The University Of Sheffield.

Department Of Mechanical Engineering.

The Little Book Of Thermofluids.

3rd Edition

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It is with some reservation that I supply equations to this book. One of the most common failings for engineering students is that they solve problems through memory rather than by applying the correct methodology based upon a fundamental understanding. This type of training does not serve the students well when they move into industry. Thus, while I welcome you to use this book as a quick reference and a study aid, I expect you to be able to derive each of these equations from basic principles. Do not be content with a shallow understanding of this subject!

CWW

Tabulated data has been generated from fitted formulæ to certain accuracies. Where differences arise between other published steam tables, these are small. This book of tables should furnish sufficient accuracy for both student and general engineering use.

MWB

The authors wish to be forgiven for any errors and take no responsibility at all for any disasters caused through the use of this book.

SBMB

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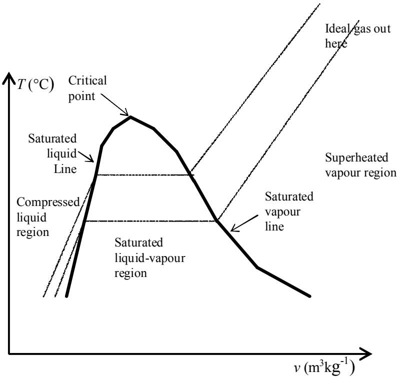
3 Changes in this edition were made in part by P. Mylon
4 Cover illustrations Simon Beck (AlphaBeck.co.uk)

Table of Contents

INTRODUCTION TO THERMODYNAMICS



Quality v used as illustration

$$\frac{v_{total} - v_f}{v_g - v_f} = x$$

where x is the quality

$$v_{total} = v_f + x(v_g - v_f)$$

Ideal gas behaviour

$$\underset{\text{kPa}}{p} \times \underset{\text{m}^3}{V} = \underset{\text{kg}}{m} \times \underset{\text{kJkg}^{-1}\text{K}^{-1}}{R} \times \underset{\text{K}}{T}$$

where $R = \frac{R_u}{M}$ and $\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$

where R_U is 8.314 kJ kmol^{-1} K^{-1}.

Gas Phase Property Summary

	Ideal Gas	Real Gas or Vapour
Equation of State	$pv = RT$	Proprietary equation *or* chart for $z = \frac{pv}{RT}$
Internal Energy	$u = h - RT$	$u = h - pv$

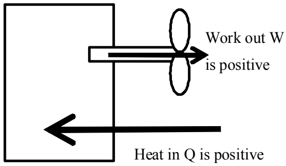
	'Perfect' Gas	'Semi'-Perfect Gas	Real Gas or Vapour
Specific Heat Capacities	c_p, c_v, γ all constant $c_p = \frac{\gamma}{\gamma - 1} R$ where $\gamma = \frac{c_p}{c_v}$	$c_p = c_p(T)$ $c_v = c_p - R$ $\gamma = \gamma(T)$	$c_p = c_p(p, T)$ $c_v = c_v(p, T)$
Enthalpy	$h_2 - h_1 = c_p(T_2 - T_1)$	$h = h_0 + \int_{T_0}^{T} c_p \, dT = h^*$ (e.g. $h_0 = 0$ when $T_0 = 25$°C for table of $\tilde{h}$)	$h = h(p, T)$ <u>or</u> chart for $\frac{h^* - h}{RT_c}$
Entropy	$s_2 - s_1 = c_p \ln\frac{T_2}{T_1} - R \ln\frac{p_2}{p_1}$ (but if $s_2 = s_1$ use $pv^\gamma =$ constant)	$s = s^\ominus - R \ln\frac{p}{p^\ominus} = s^*$ $s^\ominus$and $\tilde{s}_2 - \tilde{s}_1 = \tilde{s}_2^\ominus - \tilde{s}_1^\ominus - R_U \ln\frac{p_2}{p_1}$ where $\tilde{s}^\ominus = \int_0^T \tilde{c}_p \frac{dT}{T}$ s°	$s = s(p,T)$ <u>or</u> chart for $\frac{s^* - s}{R}$

Polytropic processes

Polytropic expansion:

$$pV^n = constant \quad \frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} = \left(\frac{V_1}{V_2}\right)^{n-1}$$

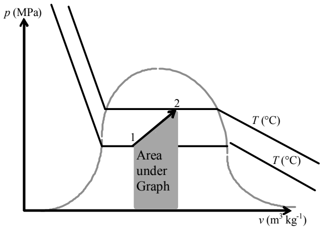
For an isentropic process, $n = \gamma$, where $\gamma = \frac{c_p}{c_v}$.



The first law of thermodynamics

The first law of thermodynamics for a closed system is:

$Q - W = \Delta U$ or $Q - W = m\Delta u$



For a reversible process, $W_{rev} = \int p\, dV$

For any process the value of the integral $\int_1^2 p\, dV$ is the area under the *p*-*V* graph.

For an ideal gas polytropic process ($n \neq 1$):

$$W = \int_1^2 p\, dV = \frac{p_1V_1 - p_2V_2}{n-1} \text{ and } Q = W \times \left(\frac{\gamma - n}{\gamma - 1}\right)$$

For an isothermal process ($n = 1$):

$$\int_1^2 p\, dV = \mathrm{p_1 V_1 \ln}\left(\frac{\mathrm{V_2}}{\mathrm{V_1}}\right)$$

The steady flow energy equation for a single stream is:

$$\dot{Q} - \dot{W} = {}^1\!/_2\,\dot{m}\left(C_2{}^2 - C_1{}^2\right) + \dot{m}g(z_2 - z_1) + \dot{m}(h_2 - h_1)$$

(Be careful to use consistent units)

For an ideal gas, a solid and most liquids:

$$\Delta h = c_p \Delta T \text{ and } \Delta u = c_v \Delta T$$

Entropy and the Second Law

In general, $dS = \left(\frac{dQ}{T}\right)_{rev}$. For ideal gases:

$$s_2 - s_1 = c_v \ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1} = c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1}$$

Isentropic efficiency of an expansion:

$$\eta_E = \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

Isentropic efficiency of a compression:

$$\eta_C = \frac{h_{2s} - h_1}{h_{2a} - h_1}$$

Gibbs free energy:

$$\tilde{g} = \tilde{h} - T\tilde{s}$$

Maximum efficiencies of cycles

Reversible heat engine:

$$\eta_{Th} = \frac{T_{high} - T_{low}}{T_{high}}$$

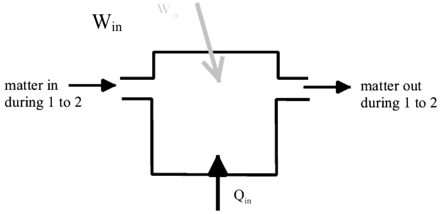
Reversible refrigerator:

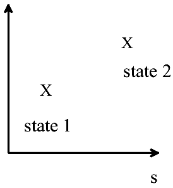
$$COP_R = \frac{T_{low}}{T_{high} - T_{low}}$$

Reversible heat pump:

$$COP_{HP} = \mathrm{COP_R} + 1 = \frac{T_{high}}{T_{high} - T_{low}}$$

Global energy conservation or Unsteady Flow Energy Equation (UFEE)





$$m_2 u_2 - m_1 u_1 = \sum m_i h_i - \sum m_e h_e + W + Q$$

Exergy

Specific exergy (function):

$$\beta = h - T_0 s$$

Thermal exergy:

$$\varepsilon^q = q\left(1 - \frac{T_0}{T}\right)$$

Rational efficiency:

$$\Psi = \frac{\sum \Delta\dot{\varepsilon}_{output}}{\sum \Delta\dot{\varepsilon}_{input}} = 1 - \frac{I}{\sum \Delta\dot{\varepsilon}_{input}} = \frac{W_{net}}{W_{max}}$$

or when applicable:

$$\Psi = \frac{W_{net}}{-\Delta G_0} \qquad i = T_0 \pi = T_0\left(s_{out} - s_{in} - \sum \frac{q}{T}\right)$$

Combustion Equations

Combustion calculations are based on the conservation of mass principle which states that the mass of each element is conserved during a chemical reaction. The ratio of mass of air to mass of fuel is called the Air Fuel Ratio.

$$AFR = \frac{m_{air}}{m_{fuel}}$$

The heating value of a fuel is defined as the amount of heat released when a fuel is burned completely in a steady process and the reactants are returned to the initial state. The higher heating value represents the value when water in the products is in the liquid form.

$$HHV = LHV + \left(m h_{fg}\right)_{H_2O}$$

Taking heat transfer to the system and work done by the system to be positive. Conservation of energy for a chemical reacting steady flow system per unit mole of fuel is given by:

$$Q_{net} - W_{net} = \sum_{Products} N_e\left[\bar{h}_f^\circ + \left(\bar{h}_T - \bar{h}^\circ\right)\right]_e - \sum_{Reactants} N_i\left[\bar{h}_f^\circ + \left(\bar{h}_T - \bar{h}^\circ\right)\right]_i$$

For a closed system this becomes:

$$Q_{net} - W_{net} = \sum_{Products} N_e\left[\bar{h}_f^\circ + \left(\bar{h}_T - \bar{h}^\circ\right) - \boldsymbol{P\bar{v}}\right]_e - \sum_{Reactants} N_i\left[\bar{h}_f^\circ + \left(\bar{h}_T - \bar{h}^\circ\right) - \boldsymbol{P\bar{v}}\right]_i$$

Vapour mixtures

For temperatures in the range about –10 to about 50°C the enthalpy of the dry air is given by:

$$\Delta h_a = [1.005(kJkg^{-1})]\Delta T, \text{with } T \text{ in } °C, \text{and } \Delta h_a \text{ in } kJkg^{-1}$$

Water / air mixtures can be treated as an ideal gas, whose pressure is the sum of that of dry air and water vapour:

$$P = P_a + P_v$$

The saturated vapour value of the enthalpy is a function of temperature and can be expressed as:

$$h_v = h_g(T)2501.5 + 1.82T(kJkg^{-1}) \text{ with } T \text{ in } °C, \text{and } \Delta h_v \text{ in } kJkg^{-1}$$

The absolute and relative humidity are defined by:

$$\omega = \frac{m_v}{m_a} = \frac{P_v V/(R_v T)}{P_a V/(R_a T)} = \frac{P_v/(R_v)}{P_a/(R_a)} = 0.622\frac{P_v}{P_a} \quad \phi = \frac{m_v}{m_g} = \frac{P_v}{P_g}$$

The absolute and relative humidity are related by:

$$\phi = \frac{\omega P}{(0.622 + \omega)P_g} \text{ and } \omega = \frac{0.622\phi P_g}{P - \phi P_g}$$

Mixture Formulæ

The composition of a gas mixture is described by specifying either the *mass fraction* mf_i or the *mole fraction* y_i of each component i:

$$mf_i = \frac{m_i}{m_m} \text{ and } y_i = \frac{N_i}{N_m}$$

The total mass of the mixture m_m and the total moles of mixture N_m are defined as:

$$N_m = \sum_{i=1}^{k} N_i \text{ and } m_m = \sum_{i=1}^{k} m_i$$

The average molar mass and gas constant are given as:

$$M_m = \frac{m_m}{N_m} = \frac{\sum m_i}{N_m} = \frac{\sum N_i M_i}{N_m} = \sum_{i=1}^{k} y_i M_i \text{ and } R_m = \frac{R_u}{M_m}$$

To change between a mole fraction analysis and a mass fraction analysis use:

$$mf_i = \frac{y_i M_i}{\sum_{i=1}^{k} y_i M_i} \text{ and } y_i = \frac{mf_i/M_i}{\sum_{i=1}^{k} mf_i/M_i}$$

Amagat's law of additive volumes states that the volume of a gas mixture is equal to the sum of the volumes each gas would occupy if it existed alone at the mixture temperature and pressure.

