ORDRE DES INGÉNIEURS DU QUÉBEC

MAY 2014 SESSION

Open-book examination
Calculators : only authorized models
Duration : 3 hours

**14-PH-B4**
**Applied Thermodynamics and Heat Transfer**

**Problem # 1 (20 %)**

An ideal Otto cycle has a compression ratio r = 8. At the beginning of compression process, air is at 27 $^{o}$C and 95 kPa. 400 kJ/kg of heat is transferred ***during the heat-rejection process***. Show the cycle on the P-v and T-s diagrams (*1%*) and determine:

a) the pressure and temperature at the end of ***heat-addition*** process (6%);
b) the net work output in kJ/kg (5%);
c) the thermal efficiency of the cycle (4%);
d) the mean effective pressure of the cycle, in kPa (4%).

*Use the variable specific heats $C_p$ and $C_v$ for air.*

**Problem #2 (20%)**

Airflow through a long rectangular heating duct that is 0.75m wide and 0.3 m high maintains the outer duct surface at 45$^{o}$C. If the duct is uninsulated and exposed to air at 15$^{o}$C in crawlspace beneath at home, what is the heat loss from the duct per meter of length? *(20%)*

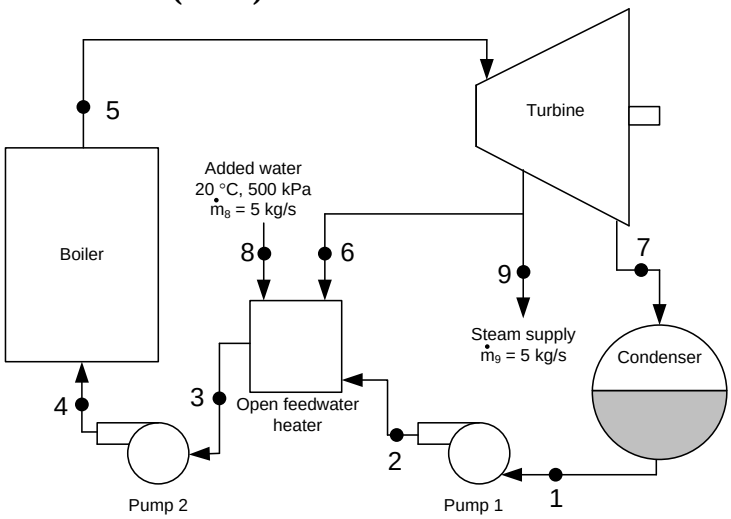
**Problem # 3 (20 %)**

A regenerative gas power plant operates on a Brayton cycle. Air enters the compressor at 300 K and 100 kPa where it is compressed to 1000 kPa and 640 K. The air enters the turbine at 1400 K. The isentropic efficiency of the turbine is 80 %. The regenerator effectiveness (ε) is 70 %. Determine:

a) The isentropic efficiency of the compressor *(6%)*;
b) The amount of heat transfer in the regenerator (in kJ/kg) *(7%)*;
c) The thermal efficiency of the cycle *(7%)*.

*Use the variable specific heats $C_p$ and $C_v$ for air.*

**Problem # 4 (20 %)**




A power plant operates on an ideal regenerative Rankine cycle with an open feedwater heater. Steam enters the turbine at 3 MPa, 600 $^{o}$C and at rate of 25 kg/s. The condenser pressure is 10 kPa. Some steam is extracted at 500 kPa: (*i*) to the open feedwater heater (state 6), (*ii*) in addition, a steam supply of 5 kg/s is taken out by industrial process (state 9) and not returned. The missing 5 kg/s water is added to the feedwater heater (state 8) from a 20 $^{o}$C, 500 kPa source. Show the cycle on a T-s diagram *(6 %)* and find:

a) the needed extraction flow rate to cover both the feedwater heater and the steam supply *(7%)*;
b) the total turbine power output *(7 %)*.

**Problem # 5 (20%)**

Refrigerant 134a enters the compressor of a refrigerator as superheated vapor at 0.14 MPa and -10$^{o}$C at a rate of 0.04 kg/s, and it leaves at 0.7 MPa and 50 $^{o}$C. The refrigerant is cooled in the condenser to 24 $^{o}$C and 0.65 MPa, and it is trottled to 0.15 MPa. Disregarding any heat transfer and pressure drops in the connecting lines between the components, show the cycle on a T-s diagram *(4%)* and determine:

a) The rate of heat removal from the refrigerated space *(4%)*;
b) The power input to the compressor ($W_{net,in}$) *(4%)*;
c) The adiabatic efficiency of the compressor *(4%)*;
d) The COP coefficient of the refrigerator *(4%)*.

