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# THERMODYNAMIQUE

## III

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**TD N 01 : Application des trois principes de la thermodynamique**

Module : **Thermodynamique II**

Responsable du module : **T.E. BOUKELIA**

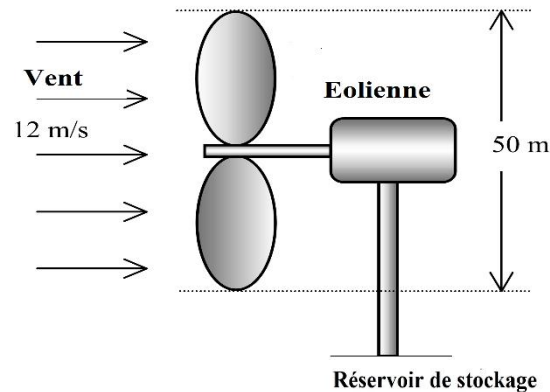
**Ex N 01.**

Déterminer le travail mis en jeu par 2 litres de gaz parfait maintenus à 25°C sous la pression de 5 atmosphères (état 1) qui se détend de façon isotherme pour occuper un volume de 10 litres (état 2) : **(a) de façon réversible, (b) de façon irréversible.**

A la même température le gaz est ramené de l'état 2 à l'état 1. Déterminer le travail que la compression s'effectue **(c) de façon réversible, (d) de façon irréversible.**

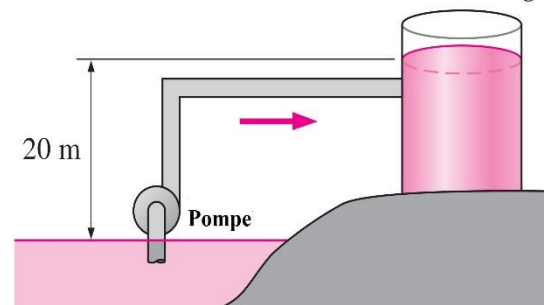
**Ex N 02.**

À un certain endroit, le vent souffle régulièrement à 12 m/s. Déterminer **(a) l'énergie mécanique de l'air par unité de masse** et **(b) le potentiel de production d'énergie d'une éolienne** avec des pales de 50 m de diamètre à cet endroit, **(c) la production d'électricité réelle** (supposant une efficacité globale de 30 %, et la masse volumique de l'air est  $\rho = 1.25 \text{ kg/m}^3$ ).



**Ex N 03**

L'eau est pompée d'un lac à un réservoir de stockage à 20 m au-dessus, avec un débit de 70 L/s, tout en consommant 20,4 kW d'énergie électrique (Figure 1). Sans tenir compte des pertes par frottement dans les tuyaux et de tout changement de l'énergie cinétique, déterminer **(a) l'efficacité globale de l'unité pompe-moteur**, et **(b) la différence de pression entre l'entrée et la sortie de la pompe.**



**Ex N 04.**

1. Calculer **(a) la variation d'entropie de 2 moles de gaz parfait** qui se détend de 30 à 50 litres de manière isotherme et irréversible, et **(b) l'entropie créée** durant le processus.

2. Même question que celle de 1, mais la détente n'est plus isotherme, la température passant de 300K à 290K. On donne  $C_v = 5 \text{ cal.mol}^{-1}.K^{-1}$

**Ex N 05.**

Une mole de gaz parfait à une température initiale de 298K se détend d'une pression de 5 atmosphères à une pression de 1 atmosphère. Dans chacun des cas suivants :

**1. détente adiabatique et réversible. 2. détente adiabatique et irréversible**

Calculer : **a) la température finale du gaz, b) la variation de l'énergie interne du gaz, c) le travail effectué par le gaz, d) la quantité de chaleur mise en jeu, e) la variation d'enthalpie du gaz**

On donne :  $C_v = 3 R/2$ , et  $C_p = 5 R/2$ .

**TD N 01 : Application des trois principes de la thermodynamique**Module : **Thermodynamique II**Responsable du module : **T.E. BOUKELIA****Ex N 01.**

**Etat 1** { détente isotherme **Etat 2**  
compression isotherme }

$$V_1 = 2 \text{ litres}$$

$$T_1 = 298 \text{ K}$$

$$P_1 = 5 \text{ atm}$$

$$V_2 = 10 \text{ litres}$$

$$T_2 = T_1 = 298 \text{ K}$$

$$P_2 = ?$$

La transformation est isotherme ( $T = \text{cte}$ ),

$$\text{Donc : } P_1 V_1 = P_2 V_2 = nRT \Rightarrow P_2 = \frac{P_1 V_1}{V_2} = \frac{5 \times 2}{10} = 1 \text{ atm}$$

**a. Travail mis en jeu (détente réversible isotherme)**

Transformation réversible (transformation très lente)  $\Rightarrow P_{\text{ext}} = P_{\text{gaz}}$  à chaque instant

$$\begin{aligned} W_{\text{rév}}(1 \rightarrow 2) &= - \int_1^2 P_{\text{ext}} dV = - \int_1^2 P_{\text{gaz}} dV = - \int_1^2 \frac{nRT}{V} dV = -nRT \ln \left( \frac{V_2}{V_1} \right) = P_1 V_1 \ln \left( \frac{V_2}{V_1} \right) \\ &= -(5 \times 1,013 \cdot 10^5)(2 \times 10^{-3}) \ln \left( \frac{10}{2} \right) = -1630,4 \text{ J} \end{aligned}$$

**b. Travail mis en jeu (détente irréversible isotherme)**

Transformation irréversible (transformation très rapide)  $\Rightarrow P_{\text{ext}} = P_{\text{final}} = P_2$ , donc, on peut supposer qu'il y a transformation isochore suivie par une transformation isobare.

$$\begin{aligned} W_{\text{irr}}(1 \rightarrow 2) &= - \int_1^2 P_{\text{ext}} dV = - \int_1^2 P_{\text{final}} dV = -P_{\text{final}} \int_1^2 dV = -P_2 (V_2 - V_1) \\ &= -(1 \times 1,013 \cdot 10^5)((10 - 2) \times 10^{-3}) = -810,4 \text{ J} \end{aligned}$$

On peut noter que nous pouvons récupérer moins de travail en détente irréversible par rapport à réversible.  $W_{\text{irr}}(1 \rightarrow 2) < W_{\text{rév}}(1 \rightarrow 2)$

**c. Travail mis en jeu (compression réversible isotherme)**

Transformation réversible (transformation très lente)  $\Rightarrow P_{\text{ext}} = P_{\text{gaz}}$  à chaque instant

$$\begin{aligned} W_{\text{rév}}(2 \rightarrow 1) &= - \int_2^1 P_{\text{ext}} dV = - \int_2^1 P_{\text{gaz}} dV = - \int_2^1 \frac{nRT}{V} dV = -nRT \ln \left( \frac{V_1}{V_2} \right) \\ &= P_1 V_1 \ln \left( \frac{V_1}{V_2} \right) = -(5 \times 1,013 \cdot 10^5)(2 \times 10^{-3}) \ln \left( \frac{2}{10} \right) = 1630,4 \text{ J} \end{aligned}$$

**d. Travail mis en jeu (compression irréversible isotherme)**

Transformation irréversible (transformation très rapide)  $\Rightarrow P_{\text{ext}} = P_{\text{final}} = P_2$ , donc, on peut supposer qu'il y a transformation isochore suivie par une transformation isobare.

$$\begin{aligned} W_{\text{irr}}(2 \rightarrow 1) &= - \int_2^1 P_{\text{ext}} dV = - \int_2^1 P_{\text{final}} dV = -P_{\text{final}} \int_2^1 dV = -P_1 (V_1 - V_2) \\ &= -(5 \times 1,013 \cdot 10^5)((2 - 10) \times 10^{-3}) = 40523 \text{ J} \end{aligned}$$



**TD N 01 : Application des trois principes de la thermodynamique**

Module : **Thermodynamique II**

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**Ex N 02.**

L'énergie cinétique est la seule forme d'énergie mécanique que le vent possède, et elle peut être convertie totalement. Par conséquent, le potentiel de puissance du vent est son énergie cinétique, qu'est égal à  $V^2/2$  per unité de masse.

Avec le 1<sup>er</sup> principe de thermodynamique (système ouvert) :

**a. L'énergie mécanique per unité de masse**

$$Q + W = \Delta H + \Delta E_{chim} + \Delta E_{pot} + \Delta E_{ciné} + \dots$$

$$w = \Delta e_{ciné} = \left( \frac{V_{sortie}^2}{2} - \frac{V_{entrée}^2}{2} \right) = \frac{V_{entrée}^2}{2} = \frac{(12 \text{ m/s})^2}{2} \left( \frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2} \right)$$

$$= 0,07 \text{ 2kJ/kg}$$

**b. Le potentiel de production d'énergie de l'éolienne**

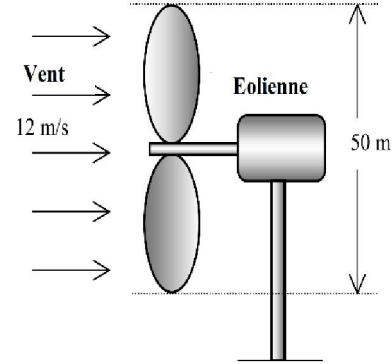
$$\dot{m}_{air} = \rho \times V \times A = \rho \times V \times \frac{\pi D^2}{4} = \left( 1,25 \frac{\text{kg}}{\text{m}^3} \right) \times \left( 12 \frac{\text{m}}{\text{s}} \right) \times \frac{\pi (50 \text{ m})^2}{4} = 29 \text{ 4375 kg/s}$$

$$\dot{W}_{max} = \dot{m}_{air} \times w = \left( 29437,5 \frac{\text{kg}}{\text{s}} \right) \times \left( 0,072 \frac{\text{kJ}}{\text{kg}} \right) = 2119,5 \text{ kW}$$

**c. La production d'électricité réelle**

$$\dot{W}_{ele} = \eta_{éolienne} \times \dot{W}_{max} = (0,30)(2119,5 \text{ kW}) = 635,85 \text{ kW}$$

(Exemple d'un ventilateur).



**Ex N 03.**

**a. L'efficacité globale de l'unité pompe-moteur**

$$Q + W = \Delta H + \Delta E_{chim} + \Delta E_{pot} + \Delta E_{ciné} + \dots$$

$$w = \Delta e_{pot} = (gz_2 - gz_1) = gz_2 = \left( 9,81 \frac{\text{m}}{\text{s}^2} \right) (20 \text{ m}) \left( \frac{1 \text{ kJ}}{1000 \text{ m}^2/\text{s}^2} \right)$$

$$= 0,19 \text{ 62kJ/kg}$$

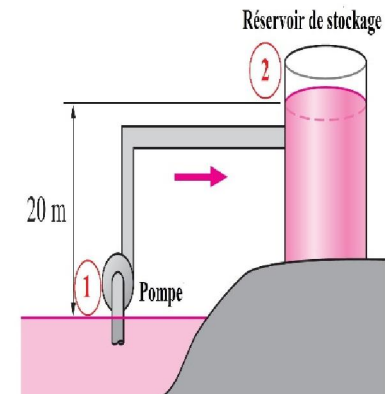
$$\dot{m}_{eau} = \rho \times \dot{V}_{eau} = \left( 1000 \frac{\text{kg}}{\text{m}^3} \right) \times \left( 0,07 \frac{\text{m}^3}{\text{s}} \right) = 70 \text{ kg/s}$$

$$\dot{W}_{idéal} = \dot{m}_{eau} \times w = \left( 70 \frac{\text{kg}}{\text{s}} \right) \times \left( 0,1962 \frac{\text{kJ}}{\text{kg}} \right) = 13,734 \text{ kW}$$

$$\eta_{pompe-moteur} = \frac{\dot{W}_{idéal}}{\dot{W}_{ele}} = \frac{13,734 \text{ kW}}{20,4 \text{ kW}} = 0,6732 = 67,32 \%$$

**b. La différence de pression entre l'entrée et la sortie de la pompe.**

$$\begin{aligned} \dot{W}_{idéal} &= \dot{m}_{eau} (e_{sortie} - e_{entrée}) = \dot{m}_{eau} \frac{P_2 - P_1}{\rho} = \dot{V}_{eau} \Delta P \Rightarrow \Delta P = \frac{\dot{W}_{idéal}}{\dot{V}_{eau}} \\ &= \frac{13,734 \text{ kJ/s}}{0,070 \frac{\text{m}^3}{\text{s}}} \left( \frac{1 \text{ kPa} \cdot \text{m}^3}{1 \text{ kJ}} \right) = 1962 \text{ kPa} \end{aligned}$$



**Ex N 04****Rappel !**

$$\Delta S_{\text{systeme}} = \Delta S_{\text{échangée}} + \Delta S_{\text{créée}}$$

Quel que soit la transformation :  $dS_{\text{sys}} = \delta Q/T$

1. Pour une transformation réversible  $\Delta S_{\text{créée}} = 0 \Rightarrow \Delta S_{\text{systeme}} = \Delta S_{\text{échangée}}$
2. Pour une transformation irréversible  $\Delta S_{\text{créée}} > 0 \Rightarrow \Delta S_{\text{systeme}} > \Delta S_{\text{échangée}}$

**1. Lors de la détente isotherme irréversible****a. Variation d'entropie du gaz parfait**

$$dS_{\text{sys}} = \delta Q/T \text{ et } dU = \delta Q + \delta W$$

Transformation isotherme  $\Rightarrow dU = nC_v dT = 0 \Rightarrow \delta Q = -\delta W = PdV \Rightarrow dS_{\text{sys}} = PdV/T =$   
 $nRTdV/TV = nRdV/V$

Entropie du systeme:  $\Delta S_{\text{systeme}} (1 \rightarrow 2) = nR \int_1^2 \frac{dV}{V} = nR \ln \left( \frac{V_2}{V_1} \right) = 2 \times 2 \ln \frac{50}{30}$   
 $= 2,04 \text{ Cal. K}^{-1}$

Entropie échangée:  $\Delta S_{\text{échangée}} (1 \rightarrow 2) = \frac{Q_{\text{irr}}}{T} = \frac{W_{\text{irr}}}{T} = P_{\text{final}} \frac{\Delta V}{T} = nR \frac{\Delta V}{V} = 2 \times 2 \frac{20}{50}$   
 $= 1,6 \text{ Cal. K}^{-1}$

**b. Entropie créée**

$$\Delta S_{\text{créée}} = \Delta S_{\text{systeme}} - \Delta S_{\text{échangée}} = 2,04 - 1,6 = 0,44 \text{ Cal. K}^{-1}$$

**2. Lors de la détente non isotherme**

$$dS_{\text{sys}} = \delta Q/T = \frac{dU - \delta W}{T} = n \left( \frac{C_v dT}{T} + \frac{RT dV}{V} \right) \Rightarrow \Delta S = \int_{T_1}^{T_2} dS = n \left( C_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1} \right)$$
$$= 2 \left( 5 \ln \frac{290}{300} + 2 \ln \frac{50}{30} \right) = 1,7 \text{ Cal. K}^{-1}$$

**Ex N 5****1. Détente adiabatique réversible:****a. Température finale du gaz**

$$dW + dQ = dU = nC_v dT, dQ = 0 \text{ (adiab)} \Rightarrow -PdV = C_v dT = -\frac{RT}{V} dV = -(C_p - C_v) T \frac{dV}{V}$$
$$\frac{dT}{T} = -\frac{(C_p - C_v)}{C_v} \frac{dV}{V} \Rightarrow \frac{dT}{T} = -\left( \frac{C_p}{C_v} - \frac{C_v}{C_v} \right) \frac{dV}{V} \Rightarrow \frac{dT}{T} = (1 - \gamma) \frac{dV}{V}$$



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$$TV^{\gamma-1} = Cte \Rightarrow \left(\frac{PV}{R}\right)V^{\gamma-1} = Cte \Rightarrow PV^{\gamma} = Cte$$

$$TV^{\gamma-1} = Cte, PV^{\gamma} = Cte, P_1^{1-\gamma}T_1^{\gamma} = P_2^{1-\gamma}T_2^{\gamma}$$

$$\gamma = \frac{C_p}{C_v} = \frac{5}{3} = 1,66$$

$$P_1^{1-\gamma}T_1^{\gamma} = P_2^{1-\gamma}T_2^{\gamma} \Rightarrow T_2 = T_1 \left(\frac{P_1}{P_2}\right)^{\frac{1-\gamma}{\gamma}} = 298 \left(\frac{5}{1}\right)^{-0.4} = 156,5 \text{ K}$$

**b. La variation de l'énergie interne**

$$\Delta U = nC_v(T_2 - T_1) = \frac{3 \times 8,31}{2} (156,6 - 298) = -17 \text{ 64 J} \cdot \text{mol}^{-1}$$

**c. La quantité de chaleur pour la détente adiabatique réversible  $Q = 0$**

**d. Le travail mis en jeu pendant le processus de la détente adiabatique réversible**

$$\Delta W + \Delta Q = \Delta U = nC_v\Delta T, \Delta Q = 0 \Rightarrow \Delta W + \Delta Q = \Delta U = -17 \text{ 64 J} \cdot \text{mol}^{-1}$$

**e. La variation de l'enthalpie**

$$\Delta H = nC_p(T_2 - T_1) = \frac{5 \times 8,31}{2} (156,6 - 298) = -29 \text{ 40 J} \cdot \text{mol}^{-1}$$

