

**ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT)**  
ORGANISATION OF ISLAMIC COOPERATION (OIC)  
DEPARTMENT OF MECHANICAL AND PRODUCTION ENGINEERING

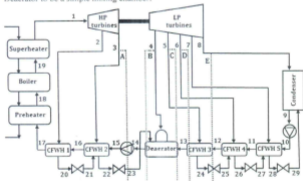
Semester Final Examination  
Course Number: ME 4405  
Course Title: Applied Thermodynamics

Summer Semester: 2022 - 2023  
Full Marks: 150  
Time: 3 Hours

There are 6 (six) questions. Answer **all** the questions. The symbols have their usual meanings. Marks of each question and corresponding CO and PO are written in brackets. Assume the reasonable values if required.

1. (a) A vapor-compression refrigeration cycle with **refrigerant-134a** as the working fluid is used to maintain a space at **-13°C** by rejecting heat to ambient air at **27°C**. R-134a enters the compressor at **100 kPa** superheated by **6.4°C** at a rate of **0.05 kg/s**. The isentropic efficiency of the compressor is **85%**. The refrigerant leaves the condenser at **39.4°C** as a saturated liquid. Determine (20)
  - i. the rate of cooling provided and the COP of the system, (CO3)
  - ii. the exergy destruction in each basic component, (PO3)
  - iii. the minimum power input and the second-law efficiency of the cycle, and
  - iv. the rate of total exergy destruction.
  
- (b) The radiator of a steam heating system has a volume of **20 L**, and is filled with superheated water vapor at **200 kPa** and **200°C**. At this moment both the inlet and the exit valves to the radiator are closed. After a while it is observed that the temperature of the steam drops to **80°C** as a result of heat transfer to the room air, which is at **27°C**. Assuming the surroundings to be at **0°C** and heat engine operates between the radiator and the surroundings, compute (12)
  - i. the amount of heat transfer to the room and (CO3)
  - ii. the maximum amount of heat that can be supplied to the room if this heat from the radiator is supplied to a heat engine that is driving a heat pump. (PO3)
  
2. (a) A turbojet aircraft is flying with a velocity of **280 m/s** at an altitude of **9150 m**, where the ambient conditions are **32 kPa** and **-32°C**. The pressure ratio across the compressor is **12**, and the temperature at the turbine inlet is **1100 K**. Air enters the compressor at a rate of **50 kg/s**, and the jet fuel has a heating value of **42,700 kJ/kg**. Assuming compressor efficiency of **80%** and a turbine efficiency of **85%** and constant specific heats for air at room temperature, compute (25)
  - i. the velocity of the exhaust gases, (CO3)
  - ii. the propulsive power developed, and (PO3)
  - iii. the rate of fuel consumption.
  
- (b) **1 kmol** of ethane (**C<sub>2</sub>H<sub>6</sub>**) is burned with an unknown amount of air during a combustion process. An analysis of the combustion products reveals that the combustion is complete, and there are **3 kmol** of free **O<sub>2</sub>** in the products. Determine (10)
  - i. the fuel-air ratio and (CO3)
  - ii. the percentage of theoretical air used during this process. (PO3)

3. (a) A steam power plant operates on an ideal regenerative Rankine cycle. Steam enters the turbine at 6 MPa and 450°C and is condensed in the condenser at 20 kPa. Steam is extracted from the turbine at 0.4 MPa to enter a closed feedwater heater. Assume that the feedwater leaves the heater at the condensation temperature of the extracted steam and that the extracted steam leaves the heater as a saturated liquid and is pumped to the line carrying the feedwater. Show the cycle on a  $T-s$  diagram, and determine
- the net work output per kilogram of steam flowing through the boiler and
  - the thermal efficiency of the cycle.
- (15)  
(CO3)  
(PO3)
- (b) Steam expands in a turbine steadily at a rate of 18,000 kg/h, entering at 7 MPa and 600°C and leaving at 50 kPa as saturated vapor. Assuming the surroundings to be at 100 kPa and 25°C, determine
- the power potential of the steam at the inlet conditions and
  - the power output of the turbine if there were no irreversibilities present.
- (10)  
(CO3)  
(PO3)
4. (a) Illustrate the  $T-s$  diagram of the following thermodynamic cycle. Assume the Deaerator to be a simple mixing chamber.
- (12)  
(CO2)  
(PO2)



