Q.1 **Question 1**

A steam power plant operates with coupled regenerative and reheat Rankine cycle with 2 connected turbines as shown in Fig. 1. Primary steam is supplied by the boiler at 120 bar and 565°C. Conditions for water/steam flows are described in Table 1.

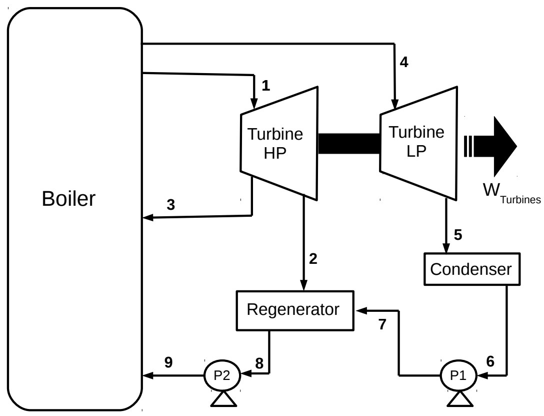

Figure 1: *Reheat and regenerative Rankine cycle with 2 turbines.*

Table 1: *Thermodynamic table of the reheat and regenerative Rankine cycle.*

Stage	P (bar)	T (^{o}C)	State	H (kJ.kg^{-1})	S (kJ.(kg.K)$^{-1}$)	Steam Quality
1	120	565	**(a)**	**(b)**	**(c)**	–
2	3	–	wet vapour	**(d)**	–	**(e)**
3	3	250	–	–	–	–
4	3	475	–	–	–	–
5	0.06	–	wet vapour	**(f)**	–	**(g)**
6	–	–	sat.liquid	**(h)**	–	–
7	3	–	–	**(i)**	–	–
8	3	–	–	–	–	–
9	120	–	–	**(j)**	–	–

(a) In Table 1, determine *(a)-(j)*. [10 marks]

Solution:

In order to fill the Table we need to calculate the thermodynamic properties for each stage of the cycle:

Stage 1: *The fluid leaving the boiler towards the first turbine is at 120 bar and 565^{o}C. This is well above the saturation temperature ($T_{sat} = 324.60^oC$) and we can thus confirm that the fluid is superheated steam . At such pressure, the superheated steam tables (SHST) results in (through linear interpolation):* **[1/10]**

[1/10] $H_1 = 3518.77\frac{kJ}{kg}$ *and*

[1/10] $S_1 = 6.6983\frac{kJ}{kg.K}$.

Stage 2: *Isentropic expansion in HP Turbine at* $P_2 = 3$ *bar* $\Leftrightarrow$ $S_2 = S_1 =$
[**1/10**] $6.6983\dfrac{kJ}{kg.K}$. *The fluid is at wet vapour state. The quality of the steam is*

$$x_2 = \frac{S_2 - S_f}{S_g - S_f} = \frac{6.6983 - 1.6716}{6.9909 - 1.6716} = 0.9450$$

[**1/10**] *Now calculating the enthalpy,*

$$x_2 = \frac{H_2 - H_f}{H_g - H_f} = 0.9450 \Leftrightarrow H_2 = 2605.72\frac{kJ}{kg}$$

Stage 3: *The fluid at* $P_3 = P_2 = 3.0$ *bar and* $T_3 = 250^oC\,(>> T_{sat} = 133.5^oC)$ *is superheated steam with* $H_3 = 2967.6\dfrac{kJ}{kg}$ *and* $S_3 = 7.517\dfrac{kJ}{kg.K}$.

Stage 4: *The steam leaves the boiler towards the LP turbine at* $P_4 = P_3 = 3.0$ *bar and* $T_4 = 475^oC$ *(also as superheated steam) with (via linear interpolation)* $H_4 = 3433.33\dfrac{kJ}{kg}$ *and* $S_4 = 8.252\dfrac{kJ}{kg}$.

Stage 5: *Isentropic expansion with* $P_5 = 0.060$ *bar* $($*with* $S_5 = S_4)$. *The quality of*
[**1/10**] *the steam is*

$$x_5 = \frac{S_5 - S_f}{S_g - S_f} = \frac{8.252 - 0.521}{8.330 - 0.521} = 0.99$$

[**1/10**] *and the enthalpy,*

$$x_5 = 0.99 = \frac{H_5 - H_f}{H_g - H_f} = \frac{H_5 - 151.5}{2567.4 - 151.5} \Leftrightarrow H_5 = 2543.24\frac{kJ}{kg}$$

Stage 6: *The fluid leaves the condenser at* $P_6 = P_5 = 0.06$ *bar is saturated liquid*
[**1/10**] *with* $H_6 = H_f\,(0.06\ bar) = 151.5\dfrac{kJ}{kg}$

Stage 7: *Saturated and incompressible liquid leaving the pump towards the regener-*
[**1/10**] *ator at* $P_7 = P_2 = 3.0$ *bar,*

$$\begin{aligned}
H_7 &\approx H_6 + V_6\,(P_7 - P_6) \\
&\approx 151.5\frac{kJ}{kg} + 0.001006\frac{m^3}{kg}\,(3 - 0.06)\,bar \times \frac{10^5\,\frac{N}{m^2}}{1\ bar} \times \frac{1\ J}{1\ N.m} \times \frac{10^{-3}\ kJ}{1\ J} \\
&\approx 151.795\ \frac{kJ}{kg}
\end{aligned}$$

Stage 8: *Saturated liquid water leaving the regenerator at* $P_8 = 3.0$ *bar with* $H_8 = H_f\,(3.0\ bar) = 561.4\dfrac{kJ}{kg}$ *and* $V_8 = 0.001068\dfrac{m^3}{kg}$.

[**1/10**] **Stage 9:** *Saturated and incompressible liquid at* $P_9 = 120$ *bar,*

$$\begin{aligned}
H_9 &\approx H_8 + V_8\,(P_9 - P_8) \\
&\approx 561.4\frac{kJ}{kg} + 0.001068\frac{m^3}{kg}\,(120 - 3)\,bar \times \frac{10^5\,\frac{N}{m^2}}{1\ bar} \times \frac{1\ J}{1\ N.m} \times \frac{10^{-3}\ kJ}{1\ J} \\
&\approx 573.97\ \frac{kJ}{kg}
\end{aligned}$$

Thus the Table becomes:

Stage	P (bar)	T (^{o}C)	State	H (kJ.kg^{-1})	S (kJ.(kg.K)$^{-1}$)	Steam Quality
1	*120*	*565*	**Superheated vapour**	**3518.77**	**6.6983**	–
2	*3*	–	*wet vapour*	**2605.72**	–	**0.9450**
3	*3*	*250*	–	–	–	–
4	*3*	*475*	–	–	–	–
5	*0.06*	–	*wet vapour*	**2543.24**	–	**0.99**
6	–	–	*sat.liquid*	**151.5**	–	–
7	*3*	–	–	**151.8**	–	–
8	*3*	–	–	–	–	–
9	*120*	–	–	**573.97**	–	–

(b) Calculate the fraction (as %) of steam supplied to the low-pressure (LP) turbine. [2 marks]

Solution:
Energy balance in the regenerator, assuming total mass of water of ($m_T =$) 1 kg, and that a fraction, $\mathcal{F}$, is bled-off from the HP turbine to the regenerator, and the remaining water-steam, $1-\mathcal{F}$ is conducted back to the boiler

$$m_T H_8 = \mathcal{F} H_2 + (1-\mathcal{F})\, H_7 \Rightarrow \mathcal{F} = 0.1669 kg$$

Thus, $m_2 = \mathcal{F} = 0.1669$ kg and $m_3 = m_4 = m_5 = m_6 = m_7 = (1-\mathcal{F}) = 0.833$ kg
[2/2] $\Longrightarrow$ *83.3% of the steam was supplied to the LP turbine.*

(c) Determine the heat supplied by the boiler. [2 marks]
Solution:
[2/2] *The heat supplied by the boiler (Q_{Boiler}) can be calculated through the energy balance,*

$$Q_{Boiler} = \left[m_T H_1 + (1-\mathcal{F})\, H_4\right] - \left[(1-\mathcal{F})\, H_3 + m_T H_9\right] \Rightarrow Q_{Boiler} = 3332.75 \frac{kJ}{kg}$$

(d) Determine the thermal efficiency of the cycle, [6 marks]

$$\eta = \frac{W_{Total}}{Q_{Boiler}} = \frac{\sum W_{\text{Turbines}} - \sum W_{\text{Pumps}}}{Q_{Boiler}}$$

Solution:
Now, in order to calculate the thermal efficiency of the cycle,

$$\eta = \frac{W_{Total}}{Q_{Boiler}} = \frac{\sum W_{Turbines} - \sum W_{Pumps}}{Q_{Boiler}}$$

We need to calculate the work associated with the turbines and pumps.

[1/6] **HP Turbine:** $W_{T,HP} = m_T H_1 - \left[\mathcal{F} H_2 + (1-\mathcal{F})\, H_3\right] = 611.86 \frac{kJ}{kg}$

[1/6] **LP Turbine:** $W_{T,LP} = (1-\mathcal{F})\,(H_4 - H_5) = 741.44 \frac{kJ}{kg}$

[**1/6**] **Pump 1:** $W_{P,1} = (1-\mathcal{F})(H_7 - H_6) = 0.246\frac{kJ}{kg}$

[**1/6**] **Pump 2:** $W_{P,2} = m_T(H_9 - H_8) = 12.57\frac{kJ}{kg}$

[**2/6**] *Thus the thermal efficiency of the cycle is,*

$$\eta = \frac{\sum W_{Turbines} - \sum W_{Pumps}}{Q_{Boiler}} = \frac{1339.76}{3332.27} = 0.4022$$

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 steam is expressed as

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

Q.2 Question 2

Refrigerant R-134a is used in a geothermal heat pump system (Fig. 2) to a storage in an industrial facility at 40°C. The heat pump uses underground water from a well to produce a heating capacity of 6 tons. Determine:

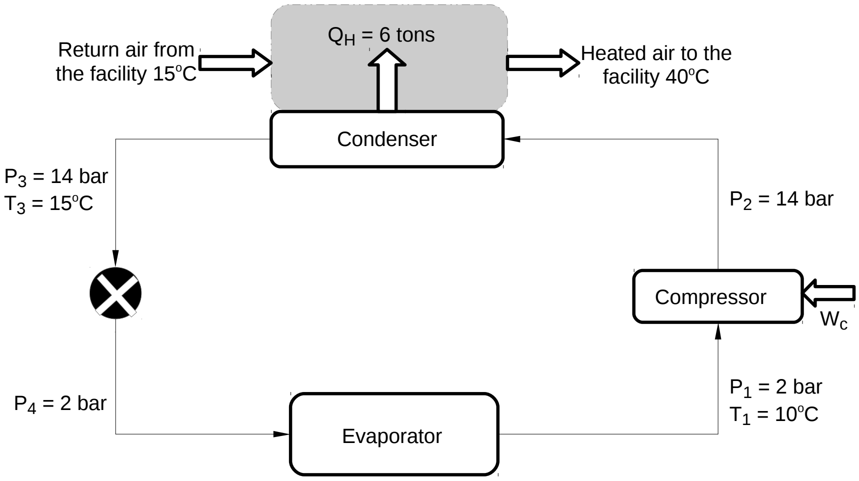

Figure 2: *Heat pump cycle.*

1. Enthalpies and Entropies: H_i, S_i with $i = \{1, 2, 3, 4\}$; [8 marks]
   Solution:
   Calculating all enthalpies and entropies of the cycle:

   Stage 1: *The refrigerant fluid leaves the evaporator at $P_1 = 2$ bar and $T_1 = 10^oC >> T_{sat} = -10.09^oC$, thus the fluid is at superheated vapour state and*
   [2/8] *with $H_1 = 258.89\dfrac{kJ}{kg}$ and $S_1 = 0.9898\dfrac{kJ}{kg.K}$.*

   Stage 2: *Isentropic compression, $S_2 = S_1$, and assuming ideal compressor at $P_2 =$*
   [2/8] *14 bar. Via linear interpolation, $H_2 = 303.66\dfrac{kJ}{kg}$ and $T_2 = 77.08^oC$.*

   Stage 3: *The fluid leaves the condenser at $P_3 = 14$ bar and $T_3 = 15^oC$ ($<< T_{sat} = 52.4^oC$)*
   [2/8] *is a sub-cooled liquid with $H_3 = 125.26\dfrac{kJ}{kg}$ and $S_3 = 0.4453\dfrac{kJ}{kg.K}$.*

   [2/8] **Stage 4:** *Isenthalpic process, $H_4 = H_3$, at $P_4 = 2$ bar. Calculating the quality of the vapour,*

   $$x_4 = \frac{H_4 - H_f}{H_g - H_f} = \frac{125.26 - 36.84}{241.30 - 36.84} = 0.4325$$

   and the entropy,

   $$x_4 = \frac{S_4 - S_f}{S_g - S_f} = \frac{S_4 - 0.1481}{0.9253 - 0.1481} \Rightarrow S_4 = 0.4842\frac{kJ}{kg.K}$$

