# Equations Summary from Inside Cover of Morrison, 2013

Mechanical
Energy Balance

$$\frac{\Delta p}{\rho} + \frac{\Delta \langle v \rangle^2}{2\alpha} + g\Delta z + F_{friction} = -\frac{W_{s,by\ fluid}}{m}$$

$$\begin{cases} \alpha_{laminar} = 0.5 \\ \alpha_{turbulent} \approx 1 \end{cases}$$

Fanning
Friction Factor
(pipe flow)

$$F_{friction} = \left[ 4f\frac{L}{D} + \sum_{fittings_i} n_i K_{f,i} \right] \frac{\langle v \rangle^2}{2}$$

$$f = \frac{F_{drag}}{\frac{1}{2}\rho\langle v \rangle^2 (2\pi RL)} = \frac{\Delta p D}{2L\rho\langle v \rangle^2}$$

Drag Coefficient
(sphere drop)

$$C_D = \frac{F_{drag}}{\frac{1}{2}\rho v_\infty^2 (\pi R^2)} = \frac{4gD(\rho_{body} - \rho)}{3\rho v_\infty^2}$$

Momentum balance on a CV
(Reynolds transport theorem)

$$\frac{d\underline{P}}{dt} + \iint_{CS} (\hat{n}\cdot\underline{v})\rho\underline{v}\,dS = \sum_{on\ CV} \underline{f}$$

<span style="color:red">**Note this is correct; there is an error on the inside cover**</span>

Hydrostatic Pressure

$$p_{bottom} = p_{top} + \rho g h$$

Hagen–Poiseuille Equation
(steady, laminar tube flow,
incompressible)

$$Q = \frac{\pi(p_0 - p_L)R^4}{8\mu L}$$

Prandtl Equation
(steady, turbulent tube flow)

$$\frac{1}{\sqrt{f}} = -4.0\log\left(\frac{4.67}{Re\sqrt{f}}\right) + 2.28$$

Stokes–Einstein–Sutherland Equation
(steady, slow flow around a sphere)

$$F_{drag} = 6\pi R\mu v_\infty$$

Macroscopic Momentum Balance on a CV

$$\frac{d\underline{P}}{dt} + \sum_{i=1}^{\#streams} \left[ \frac{\rho A\cos(\theta)\langle v \rangle^2}{\beta} \right]_{A_i} \hat{\underline{v}} \bigg|_{A_i} = \sum_{i=1}^{\#streams} [-pA\hat{n}]_{A_i} + \underline{R} + M_{cv}\underline{g}$$

$$\begin{cases} \beta_{laminar} = 0.75 \\ \beta_{turbulent} \approx 1 \end{cases}$$

Navier–Stokes equation
(microscopic momentum balance,
incompressible, Newtonian fluids)

$$\rho\left(\frac{\partial \underline{v}}{\partial t} + \underline{v}\cdot\nabla\underline{v}\right) = -\nabla p + \mu\nabla^2\underline{v} + \rho\underline{g}$$

Continuity equation
(microscopic mass balance,
incompressible fluids)

$$\nabla\cdot\underline{v} = 0$$

Total stress tensor

$$\tilde{\underline{\Pi}} = -p\underline{I} + \tilde{\underline{\tau}}$$

$$\begin{pmatrix} \tilde{\Pi}_{11} & \tilde{\Pi}_{12} & \tilde{\Pi}_{13} \\ \tilde{\Pi}_{21} & \tilde{\Pi}_{22} & \tilde{\Pi}_{23} \\ \tilde{\Pi}_{31} & \tilde{\Pi}_{32} & \tilde{\Pi}_{33} \end{pmatrix}_{123} = \begin{pmatrix} \tilde{\tau}_{11} - p & \tilde{\tau}_{12} & \tilde{\tau}_{13} \\ \tilde{\tau}_{21} & \tilde{\tau}_{22} - p & \tilde{\tau}_{23} \\ \tilde{\tau}_{31} & \tilde{\tau}_{32} & \tilde{\tau}_{33} - p \end{pmatrix}_{123}$$