Amagat's law: $V_m = \sum_{i=1}^{k} V_i(T_m, P_m)$

The partial pressure of component i is defined as the product of the mole fraction and the mixture pressure according to Dalton's law. For the component I:

$$P_i = y_i P_m$$

Dalton's law: $P_m = \sum_{i=1}^{k} P_i(T_m, V_m)$

The extensive properties of a gas mixture

The *extensive properties* of a gas mixture, in general, can be determined by summing the contributions of each component of the mixture. The evaluation of *intensive properties* of a gas mixture, however, involves averaging in terms of mass or mole fractions:

$$U_m = \sum_{i=1}^{k} U_i = \sum_{i=1}^{k} m_i u_i = \sum_{i=1}^{k} N_i \bar{u}_i \ \text{(kJ)}$$

$$H_m = \sum_{i=1}^{k} H_i = \sum_{i=1}^{k} m_i h_i = \sum_{i=1}^{k} N_i \bar{h}_i \ \text{(kJ)}$$

$$S_m = \sum_{i=1}^{k} S_i = \sum_{i=1}^{k} m_i s_i = \sum_{i=1}^{k} N_i \bar{s}_i \ (\text{kJK}^{-1})$$

and

$$u_m = \sum_{i=1}^{k} mf_i u_i \quad \text{and} \quad \bar{u}_m = \sum_{i=1}^{k} y_i \bar{u}_i \ (\text{kJ kg}^{-1} \text{ or kJ kmol}^{-1})$$

$$h_m = \sum_{i=1}^{k} mf_i h_i \quad \text{and} \quad \bar{h}_m = \sum_{i=1}^{k} y_i \bar{h}_i \ (\text{kJ kg}^{-1} \text{ or kJ kmol}^{-1})$$

$$s_m = \sum_{i=1}^{k} mf_i s_i \quad \text{and} \quad \bar{s}_m = \sum_{i=1}^{k} y_i \bar{s}_i \ (\text{kJ kg}^{-1}\text{K}^{-1} \text{ or kJ kmol}^{-1}\text{K}^{-1})$$

Specific heat capacities of mixtures

$$C_{v,m} = \sum_{i=1}^{k} mf_i C_{v,i} \text{ and } \bar{C}_{v,m} = \sum_{i=1}^{k} y_i \bar{C}_{v,i}$$

$$C_{p,m} = \sum_{i=1}^{k} mf_i C_{p,i} \text{ and } \bar{C}_{p,m} = \sum_{i=1}^{k} y_i \bar{C}_{p,i}$$

The entropy change of a mixture

The entropy change of the mixture per mass of mixture is:

$$\Delta s_m = \frac{\Delta S_m}{m_m} = \sum_{i=1}^{2} mf_i \Delta s_i = \sum_{i=1}^{k} mf_i \left(C_{p,i} \ln\left(\frac{T_2}{T_1}\right) - R_i \ln\left(\frac{P_{i,2}}{P_{i,1}}\right) \right)$$

The entropy change of the mixture per mole of mixture is:

$$\Delta \bar{s}_m = \frac{\Delta S_m}{N_m} = \sum_{i=1}^{2} y_i \Delta \bar{s}_i = \sum_{i=1}^{k} y_i \left(\bar{C}_{p,i} \ln\left(\frac{T_2}{T_1}\right) - R_i \ln\left(\frac{P_{i,2}}{P_{i,1}}\right) \right)$$

In these last two equations, remember:

$$P_{i,1} = y_{i,1} P_{m,1} \text{ and } P_{i,2} = y_{i,2} P_{m,2}$$

Formulæ related to combustion engines

Scavenge ratio or delivery ratio, λ:

$$\lambda = \frac{m_s}{m_i}$$

Scavenge efficiency, η_{sc}:

$$\eta_{sc} = \frac{m_a}{m_a + m_g}$$

Charging efficiency, η_{ch}:

$$\eta_{ch} = \frac{m_a}{m_i}$$

Trapping efficiency, η_{tr}:

$$\eta_{tr} = \frac{m_a}{m_s} = \frac{\eta_{ch}}{\lambda}$$

V_t	:	cylinder trapping volume
m_i	:	ideal trapped air mass = $\rho_s V_t$
m_a	:	actual air mass in the cylinder

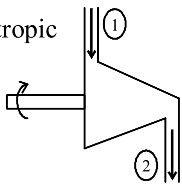
Where we use the following definition

m_g	:	mass of residual gas in the cylinder
m_s	:	mass of air supplied to the cylinder

Perfect displacement	:	$\eta_{ch} = \lambda$
Perfect mixing	:	$d\eta_{ch} = d\lambda(1 - \eta_{ch})$
Short circuit	:	$d\eta_{ch} = 0$

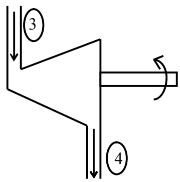
Compressor polytropic efficiency

$$\frac{T_{02}}{T_{01}} = \left(\frac{p_{02}}{p_{01}}\right)^{\frac{\gamma-1}{\gamma\eta_{\delta c}}}$$



Turbine polytropic efficiency

$$\frac{T_{04}}{T_{03}} = \left(\frac{p_{04}}{p_{03}}\right)^{\frac{\gamma-1}{\gamma}\eta_{\delta t}}$$



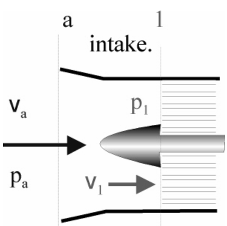
Choked nozzle:

$$T_5 = \frac{2}{\gamma + 1} T_{04}, \qquad V_5 = \sqrt{\gamma R T_5}$$

T_5 static temperature of the jet, T_{04} total temperature after the turbine.

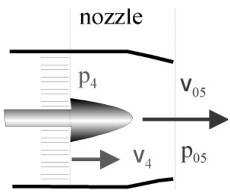
Propulsive thrust:

$$\eta_p = \frac{thrust\ power}{total\ power}$$



Intake nozzle efficiency

$$\eta_i = \frac{T_{01'} - T_a}{T_{01} - T_a}$$



Propelling nozzle efficiency

$$\eta_j = \frac{T_{04} - T_5}{T_{04} - T_{5'}}$$

Some Dimensionless Groups

Biot Number	$Bi = \frac{h_t \Delta x}{k}$	$\frac{\text{Thermal internal resistance}}{\text{Surface film resistance}}$ Δx = mid-plane distance
Cauchy Number	$Ca = \frac{\rho u^2}{E_v}$	$\frac{\text{Inertia force}}{\text{Compressibility force}}$
Froude Number	$Fr = \frac{u}{\sqrt{gL}} \left(\text{or } \frac{u^2}{gL}\right)$	$\frac{\text{Inertia force}}{\text{Gravity force}}$
Grashof Number (free convection)	$Gr = \frac{\beta g L^3 \theta}{v^2}$	$\frac{\text{Buoyancy force}}{\text{Viscous force}}$
Knudsen Number	$Kn = \frac{\lambda}{L}$	$\frac{\text{Length of mean free path}}{\text{Characteristic dimension}}$ or number of particles across dimension
Mach. Number	$M = \frac{u}{a}$	$\frac{\text{Inertia force}}{\text{Compressibility force}}$
Nusselt Number	$Nu_L = \frac{h_c L}{k}$	$\frac{\text{Convective heat transfer}}{\text{Conductive heat transfer}}$
Peclet Number	$Pe_L = \frac{c_p \rho u L}{k} = Re_L.Pr$	$\frac{\text{Bulk heat transfer}}{\text{Conductive heat transfer}}$
Prandtl Number	$Pr = \frac{c_p \mu}{k}$	$\frac{\text{Thickness of thermal boundary layer}}{\text{Thickness of fluid boundary layer}}$
Reynolds Number	$Re_L = \frac{\rho u L}{\mu} = \frac{uL}{v}$	$\frac{\text{Inertia force}}{\text{Viscous force}}$
Stanton Number	$St = \frac{h_c}{\rho u c_p} = \frac{Nu_L}{Pe_L}$	$\frac{\text{Heat transferred}}{\text{Thermal capacity of fluid}}$
Stokes Number	$\frac{nL^2}{v} = \frac{nL^2 \rho}{\mu} = Re_L.Sr$	$\frac{\text{Local inertial force}}{\text{Viscous force}}$
Strouhal Number	$Sr = \frac{nL}{u}$	$\frac{\text{Local inertial force}}{\text{Inertial force}}$
Weber Number	$We_L = \frac{\rho u^2 L}{\sigma}$	$\frac{\text{Inertia force}}{\text{Surface tension force}}$
Force Coefficient	$\frac{F}{\frac{1}{2}\rho u^2 L^2}$	$\frac{\text{Force}}{\text{Inertial force}}$
Pressure Loss Coefficient *Euler number*	$\frac{\Delta p}{\frac{1}{2}\rho u^2}$	$\frac{\text{Pressure loss}}{\text{Dynamic pressure}}$
Friction Coefficient	$(f \text{ or } c_f) = \frac{\tau_0}{\frac{1}{2}\rho \bar{u}^2}$	(Where τ_0 is fluid shear stress at a wall)

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Steam and Refrigerant Tables