R-134a

**TABLE A–11**

Saturated refrigerant-134a—Temperature table

| Temp., $T$ °C | Press., $P_{sat}$ MPa | Specific volume, m³/kg: Sat. liquid, $v_f$ | Specific volume, m³/kg: Sat. vapor, $v_g$ | Internal energy, kJ/kg: Sat. liquid, $u_f$ | Internal energy, kJ/kg: Sat. vapor, $u_g$ | Enthalpy, kJ/kg: Sat. liquid, $h_f$ | Enthalpy, kJ/kg: Evap., $h_{fg}$ | Enthalpy, kJ/kg: Sat. vapor, $h_g$ | Entropy, kJ/kg · K: Sat. liquid, $s_f$ | Entropy, kJ/kg · K: Sat. vapor, $s_g$ |
|---|---|---|---|---|---|---|---|---|---|---|
| −40 | 0.05164 | 0.0007055 | 0.3569 | −0.04 | 204.45 | 0.00 | 222.88 | 222.88 | 0.0000 | 0.9560 |
| −36 | 0.06332 | 0.0007113 | 0.2947 | 4.68 | 206.73 | 4.73 | 220.67 | 225.40 | 0.0201 | 0.9506 |
| −32 | 0.07704 | 0.0007172 | 0.2451 | 9.47 | 209.01 | 9.52 | 218.37 | 227.90 | 0.0401 | 0.9456 |
| −28 | 0.09305 | 0.0007233 | 0.2052 | 14.31 | 211.29 | 14.37 | 216.01 | 230.38 | 0.0600 | 0.9411 |
| −26 | 0.10199 | 0.0007265 | 0.1882 | 16.75 | 212.43 | 16.82 | 214.80 | 231.62 | 0.0699 | 0.9390 |
| −24 | 0.11160 | 0.0007296 | 0.1728 | 19.21 | 213.57 | 19.29 | 213.57 | 232.85 | 0.0798 | 0.9370 |
| −22 | 0.12192 | 0.0007328 | 0.1590 | 21.68 | 214.70 | 21.77 | 212.32 | 234.08 | 0.0897 | 0.9351 |
| −20 | 0.13299 | 0.0007361 | 0.1464 | 24.17 | 215.84 | 24.26 | 211.05 | 235.31 | 0.0996 | 0.9332 |
| −18 | 0.14483 | 0.0007395 | 0.1350 | 26.67 | 216.97 | 26.77 | 209.76 | 236.53 | 0.1094 | 0.9315 |
| −16 | 0.15748 | 0.0007428 | 0.1247 | 29.18 | 218.10 | 29.30 | 208.45 | 237.74 | 0.1192 | 0.9298 |
| −12 | 0.18540 | 0.0007498 | 0.1068 | 34.25 | 220.36 | 34.39 | 205.77 | 240.15 | 0.1388 | 0.9267 |
| −8 | 0.21704 | 0.0007569 | 0.0919 | 39.38 | 222.60 | 39.54 | 203.00 | 242.54 | 0.1583 | 0.9239 |
| −4 | 0.25274 | 0.0007644 | 0.0794 | 44.56 | 224.84 | 44.75 | 200.15 | 244.90 | 0.1777 | 0.9213 |
| 0 | 0.29282 | 0.0007721 | 0.0689 | 49.79 | 227.06 | 50.02 | 197.21 | 247.23 | 0.1970 | 0.9190 |
| 4 | 0.33765 | 0.0007801 | 0.0600 | 55.08 | 229.27 | 55.35 | 194.19 | 249.53 | 0.2162 | 0.9169 |
| 8 | 0.38756 | 0.0007884 | 0.0525 | 60.43 | 231.46 | 60.73 | 191.07 | 251.80 | 0.2354 | 0.9150 |