2. Volumetric flow rate of heated air to the room (m^3/s); [3 marks]
   Solution:
   In order to calculate the volumetric flow rate of heated air, we first need to determine
   [1/3] *the mass flow rate,*

$$Q_H = \dot{m}_{air}\left(H^{air}_{out} - H^{air}_{in}\right) = \dot{m}_{air}C^{air}_p\left(T^{air}_{out} - T^{air}_{in}\right)$$

$$6\ ton \times \frac{210\frac{kJ}{min}}{1\ ton} \times \frac{1\ min}{60s} = \dot{m}_{air} \times 1.004\frac{kJ}{kg.K}\left(40-15\right)^o C$$

$$\dot{m}_{air} = 0.8367\frac{kg}{s}$$

[2/3] *Now for the volumetric flow rate* ($with\ T = 40^oC\ \ and\ P = 1.01325\ bar$)

$$\begin{aligned}\dot{V}^{out}_{air} &= \dot{m}_{air}V^{out}_{air} = \dot{m}_{air}\frac{RT^{out}_{air}}{P_{air}} \\ &= 0.8367\frac{kg}{s} \times 287\frac{J}{kg.K} \times \frac{(40+273.15)\ \ K}{1.0125\ \ bar} \times \frac{1\ \ N.m}{1\ \ J} \times \frac{1\ \ bar}{10^5\ \ N/m^2} \\ &= 0.7426\frac{m^3}{s}\end{aligned}$$

3. Mass flow rate of the R-134a refrigerant fluid; [3 marks]
   Solution:

[3/3] *The mass flow rate of the refrigerant fluid R-134a can be calculated as,*

$$Q_H = \dot{m}_R\left(H_2 - H_3\right) \Rightarrow \dot{m}_R = 0.1177\frac{kg}{s}$$

4. Compressor power (W_C) in kW; [3 marks]
   Solution:

[3/3]

$$W_C = \dot{m}_R\left(H_2 - H_1\right) \Rightarrow W_C = 5.27\ kW$$

5. Coefficient of performance $\left(\text{COP} = \dfrac{Q_H}{W_C}\right)$; [3 marks]
   Solution:

[3/3]

$$COP = \frac{Q_H}{W_C} = 3.98$$

Given the heat capacity, $C^{\text{air}}_p = 1.004\ kJ.\left(kg.K\right)^{-1}$, and molecular weight, $MW^{\text{air}} = 28.97\ kg.kgmol^{-1}$ of air. Assume that air behaves as an ideal gas. Quality of the vapour is expressed as

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

Q.3 Question 3

A steady flow energy device formed of a turbine with one inlet (labelled 1), and two outlets (labelled 2 and 3), does work on an ideal gas at a rate of 120 kW. The specific gas constant $R = 287\,\mathrm{J\,kg^{-1}\,K^{-1}}$ and the specific heat capacity at constant pressure $c_p = 1003\,\mathrm{J\,kg^{-1}\,K^{-1}}$, while the known conditions at the inlet and each outlet are given in table 2.

Table 2: *Inlet and outlet conditions for the steady flow device*

Inlet/Outlet	Area A (m^2)	Volume flux q (m^3 s^{-1})	Temperature T (°C)	Pressure p (Pa)	Height z (m)
1	0.1	2.0	20	p_1	0.0
2	0.1	1.0	50	200000	10.0
3	0.05	1.0	90	100000	4.0

(a) The steady flow energy equation for a steady flow device with one inlet and one outlet is

$$\frac{\dot{Q} - \dot{W}_s}{\dot{m}} = \left(c_p T_{\text{outlet}} + \frac{u^2_{\text{outlet}}}{2} + g z_{\text{outlet}}\right) - \left(c_p T_{\text{outlet}} + \frac{u^2_{\text{outlet}}}{2} + g z_{\text{inlet}}\right),$$

where u is the gas velocity, $\dot{Q}$ is the rate of heat addition and $\dot{W}_s$ is the rate at which shaft work is done on the gas. Explain how this equation should be changed to model the device described above. [4 marks]

Solution:

The mass flux entering the device $\dot{m}_1$ is now divided between two outlets. Therefore the modified mass conservation equation would be

$$\dot{m}_1 = \dot{m}_2 + \dot{m}_3.$$

[1/4]

With two outlets, the flux of energy must also be split between the two outlets, which gives

$$\dot{Q} - \dot{W}_s = \dot{m}_2\left(c_p T_2 + \frac{u_2^2}{2} + g z_2\right) + \dot{m}_3\left(c_p T_3 + \frac{u_3^2}{2} + g z_3\right) - \dot{m}_1\left(c_p T_1 + \frac{u_1^2}{2} + g z_1\right).$$

[3/4]

(b) Calculate the gas velocity at the inlet and each outlet; [3 marks]

Solution:

The gas velocities are given by

$$\begin{aligned} u_1 &= \frac{q_1}{A_1} = \frac{2.0\,m^3\,s^{-1}}{0.1\,m^2} = 20\,m\,s^{-1},\\ u_2 &= \frac{q_2}{A_2} = \frac{1.0\,m^3\,s^{-1}}{0.1\,m^2} = 10\,m\,s^{-1},\\ u_3 &= \frac{q_3}{A_3} = \frac{1.0\,m^3\,s^{-1}}{0.05\,m^2} = 20\,m\,s^{-1}. \end{aligned}$$

[3/3]

(c) Determine the pressure at the inlet (p_1); [5 marks]

Solution:

The densities at the outlets can be obtained via the ideal gas equation

$$\begin{aligned}\rho_2 =& \frac{p_2}{RT_2} = \frac{200000\,Pa}{287\,J\,kg^{-1}\,K^{-1}\,(50+273.15)\;K} = 2.1564726\,kg\,m^{-3},\\ \rho_3 =& \frac{p_3}{RT_3} = \frac{100000\,Pa}{287\,J\,kg^{-1}\,K^{-1}\,(90+273.15)\;K} = 0.9594714\,kg\,m^{-3}.\end{aligned}$$

[2/5]

Mass conservation gives $\dot{m}_1 = \dot{m}_2 + \dot{m}_3$ *where the mass flux* $\dot{m} = \rho q$. *Therefore*

$$\begin{aligned}\rho_1 = \frac{\rho_2 q_2 + \rho_3 q_3}{q_1} =& \frac{\left(2.1564726\,kg\,m^{-3} \times 1\,m^3\,s^{-1}\right) + \left(0.9594714\,kg\,m^{-3} \times 1\,m^3\,s^{-1}\right)}{2\,m^3\,s^{-1}}\\ =& 1.557972\,kg\,m^{-3}\end{aligned}$$

[2/5]

The pressure at the inlet is now

$$p_1 = \rho_1 RT_1 = 1.557972\,kg\,m^{-3} \times 287\,J\,kg^{-1}\,K^{-1} \times (20+273.15)\;K = 131078.49\,Pa.$$

[1/5]

(d) What is the relative percentage error if the gravitational potential energy terms are neglected when calculating the rate of heat transfer $\dot{Q}$? [8 marks]

Solution:

The mass fluxes at each inlet and exit are

$$\begin{aligned}\dot{m}_1 =& \rho_1 q_1 = 1.557972\,kg\,m^{-3} \times 2\,kg/s = 3.1159440\,kg/s,\\ \dot{m}_2 =& \rho_2 q_2 = 2.1564726\,kg\,m^{-3} \times 1\,kg/s = 2.1564726\,kg/s,\\ \dot{m}_3 =& \rho_3 q_3 = 0.9594714\,kg\,m^{-3} \times 1\,kg/s = 0.9594714\,kg/s.\end{aligned}$$

[1/8]

The energy fluxes without gravitational potential energy are

$$\begin{aligned}c_p T_1 + \frac{u_1^2}{2} =& 294229.45\,m^2/s^2,\\ c_p T_2 + \frac{u_2^2}{2} =& 324169.45\,m^2/s^2,\\ c_p T_3 + \frac{u_3^2}{2} =& 364439.45\,m^2/s^2.\end{aligned}$$

[1/8]

The energy fluxes with gravitational potential energy are

$$\begin{aligned}c_p T_1 + \frac{u_1^2}{2} + gz_1 =& 294229.45\,m^2/s^2,\\ c_p T_2 + \frac{u_2^2}{2} + gz_2 =& 324267.55\,m^2/s^2,\\ c_p T_3 + \frac{u_3^2}{2} + gz_3 =& 364478.69\,m^2/s^2.\end{aligned}$$

[**1/8**]

The rate of heat addition without gravitational potential energy is

$$\begin{aligned}\dot{Q}_{with} =& \dot{W}_s + \dot{m}_2\left(c_pT_2 + \frac{u_2^2}{2}\right) + \dot{m}_3\left(c_pT_3 + \frac{u_3^2}{2}\right) - \dot{m}_1\left(c_pT_1 + \frac{u_1^2}{2}\right)\\ =& -120000 + 916802.49 + 699062.53 + 349669.25\\ =& 11929.28\ W.\end{aligned}$$

[**2/8**] *Note turbine does work on gas so $\dot{W}_s$ is negative.*

The rate of heat addition with gravitational potential energy is

$$\begin{aligned}\dot{Q}_{without} =& \dot{W}_s + \dot{m}_2\left(c_pT_2 + \frac{u_2^2}{2} + gz_2\right) + \dot{m}_3\left(c_pT_3 + \frac{u_3^2}{2} + gz_3\right) - \dot{m}_1\left(c_pT_1 + \frac{u_1^2}{2} + gz_1\right)\\ =& -120000 + 916802.49 + 699274.08 + 349706.9\\ =& 12178.48\ W.\end{aligned}$$

[**2/8**] *Note turbine does work on gas so $\dot{W}_s$ is negative.*

The relative percentage difference between the rate of heat addition with and without the gravitational potential energy terms is

$$100\%\left|\frac{\dot{Q}_{with} - \dot{Q}_{without}}{\dot{Q}_{with}}\right| = 100\%\left|\frac{12178.48 - 11929.28}{12178.48}\right| = 2.0462\%.$$

[**1/8**]

Q.4 Question 4

(a) Gas flows along a pipe of slowly varying cross section in the direction of increasing x. By considering the rate of change of the mass of gas within a small section of pipe and the gas mass fluxes into and out of this section of pipe, show that

$$\frac{\partial}{\partial t}(\rho A) + \frac{\partial}{\partial x}(\rho u A) = 0.$$

Here the gas velocity u, density ρ and pipe cross section A are all functions of x and time t. [5 marks]

Solution:

[1/5] *The total mass contained in a section of pipe of length Δx is $\rho A \Delta x$.*

The rate of change of mass in this section of pipe equals the mass flux entering the pipe $\rho u A$ minus the mass flux leaving the other end of the pipe section

$$\rho u A + \Delta x \frac{\partial}{\partial x}(\rho u A).$$

[2/5] *[Obtained via a linearized Taylor expansion.]*

Hence mass conservation implies

$$\frac{\partial}{\partial t}(\rho A) = \rho u A - \rho u A - \Delta x \frac{\partial}{\partial x}(\rho u A).$$

[2/5] *and hence dividing by Δx and rearranging gives the result.*

(b) Explain what is meant by a steady flow and show that for steady flow in a pipe of uniform cross section

$$\frac{1}{\rho}\frac{\mathrm{d}\rho}{\mathrm{d}x} + \frac{1}{u}\frac{\mathrm{d}u}{\mathrm{d}x} = 0.$$

[4 marks]

Solution:

The flow is steady if the density, velocity and cross section depend only on x and not time t. In this case the result from (a) gives

$$\frac{\mathrm{d}}{\mathrm{d}x}(\rho u A) = 0.$$

[2/4]

If the pipe has uniform cross section, then A is constant. Therefore via the chain rule

$$\rho\frac{\mathrm{d}u}{\mathrm{d}x} + u\frac{\mathrm{d}\rho}{\mathrm{d}x} = 0.$$

[2/4] *Finally dividing by ρu gives the required result.*

(c) For steady compressible flow in a uniform pipe, using the conservation of energy and the laws of thermodynamics; changes in the entropy s, is related to changes in the pressure pressure p, density ρ and velocity u, through

$$T\,\mathrm{d}s + \frac{\mathrm{d}p}{\rho} + u\,\mathrm{d}u = 0.$$

Hence show that the change in pressure and the change in entropy as fluid flows are related through

$$\left(1 - \frac{u^2}{c^2}\right)\frac{\mathrm{d}p}{\mathrm{d}x} = -\rho T\left(1 + \frac{u^2\beta}{c_p}\right)\frac{\mathrm{d}s}{\mathrm{d}x}.$$

In the derivation of this result, you may additionally assume that a change in gas density

$$\mathrm{d}\rho = \frac{\mathrm{d}p}{c^2} - \frac{\rho\beta T}{c_p}\mathrm{d}s,$$

where c is the speed of sound, β is the thermal expansion coefficient and c_p is the specific heat capacity as constant pressure. [8 marks]

Solution:

Variations over x imply

$$T\frac{\mathrm{d}s}{\mathrm{d}x} + \frac{1}{\rho}\frac{\mathrm{d}p}{\mathrm{d}x} + u\frac{\mathrm{d}u}{\mathrm{d}x} = 0, \quad \text{and} \quad \frac{\mathrm{d}\rho}{\mathrm{d}x} = \frac{1}{c^2}\frac{\mathrm{d}p}{\mathrm{d}x} - \frac{\rho\beta T}{c_p}\frac{\mathrm{d}s}{\mathrm{d}x}.$$

Using the second equation, we eliminate the $\frac{\mathrm{d}\rho}{\mathrm{d}x}$ from the mass conservation equation to give

$$\rho\frac{\mathrm{d}u}{\mathrm{d}x} + \frac{u}{c^2}\frac{\mathrm{d}p}{\mathrm{d}x} - \frac{u\rho\beta T}{c_p}\frac{\mathrm{d}s}{\mathrm{d}x} = 0.$$

[2/8]

