

# SCHOOL OF ENGINEERING

*Form to accompany draft examination papers sent to external examiners*

Course Code: EG3029

Diet of Examinations: Resit

Materials required to be provided in the examination room when the examination is sat (in addition to the question paper and answer booklets):

None

Are candidates permitted to use approved calculators in the examination?

Yes

Details of materials which candidates are permitted to take into the examination room and use when answering the examination paper (in addition to writing and drawing instruments, and approved calculators where permitted):

None

Details of any departures from the agreed syllabus for this course:

N/A

Any information which the examiners feel should be communicated to the external examiners:

N/A

The examination paper has been prepared and scrutinised following current procedures:



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20/10/2014

**Course Organiser**

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**Date**

UNIVERSITY OF ABERDEEN      SESSION 2014–2015

Degree Examination in EG3029

0<sup>th</sup> May 2015                      00.00–00.00

- Notes:*
- (i) Candidates ARE permitted to use an approved calculator.*
  - (ii) Candidates ARE permitted to use tables of thermodynamic properties of fluids, which will be provided.*
  - (iii) Data sheets are attached to the paper.*

PLEASE NOTE THE FOLLOWING

- (i) You **must not** have in your possession any material other than that expressly permitted in the rules appropriate to this examination. Where this is permitted, such material **must not** be amended, annotated or modified in any way.
- (ii) You **must not** have in your possession any material that could be determined as giving you an advantage in the examination.
- (iii) You **must not** attempt to communicate with any candidate during the exam, either orally or by passing written material, or by showing material to another candidate, nor must you attempt to view another candidate's work.

Failure to comply with the above will be regarded as cheating and may lead to disciplinary action as indicated in the Academic Quality Handbook ([www.abdn.ac.uk/registry/quality/appendix7x1.pdf](http://www.abdn.ac.uk/registry/quality/appendix7x1.pdf)) Section 4.14 and 5.

Candidates must attempt *all* questions.

**Question 1**

- (i) Saturated refrigerant R-134a vapour at  $P_1 = 400 \text{ kPa}$  is compressed by a piston to  $P_2 = 16 \text{ bar}$  in a reversible adiabatic process. Critical pressure and temperature of R-134a are 4.059 MPa and 101.06°C.
- (a) Calculate the work done by the piston; [8 marks]
- (b) Sketch the  $TS$  and  $PV$  diagrams including the constant pressure and temperature lines. [4 marks]
- (ii) A reversible power cycle receives 100 kJ by heat transfer from a hot reservoir at 327°C and rejects 40 kJ by heat transfer to a cold reservoir at temperature  $T_C$ . Calculate:
- (a) Thermal efficiency,  $\eta_T \left( = \frac{W_{\text{cycle}}}{Q_H} \right)$ , where  $W_{\text{cycle}}$  is the work produced by the cycle and  $Q_H$  is the heat associated to the hot reservoir. [4 marks]
- (b) Temperature of the cold reservoir ( $T_C$ ) in °C. [4 marks]

**Question 2**

- (i) Derive the Maxwell relations below from the fundamental thermodynamic equations. [12 marks]

$$\begin{aligned} \left(\frac{\partial T}{\partial V}\right)_S &= -\left(\frac{\partial P}{\partial S}\right)_V; & \left(\frac{\partial T}{\partial P}\right)_S &= \left(\frac{\partial V}{\partial S}\right)_P; \\ \left(\frac{\partial P}{\partial T}\right)_V &= \left(\frac{\partial S}{\partial V}\right)_T; & \left(\frac{\partial V}{\partial T}\right)_P &= -\left(\frac{\partial S}{\partial P}\right)_T \end{aligned}$$

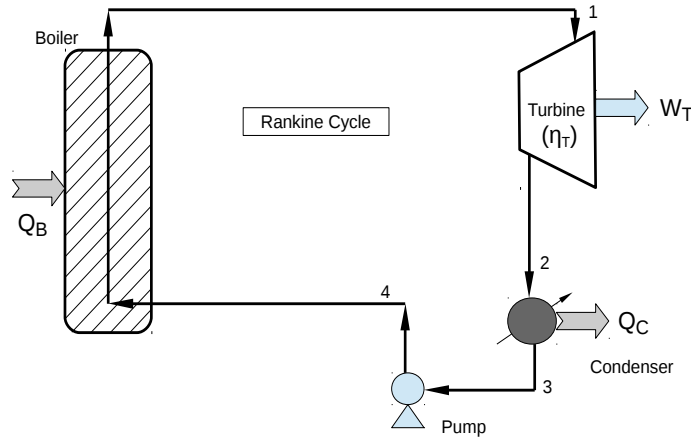
- (ii) Using the Maxwell relations above, evaluate  $\left(\frac{\partial S}{\partial V}\right)_T$  for water vapour at 240°C and specific volume of 0.4646 m<sup>3</sup>.kg<sup>-1</sup> through the Redlich-Kwong equation of state,

$$P = \frac{RT}{V - b} - \frac{a}{V(V + b)T^{1/2}}$$

with  $a = 142.59 \text{ bar} \left(\frac{\text{m}^3}{\text{kgmol}}\right)^2 (\text{K})^{\frac{1}{2}}$  and  $b = 0.0211 \frac{\text{m}^3}{\text{kgmol}}$ . [8 marks]

**Question 3**

The steam generator of a nuclear power plant produces  $25 \text{ kg.s}^{-1}$  of water-steam at  $P_1 = 140 \text{ bar}$  and  $T_1 = 415^\circ\text{C}$ . The fluid is used to drive a turbine (isentropic expansion) producing power ( $W_T$ ) at  $P_2 = 2.5 \text{ bar}$ . Before the vaporisation in the boiler, the fluid needs to be condensed into liquid water (stage 3) producing  $Q_C$  of heat.



- Calculate  $H_1, H_2, H_4, S_1$  and  $x_2$  (quality of the steam). [10 marks]
- Determine the power produced in the turbine ( $W_T$ ) in MW. [2 marks]
- Determine the heat extracted from the steam ( $Q_C$ ) in MW. [2 marks]
- Determine the heat supplied by the boiler ( $Q_B$ ) in MW. [2 marks]
- Calculate the efficiency of the cycle ( $\eta_{\text{cycle}} = \frac{W_T}{Q_B}$ ). [2 marks]
- Sketch the temperature  $\times$  entropy (TS) diagram for the process indicating the liquid and vapour saturated lines and each stage of the water-steam Rankine cycle. [2 marks]

To solve this problem, you should assume that the saturated liquid streams are incompressible, and therefore  $dH = VdP$  (where  $H$ ,  $V$  and  $P$  are enthalpy, volume and pressure, respectively). Quality of the vapour is expressed as

$$x_j = \frac{\Psi_j - \Psi_f}{\Psi_g - \Psi_f} \quad \text{with } \Psi = \{H, S\}$$

where  $S$  is the entropy.