| 12 | 0.44294 | 0.0007971 | 0.0460 | 65.83 | 233.63 | 66.18 | 187.85 | 254.03 | 0.2545 | 0.9132 |
| 16 | 0.50416 | 0.0008062 | 0.0405 | 71.29 | 235.78 | 71.69 | 184.52 | 256.22 | 0.2735 | 0.9116 |
| 20 | 0.57160 | 0.0008157 | 0.0358 | 76.80 | 237.91 | 77.26 | 181.09 | 258.35 | 0.2924 | 0.9102 |
| 24 | 0.64566 | 0.0008257 | 0.0317 | 82.37 | 240.01 | 82.90 | 177.55 | 260.45 | 0.3113 | 0.9089 |
| 26 | 0.68530 | 0.0008309 | 0.0298 | 85.18 | 241.05 | 85.75 | 175.73 | 261.48 | 0.3208 | 0.9082 |
| 28 | 0.72675 | 0.0008362 | 0.0281 | 88.00 | 242.08 | 88.61 | 173.89 | 262.50 | 0.3302 | 0.9076 |
| 30 | 0.77006 | 0.0008417 | 0.0265 | 90.84 | 243.10 | 91.49 | 172.00 | 263.50 | 0.3396 | 0.9070 |
| 32 | 0.81528 | 0.0008473 | 0.0250 | 93.70 | 244.12 | 94.39 | 170.09 | 264.48 | 0.3490 | 0.9064 |
| 34 | 0.86247 | 0.0008530 | 0.0236 | 96.58 | 245.12 | 97.31 | 168.14 | 265.45 | 0.3584 | 0.9058 |
| 36 | 0.91168 | 0.0008590 | 0.0223 | 99.47 | 246.11 | 100.25 | 166.15 | 266.40 | 0.3678 | 0.9053 |
| 38 | 0.96298 | 0.0008651 | 0.0210 | 102.38 | 247.09 | 103.21 | 164.12 | 267.33 | 0.3772 | 0.9047 |
| 40 | 1.0164 | 0.0008714 | 0.0199 | 105.30 | 248.06 | 106.19 | 162.05 | 268.24 | 0.3866 | 0.9041 |
| 42 | 1.0720 | 0.0008780 | 0.0188 | 108.25 | 249.02 | 109.19 | 159.94 | 269.14 | 0.3960 | 0.9035 |
| 44 | 1.1299 | 0.0008847 | 0.0177 | 111.22 | 249.96 | 112.22 | 157.79 | 270.01 | 0.4054 | 0.9030 |
| 48 | 1.2526 | 0.0008989 | 0.0159 | 117.22 | 251.79 | 118.35 | 153.33 | 271.68 | 0.4243 | 0.9017 |
| 52 | 1.3851 | 0.0009142 | 0.0142 | 123.31 | 253.55 | 124.58 | 148.66 | 273.24 | 0.4432 | 0.9004 |
| 56 | 1.5278 | 0.0009308 | 0.0127 | 129.51 | 255.23 | 130.93 | 143.75 | 274.68 | 0.4622 | 0.8990 |
| 60 | 1.6813 | 0.0009488 | 0.0114 | 135.82 | 256.81 | 137.42 | 138.57 | 275.99 | 0.4814 | 0.8973 |
| 70 | 2.1162 | 0.0010027 | 0.0086 | 152.22 | 260.15 | 154.34 | 124.08 | 278.43 | 0.5302 | 0.8918 |
| 80 | 2.6324 | 0.0010766 | 0.0064 | 169.88 | 262.14 | 172.71 | 106.41 | 279.12 | 0.5814 | 0.8827 |
| 90 | 3.2435 | 0.0011949 | 0.0046 | 189.82 | 261.34 | 193.69 | 82.63 | 276.32 | 0.6380 | 0.8655 |
| 100 | 3.9742 | 0.0015443 | 0.0027 | 218.60 | 248.49 | 224.74 | 34.40 | 259.13 | 0.7196 | 0.8117 |