**2. Détente adiabatique irréversible:**

**a. Température finale du gaz**

$$dQ = 0 \text{ (traf adiab)} \Rightarrow dU = \delta W \Rightarrow -PdV = C_v dT \Rightarrow -P_2(V_2 - V_1) = C_v(T_2 - T_1)$$

$$\Rightarrow C_v(T_2 - T_1) = -P_2R \left(\frac{T_2}{P_2} - \frac{T_1}{P_1}\right) \Rightarrow T_2 = 203 \text{ K}$$

**b. La variation de l'énergie interne**

$$\Delta U = nC_v(T_2 - T_1) = \frac{3 \times 8,31}{2} (203 - 298) = -1184 \text{ J} \cdot \text{mol}^{-1}$$

**c. La quantité de chaleur pour la détente adiabatique réversible  $Q = 0$**

**d. Le travail mis en jeu pendant le processus de la détente adiabatique réversible**

$$\Delta W + \Delta Q = \Delta U = nC_v\Delta T, \Delta Q = 0 \Rightarrow \Delta W + \Delta Q = \Delta U = -1184 \text{ J} \cdot \text{mol}^{-1}$$

**e. La variation de l'enthalpie**

$$\Delta H = nC_p(T_2 - T_1) = \frac{5 \times 8,31}{2} (156,6 - 298) = -19 \text{ 7 J} \cdot \text{mol}^{-1}$$

# LES TABLES THERMODYNAMIQUE



TABLE A-4

Saturated water—Temperature table

| Temp.,<br>$T$ °C | Sat.<br>press.,<br>$P_{\text{sat}}$ kPa | Specific volume,<br>$\text{m}^3/\text{kg}$ |                         | Internal energy,<br>$\text{kJ/kg}$ |                    |                         | Enthalpy,<br>$\text{kJ/kg}$ |                    |                         | Entropy,<br>$\text{kJ/kg} \cdot \text{K}$ |                    |                         |
|------------------|---|--|-------------------------|------------------------------------|--------------------|-------------------------|-----------------------------|--------------------|-------------------------|---|--------------------|-------------------------|
|                  |   | Sat.<br>liquid,<br>$v_f$                   | Sat.<br>vapor,<br>$v_g$ | Sat.<br>liquid,<br>$u_f$           | Evap.,<br>$u_{fg}$ | Sat.<br>vapor,<br>$u_g$ | Sat.<br>liquid,<br>$h_f$    | Evap.,<br>$h_{fg}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>liquid,<br>$s_f$                  | Evap.,<br>$s_{fg}$ | Sat.<br>vapor,<br>$s_g$ |
| 0.01             | 0.6117                                  | 0.001000                                   | 206.00                  | 0.000                              | 2374.9             | 2374.9                  | 0.001                       | 2500.9             | 2500.9                  | 0.0000                                    | 9.1556             | 9.1556                  |
| 5                | 0.8725                                  | 0.001000                                   | 147.03                  | 21.019                             | 2360.8             | 2381.8                  | 21.020                      | 2489.1             | 2510.1                  | 0.0763                                    | 8.9487             | 9.0249                  |
| 10               | 1.2281                                  | 0.001000                                   | 106.32                  | 42.020                             | 2346.6             | 2388.7                  | 42.022                      | 2477.2             | 2519.2                  | 0.1511                                    | 8.7488             | 8.8999                  |
| 15               | 1.7057                                  | 0.001001                                   | 77.885                  | 62.980                             | 2332.5             | 2395.5                  | 62.982                      | 2465.4             | 2528.3                  | 0.2245                                    | 8.5559             | 8.7803                  |
| 20               | 2.3392                                  | 0.001002                                   | 57.762                  | 83.913                             | 2318.4             | 2402.3                  | 83.915                      | 2453.5             | 2537.4                  | 0.2965                                    | 8.3696             | 8.6661                  |
| 25               | 3.1698                                  | 0.001003                                   | 43.340                  | 104.83                             | 2304.3             | 2409.1                  | 104.83                      | 2441.7             | 2546.5                  | 0.3672                                    | 8.1895             | 8.5567                  |
| 30               | 4.2469                                  | 0.001004                                   | 32.879                  | 125.73                             | 2290.2             | 2415.9                  | 125.74                      | 2429.8             | 2555.6                  | 0.4368                                    | 8.0152             | 8.4520                  |
| 35               | 5.6291                                  | 0.001006                                   | 25.205                  | 146.63                             | 2276.0             | 2422.7                  | 146.64                      | 2417.9             | 2564.6                  | 0.5051                                    | 7.8466             | 8.3517                  |
| 40               | 7.3851                                  | 0.001008                                   | 19.515                  | 167.53                             | 2261.9             | 2429.4                  | 167.53                      | 2406.0             | 2573.5                  | 0.5724                                    | 7.6832             | 8.2556                  |
| 45               | 9.5953                                  | 0.001010                                   | 15.251                  | 188.43                             | 2247.7             | 2436.1                  | 188.44                      | 2394.0             | 2582.4                  | 0.6386                                    | 7.5247             | 8.1633                  |
| 50               | 12.352                                  | 0.001012                                   | 12.026                  | 209.33                             | 2233.4             | 2442.7                  | 209.34                      | 2382.0             | 2591.3                  | 0.7038                                    | 7.3710             | 8.0748                  |
| 55               | 15.763                                  | 0.001015                                   | 9.5639                  | 230.24                             | 2219.1             | 2449.3                  | 230.26                      | 2369.8             | 2600.1                  | 0.7680                                    | 7.2218             | 7.9898                  |
| 60               | 19.947                                  | 0.001017                                   | 7.6670                  | 251.16                             | 2204.7             | 2455.9                  | 251.18                      | 2357.7             | 2608.8                  | 0.8313                                    | 7.0769             | 7.9082                  |
| 65               | 25.043                                  | 0.001020                                   | 6.1935                  | 272.09                             | 2190.3             | 2462.4                  | 272.12                      | 2345.4             | 2617.5                  | 0.8937                                    | 6.9360             | 7.8296                  |
| 70               | 31.202                                  | 0.001023                                   | 5.0396                  | 293.04                             | 2175.8             | 2468.9                  | 293.07                      | 2333.0             | 2626.1                  | 0.9551                                    | 6.7989             | 7.7540                  |
| 75               | 38.597                                  | 0.001026                                   | 4.1291                  | 313.99                             | 2161.3             | 2475.3                  | 314.03                      | 2320.6             | 2634.6                  | 1.0158                                    | 6.6655             | 7.6812                  |
| 80               | 47.416                                  | 0.001029                                   | 3.4053                  | 334.97                             | 2146.6             | 2481.6                  | 335.02                      | 2308.0             | 2643.0                  | 1.0756                                    | 6.5355             | 7.6111                  |
| 85               | 57.868                                  | 0.001032                                   | 2.8261                  | 355.96                             | 2131.9             | 2487.8                  | 356.02                      | 2295.3             | 2651.4                  | 1.1346                                    | 6.4089             | 7.5435                  |
| 90               | 70.183                                  | 0.001036                                   | 2.3593                  | 376.97                             | 2117.0             | 2494.0                  | 377.04                      | 2282.5             | 2659.6                  | 1.1929                                    | 6.2853             | 7.4782                  |
| 95               | 84.609                                  | 0.001040                                   | 1.9808                  | 398.00                             | 2102.0             | 2500.1                  | 398.09                      | 2269.6             | 2667.6                  | 1.2504                                    | 6.1647             | 7.4151                  |
| 100              | 101.42                                  | 0.001043                                   | 1.6720                  | 419.06                             | 2087.0             | 2506.0                  | 419.17                      | 2256.4             | 2675.6                  | 1.3072                                    | 6.0470             | 7.3542                  |
| 105              | 120.90                                  | 0.001047                                   | 1.4186                  | 440.15                             | 2071.8             | 2511.9                  | 440.28                      | 2243.1             | 2683.4                  | 1.3634                                    | 5.9319             | 7.2952                  |
| 110              | 143.38                                  | 0.001052                                   | 1.2094                  | 461.27                             | 2056.4             | 2517.7                  | 461.42                      | 2229.7             | 2691.1                  | 1.4188                                    | 5.8193             | 7.2382                  |
| 115              | 169.18                                  | 0.001056                                   | 1.0360                  | 482.42                             | 2040.9             | 2523.3                  | 482.59                      | 2216.0             | 2698.6                  | 1.4737                                    | 5.7092             | 7.1829                  |
| 120              | 198.67                                  | 0.001060                                   | 0.89133                 | 503.60                             | 2025.3             | 2528.9                  | 503.81                      | 2202.1             | 2706.0                  | 1.5279                                    | 5.6013             | 7.1292                  |
| 125              | 232.23                                  | 0.001065                                   | 0.77012                 | 524.83                             | 2009.5             | 2534.3                  | 525.07                      | 2188.1             | 2713.1                  | 1.5816                                    | 5.4956             | 7.0771                  |
| 130              | 270.28                                  | 0.001070                                   | 0.66808                 | 546.10                             | 1993.4             | 2539.5                  | 546.38                      | 2173.7             | 2720.1                  | 1.6346                                    | 5.3919             | 7.0265                  |
| 135              | 313.22                                  | 0.001075                                   | 0.58179                 | 567.41                             | 1977.3             | 2544.7                  | 567.75                      | 2159.1             | 2726.9                  | 1.6872                                    | 5.2901             | 6.9773                  |
| 140              | 361.53                                  | 0.001080                                   | 0.50850                 | 588.77                             | 1960.9             | 2549.6                  | 589.16                      | 2144.3             | 2733.5                  | 1.7392                                    | 5.1901             | 6.9294                  |
| 145              | 415.68                                  | 0.001085                                   | 0.44600                 | 610.19                             | 1944.2             | 2554.4                  | 610.64                      | 2129.2             | 2739.8                  | 1.7908                                    | 5.0919             | 6.8827                  |
| 150              | 476.16                                  | 0.001091                                   | 0.39248                 | 631.66                             | 1927.4             | 2559.1                  | 632.18                      | 2113.8             | 2745.9                  | 1.8418                                    | 4.9953             | 6.8371                  |
| 155              | 543.49                                  | 0.001096                                   | 0.34648                 | 653.19                             | 1910.3             | 2563.5                  | 653.79                      | 2098.0             | 2751.8                  | 1.8924                                    | 4.9002             | 6.7927                  |
| 160              | 618.23                                  | 0.001102                                   | 0.30680                 | 674.79                             | 1893.0             | 2567.8                  | 675.47                      | 2082.0             | 2757.5                  | 1.9426                                    | 4.8066             | 6.7492                  |
| 165              | 700.93                                  | 0.001108                                   | 0.27244                 | 696.46                             | 1875.4             | 2571.9                  | 697.24                      | 2065.6             | 2762.8                  | 1.9923                                    | 4.7143             | 6.7067                  |
| 170              | 792.18                                  | 0.001114                                   | 0.24260                 | 718.20                             | 1857.5             | 2575.7                  | 719.08                      | 2048.8             | 2767.9                  | 2.0417                                    | 4.6233             | 6.6650                  |
| 175              | 892.60                                  | 0.001121                                   | 0.21659                 | 740.02                             | 1839.4             | 2579.4                  | 741.02                      | 2031.7             | 2772.7                  | 2.0906                                    | 4.5335             | 6.6242                  |
| 180              | 1002.8                                  | 0.001127                                   | 0.19384                 | 761.92                             | 1820.9             | 2582.8                  | 763.05                      | 2014.2             | 2777.2                  | 2.1392                                    | 4.4448             | 6.5841                  |
| 185              | 1123.5                                  | 0.001134                                   | 0.17390                 | 783.91                             | 1802.1             | 2586.0                  | 785.19                      | 1996.2             | 2781.4                  | 2.1875                                    | 4.3572             | 6.5447                  |
| 190              | 1255.2                                  | 0.001141                                   | 0.15636                 | 806.00                             | 1783.0             | 2589.0                  | 807.43                      | 1977.9             | 2785.3                  | 2.2355                                    | 4.2705             | 6.5059                  |
| 195              | 1398.8                                  | 0.001149                                   | 0.14089                 | 828.18                             | 1763.6             | 2591.7                  | 829.78                      | 1959.0             | 2788.8                  | 2.2831                                    | 4.1847             | 6.4678                  |
| 200              | 1554.9                                  | 0.001157                                   | 0.12721                 | 850.46                             | 1743.7             | 2594.2                  | 852.26                      | 1939.8             | 2792.0                  | 2.3305                                    | 4.0997             | 6.4302                  |



TABLE A-4

Saturated water—Temperature table (*Continued*)