- (b) Why is regeneration not recommended in a Brayton cycle with higher pressure ratio? Evaluate with a cycle diagram.
- (08)  
(CO2)  
(PO2)
- (c) "A system may have higher second law efficiency than the first law efficiency during a process" – Do you agree with the statement? Justify in favor of your answer.
- (05)  
(CO2)  
(PO2)
5. (a) "Absorption refrigeration systems are often classified as heat-driven systems" – Justify the statement with schematic diagram of the thermodynamic cycle.
- (10)  
(CO2)  
(PO2)
- (b) "N<sub>2</sub> present in air doesn't affect the combustion reaction at all." – Do you agree with the statement? Justify your answer.
- (05)  
(CO2)  
(PO2)
6. (a) What is evaporative cooling? Why the water in a porous jug left in a breezy area is colder?
- (06)  
(CO1)  
(PO1)

(b) How the exergy of a system can be different at different environment? (06)

(CO1)  
(PO1)

(c) Define the followings:

- i. Absolute humidity
- ii. Theoretical air
- iii. Trap

(06)  
(CO1)  
(PO1)

## Property Tables

**TABLE A-11**

Saturated refrigerant-134a—Temperature table

| Temp.,<br>T °C | Sat.<br>press.,<br>P <sub>sat</sub> kPa | Specific volume,<br>m <sup>3</sup> /kg |                                  | Internal energy,<br>kJ/kg         |                           |                                  | Enthalpy,<br>kJ/kg                |                           |                                  | Entropy,<br>kJ/kg·K               |                           |                                  |
|----------------|---|--|----------------------------------|-----------------------------------|---------------------------|----------------------------------|-----------------------------------|---------------------------|----------------------------------|-----------------------------------|---------------------------|----------------------------------|
|                |   | Sat.<br>liquid,<br>v <sub>f</sub>      | Sat.<br>vapor,<br>v <sub>g</sub> | Sat.<br>liquid,<br>u <sub>f</sub> | Evap.,<br>u <sub>fg</sub> | Sat.<br>vapor,<br>u <sub>g</sub> | Sat.<br>liquid,<br>h <sub>f</sub> | Evap.,<br>h <sub>fg</sub> | Sat.<br>vapor,<br>h <sub>g</sub> | Sat.<br>liquid,<br>s <sub>f</sub> | Evap.,<br>s <sub>fg</sub> | Sat.<br>vapor,<br>s <sub>g</sub> |
| 20             | 572.07                                  | 0.0008160                              | 0.036012                         | 78.85                             | 162.19                    | 241.04                           | 79.32                             | 182.33                    | 261.64                           | 0.30062                           | 0.82192                   | 0.92254                          |
| 22             | 608.27                                  | 0.0008209                              | 0.033867                         | 81.64                             | 160.45                    | 242.09                           | 82.14                             | 180.55                    | 262.69                           | 0.31012                           | 0.81168                   | 0.92180                          |
| 24             | 646.18                                  | 0.0008260                              | 0.031869                         | 84.44                             | 158.68                    | 243.13                           | 84.98                             | 178.74                    | 263.72                           | 0.31959                           | 0.80148                   | 0.92107                          |
| 26             | 685.84                                  | 0.0008312                              | 0.030008                         | 87.26                             | 156.89                    | 244.15                           | 87.83                             | 176.90                    | 264.73                           | 0.32905                           | 0.79131                   | 0.92036                          |
| 28             | 727.31                                  | 0.0008366                              | 0.028271                         | 90.09                             | 155.08                    | 245.17                           | 90.70                             | 175.03                    | 265.73                           | 0.33849                           | 0.78117                   | 0.91967                          |
| 30             | 770.64                                  | 0.0008421                              | 0.026648                         | 92.93                             | 153.24                    | 246.17                           | 93.58                             | 173.13                    | 266.71                           | 0.34792                           | 0.77105                   | 0.91897                          |
| 32             | 815.89                                  | 0.0008477                              | 0.025131                         | 95.79                             | 151.37                    | 247.17                           | 96.49                             | 171.19                    | 267.67                           | 0.35734                           | 0.76095                   | 0.91829                          |
| 34             | 863.11                                  | 0.0008535                              | 0.023712                         | 98.67                             | 149.48                    | 248.15                           | 99.41                             | 169.21                    | 268.61                           | 0.36675                           | 0.75086                   | 0.91760                          |
| 36             | 912.35                                  | 0.0008595                              | 0.022383                         | 101.56                            | 147.55                    | 249.11                           | 102.34                            | 167.19                    | 269.53                           | 0.37615                           | 0.74077                   | 0.91692                          |
| 38             | 963.68                                  | 0.0008657                              | 0.021137                         | 104.47                            | 145.60                    | 250.07                           | 105.30                            | 165.13                    | 270.44                           | 0.38554                           | 0.73068                   | 0.91622                          |
| 40             | 1017.1                                  | 0.0008720                              | 0.019968                         | 107.39                            | 143.61                    | 251.00                           | 108.28                            | 163.03                    | 271.31                           | 0.39493                           | 0.72059                   | 0.91552                          |
| 42             | 1072.8                                  | 0.0008786                              | 0.018870                         | 110.34                            | 141.59                    | 251.92                           | 111.28                            | 160.89                    | 272.17                           | 0.40432                           | 0.71048                   | 0.91480                          |
| 44             | 1130.7                                  | 0.0008854                              | 0.017837                         | 113.30                            | 139.53                    | 252.83                           | 114.30                            | 158.70                    | 273.00                           | 0.41371                           | 0.70036                   | 0.91407                          |

