# FIS1523 - Interrogación Nro. 1

Facultad de Física
Pontificia Universidad Católica de Chile
Primer Semestre 2013

| P1 | P2 | P3 | Nota |
|---|---|---|---|
| | | | |

**Tiempo para responder: 120 minutos**

**Nombre:** _____ **Sección:** _____

**Atención!!**

- Si utiliza lápiz de grafito, perderá la posibilidad de reclamar errores de corrección.
- El profesor no se hace responsable de las respuestas que los ayudantes puedan dar a sus consultas durante el examen.

## Problema 1

Se ha formado hielo en un estanque poco profundo y se ha alcanzado un estado estacionario estando el aire de encima del hielo a $T_a = -5{,}20$ °C y el fondo del estanque a $T_f = 3{,}98$ °C. La profundidad total del hielo + agua es de 1.42 m? Suponga que las conductividades térmicas del hielo y el agua son de 1.67 y 0.502 W/m·K, respectivamente).

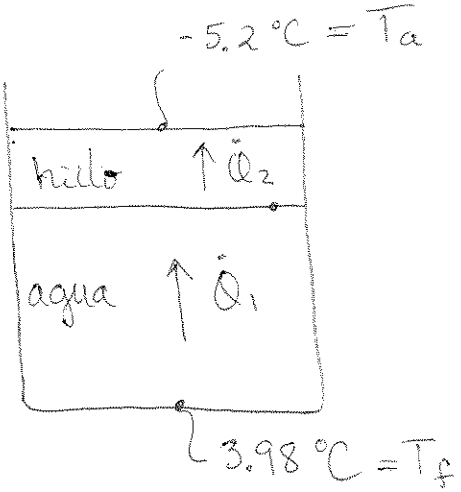
(a) (1 punto) Cuál es la temperatura en la interfaz hielo-agua?

(b) (1 punto) Escriba la condición para las tasas de transferencia de calor a través del agua $\dot{Q}_1$ y el hielo $\dot{Q}_2$ que describe el enunciado.

(b) (4 puntos) Qué espesor tiene el hielo?

# Problema 1

Consideremos la siguiente figura




a) La temperatura en la interfaz hielo-agua es 0°C, $T_i = 0\ °C$.

b) Para que el sistema se encuentre en estado estacionario la tasa de transferencia por calor a través de la capa de agua debe ser igual a la transferencia de energía por calor a través de la capa de hielo. De esta manera la energía no se acumula ni disminuye en la capa de hielo. El hielo no aumenta ni disminuye su espesor.

$$\dot{Q}_1 = \dot{Q}_2$$

c)

$$\dot{Q}_1 = \frac{k_{agua} A (T_f - T_i)}{d_{agua}} \qquad \dot{Q}_2 = \frac{k_{hielo} A (T_i - T_a)}{d_{hielo}}$$

donde $k_{agua}$ y $k_{hielo}$ son las conductividades térmicas del agua y hielo, respectivamente. Luego,

$$\frac{3.98\ k_{agua}}{5.2\ k_{hielo}} = \frac{d_{agua}}{d_{hielo}}$$

pero sabemos que $d_{agua} + d_{hielo} = 1.42\ m$

Entonces, $$\frac{3.98\,k_{agua} + 5.2\,k_{hielo}}{5.2\,k_{hielo}} = \frac{d_{agua} + d_{hielo}}{d_{hielo}} = \frac{1.42\ m}{d_{hielo}}$$

$$d_{hielo} = \frac{1.42\ m \times 5.2\,k_{hielo}}{3.98\,k_{agua} + 5.2\,k_{hielo}} = \frac{1.42 \times 5.2 \times 1.67}{3.98 \times 0.502 + 5.2 \times 1.67} = 1.15\ m$$

**Nombre:** _____

## Problema 2

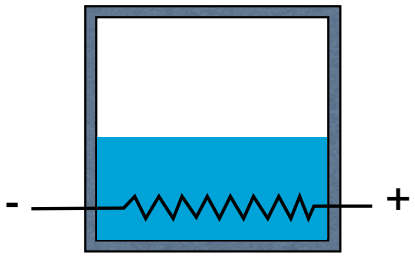
Un recipiente rígido y bien aislado contiene 5 kg de agua en mezcla saturada líquido-vapor a 200 kPa. Inicialmente, tres cuartos de la masa se encuentra es fase líquida. Al recipiente se ingresa calor por medio de una resistencia a una tasa de 800 Watts a partir de $t = 0$ hasta que toda el agua se convierte en vapor.

(a) (1.5 puntos) Muestre el proceso en un diagrama $T - \nu$.

(b) (1.5 puntos) Determine el volumen específico y la energía específica del estado inicial.

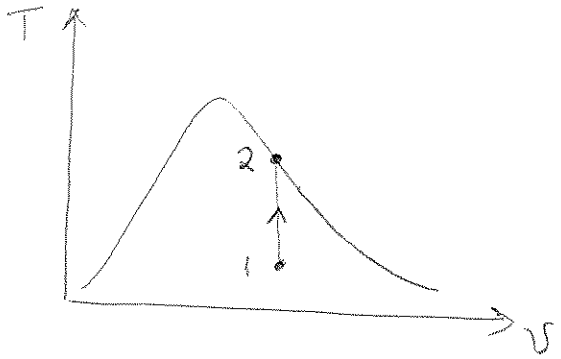
(c) (1.5 puntos) Determine el volumen específico y energía específica del estado final.

(d) (1.5 puntos) Cuanto tiempo tardará en convertirse toda el agua en vapor.



# Problema 2

a) La energía transferida por calor convierte toda el agua en vapor. El volumen del recipiente es constante




b) Ya que $\frac{3}{4}$ de la masa se encuentra en fase líquida, $x_1 = 0.25$

Si $P_1 = 200$ kPa, de la tabla para el agua saturada leemos

$v_f = 0.001061$ m³/kg  $u_f = 504.50$ kJ/kg

$v_g = 0.88578$ m³/kg  $u_g = 2529.1$ kJ/kg

$v_{fg} = 0.8847$ m³/kg  $u_{fg} = 2024.6$ kJ/kg

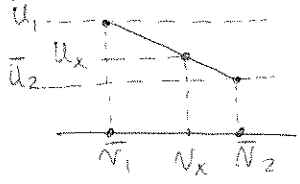
luego $v_1 = v_f + x_1 v_{fg} = 0.2222$ m³/kg