Dynamic pressure

$$\mathcal{P} \equiv p + \rho g h$$

Newtonian
constitutive equation

$$\tilde{\underline{\tau}} = \mu\left(\nabla\underline{v} + (\nabla\underline{v})^T\right)$$

$$= \mu \begin{pmatrix} 2\frac{\partial v_1}{\partial x_1} & \frac{\partial v_2}{\partial x_1} + \frac{\partial v_1}{\partial x_2} & \frac{\partial v_1}{\partial x_3} + \frac{\partial v_3}{\partial x_1} \\ \frac{\partial v_1}{\partial x_2} + \frac{\partial v_2}{\partial x_1} & 2\frac{\partial v_2}{\partial x_2} & \frac{\partial v_2}{\partial x_3} + \frac{\partial v_3}{\partial x_2} \\ \frac{\partial v_1}{\partial x_3} + \frac{\partial v_3}{\partial x_1} & \frac{\partial v_3}{\partial x_2} + \frac{\partial v_2}{\partial x_3} & 2\frac{\partial v_3}{\partial x_3} \end{pmatrix}_{123}$$

Total molecular fluid force
on a finite surface $S$

$$\underline{\mathcal{F}} = \iint_S \left[ \hat{n}\cdot\tilde{\underline{\Pi}} \right]_{at\ surface} dS$$

Stationary fluid

$$\left[ \hat{n}\cdot\tilde{\underline{\Pi}} \right] = -p\hat{n}$$

Moving fluid

$$\left[ \hat{n}\cdot\tilde{\underline{\Pi}} \right] = -p\hat{n} + \hat{n}\cdot\tilde{\underline{\tau}}$$

Total fluid torque
on a finite surface $S$

$$\underline{\mathcal{T}} = \iint_S \left[ \underline{R}\times\left(\hat{n}\cdot\tilde{\underline{\Pi}}\right) \right]_{at\ surface} dS$$

Total flow rate out
through a finite surface $S$

$$Q = \dot{V} = \iint_S [\hat{n}\cdot\underline{v}]_{at\ surface}\,dS$$

Average velocity
across a finite surface $S$

$$\langle v \rangle = \frac{Q}{S}$$

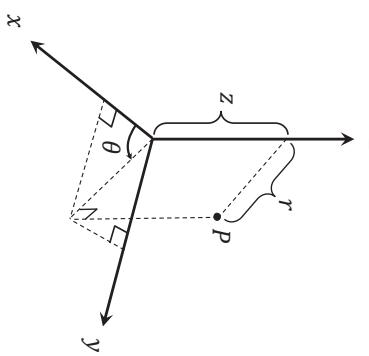| Coordinate system | surface differential $dS$ |
|---|---|
| Cartesian (top, $\hat{n} = \hat{e}_z$) | $dS = dxdy$ |
| Cartesian (side a, $\hat{n} = \hat{e}_y$) | $dS = dxdz$ |
| Cartesian (side b, $\hat{n} = \hat{e}_x$) | $dS = dydz$ |
| cylindrical (top, $\hat{n} = \hat{e}_z$) | $dS = rdrd\theta$ |
| cylindrical (side, $\hat{n} = \hat{e}_r$) | $dS = Rd\theta dz$ |
| spherical, ($\hat{n} = \hat{e}_r$) | $dS = R^2 \sin\theta d\theta d\phi$ |

| Coordinate system | volume differential $dV$ |
|---|---|
| Cartesian | $dV = dxdydz$ |
| cylindrical | $dV = rdrd\theta dz$ |
| spherical | $dV = r^2 \sin\theta dr d\theta d\phi$ |

| Coordinate system | coordinates | basis vectors |
|---|---|---|
| spherical | $x = r\sin\theta\cos\phi$ | $\hat{e}_r = (\sin\theta\cos\phi\hat{e}_x) + (\sin\theta\sin\phi\hat{e}_y) + \cos\theta\hat{e}_z$ |
| | $y = r\sin\theta\sin\phi$ | $\hat{e}_\theta = (\cos\theta\cos\phi)\hat{e}_x + (\cos\theta\sin\phi)\hat{e}_y + (-\sin\theta)\hat{e}_z$ |
| | $z = r\cos\theta$ | $\hat{e}_\phi = (-\sin\phi)\hat{e}_x + \cos\phi\hat{e}_y$ |
| cylindrical | $x = r\cos\theta$ | $\hat{e}_r = \cos\theta\hat{e}_x + \sin\theta\hat{e}_y$ |
| | $y = r\sin\theta$ | $\hat{e}_\theta = (-\sin\theta)\hat{e}_x + \cos\theta\hat{e}_y$ |
| | $z = z$ | $\hat{e}_z = \hat{e}_z$ |