**TABLE A-12**

Saturated refrigerant-134a—Pressure table

| Press.,<br>P<br>kPa | Sat.<br>temp.,<br>T <sub>sat</sub> °C | Specific volume,<br>m <sup>3</sup> /kg |                                  | Internal energy,<br>kJ/kg         |                           |                                  | Enthalpy,<br>kJ/kg                |                           |                                  | Entropy,<br>kJ/kg·K               |                           |                                  |
|---------------------|---------------------------------------|--|----------------------------------|-----------------------------------|---------------------------|----------------------------------|-----------------------------------|---------------------------|----------------------------------|-----------------------------------|---------------------------|----------------------------------|
|                     |                                       | Sat.<br>liquid,<br>v <sub>f</sub>      | Sat.<br>vapor,<br>v <sub>g</sub> | Sat.<br>liquid,<br>u <sub>f</sub> | Evap.,<br>u <sub>fg</sub> | Sat.<br>vapor,<br>u <sub>g</sub> | Sat.<br>liquid,<br>h <sub>f</sub> | Evap.,<br>h <sub>fg</sub> | Sat.<br>vapor,<br>h <sub>g</sub> | Sat.<br>liquid,<br>s <sub>f</sub> | Evap.,<br>s <sub>fg</sub> | Sat.<br>vapor,<br>s <sub>g</sub> |
| 60                  | -36.96                                | 0.0007097                              | 0.31108                          | 3.795                             | 205.34                    | 209.13                           | 3.837                             | 223.96                    | 227.80                           | 0.01633                           | 0.94812                   | 0.96445                          |
| 70                  | -33.87                                | 0.0007143                              | 0.25921                          | 7.672                             | 203.23                    | 210.90                           | 7.722                             | 222.02                    | 229.74                           | 0.03264                           | 0.92783                   | 0.96047                          |
| 80                  | -31.13                                | 0.0007184                              | 0.23749                          | 11.14                             | 201.33                    | 212.48                           | 11.20                             | 220.27                    | 231.47                           | 0.04707                           | 0.91009                   | 0.95716                          |
| 90                  | -28.65                                | 0.0007222                              | 0.21261                          | 14.30                             | 199.60                    | 213.90                           | 14.36                             | 218.67                    | 233.04                           | 0.06003                           | 0.89431                   | 0.95434                          |
| 100                 | -26.37                                | 0.0007258                              | 0.19255                          | 17.19                             | 198.01                    | 215.21                           | 17.27                             | 217.19                    | 234.46                           | 0.07182                           | 0.88008                   | 0.95191                          |
| 120                 | -22.32                                | 0.0007323                              | 0.16216                          | 22.38                             | 196.15                    | 217.53                           | 22.47                             | 214.52                    | 236.99                           | 0.09269                           | 0.85520                   | 0.94789                          |
| 1000                | 39.37                                 | 0.0008700                              | 0.020329                         | 106.47                            | 144.24                    | 250.71                           | 107.34                            | 163.70                    | 271.04                           | 0.39196                           | 0.52378                   | 0.91574                          |
| 1200                | 46.29                                 | 0.0008938                              | 0.016728                         | 116.72                            | 137.12                    | 253.84                           | 117.79                            | 156.12                    | 273.92                           | 0.42449                           | 0.48870                   | 0.91320                          |
| 1400                | 52.40                                 | 0.0009167                              | 0.014119                         | 125.96                            | 130.44                    | 256.40                           | 127.25                            | 148.92                    | 276.17                           | 0.45325                           | 0.45742                   | 0.91067                          |
| 1600                | 57.88                                 | 0.0009400                              | 0.012134                         | 134.45                            | 124.05                    | 258.50                           | 135.96                            | 141.96                    | 277.92                           | 0.47921                           | 0.42881                   | 0.90802                          |
| 1800                | 62.87                                 | 0.0009639                              | 0.010568                         | 142.36                            | 117.85                    | 260.21                           | 144.09                            | 135.14                    | 279.23                           | 0.50304                           | 0.40213                   | 0.90517                          |