*Source for Tables A–11 through A–13:* M. J. Moran and H. N. Shapiro, *Fundamentals of Engineering Thermodynamics,* 2nd ed. (New York: John Wiley & Sons, 1992), pp. 710–15. Originally based on equations from D. P. Wilson and R. S. Basu, "Thermodynamic Properties of a New Stratospherically Safe Working Fluid—Refrigerant-134a," *ASHRAE Trans.* 94, Pt. 2 (1988), pp. 2095–118. Used with permission.

## TABLE A–12

Saturated refrigerant-134a—Pressure table

| Press., $P$ MPa | Temp., $T_{sat}$ °C | Specific volume, m³/kg: Sat. liquid, $v_f$ | Specific volume, m³/kg: Sat. vapor, $v_g$ | Internal energy, kJ/kg: Sat. liquid, $u_f$ | Internal energy, kJ/kg: Sat. vapor, $u_g$ | Enthalpy, kJ/kg: Sat. liquid, $h_f$ | Enthalpy, kJ/kg: Evap., $h_{fg}$ | Enthalpy, kJ/kg: Sat. vapor, $h_g$ | Entropy, kJ/kg · K: Sat. liquid, $s_f$ | Entropy, kJ/kg · K: Sat. vapor, $s_g$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.06 | −37.07 | 0.0007097 | 0.3100 | 3.41 | 206.12 | 3.46 | 221.27 | 224.72 | 0.0147 | 0.9520 |
| 0.08 | −31.21 | 0.0007184 | 0.2366 | 10.41 | 209.46 | 10.47 | 217.92 | 228.39 | 0.0440 | 0.9447 |
| 0.10 | −26.43 | 0.0007258 | 0.1917 | 16.22 | 212.18 | 16.29 | 215.06 | 231.35 | 0.0678 | 0.9395 |
| 0.12 | −22.36 | 0.0007323 | 0.1614 | 21.23 | 214.50 | 21.32 | 212.54 | 233.86 | 0.0879 | 0.9354 |
| 0.14 | −18.80 | 0.0007381 | 0.1395 | 25.66 | 216.52 | 25.77 | 210.27 | 236.04 | 0.1055 | 0.9322 |
| 0.16 | −15.62 | 0.0007435 | 0.1229 | 29.66 | 218.32 | 29.78 | 208.18 | 237.97 | 0.1211 | 0.9295 |
| 0.18 | −12.73 | 0.0007485 | 0.1098 | 33.31 | 219.94 | 33.45 | 206.26 | 239.71 | 0.1352 | 0.9273 |
| 0.20 | −10.09 | 0.0007532 | 0.0993 | 36.69 | 221.43 | 36.84 | 204.46 | 241.30 | 0.1481 | 0.9253 |
| 0.24 | −5.37 | 0.0007618 | 0.0834 | 42.77 | 224.07 | 42.95 | 201.14 | 244.09 | 0.1710 | 0.9222 |
| 0.28 | −1.23 | 0.0007697 | 0.0719 | 48.18 | 226.38 | 48.39 | 198.13 | 246.52 | 0.1911 | 0.9197 |
| 0.32 | 2.48 | 0.0007770 | 0.0632 | 53.06 | 228.43 | 53.31 | 195.35 | 248.66 | 0.2089 | 0.9177 |
| 0.36 | 5.84 | 0.0007839 | 0.0564 | 57.54 | 230.28 | 57.82 | 192.76 | 250.58 | 0.2251 | 0.9160 |
| 0.4 | 8.93 | 0.0007904 | 0.0509 | 61.69 | 231.97 | 62.00 | 190.32 | 252.32 | 0.2399 | 0.9145 |
| 0.5 | 15.74 | 0.0008056 | 0.0409 | 70.93 | 235.64 | 71.33 | 184.74 | 256.07 | 0.2723 | 0.9117 |
| 0.6 | 21.58 | 0.0008196 | 0.0341 | 78.99 | 238.74 | 79.48 | 179.71 | 259.19 | 0.2999 | 0.9097 |
| 0.7 | 26.72 | 0.0008328 | 0.0292 | 86.19 | 241.42 | 86.78 | 175.07 | 261.85 | 0.3242 | 0.9080 |
| 0.8 | 31.33 | 0.0008454 | 0.0255 | 92.75 | 243.78 | 93.42 | 170.73 | 264.15 | 0.3459 | 0.9066 |
| 0.9 | 35.53 | 0.0008576 | 0.0226 | 98.79 | 245.88 | 99.56 | 166.62 | 266.18 | 0.3656 | 0.9054 |
| 1.0 | 39.39 | 0.0008695 | 0.0202 | 104.42 | 247.77 | 105.29 | 162.68 | 267.97 | 0.3838 | 0.9043 |
| 1.2 | 46.32 | 0.0008928 | 0.0166 | 114.69 | 251.03 | 115.76 | 155.23 | 270.99 | 0.4164 | 0.9023 |
| 1.4 | 52.43 | 0.0009159 | 0.0140 | 123.98 | 253.74 | 125.26 | 148.14 | 273.40 | 0.4453 | 0.9003 |
| 1.6 | 57.92 | 0.0009392 | 0.0121 | 132.52 | 256.00 | 134.02 | 141.31 | 275.33 | 0.4714 | 0.8982 |
| 1.8 | 62.91 | 0.0009631 | 0.0105 | 140.49 | 257.88 | 142.22 | 134.60 | 276.83 | 0.4954 | 0.8959 |
| 2.0 | 67.49 | 0.0009878 | 0.0093 | 148.02 | 259.41 | 149.99 | 127.95 | 277.94 | 0.5178 | 0.8934 |
| 2.5 | 77.59 | 0.0010562 | 0.0069 | 165.48 | 261.84 | 168.12 | 111.06 | 279.17 | 0.5687 | 0.8854 |
| 3.0 | 86.22 | 0.0011416 | 0.0053 | 181.88 | 262.16 | 185.30 | 92.71 | 278.01 | 0.6156 | 0.8735 |