| Temp.,<br>$T$ °C | Sat.<br>press.,<br>$P_{\text{sat}}$ kPa | Specific volume,<br>$\text{m}^3/\text{kg}$ |                         | Internal energy,<br>$\text{kJ/kg}$ |                    |                         | Enthalpy,<br>$\text{kJ/kg}$ |                    |                         | Entropy,<br>$\text{kJ/kg} \cdot \text{K}$ |                    |                         |
|------------------|---|--|-------------------------|------------------------------------|--------------------|-------------------------|-----------------------------|--------------------|-------------------------|---|--------------------|-------------------------|
|                  |   | Sat.<br>liquid,<br>$v_f$                   | Sat.<br>vapor,<br>$v_g$ | Sat.<br>liquid,<br>$u_f$           | Evap.,<br>$u_{fg}$ | Sat.<br>vapor,<br>$u_g$ | Sat.<br>liquid,<br>$h_f$    | Evap.,<br>$h_{fg}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>liquid,<br>$s_f$                  | Evap.,<br>$s_{fg}$ | Sat.<br>vapor,<br>$s_g$ |
| 205              | 1724.3                                  | 0.001164                                   | 0.11508                 | 872.86                             | 1723.5             | 2596.4                  | 874.87                      | 1920.0             | 2794.8                  | 2.3776                                    | 4.0154             | 6.3930                  |
| 210              | 1907.7                                  | 0.001173                                   | 0.10429                 | 895.38                             | 1702.9             | 2598.3                  | 897.61                      | 1899.7             | 2797.3                  | 2.4245                                    | 3.9318             | 6.3563                  |
| 215              | 2105.9                                  | 0.001181                                   | 0.094680                | 918.02                             | 1681.9             | 2599.9                  | 920.50                      | 1878.8             | 2799.3                  | 2.4712                                    | 3.8489             | 6.3200                  |
| 220              | 2319.6                                  | 0.001190                                   | 0.086094                | 940.79                             | 1660.5             | 2601.3                  | 943.55                      | 1857.4             | 2801.0                  | 2.5176                                    | 3.7664             | 6.2840                  |
| 225              | 2549.7                                  | 0.001199                                   | 0.078405                | 963.70                             | 1638.6             | 2602.3                  | 966.76                      | 1835.4             | 2802.2                  | 2.5639                                    | 3.6844             | 6.2483                  |
| 230              | 2797.1                                  | 0.001209                                   | 0.071505                | 986.76                             | 1616.1             | 2602.9                  | 990.14                      | 1812.8             | 2802.9                  | 2.6100                                    | 3.6028             | 6.2128                  |
| 235              | 3062.6                                  | 0.001219                                   | 0.065300                | 1010.0                             | 1593.2             | 2603.2                  | 1013.7                      | 1789.5             | 2803.2                  | 2.6560                                    | 3.5216             | 6.1775                  |
| 240              | 3347.0                                  | 0.001229                                   | 0.059707                | 1033.4                             | 1569.8             | 2603.1                  | 1037.5                      | 1765.5             | 2803.0                  | 2.7018                                    | 3.4405             | 6.1424                  |
| 245              | 3651.2                                  | 0.001240                                   | 0.054656                | 1056.9                             | 1545.7             | 2602.7                  | 1061.5                      | 1740.8             | 2802.2                  | 2.7476                                    | 3.3596             | 6.1072                  |
| 250              | 3976.2                                  | 0.001252                                   | 0.050085                | 1080.7                             | 1521.1             | 2601.8                  | 1085.7                      | 1715.3             | 2801.0                  | 2.7933                                    | 3.2788             | 6.0721                  |
| 255              | 4322.9                                  | 0.001263                                   | 0.045941                | 1104.7                             | 1495.8             | 2600.5                  | 1110.1                      | 1689.0             | 2799.1                  | 2.8390                                    | 3.1979             | 6.0369                  |
| 260              | 4692.3                                  | 0.001276                                   | 0.042175                | 1128.8                             | 1469.9             | 2598.7                  | 1134.8                      | 1661.8             | 2796.6                  | 2.8847                                    | 3.1169             | 6.0017                  |
| 265              | 5085.3                                  | 0.001289                                   | 0.038748                | 1153.3                             | 1443.2             | 2596.5                  | 1159.8                      | 1633.7             | 2793.5                  | 2.9304                                    | 3.0358             | 5.9662                  |
| 270              | 5503.0                                  | 0.001303                                   | 0.035622                | 1177.9                             | 1415.7             | 2593.7                  | 1185.1                      | 1604.6             | 2789.7                  | 2.9762                                    | 2.9542             | 5.9305                  |
| 275              | 5946.4                                  | 0.001317                                   | 0.032767                | 1202.9                             | 1387.4             | 2590.3                  | 1210.7                      | 1574.5             | 2785.2                  | 3.0221                                    | 2.8723             | 5.8944                  |
| 280              | 6416.6                                  | 0.001333                                   | 0.030153                | 1228.2                             | 1358.2             | 2586.4                  | 1236.7                      | 1543.2             | 2779.9                  | 3.0681                                    | 2.7898             | 5.8579                  |
| 285              | 6914.6                                  | 0.001349                                   | 0.027756                | 1253.7                             | 1328.1             | 2581.8                  | 1263.1                      | 1510.7             | 2773.7                  | 3.1144                                    | 2.7066             | 5.8210                  |
| 290              | 7441.8                                  | 0.001366                                   | 0.025554                | 1279.7                             | 1296.9             | 2576.5                  | 1289.8                      | 1476.9             | 2766.7                  | 3.1608                                    | 2.6225             | 5.7834                  |
| 295              | 7999.0                                  | 0.001384                                   | 0.023528                | 1306.0                             | 1264.5             | 2570.5                  | 1317.1                      | 1441.6             | 2758.7                  | 3.2076                                    | 2.5374             | 5.7450                  |
| 300              | 8587.9                                  | 0.001404                                   | 0.021659                | 1332.7                             | 1230.9             | 2563.6                  | 1344.8                      | 1404.8             | 2749.6                  | 3.2548                                    | 2.4511             | 5.7059                  |
| 305              | 9209.4                                  | 0.001425                                   | 0.019932                | 1360.0                             | 1195.9             | 2555.8                  | 1373.1                      | 1366.3             | 2739.4                  | 3.3024                                    | 2.3633             | 5.6657                  |
| 310              | 9865.0                                  | 0.001447                                   | 0.018333                | 1387.7                             | 1159.3             | 2547.1                  | 1402.0                      | 1325.9             | 2727.9                  | 3.3506                                    | 2.2737             | 5.6243                  |
| 315              | 10,556                                  | 0.001472                                   | 0.016849                | 1416.1                             | 1121.1             | 2537.2                  | 1431.6                      | 1283.4             | 2715.0                  | 3.3994                                    | 2.1821             | 5.5816                  |
| 320              | 11,284                                  | 0.001499                                   | 0.015470                | 1445.1                             | 1080.9             | 2526.0                  | 1462.0                      | 1238.5             | 2700.6                  | 3.4491                                    | 2.0881             | 5.5372                  |
| 325              | 12,051                                  | 0.001528                                   | 0.014183                | 1475.0                             | 1038.5             | 2513.4                  | 1493.4                      | 1191.0             | 2684.3                  | 3.4998                                    | 1.9911             | 5.4908                  |
| 330              | 12,858                                  | 0.001560                                   | 0.012979                | 1505.7                             | 993.5              | 2499.2                  | 1525.8                      | 1140.3             | 2666.0                  | 3.5516                                    | 1.8906             | 5.4422                  |
| 335              | 13,707                                  | 0.001597                                   | 0.011848                | 1537.5                             | 945.5              | 2483.0                  | 1559.4                      | 1086.0             | 2645.4                  | 3.6050                                    | 1.7857             | 5.3907                  |
| 340              | 14,601                                  | 0.001638                                   | 0.010783                | 1570.7                             | 893.8              | 2464.5                  | 1594.6                      | 1027.4             | 2622.0                  | 3.6602                                    | 1.6756             | 5.3358                  |
| 345              | 15,541                                  | 0.001685                                   | 0.009772                | 1605.5                             | 837.7              | 2443.2                  | 1631.7                      | 963.4              | 2595.1                  | 3.7179                                    | 1.5585             | 5.2765                  |
| 350              | 16,529                                  | 0.001741                                   | 0.008806                | 1642.4                             | 775.9              | 2418.3                  | 1671.2                      | 892.7              | 2563.9                  | 3.7788                                    | 1.4326             | 5.2114                  |
| 355              | 17,570                                  | 0.001808                                   | 0.007872                | 1682.2                             | 706.4              | 2388.6                  | 1714.0                      | 812.9              | 2526.9                  | 3.8442                                    | 1.2942             | 5.1384                  |
| 360              | 18,666                                  | 0.001895                                   | 0.006950                | 1726.2                             | 625.7              | 2351.9                  | 1761.5                      | 720.1              | 2481.6                  | 3.9165                                    | 1.1373             | 5.0537                  |
| 365              | 19,822                                  | 0.002015                                   | 0.006009                | 1777.2                             | 526.4              | 2303.6                  | 1817.2                      | 605.5              | 2422.7                  | 4.0004                                    | 0.9489             | 4.9493                  |
| 370              | 21,044                                  | 0.002217                                   | 0.004953                | 1844.5                             | 385.6              | 2230.1                  | 1891.2                      | 443.1              | 2334.3                  | 4.1119                                    | 0.6890             | 4.8009                  |
| 373.95           | 22,064                                  | 0.003106                                   | 0.003106                | 2015.7                             | 0                  | 2015.7                  | 2084.3                      | 0                  | 2084.3                  | 4.4070                                    | 0                  | 4.4070                  |

TABLE A-5

Saturated water—Pressure table

| Press.,<br><i>P</i> kPa | Sat.<br>temp.,<br><i>T</i> <sub>sat</sub> °C | Specific volume,<br>m <sup>3</sup> /kg   |   | Internal energy,<br>kJ/kg                |                                  |   | Enthalpy,<br>kJ/kg                       |                                  |   | Entropy,<br>kJ/kg · K                    |                                  |   |
|-------------------------|--|--|---|--|----------------------------------|---|--|----------------------------------|---|--|----------------------------------|---|
|                         |  | Sat.<br>liquid,<br><i>v</i> <sub>f</sub> | Sat.<br>vapor,<br><i>v</i> <sub>g</sub> | Sat.<br>liquid,<br><i>u</i> <sub>f</sub> | Evap.,<br><i>u</i> <sub>fg</sub> | Sat.<br>vapor,<br><i>u</i> <sub>g</sub> | Sat.<br>liquid,<br><i>h</i> <sub>f</sub> | Evap.,<br><i>h</i> <sub>fg</sub> | Sat.<br>vapor,<br><i>h</i> <sub>g</sub> | Sat.<br>liquid,<br><i>s</i> <sub>f</sub> | Evap.,<br><i>s</i> <sub>fg</sub> | Sat.<br>vapor,<br><i>s</i> <sub>g</sub> |
| 1.0                     | 6.97   | 0.001000                                 | 129.19                                  | 29.302                                   | 2355.2                           | 2384.5                                  | 29.303                                   | 2484.4                           | 2513.7                                  | 0.1059                                   | 8.8690                           | 8.9749                                  |
| 1.5                     | 13.02  | 0.001001                                 | 87.964                                  | 54.686                                   | 2338.1                           | 2392.8                                  | 54.688                                   | 2470.1                           | 2524.7                                  | 0.1956                                   | 8.6314                           | 8.8270                                  |
| 2.0                     | 17.50  | 0.001001                                 | 66.990                                  | 73.431                                   | 2325.5                           | 2398.9                                  | 73.433                                   | 2459.5                           | 2532.9                                  | 0.2606                                   | 8.4621                           | 8.7227                                  |
| 2.5                     | 21.08  | 0.001002                                 | 54.242                                  | 88.422                                   | 2315.4                           | 2403.8                                  | 88.424                                   | 2451.0                           | 2539.4                                  | 0.3118                                   | 8.3302                           | 8.6421                                  |
| 3.0                     | 24.08  | 0.001003                                 | 45.654                                  | 100.98                                   | 2306.9                           | 2407.9                                  | 100.98                                   | 2443.9                           | 2544.8                                  | 0.3543                                   | 8.2222                           | 8.5765                                  |
| 4.0                     | 28.96  | 0.001004                                 | 34.791                                  | 121.39                                   | 2293.1                           | 2414.5                                  | 121.39                                   | 2432.3                           | 2553.7                                  | 0.4224                                   | 8.0510                           | 8.4734                                  |
| 5.0                     | 32.87  | 0.001005                                 | 28.185                                  | 137.75                                   | 2282.1                           | 2419.8                                  | 137.75                                   | 2423.0                           | 2560.7                                  | 0.4762                                   | 7.9176                           | 8.3938                                  |
| 7.5                     | 40.29  | 0.001008                                 | 19.233                                  | 168.74                                   | 2261.1                           | 2429.8                                  | 168.75                                   | 2405.3                           | 2574.0                                  | 0.5763                                   | 7.6738                           | 8.2501                                  |
| 10                      | 45.81  | 0.001010                                 | 14.670                                  | 191.79                                   | 2245.4                           | 2437.2                                  | 191.81                                   | 2392.1                           | 2583.9                                  | 0.6492                                   | 7.4996                           | 8.1488                                  |
| 15                      | 53.97  | 0.001014                                 | 10.020                                  | 225.93                                   | 2222.1                           | 2448.0                                  | 225.94                                   | 2372.3                           | 2598.3                                  | 0.7549                                   | 7.2522                           | 8.0071                                  |
| 20                      | 60.06  | 0.001017                                 | 7.6481                                  | 251.40                                   | 2204.6                           | 2456.0                                  | 251.42                                   | 2357.5                           | 2608.9                                  | 0.8320                                   | 7.0752                           | 7.9073                                  |
| 25                      | 64.96  | 0.001020                                 | 6.2034                                  | 271.93                                   | 2190.4                           | 2462.4                                  | 271.96                                   | 2345.5                           | 2617.5                                  | 0.8932                                   | 6.9370                           | 7.8302                                  |
| 30                      | 69.09  | 0.001022                                 | 5.2287                                  | 289.24                                   | 2178.5                           | 2467.7                                  | 289.27                                   | 2335.3                           | 2624.6                                  | 0.9441                                   | 6.8234                           | 7.7675                                  |
| 40                      | 75.86  | 0.001026                                 | 3.9933                                  | 317.58                                   | 2158.8                           | 2476.3                                  | 317.62                                   | 2318.4                           | 2636.1                                  | 1.0261                                   | 6.6430                           | 7.6691                                  |
| 50                      | 81.32  | 0.001030                                 | 3.2403                                  | 340.49                                   | 2142.7                           | 2483.2                                  | 340.54                                   | 2304.7                           | 2645.2                                  | 1.0912                                   | 6.5019                           | 7.5931                                  |
| 75                      | 91.76  | 0.001037                                 | 2.2172                                  | 384.36                                   | 2111.8                           | 2496.1                                  | 384.44                                   | 2278.0                           | 2662.4                                  | 1.2132                                   | 6.2426                           | 7.4558                                  |
| 100                     | 99.61  | 0.001043                                 | 1.6941                                  | 417.40                                   | 2088.2                           | 2505.6                                  | 417.51                                   | 2257.5                           | 2675.0                                  | 1.3028                                   | 6.0562                           | 7.3589                                  |
| 101.325                 | 99.97  | 0.001043                                 | 1.6734                                  | 418.95                                   | 2087.0                           | 2506.0                                  | 419.06                                   | 2256.5                           | 2675.6                                  | 1.3069                                   | 6.0476                           | 7.3545                                  |
| 125                     | 105.97                                       | 0.001048                                 | 1.3750                                  | 444.23                                   | 2068.8                           | 2513.0                                  | 444.36                                   | 2240.6                           | 2684.9                                  | 1.3741                                   | 5.9100                           | 7.2841                                  |
| 150                     | 111.35                                       | 0.001053                                 | 1.1594                                  | 466.97                                   | 2052.3                           | 2519.2                                  | 467.13                                   | 2226.0                           | 2693.1                                  | 1.4337                                   | 5.7894                           | 7.2231                                  |
| 175                     | 116.04                                       | 0.001057                                 | 1.0037                                  | 486.82                                   | 2037.7                           | 2524.5                                  | 487.01                                   | 2213.1                           | 2700.2                                  | 1.4850                                   | 5.6865                           | 7.1716                                  |
| 200                     | 120.21                                       | 0.001061                                 | 0.88578                                 | 504.50                                   | 2024.6                           | 2529.1                                  | 504.71                                   | 2201.6                           | 2706.3                                  | 1.5302                                   | 5.5968                           | 7.1270                                  |
| 225                     | 123.97                                       | 0.001064                                 | 0.79329                                 | 520.47                                   | 2012.7                           | 2533.2                                  | 520.71                                   | 2191.0                           | 2711.7                                  | 1.5706                                   | 5.5171                           | 7.0877                                  |
| 250                     | 127.41                                       | 0.001067                                 | 0.71873                                 | 535.08                                   | 2001.8                           | 2536.8                                  | 535.35                                   | 2181.2                           | 2716.5                                  | 1.6072                                   | 5.4453                           | 7.0525                                  |
| 275                     | 130.58                                       | 0.001070                                 | 0.65732                                 | 548.57                                   | 1991.6                           | 2540.1                                  | 548.86                                   | 2172.0                           | 2720.9                                  | 1.6408                                   | 5.3800                           | 7.0207                                  |
| 300                     | 133.52                                       | 0.001073                                 | 0.60582                                 | 561.11                                   | 1982.1                           | 2543.2                                  | 561.43                                   | 2163.5                           | 2724.9                                  | 1.6717                                   | 5.3200                           | 6.9917                                  |
| 325                     | 136.27                                       | 0.001076                                 | 0.56199                                 | 572.84                                   | 1973.1                           | 2545.9                                  | 573.19                                   | 2155.4                           | 2728.6                                  | 1.7005                                   | 5.2645                           | 6.9650                                  |
| 350                     | 138.86                                       | 0.001079                                 | 0.52422                                 | 583.89                                   | 1964.6                           | 2548.5                                  | 584.26                                   | 2147.7                           | 2732.0                                  | 1.7274                                   | 5.2128                           | 6.9402                                  |
| 375                     | 141.30                                       | 0.001081                                 | 0.49133                                 | 594.32                                   | 1956.6                           | 2550.9                                  | 594.73                                   | 2140.4                           | 2735.1                                  | 1.7526                                   | 5.1645                           | 6.9171                                  |
| 400                     | 143.61                                       | 0.001084                                 | 0.46242                                 | 604.22                                   | 1948.9                           | 2553.1                                  | 604.66                                   | 2133.4                           | 2738.1                                  | 1.7765                                   | 5.1191                           | 6.8955                                  |
| 450                     | 147.90                                       | 0.001088                                 | 0.41392                                 | 622.65                                   | 1934.5                           | 2557.1                                  | 623.14                                   | 2120.3                           | 2743.4                                  | 1.8205                                   | 5.0356                           | 6.8561                                  |
| 500                     | 151.83                                       | 0.001093                                 | 0.37483                                 | 639.54                                   | 1921.2                           | 2560.7                                  | 640.09                                   | 2108.0                           | 2748.1                                  | 1.8604                                   | 4.9603                           | 6.8207                                  |
| 550                     | 155.46                                       | 0.001097                                 | 0.34261                                 | 655.16                                   | 1908.8                           | 2563.9                                  | 655.77                                   | 2096.6                           | 2752.4                                  | 1.8970                                   | 4.8916                           | 6.7886                                  |
| 600                     | 158.83                                       | 0.001101                                 | 0.31560                                 | 669.72                                   | 1897.1                           | 2566.8                                  | 670.38                                   | 2085.8                           | 2756.2                                  | 1.9308                                   | 4.8285                           | 6.7593                                  |
| 650                     | 161.98                                       | 0.001104                                 | 0.29260                                 | 683.37                                   | 1886.1                           | 2569.4                                  | 684.08                                   | 2075.5                           | 2759.6                                  | 1.9623                                   | 4.7699                           | 6.7322                                  |
| 700                     | 164.95                                       | 0.001108                                 | 0.27278                                 | 696.23                                   | 1875.6                           | 2571.8                                  | 697.00                                   | 2065.8                           | 2762.8                                  | 1.9918                                   | 4.7153                           | 6.7071                                  |
| 750                     | 167.75                                       | 0.001111                                 | 0.25552                                 | 708.40                                   | 1865.6                           | 2574.0                                  | 709.24                                   | 2056.4                           | 2765.7                                  | 2.0195                                   | 4.6642                           | 6.6837                                  |