TABLE A-13

Superheated refrigerant-134a

| T<br>°C                                    | v<br>m <sup>3</sup> /kg | u<br>kJ/kg | h<br>kJ/kg | s<br>kJ/kg·K                               | v<br>m <sup>3</sup> /kg | u<br>kJ/kg | h<br>kJ/kg | s<br>kJ/kg·K                               | v<br>m <sup>3</sup> /kg | u<br>kJ/kg | h<br>kJ/kg | s<br>kJ/kg·K |
|--|-------------------------|------------|------------|--|-------------------------|------------|------------|--|-------------------------|------------|------------|--------------|
| P = 0.06 MPa (T <sub>sat</sub> = -35.99°C) |                         |            |            | P = 0.10 MPa (T <sub>sat</sub> = -26.37°C) |                         |            |            | P = 0.14 MPa (T <sub>sat</sub> = -18.77°C) |                         |            |            |              |
| Sat.                                       | 0.31108                 | 209.13     | 227.80     | 0.9645                                     | 0.19256                 | 215.21     | 234.46     | 0.9519                                     | 0.14020                 | 219.56     | 239.19     | 0.9447       |
| -20  | 0.33608                 | 220.62     | 240.78     | 1.0175                                     | 0.19841                 | 219.68     | 239.52     | 0.9721                                     |                         |            |            |              |
| -10  | 0.35048                 | 227.57     | 248.60     | 1.0478                                     | 0.20743                 | 226.77     | 247.51     | 1.0031                                     | 0.14605                 | 225.93     | 246.37     | 0.9724       |
| 0  | 0.36476                 | 234.67     | 256.56     | 1.0775                                     | 0.21630                 | 233.97     | 255.60     | 1.0333                                     | 0.15263                 | 233.25     | 254.61     | 1.0032       |
| 10   | 0.37893                 | 241.94     | 264.68     | 1.1067                                     | 0.22506                 | 241.32     | 263.82     | 1.0628                                     | 0.15908                 | 240.68     | 262.95     | 1.0331       |
| 20   | 0.39302                 | 249.37     | 272.95     | 1.1354                                     | 0.23379                 | 248.81     | 272.18     | 1.0919                                     | 0.16544                 | 248.24     | 271.40     | 1.0625       |
| 30   | 0.40705                 | 256.97     | 281.39     | 1.1637                                     | 0.24233                 | 256.46     | 280.69     | 1.1204                                     | 0.17172                 | 255.95     | 279.99     | 1.0913       |
| 40   | 0.42102                 | 264.73     | 289.99     | 1.1916                                     | 0.25088                 | 264.27     | 289.36     | 1.1485                                     | 0.17794                 | 263.80     | 288.72     | 1.1196       |
| 50   | 0.43495                 | 272.66     | 298.76     | 1.2192                                     | 0.25937                 | 272.24     | 298.17     | 1.1762                                     | 0.18412                 | 271.81     | 297.59     | 1.1475       |
| 60   | 0.44883                 | 280.75     | 307.68     | 1.2464                                     | 0.26783                 | 280.36     | 307.15     | 1.2036                                     | 0.19025                 | 279.97     | 306.61     | 1.1750       |
| 70   | 0.46269                 | 289.01     | 316.77     | 1.2732                                     | 0.27626                 | 288.65     | 316.28     | 1.2306                                     | 0.19635                 | 288.29     | 315.78     | 1.2021       |
| 80   | 0.47651                 | 297.43     | 326.02     | 1.2998                                     | 0.28465                 | 297.10     | 325.57     | 1.2573                                     | 0.20242                 | 296.77     | 325.11     | 1.2289       |
| 90   | 0.49032                 | 306.02     | 335.43     | 1.3261                                     | 0.29303                 | 305.71     | 335.01     | 1.2836                                     | 0.20847                 | 305.40     | 334.59     | 1.2554       |
| 100  | 0.50410                 | 314.76     | 345.01     | 1.3521                                     | 0.30138                 | 314.48     | 344.61     | 1.3097                                     | 0.21449                 | 314.19     | 344.22     | 1.2815       |
