

Appendix B

Thermophysical Properties of Water

Table B.1 Thermophysical properties of pure water at atmospheric pressure

| T (°C) | ρ (kg/m ³) | μ (Pa s) | C_p (J/kg K) | k (W/m K) | Pr | β (K ⁻¹) | c (m/s) | σ (N/m) |
|-------------|--------------------------------|--------------|-------------------|----------------|--------|----------------------------|-----------|----------------|
| 5 | 1000 | 0.001519 | 4200 | 0.5576 | 11.44 | 0.00001135 | 1426 | 0.07494 |
| 10 | 999.7 | 0.001307 | 4188 | 0.5674 | 9.642 | 0.00008743 | 1448 | 0.07422 |
| 15 | 999.1 | 0.001138 | 4184 | 0.5769 | 8.253 | 0.0001523 | 1467 | 0.07348 |
| 20 | 998.2 | 0.001002 | 4183 | 0.5861 | 7.152 | 0.000209 | 1483 | 0.07273 |
| 25 | 997.1 | 0.0008905 | 4183 | 0.5948 | 6.263 | 0.0002594 | 1497 | 0.07197 |
| 30 | 995.7 | 0.0007977 | 4183 | 0.603 | 5.534 | 0.0003051 | 1509 | 0.07119 |
| 35 | 994 | 0.0007196 | 4183 | 0.6107 | 4.929 | 0.000347 | 1520 | 0.0704 |
| 40 | 992.2 | 0.0006533 | 4182 | 0.6178 | 4.422 | 0.0003859 | 1528 | 0.06959 |
| 45 | 990.2 | 0.0005963 | 4182 | 0.6244 | 3.994 | 0.0004225 | 1534 | 0.06877 |
| 50 | 988 | 0.0005471 | 4181 | 0.6305 | 3.628 | 0.0004572 | 1537 | 0.06794 |
| 55 | 985.7 | 0.0005042 | 4182 | 0.636 | 3.315 | 0.0004903 | 1538 | 0.0671 |
| 60 | 983.2 | 0.0004666 | 4183 | 0.641 | 3.045 | 0.0005221 | 1537 | 0.06624 |
| 65 | 980.6 | 0.0004334 | 4184 | 0.6455 | 2.81 | 0.0005528 | 1534 | 0.06536 |
| 70 | 977.8 | 0.000404 | 4187 | 0.6495 | 2.605 | 0.0005827 | 1529 | 0.06448 |
| 75 | 974.9 | 0.0003779 | 4190 | 0.653 | 2.425 | 0.0006118 | 1523 | 0.06358 |
| 80 | 971.8 | 0.0003545 | 4194 | 0.6562 | 2.266 | 0.0006402 | 1514 | 0.06267 |
| 85 | 968.6 | 0.0003335 | 4199 | 0.6589 | 2.125 | 0.0006682 | 1504 | 0.06175 |
| 90 | 965.3 | 0.0003145 | 4204 | 0.6613 | 2 | 0.0006958 | 1491 | 0.06081 |
| 95 | 961.9 | 0.0002974 | 4210 | 0.6634 | 1.888 | 0.000723 | 1475 | 0.05987 |
| 100 | 0.5896 | 0.00001227 | 2042 | 0.02506 | 0.9996 | 0.002881 | 472.8 | 0.05891 |

Source: Data obtained with EES software – Engineering Equation Solver (S.A. Klein, version 9.698).

T = temperature, ρ = density, μ = dynamic viscosity, c_p = specific heat, k = thermal conductivity,

Pr = Prandtl number, β = volume expansion coefficient, c = sound speed, σ = superficial

tension, $\omega = 0.3443$ = eccentric factor.

Critical parameters: $T_c = 373.984^\circ\text{C}$, $P_c = 220.64\text{ bar}$, $v_c = 3.106\text{ dm}^3/\text{kg}$.

Triple point parameters: $T_t = 0.01^\circ\text{C}$, $P_t = 611.732\text{ Pa}$.