Saturated steam: liquid and vapour: temperature based

T ºC	P(sat) kPa	$v_f \times 10^3$ m^3kg^{-1}	v_g m^3kg^{-1}	u_f kJ kg^{-1}	u_g kJ kg^{-1}	h_f kJ kg^{-1}	h_g kJ kg^{-1}	s_f kJ $kg^{-1}K^{-1}$	s_g kJ $kg^{-1}K^{-1}$
0.01	0.6117	1.000	*206*	0.0	*2375*	0	*2501*	0.0	*9.156*
5	0.8725	1.000	*147.0*	21.0	*2382*	21.0	*2510*	0.07625	*9.025*
10	1.228	1.000	*106.3*	42.0	*2389*	42.0	*2519*	0.1511	*8.900*
15	1.706	1.000	*77.89*	63.0	*2396*	63.0	*2528*	0.2245	*8.780*
20	2.339	1.001	*57.76*	83.9	*2402*	83.9	*2537*	0.2965	*8.666*
25	3.17	1.003	*43.34*	105	*2409*	105	*2547*	0.3672	*8.557*
30	4.247	1.004	*32.88*	126	*2416*	126	*2556*	0.4368	*8.452*
35	5.629	1.006	*25.20*	147	*2423*	147	*2565*	0.5051	*8.352*
40	7.385	1.007	*19.51*	168	*2429*	168	*2574*	0.5724	*8.256*
45	9.595	1.009	*15.25*	188	*2436*	188	*2582*	0.6386	*8.163*
50	12.35	1.012	*12.03*	209	*2443*	209	*2591*	0.7038	*8.075*
55	15.76	1.014	*9.564*	230	*2449*	230	*2600*	0.768	*7.990*
60	19.95	1.017	*7.667*	251	*2456*	251	*2609*	0.8313	*7.908*
65	25.04	1.019	*6.193*	272	*2462*	272	*2618*	0.8937	*7.830*
70	31.2	1.022	*5.040*	293	*2469*	293	*2626*	0.9551	*7.754*
75	38.6	1.025	*4.129*	314	*2475*	314	*2635*	1.016	*7.681*
80	47.42	1.029	*3.405*	335	*2482*	335	*2643*	1.076	*7.611*
85	57.87	1.032	*2.826*	356	*2488*	356	*2651*	1.135	*7.543*
90	70.18	1.036	*2.359*	377	*2494*	377	*2660*	1.193	*7.478*
95	84.61	1.039	*1.981*	398	*2500*	398	*2668*	1.25	*7.415*
100	101.4	1.043	*1.672*	419	*2506*	419	*2676*	1.307	*7.354*
110	143.4	1.051	*1.209*	461	*2518*	461	*2691*	1.419	*7.238*
120	198.7	1.060	*0.8913*	504	*2529*	504	*2706*	1.528	*7.129*
130	270.3	1.069	*0.6681*	546	*2540*	546	*2720*	1.635	*7.027*
140	361.5	1.079	*0.5085*	589	*2550*	589	*2733*	1.739	*6.929*
150	476.2	1.090	*0.3925*	632	*2559*	632	*2746*	1.842	*6.837*
160	618.2	1.102	*0.3068*	675	*2568*	676	*2757*	1.943	*6.749*
170	792.2	1.114	*0.2426*	718	*2576*	719	*2768*	2.042	*6.665*
180	1003	1.127	*0.1938*	762	*2583*	763	*2777*	2.139	*6.584*
190	1255	1.141	*0.1564*	806	*2589*	807	*2785*	2.235	*6.506*
200	1555	1.156	*0.1272*	851	*2594*	852	*2792*	2.331	*6.430*
220	2320	1.190	*0.08609*	941	*2601*	944	*2801*	2.518	*6.284*
240	3347	1.229	*0.05971*	1033	*2603*	1037	*2803*	2.702	*6.142*
260	4692	1.275	*0.04218*	1129	*2599*	1135	*2797*	2.885	*6.002*
280	6417	1.332	*0.03015*	1228	*2586*	1237	*2780*	3.068	*5.858*
300	8588	1.403	*0.02166*	1333	*2564*	1345	*2750*	3.255	*5.706*
320	11280	1.498	*0.01547*	1445	*2526*	1462	*2701*	3.449	*5.537*
340	14600	1.638	*0.01078*	1571	*2465*	1595	*2622*	3.66	*5.336*
360	18670	1.895	*0.00695*	1726	*2352*	1762	*2482*	3.916	*5.054*
374.14	22050	2.864	*0.00339*	1978	*2058*	2041	*2133*	4.341	*4.482*

Saturated steam: liquid and vapour: up to 1 bar

P kPa	T(sat) ºC	$v_f \times 10^3$ m^3kg^{-1}	v_g m^3kg^{-1}	u_f kJ kg^{-1}	u_g kJ kg^{-1}	h_f kJ kg^{-1}	h_g kJ kg^{-1}	s_f kJ $kg^{-1}K^{-1}$	s_g kJ $kg^{-1}K^{-1}$
0.6113	0.0	1.000	*206.1*	0	*2375*	0	*2501*	0.000	*9.156*
1.0	7.0	1.000	*129.2*	29.30	*2384*	29.30	*2514*	0.106	*8.975*
2.0	17.5	1.001	*66.99*	54.69	*2399*	73.43	*2533*	0.261	*8.723*
2.5	21.1	1.002	*54.24*	88.42	*2404*	88.42	*2539*	0.312	*8.642*
3.0	24.1	1.003	*45.65*	101.0	*2408*	101.0	*2545*	0.354	*8.576*
3.5	26.7	1.003	*39.47*	111.8	*2411*	111.8	*2550*	0.391	*8.521*
4.0	29.0	1.004	*34.79*	121.4	*2415*	121.4	*2554*	0.422	*8.473*
4.5	31.0	1.004	*31.13*	130.0	*2417*	130.0	*2557*	0.451	*8.431*
5.0	32.9	1.005	*28.19*	137.7	*2420*	137.8	2561	0.476	*8.394*
5.5	34.58	1.005	*25.76*	144.9	*2422*	144.9	2564	0.499	*8.360*
6.0	36.2	1.006	*23.73*	151.5	*2424*	151.5	2567	0.521	*8.329*
7.0	39.0	1.008	*20.52*	163.3	*2428*	163.4	2572	0.559	*8.274*
8.0	41.5	1.008	*18.10*	173.8	*2431*	173.8	*2576*	0.593	*8.227*
9.0	43.7	1.009	*16.20*	183.2	*2434*	183.3	*2580*	0.622	*8.186*
10	45.8	1.010	*14.67*	191.8	*2437*	191.8	*2584*	0.649	*8.149*
11	47.7	1.011	*13.41*	199.6	*2440*	199.7	*2587*	0.674	*8.115*
12	49.4	1.012	*12.36*	206.9	*2442*	206.9	*2590*	0.696	*8.085*
13	51.0	1.013	*11.46*	213.7	*2444*	213.7	*2593*	0.717	*8.057*
14	52.5	1.013	*10.69*	220.0	*2446*	220.0	*2596*	0.737	*8.031*
15	54.0	1.014	*10.02*	225.9	*2448*	225.9	*2598*	0.755	*8.007*
16	55.3	1.015	*9.431*	231.5	*2450*	231.6	*2601*	0.772	*7.985*
17	56.6	1.015	*8.909*	236.9	*2451*	236.9	*2603*	0.788	*7.964*
18	57.8	1.016	*8.443*	241.9	*2453*	242.0	*2605*	0.804	*7.944*
20	60.1	1.017	*7.648*	251.4	*2456*	251.4	*2609*	0.832	*7.907*
25	65.0	1.020	*6.203*	271.9	*2462*	272.0	*2617*	0.893	*7.830*
30	69.1	1.022	*5.229*	289.2	*2468*	289.3	*2625*	0.944	*7.768*
35	72.7	1.024	*4.525*	304.3	*2472*	304.3	*2631*	0.988	*7.715*
40	75.9	1.026	*3.993*	317.6	*2476*	317.6	*2636*	1.026	*7.669*
45	78.7	1.028	*3.576*	329.6	*2480*	329.6	*2641*	1.060	*7.629*
50	81.3	1.030	*3.240*	340.5	*2483*	340.5	*2645*	1.091	*7.593*
55	83.7	1.032	*2.964*	350.5	*2486*	350.6	*2649*	1.119	*7.561*
60	85.9	1.033	*2.732*	359.8	*2489*	359.9	*2653*	1.145	*7.531*
65	88.0	1.035	*2.535*	368.5	*2492*	368.6	*2656*	1.170	*7.504*
70	89.9	1.036	*2.365*	376.7	*2494*	376.8	*2659*	1.192	*7.479*
75	91.8	1.037	*2.217*	384.4	*2496*	384.4	*2662*	1.213	*7.456*
80	93.5	1.039	*2.087*	391.6	*2498*	391.7	*2665*	1.233	*7.434*
85	95.1	1.040	*1.972*	398.5	*2500*	398.6	*2668*	1.252	*7.414*
90	96.7	1.041	*1.870*	405.1	*2502*	405.2	*2670*	1.270	*7.394*
95	98.2	1.042	*1.777*	411.4	*2504*	411.5	*2673*	1.287	*7.376*
100	99.6	1.043	*1.694*	417.4	*2506*	417.5	*2675*	1.303	*7.359*

Note: The actual values of v_f are 10^3 times smaller than the figures given. For example, the specific volume of saturated liquid water at 20kPa is 0.001017 m^3kg^{-1}.