**Question 4**

Two chemical species, 1 and 2 are mixed in a solution at 25°C and atmospheric pressure. The volume change is given by the following equation,

$$\Delta V = x_1 x_2 (45x_1 + 25x_2)$$

where  $\Delta V$  is expressed in  $\text{cm}^3.\text{gmol}^{-1}$ . At these temperature and pressure conditions,  $V_1 = 110$  and  $V_2 = 90 \text{ cm}^3.\text{gmol}^{-1}$ . Determine the partial molar volumes of the chemical species in a solution containing 40%-mol of species 1. [20 marks]

### Question 5

- (i) A concentrated binary solution containing mainly species 2 (though  $x_2 \neq 1$ ) is in equilibrium with a vapour phase containing both species 1 and 2. Pressure and temperature of this two-phase system are 1 bar and 298.15 K. Given  $\mathcal{H}_1 = 200$  bar (Henry constant) and  $P_2^{\text{sat}} = 0.10$  bar, calculate  $x_1$  and  $y_1$ . [10/10 marks]
- (ii) Chemical species  $A$  and  $B$  are in vapour-liquid equilibrium at 298.15 K. The following conditions are applied to this system:

$$\begin{aligned} \ln \gamma_A &= 1.8x_B^2 & \ln \gamma_B &= 1.8x_A^2 \\ P_A^{\text{sat}} &= 1.24 \text{ bar} & P_B^{\text{sat}} &= 0.89 \text{ bar} \end{aligned}$$

Assuming that  $y_i P = x_i \gamma_i P_i^{\text{sat}}$  (where  $\gamma_i$  is the activity coefficient of species  $i$ ) is valid,

- (a) Calculate the pressure  $P$  and the vapour mole fraction  $y_A$  for a liquid mole fraction  $x_A = 0.65$ . [6 marks]
- (b) Calculate the range of overall mole fraction  $z_A$  in which this system may exist. [4 marks]

- Generic cubic equation of state:

$$Z = 1 + \beta - q\beta \frac{Z - \beta}{(Z + \epsilon\beta)(Z + \sigma\beta)} \quad (\text{vapour and vapour-like roots})$$

$$Z = 1 + \beta + (Z + \epsilon\beta)(Z + \sigma\beta) \left( \frac{1 + \beta - Z}{q\beta} \right) \quad (\text{liquid and liquid-like roots})$$

$$\text{with } \beta = \Omega \frac{P_r}{T_r} \quad \text{and} \quad q = \frac{\Psi \alpha(T_r)}{\Omega T_r}$$

$$\alpha_{\text{SRK}} = \left[ 1 + (0.480 + 1.574\omega - 0.176\omega^2) (1 - \sqrt{T_r}) \right]^2$$

$$\alpha_{\text{PR}} = \left[ 1 + (0.37464 + 1.54226\omega - 0.26992\omega^2) (1 - \sqrt{T_r}) \right]^2$$

EOS	$\alpha$	$\sigma$	$\epsilon$	$\Omega$	$\Psi$
vdW	1	0	0	1/8	27/64
RK	$T_r^{-1/2}$	1	0	0.08664	0.42748
SRK	$\alpha_{\text{SRK}}$	1	0	0.08664	0.42748
PR	$\alpha_{\text{PR}}$	$1 + \sqrt{2}$	$1 - \sqrt{2}$	0.07780	0.45724

- Newton-Raphson (root-finder) method:  $X_i = X_{i-1} - \frac{\mathcal{F}(X_{i-1})}{d\mathcal{F}/dX(X_{i-1})}$
- Fundamental thermodynamic equations:
 
$$dU = dQ + dW; \quad dH = dU + d(PV); \quad dA = dU - d(TS); \quad dG = dH - d(TS)$$

$$dU = TdS - PdV; \quad dH = TdS + VdP; \quad dA = -SdT - PdV; \quad dG = -SdT + VdP$$

$$dH = C_p dT + \left[ V - T \left( \frac{\partial V}{\partial T} \right)_P \right] dP; \quad dS = C_p \frac{dT}{T} - \left( \frac{\partial V}{\partial T} \right)_P dP$$

$$dU = C_v dT + \left[ T \left( \frac{\partial P}{\partial T} \right)_V - P \right] dV; \quad dS = C_v \frac{dT}{T} - \left( \frac{\partial P}{\partial T} \right)_V dV$$

- Polytropic Relations:

$$\frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} = \left( \frac{V_1}{V_2} \right)^{\gamma-1}; \quad TV^{\gamma-1} = \text{const}; \quad TP^{\frac{1-\gamma}{\gamma}} = \text{const}; \quad PV^\gamma = \text{const}$$

- Raoult's Law:

$$y_i P = x_i P_i^{\text{sat}} \quad \text{and} \quad y_i P = x_i \gamma_i P_i^{\text{sat}} \quad \text{with } i = 1, 2, \dots, N$$

- Henry's Law:

$$x_i \mathcal{H}_i = y_i P \quad \text{with } i = 1, 2, \dots, N$$

- Antoine Equation:

$$\log_{10} P^* = A - \frac{B}{T + C} \quad \text{with } P^* \text{ in mm-Hg and } T \text{ in } ^\circ\text{C}$$

- Solutions:

$$M^E = M - \sum_{i=1}^N x_i M_i; \quad \overline{M}_1 = M + x_2 \frac{dM}{dx_1}; \quad \overline{M}_2 = M - x_1 \frac{dM}{dx_1}$$



# Appendix A: Physical Constants and Conversion Factors

## PHYSICAL CONSTANTS

Avogadro's number,  $N_A = 6.023 \times 10^{26}$  molecules/kgmole  
 Boltzmann's constant,  $k = 1.381 \times 10^{-23}$  J/(molecule·K)  
 Electron charge,  $e = 1.602 \times 10^{-19}$  C  
 Electron mass,  $m_e = 9.110 \times 10^{-31}$  kg  
 Faraday's constant,  $F = 96,487$  kC/kgmole electrons = 96,487 kJ/(V·kgmole electrons)  
 Gravitational acceleration (standard),  $g = 32.174$  ft/s<sup>2</sup> = 9.807 m/s<sup>2</sup>  
 Gravitational constant,  $k_G = 6.67 \times 10^{-11}$  m<sup>3</sup>/(kg·s<sup>2</sup>)  
 Newton's second law constant,  $g_c = 32.174$  lbm·ft/(lbf·s<sup>2</sup>) = 1.0 kg·m/(N·s<sup>2</sup>)  
 Planck's constant,  $h = 6.626 \times 10^{-34}$  J·s/molecule  
 Stefan-Boltzmann constant,  $\sigma = 0.1714 \times 10^{-8}$  Btu/(h·ft<sup>2</sup>·R<sup>4</sup>) =  $5.670 \times 10^{-8}$  W/(m<sup>2</sup>·K<sup>4</sup>)  
 Universal gas constant  $\mathfrak{R} = 1545.35$  ft·lbf/(lbmole·R) = 8314.3 J/(kgmole·K)  
     = 8.3143 kJ/(kgmole·K) = 1.9858 Btu/(lbmole·R)  
     = 1.9858 kcal/(kgmole·K) = 1.9858 cal/(gmole·K)  
     = 0.08314 bar·m<sup>3</sup>/(kgmole·K) = 82.05 L·atm/(kgmole·K)  
 Velocity of light in a vacuum,  $c = 9.836 \times 10^8$  ft/s =  $2.998 \times 10^8$  m/s

## UNIT DEFINITIONS

1 coulomb (C) = 1 A·s	1 ohm ( $\Omega$ ) = 1 V/A
1 dyne = 1 g·cm/s <sup>2</sup>	1 pascal (Pa) = 1 N/m <sup>2</sup>
1 erg = 1 dyne·cm	1 poundal = 1 lbm·ft/s <sup>2</sup>
1 farad (F) = 1 C/V	1 siemens (S) = 1 A/V
1 henry (H) = 1 Wb/A	1 slug = 1 lbf·s <sup>2</sup> /ft
1 hertz (Hz) = 1 cycle/s	1 tesla (T) = 1 Wb/m <sup>2</sup>
1 joule (J) = 1 N·m	1 volt (V) = 1 W/A
1 lumen = 1 candela·steradian	1 watt (W) = 1 J/s
1 lux = 1 lumen/m <sup>2</sup>	1 weber (Wb) = 1 V·s
1 newton (N) = 1 kg·m/s <sup>2</sup>	