Divergence Theorem

$$\iint_S \hat{n} \cdot \underline{E} \, dS = \iiint_V \nabla \cdot \underline{E} \, dV$$
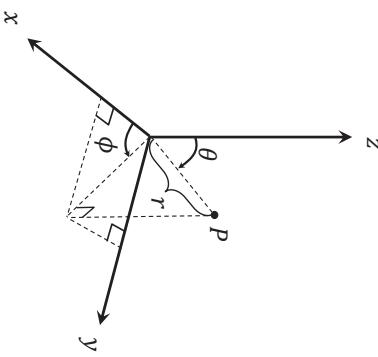
Stokes Theorem

$$\oint_C \hat{t} \cdot \underline{E} \, dl = \iint_S \hat{n} \cdot (\nabla \times \underline{E}) \, dS$$

Vector identities:

$$\nabla \cdot \nabla \times \underline{E} = 0 \quad \text{(Divergence of curl} = 0)$$
$$\nabla \times \nabla f = 0 \quad \text{(Curl of gradient} = 0)$$
$$\nabla (fg) = f\nabla g + g\nabla f$$
$$\underline{E} \cdot \nabla \underline{E} = \frac{1}{2}\nabla (\underline{E}^2) - \underline{E} \times (\nabla \times \underline{E})$$
$$\nabla \cdot (f\underline{E}) = f\nabla \cdot \underline{E} + \underline{E} \cdot \nabla f$$
$$\nabla \times \nabla \times \underline{E} = \nabla (\nabla \cdot \underline{E}) - \nabla^2 \underline{E}$$
$$\nabla \cdot (\underline{E} \times \underline{G}) = \underline{G} \cdot (\nabla \times \underline{E}) - \underline{E} \cdot (\nabla \times \underline{G})$$

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The equations in F. A. Morrison, *An Introduction to Fluid Mechanics* (Cambridge, 2013) assume the following definitions of the cylindrical and spherical coordinate systems.

**Cylindrical Coordinate System:** Note that the $\theta$-coordinate swings around the $z$-axis



**Spherical Coordinate System:** Note that the $\theta$-coordinate swings down from the $z$-axis; this is different from its definition in the cylindrical system above.

# FACTORS FOR UNIT CONVERSIONS

| Quantity | Equivalent Values |
|---|---|

**Mass**

$1 \text{ kg} = 1000 \text{ g} = 0.001 \text{ metric ton} = 2.20462 \text{ lb}_m = 35.27392 \text{ oz}$

$1 \text{ lb}_m = 16 \text{ oz} = 5 \times 10^{-4} \text{ ton} = 453.593 \text{ g} = 0.453593 \text{ kg}$

**Length**

$1 \text{ m} = 100 \text{ cm} = 1000 \text{ mm} = 10^6 \text{ microns } (\mu m) = 10^{10} \text{ angstroms (Å)}$
$= 39.3701 \text{ in} = 3.28084 \text{ ft} = 1.09361 \text{ yd} = 0.000621371 \text{ mile}$

$1 \text{ ft} = 12 \text{ in.} = 1/3 \text{ yd} = 0.3048 \text{ m} = 30.48 \text{ cm}$

**Volume**

$1 \text{ m}^3 = 1000 \text{ liters} = 10^6 \text{ cm}^3 = 10^6 \text{ ml}$
$= 35.31467 \text{ ft}^3 = 219.969 \text{ imperial gallons} = 264.172 \text{ gal}$
$= 1056.69 \text{ qt}$

$1 \text{ ft}^3 = 1728 \text{ in}^3 = 7.48052 \text{ gal} = 0.028317 \text{ m}^3 = 28.3168 \text{ liters}$
$= 28{,}316.8 \text{ cm}^3$

**Force**

$1 \text{ N} = 1 \text{ kg·m/s}^2 = 10^5 \text{ dynes} = 10^5 \text{ g·cm/s}^2 = 0.22481 \text{ lb}_f$

$1 \text{ lb}_f = 32.174 \text{ lb}_m\text{·ft/s}^2 = 4.4482 \text{ N} = 4.4482 \times 10^5 \text{ dynes}$