TABLE A-5

Saturated water—Pressure table (*Continued*)

| Press.,<br><i>P</i> kPa | Sat.<br>temp.,<br><i>T</i> <sub>sat</sub> °C | Specific volume,<br>m <sup>3</sup> /kg          |  | Internal energy,<br>kJ/kg                       |   |  | Enthalpy,<br>kJ/kg                              |   |  | Entropy,<br>kJ/kg · K                           |   |  |
|-------------------------|--|---|--|---|---|--|---|---|--|---|---|--|
|                         |  | Sat.<br>liquid,<br><i>v</i> <sub><i>f</i></sub> | Sat.<br>vapor,<br><i>v</i> <sub><i>g</i></sub> | Sat.<br>liquid,<br><i>u</i> <sub><i>f</i></sub> | Evap.,<br><i>u</i> <sub><i>fg</i></sub> | Sat.<br>vapor,<br><i>u</i> <sub><i>g</i></sub> | Sat.<br>liquid,<br><i>h</i> <sub><i>f</i></sub> | Evap.,<br><i>h</i> <sub><i>fg</i></sub> | Sat.<br>vapor,<br><i>h</i> <sub><i>g</i></sub> | Sat.<br>liquid,<br><i>s</i> <sub><i>f</i></sub> | Evap.,<br><i>s</i> <sub><i>fg</i></sub> | Sat.<br>vapor,<br><i>s</i> <sub><i>g</i></sub> |
| 800                     | 170.41                                       | 0.001115  | 0.24035  | 719.97  | 1856.1                                  | 2576.0   | 720.87  | 2047.5                                  | 2768.3   | 2.0457  | 4.6160                                  | 6.6616   |
| 850                     | 172.94                                       | 0.001118  | 0.22690  | 731.00  | 1846.9                                  | 2577.9   | 731.95  | 2038.8                                  | 2770.8   | 2.0705  | 4.5705                                  | 6.6409   |
| 900                     | 175.35                                       | 0.001121  | 0.21489  | 741.55  | 1838.1                                  | 2579.6   | 742.56  | 2030.5                                  | 2773.0   | 2.0941  | 4.5273                                  | 6.6213   |
| 950                     | 177.66                                       | 0.001124  | 0.20411  | 751.67  | 1829.6                                  | 2581.3   | 752.74  | 2022.4                                  | 2775.2   | 2.1166  | 4.4862                                  | 6.6027   |
| 1000                    | 179.88                                       | 0.001127  | 0.19436  | 761.39  | 1821.4                                  | 2582.8   | 762.51  | 2014.6                                  | 2777.1   | 2.1381  | 4.4470                                  | 6.5850   |
| 1100                    | 184.06                                       | 0.001133  | 0.17745  | 779.78  | 1805.7                                  | 2585.5   | 781.03  | 1999.6                                  | 2780.7   | 2.1785  | 4.3735                                  | 6.5520   |
| 1200                    | 187.96                                       | 0.001138  | 0.16326  | 796.96  | 1790.9                                  | 2587.8   | 798.33  | 1985.4                                  | 2783.8   | 2.2159  | 4.3058                                  | 6.5217   |
| 1300                    | 191.60                                       | 0.001144  | 0.15119  | 813.10  | 1776.8                                  | 2589.9   | 814.59  | 1971.9                                  | 2786.5   | 2.2508  | 4.2428                                  | 6.4936   |
| 1400                    | 195.04                                       | 0.001149  | 0.14078  | 828.35  | 1763.4                                  | 2591.8   | 829.96  | 1958.9                                  | 2788.9   | 2.2835  | 4.1840                                  | 6.4675   |
| 1500                    | 198.29                                       | 0.001154  | 0.13171  | 842.82  | 1750.6                                  | 2593.4   | 844.55  | 1946.4                                  | 2791.0   | 2.3143  | 4.1287                                  | 6.4430   |
| 1750                    | 205.72                                       | 0.001166  | 0.11344  | 876.12  | 1720.6                                  | 2596.7   | 878.16  | 1917.1                                  | 2795.2   | 2.3844  | 4.0033                                  | 6.3877   |
| 2000                    | 212.38                                       | 0.001177  | 0.099587                                       | 906.12  | 1693.0                                  | 2599.1   | 908.47  | 1889.8                                  | 2798.3   | 2.4467  | 3.8923                                  | 6.3390   |
| 2250                    | 218.41                                       | 0.001187  | 0.088717                                       | 933.54  | 1667.3                                  | 2600.9   | 936.21  | 1864.3                                  | 2800.5   | 2.5029  | 3.7926                                  | 6.2954   |
| 2500                    | 223.95                                       | 0.001197  | 0.079952                                       | 958.87  | 1643.2                                  | 2602.1   | 961.87  | 1840.1                                  | 2801.9   | 2.5542  | 3.7016                                  | 6.2558   |
| 3000                    | 233.85                                       | 0.001217  | 0.066667                                       | 1004.6  | 1598.5                                  | 2603.2   | 1008.3  | 1794.9                                  | 2803.2   | 2.6454  | 3.5402                                  | 6.1856   |
| 3500                    | 242.56                                       | 0.001235  | 0.057061                                       | 1045.4  | 1557.6                                  | 2603.0   | 1049.7  | 1753.0                                  | 2802.7   | 2.7253  | 3.3991                                  | 6.1244   |
| 4000                    | 250.35                                       | 0.001252  | 0.049779                                       | 1082.4  | 1519.3                                  | 2601.7   | 1087.4  | 1713.5                                  | 2800.8   | 2.7966  | 3.2731                                  | 6.0696   |
| 5000                    | 263.94                                       | 0.001286  | 0.039448                                       | 1148.1  | 1448.9                                  | 2597.0   | 1154.5  | 1639.7                                  | 2794.2   | 2.9207  | 3.0530                                  | 5.9737   |
| 6000                    | 275.59                                       | 0.001319  | 0.032449                                       | 1205.8  | 1384.1                                  | 2589.9   | 1213.8  | 1570.9                                  | 2784.6   | 3.0275  | 2.8627                                  | 5.8902   |
| 7000                    | 285.83                                       | 0.001352  | 0.027378                                       | 1258.0  | 1323.0                                  | 2581.0   | 1267.5  | 1505.2                                  | 2772.6   | 3.1220  | 2.6927                                  | 5.8148   |
| 8000                    | 295.01                                       | 0.001384  | 0.023525                                       | 1306.0  | 1264.5                                  | 2570.5   | 1317.1  | 1441.6                                  | 2758.7   | 3.2077  | 2.5373                                  | 5.7450   |
| 9000                    | 303.35                                       | 0.001418  | 0.020489                                       | 1350.9  | 1207.6                                  | 2558.5   | 1363.7  | 1379.3                                  | 2742.9   | 3.2866  | 2.3925                                  | 5.6791   |
| 10,000                  | 311.00                                       | 0.001452  | 0.018028                                       | 1393.3  | 1151.8                                  | 2545.2   | 1407.8  | 1317.6                                  | 2725.5   | 3.3603  | 2.2556                                  | 5.6159   |
| 11,000                  | 318.08                                       | 0.001488  | 0.015988                                       | 1433.9  | 1096.6                                  | 2530.4   | 1450.2  | 1256.1                                  | 2706.3   | 3.4299  | 2.1245                                  | 5.5544   |
| 12,000                  | 324.68                                       | 0.001526  | 0.014264                                       | 1473.0  | 1041.3                                  | 2514.3   | 1491.3  | 1194.1                                  | 2685.4   | 3.4964  | 1.9975                                  | 5.4939   |
| 13,000                  | 330.85                                       | 0.001566  | 0.012781                                       | 1511.0  | 985.5                                   | 2496.6   | 1531.4  | 1131.3                                  | 2662.7   | 3.5606  | 1.8730                                  | 5.4336   |
| 14,000                  | 336.67                                       | 0.001610  | 0.011487                                       | 1548.4  | 928.7                                   | 2477.1   | 1571.0  | 1067.0                                  | 2637.9   | 3.6232  | 1.7497                                  | 5.3728   |
| 15,000                  | 342.16                                       | 0.001657  | 0.010341                                       | 1585.5  | 870.3                                   | 2455.7   | 1610.3  | 1000.5                                  | 2610.8   | 3.6848  | 1.6261                                  | 5.3108   |
| 16,000                  | 347.36                                       | 0.001710  | 0.009312                                       | 1622.6  | 809.4                                   | 2432.0   | 1649.9  | 931.1                                   | 2581.0   | 3.7461  | 1.5005                                  | 5.2466   |
| 17,000                  | 352.29                                       | 0.001770  | 0.008374                                       | 1660.2  | 745.1                                   | 2405.4   | 1690.3  | 857.4                                   | 2547.7   | 3.8082  | 1.3709                                  | 5.1791   |
| 18,000                  | 356.99                                       | 0.001840  | 0.007504                                       | 1699.1  | 675.9                                   | 2375.0   | 1732.2  | 777.8                                   | 2510.0   | 3.8720  | 1.2343                                  | 5.1064   |
| 19,000                  | 361.47                                       | 0.001926  | 0.006677                                       | 1740.3  | 598.9                                   | 2339.2   | 1776.8  | 689.2                                   | 2466.0   | 3.9396  | 1.0860                                  | 5.0256   |
| 20,000                  | 365.75                                       | 0.002038  | 0.005862                                       | 1785.8  | 509.0                                   | 2294.8   | 1826.6  | 585.5                                   | 2412.1   | 4.0146  | 0.9164                                  | 4.9310   |
| 21,000                  | 369.83                                       | 0.002207  | 0.004994                                       | 1841.6  | 391.9                                   | 2233.5   | 1888.0  | 450.4                                   | 2338.4   | 4.1071  | 0.7005                                  | 4.8076   |
| 22,000                  | 373.71                                       | 0.002703  | 0.003644                                       | 1951.7  | 140.8                                   | 2092.4   | 2011.1  | 161.5                                   | 2172.6   | 4.2942  | 0.2496                                  | 4.5439   |
| 22,064                  | 373.95                                       | 0.003106  | 0.003106                                       | 2015.7  | 0                                       | 2015.7   | 2084.3  | 0                                       | 2084.3   | 4.4070  | 0                                       | 4.4070   |



TABLE A-6

Superheated water

| $T$<br>°C                         | $\nu$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $\nu$<br>m <sup>3</sup> /kg       | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $\nu$<br>m <sup>3</sup> /kg       | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K |
|-----------------------------------|-----------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|
| $P = 0.01 \text{ MPa (45.81°C)*}$ |                             |              |              |                  | $P = 0.05 \text{ MPa (81.32°C)}$  |              |              |                  | $P = 0.10 \text{ MPa (99.61°C)}$  |              |              |                  |
| Sat. †                            | 14.670                      | 2437.2       | 2583.9       | 8.1488           | 3.2403                            | 2483.2       | 2645.2       | 7.5931           | 1.6941                            | 2505.6       | 2675.0       | 7.3589           |
| 50                                | 14.867                      | 2443.3       | 2592.0       | 8.1741           |                                   |              |              |                  |                                   |              |              |                  |
| 100                               | 17.196                      | 2515.5       | 2687.5       | 8.4489           | 3.4187                            | 2511.5       | 2682.4       | 7.6953           | 1.6959                            | 2506.2       | 2675.8       | 7.3611           |
| 150                               | 19.513                      | 2587.9       | 2783.0       | 8.6893           | 3.8897                            | 2585.7       | 2780.2       | 7.9413           | 1.9367                            | 2582.9       | 2776.6       | 7.6148           |
| 200                               | 21.826                      | 2661.4       | 2879.6       | 8.9049           | 4.3562                            | 2660.0       | 2877.8       | 8.1592           | 2.1724                            | 2658.2       | 2875.5       | 7.8356           |
| 250                               | 24.136                      | 2736.1       | 2977.5       | 9.1015           | 4.8206                            | 2735.1       | 2976.2       | 8.3568           | 2.4062                            | 2733.9       | 2974.5       | 8.0346           |
| 300                               | 26.446                      | 2812.3       | 3076.7       | 9.2827           | 5.2841                            | 2811.6       | 3075.8       | 8.5387           | 2.6389                            | 2810.7       | 3074.5       | 8.2172           |
| 400                               | 31.063                      | 2969.3       | 3280.0       | 9.6094           | 6.2094                            | 2968.9       | 3279.3       | 8.8659           | 3.1027                            | 2968.3       | 3278.6       | 8.5452           |
| 500                               | 35.680                      | 3132.9       | 3489.7       | 9.8998           | 7.1338                            | 3132.6       | 3489.3       | 9.1566           | 3.5655                            | 3132.2       | 3488.7       | 8.8362           |
| 600                               | 40.296                      | 3303.3       | 3706.3       | 10.1631          | 8.0577                            | 3303.1       | 3706.0       | 9.4201           | 4.0279                            | 3302.8       | 3705.6       | 9.0999           |
| 700                               | 44.911                      | 3480.8       | 3929.9       | 10.4056          | 8.9813                            | 3480.6       | 3929.7       | 9.6626           | 4.4900                            | 3480.4       | 3929.4       | 9.3424           |
| 800                               | 49.527                      | 3665.4       | 4160.6       | 10.6312          | 9.9047                            | 3665.2       | 4160.4       | 9.8883           | 4.9519                            | 3665.0       | 4160.2       | 9.5682           |
| 900                               | 54.143                      | 3856.9       | 4398.3       | 10.8429          | 10.8280                           | 3856.8       | 4398.2       | 10.1000          | 5.4137                            | 3856.7       | 4398.0       | 9.7800           |
| 1000                              | 58.758                      | 4055.3       | 4642.8       | 11.0429          | 11.7513                           | 4055.2       | 4642.7       | 10.3000          | 5.8755                            | 4055.0       | 4642.6       | 9.9800           |
| 1100                              | 63.373                      | 4260.0       | 4893.8       | 11.2326          | 12.6745                           | 4259.9       | 4893.7       | 10.4897          | 6.3372                            | 4259.8       | 4893.6       | 10.1698          |
| 1200                              | 67.989                      | 4470.9       | 5150.8       | 11.4132          | 13.5977                           | 4470.8       | 5150.7       | 10.6704          | 6.7988                            | 4470.7       | 5150.6       | 10.3504          |
| 1300                              | 72.604                      | 4687.4       | 5413.4       | 11.5857          | 14.5209                           | 4687.3       | 5413.3       | 10.8429          | 7.2605                            | 4687.2       | 5413.3       | 10.5229          |
| $P = 0.20 \text{ MPa (120.21°C)}$ |                             |              |              |                  | $P = 0.30 \text{ MPa (133.52°C)}$ |              |              |                  | $P = 0.40 \text{ MPa (143.61°C)}$ |              |              |                  |
| Sat.                              | 0.88578                     | 2529.1       | 2706.3       | 7.1270           | 0.60582                           | 2543.2       | 2724.9       | 6.9917           | 0.46242                           | 2553.1       | 2738.1       | 6.8955           |
| 150                               | 0.95986                     | 2577.1       | 2769.1       | 7.2810           | 0.63402                           | 2571.0       | 2761.2       | 7.0792           | 0.47088                           | 2564.4       | 2752.8       | 6.9306           |
| 200                               | 1.08049                     | 2654.6       | 2870.7       | 7.5081           | 0.71643                           | 2651.0       | 2865.9       | 7.3132           | 0.53434                           | 2647.2       | 2860.9       | 7.1723           |
| 250                               | 1.19890                     | 2731.4       | 2971.2       | 7.7100           | 0.79645                           | 2728.9       | 2967.9       | 7.5180           | 0.59520                           | 2726.4       | 2964.5       | 7.3804           |
| 300                               | 1.31623                     | 2808.8       | 3072.1       | 7.8941           | 0.87535                           | 2807.0       | 3069.6       | 7.7037           | 0.65489                           | 2805.1       | 3067.1       | 7.5677           |
| 400                               | 1.54934                     | 2967.2       | 3277.0       | 8.2236           | 1.03155                           | 2966.0       | 3275.5       | 8.0347           | 0.77265                           | 2964.9       | 3273.9       | 7.9003           |
| 500                               | 1.78142                     | 3131.4       | 3487.7       | 8.5153           | 1.18672                           | 3130.6       | 3486.6       | 8.3271           | 0.88936                           | 3129.8       | 3485.5       | 8.1933           |
| 600                               | 2.01302                     | 3302.2       | 3704.8       | 8.7793           | 1.34139                           | 3301.6       | 3704.0       | 8.5915           | 1.00558                           | 3301.0       | 3703.3       | 8.4580           |
| 700                               | 2.24434                     | 3479.9       | 3928.8       | 9.0221           | 1.49580                           | 3479.5       | 3928.2       | 8.8345           | 1.12152                           | 3479.0       | 3927.6       | 8.7012           |
| 800                               | 2.47550                     | 3664.7       | 4159.8       | 9.2479           | 1.65004                           | 3664.3       | 4159.3       | 9.0605           | 1.23730                           | 3663.9       | 4158.9       | 8.9274           |
| 900                               | 2.70656                     | 3856.3       | 4397.7       | 9.4598           | 1.80417                           | 3856.0       | 4397.3       | 9.2725           | 1.35298                           | 3855.7       | 4396.9       | 9.1394           |
| 1000                              | 2.93755                     | 4054.8       | 4642.3       | 9.6599           | 1.95824                           | 4054.5       | 4642.0       | 9.4726           | 1.46859                           | 4054.3       | 4641.7       | 9.3396           |
| 1100                              | 3.16848                     | 4259.6       | 4893.3       | 9.8497           | 2.11226                           | 4259.4       | 4893.1       | 9.6624           | 1.58414                           | 4259.2       | 4892.9       | 9.5295           |
| 1200                              | 3.39938                     | 4470.5       | 5150.4       | 10.0304          | 2.26624                           | 4470.3       | 5150.2       | 9.8431           | 1.69966                           | 4470.2       | 5150.0       | 9.7102           |
| 1300                              | 3.63026                     | 4687.1       | 5413.1       | 10.2029          | 2.42019                           | 4686.9       | 5413.0       | 10.0157          | 1.81516                           | 4686.7       | 5412.8       | 9.8828           |
| $P = 0.50 \text{ MPa (151.83°C)}$ |                             |              |              |                  | $P = 0.60 \text{ MPa (158.83°C)}$ |              |              |                  | $P = 0.80 \text{ MPa (170.41°C)}$ |              |              |                  |
| Sat.                              | 0.37483                     | 2560.7       | 2748.1       | 6.8207           | 0.31560                           | 2566.8       | 2756.2       | 6.7593           | 0.24035                           | 2576.0       | 2768.3       | 6.6616           |
| 200                               | 0.42503                     | 2643.3       | 2855.8       | 7.0610           | 0.35212                           | 2639.4       | 2850.6       | 6.9683           | 0.26088                           | 2631.1       | 2839.8       | 6.8177           |
| 250                               | 0.47443                     | 2723.8       | 2961.0       | 7.2725           | 0.39390                           | 2721.2       | 2957.6       | 7.1833           | 0.29321                           | 2715.9       | 2950.4       | 7.0402           |
| 300                               | 0.52261                     | 2803.3       | 3064.6       | 7.4614           | 0.43442                           | 2801.4       | 3062.0       | 7.3740           | 0.32416                           | 2797.5       | 3056.9       | 7.2345           |
| 350                               | 0.57015                     | 2883.0       | 3168.1       | 7.6346           | 0.47428                           | 2881.6       | 3166.1       | 7.5481           | 0.35442                           | 2878.6       | 3162.2       | 7.4107           |
| 400                               | 0.61731                     | 2963.7       | 3272.4       | 7.7956           | 0.51374                           | 2962.5       | 3270.8       | 7.7097           | 0.38429                           | 2960.2       | 3267.7       | 7.5735           |
| 500                               | 0.71095                     | 3129.0       | 3484.5       | 8.0893           | 0.59200                           | 3128.2       | 3483.4       | 8.0041           | 0.44332                           | 3126.6       | 3481.3       | 7.8692           |
| 600                               | 0.80409                     | 3300.4       | 3702.5       | 8.3544           | 0.66976                           | 3299.8       | 3701.7       | 8.2695           | 0.50186                           | 3298.7       | 3700.1       | 8.1354           |
| 700                               | 0.89696                     | 3478.6       | 3927.0       | 8.5978           | 0.74725                           | 3478.1       | 3926.4       | 8.5132           | 0.56011                           | 3477.2       | 3925.3       | 8.3794           |
| 800                               | 0.98966                     | 3663.6       | 4158.4       | 8.8240           | 0.82457                           | 3663.2       | 4157.9       | 8.7395           | 0.61820                           | 3662.5       | 4157.0       | 8.6061           |
| 900                               | 1.08227                     | 3855.4       | 4396.6       | 9.0362           | 0.90179                           | 3855.1       | 4396.2       | 8.9518           | 0.67619                           | 3854.5       | 4395.5       | 8.8185           |
| 1000                              | 1.17480                     | 4054.0       | 4641.4       | 9.2364           | 0.97893                           | 4053.8       | 4641.1       | 9.1521           | 0.73411                           | 4053.3       | 4640.5       | 9.0189           |
| 1100                              | 1.26728                     | 4259.0       | 4892.6       | 9.4263           | 1.05603                           | 4258.8       | 4892.4       | 9.3420           | 0.79197                           | 4258.3       | 4891.9       | 9.2090           |
| 1200                              | 1.35972                     | 4470.0       | 5149.8       | 9.6071           | 1.13309                           | 4469.8       | 5149.6       | 9.5229           | 0.84980                           | 4469.4       | 5149.3       | 9.3898           |
| 1300                              | 1.45214                     | 4686.6       | 5412.6       | 9.7797           | 1.21012                           | 4686.4       | 5412.5       | 9.6955           | 0.90761                           | 4686.1       | 5412.2       | 9.5625           |