## CONVERSION FACTORS

Length	Energy
1 m = 3.2808 ft = 39.37 in = 10 <sup>2</sup> cm = 10 <sup>10</sup> Å	1 J = 1 N·m = 1 kg·m <sup>2</sup> /s <sup>2</sup> = 9.479 × 10 <sup>-4</sup> Btu
1 cm = 0.0328 ft = 0.394 in = 10 <sup>-2</sup> m = 10 <sup>8</sup> Å	1 kJ = 1000 J = 0.9479 Btu = 238.9 cal
1 mm = 10 <sup>-3</sup> m = 10 <sup>-1</sup> cm	1 Btu = 1055.0 J = 1.055 kJ = 778.16 ft·lbf = 252 cal
1 km = 1000 m = 0.6215 miles = 3281 ft	1 cal = 4.186 J = 3.968 × 10 <sup>-3</sup> Btu
1 in = 2.540 cm = 0.0254 m	1 Cal (in food value) = 1 kcal = 4186 J = 3.968 Btu
1 ft = 12 in = 0.3048 m	1 erg = 1 dyne·cm = 1 g·cm <sup>2</sup> /s <sup>2</sup> = 10 <sup>-7</sup> J
1 mile = 5280 ft = 1609.36 m = 1.609 km	1 eV = 1.602 × 10 <sup>-19</sup> J

(Continued)

**CONVERSION FACTORS** (Continued)**Area**

$$1 \text{ m}^2 = 10^4 \text{ cm}^2 = 10.76 \text{ ft}^2 = 1550 \text{ in}^2$$

$$1 \text{ ft}^2 = 144 \text{ in}^2 = 0.0929 \text{ m}^2 = 929.05 \text{ cm}^2$$

$$1 \text{ cm}^2 = 10^{-4} \text{ m}^2 = 1.0764 \times 10^{-3} \text{ ft}^2 = 0.155 \text{ in}^2$$

$$1 \text{ in}^2 = 6.944 \times 10^{-3} \text{ ft}^2 = 6.4516 \times 10^{-4} \text{ m}^2 = 6.4516 \text{ cm}^2$$

**Volume**

$$1 \text{ m}^3 = 35.313 \text{ ft}^3 = 6.1023 \times 10^4 \text{ in}^3 = 1000 \text{ L} = 264.171 \text{ gal}$$

$$1 \text{ L} = 10^{-3} \text{ m}^3 = 0.0353 \text{ ft}^3 = 61.03 \text{ in}^3 = 0.2642 \text{ gal}$$

$$1 \text{ gal} = 231 \text{ in}^3 = 0.13368 \text{ ft}^3 = 3.785 \times 10^{-3} \text{ m}^3$$

$$1 \text{ ft}^3 = 1728 \text{ in}^3 = 28.3168 \text{ L} = 0.02832 \text{ m}^3 = 7.4805 \text{ gal}$$

$$1 \text{ in}^3 = 16.387 \text{ cm}^3 = 1.6387 \times 10^{-5} \text{ m}^3 = 4.329 \times 10^{-3} \text{ gal}$$

**Mass**

$$1 \text{ kg} = 1000 \text{ g} = 2.2046 \text{ lbm} = 0.0685 \text{ slug}$$

$$1 \text{ lbm} = 453.6 \text{ g} = 0.4536 \text{ kg} = 3.108 \times 10^{-2} \text{ slug}$$

$$1 \text{ slug} = 32.174 \text{ lbm} = 1.459 \times 10^4 \text{ g} = 14.594 \text{ kg}$$

**Force**

$$1 \text{ N} = 10^5 \text{ dyne} = 1 \text{ kg} \cdot \text{m/s}^2 = 0.225 \text{ lbf}$$

$$1 \text{ lbf} = 4.448 \text{ N} = 32.174 \text{ poundals}$$

$$1 \text{ poundal} = 0.138 \text{ N} = 3.108 \times 10^{-2} \text{ lbf}$$

**Power**

$$1 \text{ W} = 1 \text{ J/s} = 1 \text{ kg} \cdot \text{m}^2/\text{s}^3 = 3.412 \text{ Btu/h} = 1.3405 \times 10^{-3} \text{ hp}$$

$$1 \text{ kW} = 1000 \text{ W} = 3412 \text{ Btu/h} = 737.3 \text{ ft} \cdot \text{lbf/s} = 1.3405 \text{ hp}$$

$$1 \text{ Btu/h} = 0.293 \text{ W} = 0.2161 \text{ ft} \cdot \text{lbf/s} = 3.9293 \times 10^{-4} \text{ hp}$$

$$1 \text{ hp} = 550 \text{ ft} \cdot \text{lbf/s} = 33000 \text{ ft} \cdot \text{lbf/min} = 2545 \text{ Btu/h} = 746 \text{ W}$$

**Pressure**

$$1 \text{ Pa} = 1 \text{ N/m}^2 = 1 \text{ kg}/(\text{m} \cdot \text{s}^2) = 1.4504 \times 10^{-4} \text{ lbf/in}^2$$

$$1 \text{ lbf/in}^2 = 6894.76 \text{ Pa} = 0.068 \text{ atm} = 2.036 \text{ in Hg}$$

$$1 \text{ atm} = 14.696 \text{ lbf/in}^2 = 1.01325 \times 10^5 \text{ Pa}$$

$$= 101.325 \text{ kPa} = 760 \text{ mm Hg}$$

$$1 \text{ bar} = 10^5 \text{ Pa} = 0.987 \text{ atm} = 14.504 \text{ lbf/in}^2$$

$$1 \text{ dyne/cm}^2 = 0.1 \text{ Pa} = 10^{-6} \text{ bar} = 145.04 \times 10^{-7} \text{ lbf/in}^2$$

$$1 \text{ in Hg} = 3376.8 \text{ Pa} = 0.491 \text{ lbf/in}^2$$

$$1 \text{ in H}_2\text{O} = 248.8 \text{ Pa} = 0.0361 \text{ lbf/in}^2$$

**MISCELLANEOUS UNIT CONVERSIONS****Specific Heat Units**

$$1 \text{ Btu}/(\text{lbm} \cdot ^\circ\text{F}) = 1 \text{ Btu}/(\text{lbm} \cdot \text{R})$$

$$1 \text{ kJ}/(\text{kg} \cdot \text{K}) = 0.23884 \text{ Btu}/(\text{lbm} \cdot \text{R}) = 185.8 \text{ ft} \cdot \text{lbf}/(\text{lbm} \cdot \text{R})$$

$$1 \text{ Btu}/(\text{lbm} \cdot \text{R}) = 778.16 \text{ ft} \cdot \text{lbf}/(\text{lbm} \cdot \text{R}) = 4.186 \text{ kJ}/(\text{kg} \cdot \text{K})$$

**Energy Density Units**

$$1 \text{ kJ/kg} = 1000 \text{ m}^2/\text{s}^2 = 0.4299 \text{ Btu/lbm}$$

$$1 \text{ Btu/lbm} = 2.326 \text{ kJ/kg} = 2326 \text{ m}^2/\text{s}^2$$

**Energy Flux**

$$1 \text{ W/m}^2 = 0.317 \text{ Btu}/(\text{h} \cdot \text{ft}^2)$$

$$1 \text{ Btu}/(\text{h} \cdot \text{ft}^2) = 3.154 \text{ W/m}^2$$

**Heat Transfer Coefficient**

$$1 \text{ W}/(\text{m}^2 \cdot \text{K}) = 0.1761 \text{ Btu}/(\text{h} \cdot \text{ft}^2 \cdot \text{R})$$

$$1 \text{ Btu}/(\text{h} \cdot \text{ft}^2 \cdot \text{R}) = 5.679 \text{ W}/(\text{m}^2 \cdot \text{K})$$