$u_1 = u_f + x_1 u_{fg} = 1010.6$ kJ/kg

c) El volumen se mantiene, por lo tanto $v_2 = v_1 = v_g$

los valores para $u_2$ más cercanos de la tabla son

| $v_g$ (m³/kg) | $u_g$ (kJ/kg) |
|---|---|
| 0.22690 | 2577.9 |
| 0.21489 | 2579.6 |




$$u_x = \bar{u}_1 + \frac{(\bar{u}_2 - \bar{u}_1)}{(\bar{v}_2 - \bar{v}_1)}(v_x - \bar{v}_1)$$

Interpolando $u_2 = 2578.6$ $\frac{kJ}{kg}$

d) El tiempo que tardará en convertirse el agua en vapor es

$$W \cdot \Delta t = \Delta U = m(u_2 - u_1), \quad \Delta t = \frac{5\,kg \times (2578.6 - 1010.6)\,kJ/kg}{800\ J/s}$$

$\Delta t = 9800$ seg $= 163.3$ min //

## TABLE A–5

Saturated water—Pressure table

| | | Specific volume, $m^3/kg$ | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg · K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Press., $P$ kPa | Sat. temp., $T_{sat}$ °C | Sat. liquid, $v_f$ | Sat. vapor, $v_g$ | Sat. liquid, $u_f$ | Evap., $u_{fg}$ | Sat. vapor, $u_g$ | Sat. liquid, $h_f$ | Evap., $h_{fg}$ | Sat. vapor, $h_g$ | Sat. liquid, $s_f$ | Evap., $s_{fg}$ | Sat. vapor, $s_g$ |
| 1.0 | 6.97 | 0.001000 | 129.19 | 29.302 | 2355.2 | 2384.5 | 29.303 | 2484.4 | 2513.7 | 0.1059 | 8.8690 | 8.9749 |
| 1.5 | 13.02 | 0.001001 | 87.964 | 54.686 | 2338.1 | 2392.8 | 54.688 | 2470.1 | 2524.7 | 0.1956 | 8.6314 | 8.8270 |
| 2.0 | 17.50 | 0.001001 | 66.990 | 73.431 | 2325.5 | 2398.9 | 73.433 | 2459.5 | 2532.9 | 0.2606 | 8.4621 | 8.7227 |
| 2.5 | 21.08 | 0.001002 | 54.242 | 88.422 | 2315.4 | 2403.8 | 88.424 | 2451.0 | 2539.4 | 0.3118 | 8.3302 | 8.6421 |
| 3.0 | 24.08 | 0.001003 | 45.654 | 100.98 | 2306.9 | 2407.9 | 100.98 | 2443.9 | 2544.8 | 0.3543 | 8.2222 | 8.5765 |
| 4.0 | 28.96 | 0.001004 | 34.791 | 121.39 | 2293.1 | 2414.5 | 121.39 | 2432.3 | 2553.7 | 0.4224 | 8.0510 | 8.4734 |
| 5.0 | 32.87 | 0.001005 | 28.185 | 137.75 | 2282.1 | 2419.8 | 137.75 | 2423.0 | 2560.7 | 0.4762 | 7.9176 | 8.3938 |
| 7.5 | 40.29 | 0.001008 | 19.233 | 168.74 | 2261.1 | 2429.8 | 168.75 | 2405.3 | 2574.0 | 0.5763 | 7.6738 | 8.2501 |
| 10 | 45.81 | 0.001010 | 14.670 | 191.79 | 2245.4 | 2437.2 | 191.81 | 2392.1 | 2583.9 | 0.6492 | 7.4996 | 8.1488 |
| 15 | 53.97 | 0.001014 | 10.020 | 225.93 | 2222.1 | 2448.0 | 225.94 | 2372.3 | 2598.3 | 0.7549 | 7.2522 | 8.0071 |
| 20 | 60.06 | 0.001017 | 7.6481 | 251.40 | 2204.6 | 2456.0 | 251.42 | 2357.5 | 2608.9 | 0.8320 | 7.0752 | 7.9073 |
| 25 | 64.96 | 0.001020 | 6.2034 | 271.93 | 2190.4 | 2462.4 | 271.96 | 2345.5 | 2617.5 | 0.8932 | 6.9370 | 7.8302 |
| 30 | 69.09 | 0.001022 | 5.2287 | 289.24 | 2178.5 | 2467.7 | 289.27 | 2335.3 | 2624.6 | 0.9441 | 6.8234 | 7.7675 |
| 40 | 75.86 | 0.001026 | 3.9933 | 317.58 | 2158.8 | 2476.3 | 317.62 | 2318.4 | 2636.1 | 1.0261 | 6.6430 | 7.6691 |
| 50 | 81.32 | 0.001030 | 3.2403 | 340.49 | 2142.7 | 2483.2 | 340.54 | 2304.7 | 2645.2 | 1.0912 | 6.5019 | 7.5931 |
| 75 | 91.76 | 0.001037 | 2.2172 | 384.36 | 2111.8 | 2496.1 | 384.44 | 2278.0 | 2662.4 | 1.2132 | 6.2426 | 7.4558 |
| 100 | 99.61 | 0.001043 | 1.6941 | 417.40 | 2088.2 | 2505.6 | 417.51 | 2257.5 | 2675.0 | 1.3028 | 6.0562 | 7.3589 |
| 101.325 | 99.97 | 0.001043 | 1.6734 | 418.95 | 2087.0 | 2506.0 | 419.06 | 2256.5 | 2675.6 | 1.3069 | 6.0476 | 7.3545 |
| 125 | 105.97 | 0.001048 | 1.3750 | 444.23 | 2068.8 | 2513.0 | 444.36 | 2240.6 | 2684.9 | 1.3741 | 5.9100 | 7.2841 |
| 150 | 111.35 | 0.001053 | 1.1594 | 466.97 | 2052.3 | 2519.2 | 467.13 | 2226.0 | 2693.1 | 1.4337 | 5.7894 | 7.2231 |
| 175 | 116.04 | 0.001057 | 1.0037 | 486.82 | 2037.7 | 2524.5 | 487.01 | 2213.1 | 2700.2 | 1.4850 | 5.6865 | 7.1716 |
| 200 | 120.21 | 0.001061 | 0.88578 | 504.50 | 2024.6 | 2529.1 | 504.71 | 2201.6 | 2706.3 | 1.5302 | 5.5968 | 7.1270 |
| 225 | 123.97 | 0.001064 | 0.79329 | 520.47 | 2012.7 | 2533.2 | 520.71 | 2191.0 | 2711.7 | 1.5706 | 5.5171 | 7.0877 |
| 250 | 127.41 | 0.001067 | 0.71873 | 535.08 | 2001.8 | 2536.8 | 535.35 | 2181.2 | 2716.5 | 1.6072 | 5.4453 | 7.0525 |
| 275 | 130.58 | 0.001070 | 0.65732 | 548.57 | 1991.6 | 2540.1 | 548.86 | 2172.0 | 2720.9 | 1.6408 | 5.3800 | 7.0207 |
| 300 | 133.52 | 0.001073 | 0.60582 | 561.11 | 1982.1 | 2543.2 | 561.43 | 2163.5 | 2724.9 | 1.6717 | 5.3200 | 6.9917 |
| 325 | 136.27 | 0.001076 | 0.56199 | 572.84 | 1973.1 | 2545.9 | 573.19 | 2155.4 | 2728.6 | 1.7005 | 5.2645 | 6.9650 |
| 350 | 138.86 | 0.001079 | 0.52422 | 583.89 | 1964.6 | 2548.5 | 584.26 | 2147.7 | 2732.0 | 1.7274 | 5.2128 | 6.9402 |
| 375 | 141.30 | 0.001081 | 0.49133 | 594.32 | 1956.6 | 2550.9 | 594.73 | 2140.4 | 2735.1 | 1.7526 | 5.1645 | 6.9171 |
| 400 | 143.61 | 0.001084 | 0.46242 | 604.22 | 1948.9 | 2553.1 | 604.66 | 2133.4 | 2738.1 | 1.7765 | 5.1191 | 6.8955 |
| 450 | 147.90 | 0.001088 | 0.41392 | 622.65 | 1934.5 | 2557.1 | 623.14 | 2120.3 | 2743.4 | 1.8205 | 5.0356 | 6.8561 |
| 500 | 151.83 | 0.001093 | 0.37483 | 639.54 | 1921.2 | 2560.7 | 640.09 | 2108.0 | 2748.1 | 1.8604 | 4.9603 | 6.8207 |
| 550 | 155.46 | 0.001097 | 0.34261 | 655.16 | 1908.8 | 2563.9 | 655.77 | 2096.6 | 2752.4 | 1.8970 | 4.8916 | 6.7886 |
| 600 | 158.83 | 0.001101 | 0.31560 | 669.72 | 1897.1 | 2566.8 | 670.38 | 2085.8 | 2756.2 | 1.9308 | 4.8285 | 6.7593 |
| 650 | 161.98 | 0.001104 | 0.29260 | 683.37 | 1886.1 | 2569.4 | 684.08 | 2075.5 | 2759.6 | 1.9623 | 4.7699 | 6.7322 |
| 700 | 164.95 | 0.001108 | 0.27278 | 696.23 | 1875.6 | 2571.8 | 697.00 | 2065.8 | 2762.8 | 1.9918 | 4.7153 | 6.7071 |
| 750 | 167.75 | 0.001111 | 0.25552 | 708.40 | 1865.6 | 2574.0 | 709.24 | 2056.4 | 2765.7 | 2.0195 | 4.6642 | 6.6837 |