TABLE A-6

Superheated water (*Continued*)

| $T$<br>°C                         | $v$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K |
|-----------------------------------|---------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|
| $P = 1.00 \text{ MPa (179.88°C)}$ |                           |              |              |                  | $P = 1.20 \text{ MPa (187.96°C)}$ |              |              |                  | $P = 1.40 \text{ MPa (195.04°C)}$ |              |              |                  |
| Sat.                              | 0.19437                   | 2582.8       | 2777.1       | 6.5850           | 0.16326                           | 2587.8       | 2783.8       | 6.5217           | 0.14078                           | 2591.8       | 2788.9       | 6.4675           |
| 200                               | 0.20602                   | 2622.3       | 2828.3       | 6.6956           | 0.16934                           | 2612.9       | 2816.1       | 6.5909           | 0.14303                           | 2602.7       | 2803.0       | 6.4975           |
| 250                               | 0.23275                   | 2710.4       | 2943.1       | 6.9265           | 0.19241                           | 2704.7       | 2935.6       | 6.8313           | 0.16356                           | 2698.9       | 2927.9       | 6.7488           |
| 300                               | 0.25799                   | 2793.7       | 3051.6       | 7.1246           | 0.21386                           | 2789.7       | 3046.3       | 7.0335           | 0.18233                           | 2785.7       | 3040.9       | 6.9553           |
| 350                               | 0.28250                   | 2875.7       | 3158.2       | 7.3029           | 0.23455                           | 2872.7       | 3154.2       | 7.2139           | 0.20029                           | 2869.7       | 3150.1       | 7.1379           |
| 400                               | 0.30661                   | 2957.9       | 3264.5       | 7.4670           | 0.25482                           | 2955.5       | 3261.3       | 7.3793           | 0.21782                           | 2953.1       | 3258.1       | 7.3046           |
| 500                               | 0.35411                   | 3125.0       | 3479.1       | 7.7642           | 0.29464                           | 3123.4       | 3477.0       | 7.6779           | 0.25216                           | 3121.8       | 3474.8       | 7.6047           |
| 600                               | 0.40111                   | 3297.5       | 3698.6       | 8.0311           | 0.33395                           | 3296.3       | 3697.0       | 7.9456           | 0.28597                           | 3295.1       | 3695.5       | 7.8730           |
| 700                               | 0.44783                   | 3476.3       | 3924.1       | 8.2755           | 0.37297                           | 3475.3       | 3922.9       | 8.1904           | 0.31951                           | 3474.4       | 3921.7       | 8.1183           |
| 800                               | 0.49438                   | 3661.7       | 4156.1       | 8.5024           | 0.41184                           | 3661.0       | 4155.2       | 8.4176           | 0.35288                           | 3660.3       | 4154.3       | 8.3458           |
| 900                               | 0.54083                   | 3853.9       | 4394.8       | 8.7150           | 0.45059                           | 3853.3       | 4394.0       | 8.6303           | 0.38614                           | 3852.7       | 4393.3       | 8.5587           |
| 1000                              | 0.58721                   | 4052.7       | 4640.0       | 8.9155           | 0.48928                           | 4052.2       | 4639.4       | 8.8310           | 0.41933                           | 4051.7       | 4638.8       | 8.7595           |
| 1100                              | 0.63354                   | 4257.9       | 4891.4       | 9.1057           | 0.52792                           | 4257.5       | 4891.0       | 9.0212           | 0.45247                           | 4257.0       | 4890.5       | 8.9497           |
| 1200                              | 0.67983                   | 4469.0       | 5148.9       | 9.2866           | 0.56652                           | 4468.7       | 5148.5       | 9.2022           | 0.48558                           | 4468.3       | 5148.1       | 9.1308           |
| 1300                              | 0.72610                   | 4685.8       | 5411.9       | 9.4593           | 0.60509                           | 4685.5       | 5411.6       | 9.3750           | 0.51866                           | 4685.1       | 5411.3       | 9.3036           |
| $P = 1.60 \text{ MPa (201.37°C)}$ |                           |              |              |                  | $P = 1.80 \text{ MPa (207.11°C)}$ |              |              |                  | $P = 2.00 \text{ MPa (212.38°C)}$ |              |              |                  |
| Sat.                              | 0.12374                   | 2594.8       | 2792.8       | 6.4200           | 0.11037                           | 2597.3       | 2795.9       | 6.3775           | 0.09959                           | 2599.1       | 2798.3       | 6.3390           |
| 225                               | 0.13293                   | 2645.1       | 2857.8       | 6.5537           | 0.11678                           | 2637.0       | 2847.2       | 6.4825           | 0.10381                           | 2628.5       | 2836.1       | 6.4160           |
| 250                               | 0.14190                   | 2692.9       | 2919.9       | 6.6753           | 0.12502                           | 2686.7       | 2911.7       | 6.6088           | 0.11150                           | 2680.3       | 2903.3       | 6.5475           |
| 300                               | 0.15866                   | 2781.6       | 3035.4       | 6.8864           | 0.14025                           | 2777.4       | 3029.9       | 6.8246           | 0.12551                           | 2773.2       | 3024.2       | 6.7684           |
| 350                               | 0.17459                   | 2866.6       | 3146.0       | 7.0713           | 0.15460                           | 2863.6       | 3141.9       | 7.0120           | 0.13860                           | 2860.5       | 3137.7       | 6.9583           |
| 400                               | 0.19007                   | 2950.8       | 3254.9       | 7.2394           | 0.16849                           | 2948.3       | 3251.6       | 7.1814           | 0.15122                           | 2945.9       | 3248.4       | 7.1292           |
| 500                               | 0.22029                   | 3120.1       | 3472.6       | 7.5410           | 0.19551                           | 3118.5       | 3470.4       | 7.4845           | 0.17568                           | 3116.9       | 3468.3       | 7.4337           |
| 600                               | 0.24999                   | 3293.9       | 3693.9       | 7.8101           | 0.22200                           | 3292.7       | 3692.3       | 7.7543           | 0.19962                           | 3291.5       | 3690.7       | 7.7043           |
| 700                               | 0.27941                   | 3473.5       | 3920.5       | 8.0558           | 0.24822                           | 3472.6       | 3919.4       | 8.0005           | 0.22326                           | 3471.7       | 3918.2       | 7.9509           |
| 800                               | 0.30865                   | 3659.5       | 4153.4       | 8.2834           | 0.27426                           | 3658.8       | 4152.4       | 8.2284           | 0.24674                           | 3658.0       | 4151.5       | 8.1791           |
| 900                               | 0.33780                   | 3852.1       | 4392.6       | 8.4965           | 0.30020                           | 3851.5       | 4391.9       | 8.4417           | 0.27012                           | 3850.9       | 4391.1       | 8.3925           |
| 1000                              | 0.36687                   | 4051.2       | 4638.2       | 8.6974           | 0.32606                           | 4050.7       | 4637.6       | 8.6427           | 0.29342                           | 4050.2       | 4637.1       | 8.5936           |
| 1100                              | 0.39589                   | 4256.6       | 4890.0       | 8.8878           | 0.35188                           | 4256.2       | 4889.6       | 8.8331           | 0.31667                           | 4255.7       | 4889.1       | 8.7842           |
| 1200                              | 0.42488                   | 4467.9       | 5147.7       | 9.0689           | 0.37766                           | 4467.6       | 5147.3       | 9.0143           | 0.33989                           | 4467.2       | 5147.0       | 8.9654           |
| 1300                              | 0.45383                   | 4684.8       | 5410.9       | 9.2418           | 0.40341                           | 4684.5       | 5410.6       | 9.1872           | 0.36308                           | 4684.2       | 5410.3       | 9.1384           |
| $P = 2.50 \text{ MPa (223.95°C)}$ |                           |              |              |                  | $P = 3.00 \text{ MPa (233.85°C)}$ |              |              |                  | $P = 3.50 \text{ MPa (242.56°C)}$ |              |              |                  |
| Sat.                              | 0.07995                   | 2602.1       | 2801.9       | 6.2558           | 0.06667                           | 2603.2       | 2803.2       | 6.1856           | 0.05706                           | 2603.0       | 2802.7       | 6.1244           |
| 225                               | 0.08026                   | 2604.8       | 2805.5       | 6.2629           |                                   |              |              |                  |                                   |              |              |                  |
| 250                               | 0.08705                   | 2663.3       | 2880.9       | 6.4107           | 0.07063                           | 2644.7       | 2856.5       | 6.2893           | 0.05876                           | 2624.0       | 2829.7       | 6.1764           |
| 300                               | 0.09894                   | 2762.2       | 3009.6       | 6.6459           | 0.08118                           | 2750.8       | 2994.3       | 6.5412           | 0.06845                           | 2738.8       | 2978.4       | 6.4484           |
| 350                               | 0.10979                   | 2852.5       | 3127.0       | 6.8424           | 0.09056                           | 2844.4       | 3116.1       | 6.7450           | 0.07680                           | 2836.0       | 3104.9       | 6.6601           |
| 400                               | 0.12012                   | 2939.8       | 3240.1       | 7.0170           | 0.09938                           | 2933.6       | 3231.7       | 6.9235           | 0.08456                           | 2927.2       | 3223.2       | 6.8428           |
| 450                               | 0.13015                   | 3026.2       | 3351.6       | 7.1768           | 0.10789                           | 3021.2       | 3344.9       | 7.0856           | 0.09198                           | 3016.1       | 3338.1       | 7.0074           |
| 500                               | 0.13999                   | 3112.8       | 3462.8       | 7.3254           | 0.11620                           | 3108.6       | 3457.2       | 7.2359           | 0.09919                           | 3104.5       | 3451.7       | 7.1593           |
| 600                               | 0.15931                   | 3288.5       | 3686.8       | 7.5979           | 0.13245                           | 3285.5       | 3682.8       | 7.5103           | 0.11325                           | 3282.5       | 3678.9       | 7.4357           |
| 700                               | 0.17835                   | 3469.3       | 3915.2       | 7.8455           | 0.14841                           | 3467.0       | 3912.2       | 7.7590           | 0.12702                           | 3464.7       | 3909.3       | 7.6855           |
| 800                               | 0.19722                   | 3656.2       | 4149.2       | 8.0744           | 0.16420                           | 3654.3       | 4146.9       | 7.9885           | 0.14061                           | 3652.5       | 4144.6       | 7.9156           |
| 900                               | 0.21597                   | 3849.4       | 4389.3       | 8.2882           | 0.17988                           | 3847.9       | 4387.5       | 8.2028           | 0.15410                           | 3846.4       | 4385.7       | 8.1304           |
| 1000                              | 0.23466                   | 4049.0       | 4635.6       | 8.4897           | 0.19549                           | 4047.7       | 4634.2       | 8.4045           | 0.16751                           | 4046.4       | 4632.7       | 8.3324           |
| 1100                              | 0.25330                   | 4254.7       | 4887.9       | 8.6804           | 0.21105                           | 4253.6       | 4886.7       | 8.5955           | 0.18087                           | 4252.5       | 4885.6       | 8.5236           |
| 1200                              | 0.27190                   | 4466.3       | 5146.0       | 8.8618           | 0.22658                           | 4465.3       | 5145.1       | 8.7771           | 0.19420                           | 4464.4       | 5144.1       | 8.7053           |
| 1300                              | 0.29048                   | 4683.4       | 5409.5       | 9.0349           | 0.24207                           | 4682.6       | 5408.8       | 8.9502           | 0.20750                           | 4681.8       | 5408.0       | 8.8786           |



TABLE A-6

Superheated water (*Continued*)