Saturated steam: liquid and vapour: 1 to 15 bar

P kPa	T(sat) ºC	$v_f \times 10^3$ m^3kg^{-1}	v_g m^3kg^{-1}	u_f kJ kg^{-1}	u_g kJ kg^{-1}	h_f kJ kg^{-1}	h_g kJ kg^{-1}	s_f kJ kg^{-1}K^{-1}	s_g kJ kg^{-1}K^{-1}
100	99.6	1.043	*1.694*	417.4	*2506*	417.5	*2675*	1.303	*7.359*
110	102.3	1.045	*1.550*	428.7	*2509*	428.8	*2679*	1.333	*7.327*
120	104.8	1.047	*1.429*	439.2	*2512*	439.4	*2683*	1.361	*7.298*
130	107.1	1.049	*1.325*	449.1	*2514*	449.2	*2687*	1.387	*7.271*
140	109.3	1.051	*1.237*	458.3	*2517*	458.4	*2690*	1.411	*7.246*
150	111.4	1.053	*1.159*	467.0	*2519*	467.1	*2693*	1.434	*7.223*
175	116.0	1.057	*1.004*	486.8	*2525*	487.0	*2700*	1.485	*7.172*
200	120.2	1.061	*0.886*	504.5	*2529*	504.7	*2706*	1.530	*7.127*
225	124.0	1.064	*0.793*	520.5	*2533*	520.7	*2712*	1.571	*7.088*
250	127.4	1.067	*0.719*	535.1	*2537*	535.3	*2717*	1.607	*7.053*
275	130.6	1.070	*0.657*	548.6	*2540*	548.9	*2721*	1.641	*7.021*
300	133.5	1.073	*0.606*	561.1	*2543*	561.4	*2725*	1.672	*6.992*
325	136.3	1.076	*0.562*	572.8	*2546*	573.2	*2729*	1.700	*6.965*
350	138.9	1.079	*0.524*	583.9	*2549*	584.3	*2732*	1.727	*6.940*
375	141.3	1.081	*0.491*	594.3	*2551*	594.7	*2735*	1.753	*6.917*
400	143.6	1.084	*0.462*	604.2	*2553*	604.7	*2738*	1.776	*6.896*
425	145.8	1.086	*0.437*	613.7	*2555*	614.1	*2741*	1.799	*6.875*
450	147.9	1.088	*0.414*	622.7	*2557*	623.1	*2743*	1.820	*6.856*
475	149.9	1.090	*0.393*	631.3	*2559*	631.8	*2746*	1.841	*6.838*
500	151.8	1.093	*0.375*	639.5	*2561*	640.1	*2748*	1.860	*6.821*
550	155.5	1.097	*0.343*	655.2	*2564*	655.8	*2752*	1.897	*6.789*
600	158.8	1.101	*0.316*	669.7	*2567*	670.4	*2756*	1.931	*6.759*
650	162.0	1.104	*0.293*	683.4	*2569*	684.1	*2760*	1.962	*6.732*
700	165.0	1.108	*0.273*	696.2	*2572*	697.0	*2763*	1.992	*6.707*
750	167.8	1.111	*0.256*	708.4	*2574*	709.2	*2766*	2.019	*6.684*
800	170.4	1.115	*0.240*	720.0	*2576*	720.9	*2768*	2.046	*6.662*
850	173.0	1.118	*0.227*	731.0	*2578*	732.0	*2771*	2.070	*6.641*
900	175.4	1.121	*0.215*	741.6	*2580*	742.6	*2773*	2.094	*6.621*
950	177.7	1.124	*0.204*	751.7	*2581*	752.7	*2775*	2.117	*6.603*
1000	179.9	1.127	*0.194*	761.4	*2583*	762.5	*2777*	2.138	*6.585*
1050	182.0	1.130	*0.186*	770.7	*2584*	771.9	*2779*	2.159	*6.568*
1100	184.1	1.133	*0.177*	779.8	*2585*	781.0	*2781*	2.178	*6.552*
1150	186.1	1.136	*0.170*	788.5	*2587*	789.8	*2782*	2.198	*6.537*
1200	188.0	1.138	*0.163*	797.0	*2588*	798.3	*2784*	2.216	*6.522*
1250	189.8	1.141	*0.157*	805.2	*2589*	806.6	*2785*	2.234	*6.507*
1300	191.6	1.144	*0.151*	813.1	*2590*	814.6	*2786*	2.251	*6.494*
1350	193.4	1.146	*0.146*	820.8	*2591*	822.4	*2788*	2.267	*6.480*
1400	195.1	1.149	*0.141*	828.4	*2592*	830.0	*2789*	2.284	*6.467*
1450	196.7	1.151	*0.136*	835.7	*2593*	837.3	*2790*	2.299	*6.455*
1500	198.3	1.154	*0.132*	842.8	*2593*	844.5	*2791*	2.314	*6.443*

Saturated steam: liquid and vapour: 15 bar to critical

P(sat) kPa	T(sat) ºC	$v_f \times 10^3$ m^3kg^{-1}	v_g m^3kg^{-1}	u_f kJ kg^{-1}	u_g kJ kg^{-1}	h_f kJ kg^{-1}	h_g kJ kg^{-1}	s_f kJ $kg^{-1}K^{-1}$	s_g kJ $kg^{-1}K^{-1}$
1500	198.3	1.154	*0.132*	842.8	*2593*	844.5	*2791*	2.314	*6.443*
1600	201.4	1.159	*0.124*	856.6	*2595*	858.4	*2793*	2.343	*6.420*
1700	204.3	1.163	*0.117*	869.7	*2596*	871.7	*2794*	2.371	*6.398*
1800	207.1	1.168	*0.110*	882.4	*2597*	884.5	*2796*	2.397	*6.377*
1900	209.8	1.172	*0.105*	894.5	*2598*	896.7	*2797*	2.423	*6.358*
2000	212.4	1.177	*0.100*	906.1	*2599*	908.5	*2798*	2.447	*6.339*
2200	217.3	1.185	*0.091*	928.2	*2601*	930.8	*2800*	2.492	*6.304*
2400	221.8	1.193	*0.083*	949.0	*2602*	951.8	*2801*	2.534	*6.271*
2600	226.1	1.201	*0.077*	968.5	*2602*	971.6	*2802*	2.574	*6.241*
2800	230.1	1.209	*0.071*	987.0	*2603*	990.4	*2803*	2.611	*6.212*
3000	233.9	1.217	*0.067*	1004.6	*2603*	1008.3	*2803*	2.645	*6.186*
3500	242.6	1.235	*0.057*	1045.4	*2603*	1049.7	*2803*	2.725	*6.124*
4000	250.4	1.252	*0.050*	1082.4	*2602*	1087.4	*2801*	2.797	*6.070*
4500	257.5	1.269	*0.044*	1116.4	*2600*	1122.1	*2798*	2.861	*6.020*
5000	264.0	1.286	*0.039*	1148.1	*2597*	1154.5	*2794*	2.921	*5.974*
5500	270.0	1.303	*0.036*	1177.8	*2594*	1184.9	*2790*	2.976	*5.931*
6000	275.6	1.319	*0.032*	1205.8	*2590*	1213.8	*2785*	3.027	*5.890*
6500	280.9	1.335	*0.030*	1232.5	*2586*	1241.2	*2779*	3.076	*5.852*
7000	285.9	1.352	*0.027*	1258.0	*2581*	1267.5	*2773*	3.122	*5.815*
7500	290.6	1.368	*0.025*	1282.5	*2576*	1292.7	*2766*	3.166	*5.779*
8000	295.0	1.384	*0.024*	1306.0	*2570*	1317.1	*2759*	3.208	*5.745*
8500	299.3	1.401	*0.022*	1328.8	*2565*	1340.7	*2751*	3.248	*5.712*
9000	303.4	1.418	*0.020*	1350.9	*2559*	1363.7	*2743*	3.287	*5.679*
9500	307.3	1.435	*0.019*	1372.4	*2552*	1386.0	*2734*	3.324	*5.647*
10000	311.0	1.452	*0.018*	1393.3	*2545*	1407.8	*2725*	3.36	*5.616*
10500	314.6	1.470	*0.017*	1413.8	*2538*	1429.2	*2716*	3.396	*5.585*
11000	318.1	1.488	*0.016*	1433.9	*2530*	1450.2	*2706*	3.43	*5.554*
11500	321.5	1.507	*0.015*	1453.6	*2523*	1470.9	*2696*	3.464	*5.524*
12000	324.7	1.526	*0.014*	1473.0	*2514*	1491.3	*2685*	3.496	*5.494*
12500	327.9	1.546	*0.013*	1492.1	*2506*	1511.4	*2674*	3.529	*5.464*
13000	330.9	1.566	*0.0128*	1511.0	*2497*	1531.4	*2663*	3.561	*5.434*
14000	336.7	1.610	*0.0115*	1548.4	*2477*	1571.0	*2638*	3.623	*5.373*
15000	342.2	1.657	*0.0103*	1585.5	*2456*	1610.3	*2611*	3.685	*5.311*
16000	347.4	1.710	*0.0093*	1622.6	*2432*	1649.9	*2581*	3.746	*5.247*
17000	352.3	1.770	*0.0084*	1660.2	*2405*	1690.3	*2548*	3.808	*5.179*
18000	357.0	1.840	*0.0075*	1699.1	*2375*	1732.2	*2510*	3.872	*5.106*
19000	361.5	1.926	*0.0067*	1740.3	*2339*	1776.8	*2466*	3.94	*5.026*
20000	365.8	2.038	*0.0058*	1785.8	*2295*	1826.6	*2412*	4.015	*4.931*
21000	369.9	2.207	*0.0050*	1841.6	*2233*	1888.0	*2338*	4.107	*4.808*
22060	374.0	2.938	*0.003*	1990.1	*2044*	2054.9	*2117*	4.362	*4.457*

Superheated steam - enthalpy and entropy up to 300°C

		Saturation		100°C		150°C		200°C		250°C		300°C	
P kPa	T(sat) °C	h_g kJkg^{-1}	s_g kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}
20	60.06	2609	*7.907*	2686	*8.126*	2782	*8.368*	2879	*8.584*	2977	*8.781*	3077	*8.963*
40	75.86	2636	*7.669*	2684	*7.801*	2781	*8.046*	2878	*8.263*	2976	*8.46*	3076	*8.642*
60	85.93	2653	*7.531*	2681	*7.608*	2780	*7.856*	2877	*8.074*	2976	*8.272*	3076	*8.454*
80	93.49	2665	*7.434*	2678	*7.470*	2778	*7.720*	2876	*7.940*	2975	*8.139*	3075	*8.321*
100	99.61	2675	*7.359*	2676	*7.361*	2777	*7.615*	2875	*7.836*	2975	*8.035*	3075	*8.217*
120	104.8	2683	*7.298*			2775	*7.528*	2875	*7.750*	2974	*7.950*	3074	*8.132*
140	109.3	2690	*7.246*			2774	*7.454*	2874	*7.677*	2973	*7.877*	3074	*8.061*
160	113.3	2696	*7.201*			2772	*7.39*	2873	*7.614*	2973	*7.815*	3073	*7.998*
180	116.9	2701	*7.162*			2771	*7.332*	2872	*7.558*	2972	*7.760*	3073	*7.943*
200	120.2	2706	*7.127*			2769	*7.281*	2871	*7.508*	2971	*7.710*	3072	*7.894*
250	127.4	2717	*7.053*			2765	*7.171*	2868	*7.401*	2970	*7.605*	3071	*7.789*
300	133.5	2725	*6.992*			2761	*7.079*	2866	*7.313*	2968	*7.518*	3070	*7.704*
350	138.9	2732	*6.940*			2757	*7.000*	2863	*7.238*	2966	*7.444*	3068	*7.631*
400	143.6	2738	*6.896*			2753	*6.931*	2861	*7.172*	2964	*7.38*	3067	*7.568*
500	151.8	2748	*6.821*					2856	*7.061*	2961	*7.272*	3065	*7.461*
600	158.8	2756	*6.759*					2851	*6.968*	2958	*7.183*	3062	*7.374*
700	164.9	2763	*6.707*					2845	*6.888*	2954	*7.107*	3059	*7.299*
800	170.4	2768	*6.662*					2840	*6.818*	2950	*7.04*	3057	*7.234*
900	175.4	2773	*6.621*					2834	*6.754*	2947	*6.981*	3054	*7.177*
1000	179.9	2777	*6.585*					2828	*6.696*	2943	*6.927*	3052	*7.125*
1500	198.3	2791	*6.443*					2796	*6.454*	2924	*6.711*	3038	*6.920*
2000	212.4	2798	*6.339*							2903	*6.547*	3024	*6.768*
2500	223.9	2802	*6.256*							2881	*6.411*	3010	*6.646*
3000	233.9	2803	*6.186*							2857	*6.289*	2994	*6.541*
3500	242.6	2803	*6.124*							2830	*6.176*	2978	*6.448*
4000	250.4	2801	*6.070*									2962	*6.364*
4500	257.4	2798	*6.020*									2944	*6.285*
5000	263.9	2794	*5.974*									2926	*6.211*
5500	270.0	2790	*5.931*									2906	*6.140*
6000	275.6	2785	*5.890*									2886	*6.070*
6500	280.9	2779	*5.852*									2864	*6.002*
7000	285.8	2773	*5.815*									2840	*5.934*
7500	290.5	2766	*5.779*									2814	*5.865*
8000	295.0	2759	*5.745*									2786	*5.794*
9000	303.3	2743	*5.679*										
10000	311	2725	*5.616*										
11000	318.1	2706	*5.554*										
12000	324.7	2685	*5.494*										
13000	330.9	2663	*5.434*										
14000	336.7	2638	*5.373*										
15000	342.2	2611	*5.311*										
16000	347.4	2581	*5.247*										
17000	352.3	2548	*5.179*										
18000	357.0	2510	*5.106*										
20000	365.7	2412	*4.931*										