**Pressure**

$1 \text{ atm} = 1.01325 \times 10^5 \text{ N/m}^2 \text{ (Pa)} = 101.325 \text{ kPa} = 1.01325 \text{ bars}$
$= 1.01325 \times 10^6 \text{ dynes/cm}^2$
$= 760 \text{ mm Hg at } 0° \text{ C (torr)} = 10.333 \text{ m H}_2\text{O at } 4° \text{ C}$
$= 14.696 \text{ lb}_f\text{/in}^2 \text{ (psi)} = 33.9 \text{ ft H}_2\text{O at } 4°\text{C}$

$100 \text{ kPa} = 1 \text{ bar}$

**Energy**

$1 \text{ J} = 1 \text{ N·m} = 10^7 \text{ ergs} = 10^7 \text{ dyne·cm}$
$= 2.778 \times 10^{-7} \text{ kW·h} = 0.23901 \text{ cal}$
$= 0.7376 \text{ ft·lb}_f = 9.47817 \times 10^{-4} \text{ Btu}$

**Power**

$1 \text{ W} = 1 \text{ J/s} = 0.23885 \text{ cal/s} = 0.7376 \text{ ft·lb}_f\text{/s} = 9.47817 \times 10^{-4} \text{ Btu/s} = 3.4121 \text{ Btu/h}$
$= 1.341 \times 10^{-3} \text{ hp (horsepower)}$

**Viscosity**

$1 \text{ Pa·s} = 1 \text{ N·s/m}^2 = 1 \text{ kg/m·s}$
$= 10 \text{ poise} = 10 \text{ dynes·s/cm}^2 = 10 \text{ g/cm·s}$
$= 10^3 \text{ cp (centipoise)}$
$= 0.67197 \text{ lb}_m\text{/ft·s} = 2419.088 \text{ lb}_m\text{/ft·h}$

**Density**

$1 \text{ kg/m}^3 = 10^{-3} \text{ g/cm}^3$
$= 0.06243 \text{ lb}_m\text{/ft}^3$

$10^3 \text{ kg/m}^3 = 1 \text{ g/cm}^3 = 62.428 \text{ lb}_m\text{/ft}^3$

**Volumetric Flow**

$1 \text{ m}^3\text{/s} = 35.31467 \text{ ft}^3\text{/s} = 15{,}850.32 \text{ gal/min (gpm)}$

$1 \text{ gpm} = 6.30902 \times 10^{-5} \text{ m}^3\text{/s} = 2.228009 \times 10^{-3} \text{ ft}^3\text{/s} = 3.7854 \text{ liter/min}$

$1 \text{ liter/min} = 0.26417 \text{ gpm}$

| Temperature | $T(^oC) = \frac{5}{9}\left[T(^oF) - 32\right]$ |
| | $T(^oF) = \frac{9}{5}T(^oC) + 32 = 1.8T(^oC) + 32$ |

Absolute Temperature

T(K) = T(˚C) + 273.15

T(˚R) = T(˚F) + 459.67

Temperature Interval (ΔT)

1 C˚ = 1 K = 1.8 F˚ = 1.8 R˚

1F˚ = 1 R˚ = (5/9) C˚ = (5/9) K

# USEFUL QUANTITIES

SG = $\rho$(20˚C)/$\rho$ water (4˚C)

$\rho_{water}$(4˚C) = 1000 kg/m$^3$ = 62.43 lb$_m$/ft$^3$ = 1.000 g/cm$^3$

$\rho_{water}$(25˚C) = 997.08 kg/m$^3$ = 62.25 lb$_m$/ft$^3$ = 0.99709 g/cm$^3$

g = 9.8066 m/s$^2$ = 980.66 cm/s$^2$ = 32.174 ft/s$^2$

$\mu_{water}$ (25˚C) = 8.937 x 10$^{-4}$ Pa·s = 8.937 x 10$^{-4}$ kg/m·s

= 0.8937 cp = 0.8937 x 10$^{-2}$ g/cm·s = 6.005 x 10$^{-4}$ lb$_m$/ft·s

Composition of air:

| | | |
|---|---|---|
| | N$_2$ | 78.03% |
| | O$_2$ | 20.99% |
| | Ar | 0.94% |
| | CO$_2$ | 0.03% |
| H$_2$, He, Ne, Kr, Xe | | 0.01% |
| | | 100.00% |