*(Continued)*

## TABLE A–5

Saturated water—Pressure table (*Concluded*)

| | | *Specific volume,* $m^3/kg$ | | *Internal energy,* kJ/kg | | | *Enthalpy,* kJ/kg | | | *Entropy,* kJ/kg · K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Press., $P$ kPa | Sat. temp., $T_{sat}$ °C | Sat. liquid, $v_f$ | Sat. vapor, $v_g$ | Sat. liquid, $u_f$ | Evap., $u_{fg}$ | Sat. vapor, $u_g$ | Sat. liquid, $h_f$ | Evap., $h_{fg}$ | Sat. vapor, $h_g$ | Sat. liquid, $s_f$ | Evap., $s_{fg}$ | Sat. vapor, $s_g$ |
| 800 | 170.41 | 0.001115 | 0.24035 | 719.97 | 1856.1 | 2576.0 | 720.87 | 2047.5 | 2768.3 | 2.0457 | 4.6160 | 6.6616 |
| 850 | 172.94 | 0.001118 | 0.22690 | 731.00 | 1846.9 | 2577.9 | 731.95 | 2038.8 | 2770.8 | 2.0705 | 4.5705 | 6.6409 |
| 900 | 175.35 | 0.001121 | 0.21489 | 741.55 | 1838.1 | 2579.6 | 742.56 | 2030.5 | 2773.0 | 2.0941 | 4.5273 | 6.6213 |
| 950 | 177.66 | 0.001124 | 0.20411 | 751.67 | 1829.6 | 2581.3 | 752.74 | 2022.4 | 2775.2 | 2.1166 | 4.4862 | 6.6027 |
| 1000 | 179.88 | 0.001127 | 0.19436 | 761.39 | 1821.4 | 2582.8 | 762.51 | 2014.6 | 2777.1 | 2.1381 | 4.4470 | 6.5850 |
| 1100 | 184.06 | 0.001133 | 0.17745 | 779.78 | 1805.7 | 2585.5 | 781.03 | 1999.6 | 2780.7 | 2.1785 | 4.3735 | 6.5520 |
| 1200 | 187.96 | 0.001138 | 0.16326 | 796.96 | 1790.9 | 2587.8 | 798.33 | 1985.4 | 2783.8 | 2.2159 | 4.3058 | 6.5217 |
| 1300 | 191.60 | 0.001144 | 0.15119 | 813.10 | 1776.8 | 2589.9 | 814.59 | 1971.9 | 2786.5 | 2.2508 | 4.2428 | 6.4936 |
| 1400 | 195.04 | 0.001149 | 0.14078 | 828.35 | 1763.4 | 2591.8 | 829.96 | 1958.9 | 2788.9 | 2.2835 | 4.1840 | 6.4675 |
| 1500 | 198.29 | 0.001154 | 0.13171 | 842.82 | 1750.6 | 2593.4 | 844.55 | 1946.4 | 2791.0 | 2.3143 | 4.1287 | 6.4430 |
| 1750 | 205.72 | 0.001166 | 0.11344 | 876.12 | 1720.6 | 2596.7 | 878.16 | 1917.1 | 2795.2 | 2.3844 | 4.0033 | 6.3877 |
| 2000 | 212.38 | 0.001177 | 0.099587 | 906.12 | 1693.0 | 2599.1 | 908.47 | 1889.8 | 2798.3 | 2.4467 | 3.8923 | 6.3390 |
| 2250 | 218.41 | 0.001187 | 0.088717 | 933.54 | 1667.3 | 2600.9 | 936.21 | 1864.3 | 2800.5 | 2.5029 | 3.7926 | 6.2954 |
| 2500 | 223.95 | 0.001197 | 0.079952 | 958.87 | 1643.2 | 2602.1 | 961.87 | 1840.1 | 2801.9 | 2.5542 | 3.7016 | 6.2558 |
| 3000 | 233.85 | 0.001217 | 0.066667 | 1004.6 | 1598.5 | 2603.2 | 1008.3 | 1794.9 | 2803.2 | 2.6454 | 3.5402 | 6.1856 |
| 3500 | 242.56 | 0.001235 | 0.057061 | 1045.4 | 1557.6 | 2603.0 | 1049.7 | 1753.0 | 2802.7 | 2.7253 | 3.3991 | 6.1244 |
| 4000 | 250.35 | 0.001252 | 0.049779 | 1082.4 | 1519.3 | 2601.7 | 1087.4 | 1713.5 | 2800.8 | 2.7966 | 3.2731 | 6.0696 |
| 5000 | 263.94 | 0.001286 | 0.039448 | 1148.1 | 1448.9 | 2597.0 | 1154.5 | 1639.7 | 2794.2 | 2.9207 | 3.0530 | 5.9737 |
| 6000 | 275.59 | 0.001319 | 0.032449 | 1205.8 | 1384.1 | 2589.9 | 1213.8 | 1570.9 | 2784.6 | 3.0275 | 2.8627 | 5.8902 |
| 7000 | 285.83 | 0.001352 | 0.027378 | 1258.0 | 1323.0 | 2581.0 | 1267.5 | 1505.2 | 2772.6 | 3.1220 | 2.6927 | 5.8148 |
| 8000 | 295.01 | 0.001384 | 0.023525 | 1306.0 | 1264.5 | 2570.5 | 1317.1 | 1441.6 | 2758.7 | 3.2077 | 2.5373 | 5.7450 |
| 9000 | 303.35 | 0.001418 | 0.020489 | 1350.9 | 1207.6 | 2558.5 | 1363.7 | 1379.3 | 2742.9 | 3.2866 | 2.3925 | 5.6791 |
| 10,000 | 311.00 | 0.001452 | 0.018028 | 1393.3 | 1151.8 | 2545.2 | 1407.8 | 1317.6 | 2725.5 | 3.3603 | 2.2556 | 5.6159 |
| 11,000 | 318.08 | 0.001488 | 0.015988 | 1433.9 | 1096.6 | 2530.4 | 1450.2 | 1256.1 | 2706.3 | 3.4299 | 2.1245 | 5.5544 |
| 12,000 | 324.68 | 0.001526 | 0.014264 | 1473.0 | 1041.3 | 2514.3 | 1491.3 | 1194.1 | 2685.4 | 3.4964 | 1.9975 | 5.4939 |
| 13,000 | 330.85 | 0.001566 | 0.012781 | 1511.0 | 985.5 | 2496.6 | 1531.4 | 1131.3 | 2662.7 | 3.5606 | 1.8730 | 5.4336 |
| 14,000 | 336.67 | 0.001610 | 0.011487 | 1548.4 | 928.7 | 2477.1 | 1571.0 | 1067.0 | 2637.9 | 3.6232 | 1.7497 | 5.3728 |
| 15,000 | 342.16 | 0.001657 | 0.010341 | 1585.5 | 870.3 | 2455.7 | 1610.3 | 1000.5 | 2610.8 | 3.6848 | 1.6261 | 5.3108 |
| 16,000 | 347.36 | 0.001710 | 0.009312 | 1622.6 | 809.4 | 2432.0 | 1649.9 | 931.1 | 2581.0 | 3.7461 | 1.5005 | 5.2466 |
| 17,000 | 352.29 | 0.001770 | 0.008374 | 1660.2 | 745.1 | 2405.4 | 1690.3 | 857.4 | 2547.7 | 3.8082 | 1.3709 | 5.1791 |
| 18,000 | 356.99 | 0.001840 | 0.007504 | 1699.1 | 675.9 | 2375.0 | 1732.2 | 777.8 | 2510.0 | 3.8720 | 1.2343 | 5.1064 |
| 19,000 | 361.47 | 0.001926 | 0.006677 | 1740.3 | 598.9 | 2339.2 | 1776.8 | 689.2 | 2466.0 | 3.9396 | 1.0860 | 5.0256 |
| 20,000 | 365.75 | 0.002038 | 0.005862 | 1785.8 | 509.0 | 2294.8 | 1826.6 | 585.5 | 2412.1 | 4.0146 | 0.9164 | 4.9310 |
| 21,000 | 369.83 | 0.002207 | 0.004994 | 1841.6 | 391.9 | 2233.5 | 1888.0 | 450.4 | 2338.4 | 4.1071 | 0.7005 | 4.8076 |
| 22,000 | 373.71 | 0.002703 | 0.003644 | 1951.7 | 140.8 | 2092.4 | 2011.1 | 161.5 | 2172.6 | 4.2942 | 0.2496 | 4.5439 |
| 22,064 | 373.95 | 0.003106 | 0.003106 | 2015.7 | 0 | 2015.7 | 2084.3 | 0 | 2084.3 | 4.4070 | 0 | 4.4070 |

**Nombre:** _____

## Problema 3

Determine el volumen específico del refrigerante 134a en estado de vapor a 1.0 MPa, 80 $°C$ basado en

(a) (1 punto) las tablas del refrigerante,

(b) (1 punto) la ecuación de estado del gas ideal. Determine el error con respecto a (a).

(c) (2 puntos) el gráfico generalizado de compresibilidad. Determine el error con respecto a (a). La presión y temperatura crítica son $P_{cr} = 4{,}059$ MPa y $T_{cr} = 374{,}2$ K, respectivamente. La constante del gas es $R = 0{,}08149$ kPa·m$^3$/Kg·K

(d) (2 puntos) Asuma que el refrigerante se puede tratar como un gas ideal. Calcule la energía transferida por calor si la presión disminuye a la mitad durante un proceso isotérmico.

## Problema 3

Para el refrigerante R-134a tenemos que

$$R = 0.08149 \frac{kPa\,m^3}{kg\,K} \qquad T_{cr} = 374.2\,K \qquad P_{cr} = 4.059\,MPa$$

a) Utilizando las tablas tenemos que el volumen específico es

$$v_{real} = 0.025398\ m^3/kg$$

b) Utilizando la ecuación del gas ideal $PV = R_a m T$

Notemos que $R = 0.08149 \frac{kPa\,m^3}{kg\,K}$ es la constante de gas específico, luego

$$v_{ideal} = \frac{RT}{P} = 0.08149 \frac{kPa\,m^3}{kg\,K} \times \frac{(80+273.15)K}{1\,MPa} = 0.0288 \frac{m^3}{kg}$$

El error es $100 \times \frac{v_{ideal} - v_{real}}{v_{real}} = 13.4\,\%$

c) Para utilizar el gráfico de compresibilidad generalizado debemos calcular la presión y temperatura reducida,

$$P_R = \frac{P}{P_{cr}} = \frac{1.0\,MPa}{4.059\,MPa} = 0.2464, \quad T_R = \frac{T}{T_{cr}} = \frac{80+273.15\,K}{374.2\,K} = 0.944$$