**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 ($T_{sat}$ = −37.07°C) | | | | $P$ = 0.10 MPa ($T_{sat}$ = −26.43°C) | | | | $P$ = 0.14 MPa ($T_{sat}$ = −18.80°C) | | | |
| Sat. | 0.31003 | 206.12 | 224.72 | 0.9520 | 0.19170 | 212.18 | 231.35 | 0.9395 | 0.13945 | 216.52 | 236.04 | 0.9322 |
| −20 | 0.33536 | 217.86 | 237.98 | 1.0062 | 0.19770 | 216.77 | 236.54 | 0.9602 | | | | |
| −10 | 0.34992 | 224.97 | 245.96 | 1.0371 | 0.20686 | 224.01 | 244.70 | 0.9918 | 0.14549 | 223.03 | 243.40 | 0.9606 |
| 0 | 0.36433 | 232.24 | 254.10 | 1.0675 | 0.21587 | 231.41 | 252.99 | 1.0227 | 0.15219 | 230.55 | 251.86 | 0.9922 |
| 10 | 0.37861 | 239.69 | 262.41 | 1.0973 | 0.22473 | 238.96 | 261.43 | 1.0531 | 0.15875 | 238.21 | 260.43 | 1.0230 |
| 20 | 0.39279 | 247.32 | 270.89 | 1.1267 | 0.23349 | 246.67 | 270.02 | 1.0829 | 0.16520 | 246.01 | 269.13 | 1.0532 |
| 30 | 0.40688 | 255.12 | 279.53 | 1.1557 | 0.24216 | 254.54 | 278.76 | 1.1122 | 0.17155 | 253.96 | 277.97 | 1.0828 |
| 40 | 0.42091 | 263.10 | 288.35 | 1.1844 | 0.25076 | 262.58 | 287.66 | 1.1411 | 0.17783 | 262.06 | 286.96 | 1.1120 |
| 50 | 0.43487 | 271.25 | 297.34 | 1.2126 | 0.25930 | 270.79 | 296.72 | 1.1696 | 0.18404 | 270.32 | 296.09 | 1.1407 |
| 60 | 0.44879 | 279.58 | 306.51 | 1.2405 | 0.26779 | 279.16 | 305.94 | 1.1977 | 0.19020 | 278.74 | 305.37 | 1.1690 |
| 70 | 0.46266 | 288.08 | 315.84 | 1.2681 | 0.27623 | 287.70 | 315.32 | 1.2254 | 0.19633 | 287.32 | 314.80 | 1.1969 |
| 80 | 0.47650 | 296.75 | 325.34 | 1.2954 | 0.28464 | 296.40 | 324.87 | 1.2528 | 0.20241 | 296.06 | 324.39 | 1.2244 |
| 90 | 0.49031 | 305.58 | 335.00 | 1.3224 | 0.29302 | 305.27 | 334.57 | 1.2799 | 0.20846 | 304.95 | 334.14 | 1.2516 |
| 100 | | | | | | | | | 0.21449 | 314.01 | 344.04 | 1.2785 |
| | $P$ = 0.18 MPa ($T_{sat}$ = −12.73°C) | | | | $P$ = 0.20 MPa ($T_{sat}$ = −10.09°C) | | | | $P$ = 0.24 MPa ($T_{sat}$ = −5.37°C) | | | |
| Sat. | 0.10983 | 219.94 | 239.71 | 0.9273 | 0.09933 | 221.43 | 241.30 | 0.9253 | 0.08343 | 224.07 | 244.09 | 0.9222 |
| −10 | 0.11135 | 222.02 | 242.06 | 0.9362 | 0.09938 | 221.50 | 241.38 | 0.9256 | | | | |
| 0 | 0.11678 | 229.67 | 250.69 | 0.9684 | 0.10438 | 229.23 | 250.10 | 0.9582 | 0.08574 | 228.31 | 248.89 | 0.9399 |
| 10 | 0.12207 | 237.44 | 259.41 | 0.9998 | 0.10922 | 237.05 | 258.89 | 0.9898 | 0.08993 | 236.26 | 257.84 | 0.9721 |
| 20 | 0.12723 | 245.33 | 268.23 | 1.0304 | 0.11394 | 244.99 | 267.78 | 1.0206 | 0.09339 | 244.30 | 266.85 | 1.0034 |
| 30 | 0.13230 | 253.36 | 277.17 | 1.0604 | 0.11856 | 253.06 | 276.77 | 1.0508 | 0.09794 | 252.45 | 275.95 | 1.0339 |