| P = 0.80 MPa (T <sub>sat</sub> = 31.31°C)  |                         |            |            | P = 0.90 MPa (T <sub>sat</sub> = 35.51°C)  |                         |            |            | P = 1.00 MPa (T <sub>sat</sub> = 39.37°C)  |                         |            |            |              |
| Sat.                                       | 0.025645                | 246.82     | 267.34     | 0.9185                                     | 0.022686                | 248.82     | 269.25     | 0.9169                                     | 0.020319                | 250.71     | 271.04     | 0.9157       |
| 40   | 0.027035                | 254.84     | 276.46     | 0.9481                                     | 0.023375                | 263.15     | 274.19     | 0.9328                                     | 0.020406                | 251.32     | 271.73     | 0.9180       |
| 50   | 0.028547                | 263.87     | 286.71     | 0.9803                                     | 0.024809                | 262.46     | 284.79     | 0.9661                                     | 0.021796                | 260.96     | 282.76     | 0.9526       |
| 60   | 0.029973                | 272.85     | 296.82     | 1.0111                                     | 0.026146                | 271.62     | 295.15     | 0.9977                                     | 0.023068                | 270.33     | 293.40     | 0.9851       |
| 70   | 0.031340                | 281.83     | 306.90     | 1.0409                                     | 0.027413                | 280.74     | 305.41     | 1.0280                                     | 0.024261                | 279.61     | 303.87     | 1.0160       |
| 80   | 0.032659                | 290.86     | 316.99     | 1.0699                                     | 0.028530                | 289.88     | 315.65     | 1.0574                                     | 0.025398                | 288.87     | 314.27     | 1.0459       |
| 90   | 0.033941                | 299.97     | 327.12     | 1.0982                                     | 0.029506                | 299.08     | 325.90     | 1.0861                                     | 0.026492                | 298.17     | 324.66     | 1.0749       |
| 100  | 0.035193                | 309.17     | 337.32     | 1.1259                                     | 0.030591                | 308.35     | 336.21     | 1.1141                                     | 0.027592                | 307.52     | 335.08     | 1.1032       |
| 110  | 0.036420                | 318.47     | 347.61     | 1.1531                                     | 0.032068                | 317.72     | 346.58     | 1.1415                                     | 0.028584                | 316.96     | 345.54     | 1.1309       |
| 120  | 0.037625                | 327.89     | 357.99     | 1.1798                                     | 0.033164                | 327.19     | 357.04     | 1.1684                                     | 0.029592                | 326.49     | 356.08     | 1.1580       |
| 130  | 0.038813                | 337.42     | 368.47     | 1.2062                                     | 0.034241                | 336.78     | 367.59     | 1.1949                                     | 0.030581                | 336.12     | 366.70     | 1.1847       |
| 140  | 0.039985                | 347.08     | 379.07     | 1.2321                                     | 0.035302                | 346.48     | 378.25     | 1.2211                                     | 0.031554                | 345.87     | 377.42     | 1.2110       |
| 150  | 0.041143                | 356.86     | 389.78     | 1.2577                                     | 0.036349                | 356.30     | 389.01     | 1.2468                                     | 0.032512                | 355.73     | 388.24     | 1.2369       |
| 160  | 0.042290                | 366.78     | 400.61     | 1.2830                                     | 0.037384                | 366.25     | 399.89     | 1.2722                                     | 0.033457                | 365.71     | 399.17     | 1.2624       |
| 170  | 0.043427                | 376.83     | 411.57     | 1.3081                                     | 0.038408                | 376.33     | 410.89     | 1.2973                                     | 0.034392                | 375.82     | 410.22     | 1.2876       |
| 180  | 0.044554                | 387.01     | 422.65     | 1.3328                                     | 0.039423                | 386.54     | 422.02     | 1.3221                                     | 0.035317                | 386.06     | 421.38     | 1.3125       |