**Thermal Conductivity**

$$1 \text{ W}/(\text{m} \cdot \text{K}) = 0.5778 \text{ Btu}/(\text{h} \cdot \text{ft} \cdot \text{R})$$

$$1 \text{ Btu}/(\text{h} \cdot \text{ft} \cdot \text{R}) = 1.731 \text{ W}/(\text{m} \cdot \text{K})$$

**Temperature**

$$T(^{\circ}\text{F}) = \frac{9}{5} T(^{\circ}\text{C}) + 32 = T(\text{R}) - 459.67$$

$$T(^{\circ}\text{C}) = \frac{5}{9} [T(^{\circ}\text{F}) - 32] = T(\text{K}) - 273.15$$

$$T(\text{R}) = \frac{9}{5} T(\text{K}) = (1.8) T(\text{K}) = T(^{\circ}\text{F}) + 459.67$$

$$T(\text{K}) = \frac{5}{9} T(\text{R}) = T(\text{R})/1.8 = T(^{\circ}\text{C}) + 273.15$$

**Density**

$$1 \text{ lbm/ft}^3 = 16.0187 \text{ kg/m}^3$$

$$1 \text{ kg/m}^3 = 0.062427 \text{ lbm/ft}^3 = 10^{-3} \text{ g/cm}^3$$

$$1 \text{ g/cm}^3 = 1 \text{ kg/L} = 62.4 \text{ lbm/ft}^3 = 10^3 \text{ kg/m}^3$$

**Viscosity**

$$1 \text{ Pa} \cdot \text{s} = 1 \text{ N} \cdot \text{s}/\text{m}^2 = 1 \text{ kg}/(\text{m} \cdot \text{s}) = 10 \text{ poise}$$

$$1 \text{ poise} = 1 \text{ dyne} \cdot \text{s}/\text{cm}^2 = 1 \text{ g}/(\text{cm} \cdot \text{s}) = 0.1 \text{ Pa} \cdot \text{s}$$

$$1 \text{ poise} = 2.09 \times 10^{-3} \text{ lbf} \cdot \text{s}/\text{ft}^2 = 6.72 \times 10^{-2} \text{ lbm}/(\text{ft} \cdot \text{s})$$

$$1 \text{ centipoise} = 0.01 \text{ poise} = 10^{-3} \text{ Pa} \cdot \text{s}$$

$$1 \text{ lbf} \cdot \text{s}/\text{ft}^2 = 1 \text{ slug}/(\text{ft} \cdot \text{s}) = 47.9 \text{ Pa} \cdot \text{s} = 479 \text{ poise}$$

$$1 \text{ stoke} = 1 \text{ cm}^2/\text{s} = 10^{-4} \text{ m}^2/\text{s} = 1.076 \times 10^{-3} \text{ ft}^2/\text{s}$$

$$1 \text{ centistoke} = 0.01 \text{ stoke} = 10^{-6} \text{ m}^2/\text{s} = 1.076 \times 10^{-5} \text{ ft}^2/\text{s}$$

$$1 \text{ m}^2/\text{s} = 10^4 \text{ stoke} = 10^6 \text{ centistoke} = 10.76 \text{ ft}^2/\text{s}$$

TABLE A-3 Properties of Saturated Water (Liquid–Vapor): Pressure Table

Press. bar	Temp. °C	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		Press. bar
		Sat. Liquid $v_f \times 10^3$	Sat. Vapor $v_g$	Sat. Liquid $u_f$	Sat. Vapor $u_g$	Sat. Liquid $h_f$	Evap. $h_{fg}$	Sat. Vapor $h_g$	Sat. Liquid $s_f$	Sat. Vapor $s_g$	
0.04	28.96	1.0040	34.800	121.45	2415.2	121.46	2432.9	2554.4	0.4226	8.4746	0.04
0.06	36.16	1.0064	23.739	151.53	2425.0	151.53	2415.9	2567.4	0.5210	8.3304	0.06
0.08	41.51	1.0084	18.103	173.87	2432.2	173.88	2403.1	2577.0	0.5926	8.2287	0.08
0.10	45.81	1.0102	14.674	191.82	2437.9	191.83	2392.8	2584.7	0.6493	8.1502	0.10
0.20	60.06	1.0172	7.649	251.38	2456.7	251.40	2358.3	2609.7	0.8320	7.9085	0.20
0.30	69.10	1.0223	5.229	289.20	2468.4	289.23	2336.1	2625.3	0.9439	7.7686	0.30
0.40	75.87	1.0265	3.993	317.53	2477.0	317.58	2319.2	2636.8	1.0259	7.6700	0.40
0.50	81.33	1.0300	3.240	340.44	2483.9	340.49	2305.4	2645.9	1.0910	7.5939	0.50
0.60	85.94	1.0331	2.732	359.79	2489.6	359.86	2293.6	2653.5	1.1453	7.5320	0.60
0.70	89.95	1.0360	2.365	376.63	2494.5	376.70	2283.3	2660.0	1.1919	7.4797	0.70
0.80	93.50	1.0380	2.087	391.58	2498.8	391.66	2274.1	2665.8	1.2329	7.4346	0.80
0.90	96.71	1.0410	1.869	405.06	2502.6	405.15	2265.7	2670.9	1.2695	7.3949	0.90
1.00	99.63	1.0432	1.694	417.36	2506.1	417.46	2258.0	2675.5	1.3026	7.3594	1.00
1.50	111.4	1.0528	1.159	466.94	2519.7	467.11	2226.5	2693.6	1.4336	7.2233	1.50
2.00	120.2	1.0605	0.8857	504.49	2529.5	504.70	2201.9	2706.7	1.5301	7.1271	2.00
2.50	127.4	1.0672	0.7187	535.10	2537.2	535.37	2181.5	2716.9	1.6072	7.0527	2.50
3.00	133.6	1.0732	0.6058	561.15	2543.6	561.47	2163.8	2725.3	1.6718	6.9919	3.00
3.50	138.9	1.0786	0.5243	583.95	2546.9	584.33	2148.1	2732.4	1.7275	6.9405	3.50
4.00	143.6	1.0836	0.4625	604.31	2553.6	604.74	2133.8	2738.6	1.7766	6.8959	4.00
4.50	147.9	1.0882	0.4140	622.25	2557.6	623.25	2120.7	2743.9	1.8207	6.8565	4.50
5.00	151.9	1.0926	0.3749	639.68	2561.2	640.23	2108.5	2748.7	1.8607	6.8212	5.00
6.00	158.9	1.1006	0.3157	669.90	2567.4	670.56	2086.3	2756.8	1.9312	6.7600	6.00
7.00	165.0	1.1080	0.2729	696.44	2572.5	697.22	2066.3	2763.5	1.9922	6.7080	7.00
8.00	170.4	1.1148	0.2404	720.22	2576.8	721.11	2048.0	2769.1	2.0462	6.6628	8.00
9.00	175.4	1.1212	0.2150	741.83	2580.5	742.83	2031.1	2773.9	2.0946	6.6226	9.00
10.0	179.9	1.1273	0.1944	761.68	2583.6	762.81	2015.3	2778.1	2.1387	6.5863	10.0
15.0	198.3	1.1539	0.1318	843.16	2594.5	844.84	1947.3	2792.2	2.3150	6.4448	15.0
20.0	212.4	1.1767	0.09963	906.44	2600.3	908.79	1890.7	2799.5	2.4474	6.3409	20.0
25.0	224.0	1.1973	0.07998	959.11	2603.1	962.11	1841.0	2803.1	2.5547	6.2575	25.0
30.0	233.9	1.2165	0.06668	1004.8	2604.1	1008.4	1795.7	2804.2	2.6457	6.1869	30.0
35.0	242.6	1.2347	0.05707	1045.4	2603.7	1049.8	1753.7	2803.4	2.7253	6.1253	35.0
40.0	250.4	1.2522	0.04978	1082.3	2602.3	1087.3	1714.1	2801.4	2.7964	6.0701	40.0
45.0	257.5	1.2692	0.04406	1116.2	2600.1	1121.9	1676.4	2798.3	2.8610	6.0199	45.0
50.0	264.0	1.2859	0.03944	1147.8	2597.1	1154.2	1640.1	2794.3	2.9202	5.9734	50.0
60.0	275.6	1.3187	0.03244	1205.4	2589.7	1213.4	1571.0	2784.3	3.0267	5.8892	60.0
70.0	285.9	1.3513	0.02737	1257.6	2580.5	1267.0	1505.1	2772.1	3.1211	5.8133	70.0
80.0	295.1	1.3842	0.02352	1305.6	2569.8	1316.6	1441.3	2758.0	3.2068	5.7432	80.0
90.0	303.4	1.4178	0.02048	1350.5	2557.8	1363.3	1378.9	2742.1	3.2858	5.6772	90.0
100.	311.1	1.4524	0.01803	1393.0	2544.4	1407.6	1317.1	2724.7	3.3596	5.6141	100.
110.	318.2	1.4886	0.01599	1433.7	2529.8	1450.1	1255.5	2705.6	3.4295	5.5527	110.