| 40 | 0.13730 | 261.53 | 286.24 | 1.0898 | 0.12311 | 261.26 | 285.88 | 1.0804 | 0.10181 | 260.72 | 285.16 | 1.0637 |
| 50 | 0.14222 | 269.85 | 295.45 | 1.1187 | 0.12758 | 269.61 | 295.12 | 1.1094 | 0.10562 | 269.12 | 294.47 | 1.0930 |
| 60 | 0.14710 | 278.31 | 304.79 | 1.1472 | 0.13201 | 278.10 | 304.50 | 1.1380 | 0.10937 | 277.67 | 303.91 | 1.1218 |
| 70 | 0.15193 | 286.93 | 314.28 | 1.1753 | 0.13639 | 286.74 | 314.02 | 1.1661 | 0.11307 | 286.35 | 313.49 | 1.1501 |
| 80 | 0.15672 | 295.71 | 323.92 | 1.2030 | 0.14073 | 295.53 | 323.68 | 1.1939 | 0.11674 | 295.18 | 323.19 | 1.1780 |
| 90 | 0.16148 | 304.63 | 333.70 | 1.2303 | 0.14504 | 304.47 | 333.48 | 1.2212 | 0.12037 | 304.15 | 333.04 | 1.2055 |
| 100 | 0.16622 | 313.72 | 343.63 | 1.2573 | 0.14932 | 313.57 | 343.43 | 1.2483 | 0.12398 | 313.27 | 343.03 | 1.2326 |
| | $P$ = 0.28 MPa ($T_{sat}$ = −1.23°C) | | | | $P$ = 0.32 MPa ($T_{sat}$ = 2.48°C) | | | | $P$ = 0.40 MPa ($T_{sat}$ = 8.93°C) | | | |
| Sat. | 0.07193 | 226.38 | 246.52 | 0.9197 | 0.06322 | 228.43 | 248.66 | 0.9177 | 0.05089 | 231.97 | 252.32 | 0.9145 |
| 0 | 0.07240 | 227.37 | 247.64 | 0.9238 | | | | | | | | |
| 10 | 0.07613 | 235.44 | 256.76 | 0.9566 | 0.06576 | 234.61 | 255.65 | 0.9427 | 0.05119 | 232.87 | 253.35 | 0.9182 |
| 20 | 0.07972 | 243.59 | 265.91 | 0.9883 | 0.06901 | 242.87 | 264.95 | 0.9749 | 0.05397 | 241.37 | 262.96 | 0.9515 |
| 30 | 0.08320 | 251.83 | 275.12 | 1.0192 | 0.07214 | 251.19 | 274.28 | 1.0062 | 0.05662 | 249.89 | 272.54 | 0.9837 |
| 40 | 0.08660 | 260.17 | 284.42 | 1.0494 | 0.07518 | 259.61 | 283.67 | 1.0367 | 0.05917 | 258.47 | 282.14 | 1.0148 |
| 50 | 008992 | 268.64 | 293.81 | 1.0789 | 0.07815 | 268.14 | 293.15 | 1.0665 | 0.06164 | 267.13 | 291.79 | 1.0452 |
| 60 | 0.09319 | 277.23 | 303.32 | 1.1079 | 0.08106 | 276.79 | 302.72 | 1.0957 | 0.06405 | 275.89 | 301.51 | 1.0748 |
| 70 | 0.09641 | 285.96 | 312.95 | 1.1364 | 0.08392 | 285.56 | 312.41 | 1.1243 | 0.06641 | 284.75 | 311.32 | 1.1038 |
| 80 | 0.09960 | 294.82 | 322.71 | 1.1644 | 0.08674 | 294.46 | 322.22 | 1.1525 | 0.06873 | 293.73 | 321.23 | 1.1322 |
| 90 | 0.10275 | 303.83 | 332.60 | 1.1920 | 0.08953 | 303.50 | 332.15 | 1.1802 | 0.07102 | 302.84 | 331.25 | 1.1602 |
| 100 | 0.10587 | 312.98 | 342.62 | 1.2193 | 0.09229 | 312.68 | 342.21 | 1.1076 | 0.07327 | 312.07 | 341.38 | 1.1878 |
| 110 | 0.10897 | 322.27 | 352.78 | 1.2461 | 0.09503 | 322.00 | 352.40 | 1.2345 | 0.07550 | 321.44 | 351.64 | 1.2149 |
| 120 | 0.11205 | 331.71 | 363.08 | 1.2727 | 0.09774 | 331.45 | 362.73 | 1.2611 | 0.07771 | 330.94 | 362.03 | 1.2417 |
| 130 | | | | | | | | | 0.07991 | 340.58 | 372.54 | 1.2681 |
| 140 | | | | | | | | | 0.08208 | 350.35 | 383.18 | 1.2941 |