M$_{air}$ = 29 g/mol = 29 kg/kmol = 29 lb$_m$/lbmole

$\hat{C}_{p,water}$ (25˚C) = 4.182 kJ/kg K = 0.9989 cal/g˚C = 0.9997 Btu/lb$_m$˚F

R = 8.314 m$^3$·Pa/mol·K = 0.08314 liter·bar/mol·K = 0.08206 liter·atm/mol·K

= 62.36 liter·mm Hg/mol·K = 0.7302 ft$^3$·atm/lbmole·˚R

= 10.73 ft$^3$·psia/lbmole·˚R

= 8.314 J/mol·K

= 1.987 cal/mol·K = 1.987 Btu/lbmole·˚R

## A.2-11 Heat-Transfer Properties of Liquid Water, SI Units

| $T$ (°C) | $T$ (K) | $\rho$ (kg/m³) | $c_p$ (kJ/kg·K) | $\mu \times 10^3$ (Pa·s, or kg/m·s) | $k$ (W/m·K) | $N_{Pr}$ | $\beta \times 10^4$ (1/K) | $(g\beta\rho^2/\mu^2) \times 10^{-8}$ (1/K·m³) |
|---|---|---|---|---|---|---|---|---|
| 0 | 273.2 | 999.6 | 4.229 | 1.786 | 0.5694 | 13.3 | −0.630 | |
| 15.6 | 288.8 | 998.0 | 4.187 | 1.131 | 0.5884 | 8.07 | 1.44 | 10.93 |
| 26.7 | 299.9 | 996.4 | 4.183 | 0.860 | 0.6109 | 5.89 | 2.34 | 30.70 |
| 37.8 | 311.0 | 994.7 | 4.183 | 0.682 | 0.6283 | 4.51 | 3.24 | 68.0 |
| 65.6 | 338.8 | 981.9 | 4.187 | 0.432 | 0.6629 | 2.72 | 5.04 | 256.2 |
| 93.3 | 366.5 | 962.7 | 4.229 | 0.3066 | 0.6802 | 1.91 | 6.66 | 642 |
| 121.1 | 394.3 | 943.5 | 4.271 | 0.2381 | 0.6836 | 1.49 | 8.46 | 1300 |
| 148.9 | 422.1 | 917.9 | 4.312 | 0.1935 | 0.6836 | 1.22 | 10.08 | 2231 |
| 204.4 | 477.6 | 858.6 | 4.522 | 0.1384 | 0.6611 | 0.950 | 14.04 | 5308 |
| 260.0 | 533.2 | 784.9 | 4.982 | 0.1042 | 0.6040 | 0.859 | 19.8 | 11 030 |
| 315.6 | 588.8 | 679.2 | 6.322 | 0.0862 | 0.5071 | 1.07 | 31.5 | 19 260 |

## A.2-11 Heat-Transfer Properties of Liquid Water, English Units

| $T$ (°F) | $\rho$ $\left(\dfrac{lb_m}{ft^3}\right)$ | $c_p$ $\left(\dfrac{btu}{lb_m \cdot °F}\right)$ | $\mu \times 10^3$ $\left(\dfrac{lb_m}{ft \cdot s}\right)$ | $k$ $\left(\dfrac{btu}{h \cdot ft \cdot °F}\right)$ | $N_{Pr}$ | $\beta \times 10^4$ (1/°R) | $(g\beta\rho^2/\mu^2) \times 10^{-6}$ (1/°R·ft³) |
|---|---|---|---|---|---|---|---|
| 32 | 62.4 | 1.01 | 1.20 | 0.329 | 13.3 | −0.350 | |
| 60 | 62.3 | 1.00 | 0.760 | 0.340 | 8.07 | 0.800 | 17.2 |
| 80 | 62.2 | 0.999 | 0.578 | 0.353 | 5.89 | 1.30 | 48.3 |
| 100 | 62.1 | 0.999 | 0.458 | 0.363 | 4.51 | 1.80 | 107 |
| 150 | 61.3 | 1.00 | 0.290 | 0.383 | 2.72 | 2.80 | 403 |
| 200 | 60.1 | 1.01 | 0.206 | 0.393 | 1.91 | 3.70 | 1010 |
| 250 | 58.9 | 1.02 | 0.160 | 0.395 | 1.49 | 4.70 | 2045 |
| 300 | 57.3 | 1.03 | 0.130 | 0.395 | 1.22 | 5.60 | 3510 |
| 400 | 53.6 | 1.08 | 0.0930 | 0.382 | 0.950 | 7.80 | 8350 |
| 500 | 49.0 | 1.19 | 0.0700 | 0.349 | 0.859 | 11.0 | 17 350 |
| 600 | 42.4 | 1.51 | 0.0579 | 0.293 | 1.07 | 17.5 | 30 300 |