Table B.2 Thermophysical properties of water at saturation

| T (°C) | P (bar) | σ (mN/m) | ρ_L (kg/m ³) | C_{pl} (kJ/kg K) | k_l (mW/m K) | μ (μPa s) | $P\eta$ | β_l (m/K) | ν_v (m ³ /kg) | C_{pv} (kJ/kg K) | k_v (mW/m K) | μ_v (μPa s) | Pr_v | β_v (m/K) | γ |
|-------------|-----------|--------------------|----------------------------------|-----------------------|-------------------|---------------|---------|--------------------|---------------------------------|-----------------------|-------------------|-----------------|--------|--------------------|----------|
| 0.01 | 0.00612 | 75.64 | 1000 | 4.23 | 547.5 | 1792 | 13.84 | N/A | 206.0 | 1.87 | 17.07 | 9.216 | 1.008 | 3.672 | 1.33 |
| 10 | 0.0123 | 74.22 | 999.7 | 4.19 | 567.4 | 1307 | 9.645 | 0.0872 | 106.3 | 1.87 | 17.62 | 9.461 | 1.006 | 3.548 | 1.33 |
| 20 | 0.0234 | 72.73 | 998.2 | 4.18 | 586 | 1002 | 7.154 | 0.209 | 57.78 | 1.88 | 18.22 | 9.727 | 1.004 | 3.435 | 1.33 |
| 30 | 0.0425 | 71.19 | 995.6 | 4.18 | 602.9 | 797.7 | 5.535 | 0.305 | 32.9 | 1.89 | 18.88 | 10.01 | 1.003 | 3.332 | 1.33 |
| 40 | 0.0738 | 69.59 | 992.2 | 4.18 | 617.8 | 653.3 | 4.423 | 0.386 | 19.53 | 1.90 | 19.59 | 10.31 | 1.002 | 3.239 | 1.33 |
| 50 | 0.1234 | 67.94 | 988 | 4.18 | 630.4 | 547.1 | 3.629 | 0.457 | 12.04 | 1.92 | 20.36 | 10.62 | 1.001 | 3.156 | 1.33 |
| 60 | 0.1993 | 66.24 | 983.2 | 4.18 | 640.9 | 466.6 | 3.045 | 0.522 | 7.674 | 1.94 | 21.18 | 10.93 | 1 | 3.082 | 1.33 |
| 70 | 0.3118 | 64.48 | 977.7 | 4.19 | 649.5 | 404 | 2.605 | 0.583 | 5.045 | 1.96 | 22.06 | 11.26 | 0.9995 | 3.017 | 1.33 |
| 80 | 0.4737 | 62.67 | 971.8 | 4.19 | 656.2 | 354.5 | 2.266 | 0.64 | 3.409 | 1.98 | 23 | 11.59 | 0.9993 | 2.962 | 1.33 |
| 90 | 0.7012 | 60.81 | 965.3 | 4.20 | 661.3 | 314.5 | 2 | 0.696 | 2.362 | 2.01 | 24 | 11.93 | 0.9994 | 2.917 | 1.34 |
| 100 | 1.013 | 58.91 | 958.4 | 4.22 | 665.1 | 281.9 | 1.787 | 0.75 | 1.674 | 2.04 | 25.08 | 12.27 | 1 | 2.882 | 1.34 |
| 110 | 1.432 | 56.96 | 951 | 4.23 | 667.6 | 254.8 | 1.615 | 0.804 | 1.211 | 2.08 | 26.22 | 12.61 | 1.001 | 2.857 | 1.34 |
| 120 | 1.985 | 54.96 | 943.2 | 4.25 | 669.1 | 232.1 | 1.474 | 0.858 | 0.892 | 2.12 | 27.44 | 12.96 | 1.004 | 2.843 | 1.35 |
| 130 | 2.7 | 52.93 | 934.9 | 4.27 | 669.7 | 213 | 1.357 | 0.912 | 0.669 | 2.17 | 28.73 | 13.3 | 1.007 | 2.84 | 1.36 |
| 140 | 3.612 | 50.85 | 926.2 | 4.29 | 669.4 | 196.6 | 1.259 | 0.968 | 0.509 | 2.23 | 30.09 | 13.65 | 1.012 | 2.849 | 1.36 |
| 150 | 4.757 | 48.74 | 917.1 | 4.31 | 668.3 | 182.5 | 1.178 | 1.026 | 0.393 | 2.30 | 31.54 | 13.99 | 1.02 | 2.872 | 1.37 |
| 160 | 6.177 | 46.59 | 907.5 | 4.34 | 666.4 | 170.3 | 1.109 | 1.087 | 0.3071 | 2.37 | 33.06 | 14.34 | 1.029 | 2.908 | 1.39 |
| 170 | 7.915 | 44.4 | 897.5 | 4.37 | 663.7 | 159.6 | 1.051 | 1.152 | 0.243 | 2.46 | 34.66 | 14.68 | 1.042 | 2.959 | 1.40 |
| 180 | 10.02 | 42.19 | 887.1 | 4.40 | 660.2 | 150.2 | 1.002 | 1.221 | 0.194 | 2.56 | 36.34 | 15.03 | 1.057 | 3.027 | 1.42 |
| 190 | 12.54 | 39.94 | 876.1 | 4.44 | 655.9 | 141.8 | 0.9607 | 1.296 | 0.156 | 2.67 | 38.09 | 15.37 | 1.077 | 3.114 | 1.44 |
| 200 | 15.54 | 37.67 | 864.7 | 4.49 | 650.7 | 134.4 | 0.9269 | 1.377 | 0.127 | 2.80 | 39.93 | 15.71 | 1.1 | 3.221 | 1.46 |
| 210 | 19.06 | 35.38 | 852.8 | 4.54 | 644.7 | 127.7 | 0.8994 | 1.467 | 0.104 | 2.94 | 41.85 | 16.06 | 1.129 | 3.351 | 1.48 |
| 220 | 23.18 | 33.06 | 840.3 | 4.60 | 637.6 | 121.6 | 0.8777 | 1.567 | 0.086 | 3.11 | 43.86 | 16.41 | 1.162 | 3.508 | 1.52 |
| 230 | 27.95 | 30.73 | 827.3 | 4.67 | 629.5 | 116 | 0.8615 | 1.679 | 0.071 | 3.30 | 45.96 | 16.76 | 1.203 | 3.697 | 1.55 |
| 240 | 33.45 | 28.39 | 813.5 | 4.76 | 620.3 | 110.9 | 0.8508 | 1.807 | 0.06 | 3.51 | 48.15 | 17.12 | 1.25 | 3.923 | 1.59 |