## 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 ($T_{sat}$ = 15.74°C) | | | | $P$ = 0.60 MPa ($T_{sat}$ = 21.58°C) | | | | $P$ = 0.70 MPa ($T_{sat}$ = 26.72°C) | | | |
| Sat. | 0.04086 | 253.64 | 256.07 | 0.9117 | 0.03408 | 238.74 | 259.19 | 0.9097 | 0.02918 | 241.42 | 261.85 | 0.9080 |
| 20 | 0.04188 | 239.40 | 260.34 | 0.9264 | | | | | | | | |
| 30 | 0.04416 | 248.20 | 270.28 | 0.9597 | 0.03581 | 246.41 | 267.89 | 0.9388 | 0.02979 | 244.51 | 265.37 | 0.9197 |
| 40 | 0.04633 | 256.99 | 280.16 | 0.9918 | 0.03774 | 255.45 | 278.09 | 0.9719 | 0.03157 | 253.83 | 275.93 | 0.9539 |
| 50 | 0.04842 | 265.83 | 290.04 | 1.0229 | 0.03958 | 264.48 | 288.23 | 1.0037 | 0.03324 | 263.08 | 286.35 | 0.9867 |
| 60 | 0.05043 | 274.73 | 299.95 | 1.0531 | 0.04134 | 273.54 | 298.35 | 1.0346 | 0.03482 | 272.31 | 296.69 | 1.0182 |
| 70 | 0.05240 | 283.72 | 309.92 | 1.0825 | 0.04304 | 282.66 | 308.48 | 1.0645 | 0.03634 | 281.57 | 307.01 | 1.0487 |
| 80 | 0.05432 | 292.80 | 319.96 | 1.1114 | 0.04469 | 291.86 | 318.67 | 1.0938 | 0.03781 | 290.88 | 317.35 | 1.0784 |
| 90 | 0.05620 | 302.00 | 330.10 | 1.1397 | 0.04631 | 301.14 | 328.93 | 1.1225 | 0.03924 | 300.27 | 327.74 | 1.1074 |
| 100 | 0.05805 | 311.31 | 340.33 | 1.1675 | 0.04790 | 310.53 | 339.27 | 1.1505 | 0.04064 | 309.74 | 338.19 | 1.1358 |
| 110 | 0.05988 | 320.74 | 350.68 | 1.1949 | 0.04946 | 320.03 | 349.70 | 1.1781 | 0.04201 | 319.31 | 348.71 | 1.1637 |
| 120 | 0.06168 | 330.30 | 361.14 | 1.2218 | 0.05099 | 329.64 | 360.24 | 1.2053 | 0.04335 | 328.98 | 359.33 | 1.1910 |
| 130 | 0.06347 | 339.98 | 371.72 | 1.2484 | 0.05251 | 339.38 | 370.88 | 1.2320 | 0.04468 | 338.76 | 370.04 | 1.2179 |
| 140 | 0.06524 | 349.79 | 382.42 | 1.2746 | 0.05402 | 349.23 | 381.64 | 1.2584 | 0.04599 | 348.66 | 380.86 | 1.2444 |
| 150 | | | | | 0.05550 | 359.21 | 392.52 | 1.2844 | 0.04729 | 358.68 | 391.79 | 1.2706 |
| 160 | | | | | 0.05698 | 369.32 | 403.51 | 1.3100 | 0.04857 | 368.82 | 402.82 | 1.2963 |
| | $P$ = 0.80 MPa ($T_{sat}$ = 31.33°C) | | | | $P$ = 0.90 MPa ($T_{sat}$ = 35.53°C) | | | | $P$ = 1.00 MPa ($T_{sat}$ = 39.39°C) | | | |
| Sat. | 0.02547 | 243.78 | 264.15 | 0.9066 | 0.02255 | 245.88 | 266.18 | 0.9054 | 0.02020 | 247.77 | 267.97 | 0.9043 |
| 40 | 0.02691 | 252.13 | 273.66 | 0.9374 | 0.02325 | 250.32 | 271.25 | 0.9217 | 0.02029 | 248.39 | 268.68 | 0.9066 |
| 50 | 0.02846 | 261.62 | 284.39 | 0.9711 | 0.02472 | 260.09 | 282.34 | 0.9566 | 0.02171 | 258.48 | 280.19 | 0.9428 |
| 60 | 0.02992 | 271.04 | 294.98 | 1.0034 | 0.02609 | 269.72 | 293.21 | 0.9897 | 0.02301 | 268.35 | 291.36 | 0.9768 |
| 70 | 0.03131 | 280.45 | 305.50 | 1.0345 | 0.02738 | 279.30 | 303.94 | 1.0214 | 0.02423 | 278.11 | 302.34 | 1.0093 |
| 80 | 0.03264 | 289.89 | 316.00 | 1.0647 | 0.02861 | 288.87 | 314.62 | 1.0521 | 0.02538 | 287.82 | 313.20 | 1.0405 |
| 90 | 0.03393 | 299.37 | 326.52 | 1.0940 | 0.02980 | 298.46 | 325.28 | 1.0819 | 0.02649 | 297.53 | 324.01 | 1.0707 |
| 100 | 0.03519 | 308.93 | 337.08 | 1.1227 | 0.03095 | 308.11 | 335.96 | 1.1109 | 0.02755 | 307.27 | 334.82 | 1.1000 |
