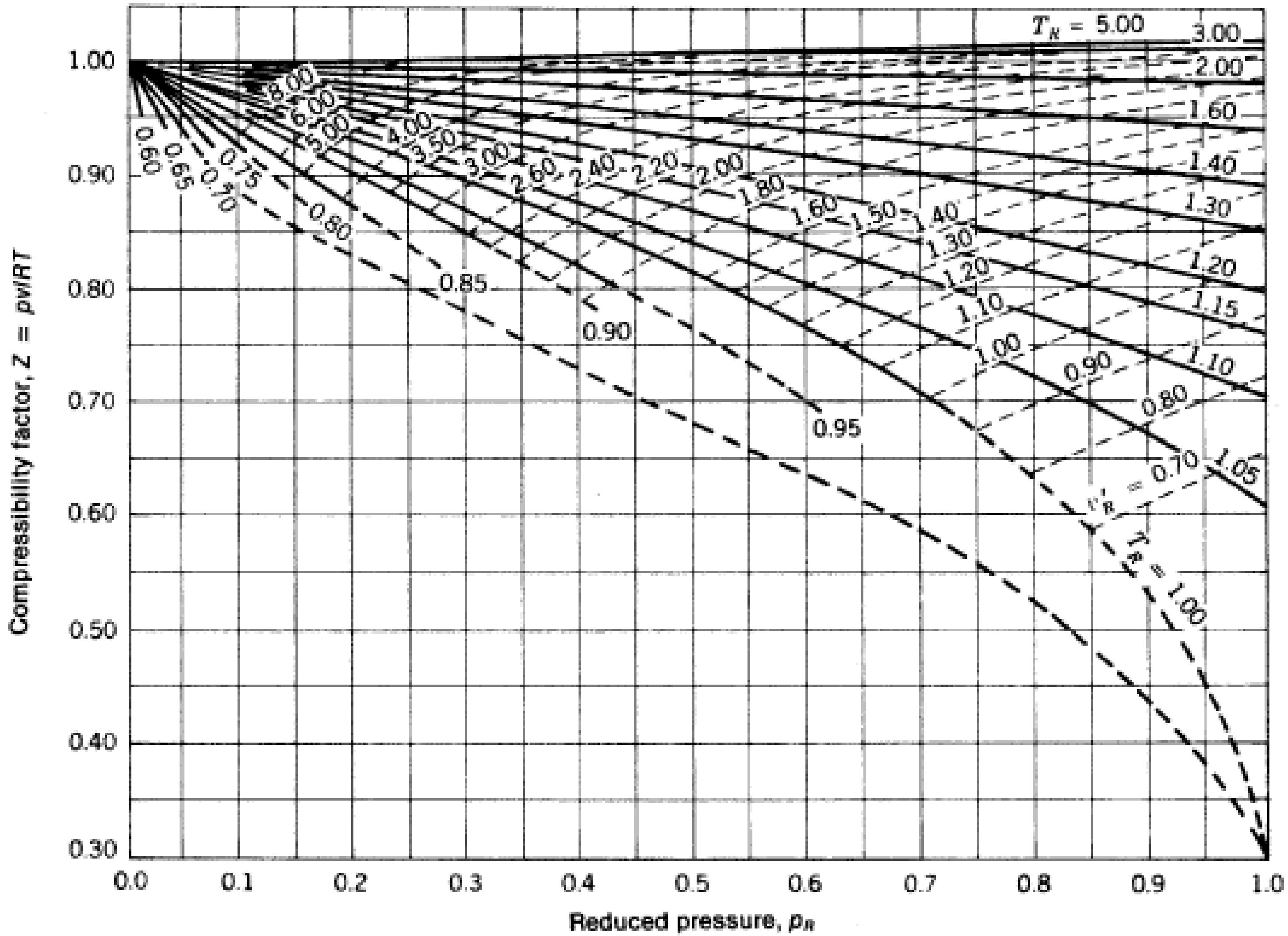

Figure A-1 Generalized compressibility chart, $p_R \leq 1.0$. *Source:* E. F. Obert, *Concepts of Thermodynamics*, McGraw-Hill, New York, 1960.