Superheated steam – enthalpy and entropy 350°C to 700°C

350°C		400°C		450°C		500°C		600°C		700°C		
h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	P kPa
3177	*9.131*	3280	*9.289*	3384	*9.438*	3490	*9.58*	3706	*9.843*	3930	*10.09*	20
3177	*8.811*	3279	*8.969*	3384	*9.118*	3489	*9.26*	3706	*9.523*	3930	*9.766*	40
3177	*8.623*	3279	*8.782*	3383	*8.931*	3489	*9.072*	3706	*9.336*	3930	*9.578*	60
3176	*8.49*	3279	*8.649*	3383	*8.798*	3489	*8.939*	3706	*9.203*	3930	*9.446*	80
3176	*8.387*	3279	*8.545*	3383	*8.695*	3489	*8.836*	3706	*9.100*	3929	*9.342*	100
3175	*8.302*	3278	*8.461*	3383	*8.610*	3489	*8.752*	3705	*9.016*	3929	*9.258*	120
3175	*8.23*	3278	*8.389*	3382	*8.539*	3488	*8.68*	3705	*8.944*	3929	*9.187*	140
3175	*8.168*	3278	*8.327*	3382	*8.477*	3488	*8.619*	3705	*8.883*	3929	*9.125*	160
3174	*8.114*	3277	*8.273*	3382	*8.422*	3488	*8.564*	3705	*8.828*	3929	*9.071*	180
3174	*8.064*	3277	*8.224*	3382	*8.373*	3488	*8.515*	3705	*8.779*	3929	*9.022*	200
3173	*7.96*	3276	*8.12*	3381	*8.270*	3487	*8.412*	3704	*8.676*	3929	*8.919*	250
3172	*7.875*	3275	*8.035*	3380	*8.185*	3487	*8.327*	3704	*8.591*	3928	*8.834*	300
3171	*7.803*	3275	*7.963*	3380	*8.113*	3486	*8.255*	3704	*8.520*	3928	*8.763*	350
3170	*7.74*	3274	*7.9*	3379	*8.051*	3486	*8.193*	3703	*8.458*	3928	*8.701*	400
3168	*7.635*	3272	*7.796*	3378	*7.947*	3484	*8.089*	3702	*8.354*	3927	*8.598*	500
3166	*7.548*	3271	*7.71*	3376	*7.861*	3483	*8.004*	3702	*8.270*	3926	*8.513*	600
3164	*7.475*	3269	*7.637*	3375	*7.789*	3482	*7.932*	3701	*8.198*	3926	*8.442*	700
3162	*7.411*	3268	*7.573*	3374	*7.726*	3481	*7.869*	3700	*8.135*	3925	*8.379*	800
3160	*7.354*	3266	*7.517*	3373	*7.670*	3480	*7.814*	3699	*8.080*	3925	*8.325*	900
3158	*7.303*	3264	*7.467*	3371	*7.620*	3479	*7.764*	3699	*8.031*	3924	*8.276*	1000
3148	*7.104*	3256	*7.271*	3365	*7.426*	3474	*7.572*	3695	*7.841*	3921	*8.086*	1500
3138	*6.958*	3248	*7.129*	3358	*7.287*	3468	*7.434*	3691	*7.704*	3918	*7.951*	2000
3127	*6.842*	3240	*7.017*	3352	*7.177*	3463	*7.325*	3687	*7.598*	3915	*7.846*	2500
3116	*6.745*	3232	*6.923*	3345	*7.086*	3457	*7.236*	3683	*7.510*	3912	*7.759*	3000
3105	*6.66*	3223	*6.843*	3338	*7.007*	3452	*7.159*	3679	*7.436*	3909	*7.685*	3500
3093	*6.584*	3214	*6.771*	3331	*6.939*	3446	*7.092*	3675	*7.371*	3906	*7.621*	4000
3081	*6.515*	3206	*6.707*	3324	*6.877*	3440	*7.032*	3671	*7.313*	3903	*7.565*	4500
3069	*6.452*	3197	*6.648*	3317	*6.821*	3435	*6.978*	3667	*7.261*	3900	*7.514*	5000
3057	*6.392*	3188	*6.594*	3310	*6.770*	3429	*6.928*	3663	*7.213*	3897	*7.467*	5500
3044	*6.336*	3178	*6.543*	3303	*6.722*	3423	*6.883*	3659	*7.169*	3894	*7.425*	6000
3031	*6.282*	3169	*6.495*	3296	*6.677*	3417	*6.840*	3655	*7.129*	3891	*7.385*	6500
3017	*6.23*	3159	*6.45*	3288	*6.635*	3411	*6.800*	3651	*7.091*	3888	*7.349*	7000
3003	*6.181*	3149	*6.407*	3281	*6.596*	3405	*6.762*	3647	*7.056*	3885	*7.314*	7500
2988	*6.132*	3139	*6.366*	3273	*6.558*	3400	*6.727*	3642	*7.022*	3882	*7.282*	8000
2957	*6.038*	3119	*6.288*	3258	*6.487*	3387	*6.66*	3634	*6.960*	3876	*7.223*	9000
2924	*5.946*	3097	*6.214*	3242	*6.422*	3375	*6.599*	3626	*6.905*	3870	*7.169*	10000
2888	*5.854*	3075	*6.144*	3226	*6.361*	3363	*6.543*	3617	*6.853*	3864	*7.12*	11000
2848	*5.761*	3052	*6.076*	3210	*6.303*	3350	*6.490*	3609	*6.805*	3858	*7.075*	12000
2804	*5.664*	3028	*6.011*	3193	*6.248*	3337	*6.441*	3600	*6.761*	3852	*7.033*	13000
2753	*5.56*	3002	*5.946*	3176	*6.195*	3324	*6.393*	3592	*6.719*	3845	*6.994*	14000
2693	*5.444*	2976	*5.882*	3158	*6.143*	3311	*6.348*	3583	*6.680*	3839	*6.957*	15000
2617	*5.305*	2948	*5.818*	3140	*6.094*	3297	*6.305*	3574	*6.642*	3833	*6.922*	16000
		2918	*5.754*	3121	*6.045*	3284	*6.263*	3566	*6.606*	3827	*6.889*	17000
		2886	*5.688*	3102	*5.998*	3270	*6.222*	3557	*6.572*	3820	*6.858*	18000
		2817	*5.553*	3062	*5.904*	3241	*6.145*	3539	*6.508*	3808	6.799	20000

Superheated steam – internal energy and specific volume up to 300°C

		Saturation		100°C		150°C		200°C		250°C		300°C	
P kPa	T(sat) ºC	u_g $kJkg^{-1}$	v_g m^3kg^{-1}	u $kJkg^{-1}$	v m^3kg^{-1}	u $kJkg^{-1}$	v m^3kg^{-1}	u $kJkg^{-1}$	v m^3kg^{-1}	u $kJkg^{-1}$	v m^3kg^{-1}	u $kJkg^{-1}$	v m^3kg^{-1}
0.6117	36.6	2425	*23.26*	2516	*28.07*	2588	*31.84*	2661	*35.61*	2736	*39.38*	2812	*43.15*
20	60.1	2456	*7.648*	2515	*8.586*	2587	*9.749*	2661	*10.91*	2736	*12.06*	2812	*13.22*
40	75.9	2476	*3.993*	2513	*4.280*	2586	*4.866*	2660	*5.448*	2735	*6.028*	2812	*6.607*
60	85.9	2489	*2.732*	2510	*2.845*	2585	*3.239*	2660	*3.628*	2735	*4.016*	2811	*4.402*
80	93.5	2498	*2.087*	2508	*2.127*	2584	*2.425*	2659	*2.718*	2734	*3.01*	2811	*3.300*
100	99.6	2506	*1.694*	2506	*1.696*	2583	*1.937*	2658	*2.172*	2734	*2.406*	2811	*2.639*
120	104.8	2512	*1.429*			2582	*1.611*	2658	*1.808*	2733	*2.004*	2810	*2.198*
140	109.3	2517	*1.237*			2581	*1.379*	2657	*1.548*	2733	*1.716*	2810	*1.883*
160	113.3	2521	*1.091*			2579	*1.204*	2656	*1.353*	2732	*1.501*	2810	*1.647*
180	116.9	2525	*0.9776*			2578	*1.068*	2655	*1.202*	2732	*1.333*	2809	*1.463*
200	120.2	2529	*0.8858*			2577	*0.9599*	2655	*1.0800*	2731	*1.199*	2809	*1.316*
250	127.4	2537	*0.7187*			2574	*0.7644*	2653	*0.8621*	2730	*0.9574*	2808	*1.052*
300	133.5	2543	*0.6058*			2571	*0.6340*	2651	*0.7164*	2729	*0.7964*	2807	*0.8753*
350	138.9	2549	*0.5242*			2568	*0.5408*	2649	*0.6124*	2728	*0.6815*	2806	*0.7494*
400	143.6	2553	*0.4624*			2564	*0.4709*	2647	*0.5343*	2726	*0.5952*	2805	*0.6549*
500	151.8	2561	*0.3748*					2643	*0.425*	2724	*0.4744*	2803	*0.5226*
600	158.8	2567	*0.3156*					2639	*0.3521*	2721	*0.3939*	2801	*0.4344*
700	164.9	2572	*0.2728*					2635	*0.3000*	2719	*0.3364*	2799	*0.3714*
800	170.4	2576	*0.2403*					2631	*0.2609*	2716	*0.2932*	2798	*0.3242*
900	175.4	2580	*0.2149*					2627	*0.2304*	2713	*0.2596*	2796	*0.2874*
1000	179.9	2583	*0.1944*					2622	*0.206*	2710	*0.2327*	2794	*0.2580*
1500	198.3	2593	*0.1317*							2696	*0.1520*	2784	*0.1697*
2000	212.4	2599	*0.0996*							2680	*0.1115*	2773	*0.1255*
2500	223.9	2602	*0.0800*							2663	*0.0870*	2762	*0.09894*
3000	233.9	2603	*0.0667*							2645	*0.0706*	2751	*0.08118*
3500	242.6	2603	*0.0571*							2624	*0.0587*	2739	*0.06845*
4000	250.4	2602	*0.0498*									2726	*0.05887*
4500	257.4	2600	*0.0441*									2713	*0.05138*
5000	263.9	2597	*0.0395*									2699	*0.04535*
5500	270.0	2594	*0.0356*									2684	*0.04037*
6000	275.6	2590	*0.0325*									2668	*0.03619*
6500	280.9	2586	*0.0297*									2652	*0.03261*
7000	285.8	2581	*0.0274*									2633	*0.02949*
7500	290.5	2576	*0.0253*									2614	*0.02674*
8000	295.0	2570	*0.0235*									2592	*0.02428*
9000	303.3	2559	*0.0205*										
10000	311.0	2545	*0.0180*										
11000	318.1	2530	*0.0160*										
12000	324.7	2514	*0.0143*										
13000	330.9	2497	*0.0128*										
14000	336.7	2477	*0.0115*										
15000	342.2	2456	*0.0103*										
16000	347.4	2432	*0.0093*										
17000	352.3	2405	*0.0084*										
18000	357.0	2375	*0.0075*										
20000	365.7	2295	*0.0059*										