TABLE A-3 (Continued)

Press. bar	Temp. °C	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		Press. bar
		Sat. Liquid $v_f \times 10^3$	Sat. Vapor $v_g$	Sat. Liquid $u_f$	Sat. Vapor $u_g$	Sat. Liquid $h_f$	Evap. $h_{fg}$	Sat. Vapor $h_g$	Sat. Liquid $s_f$	Sat. Vapor $s_g$	
120.	324.8	1.5267	0.01426	1473.0	2513.7	1491.3	1193.6	2684.9	3.4962	5.4924	120.
130.	330.9	1.5671	0.01278	1511.1	2496.1	1531.5	1130.7	2662.2	3.5606	5.4323	130.
140.	336.8	1.6107	0.01149	1548.6	2476.8	1571.1	1066.5	2637.6	3.6232	5.3717	140.
150.	342.2	1.6581	0.01034	1585.6	2455.5	1610.5	1000.0	2610.5	3.6848	5.3098	150.
160.	347.4	1.7107	0.009306	1622.7	2431.7	1650.1	930.6	2580.6	3.7461	5.2455	160.
170.	352.4	1.7702	0.008364	1660.2	2405.0	1690.3	856.9	2547.2	3.8079	5.1777	170.
180.	357.1	1.8397	0.007489	1698.9	2374.3	1732.0	777.1	2509.1	3.8715	5.1044	180.
190.	361.5	1.9243	0.006657	1739.9	2338.1	1776.5	688.0	2464.5	3.9388	5.0228	190.
200.	365.8	2.036	0.005834	1785.6	2293.0	1826.3	583.4	2409.7	4.0139	4.9269	200.
220.9	374.1	3.155	0.003155	2029.6	2029.6	2099.3	0	2099.3	4.4298	4.4298	220.9

H<sub>2</sub>O

TABLE A-4 Properties of Superheated Water Vapor

$T$ °C	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg · K	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg · K
$p = 0.06 \text{ bar} = 0.006 \text{ MPa}$ ( $T_{\text{sat}} = 36.16^\circ\text{C}$ )					$p = 0.35 \text{ bar} = 0.035 \text{ MPa}$ ( $T_{\text{sat}} = 72.69^\circ\text{C}$ )			
Sat.	23.739	2425.0	2567.4	8.3304	4.526	2473.0	2631.4	7.7158
80	27.132	2487.3	2650.1	8.5804	4.625	2483.7	2645.6	7.7564
120	30.219	2544.7	2726.0	8.7840	5.163	2542.4	2723.1	7.9644
160	33.302	2602.7	2802.5	8.9693	5.696	2601.2	2800.6	8.1519
200	36.383	2661.4	2879.7	9.1398	6.228	2660.4	2878.4	8.3237
240	39.462	2721.0	2957.8	9.2982	6.758	2720.3	2956.8	8.4828
280	42.540	2781.5	3036.8	9.4464	7.287	2780.9	3036.0	8.6314
320	45.618	2843.0	3116.7	9.5859	7.815	2842.5	3116.1	8.7712
360	48.696	2905.5	3197.7	9.7180	8.344	2905.1	3197.1	8.9034
400	51.774	2969.0	3279.6	9.8435	8.872	2968.6	3279.2	9.0291
440	54.851	3033.5	3362.6	9.9633	9.400	3033.2	3362.2	9.1490
500	59.467	3132.3	3489.1	10.1336	10.192	3132.1	3488.8	9.3194
$p = 0.70 \text{ bar} = 0.07 \text{ MPa}$ ( $T_{\text{sat}} = 89.95^\circ\text{C}$ )					$p = 1.0 \text{ bar} = 0.10 \text{ MPa}$ ( $T_{\text{sat}} = 99.63^\circ\text{C}$ )			
Sat.	2.365	2494.5	2660.0	7.4797	1.694	2506.1	2675.5	7.3594
100	2.434	2509.7	2680.0	7.5341	1.696	2506.7	2676.2	7.3614
120	2.571	2539.7	2719.6	7.6375	1.793	2537.3	2716.6	7.4668
160	2.841	2599.4	2798.2	7.8279	1.984	2597.8	2796.2	7.6597
200	3.108	2659.1	2876.7	8.0012	2.172	2658.1	2875.3	7.8343
240	3.374	2719.3	2955.5	8.1611	2.359	2718.5	2954.5	7.9949
280	3.640	2780.2	3035.0	8.3162	2.546	2779.6	3034.2	8.1445
320	3.905	2842.0	3115.3	8.4504	2.732	2841.5	3114.6	8.2849
360	4.170	2904.6	3196.5	8.5828	2.917	2904.2	3195.9	8.4175
400	4.434	2968.2	3278.6	8.7086	3.103	2967.9	3278.2	8.5435
440	4.698	3032.9	3361.8	8.8286	3.288	3032.6	3361.4	8.6636
500	5.095	3131.8	3488.5	8.9991	3.565	3131.6	3488.1	8.8342
$p = 1.5 \text{ bar} = 0.15 \text{ MPa}$ ( $T_{\text{sat}} = 111.37^\circ\text{C}$ )					$p = 3.0 \text{ bar} = 0.30 \text{ MPa}$ ( $T_{\text{sat}} = 133.55^\circ\text{C}$ )			
Sat.	1.159	2519.7	2693.6	7.2233	0.606	2543.6	2725.3	6.9919
120	1.188	2533.3	2711.4	7.2693				
160	1.317	2595.2	2792.8	7.4665	0.651	2587.1	2782.3	7.1276
200	1.444	2656.2	2872.9	7.6433	0.716	2650.7	2865.5	7.3115
240	1.570	2717.2	2952.7	7.8052	0.781	2713.1	2947.3	7.4774
280	1.695	2778.6	3032.8	7.9555	0.844	2775.4	3028.6	7.6299
320	1.819	2840.6	3113.5	8.0964	0.907	2838.1	3110.1	7.7722
360	1.943	2903.5	3195.0	8.2293	0.969	2901.4	3192.2	7.9061
400	2.067	2967.3	3277.4	8.3555	1.032	2965.6	3275.0	8.0330
440	2.191	3032.1	3360.7	8.4757	1.094	3030.6	3358.7	8.1538
500	2.376	3131.2	3487.6	8.6466	1.187	3130.0	3486.0	8.3251
600	2.685	3301.7	3704.3	8.9101	1.341	3300.8	3703.2	8.5892