Del gráfico obtenemos que $Z \approx 0.89$

luego $v = Z\frac{RT}{P} = Z v_{ideal} = 0.0256\ m^3/kg$

El error es $100 \times \left(\frac{v - v_{real}}{v_{real}}\right) = 0.8\,\%$

d) Si podemos tratar al refrigerante como un gas ideal, su energía interna no cambia durante un proceso isotérmico, $\Delta U = 0$. Luego, aplicando la primera ley tenemos

$$\Delta U = Q - W = 0 \quad \rightarrow \quad Q = W$$

El trabajo efectuado por el sistema durante un proceso isotérmico es,

$$W = \int_1^2 P\,dV = C\int_1^2 \frac{dV}{V} = C \ln \frac{V_2}{V_1}$$

donde $C = PV = nRT$. Entonces,

$$W = nRT \ln \frac{V_2}{V_1} \qquad \text{donde} \quad T = T_1 = T_2$$

y $$Q = nRT_1 \ln \frac{V_2}{V_1} = nRT_1 \ln \frac{P_1}{P_2}$$

Evaluando,

$$Q = \left(\frac{m}{M}\right) RT_1 \ln \frac{P_1}{P_2} = \frac{1\ kg}{102.03\ kg} \frac{1000\ mol}{} \times 8.314\ \frac{J}{mol \cdot K} \cdot (273.15 + 80) \ln 2$$