(continued overleaf)

Table B.2 (continued)

| <i>T</i> (°C) | <i>P</i> (bar) | σ (mN/m) | ρ_L (kg/m ³) | <i>C_p</i> (kJ/kg K) | <i>k_l</i> (mW/m K) | μ_l (μPa s) | <i>P_η</i> | β_l (m/K) | v_v (m ³ /kg) | <i>C_p</i> (kJ/kg K) | <i>k_v</i> (mW/m K) | μ_v (μPa s) | <i>P_r</i> _v | β_v (m/K) | γ |
|------------------|----------------|--------------------|----------------------------------|-----------------------------------|----------------------------------|-----------------|----------------------|--------------------|-------------------------------|-----------------------------------|----------------------------------|-----------------|-----------------------------------|--------------------|----------|
| 250 | 39.74 | 26.04 | 799.1 | 4.86 | 609.8 | 106.2 | 0.8455 | 1.954 | 0.050 | 3.77 | 50.46 | 17.49 | 1.306 | 4.195 | 1.64 |
| 260 | 46.89 | 23.68 | 783.8 | 4.97 | 598 | 101.7 | 0.846 | 2.126 | 0.042 | 4.06 | 52.9 | 17.88 | 1.373 | 4.523 | 1.70 |
| 270 | 55 | 21.33 | 767.7 | 5.11 | 584.5 | 97.55 | 0.853 | 2.33 | 0.036 | 4.41 | 55.49 | 18.28 | 1.453 | 4.923 | 1.77 |
| 280 | 64.13 | 18.99 | 750.5 | 5.28 | 569.4 | 93.56 | 0.8673 | 2.576 | 0.031 | 4.83 | 58.28 | 18.7 | 1.549 | 5.415 | 1.86 |
| 290 | 74.38 | 16.66 | 732.2 | 5.48 | 552.3 | 89.71 | 0.8908 | 2.88 | 0.026 | 5.33 | 61.31 | 19.15 | 1.666 | 6.032 | 1.97 |
| 300 | 85.84 | 14.35 | 712.4 | 5.74 | 533.1 | 85.95 | 0.9262 | 3.266 | 0.022 | 5.97 | 64.67 | 19.65 | 1.813 | 6.822 | 2.11 |
| 310 | 98.61 | 12.08 | 691 | 6.08 | 511.3 | 82.22 | 0.9782 | 3.773 | 0.018 | 6.78 | 68.45 | 20.21 | 2.001 | 7.861 | 2.29 |
| 320 | 112.8 | 9.858 | 667.4 | 6.54 | 486.8 | 78.46 | 1.054 | 4.47 | 0.015 | 7.87 | 72.84 | 20.84 | 2.251 | 9.278 | 2.54 |
| 330 | 128.5 | 7.697 | 641 | 7.2 | 458.8 | 74.57 | 1.17 | 5.489 | 0.013 | 9.41 | 78.1 | 21.6 | 2.603 | 11.31 | 2.91 |
| 340 | 145.9 | 5.62 | 610.8 | 8.24 | 426.9 | 70.45 | 1.359 | 7.116 | 0.011 | 11.8 | 84.68 | 22.55 | 3.137 | 14.43 | 3.47 |
| 350 | 165.2 | 3.66 | 574.7 | 10.1 | 389.7 | 65.88 | 1.711 | 10.1 | 0.0088 | 15.9 | 93.48 | 23.81 | 4.058 | 19.77 | 4.47 |
| 360 | 186.6 | 1.872 | 528.1 | 14.7 | 344.4 | 60.39 | 2.574 | 17.11 | 0.007 | 25.2 | 106.6 | 25.71 | 6.085 | 30.79 | 6.74 |
| 370 | 210.3 | 0.3846 | 453.1 | 41.7 | 280.7 | 52.25 | 7.765 | 45.88 | 0.0050 | 70.4 | 132.6 | 29.57 | 15.7 | 64.53 | 18.0 |
| 373.9 | 220.4 | 0.0004 | 349.4 | N/A | 210.8 | 41.95 | 277.1 | 87.51 | 0.0034 | 340.1 | 180 | 37 | 69.91 | 104.5 | 84.5 |

Source: Data obtained with EES software – Engineering Equation Solver (S.A. Klein, version 9.698).

T = temperature, *P* = pressure, σ = surface tension, ρ = density, *c_p* = specific heat, *k* = thermal conductivity, μ = dynamic viscosity, *P_r* = Prandtl number, β = volumetric expansion coefficient, *v* = specific volume, γ = isentropic expansion coefficient of saturated vapor, indices: l = liquid; v = vapor.