TABLE A-4 (Continued)

$T$ °C	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg · K	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg · K
$p = 40 \text{ bar} = 4.0 \text{ MPa}$ ( $T_{\text{sat}} = 250.4^\circ\text{C}$ )					$p = 60 \text{ bar} = 6.0 \text{ MPa}$ ( $T_{\text{sat}} = 275.64^\circ\text{C}$ )			
Sat.	0.04978	2602.3	2801.4	6.0701	0.03244	2589.7	2784.3	5.8892
280	0.05546	2680.0	2901.8	6.2568	0.03317	2605.2	2804.2	5.9252
320	0.06199	2767.4	3015.4	6.4553	0.03876	2720.0	2952.6	6.1846
360	0.06788	2845.7	3117.2	6.6215	0.04331	2811.2	3071.1	6.3782
400	0.07341	2919.9	3213.6	6.7690	0.04739	2892.9	3177.2	6.5408
440	0.07872	2992.2	3307.1	6.9041	0.05122	2970.0	3277.3	6.6853
500	0.08643	3099.5	3445.3	7.0901	0.05665	3082.2	3422.2	6.8803
540	0.09145	3171.1	3536.9	7.2056	0.06015	3156.1	3517.0	6.9999
600	0.09885	3279.1	3674.4	7.3688	0.06525	3266.9	3658.4	7.1677
640	0.1037	3351.8	3766.6	7.4720	0.06859	3341.0	3752.6	7.2731
700	0.1110	3462.1	3905.9	7.6198	0.07352	3453.1	3894.1	7.4234
740	0.1157	3536.6	3999.6	7.7141	0.07677	3528.3	3989.2	7.5190
$p = 80 \text{ bar} = 8.0 \text{ MPa}$ ( $T_{\text{sat}} = 295.06^\circ\text{C}$ )					$p = 100 \text{ bar} = 10.0 \text{ MPa}$ ( $T_{\text{sat}} = 311.06^\circ\text{C}$ )			
Sat.	0.02352	2569.8	2758.0	5.7432	0.01803	2544.4	2724.7	5.6141
320	0.02682	2662.7	2877.2	5.9489	0.01925	2588.8	2781.3	5.7103
360	0.03089	2772.7	3019.8	6.1819	0.02331	2729.1	2962.1	6.0060
400	0.03432	2863.8	3138.3	6.3634	0.02641	2832.4	3096.5	6.2120
440	0.03742	2946.7	3246.1	6.5190	0.02911	2922.1	3213.2	6.3805
480	0.04034	3025.7	3348.4	6.6586	0.03160	3005.4	3321.4	6.5282
520	0.04313	3102.7	3447.7	6.7871	0.03394	3085.6	3425.1	6.6622
560	0.04582	3178.7	3545.3	6.9072	0.03619	3164.1	3526.0	6.7864
600	0.04845	3254.4	3642.0	7.0206	0.03837	3241.7	3625.3	6.9029
640	0.05102	3330.1	3738.3	7.1283	0.04048	3318.9	3723.7	7.0131
700	0.05481	3443.9	3882.4	7.2812	0.04358	3434.7	3870.5	7.1687
740	0.05729	3520.4	3978.7	7.3782	0.04560	3512.1	3968.1	7.2670
$p = 120 \text{ bar} = 12.0 \text{ MPa}$ ( $T_{\text{sat}} = 324.75^\circ\text{C}$ )					$p = 140 \text{ bar} = 14.0 \text{ MPa}$ ( $T_{\text{sat}} = 336.75^\circ\text{C}$ )			
Sat.	0.01426	2513.7	2684.9	5.4924	0.01149	2476.8	2637.6	5.3717
360	0.01811	2678.4	2895.7	5.8361	0.01422	2617.4	2816.5	5.6602
400	0.02108	2798.3	3051.3	6.0747	0.01722	2760.9	3001.9	5.9448
440	0.02355	2896.1	3178.7	6.2586	0.01954	2868.6	3142.2	6.1474
480	0.02576	2984.4	3293.5	6.4154	0.02157	2962.5	3264.5	6.3143
520	0.02781	3068.0	3401.8	6.5555	0.02343	3049.8	3377.8	6.4610
560	0.02977	3149.0	3506.2	6.6840	0.02517	3133.6	3486.0	6.5941
600	0.03164	3228.7	3608.3	6.8037	0.02683	3215.4	3591.1	6.7172
640	0.03345	3307.5	3709.0	6.9164	0.02843	3296.0	3694.1	6.8326
700	0.03610	3425.2	3858.4	7.0749	0.03075	3415.7	3846.2	6.9939
740	0.03781	3503.7	3957.4	7.1746	0.03225	3495.2	3946.7	7.0952

**TABLE A-11** Properties of Saturated Refrigerant 134a (Liquid–Vapor): Pressure Table

Press. bar	Temp. °C	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		Press. bar
		Sat. Liquid $v_f \times 10^3$	Sat. Vapor $v_g$	Sat. Liquid $u_f$	Sat. Vapor $u_g$	Sat. Liquid $h_f$	Evap. $h_{fg}$	Sat. Vapor $h_g$	Sat. Liquid $s_f$	Sat. Vapor $s_g$	
0.6	−37.07	0.7097	0.3100	3.41	206.12	3.46	221.27	224.72	0.0147	0.9520	0.6
0.8	−31.21	0.7184	0.2366	10.41	209.46	10.47	217.92	228.39	0.0440	0.9447	0.8
1.0	−26.43	0.7258	0.1917	16.22	212.18	16.29	215.06	231.35	0.0678	0.9395	1.0
1.2	−22.36	0.7323	0.1614	21.23	214.50	21.32	212.54	233.86	0.0879	0.9354	1.2
1.4	−18.80	0.7381	0.1395	25.66	216.52	25.77	210.27	236.04	0.1055	0.9322	1.4
1.6	−15.62	0.7435	0.1229	29.66	218.32	29.78	208.19	237.97	0.1211	0.9295	1.6
1.8	−12.73	0.7485	0.1098	33.31	219.94	33.45	206.26	239.71	0.1352	0.9273	1.8
2.0	−10.09	0.7532	0.0993	36.69	221.43	36.84	204.46	241.30	0.1481	0.9253	2.0
2.4	−5.37	0.7618	0.0834	42.77	224.07	42.95	201.14	244.09	0.1710	0.9222	2.4
2.8	−1.23	0.7697	0.0719	48.18	226.38	48.39	198.13	246.52	0.1911	0.9197	2.8
3.2	2.48	0.7770	0.0632	53.06	228.43	53.31	195.35	248.66	0.2089	0.9177	3.2
3.6	5.84	0.7839	0.0564	57.54	230.28	57.82	192.76	250.58	0.2251	0.9160	3.6
4.0	8.93	0.7904	0.0509	61.69	231.97	62.00	190.32	252.32	0.2399	0.9145	4.0
5.0	15.74	0.8056	0.0409	70.93	235.64	71.33	184.74	256.07	0.2723	0.9117	5.0
6.0	21.58	0.8196	0.0341	78.99	238.74	79.48	179.71	259.19	0.2999	0.9097	6.0
7.0	26.72	0.8328	0.0292	86.19	241.42	86.78	175.07	261.85	0.3242	0.9080	7.0
8.0	31.33	0.8454	0.0255	92.75	243.78	93.42	170.73	264.15	0.3459	0.9066	8.0
9.0	35.53	0.8576	0.0226	98.79	245.88	99.56	166.62	266.18	0.3656	0.9054	9.0
10.0	39.39	0.8695	0.0202	104.42	247.77	105.29	162.68	267.97	0.3838	0.9043	10.0
12.0	46.32	0.8928	0.0166	114.69	251.03	115.76	155.23	270.99	0.4164	0.9023	12.0
14.0	52.43	0.9159	0.0140	123.98	253.74	125.26	148.14	273.40	0.4453	0.9003	14.0
16.0	57.92	0.9392	0.0121	132.52	256.00	134.02	141.31	275.33	0.4714	0.8982	16.0
18.0	62.91	0.9631	0.0105	140.49	257.88	142.22	134.60	276.83	0.4954	0.8959	18.0
20.0	67.49	0.9878	0.0093	148.02	259.41	149.99	127.95	277.94	0.5178	0.8934	20.0
25.0	77.59	1.0562	0.0069	165.48	261.84	168.12	111.06	279.17	0.5687	0.8854	25.0
30.0	86.22	1.1416	0.0053	181.88	262.16	185.30	92.71	278.01	0.6156	0.8735	30.0