| $T$<br>°C                        | $v$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K |
|----------------------------------|---------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|
| $P = 4.0 \text{ MPa (250.35°C)}$ |                           |              |              |                  | $P = 4.5 \text{ MPa (257.44°C)}$  |              |              |                  | $P = 5.0 \text{ MPa (263.94°C)}$  |              |              |                  |
| Sat.                             | 0.04978                   | 2601.7       | 2800.8       | 6.0696           | 0.04406                           | 2599.7       | 2798.0       | 6.0198           | 0.03945                           | 2597.0       | 2794.2       | 5.9737           |
| 275                              | 0.05461                   | 2668.9       | 2887.3       | 6.2312           | 0.04733                           | 2651.4       | 2864.4       | 6.1429           | 0.04144                           | 2632.3       | 2839.5       | 6.0571           |
| 300                              | 0.05887                   | 2726.2       | 2961.7       | 6.3639           | 0.05138                           | 2713.0       | 2944.2       | 6.2854           | 0.04535                           | 2699.0       | 2925.7       | 6.2111           |
| 350                              | 0.06647                   | 2827.4       | 3093.3       | 6.5843           | 0.05842                           | 2818.6       | 3081.5       | 6.5153           | 0.05197                           | 2809.5       | 3069.3       | 6.4516           |
| 400                              | 0.07343                   | 2920.8       | 3214.5       | 6.7714           | 0.06477                           | 2914.2       | 3205.7       | 6.7071           | 0.05784                           | 2907.5       | 3196.7       | 6.6483           |
| 450                              | 0.08004                   | 3011.0       | 3331.2       | 6.9386           | 0.07076                           | 3005.8       | 3324.2       | 6.8770           | 0.06332                           | 3000.6       | 3317.2       | 6.8210           |
| 500                              | 0.08644                   | 3100.3       | 3446.0       | 7.0922           | 0.07652                           | 3096.0       | 3440.4       | 7.0323           | 0.06858                           | 3091.8       | 3434.7       | 6.9781           |
| 600                              | 0.09886                   | 3279.4       | 3674.9       | 7.3706           | 0.08766                           | 3276.4       | 3670.9       | 7.3127           | 0.07870                           | 3273.3       | 3666.9       | 7.2605           |
| 700                              | 0.11098                   | 3462.4       | 3906.3       | 7.6214           | 0.09850                           | 3460.0       | 3903.3       | 7.5647           | 0.08852                           | 3457.7       | 3900.3       | 7.5136           |
| 800                              | 0.12292                   | 3650.6       | 4142.3       | 7.8523           | 0.10916                           | 3648.8       | 4140.0       | 7.7962           | 0.09816                           | 3646.9       | 4137.7       | 7.7458           |
| 900                              | 0.13476                   | 3844.8       | 4383.9       | 8.0675           | 0.11972                           | 3843.3       | 4382.1       | 8.0118           | 0.10769                           | 3841.8       | 4380.2       | 7.9619           |
| 1000                             | 0.14653                   | 4045.1       | 4631.2       | 8.2698           | 0.13020                           | 4043.9       | 4629.8       | 8.2144           | 0.11715                           | 4042.6       | 4628.3       | 8.1648           |
| 1100                             | 0.15824                   | 4251.4       | 4884.4       | 8.4612           | 0.14064                           | 4250.4       | 4883.2       | 8.4060           | 0.12655                           | 4249.3       | 4882.1       | 8.3566           |
| 1200                             | 0.16992                   | 4463.5       | 5143.2       | 8.6430           | 0.15103                           | 4462.6       | 5142.2       | 8.5880           | 0.13592                           | 4461.6       | 5141.3       | 8.5388           |
| 1300                             | 0.18157                   | 4680.9       | 5407.2       | 8.8164           | 0.16140                           | 4680.1       | 5406.5       | 8.7616           | 0.14527                           | 4679.3       | 5405.7       | 8.7124           |
| $P = 6.0 \text{ MPa (275.59°C)}$ |                           |              |              |                  | $P = 7.0 \text{ MPa (285.83°C)}$  |              |              |                  | $P = 8.0 \text{ MPa (295.01°C)}$  |              |              |                  |
| Sat.                             | 0.03245                   | 2589.9       | 2784.6       | 5.8902           | 0.027378                          | 2581.0       | 2772.6       | 5.8148           | 0.023525                          | 2570.5       | 2758.7       | 5.7450           |
| 300                              | 0.03619                   | 2668.4       | 2885.6       | 6.0703           | 0.029492                          | 2633.5       | 2839.9       | 5.9337           | 0.024279                          | 2592.3       | 2786.5       | 5.7937           |
| 350                              | 0.04225                   | 2790.4       | 3043.9       | 6.3357           | 0.035262                          | 2770.1       | 3016.9       | 6.2305           | 0.029975                          | 2748.3       | 2988.1       | 6.1321           |
| 400                              | 0.04742                   | 2893.7       | 3178.3       | 6.5432           | 0.039958                          | 2879.5       | 3159.2       | 6.4502           | 0.034344                          | 2864.6       | 3139.4       | 6.3658           |
| 450                              | 0.05217                   | 2989.9       | 3302.9       | 6.7219           | 0.044187                          | 2979.0       | 3288.3       | 6.6353           | 0.038194                          | 2967.8       | 3273.3       | 6.5579           |
| 500                              | 0.05667                   | 3083.1       | 3423.1       | 6.8826           | 0.048157                          | 3074.3       | 3411.4       | 6.8000           | 0.041767                          | 3065.4       | 3399.5       | 6.7266           |
| 550                              | 0.06102                   | 3175.2       | 3541.3       | 7.0308           | 0.051966                          | 3167.9       | 3531.6       | 6.9507           | 0.045172                          | 3160.5       | 3521.8       | 6.8800           |
| 600                              | 0.06527                   | 3267.2       | 3658.8       | 7.1693           | 0.055665                          | 3261.0       | 3650.6       | 7.0910           | 0.048463                          | 3254.7       | 3642.4       | 7.0221           |
| 700                              | 0.07355                   | 3453.0       | 3894.3       | 7.4247           | 0.062850                          | 3448.3       | 3888.3       | 7.3487           | 0.054829                          | 3443.6       | 3882.2       | 7.2822           |
| 800                              | 0.08165                   | 3643.2       | 4133.1       | 7.6582           | 0.069856                          | 3639.5       | 4128.5       | 7.5836           | 0.061011                          | 3635.7       | 4123.8       | 7.5185           |
| 900                              | 0.08964                   | 3838.8       | 4376.6       | 7.8751           | 0.076750                          | 3835.7       | 4373.0       | 7.8014           | 0.067082                          | 3832.7       | 4369.3       | 7.7372           |
| 1000                             | 0.09756                   | 4040.1       | 4625.4       | 8.0786           | 0.083571                          | 4037.5       | 4622.5       | 8.0055           | 0.073079                          | 4035.0       | 4619.6       | 7.9419           |
| 1100                             | 0.10543                   | 4247.1       | 4879.7       | 8.2709           | 0.090341                          | 4245.0       | 4877.4       | 8.1982           | 0.079025                          | 4242.8       | 4875.0       | 8.1350           |
| 1200                             | 0.11326                   | 4459.8       | 5139.4       | 8.4534           | 0.097075                          | 4457.9       | 5137.4       | 8.3810           | 0.084934                          | 4456.1       | 5135.5       | 8.3181           |
| 1300                             | 0.12107                   | 4677.7       | 5404.1       | 8.6273           | 0.103781                          | 4676.1       | 5402.6       | 8.5551           | 0.090817                          | 4674.5       | 5401.0       | 8.4925           |
| $P = 9.0 \text{ MPa (303.35°C)}$ |                           |              |              |                  | $P = 10.0 \text{ MPa (311.00°C)}$ |              |              |                  | $P = 12.5 \text{ MPa (327.81°C)}$ |              |              |                  |
| Sat.                             | 0.020489                  | 2558.5       | 2742.9       | 5.6791           | 0.018028                          | 2545.2       | 2725.5       | 5.6159           | 0.013496                          | 2505.6       | 2674.3       | 5.4638           |
| 325                              | 0.023284                  | 2647.6       | 2857.1       | 5.8738           | 0.019877                          | 2611.6       | 2810.3       | 5.7596           |                                   |              |              |                  |
| 350                              | 0.025816                  | 2725.0       | 2957.3       | 6.0380           | 0.022440                          | 2699.6       | 2924.0       | 5.9460           | 0.016138                          | 2624.9       | 2826.6       | 5.7130           |
| 400                              | 0.029960                  | 2849.2       | 3118.8       | 6.2876           | 0.026436                          | 2833.1       | 3097.5       | 6.2141           | 0.020030                          | 2789.6       | 3040.0       | 6.0433           |
| 450                              | 0.033524                  | 2956.3       | 3258.0       | 6.4872           | 0.029782                          | 2944.5       | 3242.4       | 6.4219           | 0.023019                          | 2913.7       | 3201.5       | 6.2749           |
| 500                              | 0.036793                  | 3056.3       | 3387.4       | 6.6603           | 0.032811                          | 3047.0       | 3375.1       | 6.5995           | 0.025630                          | 3023.2       | 3343.6       | 6.4651           |
| 550                              | 0.039885                  | 3153.0       | 3512.0       | 6.8164           | 0.035655                          | 3145.4       | 3502.0       | 6.7585           | 0.028033                          | 3126.1       | 3476.5       | 6.6317           |
| 600                              | 0.042861                  | 3248.4       | 3634.1       | 6.9605           | 0.038378                          | 3242.0       | 3625.8       | 6.9045           | 0.030306                          | 3225.8       | 3604.6       | 6.7828           |
| 650                              | 0.045755                  | 3343.4       | 3755.2       | 7.0954           | 0.041018                          | 3338.0       | 3748.1       | 7.0408           | 0.032491                          | 3324.1       | 3730.2       | 6.9227           |
| 700                              | 0.048589                  | 3438.8       | 3876.1       | 7.2229           | 0.043597                          | 3434.0       | 3870.0       | 7.1693           | 0.034612                          | 3422.0       | 3854.6       | 7.0540           |
| 800                              | 0.054132                  | 3632.0       | 4119.2       | 7.4606           | 0.048629                          | 3628.2       | 4114.5       | 7.4085           | 0.038724                          | 3618.8       | 4102.8       | 7.2967           |
| 900                              | 0.059562                  | 3829.6       | 4365.7       | 7.6802           | 0.053547                          | 3826.5       | 4362.0       | 7.6290           | 0.042720                          | 3818.9       | 4352.9       | 7.5195           |
| 1000                             | 0.064919                  | 4032.4       | 4616.7       | 7.8855           | 0.058391                          | 4029.9       | 4613.8       | 7.8349           | 0.046641                          | 4023.5       | 4606.5       | 7.7269           |
| 1100                             | 0.070224                  | 4240.7       | 4872.7       | 8.0791           | 0.063183                          | 4238.5       | 4870.3       | 8.0289           | 0.050510                          | 4233.1       | 4864.5       | 7.9220           |
| 1200                             | 0.075492                  | 4454.2       | 5133.6       | 8.2625           | 0.067938                          | 4452.4       | 5131.7       | 8.2126           | 0.054342                          | 4447.7       | 5127.0       | 8.1065           |
| 1300                             | 0.080733                  | 4672.9       | 5399.5       | 8.4371           | 0.072667                          | 4671.3       | 5398.0       | 8.3874           | 0.058147                          | 4667.3       | 5394.1       | 8.2819           |

TABLE A-6

Superheated water (*Concluded*)

| $T$<br>°C                         | $v$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K |
|-----------------------------------|---------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|
| $P = 15.0 \text{ MPa (342.16°C)}$ |                           |              |              |                  | $P = 17.5 \text{ MPa (354.67°C)}$ |              |              |                  | $P = 20.0 \text{ MPa (365.75°C)}$ |              |              |                  |
| Sat.                              | 0.010341                  | 2455.7       | 2610.8       | 5.3108           | 0.007932                          | 2390.7       | 2529.5       | 5.1435           | 0.005862                          | 2294.8       | 2412.1       | 4.9310           |
| 350                               | 0.011481                  | 2520.9       | 2693.1       | 5.4438           |                                   |              |              |                  |                                   |              |              |                  |
| 400                               | 0.015671                  | 2740.6       | 2975.7       | 5.8819           | 0.012463                          | 2684.3       | 2902.4       | 5.7211           | 0.009950                          | 2617.9       | 2816.9       | 5.5526           |
| 450                               | 0.018477                  | 2880.8       | 3157.9       | 6.1434           | 0.015204                          | 2845.4       | 3111.4       | 6.0212           | 0.012721                          | 2807.3       | 3061.7       | 5.9043           |
| 500                               | 0.020828                  | 2998.4       | 3310.8       | 6.3480           | 0.017385                          | 2972.4       | 3276.7       | 6.2424           | 0.014793                          | 2945.3       | 3241.2       | 6.1446           |
| 550                               | 0.022945                  | 3106.2       | 3450.4       | 6.5230           | 0.019305                          | 3085.8       | 3423.6       | 6.4266           | 0.016571                          | 3064.7       | 3396.2       | 6.3390           |
| 600                               | 0.024921                  | 3209.3       | 3583.1       | 6.6796           | 0.021073                          | 3192.5       | 3561.3       | 6.5890           | 0.018185                          | 3175.3       | 3539.0       | 6.5075           |
| 650                               | 0.026804                  | 3310.1       | 3712.1       | 6.8233           | 0.022742                          | 3295.8       | 3693.8       | 6.7366           | 0.019695                          | 3281.4       | 3675.3       | 6.6593           |
| 700                               | 0.028621                  | 3409.8       | 3839.1       | 6.9573           | 0.024342                          | 3397.5       | 3823.5       | 6.8735           | 0.021134                          | 3385.1       | 3807.8       | 6.7991           |
| 800                               | 0.032121                  | 3609.3       | 4091.1       | 7.2037           | 0.027405                          | 3599.7       | 4079.3       | 7.1237           | 0.023870                          | 3590.1       | 4067.5       | 7.0531           |
| 900                               | 0.035503                  | 3811.2       | 4343.7       | 7.4288           | 0.030348                          | 3803.5       | 4334.6       | 7.3511           | 0.026484                          | 3795.7       | 4325.4       | 7.2829           |
| 1000                              | 0.038808                  | 4017.1       | 4599.2       | 7.6378           | 0.033215                          | 4010.7       | 4592.0       | 7.5616           | 0.029020                          | 4004.3       | 4584.7       | 7.4950           |
| 1100                              | 0.042062                  | 4227.7       | 4858.6       | 7.8339           | 0.036029                          | 4222.3       | 4852.8       | 7.7588           | 0.031504                          | 4216.9       | 4847.0       | 7.6933           |
| 1200                              | 0.045279                  | 4443.1       | 5122.3       | 8.0192           | 0.038806                          | 4438.5       | 5117.6       | 7.9449           | 0.033952                          | 4433.8       | 5112.9       | 7.8802           |
| 1300                              | 0.048469                  | 4663.3       | 5390.3       | 8.1952           | 0.041556                          | 4659.2       | 5386.5       | 8.1215           | 0.036371                          | 4655.2       | 5382.7       | 8.0574           |
| $P = 25.0 \text{ MPa}$            |                           |              |              |                  | $P = 30.0 \text{ MPa}$            |              |              |                  | $P = 35.0 \text{ MPa}$            |              |              |                  |
| 375                               | 0.001978                  | 1799.9       | 1849.4       | 4.0345           | 0.001792                          | 1738.1       | 1791.9       | 3.9313           | 0.001701                          | 1702.8       | 1762.4       | 3.8724           |
| 400                               | 0.006005                  | 2428.5       | 2578.7       | 5.1400           | 0.002798                          | 2068.9       | 2152.8       | 4.4758           | 0.002105                          | 1914.9       | 1988.6       | 4.2144           |
| 425                               | 0.007886                  | 2607.8       | 2805.0       | 5.4708           | 0.005299                          | 2452.9       | 2611.8       | 5.1473           | 0.003434                          | 2253.3       | 2373.5       | 4.7751           |
| 450                               | 0.009176                  | 2721.2       | 2950.6       | 5.6759           | 0.006737                          | 2618.9       | 2821.0       | 5.4422           | 0.004957                          | 2497.5       | 2671.0       | 5.1946           |
| 500                               | 0.011143                  | 2887.3       | 3165.9       | 5.9643           | 0.008691                          | 2824.0       | 3084.8       | 5.7956           | 0.006933                          | 2755.3       | 2997.9       | 5.6331           |
| 550                               | 0.012736                  | 3020.8       | 3339.2       | 6.1816           | 0.010175                          | 2974.5       | 3279.7       | 6.0403           | 0.008348                          | 2925.8       | 3218.0       | 5.9093           |
| 600                               | 0.014140                  | 3140.0       | 3493.5       | 6.3637           | 0.011445                          | 3103.4       | 3446.8       | 6.2373           | 0.009523                          | 3065.6       | 3399.0       | 6.1229           |
| 650                               | 0.015430                  | 3251.9       | 3637.7       | 6.5243           | 0.012590                          | 3221.7       | 3599.4       | 6.4074           | 0.010565                          | 3190.9       | 3560.7       | 6.3030           |
| 700                               | 0.016643                  | 3359.9       | 3776.0       | 6.6702           | 0.013654                          | 3334.3       | 3743.9       | 6.5599           | 0.011523                          | 3308.3       | 3711.6       | 6.4623           |
| 800                               | 0.018922                  | 3570.7       | 4043.8       | 6.9322           | 0.015628                          | 3551.2       | 4020.0       | 6.8301           | 0.013278                          | 3531.6       | 3996.3       | 6.7409           |
| 900                               | 0.021075                  | 3780.2       | 4307.1       | 7.1668           | 0.017473                          | 3764.6       | 4288.8       | 7.0695           | 0.014904                          | 3749.0       | 4270.6       | 6.9853           |
| 1000                              | 0.023150                  | 3991.5       | 4570.2       | 7.3821           | 0.019240                          | 3978.6       | 4555.8       | 7.2880           | 0.016450                          | 3965.8       | 4541.5       | 7.2069           |
| 1100                              | 0.025172                  | 4206.1       | 4835.4       | 7.5825           | 0.020954                          | 4195.2       | 4823.9       | 7.4906           | 0.017942                          | 4184.4       | 4812.4       | 7.4118           |
| 1200                              | 0.027157                  | 4424.6       | 5103.5       | 7.7710           | 0.022630                          | 4415.3       | 5094.2       | 7.6807           | 0.019398                          | 4406.1       | 5085.0       | 7.6034           |
| 1300                              | 0.029115                  | 4647.2       | 5375.1       | 7.9494           | 0.024279                          | 4639.2       | 5367.6       | 7.8602           | 0.020827                          | 4631.2       | 5360.2       | 7.7841           |
| $P = 40.0 \text{ MPa}$            |                           |              |              |                  | $P = 50.0 \text{ MPa}$            |              |              |                  | $P = 60.0 \text{ MPa}$            |              |              |                  |
| 375                               | 0.001641                  | 1677.0       | 1742.6       | 3.8290           | 0.001560                          | 1638.6       | 1716.6       | 3.7642           | 0.001503                          | 1609.7       | 1699.9       | 3.7149           |
| 400                               | 0.001911                  | 1855.0       | 1931.4       | 4.1145           | 0.001731                          | 1787.8       | 1874.4       | 4.0029           | 0.001633                          | 1745.2       | 1843.2       | 3.9317           |
| 425                               | 0.002538                  | 2097.5       | 2199.0       | 4.5044           | 0.002009                          | 1960.3       | 2060.7       | 4.2746           | 0.001816                          | 1892.9       | 2001.8       | 4.1630           |
| 450                               | 0.003692                  | 2364.2       | 2511.8       | 4.9449           | 0.002487                          | 2160.3       | 2284.7       | 4.5896           | 0.002086                          | 2055.1       | 2180.2       | 4.4140           |
| 500                               | 0.005623                  | 2681.6       | 2906.5       | 5.4744           | 0.003890                          | 2528.1       | 2722.6       | 5.1762           | 0.002952                          | 2393.2       | 2570.3       | 4.9356           |
| 550                               | 0.006985                  | 2875.1       | 3154.4       | 5.7857           | 0.005118                          | 2769.5       | 3025.4       | 5.5563           | 0.003955                          | 2664.6       | 2901.9       | 5.3517           |
| 600                               | 0.008089                  | 3026.8       | 3350.4       | 6.0170           | 0.006108                          | 2947.1       | 3252.6       | 5.8245           | 0.004833                          | 2866.8       | 3156.8       | 5.6527           |
| 650                               | 0.009053                  | 3159.5       | 3521.6       | 6.2078           | 0.006957                          | 3095.6       | 3443.5       | 6.0373           | 0.005591                          | 3031.3       | 3366.8       | 5.8867           |
| 700                               | 0.009930                  | 3282.0       | 3679.2       | 6.3740           | 0.007717                          | 3228.7       | 3614.6       | 6.2179           | 0.006265                          | 3175.4       | 3551.3       | 6.0814           |
| 800                               | 0.011521                  | 3511.8       | 3972.6       | 6.6613           | 0.009073                          | 3472.2       | 3925.8       | 6.5225           | 0.007456                          | 3432.6       | 3880.0       | 6.4033           |
| 900                               | 0.012980                  | 3733.3       | 4252.5       | 6.9107           | 0.010296                          | 3702.0       | 4216.8       | 6.7819           | 0.008519                          | 3670.9       | 4182.1       | 6.6725           |
| 1000                              | 0.014360                  | 3952.9       | 4527.3       | 7.1355           | 0.011441                          | 3927.4       | 4499.4       | 7.0131           | 0.009504                          | 3902.0       | 4472.2       | 6.9099           |
| 1100                              | 0.015686                  | 4173.7       | 4801.1       | 7.3425           | 0.012534                          | 4152.2       | 4778.9       | 7.2244           | 0.010439                          | 4130.9       | 4757.3       | 7.1255           |
| 1200                              | 0.016976                  | 4396.9       | 5075.9       | 7.5357           | 0.013590                          | 4378.6       | 5058.1       | 7.4207           | 0.011339                          | 4360.5       | 5040.8       | 7.3248           |
| 1300                              | 0.018239                  | 4623.3       | 5352.8       | 7.7175           | 0.014620                          | 4607.5       | 5338.5       | 7.6048           | 0.012213                          | 4591.8       | 5324.5       | 7.5111           |