$$= 19.95\ kJ$$

## TABLE A–13

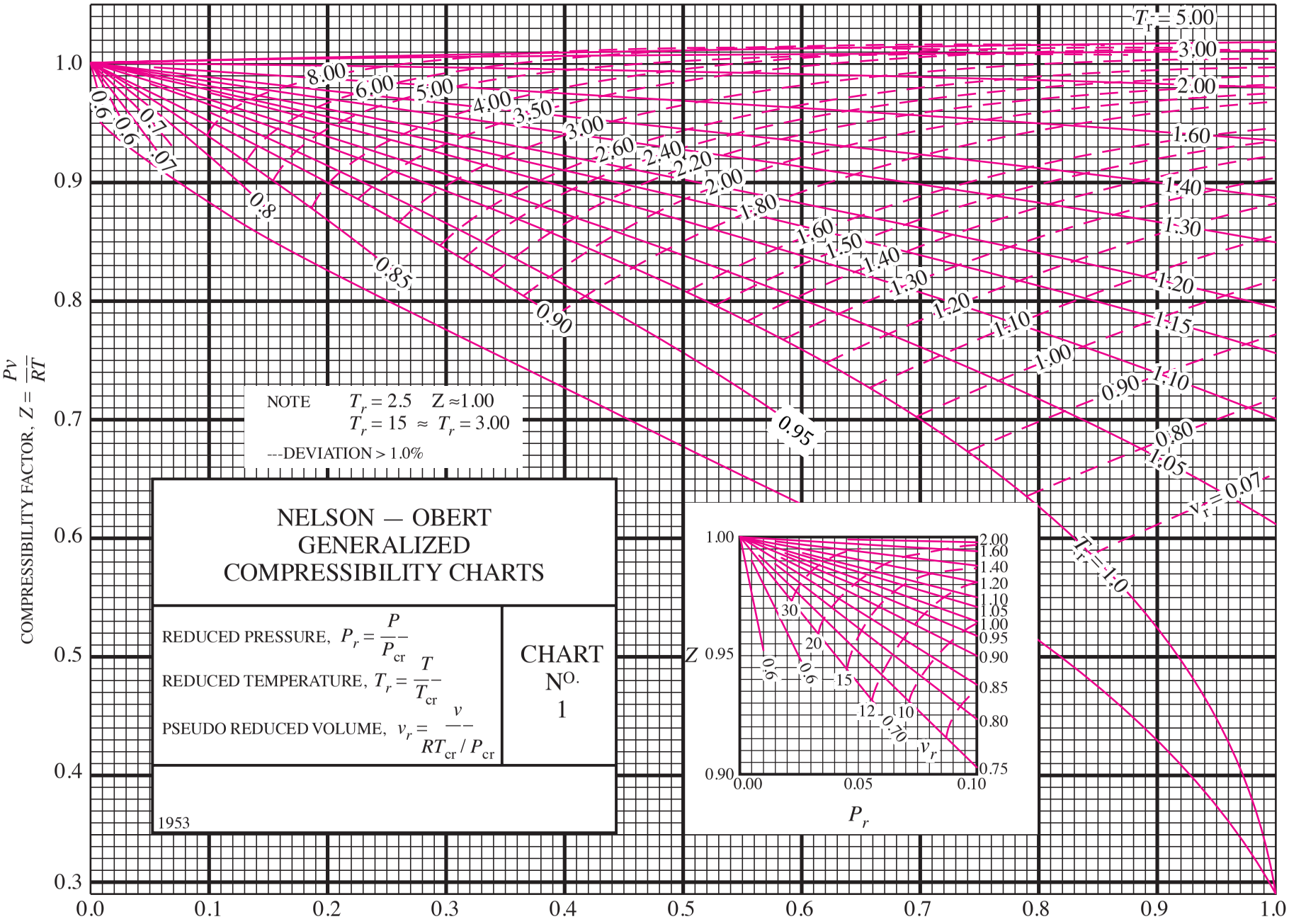
Superheated refrigerant-134a

| $T$ °C | $v$ m³/kg | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K | $v$ m³/kg | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K | $v$ m³/kg | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ = 0.06 MPa ($T_{sat}$ = −36.95°C) | | | | $P$ = 0.10 MPa ($T_{sat}$ = −26.37°C) | | | | $P$ = 0.14 MPa ($T_{sat}$ = −18.77°C) | | | |
| Sat. | 0.31121 | 209.12 | 227.79 | 0.9644 | 0.19254 | 215.19 | 234.44 | 0.9518 | 0.14014 | 219.54 | 239.16 | 0.9446 |
| −20 | 0.33608 | 220.60 | 240.76 | 1.0174 | 0.19841 | 219.66 | 239.50 | 0.9721 | | | | |
| −10 | 0.35048 | 227.55 | 248.58 | 1.0477 | 0.20743 | 226.75 | 247.49 | 1.0030 | 0.14605 | 225.91 | 246.36 | 0.9724 |
| 0 | 0.36476 | 234.66 | 256.54 | 1.0774 | 0.21630 | 233.95 | 255.58 | 1.0332 | 0.15263 | 233.23 | 254.60 | 1.0031 |
| 10 | 0.37893 | 241.92 | 264.66 | 1.1066 | 0.22506 | 241.30 | 263.81 | 1.0628 | 0.15908 | 240.66 | 262.93 | 1.0331 |
| 20 | 0.39302 | 249.35 | 272.94 | 1.1353 | 0.23373 | 248.79 | 272.17 | 1.0918 | 0.16544 | 248.22 | 271.38 | 1.0624 |
| 30 | 0.40705 | 256.95 | 281.37 | 1.1636 | 0.24233 | 256.44 | 280.68 | 1.1203 | 0.17172 | 255.93 | 279.97 | 1.0912 |
| 40 | 0.42102 | 264.71 | 289.97 | 1.1915 | 0.25088 | 264.25 | 289.34 | 1.1484 | 0.17794 | 263.79 | 288.70 | 1.1195 |
| 50 | 0.43495 | 272.64 | 298.74 | 1.2191 | 0.25937 | 272.22 | 298.16 | 1.1762 | 0.18412 | 271.79 | 297.57 | 1.1474 |
| 60 | 0.44883 | 280.73 | 307.66 | 1.2463 | 0.26783 | 280.35 | 307.13 | 1.2035 | 0.19025 | 279.96 | 306.59 | 1.1749 |
| 70 | 0.46269 | 288.99 | 316.75 | 1.2732 | 0.27626 | 288.64 | 316.26 | 1.2305 | 0.19635 | 288.28 | 315.77 | 1.2020 |
| 80 | 0.47651 | 297.41 | 326.00 | 1.2997 | 0.28465 | 297.08 | 325.55 | 1.2572 | 0.20242 | 296.75 | 325.09 | 1.2288 |
| 90 | 0.49032 | 306.00 | 335.42 | 1.3260 | 0.29303 | 305.69 | 334.99 | 1.2836 | 0.20847 | 305.38 | 334.57 | 1.2553 |
| 100 | 0.50410 | 314.74 | 344.99 | 1.3520 | 0.30138 | 314.46 | 344.60 | 1.3096 | 0.21449 | 314.17 | 344.20 | 1.2814 |
| | $P$ = 0.18 MPa ($T_{sat}$ = −12.73°C) | | | | $P$ = 0.20 MPa ($T_{sat}$ = −10.09°C) | | | | $P$ = 0.24 MPa ($T_{sat}$ = −5.38°C) | | | |
| Sat. | 0.11041 | 222.99 | 242.86 | 0.9397 | 0.09987 | 224.48 | 244.46 | 0.9377 | 0.08390 | 227.14 | 247.28 | 0.9346 |
| −10 | 0.11189 | 225.02 | 245.16 | 0.9484 | 0.09991 | 224.55 | 244.54 | 0.9380 | | | | |
| 0 | 0.11722 | 232.48 | 253.58 | 0.9798 | 0.10481 | 232.09 | 253.05 | 0.9698 | 0.08617 | 231.29 | 251.97 | 0.9519 |
| 10 | 0.12240 | 240.00 | 262.04 | 1.0102 | 0.10955 | 239.67 | 261.58 | 1.0004 | 0.09026 | 238.98 | 260.65 | 0.9831 |
| 20 | 0.12748 | 247.64 | 270.59 | 1.0399 | 0.11418 | 247.35 | 270.18 | 1.0303 | 0.09423 | 246.74 | 269.36 | 1.0134 |
| 30 | 0.13248 | 255.41 | 279.25 | 1.0690 | 0.11874 | 255.14 | 278.89 | 1.0595 | 0.09812 | 254.61 | 278.16 | 1.0429 |