R-134a

TABLE A-12 Properties of Superheated Refrigerant 134a Vapor

$T$ °C	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg · K	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg · K
$p = 0.6 \text{ bar} = 0.06 \text{ MPa}$ ( $T_{\text{sat}} = -37.07^\circ\text{C}$ )					$p = 1.0 \text{ bar} = 0.10 \text{ MPa}$ ( $T_{\text{sat}} = -26.43^\circ\text{C}$ )			
Sat.	0.31003	206.12	224.72	0.9520	0.19170	212.18	231.35	0.9395
-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	0.36433	232.24	254.10	1.0675	0.21587	231.41	252.99	1.0227
10	0.37861	239.69	262.41	1.0973	0.22473	238.96	261.43	1.0531
20	0.39279	247.32	270.89	1.1267	0.23349	246.67	270.02	1.0829
30	0.40688	255.12	279.53	1.1557	0.24216	254.54	278.76	1.1122
40	0.42091	263.10	288.35	1.1844	0.25076	262.58	287.66	1.1411
50	0.43487	271.25	297.34	1.2126	0.25930	270.79	296.72	1.1696
60	0.44879	279.58	306.51	1.2405	0.26779	279.16	305.94	1.1977
70	0.46266	288.08	315.84	1.2681	0.27623	287.70	315.32	1.2254
80	0.47650	296.75	325.34	1.2954	0.28464	296.40	324.87	1.2528
90	0.49031	305.58	335.00	1.3224	0.29302	305.27	334.57	1.2799
$p = 1.4 \text{ bar} = 0.14 \text{ MPa}$ ( $T_{\text{sat}} = -18.80^\circ\text{C}$ )					$p = 1.8 \text{ bar} = 0.18 \text{ MPa}$ ( $T_{\text{sat}} = -12.73^\circ\text{C}$ )			
Sat.	0.13945	216.52	236.04	0.9322	0.10983	219.94	239.71	0.9273
-10	0.14549	223.03	243.40	0.9606	0.11135	222.02	242.06	0.9362
0	0.15219	230.55	251.86	0.9922	0.11678	229.67	250.69	0.9684
10	0.15875	238.21	260.43	1.0230	0.12207	237.44	259.41	0.9998
20	0.16520	246.01	269.13	1.0532	0.12723	245.33	268.23	1.0304
30	0.17155	253.96	277.97	1.0828	0.13230	253.36	277.17	1.0604
40	0.17783	262.06	286.96	1.1120	0.13730	261.53	286.24	1.0898
50	0.18404	270.32	296.09	1.1407	0.14222	269.85	295.45	1.1187
60	0.19020	278.74	305.37	1.1690	0.14710	278.31	304.79	1.1472
70	0.19633	287.32	314.80	1.1969	0.15193	286.93	314.28	1.1753
80	0.20241	296.06	324.39	1.2244	0.15672	295.71	323.92	1.2030
90	0.20846	304.95	334.14	1.2516	0.16148	304.63	333.70	1.2303
100	0.21449	314.01	344.04	1.2785	0.16622	313.72	343.63	1.2573
$p = 2.0 \text{ bar} = 0.20 \text{ MPa}$ ( $T_{\text{sat}} = -10.09^\circ\text{C}$ )					$p = 2.4 \text{ bar} = 0.24 \text{ MPa}$ ( $T_{\text{sat}} = -5.37^\circ\text{C}$ )			
Sat.	0.09933	221.43	241.30	0.9253	0.08343	224.07	244.09	0.9222
-10	0.09938	221.50	241.38	0.9256				
0	0.10438	229.23	250.10	0.9582	0.08574	228.31	248.89	0.9399
10	0.10922	237.05	258.89	0.9898	0.08993	236.26	257.84	0.9721
20	0.11394	244.99	267.78	1.0206	0.09399	244.30	266.85	1.0034
30	0.11856	253.06	276.77	1.0508	0.09794	252.45	275.95	1.0339
40	0.12311	261.26	285.88	1.0804	0.10181	260.72	285.16	1.0637
50	0.12758	269.61	295.12	1.1094	0.10562	269.12	294.47	1.0930
60	0.13201	278.10	304.50	1.1380	0.10937	277.67	303.91	1.1218
70	0.13639	286.74	314.02	1.1661	0.11307	286.35	313.49	1.1501
80	0.14073	295.53	323.68	1.1939	0.11674	295.18	323.19	1.1780
90	0.14504	304.47	333.48	1.2212	0.12037	304.15	333.04	1.2055
100	0.14932	313.57	343.43	1.2483	0.12398	313.27	343.03	1.2326



TABLE A-12 (Continued)