TABLE A-4

Saturated water—Temperature table

| Temp.,<br>T °C | Sat. press.,<br>P <sub>sat</sub> kPa | Specific volume,<br>m <sup>3</sup> /kg |                               | Internal energy,<br>kJ/kg      |                           |                               | Enthalpy,<br>kJ/kg             |                           |                               | Entropy,<br>kJ/kg·K            |                           |                               |
|----------------|--------------------------------------|--|-------------------------------|--------------------------------|---------------------------|-------------------------------|--------------------------------|---------------------------|-------------------------------|--------------------------------|---------------------------|-------------------------------|
|                |                                      | Sat. liquid,<br>v <sub>f</sub>         | Sat. vapor,<br>v <sub>g</sub> | Sat. liquid,<br>u <sub>f</sub> | Evap.,<br>u <sub>fg</sub> | Sat. vapor,<br>u <sub>g</sub> | Sat. liquid,<br>h <sub>f</sub> | Evap.,<br>h <sub>fg</sub> | Sat. vapor,<br>h <sub>g</sub> | Sat. liquid,<br>s <sub>f</sub> | Evap.,<br>s <sub>fg</sub> | Sat. vapor,<br>s <sub>g</sub> |
| 50             | 12.352                               | 0.001012                               | 12.026                        | 209.33                         | 2233.4                    | 2442.7                        | 209.34                         | 2382.0                    | 2591.3                        | 0.7038                         | 7.3710                    | 8.0748                        |
| 55             | 15.763                               | 0.001015                               | 9.9639                        | 210.24                         | 2219.1                    | 2449.3                        | 230.26                         | 2369.8                    | 2600.1                        | 0.7680                         | 7.2218                    | 7.9898                        |
| 60             | 19.947                               | 0.001017                               | 7.6670                        | 251.16                         | 2204.7                    | 2455.9                        | 251.18                         | 2357.7                    | 2608.8                        | 0.8313                         | 7.0769                    | 7.9082                        |
| 65             | 25.043                               | 0.001020                               | 6.1995                        | 272.09                         | 2190.3                    | 2462.4                        | 272.12                         | 2345.4                    | 2617.5                        | 0.8937                         | 6.9360                    | 7.8296                        |
| 70             | 31.202                               | 0.001023                               | 5.0395                        | 293.04                         | 2175.8                    | 2468.9                        | 293.07                         | 2333.0                    | 2626.1                        | 0.9551                         | 6.7989                    | 7.7540                        |
| 75             | 38.597                               | 0.001026                               | 4.1291                        | 313.99                         | 2161.3                    | 2475.3                        | 314.03                         | 2320.6                    | 2634.6                        | 1.0158                         | 6.6695                    | 7.6812                        |
| 80             | 47.416                               | 0.001029                               | 3.4063                        | 334.97                         | 2146.6                    | 2481.6                        | 335.02                         | 2308.0                    | 2643.0                        | 1.0756                         | 6.5355                    | 7.6111                        |
| 85             | 57.868                               | 0.001032                               | 2.8261                        | 355.95                         | 2131.9                    | 2487.8                        | 356.02                         | 2295.3                    | 2651.4                        | 1.1346                         | 6.4089                    | 7.5435                        |
| 90             | 70.183                               | 0.001036                               | 2.3593                        | 376.97                         | 2117.0                    | 2494.0                        | 377.04                         | 2282.5                    | 2659.6                        | 1.1929                         | 6.2853                    | 7.4782                        |
| 95             | 84.609                               | 0.001040                               | 1.9808                        | 398.00                         | 2102.0                    | 2500.1                        | 398.09                         | 2269.6                    | 2667.6                        | 1.2504                         | 6.1647                    | 7.4151                        |

TABLE A-5

Saturated water—Pressure table

| Press.,<br>$P$ , kPa | Sat.<br>temp.,<br>$T_{sat}$ , °C | Specific volume,<br>$m^3/kg$ |                         |                         | Internal energy,<br>kJ/kg |                    |                         | Enthalpy,<br>kJ/kg       |                    |                         | Entropy,<br>kJ/kg·K      |                    |                         |
|----------------------|----------------------------------|------------------------------|-------------------------|-------------------------|---------------------------|--------------------|-------------------------|--------------------------|--------------------|-------------------------|--------------------------|--------------------|-------------------------|
|                      |                                  | Sat.<br>liquid,<br>$v_f$     | Sat.<br>vapor,<br>$v_g$ | Sat.<br>vapor,<br>$v_g$ | Sat.<br>liquid,<br>$u_f$  | Evap.,<br>$u_{fg}$ | Sat.<br>vapor,<br>$u_g$ | Sat.<br>liquid,<br>$h_f$ | Evap.,<br>$h_{fg}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>liquid,<br>$s_f$ | Evap.,<br>$s_{fg}$ | Sat.<br>vapor,<br>$s_g$ |
| 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                  | 418.96                  | 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                     | 1.1994                  | 466.97                  | 2052.3                    | 2519.2             | 467.13                  | 2226.0                   | 2693.1             | 1.4337                  | 5.7894                   | 7.2231             |                         |
| 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                  | 2156.4                   | 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             |                         |