| 40 | 0.13741 | 263.31 | 288.05 | 1.0975 | 0.12322 | 263.08 | 287.72 | 1.0882 | 0.10193 | 262.59 | 287.06 | 1.0718 |
| 50 | 0.14230 | 271.36 | 296.98 | 1.1256 | 0.12766 | 271.15 | 296.68 | 1.1163 | 0.10570 | 270.71 | 296.08 | 1.1001 |
| 60 | 0.14715 | 279.56 | 306.05 | 1.1532 | 0.13206 | 279.37 | 305.78 | 1.1441 | 0.10942 | 278.97 | 305.23 | 1.1280 |
| 70 | 0.15196 | 287.91 | 315.27 | 1.1805 | 0.13641 | 287.73 | 315.01 | 1.1714 | 0.11310 | 287.36 | 314.51 | 1.1554 |
| 80 | 0.15673 | 296.42 | 324.63 | 1.2074 | 0.14074 | 296.25 | 324.40 | 1.1983 | 0.11675 | 295.91 | 323.93 | 1.1825 |
| 90 | 0.16149 | 305.07 | 334.14 | 1.2339 | 0.14504 | 304.92 | 333.93 | 1.2249 | 0.12038 | 304.60 | 333.49 | 1.2092 |
| 100 | 0.16622 | 313.88 | 343.80 | 1.2602 | 0.14933 | 313.74 | 343.60 | 1.2512 | 0.12398 | 313.44 | 343.20 | 1.2356 |
| | $P$ = 0.28 MPa ($T_{sat}$ = −1.25°C) | | | | $P$ = 0.32 MPa ($T_{sat}$ = 2.46°C) | | | | $P$ = 0.40 MPa ($T_{sat}$ = 8.91°C) | | | |
| Sat. | 0.07235 | 229.46 | 249.72 | 0.9321 | 0.06360 | 231.52 | 251.88 | 0.9301 | 0.051201 | 235.07 | 255.55 | 0.9269 |
| 0 | 0.07282 | 230.44 | 250.83 | 0.9362 | | | | | | | | |
| 10 | 0.07646 | 238.27 | 259.68 | 0.9680 | 0.06609 | 237.54 | 258.69 | 0.9544 | 0.051506 | 235.97 | 256.58 | 0.9305 |
| 20 | 0.07997 | 246.13 | 268.52 | 0.9987 | 0.06925 | 245.50 | 267.66 | 0.9856 | 0.054213 | 244.18 | 265.86 | 0.9628 |
| 30 | 0.08338 | 254.06 | 277.41 | 1.0285 | 0.07231 | 253.50 | 276.65 | 1.0157 | 0.056796 | 252.36 | 275.07 | 0.9937 |
| 40 | 0.08672 | 262.10 | 286.38 | 1.0576 | 0.07530 | 261.60 | 285.70 | 1.0451 | 0.059292 | 260.58 | 284.30 | 1.0236 |
| 50 | 0.09000 | 270.27 | 295.47 | 1.0862 | 0.07823 | 269.82 | 294.85 | 1.0739 | 0.061724 | 268.90 | 293.59 | 1.0528 |
| 60 | 0.09324 | 278.56 | 304.67 | 1.1142 | 0.08111 | 278.15 | 304.11 | 1.1021 | 0.064104 | 277.32 | 302.96 | 1.0814 |
| 70 | 0.09644 | 286.99 | 314.00 | 1.1418 | 0.08395 | 286.62 | 313.48 | 1.1298 | 0.066443 | 285.86 | 312.44 | 1.1094 |
| 80 | 0.09961 | 295.57 | 323.46 | 1.1690 | 0.08675 | 295.22 | 322.98 | 1.1571 | 0.068747 | 294.53 | 322.02 | 1.1369 |
| 90 | 0.10275 | 304.29 | 333.06 | 1.1958 | 0.08953 | 303.97 | 332.62 | 1.1840 | 0.071023 | 303.32 | 331.73 | 1.1640 |
| 100 | 0.10587 | 313.15 | 342.80 | 1.2222 | 0.09229 | 312.86 | 342.39 | 1.2105 | 0.073274 | 312.26 | 341.57 | 1.1907 |
| 110 | 0.10897 | 322.16 | 352.68 | 1.2483 | 0.09503 | 321.89 | 352.30 | 1.2367 | 0.075504 | 321.33 | 351.53 | 1.2171 |
| 120 | 0.11205 | 331.32 | 362.70 | 1.2742 | 0.09775 | 331.07 | 362.35 | 1.2626 | 0.077717 | 330.55 | 361.63 | 1.2431 |
| 130 | 0.11512 | 340.63 | 372.87 | 1.2997 | 0.10045 | 340.39 | 372.54 | 1.2882 | 0.079913 | 339.90 | 371.87 | 1.2688 |
| 140 | 0.11818 | 350.09 | 383.18 | 1.3250 | 0.10314 | 349.86 | 382.87 | 1.3135 | 0.082096 | 349.41 | 382.24 | 1.2942 |