Superheated steam – internal energy and specific volume 350°C to 700°C

350°C		400°C		450°C		500°C		600°C		700°C		
u kJkg^{-1}	v m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}	P kPa
2890	*46.91*	2969	*50.68*	3050	*54.71*	3133	*58.49*	3303	*66.06*	3481	*73.63*	0.6117
2890	*14.37*	2969	*15.53*	3050	*16.68*	3133	*17.84*	3303	*20.15*	3481	*22.46*	20
2890	*7.185*	2969	*7.763*	3050	*8.340*	3133	*8.918*	3303	*10.07*	3481	*11.23*	40
2889	*4.788*	2969	*5.174*	3050	*5.559*	3133	*5.944*	3303	*6.714*	3481	*7.484*	60
2889	*3.590*	2969	*3.879*	3050	*4.169*	3132	*4.458*	3303	*5.035*	3480	*5.613*	80
2889	*2.871*	2968	*3.103*	3049	*3.334*	3132	*3.566*	3303	*4.028*	3480	*4.490*	100
2888	*2.392*	2968	*2.585*	3049	*2.778*	3132	*2.971*	3303	*3.356*	3480	*3.741*	120
2888	*2.049*	2968	*2.215*	3049	*2.381*	3132	*2.546*	3303	*2.877*	3480	*3.207*	140
2888	*1.792*	2968	*1.938*	3049	*2.083*	3132	*2.227*	3302	*2.517*	3480	*2.806*	160
2888	*1.593*	2967	*1.722*	3049	*1.851*	3132	*1.908*	3302	*2.237*	3480	*2.494*	180
2887	*1.433*	2967	*1.549*	3048	*1.665*	3131	*1.781*	3302	*2.013*	3480	*2.244*	200
2887	*1.145*	2967	*1.239*	3048	*1.332*	3131	*1.4250*	3302	*1.610*	3480	*1.795*	250
2886	*0.9536*	2966	*1.032*	3048	*1.109*	3131	*1.187*	3302	*1.341*	3479	*1.496*	300
2885	*0.8167*	2965	*0.8836*	3047	*0.9503*	3130	*1.017*	3301	*1.149*	3479	*1.282*	350
2884	*0.7140*	2965	*0.7726*	3047	*0.8311*	3130	*0.8894*	3301	*1.006*	3479	*1.122*	400
2883	*0.5702*	2964	*0.6173*	3046	*0.6642*	3129	*0.7109*	3300	*0.8041*	3479	*0.8970*	500
2882	*0.4743*	2963	*0.5137*	3045	*0.5503*	3128	*0.5920*	3300	*0.6698*	3478	*0.7472*	600
2880	*0.4058*	2961	*0.4398*	3044	*0.4735*	3127	*0.5070*	3299	*0.5738*	3478	*0.6403*	700
2879	*0.3544*	2960	*0.3843*	3043	*0.4139*	3127	*0.4433*	3299	*0.5019*	3477	*0.5601*	800
2877	*0.3145*	2959	*0.3411*	3042	*0.3675*	3126	*0.3938*	3298	*0.4459*	3477	*0.4977*	900
2876	*0.2825*	2958	*0.3066*	3041	*0.3304*	3125	*0.3541*	3297	*0.4011*	3476	*0.4478*	1000
2868	*0.1866*	2952	*0.2030*	3036	*0.2192*	3121	*0.2352*	3295	*0.2668*	3474	*0.2981*	1500
2860	*0.1386*	2946	*0.1512*	3031	*0.1635*	3117	*0.1757*	3292	*0.1996*	3472	*0.2233*	2000
2853	*0.1098*	2940	*0.1201*	3026	*0.1302*	3113	*0.1400*	3289	*0.1593*	3469	*0.1783*	2500
2844	*0.09056*	2934	*0.09938*	3021	*0.1079*	3109	*0.1162*	3286	*0.1324*	3467	*0.1484*	3000
2836	*0.07680*	2927	*0.08456*	3016	*0.09198*	3104	*0.09919*	3282	*0.1133*	3465	*0.1270*	3500
2827	*0.06647*	2921	*0.07343*	3011	*0.08004*	3100	*0.08644*	3279	*0.09886*	3462	*0.1110*	4000
2819	*0.05842*	2914	*0.06477*	3006	*0.07076*	3096	*0.07652*	3276	*0.08766*	3460	*0.0985*	4500
2809	*0.05197*	2907	*0.05784*	3001	*0.06332*	3092	*0.06858*	3273	*0.0787*	3458	*0.08852*	5000
2800	*0.04668*	2901	*0.05216*	2995	*0.05724*	3087	*0.06209*	3270	*0.07137*	3455	*0.08035*	5500
2790	*0.04225*	2894	*0.04742*	2990	*0.05217*	3083	*0.05667*	3267	*0.06527*	3453	*0.07355*	6000
2780	*0.03849*	2887	*0.04340*	2984	*0.04787*	3079	*0.05209*	3264	*0.06010*	3451	*0.06779*	6500
2770	*0.03526*	2879	*0.03996*	2979	*0.04419*	3074	*0.04816*	3261	*0.05567*	3448	*0.06285*	7000
2759	*0.03245*	2872	*0.03697*	2973	*0.04099*	3070	*0.04475*	3258	*0.05182*	3446	*0.05857*	7500
2748	*0.02997*	2865	*0.03434*	2968	*0.03819*	3065	*0.04177*	3255	*0.04846*	3444	*0.05483*	8000
2725	*0.02582*	2849	*0.02996*	2956	*0.03352*	3056	*0.03679*	3248	*0.04286*	3439	*0.04859*	9000
2700	*0.02244*	2833	*0.02644*	2945	*0.02978*	3047	*0.03281*	3242	*0.03838*	3434	*0.04360*	10000
2672	*0.01963*	2816	*0.02354*	2932	*0.02671*	3038	*0.02955*	3236	*0.03471*	3429	*0.03951*	11000
2641	*0.01722*	2799	*0.02111*	2920	*0.02415*	3028	*0.02683*	3229	*0.03165*	3424	*0.03611*	12000
2607	*0.01512*	2780	*0.01903*	2907	*0.02197*	3018	*0.02452*	3223	*0.02906*	3420	*0.03323*	13000
2568	*0.01323*	2761	*0.01724*	2894	*0.02010*	3008	*0.02254*	3216	*0.02684*	3415	*0.03076*	14000
2521	*0.01148*	2741	*0.01567*	2881	*0.01848*	2998	*0.02083*	3209	*0.02492*	3410	*0.02862*	15000
2461	*0.009766*	2719	*0.01428*	2867	*0.01705*	2988	*0.01932*	3203	*0.02324*	3405	*0.02675*	16000
		2696	*0.01304*	2853	*0.01578*	2978	*0.01799*	3196	*0.02175*	3400	*0.02510*	17000
		2672	*0.01192*	2838	*0.01465*	2967	*0.01681*	3189	*0.02043*	3395	*0.02363*	18000
		2618	*0.00995*	2807	*0.01272*	2945	*0.01479*	3175	*0.01818*	3385	*0.02113*	20000

Supercritical steam

Supercritical steam - enthalpy and entropy

T (°C)	400°C		600°C		800°C		1000°C		2000°C	
P (MPa)	h kJ kg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}
22	2736	*5.405*	3521	*6.447*	4058	*7.002*	4579	*7.447*	7372	*9.056*
24	2637	*5.237*	3503	*6.391*	4049	*6.955*	4573	*7.403*	7371	*9.016*
26	2510	*5.030*	3484	*6.337*	4039	*6.911*	4567	*7.362*	7371	*8.978*
28	2335	*4.756*	3466	*6.286*	4030	*6.869*	4562	*7.324*	7371	*8.943*
30	2153	*4.476*	3447	*6.237*	4020	*6.830*	4556	*7.288*	7370	*8.911*
35	1989	*4.214*	3399	*6.123*	3996	*6.741*	4542	*7.207*	7369	*8.838*
40	1931	*4.115*	3350	*6.017*	3973	*6.661*	4527	*7.135*	7368	*8.775*
45	1898	*4.051*	3301	*5.918*	3949	*6.589*	4513	*7.071*	7367	*8.719*
50	1874	*4.003*	3253	*5.825*	3926	*6.523*	4499	*7.013*	7366	*8.669*
55	1857	*3.964*	3204	*5.736*	3903	*6.461*	4486	*6.960*	7365	*8.624*
60	1843	*3.932*	3157	*5.653*	3880	*6.403*	4472	*6.910*	7364	*8.582*
70	1823	*3.878*	3067	*5.500*	3836	*6.298*	4446	*6.820*	7363	*8.508*
80	1809	*3.834*	2988	*5.367*	3793	*6.204*	4421	*6.741*	7361	*8.444*
90	1799	*3.797*	2921	*5.254*	3753	*6.118*	4396	*6.669*	7360	*8.387*
100	1791	*3.764*	2865	*5.158*	3715	*6.041*	4373	*6.604*	7359	*8.335*
150	1777	*3.640*	2707	*4.848*	3566	*5.737*	4275	*6.344*	7357	*8.136*
200	1782	*3.552*	2645	*4.673*	3477	*5.532*	4205	*6.156*	7359	*7.992*