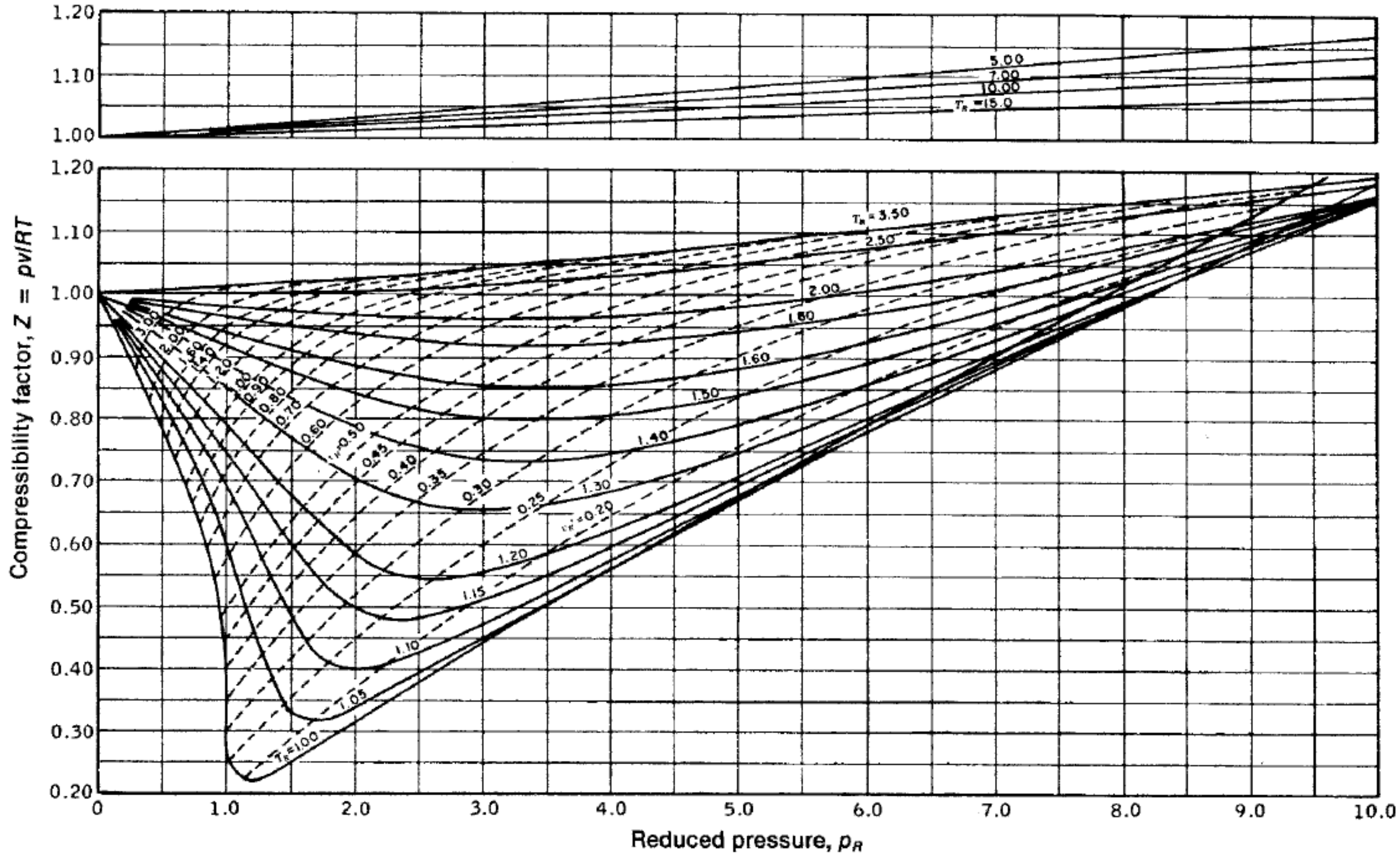

Figure A-2 Generalized compressibility chart, $p_R \leq 10.0$. *Source:* E. F. Obert, *Concepts of Thermodynamics,* McGraw-Hill, New York, 1960.

Analysis The gas constant, the critical pressure, and the critical temperature of refrigerant-134a are determined from Table A–1 to be

$$R = 0.0815 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K}$$

$$P_{cr} = 4.059 \text{ MPa}$$

$$T_{cr} = 374.2 \text{ K}$$

(*b*) To determine the correction factor Z from the compressibility chart, we first need to calculate the reduced pressure and temperature:

$$\left.\begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{1 \text{ MPa}}{4.059 \text{ MPa}} = 0.246 \\ T_R &= \frac{T}{T_{cr}} = \frac{323 \text{ K}}{374.2 \text{ K}} = 0.863 \end{aligned}\right\} \quad Z = 0.84$$

Thus

$$v = Zv_{ideal} = (0.84)(0.026325 \text{ m}^3/\text{kg}) = \mathbf{0.022113\ m^3/kg}$$