Next we eliminate $\frac{\mathrm{d}u}{\mathrm{d}x}$ to give

$$\frac{T}{u}\frac{\mathrm{d}s}{\mathrm{d}x} + \frac{1}{\rho u}\frac{\mathrm{d}p}{\mathrm{d}x} = -\frac{\mathrm{d}u}{\mathrm{d}x} = \frac{u}{\rho c^2}\frac{\mathrm{d}p}{\mathrm{d}x} - \frac{u\beta T}{c_p}\frac{\mathrm{d}s}{\mathrm{d}x}.$$

[2/8]

Collecting all the terms involving $\frac{\mathrm{d}p}{\mathrm{d}x}$ on one side and all the terms involving $\frac{\mathrm{d}s}{\mathrm{d}x}$ on the other side

$$\frac{1}{\rho u}\frac{\mathrm{d}p}{\mathrm{d}x} - \frac{u}{\rho c^2}\frac{\mathrm{d}p}{\mathrm{d}x} = -\frac{u\beta T}{c_p}\frac{\mathrm{d}s}{\mathrm{d}x} - \frac{T}{u}\frac{\mathrm{d}s}{\mathrm{d}x}.$$

$$\left(\frac{1}{\rho u} - \frac{u}{\rho c^2}\right)\frac{\mathrm{d}p}{\mathrm{d}x} = -T\left(\frac{u\beta}{c_p} + \frac{1}{u}\right)\frac{\mathrm{d}s}{\mathrm{d}x}.$$

[3/8]

If we multiply by ρu, then

$$\left(1 - \frac{u^2}{c^2}\right)\frac{\mathrm{d}p}{\mathrm{d}x} = -\rho T\left(1 + \frac{u^2\beta}{c_p}\right)\frac{\mathrm{d}s}{\mathrm{d}x}.$$

[1/8]

(d) Define a Mach number, and (with reference to the result derived in part (c)), explain how the pressure changes as a compressible fluid flows subsonically along a pipe of uniform cross section. [3 marks]

Solution:

The Mach number Ma *is the ratio of the actual speed u to the speed of sound c, i.e.*

$$\mathrm{Ma} = \frac{u}{c}.$$

[1/3]

For subsonic flow $\mathrm{Ma} < 1$*, so the coefficient of* $\frac{\partial p}{\partial x}$ *is positive. The density, temperature and velocity are all positive, so the* $-\rho T \left(1 + \frac{u^2 \beta}{c_p}\right)$ *is negative, while the entropy must*

[1/3] *increase with flow along the pipe (i.e.* $\frac{\mathrm{d}s}{\mathrm{d}x} > 0$*).*

[1/3] *Consequently the pressure must fall as fluid flows along the pipe.*

Q.5 Question 5

(a) Define the specific humidity ω. Assuming both dry air and water vapour behave like ideal gases with specific gas constants $R_a = 0.2871$ kJ/(kg.K) and $R_v = 0.4615$ kJ/(kg.K), respectively, show that

$$\omega = \frac{0.622 p_v}{p - p_v},$$

where p is the absolute pressure and p_v is the partial pressure of water vapour. [5 marks]

Solution:

The specific humidity ω is the ratio of the mass of water vapour m_v to the mass of
[1/5] *dry air m_a in a volume V, i.e.*

$$\omega = \frac{m_v}{m_a}.$$

[1/5]

In terms of densities

$$\omega = \frac{\rho_v V}{\rho_a V} = \frac{\rho_v}{\rho_a}.$$

Treat both water vapour and dry air as ideal gases, so that

$$\omega = \frac{p_v}{R_v T}\frac{R_a T}{p_a} = \frac{0.622 p_v}{p_a}.$$

[2/5]

Finally the partial pressure of water vapour and dry air $p_v + p_a = p$, so

$$\omega = \frac{0.622 p_v}{p - p_v}.$$

[1/5]

(b) Define the relative humidity φ, and hence show that

$$\omega = \frac{0.622 \varphi p_g}{p - \varphi p_g},$$

where the saturation pressure of water is denoted p_g. [3 marks]

Solution:

The relative humidity φ is the ratio of the mass of water vapour m_v to the mass of water vapour at saturation m_g, i.e.

$$\varphi = \frac{m_v}{m_g}.$$

[1/3]

Again using the ideal gas equation

$$\varphi = \frac{m_v}{m_g} = \frac{\rho_v V}{\rho_g V} = \frac{p_v}{R_v T}\frac{R_v T}{p_g} = \frac{p_v}{p_g}.$$

[1/3]

[1/3] *Therefore writing $p_v = \varphi p_g$ in the equation from part (a), gives the required result.*

(c) Air enters an air-conditioning system at 1 atm, 35°C and 60% relative humidity, at a rate of 12 m^3/min. Saturated air leaves the air-conditioning system at a temperature of 16°C. The moisture in the air that condenses during the process is removed at 16°C, while the specific enthalpy of liquid water at 16°C is 67.22 kJ/kg.

i) Determine the rate of moisture removal from the air; [7 marks]

Solution:

The inlet and outlet are at 1 atm (= 101.325 kPa) so we can determine the conditions using the psychrometric chart, which gives

$$h_1 = 80.0\,kJ/kg \text{ dry air}, \qquad h_2 = 45.6\,kJ/kg \text{ dry air},$$
$$\omega_1 = 0.022\,kg \text{ water}/kg \text{ dry air}, \qquad \omega_2 = 0.016\,kg \text{ water}/kg \text{ dry air},$$
$$V_1 = 0.866\,m^3/\,kg \text{ dry air}.$$

[3/7]

In the cooling section:

$$\text{Conservation of dry air:} \qquad \dot{m}_{a_1} = \dot{m}_{a_2} = \dot{m}_a,$$
$$\text{Conservation of water vapour:} \qquad \dot{m}_{a_1}\omega_1 = \dot{m}_{a_2}\omega_2 + \dot{m}_w,$$
$$\Rightarrow \dot{m}_w = \dot{m}_a\left(\omega_1 - \omega_2\right).$$

[2/7]

The mass flux of dry air is given by

$$\dot{m}_a = \frac{\dot{V}_1}{V_1} = \frac{12\,m^3/min}{0.866\,m^3/\,kg \text{ dry air}} = 13.86\,kg/min.$$

[1/7]

Hence the conservation of water vapour gives

$$\begin{aligned}\dot{m}_w =& \dot{m}_a\left(\omega_1 - \omega_2\right)\\ =& 13.86\,kg/min \times (0.022 - 0.016)\\ =& 0.083\,kg/min.\end{aligned}$$

[1/7]

ii) Determine the rate of heat removal from the air. [5 marks]

Solution:

In the cooling section:

$$\text{Conservation of energy:} \qquad \dot{Q} = \dot{m}_a\left(h_2 - h_1\right) + \dot{m}_w h_w.$$

[1/5]

The heat supplied to the system $\dot{Q}$ is given by the energy conservation equation

$$\begin{aligned}\dot{Q} =& \dot{m}_a\left(h_2 - h_1\right) + \dot{m}_w h_w\\ =& 13.86\,kg/min\,(45.6 - 80.0)\;kJ/kg + (0.083\,kg/min \times 67.22\,kJ/kg)\\ =& -476.674\,kJ/min + 5.589\,kJ/min\\ =& -471.1\,kJ/min.\end{aligned}$$

[3/5]

The rate of heat addition $\dot{Q}$ is negative indicating heat removal from the cooling section. Therefore the rate of heat removal is 471.1 kJ/min.

[1/5]

END OF PAPER

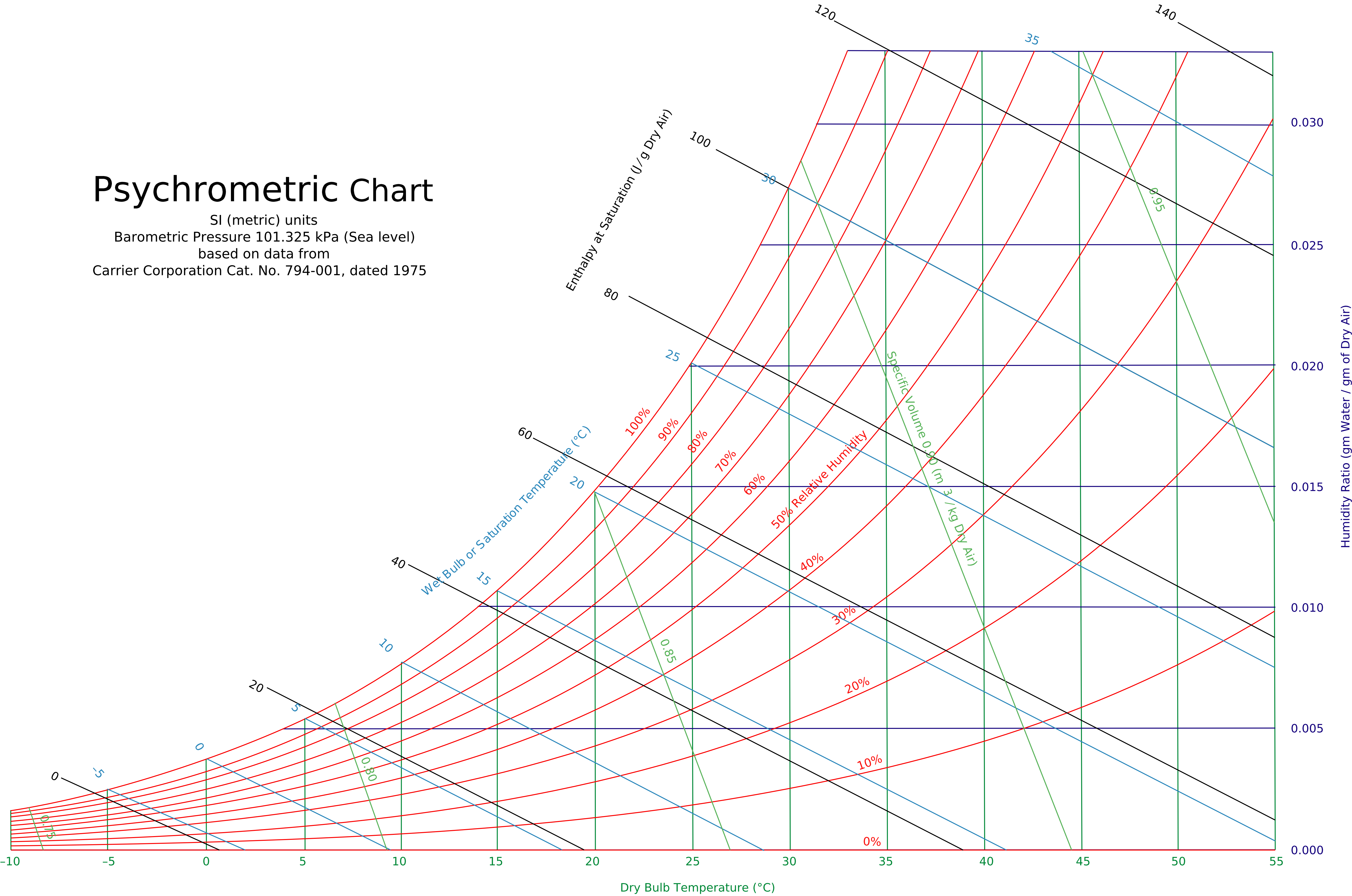
Psychrometric Chart
SI (metric) units
Barometric Pressure 101.325 kPa (Sea level)
based on data from
Carrier Corporation Cat. No. 794-001, dated 1975
Enthalpy at Saturation (J / g Dry Air)
Wet Bulb or Saturation Temperature (°C)
Relative Humidity
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Specific Volume (m 3 /kg Dry Air)
0.75
0.80
0.85
0.90
0.95
Humidity Ratio (gm Water / gm of Dry Air)
0.000
0.005
0.010
0.015
0.020
0.025
0.030
Dry Bulb Temperature (°C)
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
0
20
40
60
80
100
120
140

TABLE V

Conversion Factors

Force

1 newton	=	1 kg-m/sec^2
	=	0.012 kgf
1 kgf	=	9.81 N

Pressure

1 bar	=	750.06 mm Hg
	=	0.9869 atm
	=	10^5 N/m^2
	=	10^3 kg/m-sec^2
1 N/m^2	=	1 pascal
	=	10^{-5} bar
	=	10^{-2} kg/m-sec^2
1 atm	=	760 mm Hg
	=	1.03 kgf/cm^2 = 1.01325 bar
	=	1.01325×10^5 N/m^2

Work, Energy or Heat

1 joule	=	1 newton metre
	=	1 watt-sec
	=	2.7778×10^{-7} kWh
	=	0.239 cal
	=	0.239×10^{-3} kcal
1 cal	=	4.184 joule
	=	1.1622×10^{-6} kWh
1 kcal	=	4.184×10^3 joule
	=	427 kgfm
	=	1.1622×10^{-3} kWh
1 kWh	=	8.6×10^5 cal
	=	860 kcal
	=	3.6×10^6 joule
1 kgfm	=	$\left(\frac{1}{427}\right)$ kcal = 9.81 joules

Power

1 watt	=	1 joule/sec = 0.86 kcal/h
1 h.p.	=	75 mkgf/sec = 0.1757 kcal/sec
	=	735.3 watt
1 kW	=	1000 watts
	=	860 kcal/h

Specific heat

1 kcal/kg - °K	=	4.18 kJ/kg-K

Thermal conductivity

1 watt/m-K	=	0.8598 kcal/h-m-°C
1 kcal/h-m-°C	=	1.16123 watt/m-K
	=	1.16123 joules/s-m-K