Supercritical steam - internal energy and specific volume

T (°C)	400°C		600°C		800°C		1000°C		2000°C	
P (MPa)	u kJkg^{-1}	v m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}
22	2554	*0.008256*	3161	*0.01635*	3582	*0.02162*	3999	*0.026350*	5108	*0.03744*
24	2476	*0.006732*	3147	*0.01481*	3575	*0.01975*	3994	*0.024130*	5106	*0.03434*
26	2373	*0.005285*	3133	*0.01352*	3567	*0.01816*	3989	*0.022250*	5103	*0.03172*
28	2227	*0.003854*	3118	*0.01241*	3559	*0.01680*	3984	*0.020640*	5101	*0.02947*
30	2069	*0.002798*	3103	*0.01144*	3551	*0.01563*	3979	*0.019240*	5099	*0.02752*
35	1915	*0.002105*	3066	*0.009523*	3532	*0.01328*	3966	*0.016450*	5092	*0.02363*
40	1855	*0.001911*	3027	*0.008089*	3512	*0.01152*	3953	*0.014360*	5086	*0.02071*
45	1817	*0.001803*	2987	*0.006983*	3492	*0.01016*	3940	*0.012740*	5080	*0.01844*
50	1788	*0.001731*	2947	*0.006108*	3472	*0.009072*	3927	*0.011440*	5074	*0.01663*
55	1765	*0.001676*	2907	*0.005405*	3452	*0.008188*	3915	*0.010380*	5068	*0.01514*
60	1745	*0.001633*	2867	*0.004833*	3433	*0.007456*	3902	*0.009504*	5062	*0.01391*
70	1713	*0.001566*	2789	*0.003975*	3394	*0.006317*	3877	*0.008129*	5050	*0.01197*
80	1688	*0.001516*	2717	*0.003384*	3355	*0.005477*	3852	*0.007105*	5038	*0.01052*
90	1666	*0.001476*	2653	*0.002969*	3318	*0.004836*	3828	*0.006316*	5027	*0.00939*
100	1647	*0.001443*	2598	*0.002672*	3282	*0.004336*	3804	*0.005690*	5015	*0.00849*
150	1577	*0.001331*	2412	*0.001969*	3125	*0.002942*	3694	*0.003869*	4961	*0.00582*
200	1530	*0.001262*	2306	*0.001697*	3008	*0.002343*	3602	*0.003017*	4911	*0.00450*

Low pressure (<100 kPa) superheated steam - enthalpy and entropy

T (°C)	Saturation		50°C		100°C		200°C		400°C	
P (kPa)	h_g kJ kg^{-1}	s_g kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}	h kJkg^{-1}	s kJkg^{-1}K^{-1}
0.61	2504	*9.156*	2594	*9.408*	2689	*9.679*	2880	*10.13*	3280	*10.84*
1	2514	*8.975*	2594	*9.243*	2689	*9.514*	2880	*9.968*	3280	*10.67*
2	2533	*8.723*	2594	*8.922*	2688	*9.194*	2880	*9.648*	3280	*10.35*
4	2554	*8.473*	2594	*8.601*	2688	*8.873*	2880	*9.328*	3280	*10.03*
6	2567	*8.329*	2593	*8.413*	2688	*8.686*	2880	*9.141*	3280	*9.845*
8	2576	*8.227*	2593	*8.279*	2688	*8.552*	2880	*9.008*	3280	*9.712*
10	2584	*8.149*	2592	*8.174*	2687	*8.449*	2880	*8.905*	3280	*9.609*
12	2590	*8.085*	2591	*8.088*	2687	*8.364*	2880	*8.821*	3280	*9.525*
15	2598	*8.007*			2687	*8.260*	2879	*8.717*	3280	*9.422*
20	2609	*7.907*			2686	*8.126*	2879	*8.584*	3280	*9.289*
30	2625	*7.768*			2685	*7.937*	2879	*8.396*	3280	*9.102*
40	2636	*7.669*			2684	*7.801*	2878	*8.263*	3279	*8.969*
50	2645	*7.593*			2682	*7.695*	2878	*8.159*	3279	*8.866*
60	2653	*7.531*			2681	*7.608*	2877	*8.074*	3279	*8.782*
70	2659	*7.479*			2680	*7.534*	2877	*8.002*	3279	*8.710*
80	2665	*7.434*			2678	*7.470*	2876	*7.940*	3279	*8.649*
90	2670	*7.394*			2677	*7.413*	2876	*7.885*	3279	*8.594*
100	2675	*7.359*			2676	*7.361*	2875	*7.836*	3279	*8.545*

Low pressure (<100 kPa) superheated steam – int. energy and specific volume

T (°C)	Saturation		50°C		100°C		200°C		400°C	
P (kPa)	u_g kJkg^{-1}	v_g m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}	u kJkg^{-1}	v m^{3}kg^{-1}
0.61	2378	*206.1*	2445	*213*	2516	*24.06*	2662	*311.9*	*2969*	*509.3*
1	2384	*129.2*	2445	*149.1*	2516	*172.2*	2662	*218.4*	*2969*	*310.7*
2	2399	*66.99*	2445	*74.52*	2516	*86.08*	2662	*109.2*	*2969*	*155.3*
4	2415	*34.79*	2445	*37.24*	2516	*43.03*	2662	*54.58*	*2969*	*77.66*
6	2424	*23.73*	2444	*24.81*	2516	*28.68*	2661	*36.38*	*2969*	*51.77*
8	2431	*18.10*	2444	*18.60*	2516	*21.50*	2661	*27.28*	*2969*	*38.83*
10	2437	*14.67*	2443	*14.87*	2516	*17.20*	2661	*21.83*	*2969*	*31.06*
12	2442	*12.36*	2443	*12.38*	2515	*14.33*	2661	*18.19*	*2969*	*25.89*
15	2448	*10.02*			2515	*11.46*	2661	*14.55*	*2969*	*20.71*
20	2456	*7.648*			2515	*8.586*	2661	*10.91*	*2969*	*15.53*
30	2468	*5.229*			2514	*5.715*	2661	*7.268*	*2969*	*10.35*
40	2476	*3.993*			2513	*4.280*	2660	*5.448*	*2969*	*7.763*
50	2483	*3.240*			2511	*3.419*	2660	*4.356*	*2969*	*6.209*
60	2489	*2.732*			2510	*2.845*	2660	*3.628*	*2969*	*5.174*
70	2494	*2.365*			2509	*2.434*	2659	*3.108*	*2969*	*4.434*
80	2498	*2.087*			2508	*2.127*	2659	*2.718*	*2969*	*3.879*
90	2502	*1.870*			2507	*1.887*	2659	*2.415*	*2968*	*3.448*
100	2506	*1.694*			2506	*1.696*	2658	*2.172*	*2968*	*3.103*

Compressed liquid water

This table is provided for completeness.

Generally speaking, the enthalpy and internal energy of a compressed liquid are almost equal to a saturated liquid at the same temperature.

The exception to this is that the enthalpy change after a compression in the compressed liquid region can be defined as:

$$\Delta h = v(p_2 - p_1)/\eta_{isen}$$

Compressed liquid water - enthalpy and entropy

T (°C)	25		100		200		300		350	
	P_{sat} (MPa) 0.00317		P_{sat} (MPa) 0.101325		P_{sat} (MPa) 1.554		P_{sat} (MPa) 8.588		P_{sat} (MPa) 16.54	
	h_f kJ kg^{-1}	s_f kJ kg^{-1} K^{-1}	h_f kJ kg^{-1}	s_f kJ kg^{-1} K^{-1}	h_f kJ kg^{-1}	s_f kJ kg^{-1} K^{-1}	h_f kJ kg^{-1}	s_f kJ kg^{-1} K^{-1}	h_f kJ kg^{-1}	s_f kJ kg^{-1} K^{-1}
	104.8	*0.367*	419.1	*1.307*	852.3	*2.330*	1345	*3.255*	1672	*3.781*
P (MPa)	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}	h kJ kg^{-1}	s kJ kg^{-1} K^{-1}
1	105.7	*0.367*	419.7	*1.306*						
10	114.0	*0.364*	426.5	*1.299*	855.9	*2.318*	1343	*3.249*		
20	123.1	*0.362*	434.0	*1.292*	860.4	*2.303*	1334	*3.209*	1647	*3.731*
30	132.2	*0.359*	441.6	*1.284*	865.2	*2.289*	1329	*3.176*	1610	*3.645*
40	141.2	*0.356*	449.2	*1.277*	870.2	*2.276*	1325	*3.147*	1590	*3.588*
50	150.2	*0.353*	456.8	*1.270*	875.4	*2.263*	1324	*3.121*	1576	*3.542*
60	159.1	*0.349*	464.4	*1.263*	880.7	*2.251*	1323	*3.097*	1566	*3.501*
70	167.9	*0.346*	472.1	*1.256*	886.2	*2.239*	1323	*3.074*	1558	*3.465*
80	176.7	*0.342*	479.7	*1.249*	891.8	*2.227*	1324	*3.053*	1553	*3.434*
90	185.3	*0.338*	487.4	*1.243*	897.6	*2.216*	1326	*3.034*	1550	*3.407*
100	193.9	*0.334*	495.1	*1.236*	903.5	*2.205*	1329	*3.017*	1551	*3.385*