$T$ °C	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg · K	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg · K
$p = 2.8 \text{ bar} = 0.28 \text{ MPa}$ ( $T_{\text{sat}} = -1.23^\circ\text{C}$ )					$p = 3.2 \text{ bar} = 0.32 \text{ MPa}$ ( $T_{\text{sat}} = 2.48^\circ\text{C}$ )			
Sat.	0.07193	226.38	246.52	0.9197	0.06322	228.43	248.66	0.9177
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
20	0.07972	243.59	265.91	0.9883	0.06901	242.87	264.95	0.9749
30	0.08320	251.83	275.12	1.0192	0.07214	251.19	274.28	1.0062
40	0.08660	260.17	284.42	1.0494	0.07518	259.61	283.67	1.0367
50	0.08992	268.64	293.81	1.0789	0.07815	268.14	293.15	1.0665
60	0.09319	277.23	303.32	1.1079	0.08106	276.79	302.72	1.0957
70	0.09641	285.96	312.95	1.1364	0.08392	285.56	312.41	1.1243
80	0.09960	294.82	322.71	1.1644	0.08674	294.46	322.22	1.1525
90	0.10275	303.83	332.60	1.1920	0.08953	303.50	332.15	1.1802
100	0.10587	312.98	342.62	1.2193	0.09229	312.68	342.21	1.2076
110	0.10897	322.27	352.78	1.2461	0.09503	322.00	352.40	1.2345
120	0.11205	331.71	363.08	1.2727	0.09774	331.45	362.73	1.2611
$p = 4.0 \text{ bar} = 0.40 \text{ MPa}$ ( $T_{\text{sat}} = 8.93^\circ\text{C}$ )					$p = 5.0 \text{ bar} = 0.50 \text{ MPa}$ ( $T_{\text{sat}} = 15.74^\circ\text{C}$ )			
Sat.	0.05089	231.97	252.32	0.9145	0.04086	235.64	256.07	0.9117
10	0.05119	232.87	253.35	0.9182				
20	0.05397	241.37	262.96	0.9515	0.04188	239.40	260.34	0.9264
30	0.05662	249.89	272.54	0.9837	0.04416	248.20	270.28	0.9597
40	0.05917	258.47	282.14	1.0148	0.04633	256.99	280.16	0.9918
50	0.06164	267.13	291.79	1.0452	0.04842	265.83	290.04	1.0229
60	0.06405	275.89	301.51	1.0748	0.05043	274.73	299.95	1.0531
70	0.06641	284.75	311.32	1.1038	0.05240	283.72	309.92	1.0825
80	0.06873	293.73	321.23	1.1322	0.05432	292.80	319.96	1.1114
90	0.07102	302.84	331.25	1.1602	0.05620	302.00	330.10	1.1397
100	0.07327	312.07	341.38	1.1878	0.05805	311.31	340.33	1.1675
110	0.07550	321.44	351.64	1.2149	0.05988	320.74	350.68	1.1949
120	0.07771	330.94	362.03	1.2417	0.06168	330.30	361.14	1.2218
130	0.07991	340.58	372.54	1.2681	0.06347	339.98	371.72	1.2484
140	0.08208	350.35	383.18	1.2941	0.06524	349.79	382.42	1.2746
$p = 6.0 \text{ bar} = 0.60 \text{ MPa}$ ( $T_{\text{sat}} = 21.58^\circ\text{C}$ )					$p = 7.0 \text{ bar} = 0.70 \text{ MPa}$ ( $T_{\text{sat}} = 26.72^\circ\text{C}$ )			
Sat.	0.03408	238.74	259.19	0.9097	0.02918	241.42	261.85	0.9080
30	0.03581	246.41	267.89	0.9388	0.02979	244.51	265.37	0.9197
40	0.03774	255.45	278.09	0.9719	0.03157	253.83	275.93	0.9539
50	0.03958	264.48	288.23	1.0037	0.03324	263.08	286.35	0.9867
60	0.04134	273.54	298.35	1.0346	0.03482	272.31	296.69	1.0182
70	0.04304	282.66	308.48	1.0645	0.03634	281.57	307.01	1.0487
80	0.04469	291.86	318.67	1.0938	0.03781	290.88	317.35	1.0784
90	0.04631	301.14	328.93	1.1225	0.03924	300.27	327.74	1.1074
100	0.04790	310.53	339.27	1.1505	0.04064	309.74	338.19	1.1358
110	0.04946	320.03	349.70	1.1781	0.04201	319.31	348.71	1.1637
120	0.05099	329.64	360.24	1.2053	0.04335	328.98	359.33	1.1910
130	0.05251	339.38	370.88	1.2320	0.04468	338.76	370.04	1.2179
140	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

TABLE A-12 (Continued)

$T$ °C	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg · K	$v$ m <sup>3</sup> /kg	$u$ kJ/kg	$h$ kJ/kg	$s$ kJ/kg · K
$p = 8.0 \text{ bar} = 0.80 \text{ MPa}$ ( $T_{\text{sat}} = 31.33^\circ\text{C}$ )					$p = 9.0 \text{ bar} = 0.90 \text{ MPa}$ ( $T_{\text{sat}} = 35.53^\circ\text{C}$ )			
Sat.	0.02547	243.78	264.15	0.9066	0.02255	245.88	266.18	0.9054
40	0.02691	252.13	273.66	0.9374	0.02325	250.32	271.25	0.9217
50	0.02846	261.62	284.39	0.9711	0.02472	260.09	282.34	0.9566
60	0.02992	271.04	294.98	1.0034	0.02609	269.72	293.21	0.9897
70	0.03131	280.45	305.50	1.0345	0.02738	279.30	303.94	1.0214
80	0.03264	289.89	316.00	1.0647	0.02861	288.87	314.62	1.0521
90	0.03393	299.37	326.52	1.0940	0.02980	298.46	325.28	1.0819
100	0.03519	308.93	337.08	1.1227	0.03095	308.11	335.96	1.1109
110	0.03642	318.57	347.71	1.1508	0.03207	317.82	346.68	1.1392
120	0.03762	328.31	358.40	1.1784	0.03316	327.62	357.47	1.1670
130	0.03881	338.14	369.19	1.2055	0.03423	337.52	368.33	1.1943
140	0.03997	348.09	380.07	1.2321	0.03529	347.51	379.27	1.2211
150	0.04113	358.15	391.05	1.2584	0.03633	357.61	390.31	1.2475
160	0.04227	368.32	402.14	1.2843	0.03736	367.82	401.44	1.2735
170	0.04340	378.61	413.33	1.3098	0.03838	378.14	412.68	1.2992
180	0.04452	389.02	424.63	1.3351	0.03939	388.57	424.02	1.3245
$p = 10.0 \text{ bar} = 1.00 \text{ MPa}$ ( $T_{\text{sat}} = 39.39^\circ\text{C}$ )					$p = 12.0 \text{ bar} = 1.20 \text{ MPa}$ ( $T_{\text{sat}} = 46.32^\circ\text{C}$ )			
Sat.	0.02020	247.77	267.97	0.9043	0.01663	251.03	270.99	0.9023
40	0.02029	248.39	268.68	0.9066				
50	0.02171	258.48	280.19	0.9428	0.01712	254.98	275.52	0.9164
60	0.02301	268.35	291.36	0.9768	0.01835	265.42	287.44	0.9527
70	0.02423	278.11	302.34	1.0093	0.01947	275.59	298.96	0.9868
80	0.02538	287.82	313.20	1.0405	0.02051	285.62	310.24	1.0192
90	0.02649	297.53	324.01	1.0707	0.02150	295.59	321.39	1.0503
100	0.02755	307.27	334.82	1.1000	0.02244	305.54	332.47	1.0804
110	0.02858	317.06	345.65	1.1286	0.02335	315.50	343.52	1.1096
120	0.02959	326.93	356.52	1.1567	0.02423	325.51	354.58	1.1381
130	0.03058	336.88	367.46	1.1841	0.02508	335.58	365.68	1.1660
140	0.03154	346.92	378.46	1.2111	0.02592	345.73	376.83	1.1933
150	0.03250	357.06	389.56	1.2376	0.02674	355.95	388.04	1.2201
160	0.03344	367.31	400.74	1.2638	0.02754	366.27	399.33	1.2465
170	0.03436	377.66	412.02	1.2895	0.02834	376.69	410.70	1.2724
180	0.03528	388.12	423.40	1.3149	0.02912	387.21	422.16	1.2980
$p = 14.0 \text{ bar} = 1.40 \text{ MPa}$ ( $T_{\text{sat}} = 52.43^\circ\text{C}$ )					$p = 16.0 \text{ bar} = 1.60 \text{ MPa}$ ( $T_{\text{sat}} = 57.92^\circ\text{C}$ )			
Sat.	0.01405	253.74	273.40	0.9003	0.01208	256.00	275.33	0.8982
60	0.01495	262.17	283.10	0.9297	0.01233	258.48	278.20	0.9069
70	0.01603	272.87	295.31	0.9658	0.01340	269.89	291.33	0.9457
80	0.01701	283.29	307.10	0.9997	0.01435	280.78	303.74	0.9813
90	0.01792	293.55	318.63	1.0319	0.01521	291.39	315.72	1.0148
100	0.01878	303.73	330.02	1.0628	0.01601	301.84	327.46	1.0467
110	0.01960	313.88	341.32	1.0927	0.01677	312.20	339.04	1.0773
120	0.02039	324.05	352.59	1.1218	0.01750	322.53	350.53	1.1069
130	0.02115	334.25	363.86	1.1501	0.01820	332.87	361.99	1.1357
140	0.02189	344.50	375.15	1.1777	0.01887	343.24	373.44	1.1638
150	0.02262	354.82	386.49	1.2048	0.01953	353.66	384.91	1.1912
160	0.02333	365.22	397.89	1.2315	0.02017	364.15	396.43	1.2181
170	0.02403	375.71	409.36	1.2576	0.02080	374.71	407.99	1.2445
180	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