## TABLE A–13

Superheated refrigerant-134a (*Concluded*)

| $T$ °C | $v$ m³/kg | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K | $v$ m³/kg | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K | $v$ m³/kg | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ = 0.50 MPa ($T_{sat}$ = 15.71°C) | | | | $P$ = 0.60 MPa ($T_{sat}$ = 21.55°C) | | | | $P$ = 0.70 MPa ($T_{sat}$ = 26.69°C) | | | |
| Sat. | 0.041118 | 238.75 | 259.30 | 0.9240 | 0.034295 | 241.83 | 262.40 | 0.9218 | 0.029361 | 244.48 | 265.03 | 0.9199 |
| 20 | 0.042115 | 242.40 | 263.46 | 0.9383 | | | | | | | | |
| 30 | 0.044338 | 250.84 | 273.01 | 0.9703 | 0.035984 | 249.22 | 270.81 | 0.9499 | 0.029966 | 247.48 | 268.45 | 0.9313 |
| 40 | 0.046456 | 259.26 | 282.48 | 1.0011 | 0.037865 | 257.86 | 280.58 | 0.9816 | 0.031696 | 256.39 | 278.57 | 0.9641 |
| 50 | 0.048499 | 267.72 | 291.96 | 1.0309 | 0.039659 | 266.48 | 290.28 | 1.0121 | 0.033322 | 265.20 | 288.53 | 0.9954 |
| 60 | 0.050485 | 276.25 | 301.50 | 1.0599 | 0.041389 | 275.15 | 299.98 | 1.0417 | 0.034875 | 274.01 | 298.42 | 1.0256 |
| 70 | 0.052427 | 284.89 | 311.10 | 1.0883 | 0.043069 | 283.89 | 309.73 | 1.0705 | 0.036373 | 282.87 | 308.33 | 1.0549 |
| 80 | 0.054331 | 293.64 | 320.80 | 1.1162 | 0.044710 | 292.73 | 319.55 | 1.0987 | 0.037829 | 291.80 | 318.28 | 1.0835 |
| 90 | 0.056205 | 302.51 | 330.61 | 1.1436 | 0.046318 | 301.67 | 329.46 | 1.1264 | 0.039250 | 300.82 | 328.29 | 1.1114 |
| 100 | 0.058053 | 311.50 | 340.53 | 1.1705 | 0.047900 | 310.73 | 339.47 | 1.1536 | 0.040642 | 309.95 | 338.40 | 1.1389 |
| 110 | 0.059880 | 320.63 | 350.57 | 1.1971 | 0.049458 | 319.91 | 349.59 | 1.1803 | 0.042010 | 319.19 | 348.60 | 1.1658 |
| 120 | 0.061687 | 329.89 | 360.73 | 1.2233 | 0.050997 | 329.23 | 359.82 | 1.2067 | 0.043358 | 328.55 | 358.90 | 1.1924 |
| 130 | 0.063479 | 339.29 | 371.03 | 1.2491 | 0.052519 | 338.67 | 370.18 | 1.2327 | 0.044688 | 338.04 | 369.32 | 1.2186 |
| 140 | 0.065256 | 348.83 | 381.46 | 1.2747 | 0.054027 | 348.25 | 380.66 | 1.2584 | 0.046004 | 347.66 | 379.86 | 1.2444 |
| 150 | 0.067021 | 358.51 | 392.02 | 1.2999 | 0.055522 | 357.96 | 391.27 | 1.2838 | 0.047306 | 357.41 | 390.52 | 1.2699 |
| 160 | 0.068775 | 368.33 | 402.72 | 1.3249 | 0.057006 | 367.81 | 402.01 | 1.3088 | 0.048597 | 367.29 | 401.31 | 1.2951 |
| | $P$ = 0.80 MPa ($T_{sat}$ = 31.31°C) | | | | $P$ = 0.90 MPa ($T_{sat}$ = 35.51°C) | | | | $P$ = 1.00 MPa ($T_{sat}$ = 39.37°C) | | | |
| Sat. | 0.025621 | 246.79 | 267.29 | 0.9183 | 0.022683 | 248.85 | 269.26 | 0.9169 | 0.020313 | 250.68 | 270.99 | 0.9156 |
| 40 | 0.027035 | 254.82 | 276.45 | 0.9480 | 0.023375 | 253.13 | 274.17 | 0.9327 | 0.020406 | 251.30 | 271.71 | 0.9179 |
| 50 | 0.028547 | 263.86 | 286.69 | 0.9802 | 0.024809 | 262.44 | 284.77 | 0.9660 | 0.021796 | 260.94 | 282.74 | 0.9525 |
| 60 | 0.029973 | 272.83 | 296.81 | 1.0110 | 0.026146 | 271.60 | 295.13 | 0.9976 | 0.023068 | 270.32 | 293.38 | 0.9850 |
| 70 | 0.031340 | 281.81 | 306.88 | 1.0408 | 0.027413 | 280.72 | 305.39 | 1.0280 | 0.024261 | 279.59 | 303.85 | 1.0160 |
| 80 | 0.032659 | 290.84 | 316.97 | 1.0698 | 0.028630 | 289.86 | 315.63 | 1.0574 | 0.025398 | 288.86 | 314.25 | 1.0458 |
| 90 | 0.033941 | 299.95 | 327.10 | 1.0981 | 0.029806 | 299.06 | 325.89 | 1.0860 | 0.026492 | 298.15 | 324.64 | 1.0748 |
| 100 | 0.035193 | 309.15 | 337.30 | 1.1258 | 0.030951 | 308.34 | 336.19 | 1.1140 | 0.027552 | 307.51 | 335.06 | 1.1031 |