Heat transfer co-efficient

1 watt/m^2-K	=	0.86 kcal/m^2-h-°C
1 kcal/m^2-h-°C	=	1.163 watt/m^2-K

IMPORTANT ENGINEERING CONSTANTS AND EXPRESSIONS IN SI UNITS

	Engineering constants and expressions	*M.K.S. system*	*S.I. units*
1.	Value of g_0	9.81 kg-m/kgf-sec^2	1 kg-m/N-sec^2
2.	Universal gas constant	848 kgf-m/kg mole-°K	848 × 9.81 = 8314 J/kg-mole-°K (∵ 1 kgf-m = 9.81 joules)
3.	Gas constant (R)	29.27 kgf m/kg-°K for air	$\frac{8314}{29}$ = 287 joules/kg-K for air
4.	Specific heats (for air)	c_v = 0.17 kcal/kg-°K c_p = 0.24 kcal/kg-°K	c_v = 0.17 × 4.184 = 0.71128 kJ/kg-K c_p = 0.24 × 4.184 = 1 kJ/kg-K
5.	Flow through nozzle-exit velocity (C_2)	91.5 $\sqrt{U}$ where U is in kcal	44.7 $\sqrt{U}$ where U is in kJ
6.	Refrigeration 1 ton	= 50 kcal/min	= 210 kJ/min
7.	**Heat transfer** The Stefan Boltzman Law is given by :	Q = σT^4 kcal/m^2-h when $\sigma = 4.9 \times 10^{-8}$ kcal/h-m^2-°K^4	Q = σT^4 watts/m^2-h when $\sigma = 5.67 \times 10^{-8}$ W/m^2K^4

TABLE II

Saturated Water and Steam (Pressure) Tables

Absolute pressure (bar)	*Temp. (°C)*	*Specific enthalpy (kJ/kg)*			*Specific entropy (kJ/kg K)*			*Specific volume (m^3/kg)*	
p	t_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
0.006113	0.01	0.01	2 501.3	2 501.4	0.000	9.156	9.156	0.0010002	206.14
0.010	7.0	29.3	2 484.9	2 514.2	0.106	8.870	8.976	0.0010000	129.21
0.015	13.0	54.7	2 470.6	2 525.3	0.196	8.632	8.828	0.0010007	87.98
0.020	17.0	73.5	2 460.0	2 533.5	0.261	8.463	8.724	0.001001	67.00
0.025	21.1	88.5	2 451.6	2 540.1	0.312	8.331	8.643	0.001002	54.25
0.030	24.1	101.0	2 444.5	2 545.5	0.355	8.223	8.578	0.001003	45.67
0.035	26.7	111.9	2 438.4	2 550.3	0.391	8.132	8.523	0.001003	39.50
0.040	29.0	121.5	2 432.9	2 554.4	0.423	8.052	8.475	0.001004	34.80
0.045	31.0	130.0	2 428.2	2 558.2	0.451	7.982	8.433	0.001005	31.13
0.050	32.9	137.8	2 423.7	2 561.5	0.476	7.919	8.395	0.001005	28.19
0.055	34.6	144.9	2 419.6	2 565.5	0.500	7.861	8.361	0.001006	25.77
0.060	36.2	151.5	2 415.9	2 567.4	0.521	7.809	8.330	0.001006	23.74
0.065	37.6	157.7	2 412.4	2 570.1	0.541	7.761	8.302	0.001007	22.01
0.070	39.0	163.4	2 409.1	2 572.5	0.559	7.717	8.276	0.001007	20.53
0.075	40.3	168.8	2 406.0	2 574.8	0.576	7.675	8.251	0.001008	19.24
0.080	41.5	173.9	2 403.1	2 577.0	0.593	7.636	8.229	0.001008	18.10
0.085	42.7	178.7	2 400.3	2 579.0	0.608	7.599	8.207	0.001009	17.10
0.090	43.8	183.3	2 397.7	2 581.0	0.622	7.565	8.187	0.001009	16.20
0.095	44.8	187.7	2 395.2	2 582.9	0.636	7.532	8.168	0.001010	15.40
0.10	45.8	191.8	2 392.8	2 584.7	0.649	7.501	8.150	0.001010	14.67
0.11	47.7	199.7	2 388.3	2 588.0	0.674	7.453	8.117	0.001011	13.42
0.12	49.4	206.9	2 384.2	2 591.1	0.696	7.390	8.086	0.001012	12.36
0.13	51.0	213.7	2 380.2	2 593.9	0.717	7.341	8.058	0.001013	11.47
0.14	52.6	220.0	2 376.6	2 596.6	0.737	7.296	8.033	0.001013	10.69
0.15	54.0	226.0	2 373.2	2 599.2	0.754 9	7.254 4	8.009 3	0.001014	10.022
0.16	55.3	231.6	2 370.0	2 601.6	0.772 1	7.214 8	7.986 9	0.001015	9.433
0.17	56.6	236.9	2 366.9	2 603.8	0.788 3	7.177 5	7.965 8	0.001015	8.911
0.18	57.8	242.0	2 363.9	2 605.9	0.803 6	7.142 4	7.945 9	0.001016	8.445
0.19	59.0	246.8	2 361.1	2 607.9	0.818 2	7.109 0	7.927 2	0.001017	8.027
0.20	60.1	251.5	2 358.4	2 609.9	0.832 1	7.077 3	7.909 4	0.001017	7.650
0.21	61.1	255.9	2 355.8	2 611.7	0.845 3	7.047 2	7.892 5	0.001018	7.307
0.22	62.2	260.1	2 353.3	2 613.5	0.858 1	7.018 4	7.876 4	0.001018	6.995
0.23	63.1	264.2	2 350.9	2 615.2	0.870 2	6.990 8	7.861 1	0.001019	6.709
0.24	64.1	268.2	2 348.6	2 616.8	0.882 0	6.964 4	7.846 4	0.001019	6.447

Absolute pressure (bar)	*Temp. (°C)*	*Specific enthalpy (kJ/kg)*			*Specific entropy (kJ/kg K)*			*Specific volume (m^3/kg)*	
p	t_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
0.25	65.0	272.0	2 346.4	2 618.3	0.893 2	6.939 1	7.832 3	0.001020	6.205
0.26	65.9	275.7	2 344.2	2 619.9	0.904 1	6.914 7	7.818 8	0.001020	5.980
0.27	66.7	279.2	2 342.1	2 621.3	0.914 6	6.891 2	7.805 8	0.001021	5.772
0.28	67.5	282.7	2 340.0	2 622.7	0.924 8	6.868 5	7.793 3	0.001021	5.579
0.29	68.3	286.0	2 338.1	2 624.1	0.934 6	6.846 6	7.781 2	0.001022	5.398
0.30	69.1	289.3	2 336.1	2 625.4	0.944 1	6.825 4	7.769 5	0.001022	5.229
0.32	70.6	295.5	2 332.4	2 628.0	0.962 3	6.785 0	7.747 4	0.001023	4.922
0.34	72.0	301.5	2 328.9	2 630.4	0.979 5	6.747 0	7.726 5	0.001024	4.650
0.36	73.4	307.1	2 325.5	2 632.6	0.995 8	6.711 1	7.707 0	0.001025	4.408
0.38	74.7	312.5	2 322.3	2 634.8	1.011 3	6.677 1	7.688 4	0.001026	4.190
0.40	75.9	317.7	2 319.2	2 636.9	1.026 1	6.644 8	7.670 9	0.001026	3.993
0.42	77.1	322.6	2 316.3	2 638.9	1.040 2	6.614 0	7.654 2	0.001027	3.815
0.44	78.2	327.3	2 313.4	2 640.7	1.053 7	6.584 6	7.638 3	0.001028	3.652
0.46	79.3	331.9	2 310.7	2 642.6	1.066 7	6.556 4	7.623 1	0.001029	3.503
0.48	80.3	336.3	2 308.0	2 644.3	1.079 2	6.529 4	7.608 6	0.001029	3.367
0.50	81.3	340.6	2 305.4	2 646.0	1.091 2	6.503 5	7.594 7	0.001030	3.240
0.55	83.7	350.6	2 299.3	2 649.9	1.119 4	6.442 8	7.562 3	0.001032	2.964
0.60	86.0	359.9	2 293.6	2 653.6	1.145 4	6.387 3	7.532 7	0.001033	2.732
0.65	88.0	368.6	2 288.3	2 656.9	1.169 6	6.336 0	7.505 5	0.001035	2.535
0.70	90.0	376.8	2 283.3	2 660.1	1.192 1	6.288 3	7.480 4	0.001036	2.369
0.75	92.0	384.5	2 278.6	2 663.0	1.213 1	6.243 9	7.457 0	0.001037	2.217
0.80	93.5	391.7	2 274.0	2 665.8	1.233 0	6.202 2	7.435 2	0.001039	2.087
0.85	95.1	398.6	2 269.8	2 668.4	1.251 8	3.162 9	7.414 7	0.001040	1.972
0.90	96.7	405.2	2 265.6	2 670.9	1.269 6	6.125 8	7.395 4	0.001041	1.869
0.95	98.2	411.5	2 261.7	2 673.2	1.286 5	6.090 6	7.377 1	0.001042	1.777
1.0	99.6	417.5	2 257.9	2 675.4	1.302 7	6.057 1	7.359 8	0.001043	1.694
1.1	102.3	428.8	2 250.8	2 679.6	1.333 0	5.994 7	7.327 7	0.001046	1.549
1.2	104.8	439.4	2 244.1	2 683.4	1.360 9	5.937 5	7.298 4	0.001048	1.428
1.3	107.1	449.2	2 237.8	2 687.0	1.386 8	5.884 7	7.271 5	0.001050	1.325
1.4	109.3	458.4	2 231.9	2 690.3	1.410 9	5.835 6	7.246 5	0.001051	1.236
1.5	111.3	467.1	2 226.2	2 693.4	1.433 6	5.789 8	7.233 4	0.001053	1.159
1.6	113.3	475.4	2 220.9	2 696.2	1.455 0	5.746 7	7.201 7	0.001055	1.091
1.7	115.2	483.2	2 215.7	2 699.0	1.475 2	5.706 1	7.181 3	0.001056	1.031
1.8	116.9	490.7	2 210.8	2 701.5	1.494 4	5.667 8	7.162 2	0.001058	0.977
1.9	118.6	497.8	2 206.1	2 704.0	1.512 7	5.631 4	7.144 0	0.001060	0.929

Absolute pressure (bar) p	*Temp. (°C)* t_s	*Specific enthalpy (kJ/kg)* h_f	h_{fg}	h_g	*Specific entropy (kJ/kg K)* s_f	s_{fg}	s_g	*Specific volume* (m^3/kg) v_f	v_g
2.0	120.2	504.7	2 201.6	2 706.3	1.530 1	5.596 7	7.126 8	0.001061	0.885
2.1	121.8	511.3	2 197.2	2 708.5	1.546 8	5.563 7	7.110 5	0.001062	0.846
2.2	123.3	517.6	2 193.0	2 710.6	1.562 7	5.532 1	7.094 9	0.001064	0.810
2.3	124.7	523.7	2 188.9	2 712.6	1.578 1	5.501 9	7.080 0	0.001065	0.777
2.4	126.1	529.6	2 184.9	2 714.5	1.592 9	5.472 8	7.065 7	0.001066	0.746
2.5	127.4	535.3	2 181.0	2 716.4	1.607 1	5.444 9	7.052 0	0.001068	0.718
2.6	128.7	540.9	2 177.3	2 718.2	1.620 9	5.418 0	7.038 9	0.001069	0.693
2.7	129.9	546.2	2 173.6	2 719.9	1.634 2	5.392 0	7.026 2	0.001070	0.668
2.8	131.2	551.4	2 170.1	2 721.5	1.647 1	5.367 0	7.014 0	0.001071	0.646
2.9	132.4	556.5	2 166.6	2 723.1	1.659 5	5.342 7	7.002 3	0.001072	0.625
3.0	133.5	561.4	2 163.2	2 724.7	1.671 6	5.319 3	6.990 9	0.001074	0.606
3.1	134.6	566.2	2 159.9	2 726.1	1.683 4	5.296 5	6.979 9	0.001075	0.587
3.2	135.7	570.9	2 156.7	2 727.6	1.694 8	5.274 4	6.969 2	0.001076	0.570
3.3	136.8	575.5	2 153.5	2 729.0	1.705 9	5.253 0	6.958 9	0.001077	0.554
3.4	137.8	579.9	2 150.4	2 730.3	1.716 8	5.232 2	6.948 9	0.001078	0.538
3.5	138.8	584.3	2 147.4	2 731.6	1.727 3	5.211 9	6.939 2	0.001079	0.524
3.6	139.8	588.5	2 144.4	2 732.9	1.737 6	5.192 1	6.929 7	0.001080	0.510
3.7	140.8	592.7	2 141.4	2 734.1	1.747 6	5.172 9	6.920 5	0.001081	0.497
3.8	141.8	596.8	2 138.6	2 735.3	1.757 4	5.154 1	6.911 6	0.001082	0.486
3.9	142.7	600.8	2 135.7	2 736.5	1.767 0	5.135 8	6.902 8	0.001083	0.473
4.0	143.6	604.7	2 133.0	2 737.6	1.776 4	5.117 9	6.894 3	0.001084	0.462
4.2	145.4	612.3	2 127.5	2 739.8	1.794 5	5.083 4	6.877 9	0.001086	0.441
4.4	147.1	619.6	2 122.3	2 741.9	1.812 0	5.050 3	6.862 3	0.001088	0.423
4.6	148.7	626.7	2 117.2	2 743.9	1.828 7	5.018 6	6.847 3	0.001089	0.405
4.8	150.3	633.5	2 112.2	2 745.7	1.844 8	4.988 1	6.832 9	0.001091	0.390
5.0	151.8	640.1	2 107.4	2 747.5	1.860 4	4.958 8	6.819 2	0.001093	0.375
5.2	153.3	646.5	2 102.7	2 749.3	1.875 4	4.930 6	6.805 9	0.001094	0.361
5.4	154.7	652.8	2 098.1	2 750.9	1.889 9	4.903 3	6.793 2	0.001096	0.348
5.6	156.2	658.8	2 093.7	2 752.5	1.904 0	4.876 9	6.780 9	0.001098	0.337
5.8	157.5	664.7	2 089.3	2 754.0	1.917 6	4.851 4	6.769 0	0.001099	0.326
6.0	158.8	670.4	2 085.0	2 755.5	1.930 8	4.826 7	6.757 5	0.001101	0.315
6.2	160.1	676.0	2 080.9	2 756.9	1.943 7	4.802 7	6.746 4	0.001102	0.306
6.4	161.4	681.5	2 076.8	2 758.2	1.956 2	4.779 4	6.735 6	0.001104	0.297
6.6	162.6	686.8	2 072.7	2 759.5	1.968 4	4.756 8	6.725 2	0.001105	0.288
6.8	163.8	692.0	2 068.8	2 760.8	1.980 2	4.734 8	6.715 0	0.001107	0.280