| 110 | 0.03642 | 318.57 | 347.71 | 1.1508 | 0.03207 | 317.82 | 346.68 | 1.1392 | 0.02858 | 317.06 | 345.65 | 1.1286 |
| 120 | 0.03762 | 328.31 | 358.40 | 1.1784 | 0.03316 | 327.62 | 357.47 | 1.1670 | 0.02959 | 326.93 | 356.52 | 1.1567 |
| 130 | 0.03881 | 338.14 | 369.19 | 1.2055 | 0.03423 | 337.52 | 368.33 | 1.1943 | 0.03058 | 336.88 | 367.46 | 1.1841 |
| 140 | 0.03997 | 348.09 | 380.07 | 1.2321 | 0.03529 | 347.51 | 379.27 | 1.2211 | 0.03154 | 346.92 | 378.46 | 1.2111 |
| 150 | 0.04113 | 358.15 | 391.05 | 1.2584 | 0.03633 | 357.61 | 390.31 | 1.2475 | 0.03250 | 357.06 | 389.56 | 1.2376 |
| 160 | 0.04227 | 368.32 | 402.14 | 1.2843 | 0.03736 | 367.82 | 401.44 | 1.2735 | 0.03344 | 367.31 | 400.74 | 1.2638 |
| 170 | 0.04340 | 378.61 | 413.33 | 1.3098 | 0.03838 | 378.14 | 412.68 | 1.2992 | 0.03436 | 377.66 | 412.02 | 1.2895 |
| 180 | 0.04452 | 389.02 | 424.63 | 1.3351 | 0.03939 | 388.57 | 424.02 | 1.3245 | 0.03528 | 388.12 | 423.40 | 1.3149 |
| | $P$ = 1.20 MPa ($T_{sat}$ = 46.32°C) | | | | $P$ = 1.40 MPa ($T_{sat}$ = 52.43°C) | | | | $P$ = 1.60 MPa ($T_{sat}$ = 57.92°C) | | | |
| Sat. | 0.01663 | 251.03 | 270.99 | 0.9023 | 0.01405 | 253.74 | 273.40 | 0.9003 | 0.01208 | 256.00 | 275.33 | 0.8982 |
| 50 | 0.01712 | 254.98 | 275.52 | 0.9164 | | | | | | | | |
| 60 | 0.01835 | 265.42 | 287.44 | 0.9527 | 0.01495 | 262.17 | 283.10 | 0.9297 | 0.01233 | 258.48 | 278.20 | 0.9069 |
| 70 | 0.01947 | 275.59 | 298.96 | 0.9868 | 0.01603 | 272.87 | 295.31 | 0.9658 | 0.01340 | 269.89 | 291.33 | 0.9457 |
| 80 | 0.02051 | 285.62 | 310.24 | 1.0192 | 0.01701 | 283.29 | 307.10 | 0.9997 | 0.01435 | 280.78 | 303.74 | 0.9813 |
| 90 | 0.02150 | 295.59 | 321.39 | 1.0503 | 0.01792 | 293.55 | 318.63 | 1.0319 | 0.01521 | 291.39 | 315.72 | 1.0148 |
| 100 | 0.02244 | 305.54 | 332.47 | 1.0804 | 0.01878 | 303.73 | 330.02 | 1.0628 | 0.01601 | 301.84 | 327.46 | 1.0467 |
| 110 | 0.02335 | 315.50 | 343.52 | 1.1096 | 0.01960 | 313.88 | 341.32 | 1.0927 | 0.01677 | 312.20 | 339.04 | 1.0773 |
| 120 | 0.02423 | 325.51 | 354.58 | 1.1381 | 0.02039 | 324.05 | 352.59 | 1.1218 | 0.01750 | 322.53 | 350.53 | 1.1069 |
| 130 | 0.02508 | 335.58 | 365.68 | 1.1660 | 0.02115 | 334.25 | 363.86 | 1.1501 | 0.01820 | 332.87 | 361.99 | 1.1357 |
| 140 | 0.02592 | 345.73 | 376.83 | 1.1933 | 0.02189 | 344.50 | 375.15 | 1.1777 | 0.01887 | 343.24 | 373.44 | 1.1638 |
| 150 | 0.02674 | 355.95 | 388.04 | 1.2201 | 0.02262 | 354.82 | 386.49 | 1.2048 | 0.01953 | 353.66 | 384.91 | 1.1912 |
| 160 | 0.02754 | 366.27 | 399.33 | 1.2465 | 0.02333 | 365.22 | 397.89 | 1.2315 | 0.02017 | 364.15 | 396.43 | 1.2181 |
| 170 | 0.02834 | 376.69 | 410.70 | 1.2724 | 0.02403 | 375.71 | 409.36 | 1.2576 | 0.02080 | 374.71 | 407.99 | 1.2445 |
| 180 | 0.02912 | 387.21 | 422.16 | 1.2980 | 0.02472 | 386.29 | 420.90 | 1.2834 | 0.02142 | 385.35 | 419.62 | 1.2704 |
| 190 | | | | | 0.02541 | 396.96 | 432.53 | 1.3088 | 0.02203 | 396.08 | 431.33 | 1.2960 |
| 200 | | | | | 0.02608 | 407.73 | 444.24 | 1.3338 | 0.02263 | 406.90 | 443.11 | 1.3212 |