**Geankoplis, 4th edition**

**NOTE: Equate the label to the provided quantity in the supplied units. For example, for <u>water</u> at $0°C$:**

$$\mu \times 10^3 = 1.786 \ Pa \ s$$

$$\mu = 1.786 \times 10^{-3} Pa \ s$$

## A.3-3 Physical Properties of Air at 101.325 kPa (1 Atm Abs), SI Units

| $T$ (°C) | $T$ (K) | $\rho$ (kg/m$^3$) | $c_p$ (kJ/kg·K) | $\mu \times 10^5$ (Pa·s, or kg/m·s) | $k$ (W/m·K) | $N_{Pr}$ | $\beta \times 10^3$ (1/K) | $g\beta\rho^2/\mu^2$ (1/K·m$^3$) |
|---|---|---|---|---|---|---|---|---|
| −17.8 | 255.4 | 1.379 | 1.0048 | 1.62 | 0.02250 | 0.720 | 3.92 | $2.79 \times 10^8$ |
| 0 | 273.2 | 1.293 | 1.0048 | 1.72 | 0.02423 | 0.715 | 3.65 | $2.04 \times 10^8$ |
| 10.0 | 283.2 | 1.246 | 1.0048 | 1.78 | 0.02492 | 0.713 | 3.53 | $1.72 \times 10^8$ |
| 37.8 | 311.0 | 1.137 | 1.0048 | 1.90 | 0.02700 | 0.705 | 3.22 | $1.12 \times 10^8$ |
| 65.6 | 338.8 | 1.043 | 1.0090 | 2.03 | 0.02925 | 0.702 | 2.95 | $0.775 \times 10^8$ |
| 93.3 | 366.5 | 0.964 | 1.0090 | 2.15 | 0.03115 | 0.694 | 2.74 | $0.534 \times 10^8$ |
| 121.1 | 394.3 | 0.895 | 1.0132 | 2.27 | 0.03323 | 0.692 | 2.54 | $0.386 \times 10^8$ |
| 148.9 | 422.1 | 0.838 | 1.0174 | 2.37 | 0.03531 | 0.689 | 2.38 | $0.289 \times 10^8$ |
| 176.7 | 449.9 | 0.785 | 1.0216 | 2.50 | 0.03721 | 0.687 | 2.21 | $0.214 \times 10^8$ |
| 204.4 | 477.6 | 0.740 | 1.0258 | 2.60 | 0.03894 | 0.686 | 2.09 | $0.168 \times 10^8$ |
| 232.2 | 505.4 | 0.700 | 1.0300 | 2.71 | 0.04084 | 0.684 | 1.98 | $0.130 \times 10^8$ |
| 260.0 | 533.2 | 0.662 | 1.0341 | 2.80 | 0.04258 | 0.680 | 1.87 | $0.104 \times 10^8$ |