Absolute pressure (bar)	*Temp. (°C)*	*Specific enthalpy (kJ/kg)*			*Specific entropy (kJ/kg K)*			*Specific volume (m^3/kg)*	
p	t_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
7.0	165.0	697.1	2 064.9	2 762.0	1.991 8	4.713 4	6.705 2	0.001108	0.273
7.2	166.1	702.0	2 061.1	2 763.2	2.003 1	4.692 5	6.695 6	0.001110	0.265
7.4	167.2	706.9	2 057.4	2 764.3	2.014 1	4.672 1	6.686 2	0.001111	0.258
7.6	168.3	711.7	2 053.7	2 765.4	2.024 9	4.652 2	6.677 1	0.001112	0.252
7.8	169.4	716.3	2 050.1	2 766.4	2.035 4	4.632 8	6.668 3	0.001114	0.246
8.0	170.4	720.9	2 046.5	2 767.5	2.045 7	4.613 9	6.659 6	0.001115	0.240
8.2	171.4	725.4	2 043.0	2 768.5	2.055 8	4.595 3	6.651 1	0.001116	0.235
8.4	172.4	729.9	2 039.6	2 769.4	2.065 7	4.577 2	6.642 9	0.001118	0.229
8.6	173.4	734.2	2 036.2	2 770.4	2.075 3	4.559 4	6.634 8	0.001119	0.224
8.8	174.4	738.5	2 032.8	2 771.3	2.084 8	4.542 1	6.626 9	0.001120	0.219
9.0	175.4	742.6	2 029.5	2 772.1	2.094 1	4.525 0	6.619 2	0.001121	0.215
9.2	176.3	746.8	2 026.2	2 773.0	2.103 3	4.508 3	6.611 6	0.001123	0.210
9.4	177.2	750.8	2 023.0	2 773.8	2.112 2	4.492 0	6.604 2	0.001124	0.206
9.6	178.1	754.8	2 019.8	2 774.6	2.121 0	4.475 9	6.596 9	0.001125	0.202
9.8	179.0	758.7	2 016.7	2 775.4	2.129 7	4.460 1	6.589 8	0.001126	0.198
10.0	179.9	762.6	2 013.6	2 776.2	2.138 2	4.444 6	6.582 8	0.001127	0.194
10.5	182.0	772.0	2 005.9	2 778.0	2.158 8	4.407 1	6.565 9	0.001130	0.185
11.0	184.1	781.1	1 998.5	2 779.7	2.178 6	4.371 1	6.549 7	0.001133	0.177
11.5	186.0	789.9	1 991.3	2 781.3	2.197 7	4.336 6	6.534 2	0.001136	0.170
12.0	188.0	798.4	1 984.3	2 782.7	2.216 1	4.303 3	6.519 4	0.001139	0.163
12.5	189.8	806.7	1 977.4	2 784.1	2.233 8	4.271 2	6.505 0	0.001141	0.157
13.0	191.6	814.7	1 970.7	2 785.4	2.251 0	4.240 3	6.491 3	0.001144	0.151
13.5	193.3	822.5	1 964.2	2 786.6	2.267 6	4.210 4	6.477 9	0.001146	0.146
14.0	195.0	830.1	1 957.7	2 787.8	2.283 7	4.181 4	6.465 1	0.001149	0.141
14.5	196.7	837.5	1 951.4	2 788.9	2.299 3	4.153 3	6.452 6	0.001151	0.136
15.0	198.3	844.7	1 945.2	2 789.9	2.314 5	4.126 1	6.440 6	0.001154	0.132
15.5	199.8	851.7	1 939.2	2 790.8	2.329 2	4.099 6	6.428 9	0.001156	0.128
16.0	201.4	858.6	1 933.2	2 791.7	2.343 6	4.073 9	6.417 5	0.001159	0.124
16.5	202.8	865.3	1 927.3	2 792.6	2.357 6	4.048 9	6.406 5	0.001161	0.120
17.0	204.3	871.8	1 921.5	2 793.4	2.371 3	4.024 5	6.395 7	0.001163	0.117
17.5	205.7	878.3	1 915.9	2 794.1	2.384 6	4.000 7	6.385 3	0.001166	0.113
18.0	207.1	884.6	1 910.3	2 794.8	2.397 6	3.977 5	6.375 1	0.001168	0.110
18.5	208.4	890.7	1 904.7	2 795.5	2.410 3	3.954 8	6.365 1	0.001170	0.107
19.0	209.8	896.8	1 899.3	2 796.1	2.422 8	3.932 6	6.355 4	0.001172	0.105
19.5	211.1	902.8	1 893.9	2 796.7	2.434 9	3.911 0	6.345 9	0.001174	0.102

Absolute pressure (bar)	*Temp. (°C)*	*Specific enthalpy (kJ/kg)*			*Specific entropy (kJ/kg K)*			*Specific volume (m^3/kg)*	
p	t_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
20.0	212.4	908.6	1 888.6	2 797.2	2.446 9	3.889 8	6.336 6	0.001177	0.0995
20.5	213.6	914.3	1 883.4	2 797.7	2.458 5	3.869 0	6.327 6	0.001179	0.0971
21.0	214.8	920.0	1 878.2	2 798.2	2.470 0	3.848 7	6.318 7	0.001181	0.0949
21.5	216.1	925.5	1 873.1	2 798.6	2.481 2	3.828 8	6.310 0	0.001183	0.0927
22.0	217.2	931.0	1 868.1	2 799.1	2.492 2	3.809 3	6.301 5	0.001185	0.0907
22.5	218.4	936.3	1 863.1	2 799.4	2.503 0	3.790 1	6.293 1	0.001187	0.0887
23.0	219.5	941.6	1 858.2	2 799.8	2.513 6	3.771 3	6.284 9	0.001189	0.0868
23.5	220.7	946.8	1 853.3	2 800.1	2.524 1	3.752 8	6.276 9	0.001191	0.0849
24.0	221.8	951.9	1 848.5	2 800.4	2.534 3	3.734 7	6.269 0	0.001193	0.0832
24.5	222.9	957.0	1 843.7	2 800.7	2.544 4	3.716 8	6.261 2	0.001195	0.0815
25.0	223.9	962.0	1 839.0	2 800.9	2.554 3	3.699 3	6.253 6	0.001197	0.0799
25.5	225.0	966.9	1 834.3	2 801.2	2.564 0	3.682 1	6.246 1	0.001199	0.0783
26.0	226.0	971.7	1 829.6	2 801.4	2.573 6	3.665 1	6.238 7	0.001201	0.0769
26.5	227.1	976.5	1 825.1	2 801.6	2.583 1	3.648 4	6.231 5	0.001203	0.0754
27.0	228.1	981.2	1 820.5	2 801.7	2.592 4	3.632 0	6.224 4	0.001205	0.0740
27.5	229.1	985.9	1 816.0	2 801.9	2.601 6	3.615 8	6.217 3	0.001207	0.0727
28.0	230.0	990.5	1 811.5	2 802.0	2.610 6	3.599 8	6.210 4	0.001209	0.0714
28.5	231.0	995.0	1 807.1	2 802.1	2.619 5	3.584 1	6.203 6	0.001211	0.0701
29.0	232.0	999.5	1 802.6	2 802.2	2.628 3	3.568 6	6.196 9	0.001213	0.0689
29.5	233.0	1 004.0	1 798.3	2 802.2	2.637 0	3.553 3	6.190 2	0.001214	0.0677
30.0	233.8	1 008.4	1 793.9	2 802.3	2.645 5	3.538 2	6.183 7	0.001216	0.0666
30.5	234.7	1 012.7	1 789.6	2 802.3	2.653 9	3.523 3	6.177 2	0.001218	0.0655
31.0	235.6	1 017.0	1 785.4	2 802.3	2.662 3	3.508 7	6.170 9	0.001220	0.0645
31.5	236.5	1 021.2	1 781.1	2 802.3	2.670 5	3.494 2	6.164 7	0.001222	0.0634
32.0	237.4	1 025.4	1 776.9	2 802.3	2.678 6	3.479 9	6.158 5	0.001224	0.0624
32.5	238.3	1 029.6	1 772.7	2 802.3	2.686 6	3.465 7	6.152 3	0.001225	0.0615
33.0	239.2	1 033.7	1 768.6	2 802.3	2.694 5	3.451 8	6.146 3	0.001227	0.0605
33.5	240.0	1 037.8	1 764.4	2 802.2	2.702 3	3.438 0	6.140 3	0.001229	0.0596
34.0	240.9	1 041.8	1 760.3	2 802.1	2.710 1	3.424 4	6.134 4	0.001231	0.0587
34.5	241.7	1 045.8	1 756.3	2 802.1	2.717 7	3.410 9	6.128 6	0.001233	0.0579
35.0	242.5	1 049.8	1 752.2	2 802.0	2.725 3	3.397 6	6.122 8	0.001234	0.0570
35.5	243.3	1 053.7	1 748.2	2 801.8	2.732 7	3.384 4	6.117 1	0.001236	0.0562
36.0	244.2	1 057.6	1 744.2	2 801.7	2.740 1	3.371 4	6.111 5	0.001238	0.0554
36.5	245.0	1 061.4	1 740.2	2 801.6	2.747 4	3.358 5	6.105 9	0.001239	0.0546
37.0	245.7	1 065.2	1 736.2	2 801.4	2.754 7	3.345 8	6.100 4	0.001242	0.0539

Absolute pressure (bar)	Temp. (°C)	Specific enthalpy (kJ/kg)			Specific entropy (kJ/kg K)			Specific volume (m^3/kg)	
p	t_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
37.5	246.5	1 069.0	1 732.3	2 801.3	2.761 8	3.333 2	6.095 0	0.001243	0.0531
38.0	247.3	1 072.7	1 728.4	2 801.1	2.768 9	3.320 7	6.089 6	0.001245	0.0524
38.5	248.1	1 076.4	1 724.5	2 800.9	2.775 9	3.308 3	6.084 2	0.001247	0.0517
39.0	248.8	1 080.1	1 720.6	2 800.8	2.782 9	3.296 1	6.078 9	0.001249	0.0511
39.5	249.6	1 083.8	1 716.8	2 800.5	2.789 7	3.284 0	6.073 7	0.001250	0.0504
40.0	250.3	1 087.4	1 712.9	2 800.3	2.796 5	3.272 0	6.068 5	0.001252	0.0497
41.0	251.8	1 094.6	1 705.3	2 799.9	2.809 9	3.248 3	6.058 2	0.001255	0.0485
42.0	253.2	1 101.6	1 697.8	2 799.4	2.823 1	3.225 1	6.048 2	0.001259	0.0473
43.0	254.6	1 108.5	1 690.3	2 798.8	2.836 0	3.202 3	6.038 3	0.001262	0.0461
44.0	256.0	1 115.4	1 682.9	2 798.3	2.848 7	3.179 9	6.028 6	0.001266	0.0451
45.0	257.4	1 122.1	1 675.6	2 797.7	2.861 2	3.157 9	6.019 1	0.001269	0.0440
46.0	258.7	1 128.8	1 668.3	2 797.0	2.873 5	3.136 2	6.009 7	0.001272	0.0430
47.0	260.1	1 135.3	1 661.1	2 796.4	2.885 5	3.114 9	6.000 4	0.001276	0.0421
48.0	261.4	1 141.8	1 653.9	2 795.7	2.897 4	3.093 9	5.991 3	0.001279	0.0412
49.0	262.6	1 148.2	1 646.8	2 794.9	2.909 1	3.073 3	5.982 3	0.001282	0.0403
50.0	263.9	1 154.5	1 639.7	2 794.2	2.920 6	3.052 9	5.973 5	0.001286	0.0394
51.0	265.1	1 160.7	1 632.7	2 793.4	2.931 9	3.032 8	5.964 8	0.001289	0.0386
52.0	266.4	1 166.8	1 625.7	2 792.6	2.943 1	3.013 0	5.956 1	0.001292	0.0378
53.0	267.6	1 172.9	1 618.8	2 791.7	2.954 1	2.993 5	5.947 6	0.001296	0.0371
54.0	268.7	1 178.9	1 611.9	2 790.8	2.965 0	2.974 2	5.939 2	0.001299	0.0363
55.0	269.9	1 184.9	1 605.0	2 789.9	2.975 7	2.955 2	5.930 9	0.001302	0.0356
56.0	271.1	1 190.8	1 598.2	2 789.0	2.986 3	2.936 4	5.922 7	0.001306	0.0349
57.0	272.2	1 196.6	1 591.4	2 788.0	2.996 7	2.917 9	5.914 6	0.001309	0.0343
58.0	273.3	1 202.3	1 584.7	2 787.0	3.007 1	2.899 5	5.906 6	0.001312	0.0336
59.0	274.4	1 208.0	1 578.0	2 786.0	3.017 2	2.881 4	5.898 6	0.001315	0.0330
60.0	275.5	1 213.7	1 571.3	2 785.0	3.027 3	2.863 5	5.890 8	0.001318	0.0324
61.0	276.6	1 219.3	1 564.7	2 784.0	3.037 2	2.845 8	5.883 0	0.001322	0.0319
62.0	277.7	1 224.8	1 558.0	2 782.9	3.047 1	2.828 3	5.875 3	0.001325	0.0313
63.0	278.7	1 230.3	1 551.5	2 781.8	3.056 8	2.810 9	5.867 7	0.001328	0.0308
64.0	279.8	1 235.7	1 544.9	2 780.6	3.066 4	2.793 8	5.860 1	0.001332	0.0302
65.0	280.8	1 241.1	1 538.4	2 779.5	3.075 9	2.776 8	5.852 7	0.001335	0.0297
66.0	281.8	1 246.5	1 531.9	2 778.3	3.085 3	2.760 0	5.845 2	0.001338	0.0292
67.0	282.8	1 251.8	1 525.4	2 777.1	3.094 6	2.743 3	5.837 9	0.001341	0.0287
68.0	283.8	1 257.0	1 518.9	2 775.9	3.103 8	2.726 8	5.830 6	0.001345	0.0283
69.0	284.8	1 262.2	1 512.5	2 774.7	3.112 9	2.710 5	5.823 3	0.001348	0.0278