| 110 | 0.036420 | 318.45 | 347.59 | 1.1530 | 0.032068 | 317.70 | 346.56 | 1.1414 | 0.028584 | 316.94 | 345.53 | 1.1308 |
| 120 | 0.037625 | 327.87 | 357.97 | 1.1798 | 0.033164 | 327.18 | 357.02 | 1.1684 | 0.029592 | 326.47 | 356.06 | 1.1580 |
| 130 | 0.038813 | 337.40 | 368.45 | 1.2061 | 0.034241 | 336.76 | 367.58 | 1.1949 | 0.030581 | 336.11 | 366.69 | 1.1846 |
| 140 | 0.039985 | 347.06 | 379.05 | 1.2321 | 0.035302 | 346.46 | 378.23 | 1.2210 | 0.031554 | 345.85 | 377.40 | 1.2109 |
| 150 | 0.041143 | 356.85 | 389.76 | 1.2577 | 0.036349 | 356.28 | 389.00 | 1.2467 | 0.032512 | 355.71 | 388.22 | 1.2368 |
| 160 | 0.042290 | 366.76 | 400.59 | 1.2830 | 0.037384 | 366.23 | 399.88 | 1.2721 | 0.033457 | 365.70 | 399.15 | 1.2623 |
| 170 | 0.043427 | 376.81 | 411.55 | 1.3080 | 0.038408 | 376.31 | 410.88 | 1.2972 | 0.034392 | 375.81 | 410.20 | 1.2875 |
| 180 | 0.044554 | 386.99 | 422.64 | 1.3327 | 0.039423 | 386.52 | 422.00 | 1.3221 | 0.035317 | 386.04 | 421.36 | 1.3124 |
| | $P$ = 1.20 MPa ($T_{sat}$ = 46.29°C) | | | | $P$ = 1.40 MPa ($T_{sat}$ = 52.40°C) | | | | $P$ = 1.60 MPa ($T_{sat}$ = 57.88°C) | | | |
| Sat. | 0.016715 | 253.81 | 273.87 | 0.9130 | 0.014107 | 256.37 | 276.12 | 0.9105 | 0.012123 | 258.47 | 277.86 | 0.9078 |
| 50 | 0.017201 | 257.63 | 278.27 | 0.9267 | | | | | | | | |
| 60 | 0.018404 | 267.56 | 289.64 | 0.9614 | 0.015005 | 264.46 | 285.47 | 0.9389 | 0.012372 | 260.89 | 280.69 | 0.9163 |
| 70 | 0.019502 | 277.21 | 300.61 | 0.9938 | 0.016060 | 274.62 | 297.10 | 0.9733 | 0.013430 | 271.76 | 293.25 | 0.9535 |
| 80 | 0.020529 | 286.75 | 311.39 | 1.0248 | 0.017023 | 284.51 | 308.34 | 1.0056 | 0.014362 | 282.09 | 305.07 | 0.9875 |
| 90 | 0.021506 | 296.26 | 322.07 | 1.0546 | 0.017923 | 294.28 | 319.37 | 1.0364 | 0.015215 | 292.17 | 316.52 | 1.0194 |
| 100 | 0.022442 | 305.80 | 332.73 | 1.0836 | 0.018778 | 304.01 | 330.30 | 1.0661 | 0.016014 | 302.14 | 327.76 | 1.0500 |
| 110 | 0.023348 | 315.38 | 343.40 | 1.1118 | 0.019597 | 313.76 | 341.19 | 1.0949 | 0.016773 | 312.07 | 338.91 | 1.0795 |
| 120 | 0.024228 | 325.03 | 354.11 | 1.1394 | 0.020388 | 323.55 | 352.09 | 1.1230 | 0.017500 | 322.02 | 350.02 | 1.1081 |
| 130 | 0.025086 | 334.77 | 364.88 | 1.1664 | 0.021155 | 333.41 | 363.02 | 1.1504 | 0.018201 | 332.00 | 361.12 | 1.1360 |
| 140 | 0.025927 | 344.61 | 375.72 | 1.1930 | 0.021904 | 343.34 | 374.01 | 1.1773 | 0.018882 | 342.05 | 372.26 | 1.1632 |
| 150 | 0.026753 | 354.56 | 386.66 | 1.2192 | 0.022636 | 353.37 | 385.07 | 1.2038 | 0.019545 | 352.17 | 383.44 | 1.1900 |
| 160 | 0.027566 | 364.61 | 397.69 | 1.2449 | 0.023355 | 363.51 | 396.20 | 1.2298 | 0.020194 | 362.38 | 394.69 | 1.2163 |
| 170 | 0.028367 | 374.78 | 408.82 | 1.2703 | 0.024061 | 373.75 | 407.43 | 1.2554 | 0.020830 | 372.69 | 406.02 | 1.2421 |
| 180 | 0.029158 | 385.08 | 420.07 | 1.2954 | 0.024757 | 384.10 | 418.76 | 1.2807 | 0.021456 | 383.11 | 417.44 | 1.2676 |


COMPRESSIBILITY FACTOR, $Z = \frac{Pv}{RT}$
$T_r = 5.00$
3.00
2.00
1.60
1.40
1.30
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.70
0.60
NOTE $T_r = 2.5$ $Z \approx 1.00$
$T_r = 15 \approx T_r = 3.00$
---DEVIATION > 1.0%
NELSON — OBERT
GENERALIZED
COMPRESSIBILITY CHARTS
REDUCED PRESSURE, $P_r = \frac{P}{P_{cr}}$
REDUCED TEMPERATURE, $T_r = \frac{T}{T_{cr}}$
PSEUDO REDUCED VOLUME, $v_r = \frac{v}{RT_{cr}/P_{cr}}$
CHART NO. 1
1953
$v_r = 0.07$
$T_r = 1.0$
Z
$P_r$
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.00
0.05
0.10
0.75
30
20
15
12
10