Compressed liquid water

| $T$<br>°C                       | $v$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg       | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg       | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K |
|---------------------------------|---------------------------|--------------|--------------|------------------|---------------------------------|--------------|--------------|------------------|---------------------------------|--------------|--------------|------------------|
| $P = 5 \text{ MPa (263.94°C)}$  |                           |              |              |                  | $P = 10 \text{ MPa (311.00°C)}$ |              |              |                  | $P = 15 \text{ MPa (342.16°C)}$ |              |              |                  |
| Sat.                            | 0.0012862                 | 1148.1       | 1154.5       | 2.9207           | 0.0014522                       | 1393.3       | 1407.9       | 3.3603           | 0.0016572                       | 1585.5       | 1610.3       | 3.6848           |
| 0                               | 0.0009977                 | 0.04         | 5.03         | 0.0001           | 0.0009952                       | 0.12         | 10.07        | 0.0003           | 0.0009928                       | 0.18         | 15.07        | 0.0004           |
| 20                              | 0.0009996                 | 83.61        | 88.61        | 0.2954           | 0.0009973                       | 83.31        | 93.28        | 0.2943           | 0.0009951                       | 83.01        | 97.93        | 0.2932           |
| 40                              | 0.0010057                 | 166.92       | 171.95       | 0.5705           | 0.0010035                       | 166.33       | 176.37       | 0.5685           | 0.0010013                       | 165.75       | 180.77       | 0.5666           |
| 60                              | 0.0010149                 | 250.29       | 255.36       | 0.8287           | 0.0010127                       | 249.43       | 259.55       | 0.8260           | 0.0010105                       | 248.58       | 263.74       | 0.8234           |
| 80                              | 0.0010267                 | 333.82       | 338.96       | 1.0723           | 0.0010244                       | 332.69       | 342.94       | 1.0691           | 0.0010221                       | 331.59       | 346.92       | 1.0659           |
| 100                             | 0.0010410                 | 417.65       | 422.85       | 1.3034           | 0.0010385                       | 416.23       | 426.62       | 1.2996           | 0.0010361                       | 414.85       | 430.39       | 1.2958           |
| 120                             | 0.0010576                 | 501.91       | 507.19       | 1.5236           | 0.0010549                       | 500.18       | 510.73       | 1.5191           | 0.0010522                       | 498.50       | 514.28       | 1.5148           |
| 140                             | 0.0010769                 | 586.80       | 592.18       | 1.7344           | 0.0010738                       | 584.72       | 595.45       | 1.7293           | 0.0010708                       | 582.69       | 598.75       | 1.7243           |
| 160                             | 0.0010988                 | 672.55       | 678.04       | 1.9374           | 0.0010954                       | 670.06       | 681.01       | 1.9316           | 0.0010920                       | 667.63       | 684.01       | 1.9259           |
| 180                             | 0.0011240                 | 759.47       | 765.09       | 2.1338           | 0.0011200                       | 756.48       | 767.68       | 2.1271           | 0.0011160                       | 753.58       | 770.32       | 2.1206           |
| 200                             | 0.0011531                 | 847.92       | 853.68       | 2.3251           | 0.0011482                       | 844.32       | 855.80       | 2.3174           | 0.0011435                       | 840.84       | 858.00       | 2.3100           |
| 220                             | 0.0011868                 | 938.39       | 944.32       | 2.5127           | 0.0011809                       | 934.01       | 945.82       | 2.5037           | 0.0011752                       | 929.81       | 947.43       | 2.4951           |
| 240                             | 0.0012268                 | 1031.6       | 1037.7       | 2.6983           | 0.0012192                       | 1026.2       | 1038.3       | 2.6876           | 0.0012121                       | 1021.0       | 1039.2       | 2.6774           |
| 260                             | 0.0012755                 | 1128.5       | 1134.9       | 2.8841           | 0.0012653                       | 1121.6       | 1134.3       | 2.8710           | 0.0012560                       | 1115.1       | 1134.0       | 2.8586           |
| 280                             |                           |              |              |                  | 0.0013226                       | 1221.8       | 1235.0       | 3.0565           | 0.0013096                       | 1213.4       | 1233.0       | 3.0410           |
| 300                             |                           |              |              |                  | 0.0013980                       | 1329.4       | 1343.3       | 3.2488           | 0.0013783                       | 1317.6       | 1338.3       | 3.2279           |
| 320                             |                           |              |              |                  |                                 |              |              |                  | 0.0014733                       | 1431.9       | 1454.0       | 3.4263           |
| 340                             |                           |              |              |                  |                                 |              |              |                  | 0.0016311                       | 1567.9       | 1592.4       | 3.6555           |
| $P = 20 \text{ MPa (365.75°C)}$ |                           |              |              |                  | $P = 30 \text{ MPa}$            |              |              |                  | $P = 50 \text{ MPa}$            |              |              |                  |
| Sat.                            | 0.0020378                 | 1785.8       | 1826.6       | 4.0146           |                                 |              |              |                  |                                 |              |              |                  |
| 0                               | 0.0009904                 | 0.23         | 20.03        | 0.0005           | 0.0009857                       | 0.29         | 29.86        | 0.0003           | 0.0009767                       | 0.29         | 49.13        | −0.0010          |
| 20                              | 0.0009929                 | 82.71        | 102.57       | 0.2921           | 0.0009886                       | 82.11        | 111.77       | 0.2897           | 0.0009805                       | 80.93        | 129.95       | 0.2845           |
| 40                              | 0.0009992                 | 165.17       | 185.16       | 0.5646           | 0.0009951                       | 164.05       | 193.90       | 0.5607           | 0.0009872                       | 161.90       | 211.25       | 0.5528           |
| 60                              | 0.0010084                 | 247.75       | 267.92       | 0.8208           | 0.0010042                       | 246.14       | 276.26       | 0.8156           | 0.0009962                       | 243.08       | 292.88       | 0.8055           |
| 80                              | 0.0010199                 | 330.50       | 350.90       | 1.0627           | 0.0010155                       | 328.40       | 358.86       | 1.0564           | 0.0010072                       | 324.42       | 374.78       | 1.0442           |
| 100                             | 0.0010337                 | 413.50       | 434.17       | 1.2920           | 0.0010290                       | 410.87       | 441.74       | 1.2847           | 0.0010201                       | 405.94       | 456.94       | 1.2705           |
| 120                             | 0.0010496                 | 496.85       | 517.84       | 1.5105           | 0.0010445                       | 493.66       | 525.00       | 1.5020           | 0.0010349                       | 487.69       | 539.43       | 1.4859           |
| 140                             | 0.0010679                 | 580.71       | 602.07       | 1.7194           | 0.0010623                       | 576.90       | 608.76       | 1.7098           | 0.0010517                       | 569.77       | 622.36       | 1.6916           |
| 160                             | 0.0010886                 | 665.28       | 687.05       | 1.9203           | 0.0010823                       | 660.74       | 693.21       | 1.9094           | 0.0010704                       | 652.33       | 705.85       | 1.8889           |
| 180                             | 0.0011122                 | 750.78       | 773.02       | 2.1143           | 0.0011049                       | 745.40       | 778.55       | 2.1020           | 0.0010914                       | 735.49       | 790.06       | 2.0790           |
| 200                             | 0.0011390                 | 837.49       | 860.27       | 2.3027           | 0.0011304                       | 831.11       | 865.02       | 2.2888           | 0.0011149                       | 819.45       | 875.19       | 2.2628           |
| 220                             | 0.0011697                 | 925.77       | 949.16       | 2.4867           | 0.0011595                       | 918.15       | 952.93       | 2.4707           | 0.0011412                       | 904.39       | 961.45       | 2.4414           |
| 240                             | 0.0012053                 | 1016.1       | 1040.2       | 2.6676           | 0.0011927                       | 1006.9       | 1042.7       | 2.6491           | 0.0011708                       | 990.55       | 1049.1       | 2.6156           |
| 260                             | 0.0012472                 | 1109.0       | 1134.0       | 2.8469           | 0.0012314                       | 1097.8       | 1134.7       | 2.8250           | 0.0012044                       | 1078.2       | 1138.4       | 2.7864           |
| 280                             | 0.0012978                 | 1205.6       | 1231.5       | 3.0265           | 0.0012770                       | 1191.5       | 1229.8       | 3.0001           | 0.0012430                       | 1167.7       | 1229.9       | 2.9547           |
| 300                             | 0.0013611                 | 1307.2       | 1334.4       | 3.2091           | 0.0013322                       | 1288.9       | 1328.9       | 3.1761           | 0.0012879                       | 1259.6       | 1324.0       | 3.1218           |
| 320                             | 0.0014450                 | 1416.6       | 1445.5       | 3.3996           | 0.0014014                       | 1391.7       | 1433.7       | 3.3558           | 0.0013409                       | 1354.3       | 1421.4       | 3.2888           |
| 340                             | 0.0015693                 | 1540.2       | 1571.6       | 3.6086           | 0.0014932                       | 1502.4       | 1547.1       | 3.5438           | 0.0014049                       | 1452.9       | 1523.1       | 3.4575           |
| 360                             | 0.0018248                 | 1703.6       | 1740.1       | 3.8787           | 0.0016276                       | 1626.8       | 1675.6       | 3.7499           | 0.0014848                       | 1556.5       | 1630.7       | 3.6301           |
| 380                             |                           |              |              |                  | 0.0018729                       | 1782.0       | 1838.2       | 4.0026           | 0.0015884                       | 1667.1       | 1746.5       | 3.8102           |



**TD N 02 : Propriétés thermodynamiques des substances pures (L'eau)**

Module : **Thermodynamique II**

Responsable du module : **T.E. BOUKELIA**

**Ex N 01.**

Un réservoir de  $1,8 \text{ m}^3$  contient de la vapeur à  $220^\circ \text{C}$ . Un tiers du volume est en phase liquide et le reste est sous forme de vapeur. Déterminer

- La pression de la vapeur.
- La qualité du mélange saturé (le titre).
- La masse volumique du mélange.

**Ex N 02.**

Un récipient dont  $V=0.5 \text{ m}^3$  contient 3 kg de mélange eau-vapeur en équilibre à  $168^\circ \text{C}$ . Calculer :

- La pression de la vapeur.
- La chaleur latente  $h_{fg}$ .
- Le titre  $x$ .
- La masse de vapeur  $m_g$ , et la masse de liquide  $m_f$ .
- Le volume de vapeur  $V_g$ , et le volume de liquide  $V_f$ .

**Ex N 03.**

1 kg de vapeur d'eau sèche est détendu isentropiquement de  $T_1=175^\circ \text{C}$  à  $T_2=60^\circ \text{C}$ .

- Représenter la détente sur un diagramme  $(P, V)$ , et sur un diagramme  $(T, S)$ .
- Déterminer le titre en fin de détente.
- Evaluer la chute d'enthalpie
- Calculer les pressions et les volumes des points (1 et 2).

**Ex N 04.**

Déterminer la quantité de chaleur nécessaire pour produire 1 kg de vapeur, à une pression de 6 bars, et à une température de  $25^\circ \text{C}$  dans les conditions suivantes.

- Lorsque la vapeur est humide, ayant un titre de vapeur de 0,9.
- Lorsque la vapeur est saturée sèche.
- Lorsqu'elle est surchauffée à une pression constante à  $250^\circ \text{C}$ .

Supposons que la chaleur spécifique moyenne de la vapeur surchauffée soit de  $2,3 \text{ kJ/kg}$ .



**TD N 02 : Propriétés thermodynamiques des substances pures (L'eau)**

Module : **Thermodynamique II**

Responsable du module : **T.E. BOUKELIA**

**Ex N 01.**

**a. La pression de la vapeur.**

A partir du Tableau de vapeur saturée (A-4)

$$P = T_{sat@220\text{ }^{\circ}\text{C}} = \mathbf{2320\text{ kPa}}$$

**b. La qualité du mélange saturé (le titre).**

A partir du Tableau de vapeur saturée (A-4)

$$v_f = v_{f@220\text{ }^{\circ}\text{C}} = \mathbf{0,001190\text{ }\frac{m^3}{kg}} \text{ et } v_g = v_{g@220\text{ }^{\circ}\text{C}} = \mathbf{0,08609\text{ }\frac{m^3}{kg}}$$

$$m_f = \frac{V_f}{v_f} = \frac{\frac{1}{3} \times 1,8\text{ }m^3}{0,001190} = \mathbf{504,2\text{ kg}}$$

$$m_g = \frac{V_g}{v_g} = \frac{\frac{2}{3} \times 1,8\text{ }m^3}{0,08609} = \mathbf{13,94\text{ kg}}$$

$$m_t = m_f + m_g = 504,2 + 13,94 = \mathbf{518,1\text{ kg}}$$

$$x = \frac{m_g}{m_t} = \frac{13,94}{518,1} = \mathbf{0,0269}$$

**c. La masse volumique**

$$v_{mél@220\text{ }^{\circ}\text{C}} = v_f + x(v_g - v_f) = 0,001190 + 0,0269(0,0849) = \mathbf{0,003474\text{ }\frac{m^3}{kg}}$$

$$\rho_{mél@220\text{ }^{\circ}\text{C}} = \frac{1}{v_{mél@220\text{ }^{\circ}\text{C}}} = \frac{1}{0,003474} = \mathbf{287,8\text{ }\frac{kg}{m^3}}$$

**Vapeur**  
 **$V = 1,8\text{ }m^3$**   
 **$T = 220\text{ }^{\circ}\text{C}$**

**Ex N 02**

**a. La pression de la vapeur.**

A partir du Tableau de vapeur saturée (A-4) et l'interpolation linéaire :

$$x_a = T_a = 165$$

$$x_2 = T_{P=15} = 168$$

$$x_b = T_b = 170$$

$$y_a = P_a = 700,93\text{ kPa}$$

$$y_2 = P_{@168} = ?$$

$$y_b = P_b = 792,18\text{ kPa}$$

$$P_{@168} = P_a + (P_b - P_a) \times \frac{T_{@168} - T_a}{T_b - T_a} = 700,93 + (792,18 - 700,93) \times \frac{168 - 165}{170 - 165} = \mathbf{755,68\text{ kPa}}$$

**b. La chaleur latente  $h_{fg}$ .**

A partir du Tableau de vapeur saturée (A-4)

$$h_{f@168\text{ }^{\circ}\text{C}} = 709,3\text{ kJ/kg}$$

$$v_{f@168\text{ }^{\circ}\text{C}} = 0,00112\text{ }m^3/kg$$

$$h_{g@168\text{ }^{\circ}\text{C}} = 2765,8\text{ kJ/kg}$$

$$v_{g@168\text{ }^{\circ}\text{C}} = 0,2556\text{ }m^3/kg$$

Et l'interpolation linéaire :

$$h_{fg@168\text{ }^{\circ}\text{C}} = h_{g@168\text{ }^{\circ}\text{C}} - h_{f@168\text{ }^{\circ}\text{C}} = 2765,8 - 709,3 = \mathbf{2056,5\text{ kJ/kg}}$$