Absolute pressure (bar) p	Temp. (°C) t_s	Specific enthalpy (kJ/kg) h_f	h_{fg}	h_g	Specific entropy (kJ/kg K) s_f	s_{fg}	s_g	Specific volume (m^3/kg) v_f	v_g
70.0	285.8	1 267.4	1 506.0	2 773.5	3.121 9	2.694 3	5.816 2	0.001351	0.0274
71.0	286.7	1 272.5	1 499.6	2 772.2	3.130 8	2.678 2	5.809 0	0.001355	0.0269
72.0	287.7	1 277.6	1 493.3	2 770.9	3.139 7	2.662 3	5.802 0	0.001358	0.0265
73.0	288.6	1 282.7	1 486.9	2 769.6	3.148 4	2.646 5	5.794 9	0.001361	0.0261
74.0	289.6	1 287.7	1 480.5	2 768.3	3.157 1	2.630 9	5.788 0	0.001364	0.0257
75.0	290.5	1 292.7	1 474.2	2 766.9	3.165 7	2.615 3	5.781 0	0.001368	0.0253
76.0	291.4	1 297.6	1 467.9	2 765.5	3.174 2	2.599 9	5.774 2	0.001371	0.0249
77.0	292.3	1 302.5	1 461.6	2 764.2	3.182 7	2.584 6	5.767 3	0.001374	0.0246
78.0	293.2	1 307.4	1 455.3	2 762.8	3.191 1	2.569 5	5.760 5	0.001378	0.0242
79.0	294.1	1 312.3	1 449.1	2 761.3	3.199 4	2.554 4	5.753 8	0.001381	0.0239
80.0	294.9	1 317.1	1 442.8	2 759.9	3.207 6	2.539 5	5.747 1	0.001384	0.0235
81.0	295.8	1 321.9	1 436.6	2 758.4	3.215 8	2.524 6	5.740 4	0.001387	0.0232
82.0	296.7	1 326.6	1 430.3	2 757.0	3.223 9	2.509 9	5.733 8	0.001391	0.0229
83.0	297.5	1 331.4	1 424.1	2 755.5	3.232 0	2.495 2	5.727 2	0.001394	0.0225
84.0	298.4	1 336.1	1 417.9	2 754.0	3.239 9	2.480 7	5.720 6	0.001397	0.0222
85.0	299.2	1 340.7	1 411.7	2 752.5	3.247 9	2.466 3	5.714 1	0.001401	0.0219
86.0	300.1	1 345.4	1 405.5	2 750.9	3.255 7	2.451 9	5.707 6	0.001404	0.0216
87.0	300.9	1 350.0	1 399.3	2 749.4	3.263 6	2.437 6	5.701 2	0.001408	0.0213
88.0	301.7	1 354.6	1 393.2	2 747.8	3.271 3	2.423 5	5.694 8	0.001411	0.0211
89.0	302.5	1 359.2	1 387.0	2 746.2	3.279 0	2.409 4	5.688 4	0.001414	0.0208
90.0	303.3	1 363.7	1 380.9	2 744.6	3.286 7	2.395 3	5.682 0	0.001418	0.0205
91.0	304.1	1 368.3	1 374.7	2 743.0	3.294 3	2.381 4	5.675 7	0.001421	0.0202
92.0	304.9	1 372.8	1 368.6	2 741.4	3.301 8	2.367 6	5.669 4	0.001425	0.0199
93.0	305.7	1 377.2	1 362.5	2 739.7	3.309 3	2.353 8	5.663 1	0.001428	0.0197
94.0	306.4	1 381.7	1 356.3	2 738.0	3.316 8	2.340 1	5.656 8	0.001432	0.0194
95.0	307.2	1 386.1	1 350.2	2 736.4	3.324 2	2.326 4	5.650 6	0.001435	0.0192
96.0	308.0	1 390.6	1 344.1	2 734.7	3.331 5	2.312 9	5.644 4	0.001438	0.0189
97.0	308.7	1 395.0	1 338.0	2 733.0	3.338 8	2.299 4	5.638 2	0.001442	0.0187
98.0	309.4	1 399.3	1 331.9	2 731.2	3.346 1	2.285 9	5.632 1	0.001445	0.0185
99.0	310.2	1 403.7	1 325.8	2 729.5	3.353 4	2.272 6	5.625 9	0.001449	0.0183
100.0	311.1	1 408.0	1 319.7	2 727.7	3.360 5	2.259 3	5.619 8	0.001452	0.0181
102.0	312.4	1 416.7	1 307.5	2 724.2	3.374 8	2.232 8	5.607 6	0.001459	0.0176
104.0	313.8	1 425.2	1 295.3	2 720.5	3.388 9	2.206 6	5.595 5	0.001467	0.0172
106.0	315.3	1 433.7	1 283.1	2 716.8	3.402 9	2.180 6	5.583 5	0.001474	0.0168
108.0	316.6	1 442.2	1 270.9	2 713.1	3.416 7	2.154 8	5.571 5	0.001481	0.0164

Absolute pressure (bar) p	Temp. (°C) t_s	Specific enthalpy (kJ/kg) h_f	h_{fg}	h_g	Specific entropy (kJ/kg K) s_f	s_{fg}	s_g	Specific volume (m^3/kg) v_f	v_g
110.0	318.0	1 450.6	1 258.7	2 709.3	3.430 4	2.129 1	5.559 5	0.001488	0.0160
112.0	319.4	1 458.9	1 246.5	2 705.4	3.444 0	2.103 6	5.547 6	0.001496	0.0157
114.0	320.7	1 467.2	1 234.3	2 701.5	3.457 4	2.078 3	5.535 7	0.001504	0.0153
116.0	322.1	1 475.4	1 222.0	2 697.4	3.470 8	2.053 1	5.523 9	0.001511	0.0149
118.0	323.4	1 483.6	1 209.7	2 693.3	3.484 0	2.028 0	5.512 1	0.001519	0.0146
120.0	324.6	1 491.8	1 197.4	2 689.2	3.497 2	2.003 0	5.500 2	0.001527	0.0143
122.0	325.9	1 499.9	1 185.0	2 684.9	3.510 2	1.978 2	5.488 4	0.001535	0.0139
124.0	327.1	1 508.0	1 172.6	2 680.6	3.523 2	1.953 3	5.476 5	0.001543	0.0137
126.0	328.4	1 516.0	1 160.1	2 676.1	3.536 0	1.928 6	5.464 6	0.001551	0.0134
128.0	329.6	1 524.0	1 147.6	2 671.6	3.548 8	1.903 9	5.452 7	0.001559	0.0131
130.0	330.8	1 532.0	1 135.0	2 667.0	3.561 6	1.879 2	5.440 8	0.001567	0.0128
132.0	332.0	1 540.0	1 122.3	2 662.3	3.574 2	1.854 6	5.428 8	0.001576	0.0125
134.0	333.2	1 547.9	1 109.5	2 657.4	3.586 8	1.830 0	5.416 8	0.001584	0.0123
136.0	334.3	1 555.8	1 096.7	2 652.5	3.599 3	1.805 3	5.404 7	0.001593	0.0120
138.0	335.5	1 563.7	1 083.8	2 647.5	3.611 8	1.780 7	5.392 5	0.001602	0.0117
140.0	336.6	1 571.6	1 070.7	2 642.4	3.624 2	1.756 0	5.380 3	0.001611	0.0115
142.0	337.7	1 579.5	1 057.6	2 637.1	3.636 6	1.731 3	5.367 9	0.001619	0.0112
144.0	338.8	1 587.4	1 044.4	2 631.8	3.649 0	1.706 6	5.355 5	0.001629	0.0110
146.0	339.9	1 595.3	1 031.0	2 626.3	3.661 3	1.681 8	5.343 1	0.001638	0.0108
148.0	341.1	1 603.1	1 017.6	2 620.7	3.673 6	1.656 9	5.330 5	0.001648	0.0106
150.0	342.1	1 611.0	1 004.0	2 615.0	3.685 9	1.632 0	5.317 9	0.001658	0.0103
152.0	343.2	1 618.9	990.3	2 609.2	3.698 1	1.607 0	5.305 1	0.001668	0.0101
154.0	344.2	1 626.8	976.5	2 603.3	3.710 3	1.581 9	5.292 2	0.001678	0.00991
156.0	345.3	1 634.7	962.6	2 597.3	3.722 6	1.556 7	5.279 3	0.001689	0.00971
158.0	346.3	1 642.6	948.5	2 591.1	3.734 8	1.531 4	5.266 3	0.001699	0.00951
160.0	347.3	1 650.5	934.3	2 584.9	3.747 1	1.506 0	5.253 1	0.001710	0.00931
162.0	348.3	1 658.5	920.0	2 578.5	3.759 4	1.480 6	5.239 9	0.001721	0.00911
164.0	349.3	1 666.5	905.6	2 572.1	3.771 7	1.455 0	5.226 7	0.001733	0.00893
166.0	350.3	1 674.5	891.0	2 565.5	3.784 2	1.429 0	5.213 2	0.001745	0.00874
168.0	351.3	1 683.0	875.6	2 558.6	3.797 4	1.402 1	5.199 4	0.001757	0.00855
170.0	352.3	1 691.7	859.9	2 551.6	3.810 7	1.374 8	5.185 5	0.001769	0.00837
172.0	353.2	1 700.4	844.0	2 544.4	3.824 0	1.347 3	5.171 3	0.001783	0.00819
174.0	354.2	1 709.0	828.1	2 537.1	3.837 2	1.319 8	5.157 0	0.001796	0.00801
176.0	355.1	1 717.6	811.9	2 529.5	3.850 4	1.292 2	5.142 5	0.001810	0.00784
178.0	356.0	1 726.2	795.6	2 521.8	3.863 5	1.264 3	5.127 8	0.001825	0.00767