TABLE A-6

Superheated water

| T<br>°C                 | v<br>m <sup>3</sup> /kg | u<br>kJ/kg | h<br>kJ/kg | s<br>kJ/kg·K            | v<br>m <sup>3</sup> /kg | u<br>kJ/kg | h<br>kJ/kg | s<br>kJ/kg·K            | v<br>m <sup>3</sup> /kg | u<br>kJ/kg | h<br>kJ/kg | s<br>kJ/kg·K |
|-------------------------|-------------------------|------------|------------|-------------------------|-------------------------|------------|------------|-------------------------|-------------------------|------------|------------|--------------|
| P = 0.20 MPa (120.21°C) |                         |            |            | P = 0.30 MPa (133.52°C) |                         |            |            | P = 0.40 MPa (143.61°C) |                         |            |            |              |
| Sat.                    | 0.88578                 | 2529.1     | 2706.3     | 7.1270                  | 0.60582                 | 2543.2     | 2724.9     | 6.9917                  | 0.46242                 | 2553.1     | 2738.1     | 6.8955       |
| 150                     | 0.95986                 | 2577.1     | 2769.1     | 7.2810                  | 0.63402                 | 2571.0     | 2761.2     | 7.0792                  | 0.47088                 | 2564.4     | 2752.8     | 6.9306       |
| 200                     | 1.08049                 | 2654.6     | 2870.7     | 7.5081                  | 0.71643                 | 2651.0     | 2865.9     | 7.3132                  | 0.53434                 | 2647.2     | 2860.9     | 7.1723       |
| 250                     | 1.19890                 | 2731.4     | 2971.2     | 7.7100                  | 0.79645                 | 2728.9     | 2967.9     | 7.5180                  | 0.59520                 | 2726.4     | 2964.5     | 7.3804       |
| 300                     | 1.31623                 | 2808.8     | 3072.1     | 7.8941                  | 0.87535                 | 2807.0     | 3069.6     | 7.7037                  | 0.65489                 | 2805.1     | 3067.1     | 7.5677       |
| 400                     | 1.54934                 | 2967.2     | 3277.0     | 8.2236                  | 1.03155                 | 2966.0     | 3275.5     | 8.0347                  | 0.88936                 | 3129.8     | 3485.5     | 8.1933       |
| 500                     | 1.78142                 | 3131.4     | 3487.7     | 8.5153                  | 1.18672                 | 3130.6     | 3486.6     | 8.3271                  | 1.12152                 | 3479.0     | 3927.6     | 8.7012       |
| 600                     | 2.01302                 | 3302.2     | 3704.8     | 8.7793                  | 1.34139                 | 3301.6     | 3704.0     | 8.5915                  | 1.00588                 | 3301.0     | 3703.3     | 8.4580       |
| 700                     | 2.24434                 | 3479.9     | 3928.8     | 9.0221                  | 1.49580                 | 3479.5     | 3928.2     | 8.8345                  | 1.12152                 | 3479.0     | 3927.6     | 8.7012       |
| 800                     | 2.47550                 | 3664.7     | 4159.8     | 9.2479                  | 1.65004                 | 3664.3     | 4159.3     | 9.0605                  | 1.23730                 | 3663.9     | 4158.9     | 8.9274       |
| 900                     | 2.70656                 | 3856.3     | 4397.7     | 9.4598                  | 1.80417                 | 3856.0     | 4397.3     | 9.2725                  | 1.35298                 | 3856.7     | 4396.9     | 9.1394       |
| 1000                    | 2.93755                 | 4054.8     | 4642.3     | 9.6599                  | 1.95824                 | 4054.5     | 4642.0     | 9.4726                  | 1.46859                 | 4054.3     | 4641.7     | 9.3396       |
| 1100                    | 3.16848                 | 4259.6     | 4893.3     | 9.8497                  | 2.11226                 | 4259.4     | 4893.1     | 9.6624                  | 1.58414                 | 4259.2     | 4892.9     | 9.5295       |
| 1200                    | 3.39938                 | 4470.5     | 5150.4     | 10.0304                 | 2.26624                 | 4470.3     | 5150.2     | 9.8431                  | 1.69966                 | 4470.2     | 5150.0     | 9.7102       |