**c. Le titre**



**TD N 02 : Propriétés thermodynamiques des substances pures (L'eau)**

Module : **Thermodynamique II**

Responsable du module : **T.E. BOUKELIA**

$$h_{mél@168^{\circ}\text{C}} = (1-x)h_f + xh_g = h_f - xh_f + xh_g = h_f + x(h_g - h_f) = h_f + xh_{fg} \Rightarrow x = \frac{h_{mél@168^{\circ}\text{C}} - h_f}{h_g - h_f} = \frac{v_{mél@168^{\circ}\text{C}} - v_f}{v_g - v_f} = \frac{0,1666 - 0,00112}{0,2556 - 0,00112} = \mathbf{0,65}$$

$$v_{mél@168^{\circ}\text{C}} = \frac{V_{mél}}{m_{mél}} = \frac{0,5}{3} = \mathbf{0,1666 \text{ m}^3/\text{kg}}$$

d. La masse de vapeur  $m_g$ , et la masse de liquide  $m_f$ .

$$m_g = xm_{mél} = 0,65 \times 3 = 1,95 \text{ kg}$$

$$m_f = (1-x)m_{mél} = (1-0,65) \times 3 = 1,05 \text{ kg}$$

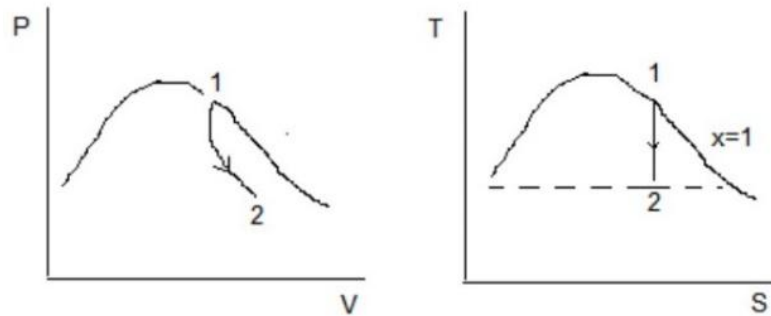
e. Le volume de vapeur  $V_g$ , et le volume de liquide  $V_f$ .

$$V_f = v_f \times m_f = 0,00112 \times 1,05 = \mathbf{0,001176 \text{ m}^3}$$

$$V_g = v_g \times m_g = 0,2556 \times 1,95 = \mathbf{0,4984 \text{ m}^3}$$

**Exercice 3**

a. Représentation graphique de la détente isentropique de la vapeur d'eau saturée



b. Le titre à la fin de détente

| T°C   | P (kPa) | $v_f(\text{m}^3/\text{kg})$ | $v_g(\text{m}^3/\text{kg})$ | $h_f(\text{kJ}/\text{kg})$ | $h_g(\text{kJ}/\text{kg})$ | $s_f(\text{kJ}/\text{kg} \cdot \text{K})$ | $s_g(\text{kJ}/\text{kg} \cdot \text{K})$ |
|-------|---------|-----------------------------|-----------------------------|----------------------------|----------------------------|---|---|
| 175°C | 892,6   | 0,001121                    | 0,21659                     | 741,02                     | 2772,7                     | 2,0906                                    | 6,6242                                    |
| 60°C  | 19,947  | 0,001017                    | 7,6670                      | 251,18                     | 2608,8                     | 0,8313                                    | 7,9082                                    |

Détente isentropique, donc  $s_1 = s_{g1} = s_2$

$$x = \frac{s_{g1} - s_{f2}}{s_{g2} - s_{f2}} = \frac{6,6242 - 0,8313}{7,9082 - 0,8313} = \mathbf{0,8186}$$

c. La chute d'enthalpie

$$h_2 = (1-x_2)h_{f2} + x_2h_{g2} = (1-0,8186)251,18 + 0,8186 \times 2608,8 = \mathbf{2181,128 \text{ kJ}/\text{kg}}$$

$$\Delta h = h_1 - h_2 = \Delta h = h_{g1} - h_2 = 2772,7 - 2181,128 = \mathbf{591,57 \text{ kJ}/\text{kg}}$$

d. Les pressions et les volumes des points (1 et 2).

$$V_1 = m \times v_1 = 1 \times 0,21659 = \mathbf{0,21659 \text{ m}^3}$$



**TD N 02 : Propriétés thermodynamiques des substances pures (L'eau)**

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$$\begin{aligned}v_2 &= (1 - x_2)v_{f2} + x_2v_{g2} = (1 - 0,8186)0,001017 + 0,8186 \times 7,6670 \\&= \mathbf{6,2764 \text{ m}^3/\text{kg}} \\V_2 &= m \times v_2 = 1 \times 6,2764 = \mathbf{6,2764 \text{ m}^3}\end{aligned}$$

**Exercice 04**

**Déterminer la quantité de chaleur nécessaire pour produire 1 kg de vapeur**

Puisque l'eau est à une température de 25 °C, la chaleur est déjà dans l'eau

$$h_{1@25^\circ\text{C}} = C_p T_1 = 4,2 \times 25 = 105 \text{ kJ/kg}$$

**a. Lorsque la vapeur est humide, ayant un titre de vapeur de 0,9.**

A partir du Tableau de vapeur saturée (A-4)

$$T_{\text{sat}@6 \text{ bar}} = 158,83 \text{ }^\circ\text{C}, h_{f@6 \text{ bar}} = 670,38 \text{ kJ/kg}, h_{fg@6 \text{ bar}} = 2085,8 \text{ kJ/kg}$$

$$h_2 = (1 - x)h_f + xh_g = h_f + xh_{fg} = 670,38 + 0,9(2085,8) = 2547,6 \text{ kJ/kg}$$

$$Q = m(h_2 - h_1) = 1 \times (2547,6 - 105) = \mathbf{2442,6 \text{ kJ}}$$

**b. Lorsque la vapeur est saturée sèche.**

$$h_2 = h_g = h_f + h_{fg} = 670,38 + 2085,8 = 2756,18 \text{ kJ/kg}$$

$$Q = m(h_2 - h_1) = 1 \times (2756,18 - 105) = \mathbf{2651,18 \text{ kJ}}$$

**c. Lorsqu'elle est surchauffée à une pression constante à 250 °C.**

$$\begin{aligned}h_2 &= h_{\text{sur}} = h_g + C_p (T_{\text{sur}} - t) = h_g + C_p (T_{\text{sur}} - t) = 2756,18 + 2,3(250 - 158,83) \\&= 2965,87 \text{ kJ/kg}\end{aligned}$$

$$Q = m(h_2 - h_1) = 1 \times (2965,87 - 105) = \mathbf{2860,87 \text{ kJ}}$$

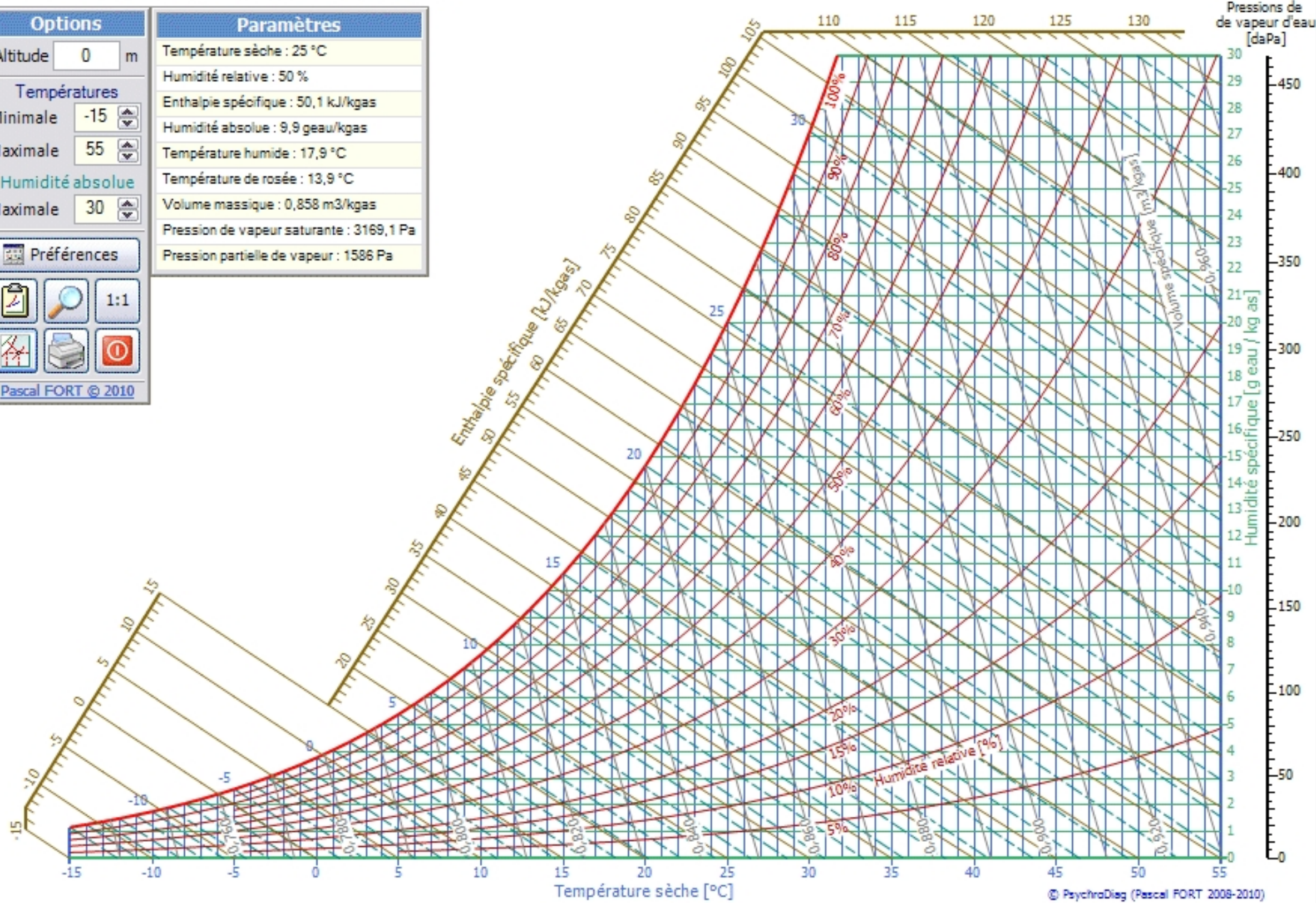


# DIAGRAMME DE L'AIR HUMIDE

Pression atmosphérique 101325 Pa Altitude 0 m

| Options            |     |
|--------------------|-----|
| Altitude           | 0 m |
| Températures       |     |
| Minimale           | -15 |
| Maximale           | 55  |
| Humidité absolue   |     |
| Maximale           | 30  |
| Préférences        |     |
|                    |     |
|                    |     |
| Pascal FORT © 2010 |     |

| Paramètres                               |
|--|
| Température sèche : 25 °C                |
| Humidité relative : 50 %                 |
| Enthalpie spécifique : 50,1 kJ/kgas      |
| Humidité absolue : 9,9 geau/kgas         |
| Température humide : 17,9 °C             |
| Température de rosée : 13,9 °C           |
| Volume massique : 0,858 m3/kgas          |
| Pression de vapeur saturante : 3169,1 Pa |
| Pression partielle de vapeur : 1586 Pa   |



**TD N 03 : Propriétés thermodynamiques des substances pures (Air humide)**Module : **Thermodynamique II**Responsable du module : **T.E. BOUKELIA**

$\theta_h$  : La température humide.  $\theta_s$  : La température sèche.  $\theta_r$  : La température de rosée.  
 $r_s$  : La teneur d'eau (humidité absolue). HR : Le degré hygrométrique (humidité relative)

**Ex N 01.**

Dans un local, on relève au psychromètre:  $\theta_s = 22^\circ\text{C}$  et  $\theta_h = 17^\circ\text{C}$ .

Rechercher les caractéristiques de l'ambiance du local considéré.

**Ex N 02.**

A l'aide du diagramme de l'air humide, compléter le tableau suivant :

| $h$ en kcal/kg as | $\theta_h$ en $^\circ\text{C}$ | $\theta_s$ en $^\circ\text{C}$ | $r_s$ en g/kg as | HR en % |
|-------------------|--------------------------------|--------------------------------|------------------|---------|
|                   | 13,5                           | 21                             |                  |         |
|                   | 11,5                           | 17                             |                  |         |
|                   | 12                             |                                | 7,5              |         |
|                   | 18                             | 4                              |                  |         |
|                   |                                | 26                             | 14.8             |         |

**Ex N 03.****Air 1**

$m_{as1} = 10 \text{ kg}_{as}$

$\theta_{s1} = -5^\circ\text{C}$

HR = 80 %

**Air 2**

$m_{as2} = 20 \text{ kg}_{as}$

$\theta_{s1} = 20^\circ\text{C}$

HR = 80 %

Déterminer les caractéristiques du mélange.

**Ex N 04**

On cherche à connaître la puissance et l'efficacité d'une batterie froide. La température avant la batterie est de  $25^\circ\text{C}$  la température après la batterie est de  $10^\circ\text{C}$ , l'humidité spécifique passe de 11 g/kg air sec à 7.5 g/kg air sec. Le débit d'air est de 3 kg/s.

**Ex N 05.****Air 1**

$m_{as1} = 10 \text{ kg}_{as}$

$\theta_{s1} = 18^\circ\text{C}$

$\theta_{h1} = 7^\circ\text{C}$

**Air 2**

$m_{as2} = 20 \text{ kg}_{as}$

$\theta_{s2} = 24^\circ\text{C}$

$\theta_{h2} = 17^\circ\text{C}$

- Calculer l'enthalpie  $h_m$  [kJ/kg] et la teneur d'eau  $r_{sm}$  [g eau /kg air] du mélange (air 1 + air 2).
- Déterminer les autres caractéristiques à partir de l'enthalpie et la teneur d'eau du mélange (températures humide et sèche [ $^\circ\text{C}$ ], pression de la vapeur d'eau [Pa], volume spécifique [ $\text{m}^3/\text{kg}$ ], humidité relative [%]).
- Si la puissance absorbée par la batterie est 1000 kW, et la température sèche et l'humidité relative du mélange après la batterie sont  $30^\circ\text{C}$  et 60 % respectivement, calculer le rendement de la batterie (le débit d'air est de 30 kg/s).



**TD N 03 : Propriétés thermodynamiques des substances pures (Air humide)**Module : **Thermodynamique II**Responsable du module : **T.E. BOUKELIA**

A partir du diagramme de l'air humide.

**Ex N 01.**Les caractéristiques de l'ambiance d'un local avec  $\theta_s = 22\text{ °C}$  et  $\theta_h = 17\text{ °C}$ .

$$r_m = 10\text{ g eau/kg as},$$

$$P_m = 1060\text{ Pa},$$

$$h_m = 47,5\text{ kJ/kg as},$$

$$v_m = 0,850\text{ m}^3/\text{kg as},$$

$$HR_m = 60\%$$

**Ex N 02.**

| h en kcal/kg as | $\theta_h$ en °C | $\theta_s$ en °C | $r_s$ en g/kg as | HR en % |
|-----------------|------------------|------------------|------------------|---------|
| 37              | 13,5             | 21               | 6,7              | 42      |
| 32              | 11,5             | 17               | 6                | 50      |
| 34              | 12               | 15               | 7,5              | 70      |
| /               | 18               | 4                | /                | /       |
| 79              | 41,5             | 26               | 14,8             | 29      |

**Ex N 03.**

Les caractéristiques du mélange.

La même méthode que la première partie de l'Ex N 05

**Ex N 04.**

La même méthode que la dernière partie de l'Ex N 05

**Ex N 05.****a. L'enthalpie et la teneur d'eau du mélange**

Avec le diagramme de l'air humide

Pour l'air 1 :  $h_1 = 22\text{ kJ/kg as}$ ,  $r_{s1} = 1,7\text{ g eau/kg as}$ Pour l'air 2 :  $h_2 = 47,5\text{ kJ/kg as}$ ,  $r_{s2} = 9,2\text{ g eau/kg as}$ Donc l'enthalpie  $h_m$  et la teneur d'eau  $r_{sm}$  du mélange :

$$h_m = \frac{m_{a1} \times h_1 + m_{a2} \times h_2}{m_{a1} + m_{a2}} = \frac{10 \times 22 + 20 \times 47,5}{10 + 20} = 39\text{ kJ/kg as}$$
$$r_m = \frac{m_{a1} \times r_1 + m_{a2} \times r_2}{m_{a1} + m_{a2}} = \frac{10 \times 1,7 + 20 \times 9,2}{10 + 20} = 6,7\text{ g eau/kg as}$$



**TD N 03 : Propriétés thermodynamique des substances pures (Air humide)**

Module : **Thermodynamique II**

Responsable du module : **T.E. BOUKELIA**

**b. Les autres caractéristiques du mélange**

Avec le diagramme de l'air humide

$$\theta_{sm} = 22 \text{ °C} \quad \theta_{hm} = 14 \text{ °C} \quad P_m = 1070 \text{ Pa} \quad v_m = 0,845 \text{ m}^3/\text{kg as} \quad HR_m = 40 \%$$

**c. La puissance de la batterie**

Avec le diagramme de l'air humide

$$h_{m2} = 71 \text{ kJ/kg as}$$

$$P = \dot{m}(h_{m2} - h_{m1}) = 30(71 - 39) = \mathbf{960 \text{ kW}}$$

$$\eta_{batterie} = \frac{P_{réel}}{P_{abs}} = \frac{960}{1000} = 0,96 = \mathbf{96 \%}$$