Absolute pressure (bar)	Temp. (°C)	Specific enthalpy (kJ/kg)			Specific entropy (kJ/kg K)			Specific volume (m^3/kg)	
p	t_s	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	v_f	v_g
180.0	356.9	1 734.8	779.1	2 513.9	3.876 5	1.236 2	5.112 8	0.001840	0.00750
182.0	357.8	1 743.4	762.3	2 505.8	3.889 6	1.207 9	5.097 5	0.001856	0.00733
184.0	358.7	1 752.1	745.3	2 497.4	3.902 8	1.179 2	5.082 0	0.001872	0.00717
186.0	359.6	1 760.9	727.9	2 488.8	3.916 0	1.150 1	5.066 1	0.001889	0.00701
188.0	360.5	1 769.7	710.1	2 479.8	3.929 4	1.120 5	5.049 8	0.001907	0.00684
190.0	361.4	1 778.7	692.0	2 470.6	3.942 9	1.090 3	5.033 2	0.001926	0.00668
192.0	362.3	1 787.8	673.3	2 461.1	3.956 6	1.059 4	5.016 0	0.001946	0.00652
194.0	363.2	1 797.0	654.1	2 451.1	3.970 6	1.027 8	4.998 3	0.001967	0.00636
196.0	364.0	1 806.6	634.2	2 440.7	3.984 9	0.995 1	4.980 0	0.001989	0.00620
198.0	364.8	1 816.3	613.5	2 429.8	3.999 6	0.961 4	4.961 1	0.002012	0.00604
200.0	365.7	1 826.5	591.9	2 418.4	4.014 9	0.926 3	4.941 2	0.002037	0.00588
202.0	366.5	1 837.0	569.2	2 406.2	4.030 8	0.889 7	4.920 4	0.002064	0.00571
204.0	367.3	1 848.1	545.1	2 393.3	4.047 4	0.851 0	4.898 4	0.002093	0.00555
206.0	368.2	1 859.9	519.5	2 379.4	4.065 1	0.809 9	4.875 0	0.002125	0.00538
208.0	368.9	1 872.5	491.7	2 364.2	4.084 1	0.765 7	4.849 8	0.002161	0.00521
210.0	369.8	1 886.3	461.3	2 347.6	4.104 8	0.717 5	4.822 3	0.002201	0.00502
212.0	370.6	1 901.5	427.4	2 328.9	4.127 9	0.663 9	4.791 7	0.002249	0.00483
214.0	371.3	1 919.0	388.4	2 307.4	4.154 3	0.602 6	4.756 9	0.002306	0.00462
216.0	372.1	1 939.9	341.6	2 281.6	4.186 1	0.529 3	4.715 4	0.002379	0.00439
218.0	372.9	1 967.2	280.8	2 248.0	4.227 6	0.434 6	4.662 2	0.002483	0.00412
220.0	373.7	2 011.1	184.5	2 195.6	4.294 7	0.285 2	4.579 9	0.002671	0.00373
221.2	374.1	2 107.4	0.0	2 107.4	4.442 9	0.0	4.442 9	0.003170	0.00317

TABLE III

Superheated Steam at Various Pressures and Temperatures

↓*p* (bar) (t_s)	*t* (°C) →	50	100	150	200	250	300	400	500
	v	149.1	172.2	195.3	218.4	241.5	264.5	310.7	356.8
0.01	*u*	2445.4	2516.4	2588.4	2661.6	2736.9	2812.2	2969.0	3132.4
(7.0)	*h*	2594.5	2688.6	2783.6	2880.0	2978.4	3076.8	3279.7	3489.2
	s	9.242	9.513	9.752	9.967	10.163	10.344	10.671	10.960
	v	29.78	34.42	39.04	48.66	48.28	52.9	62.13	71.36
0.05	*u*	2444.8	2516.2	2588.4	2661.9	2736.6	2812.6	2969.6	3133.0
(32.9)	*h*	2593.7	2688.1	2783.4	2879.9	2977.6	3076.7	3279.7	3489.2
	s	8.498	8.770	9.009	9.225	9.421	9.602	9.928	10.218
	v	14.57	17.19	19.51	21.82	24.14	26.44	31.06	35.68
0.1	*u*	2443.9	2515.5	2587.9	2661.3	2736.0	2812.1	2968.9	3132.3
(45.8)	*h*	2592.6	2687.5	2783.0	2879.5	2977.3	3076.5	3279.6	3489.1
	s	8.175	8.448	8.688	8.904	9.100	9.281	9.608	9.898
	v		34.18	3.889	43.56	4.821	5.284	6.209	7.134
0.5	*u*		2511.6	2585.6	2659.9	2735.0	2811.3	2968.5	3132.0
(81.3)	*h*		2682.5	2780.1	2877.7	2976.0	3075.5	3278.9	3488.7
	s		7.695	7.940	8.158	8.356	8.537	8.864	9.155
	v		2.27	2.587	2.900	3.211	3.520	4.138	4.755
0.75	*u*		2509.2	2584.2	2659.0	2734.4	2810.9	2968.2	3131.8
(92.0)	*h*		2679.4	2778.2	2876.5	2975.2	3074.9	3278.5	3488.4
	s		7.501	7.749	7.969	8.167	8.349	8.677	8.967
	v		1.696	1.936	2.172	2.406	2.639	3.103	3.565
1.0	*u*		2506.2	2582.8	2658.1	2733.7	2810.4	2967.9	3131.6
(99.6)	*h*		2676.2	2776.4	2875.3	2974.3	3074.3	3278.2	3488.1
	s		7.361	7.613	7.834	8.033	8.216	8.544	8.834
	v			1.912	2.146	2.375	2.603	3.062	3.519
1.01325	*u*			2582.6	2658.0	2733.6	2810.3	2967.8	3131.5
(100)	*h*			2776.3	2875.2	2974.2	3074.2	3278.1	3488.0
	s			7.828	7.827	8.027	8.209	8.538	8.828
	v			1.285	1.143	1.601	1.757	2.067	2.376
1.5	*u*			2579.8	2656.2	2732.5	2809.5	2967.3	3131.2
(111.4)	*h*			2772.6	2872.9	2972.7	3073.1	3277.4	3487.6
	s			7.419	7.643	7.844	8.027	8.356	8.647

↓*p (bar)* (t_s)	*t (°C)* →	*50*	*100*	*150*	*200*	*250*	*300*	*400*	*500*
	v			0.960	1.080	1.199	1.316	1.549	1.781
2.0	*u*			2576.9	2654.4	2731.2	2808.6	2966.7	3130.8
(120.2)	*h*			2768.8	2870.5	2971.0	3071.8	3276.6	3487.1
	s			7.279	7.507	7.709	7.893	8.222	8.513
	v			0.764	0.862	0.957	1.052	1.238	1.424
2.5	*u*			2574.7	2655.7	2734.9	2813.8	2973.9	3139.6
(127.4)	*h*			2764.5	2868.0	2969.6	3070.9	3275.9	3486.5
	s			7.169	7.401	7.604	7.789	8.119	8.410
	v			0.634	0.716	0.796	0.875	1.031	1.187
3.0	*u*			2570.8	2650.7	2728.7	2806.7	2965.6	3130.0
(133.5)	*h*			2761.0	2865.6	2967.6	3069.3	3275.0	3486.1
	s			7.078	7.311	7.517	7.702	8.033	8.325
	v			0.471	0.534	0.595	0.655	0.773	0.889
4.0	*u*			2564.5	2646.8	2726.1	2804.8	2964.4	3129.2
(143.6)	*h*			2752.8	2860.5	2964.2	3066.8	3273.4	3484.9
	s			6.930	7.171	7.379	7.566	7.899	8.191

↓*p (bar)* (t_s)	*t (°C)* →	*200*	*250*	*300*	*350*	*400*	*450*	*500*	*600*
	v	0.425	0.474	0.523	0.570	0.617	0.664	0.711	0.804
5.0	*u*	2642.9	2723.5	2802.9	2882.6	2963.2	3045.3	3128.4	3299.6
(151.8)	*h*	2855.4	2960.7	3064.2	3167.7	3271.9	3377.2	3483.9	3701.7
	s	7.059	7.271	7.460	7.633	7.794	7.945	8.087	8.353
	v	0.352	0.394	0.434	0.474	0.514	0.553	0.592	0.670
6.0	*u*	2638.9	2720.9	2801.0	2881.2	2962.1	3044.2	3127.6	3299.1
(158.8)	*h*	2850.1	2957.2	3061.6	3165.7	3270.3	3376.0	3482.8	3700.9
	s	6.967	7.182	7.372	7.546	7.708	7.859	8.002	8.267
	v	0.300	0.336	0.371	0.406	0.440	0.473	0.507	0.574
7.0	*u*	2634.8	2718.2	2799.1	2879.7	2960.9	3043.2	3126.8	3298.5
(165.0)	*h*	2844.8	2953.6	3059.1	3163.7	3268.7	3374.7	3481.7	3700.2
	s	6.886	7.105	7.298	7.473	7.635	7.787	7.930	8.196
	v	0.261	0.293	0.324	0.354	0.384	0.414	0.443	0.502
8.0	*u*	2630.6	2715.5	2797.2	2878.2	2959.7	3042.3	3126.0	3297.8
(170.4)	*h*	2839.3	2950.1	3056.5	3161.7	3267.1	3373.4	3480.6	3699.4
	s	6.816	7.038	7.233	7.409	7.572	7.724	7.867	8.133

↓*p* (bar) (t_s)	*t* (°C) →	200	250	300	350	400	450	500	600
	v	0.230	0.260	0.287	0.314	0.341	0.367	0.394	0.446
9.0	*u*	2626.3	2712.7	2795.2	2876.7	2958.5	3041.3	3125.2	3297.3
(175.4)	*h*	2833.6	2946.3	3053.8	3159.7	3265.5	3372.1	3479.6	3698.6
	s	6.752	6.979	7.175	7.352	7.516	7.668	7.812	8.078
	v	0.206	0.233	0.258	0.282	0.307	0.330	0.354	0.401
10.0	*u*	2621.9	2709.9	2793.2	2875.2	2957.3	3040.3	3124.4	3296.8
(179.9)	*h*	2827.9	2942.6	3051.2	3157.8	3263.9	3370.7	3478.5	3697.9
	s	6.694	6.925	7.123	7.301	7.465	7.618	7.762	8.029
	v	0.132	0.152	0.169	0.187	0.203	0.219	0.235	0.267
15.0	*u*	2598.8	2695.3	2783.1	2867.6	2951.3	3035.3	3120.3	3293.9
(198.3)	*h*	2796.8	2923.3	3037.6	3147.5	3255.8	3364.2	3473.1	3694.0
	s	6.455	6.709	6.918	7.102	7.269	7.424	7.570	7.839
	v		0.111	0.125	0.139	0.151	0.163	0.176	0.200
20.0	*u*		2679.6	2772.6	2859.8	2945.2	3030.5	3116.2	3290.9
(212.4)	*h*		2902.5	3023.5	3137.0	3247.6	3357.5	3467.6	3690.1
	s		6.545	6.766	6.956	7.127	7.285	7.432	7.702
	v		0.0870	0.0989	0.109	0.120	0.130	0.140	0.159
25	*u*		2662.6	2761.6	2851.9	2939.1	3025.5	3112.1	3288.0
(223.9)	*h*		2880.1	3008.8	3126.3	3239.3	3350.8	3462.1	3686.3
	s		6.408	6.644	6.840	7.015	7.175	7.323	7.596
	v		0.0706	0.0811	0.0905	0.0994	0.108	0.116	0.132
30	*u*		2644.0	2750.1	2843.7	2932.8	3020.4	3108.0	3285.0
(233.8)	*h*		2855.8	2993.5	3115.3	3230.9	3344.0	3456.5	3682.3
	s		6.287	6.539	6.743	6.921	7.083	7.234	7.509
	v			0.0588	0.0664	0.0734	0.080	0.0864	0.0989
40	*u*			2725.3	2826.7	2919.9	3010.2	3099.5	3279.1
(250.4)	*h*			2960.7	3092.5	3213.6	3330.3	3445.3	3674.4
	s			6.362	6.582	6.769	6.936	7.090	7.369
	v			0.0453	0.0519	0.0578	0.0633	0.0686	0.0787
50	*u*			2698.0	2808.7	2906.6	2999.7	3091.0	3273.0
(263.9)	*h*			2924.5	3068.4	3195.7	3316.2	3433.8	3666.5
	s			6.208	6.449	6.646	6.819	6.976	7.259

↓p (bar) (t_s)	t (°C) →	200	250	300	350	400	450	500	600
	v			0.0362	0.0422	0.0474	0.0521	0.0567	0.0653
60	u			2667.2	2789.6	2892.9	2988.9	3082.2	3266.9
(275.5)	h			2884.2	3043.0	3177.2	3301.8	3422.2	3658.4
	s			6.067	6.333	6.541	6.719	6.880	7.168
	v			0.0295	0.0352	0.0399	0.0442	0.0481	0.0557
70	u			2632.2	2769.4	2878.6	2978.0	3073.4	3260.7
(285.8)	h			2838.4	3016.0	3158.1	3287.1	3410.3	3650.3
	s			5.931	6.228	6.448	6.633	6.798	7.089

↓p (bar) (t_s)	t (°C) →	350	375	400	450	500	550	600	700
80	v	0.02995	0.03222	0.03432	0.03817	0.04175	0.04516	0.04845	0.05481
(294.9)	h	2987.3	3066.1	3138.3	3272.0	3398.3	3521.0	3642.0	3882.4
	s	6.130	6.254	6.363	6.555	6.724	6.878	7.021	7.281
90	v	0.0258	0.02796	0.02993	0.03350	0.03677	0.03987	0.04285	0.04857
(303.3)	h	2956.6	3041.3	3117.8	3256.6	3386.1	3511.0	3633.7	3876.5
	s	6.036	6.169	6.285	6.484	6.658	6.814	6.959	7.222
100	v	0.02242	0.02453	0.02641	0.02975	0.03279	0.03564	0.03837	0.04358
(311.0)	h	2923.4	3015.4	3096.5	3240.9	3373.7	3500.9	3625.3	3870.5
	s	5.944	6.089	6.212	6.419	6.597	6.756	6.903	7.169
110	v	0.01961	0.02169	0.02351	0.02668	0.02952	0.03217	0.03470	0.03950
(318.0)	h	2887.3	2988.2	3074.3	3224.7	3361.0	3490.7	3616.9	3864.5
	s	5.853	6.011	6.142	6.358	6.540	6.703	6.851	7.120
120	v	0.01721	0.01931	0.02108	0.02412	0.02680	0.02929	0.03164	0.03610
(324.6)	h	2847.7	2958.9	3051.3	3208.2	3348.2	3480.4	3608.3	3858.4
	s	5.760	5.935	6.075	6.300	6.487	6.653	6.804	7.075
130	v	0.01511	0.01725	0.01900	0.02194	0.0245	0.02684	0.02905	0.03322
(330.8)	h	2803.3	2927.9	3027.2	3191.3	3335.2	3469.9	3599.7	3852.3
	s	5.663	5.859	6.009	6.245	6.437	6.606	6.759	7.033
140	v	0.01322	0.01546	0.01722	0.02007	0.02252	0.02474	0.02683	0.03075
(336.6)	h	2752.6	2894.5	3001.9	3174.0	3322.0	3459.3	3591.1	3846.2
	s	5.559	5.782	5.945	6.192	6.390	6.562	6.712	6.994
150	v	0.01145	0.01388	0.01565	0.01845	0.02080	0.02293	0.02491	0.02861
(342.1)	h	2692.4	2858.4	2975.5	3156.2	3308.6	3448.6	3582.3	3840.1
	s	5.442	5.703	5.881	6.140	6.344	6.520	6.679	6.957