## A.3-3 Physical Properties of Air at 101.325 kPa (1 Atm Abs), English Units

| $T$ (°F) | $\rho$ $\left(\dfrac{lb_m}{ft^3}\right)$ | $c_p$ $\left(\dfrac{btu}{lb_m \cdot °F}\right)$ | $\mu$ (centipoise) | $k$ $\left(\dfrac{btu}{h \cdot ft \cdot °F}\right)$ | $N_{Pr}$ | $\beta \times 10^3$ (1/°R) | $g\beta\rho^2/\mu^2$ (1/°R·ft$^3$) |
|---|---|---|---|---|---|---|---|
| 0 | 0.0861 | 0.240 | 0.0162 | 0.0130 | 0.720 | 2.18 | $4.39 \times 10^6$ |
| 32 | 0.0807 | 0.240 | 0.0172 | 0.0140 | 0.715 | 2.03 | $3.21 \times 10^6$ |
| 50 | 0.0778 | 0.240 | 0.0178 | 0.0144 | 0.713 | 1.96 | $2.70 \times 10^6$ |
| 100 | 0.0710 | 0.240 | 0.0190 | 0.0156 | 0.705 | 1.79 | $1.76 \times 10^6$ |
| 150 | 0.0651 | 0.241 | 0.0203 | 0.0169 | 0.702 | 1.64 | $1.22 \times 10^6$ |
| 200 | 0.0602 | 0.241 | 0.0215 | 0.0180 | 0.694 | 1.52 | $0.840 \times 10^6$ |
| 250 | 0.0559 | 0.242 | 0.0227 | 0.0192 | 0.692 | 1.41 | $0.607 \times 10^6$ |
| 300 | 0.0523 | 0.243 | 0.0237 | 0.0204 | 0.689 | 1.32 | $0.454 \times 10^6$ |
| 350 | 0.0490 | 0.244 | 0.0250 | 0.0215 | 0.687 | 1.23 | $0.336 \times 10^6$ |
| 400 | 0.0462 | 0.245 | 0.0260 | 0.0225 | 0.686 | 1.16 | $0.264 \times 10^6$ |
| 450 | 0.0437 | 0.246 | 0.0271 | 0.0236 | 0.674 | 1.10 | $0.204 \times 10^6$ |
| 500 | 0.0413 | 0.247 | 0.0280 | 0.0246 | 0.680 | 1.04 | $0.163 \times 10^6$ |