| 1300                    | 3.63026                 | 4687.1     | 5413.1     | 10.2029                 | 2.42019                 | 4686.9     | 5413.0     | 10.0157                 | 1.81516                 | 4686.7     | 5412.8     | 9.8828       |
| P = 6.0 MPa (275.59°C)  |                         |            |            | P = 7.0 MPa (285.83°C)  |                         |            |            | P = 8.0 MPa (295.01°C)  |                         |            |            |              |
| Sat.                    | 0.03245                 | 2589.9     | 2784.6     | 5.8902                  | 0.027378                | 2581.0     | 2772.6     | 5.8148                  | 0.023525                | 2570.5     | 2758.7     | 5.7450       |
| 300                     | 0.03619                 | 2668.4     | 2885.6     | 6.0703                  | 0.029492                | 2633.5     | 2839.9     | 5.9337                  | 0.024279                | 2592.3     | 2785.5     | 5.7937       |
| 350                     | 0.04225                 | 2790.4     | 3043.9     | 6.3357                  | 0.035262                | 2770.1     | 3016.9     | 6.2305                  | 0.029975                | 2748.3     | 2988.1     | 6.1321       |
| 400                     | 0.04742                 | 2893.7     | 3178.3     | 6.5432                  | 0.039958                | 2879.5     | 3159.2     | 6.4502                  | 0.034344                | 2864.6     | 3139.4     | 6.3658       |
| 450                     | 0.05217                 | 2989.9     | 3302.9     | 6.7219                  | 0.044187                | 2979.0     | 3288.3     | 6.6353                  | 0.038194                | 2967.8     | 3273.3     | 6.5579       |
| 500                     | 0.05667                 | 3083.1     | 3423.1     | 6.8826                  | 0.048157                | 3074.3     | 3411.4     | 6.8000                  | 0.041767                | 3065.4     | 3399.5     | 6.7266       |
| 550                     | 0.06102                 | 3175.2     | 3541.3     | 7.0308                  | 0.051966                | 3167.9     | 3531.6     | 6.9507                  | 0.045172                | 3160.5     | 3521.8     | 6.8800       |
| 600                     | 0.06527                 | 3267.2     | 3658.8     | 7.1693                  | 0.055665                | 3261.0     | 3650.6     | 7.0910                  | 0.048463                | 3254.7     | 3642.4     | 7.0221       |
| 700                     | 0.07355                 | 3453.0     | 3894.3     | 7.4247                  | 0.062850                | 3448.3     | 3888.3     | 7.3487                  | 0.054829                | 3443.6     | 3882.2     | 7.2822       |
| 800                     | 0.08165                 | 3643.2     | 4133.1     | 7.6582                  | 0.069856                | 3639.5     | 4128.5     | 7.5836                  | 0.061011                | 3635.7     | 4123.8     | 7.5185       |
| 900                     | 0.08964                 | 3838.8     | 4376.6     | 7.8751                  | 0.076750                | 3835.7     | 4373.0     | 7.8014                  | 0.067082                | 3832.7     | 4369.3     | 7.7372       |
| 1000                    | 0.09756                 | 4040.1     | 4625.4     | 8.0786                  | 0.083571                | 4037.5     | 4622.5     | 8.0055                  | 0.073079                | 4035.0     | 4619.6     | 7.9419       |
| 1100                    | 0.10543                 | 4247.1     | 4879.7     | 8.2709                  | 0.090341                | 4245.0     | 4877.4     | 8.1982                  | 0.079025                | 4242.8     | 4875.0     | 8.1350       |
| 1200                    | 0.11326                 | 4459.8     | 5139.4     | 8.4534                  | 0.097075                | 4457.9     | 5137.4     | 8.3810                  | 0.084934                | 4456.1     | 5135.5     | 8.3181       |
| 1300                    | 0.12107                 | 4677.7     | 5404.1     | 8.6273                  | 0.103781                | 4676.1     | 5402.6     | 8.5551                  | 0.090817                | 4674.5     | 5401.0     | 8.4925       |