↓*p* (bar) (t_s)	*t* (°C) →	*350*	*375*	*400*	*450*	*500*	*550*	*600*	*700*
160	*v*	0.00975	0.01245	0.01426	0.01701	0.01930	0.02134	0.02323	0.02674
(347.3)	*h*	2615.7	2818.9	2947.6	3138.0	3294.9	3437.8	3573.5	3833.9
	s	5.302	5.622	5.188	6.091	6.301	6.480	6.640	6.922
170	*v*		0.01117	0.01302	0.01575	0.01797	0.01993	0.02174	0.02509
(352.3)	*h*		2776.8	2918.2	3119.3	3281.1	3426.9	3564.6	3827.7
	s		5.539	5.754	6.042	6.259	6.442	6.604	6.889
180	*v*		0.00996	0.01190	0.01462	0.01678	0.01868	0.02042	0.02362
(356.9)	*h*		2727.9	2887.0	3100.1	3267.0	3415.9	3555.6	3821.5
	s		5.448	5.689	5.995	6.218	6.405	6.570	6.858
190	*v*		0.00881	0.01088	0.01361	0.01572	0.01756	0.01924	0.02231
(361.4)	*h*		2671.3	2853.8	3080.4	3252.7	3404.7	3546.6	3815.3
	s		5.346	5.622	5.948	6.179	6.369	6.537	6.828
200	*v*		0.00767	0.00994	0.01269	0.9477	0.01655	0.01818	0.02113
(365.7)	*h*		2602.5	2818.1	3060.1	3238.2	3393.5	3537.6	3809.0
	s		5.227	5.554	5.902	6.140	6.335	6.505	6.799
210	*v*		0.00645	0.00907	0.01186	0.01390	0.01564	0.01722	0.02006
(369.8)	*h*		2511.0	2779.6	3039.3	3223.5	3382.1	3528.4	3802.8
	s		5.075	5.483	5.856	6.103	6.301	6.474	6.772
220	*v*		0.00482	0.00825	0.01110	0.01312	0.01481	0.01634	0.01909
(373.7)	*h*		2345.1	2737.6	3017.9	3208.6	3370.6	3519.2	3796.5
	s		4.810	5.407	5.811	6.066	6.269	6.444	6.745

TABLE IV

Supercritical Steam

p(bar)	t (°C) →	350	375	400	425	450	500	600	700	800
230	*v*	0.00162	0.00221	0.00748	0.00915	0.01040	0.01239	0.01554	0.01821	0.02063
	h	1632.8	1912.2	2691.2	2869.2	2995.8	3193.4	3510.0	3790.2	4056.2
	s	3.137	4.137	5.327	5.587	5.765	6.030	6.415	6.719	6.980
250	*v*	0.00160	0.00197	0.00600	0.00788	0.00916	0.01112	0.01414	0.01665	0.01891
	h	1623.5	1848.0	2580.2	2806.3	2949.7	3162.4	3491.4	3775.5	4047.1
	s	3.680	4.032	5.142	5.472	5.674	5.959	6.360	6.671	6.934
300	*v*	0.00155	0.00179	0.00279	0.00530	0.00673	0.00868	0.01145	0.01366	0.01562
	h	1608.5	1791.5	2151.1	2614.2	2821.4	3081.1	3443.9	3745.6	4024.2
	s	3.643	3.930	4.473	5.150	5.442	5.790	6.233	6.561	6.833
350	*v*	0.00152	0.00110	0.00210	0.00343	0.00496	0.00693	0.00953	0.01153	0.01328
	h	1597.1	1762.4	1987.6	2373.4	2672.4	2994.4	3395.5	3713.5	4001.5
	s	3.612	3.872	4.213	4.775	5.196	5.628	6.118	6.463	6.745
400	*v*	0.00149	0.00164	0.00191	0.00253	0.00369	0.00562	0.00809	0.00994	0.01152
	h	1588.3	1742.8	1930.9	2198.1	2512.8	2903.3	3346.4	3681.2	3978.7
	s	3.586	3.829	4.113	4.503	4.946	5.470	6.011	6.375	6.666
500	*v*	0.00144	0.00156	0.00173	0.00201	0.00249	0.00389	0.00611	0.00773	0.00908
	h	1575.3	1716.6	1874.6	2060.0	2284.0	2720.1	3247.6	3616.8	3933.6
	s	3.542	3.764	4.003	4.273	4.588	5.173	5.818	6.219	6.529
600	*v*	0.00140	0.00150	0.00163	0.00182	0.00209	0.00296	0.00483	0.00627	0.00746
	h	1566.4	1699.5	1843.4	2001.7	2179.0	2567.9	3151.2	3553.5	3889.1
	s	3.505	3.764	3.932	4.163	4.412	4.932	5.645	6.082	6.411
700	*v*	0.00137	0.00146	0.00157	0.00171	0.00189	0.00247	0.00398	0.00526	0.00632
	h	1560.4	1687.7	1822.8	1967.2	2122.7	2463.2	3061.7	3492.4	3845.7
	s	3.473	3.673	3.877	4.088	4.307	4.762	5.492	5.961	6.307
800	*v*	0.00135	0.00142	0.00152	0.00163	0.00177	0.00219	0.00339	0.00452	0.00548
	h	1556.4	1679.4	1808.3	1943.9	2086.9	2394.0	2982.7	3434.6	3803.8
	s	3.444	3.638	3.833	4.031	4.232	4.642	5.360	5.851	6.213
900	*v*	0.00133	0.00139	0.00147	0.00157	0.00169	0.00201	0.00297	0.00397	0.00484
	h	1553.9	1673.4	1797.7	1927.2	2062.0	2346.7	2915.6	3381.1	3763.8
	s	3.419	3.607	3.795	3.984	4.174	4.554	5.247	5.753	6.128
1000	*v*	0.01308	0.00137	0.00144	0.00152	0.00163	0.00189	0.00267	0.00355	0.00434
	h	1552.7	1669.4	1790.0	1914.8	2043.8	2312.8	2859.8	3332.3	3726.1
	s	3.396	3.579	3.762	3.944	4.126	4.485	5.151	5.664	6.050

TABLE A-10 Properties of Saturated Refrigerant 134a (Liquid–Vapor): Temperature Table

		Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		
Temp. °C	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	Temp. °C
−40	0.5164	0.7055	0.3569	−0.04	204.45	0.00	222.88	222.88	0.0000	0.9560	−40
−36	0.6332	0.7113	0.2947	4.68	206.73	4.73	220.67	225.40	0.0201	0.9506	−36
−32	0.7704	0.7172	0.2451	9.47	209.01	9.52	218.37	227.90	0.0401	0.9456	−32
−28	0.9305	0.7233	0.2052	14.31	211.29	14.37	216.01	230.38	0.0600	0.9411	−28
−26	1.0199	0.7265	0.1882	16.75	212.43	16.82	214.80	231.62	0.0699	0.9390	−26
−24	1.1160	0.7296	0.1728	19.21	213.57	19.29	213.57	232.85	0.0798	0.9370	−24
−22	1.2192	0.7328	0.1590	21.68	214.70	21.77	212.32	234.08	0.0897	0.9351	−22
−20	1.3299	0.7361	0.1464	24.17	215.84	24.26	211.05	235.31	0.0996	0.9332	−20
−18	1.4483	0.7395	0.1350	26.67	216.97	26.77	209.76	236.53	0.1094	0.9315	−18
−16	1.5748	0.7428	0.1247	29.18	218.10	29.30	208.45	237.74	0.1192	0.9298	−16
−12	1.8540	0.7498	0.1068	34.25	220.36	34.39	205.77	240.15	0.1388	0.9267	−12
−8	2.1704	0.7569	0.0919	39.38	222.60	39.54	203.00	242.54	0.1583	0.9239	−8
−4	2.5274	0.7644	0.0794	44.56	224.84	44.75	200.15	244.90	0.1777	0.9213	−4
0	2.9282	0.7721	0.0689	49.79	227.06	50.02	197.21	247.23	0.1970	0.9190	0
4	3.3765	0.7801	0.0600	55.08	229.27	55.35	194.19	249.53	0.2162	0.9169	4
8	3.8756	0.7884	0.0525	60.43	231.46	60.73	191.07	251.80	0.2354	0.9150	8
12	4.4294	0.7971	0.0460	65.83	233.63	66.18	187.85	254.03	0.2545	0.9132	12
16	5.0416	0.8062	0.0405	71.29	235.78	71.69	184.52	256.22	0.2735	0.9116	16
20	5.7160	0.8157	0.0358	76.80	237.91	77.26	181.09	258.36	0.2924	0.9102	20
24	6.4566	0.8257	0.0317	82.37	240.01	82.90	177.55	260.45	0.3113	0.9089	24
26	6.8530	0.8309	0.0298	85.18	241.05	85.75	175.73	261.48	0.3208	0.9082	26
28	7.2675	0.8362	0.0281	88.00	242.08	88.61	173.89	262.50	0.3302	0.9076	28
30	7.7006	0.8417	0.0265	90.84	243.10	91.49	172.00	263.50	0.3396	0.9070	30
32	8.1528	0.8473	0.0250	93.70	244.12	94.39	170.09	264.48	0.3490	0.9064	32
34	8.6247	0.8530	0.0236	96.58	245.12	97.31	168.14	265.45	0.3584	0.9058	34
36	9.1168	0.8590	0.0223	99.47	246.11	100.25	166.15	266.40	0.3678	0.9053	36
38	9.6298	0.8651	0.0210	102.38	247.09	103.21	164.12	267.33	0.3772	0.9047	38
40	10.164	0.8714	0.0199	105.30	248.06	106.19	162.05	268.24	0.3866	0.9041	40
42	10.720	0.8780	0.0188	108.25	249.02	109.19	159.94	269.14	0.3960	0.9035	42
44	11.299	0.8847	0.0177	111.22	249.96	112.22	157.79	270.01	0.4054	0.9030	44
48	12.526	0.8989	0.0159	117.22	251.79	118.35	153.33	271.68	0.4243	0.9017	48
52	13.851	0.9142	0.0142	123.31	253.55	124.58	148.66	273.24	0.4432	0.9004	52
56	15.278	0.9308	0.0127	129.51	255.23	130.93	143.75	274.68	0.4622	0.8990	56
60	16.813	0.9488	0.0114	135.82	256.81	137.42	138.57	275.99	0.4814	0.8973	60
70	21.162	1.0027	0.0086	152.22	260.15	154.34	124.08	278.43	0.5302	0.8918	70
80	26.324	1.0766	0.0064	169.88	262.14	172.71	106.41	279.12	0.5814	0.8827	80
90	32.435	1.1949	0.0046	189.82	261.34	193.69	82.63	276.32	0.6380	0.8655	90
100	39.742	1.5443	0.0027	218.60	248.49	224.74	34.40	259.13	0.7196	0.8117	100

Source: Tables A-10 through A-12 are calculated based on equations from D. P. Wilson and R. S. Basu, "Thermodynamic Properties of a New Stratospherically Safe Working Fluid—Refrigerant 134a," *ASHRAE Trans.*, Vol. 94, Pt. 2, 1988, pp. 2095–2118.

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

		Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		
Press. bar	Temp. °C	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	Press. bar
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

TABLE A-12 Properties of Superheated Refrigerant 134a Vapor

T °C	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 0.6 bar = 0.06 MPa (T_{sat} = −37.07°C)				p = 1.0 bar = 0.10 MPa (T_{sat} = −26.43°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 bar = 0.14 MPa (T_{sat} = −18.80°C)				p = 1.8 bar = 0.18 MPa (T_{sat} = −12.73°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 bar = 0.20 MPa (T_{sat} = −10.09°C)				p = 2.4 bar = 0.24 MPa (T_{sat} = −5.37°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 m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 2.8 bar = 0.28 MPa (T_{sat} = −1.23°C)				p = 3.2 bar = 0.32 MPa (T_{sat} = 2.48°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

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 4.0 bar = 0.40 MPa (T_{sat} = 8.93°C)				p = 5.0 bar = 0.50 MPa (T_{sat} = 15.74°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

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 6.0 bar = 0.60 MPa (T_{sat} = 21.58°C)				p = 7.0 bar = 0.70 MPa (T_{sat} = 26.72°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 m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 8.0 bar = 0.80 MPa (T_{sat} = 31.33°C)				p = 9.0 bar = 0.90 MPa (T_{sat} = 35.53°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

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 10.0 bar = 1.00 MPa (T_{sat} = 39.39°C)				p = 12.0 bar = 1.20 MPa (T_{sat} = 46.32°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

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 14.0 bar = 1.40 MPa (T_{sat} = 52.43°C)				p = 16.0 bar = 1.60 MPa (T_{sat} = 57.92°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