**Geankoplis, 4th edition**

**NOTE: Equate the label to the provided quantity in the supplied units. For example, for <u>air</u> at $0°C$:**

$$\mu \times 10^5 = 1.72 \; Pa\,s$$

$$\mu = 1.72 \times 10^{-5} Pa\,s$$

**A.2-9 Properties of Saturated Steam and Water (Steam Table), SI Units**

| Temper-ature (°C) | Vapor Pressure (kPa) | Specific Volume (m³/kg) | | Enthalpy (kJ/kg) | | Entropy (kJ/kg · K) | |
|---|---|---|---|---|---|---|---|
| | | Liquid | Sat'd Vapor | Liquid | Sat'd Vapor | Liquid | Sat'd Vapor |
| 0.01 | 0.6113 | 0.0010002 | 206.136 | 0.00 | 2501.4 | 0.0000 | 9.1562 |
| 3 | 0.7577 | 0.0010001 | 168.132 | 12.57 | 2506.9 | 0.0457 | 9.0773 |
| 6 | 0.9349 | 0.0010001 | 137.734 | 25.20 | 2512.4 | 0.0912 | 9.0003 |
| 9 | 1.1477 | 0.0010003 | 113.386 | 37.80 | 2517.9 | 0.1362 | 8.9253 |
| 12 | 1.4022 | 0.0010005 | 93.784 | 50.41 | 2523.4 | 0.1806 | 8.8524 |
| 15 | 1.7051 | 0.0010009 | 77.926 | 62.99 | 2528.9 | 0.2245 | 8.7814 |
| 18 | 2.0640 | 0.0010014 | 65.038 | 75.58 | 2534.4 | 0.2679 | 8.7123 |
| 21 | 2.487 | 0.0010020 | 54.514 | 88.14 | 2539.9 | 0.3109 | 8.6450 |
| 24 | 2.985 | 0.0010027 | 45.883 | 100.70 | 2545.4 | 0.3534 | 8.5794 |
| 25 | 3.169 | 0.0010029 | 43.360 | 104.89 | 2547.2 | 0.3674 | 8.5580 |
| 27 | 3.567 | 0.0010035 | 38.774 | 113.25 | 2550.8 | 0.3954 | 8.5156 |
| 30 | 4.246 | 0.0010043 | 32.894 | 125.79 | 2556.3 | 0.4369 | 8.4533 |
| 33 | 5.034 | 0.0010053 | 28.011 | 138.33 | 2561.7 | 0.4781 | 8.3927 |
| 36 | 5.947 | 0.0010063 | 23.940 | 150.86 | 2567.1 | 0.5188 | 8.3336 |
| 40 | 7.384 | 0.0010078 | 19.523 | 167.57 | 2574.3 | 0.5725 | 8.2570 |
| 45 | 9.593 | 0.0010099 | 15.258 | 188.45 | 2583.2 | 0.6387 | 8.1648 |
| 50 | 12.349 | 0.0010121 | 12.032 | 209.33 | 2592.1 | 0.7038 | 8.0763 |
| 55 | 15.758 | 0.0010146 | 9.568 | 230.23 | 2600.9 | 0.7679 | 7.9913 |
| 60 | 19.940 | 0.0010172 | 7.671 | 251.13 | 2609.6 | 0.8312 | 7.9096 |
| 65 | 25.03 | 0.0010199 | 6.197 | 272.06 | 2618.3 | 0.8935 | 7.8310 |
| 70 | 31.19 | 0.0010228 | 5.042 | 292.98 | 2626.8 | 0.9549 | 7.7553 |
| 75 | 38.58 | 0.0010259 | 4.131 | 313.93 | 2635.3 | 1.0155 | 7.6824 |
| 80 | 47.39 | 0.0010291 | 3.407 | 334.91 | 2643.7 | 1.0753 | 7.6122 |
| 85 | 57.83 | 0.0010325 | 2.828 | 355.90 | 2651.9 | 1.1343 | 7.5445 |
| 90 | 70.14 | 0.0010360 | 2.361 | 376.92 | 2660.1 | 1.1925 | 7.4791 |
| 95 | 84.55 | 0.0010397 | 1.9819 | 397.96 | 2668.1 | 1.2500 | 7.4159 |
| 100 | 101.35 | 0.0010435 | 1.6729 | 419.04 | 2676.1 | 1.3069 | 7.3549 |
| 105 | 120.82 | 0.0010475 | 1.4194 | 440.15 | 2683.8 | 1.3630 | 7.2958 |
| 110 | 143.27 | 0.0010516 | 1.2102 | 461.30 | 2691.5 | 1.4185 | 7.2387 |
| 115 | 169.06 | 0.0010559 | 1.0366 | 482.48 | 2699.0 | 1.4734 | 7.1833 |
| 120 | 198.53 | 0.0010603 | 0.8919 | 503.71 | 2706.3 | 1.5276 | 7.1296 |
| 125 | 232.1 | 0.0010649 | 0.7706 | 524.99 | 2713.5 | 1.5813 | 7.0775 |
| 130 | 270.1 | 0.0010697 | 0.6685 | 546.31 | 2720.5 | 1.6344 | 7.0269 |
| 135 | 313.0 | 0.0010746 | 0.5822 | 567.69 | 2727.3 | 1.6870 | 6.9777 |
| 140 | 316.3 | 0.0010797 | 0.5089 | 589.13 | 2733.9 | 1.7391 | 6.9299 |
| 145 | 415.4 | 0.0010850 | 0.4463 | 610.63 | 2740.3 | 1.7907 | 6.8833 |
| 150 | 475.8 | 0.0010905 | 0.3928 | 632.20 | 2746.5 | 1.8418 | 6.8379 |
| 155 | 543.1 | 0.0010961 | 0.3468 | 653.84 | 2752.4 | 1.8925 | 6.7935 |
| 160 | 617.8 | 0.0011020 | 0.3071 | 675.55 | 2758.1 | 1.9427 | 6.7502 |
| 165 | 700.5 | 0.0011080 | 0.2727 | 697.34 | 2763.5 | 1.9925 | 6.7078 |
| 170 | 791.7 | 0.0011143 | 0.2428 | 719.21 | 2768.7 | 2.0419 | 6.6663 |
| 175 | 892.0 | 0.0011207 | 0.2168 | 741.17 | 2773.6 | 2.0909 | 6.6256 |
| 180 | 1002.1 | 0.0011274 | 0.19405 | 763.22 | 2778.2 | 2.1396 | 6.5857 |
| 190 | 1254.4 | 0.0011414 | 0.15654 | 807.62 | 2786.4 | 2.2359 | 6.5079 |
| 200 | 1553.8 | 0.0011565 | 0.12736 | 852.45 | 2793.2 | 2.3309 | 6.4323 |
| 225 | 2548 | 0.0011992 | 0.07849 | 966.78 | 2803.3 | 2.5639 | 6.2503 |
| 250 | 3973 | 0.0012512 | 0.05013 | 1085.36 | 2801.5 | 2.7927 | 6.0730 |
| 275 | 5942 | 0.0013168 | 0.03279 | 1210.07 | 2785.0 | 3.0208 | 5.8938 |
| 300 | 8581 | 0.0010436 | 0.02167 | 1344.0 | 2749.0 | 3.2534 | 5.7045 |

From Geankoplis 4th Edition

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