Compressed liquid water - internal energy and specific volume*

T (°C)	25		100		200		300		350	
	P_{sat} (MPa) 0.00317		P_{sat} (MPa) 0.101325		P_{sat} (MPa) 1.554		P_{sat} (MPa) 8.588		P_{sat} (MPa) 16.54	
	u_f kJ kg^{-1}	$v_f \times 10^3$ m^3 kg^{-1}	u_f kJ kg^{-1}	$v_f \times 10^3$ m^3 kg^{-1}	u_f kJ kg^{-1}	$v_f \times 10^3$ m^3 kg^{-1}	u_f kJ kg^{-1}	$v_f \times 10^3$ m^3 kg^{-1}	u_f kJ kg^{-1}	$v_f \times 10^3$ m^3 kg^{-1}
	104.8	*1.003*	419.0	*1.044*	850.5	*1.157*	1333	*1.404*	1643	*1.739*
P (MPa)	u kJ kg^{-1}	$v \times 10^3$ m^3 kg^{-1}	u kJ kg^{-1}	$v \times 10^3$ m^3 kg^{-1}	u kJ kg^{-1}	$v \times 10^3$ m^3 kg^{-1}	u kJ kg^{-1}	$v \times 10^3$ m^3 kg^{-1}	u kJ kg^{-1}	$v \times 10^3$ m^3 kg^{-1}
1	104.7	*1.002*	418.7	*1.043*						
10	104.0	*0.998*	416.1	*1.038*	844.4	*1.148*	1329	*1.399*		
20	103.3	*0.994*	413.4	*1.034*	837.7	*1.139*	1307	*1.361*	1614	*1.667*
30	102.5	*0.990*	410.8	*1.029*	831.3	*1.130*	1289	*1.332*	1563	*1.553*
40	101.8	*0.986*	408.2	*1.025*	825.3	*1.122*	1273	*1.307*	1530	*1.490*
50	101.1	*0.982*	405.8	*1.020*	819.7	*1.115*	1259	*1.287*	1504	*1.443*
60	100.4	*0.978*	403.5	*1.016*	814.3	*1.108*	1247	*1.269*	1481	*1.404*
70	99.7	*0.975*	401.3	*1.012*	809.2	*1.101*	1235	*1.253*	1461	*1.372*
80	99.0	*0.971*	399.1	*1.008*	804.3	*1.094*	1225	*1.239*	1444	*1.347*
90	98.2	*0.967*	397.1	*1.004*	799.7	*1.088*	1215	*1.226*	1430	*1.328*
100	97.5	*0.963*	395.1	*1.000*	795.3	*1.082*	1207	*1.215*	1419	*1.314*

***Note**: The actual values of v_f and v are 10^3 times smaller than the figures given. For example, the specific volume of compressed liquid water at 100ºC and 40 MPa is 0.001025 m^3 kg^{-1}.

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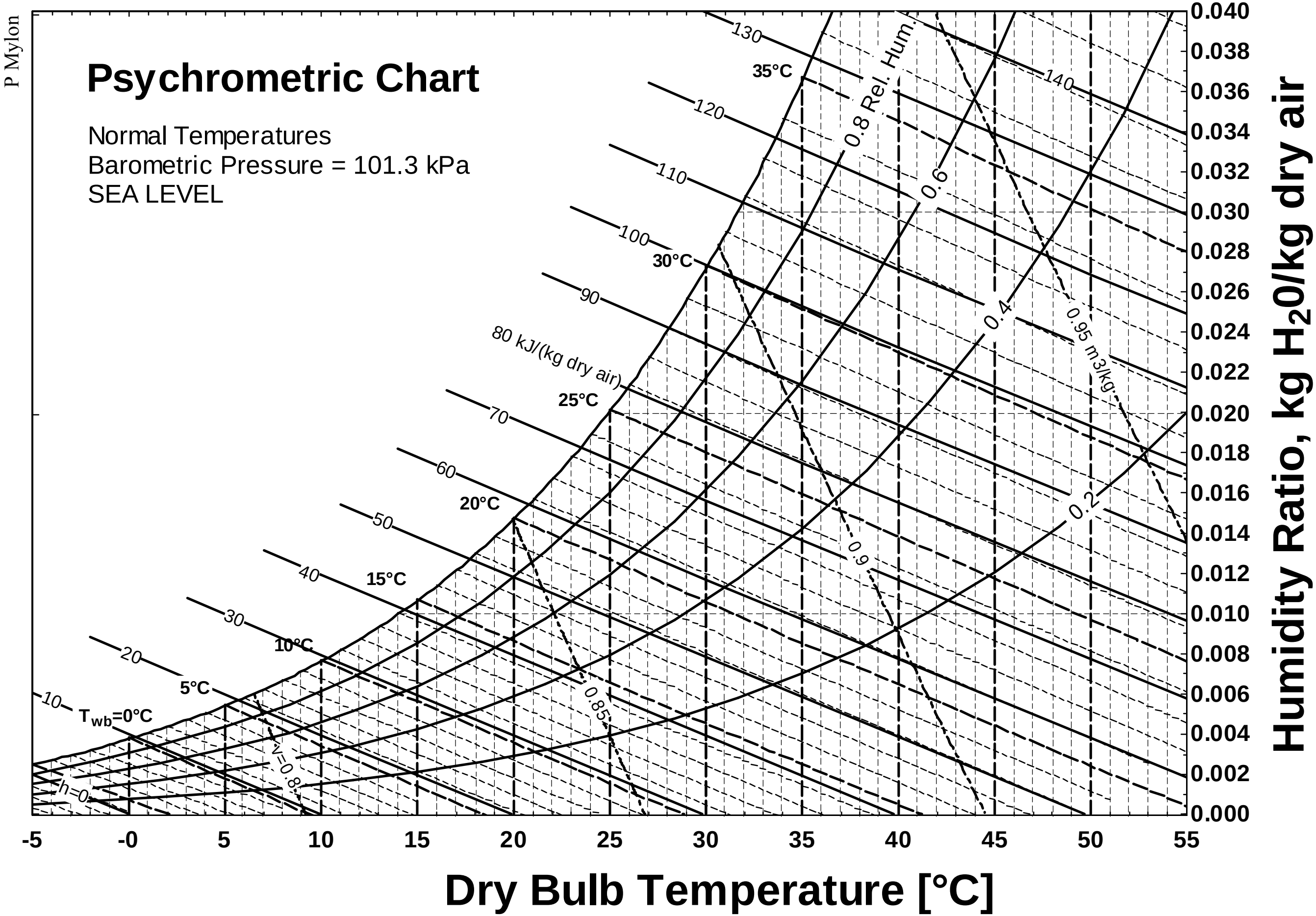

P Mylon
Psychrometric Chart
Normal Temperatures
Barometric Pressure = 101.3 kPa
SEA LEVEL
Humidity Ratio, kg H20/kg dry air
Dry Bulb Temperature [°C]
80 kJ/(kg dry air)
0.8 Rel. Hum.
0.6
0.4
0.2
0.95 m3/kg
0.9
0.85
v=0.8
h=0
Twb=0°C
5°C
10°C
15°C
20°C
25°C
30°C
35°C
10
20
30
40
50
60
70
90
100
110
120
130
140
-5
-0
5
10
15
20
25
30
35
40
45
50
55
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.020
0.022
0.024
0.026
0.028
0.030
0.032
0.034
0.036
0.038
0.040

How to use the psychrometric chart

Find the wet bulb temperature on the top, left-hand (curved) edge of the chart which is the saturation line. Travel down the dotted line of constant wet bulb temperature (at around 30° to the horizontal) until it intersects the vertical line coming up from the dry bulb temperature (which is found on the horizontal axis). The point at which the two lines meet fully describes the conditions. The humidity ratio (or specific humidity) can be read off the vertical axis. The specific enthalpy of the air/vapour mixture per kg of dry air can be found by travelling up the solid lines approximately parallel to the wet bulb lines, while the specific volume of the mixture can be found by interpolating between the lines at approximately 70° to the horizontal.

Thermodynamic properties of dry and saturated air

T_{db} (°C)	h_{dry} $kJkg^{-1}$	h_{sat} $kJkg^{-1}$	v_{dry} kgm^{-3}	v_{sat} kgm^{-3}
-5	-5.03	1.16	0.76	0.76
0	0.00	9.48	0.77	0.78
5	5.03	18.65	0.79	0.80
10	10.06	29.37	0.80	0.81
15	15.10	42.13	0.82	0.83
20	20.13	57.58	0.83	0.85
25	25.16	76.52	0.84	0.87
30	30.20	100.01	0.86	0.90
35	35.23	129.43	0.87	0.92

R134a saturated refrigerant: liquid and vapour
Pressure table

P kPa	T(sat) ºC	v_f m^3kg^{-1}	v_g m^3kg^{-1}	h_f kJ kg^{-1}	h_g kJ kg^{-1}	s_f kJ $kg^{-1}K^{-1}$	s_g kJ $kg^{-1}K^{-1}$
60	-36.95	0.000710	0.3112	3.841	227.8	0.01634	0.9644
80	-31.13	0.000719	0.2375	11.21	231.5	0.04711	0.9571
100	-26.37	0.000726	0.1925	17.28	234.4	0.07188	0.9518
120	-22.32	0.000732	0.1621	22.49	237.0	0.09275	0.9478
140	-18.77	0.000738	0.1401	27.08	239.2	0.1109	0.9446
160	-15.60	0.000744	0.1235	31.21	241.1	0.1269	0.9419
180	-12.73	0.000749	0.1104	34.97	242.9	0.1414	0.9397
200	-10.09	0.000753	0.09987	38.43	244.5	0.1546	0.9377
240	-5.384	0.000762	0.08390	44.66	247.3	0.1779	0.9346
280	-1.247	0.000770	0.07235	50.18	249.7	0.1983	0.9321
320	2.457	0.000777	0.06360	55.16	251.9	0.2164	0.9301
360	5.821	0.000784	0.05674	59.72	253.8	0.2327	0.9284
400	8.910	0.000791	0.05120	63.94	255.6	0.2476	0.9269
500	15.71	0.000806	0.04112	73.33	259.3	0.2802	0.9240
600	21.55	0.000820	0.03430	81.51	262.4	0.3080	0.9218
700	26.69	0.000833	0.02936	88.82	265.0	0.3323	0.9199
800	31.31	0.000846	0.02562	95.47	267.3	0.3540	0.9183
900	35.51	0.000858	0.02268	101.6	269.3	0.3738	0.9169
1000	39.37	0.000870	0.02031	107.3	271.0	0.3919	0.9156
1200	46.29	0.000893	0.01672	117.8	273.9	0.4244	0.9130
1400	52.40	0.000917	0.01411	127.2	276.1	0.4532	0.9105
1600	57.88	0.000940	0.01212	135.9	277.9	0.4791	0.9078
1800	62.87	0.000964	0.01056	144.1	279.2	0.5029	0.9050
2000	67.45	0.000989	0.009288	151.8	280.1	0.5251	0.9018
2500	77.54	0.001057	0.006936	169.6	280.8	0.5753	0.8923
3000	86.16	0.001141	0.005275	186.5	279.1	0.6212	0.8789

R134a saturated refrigerant: temperature table

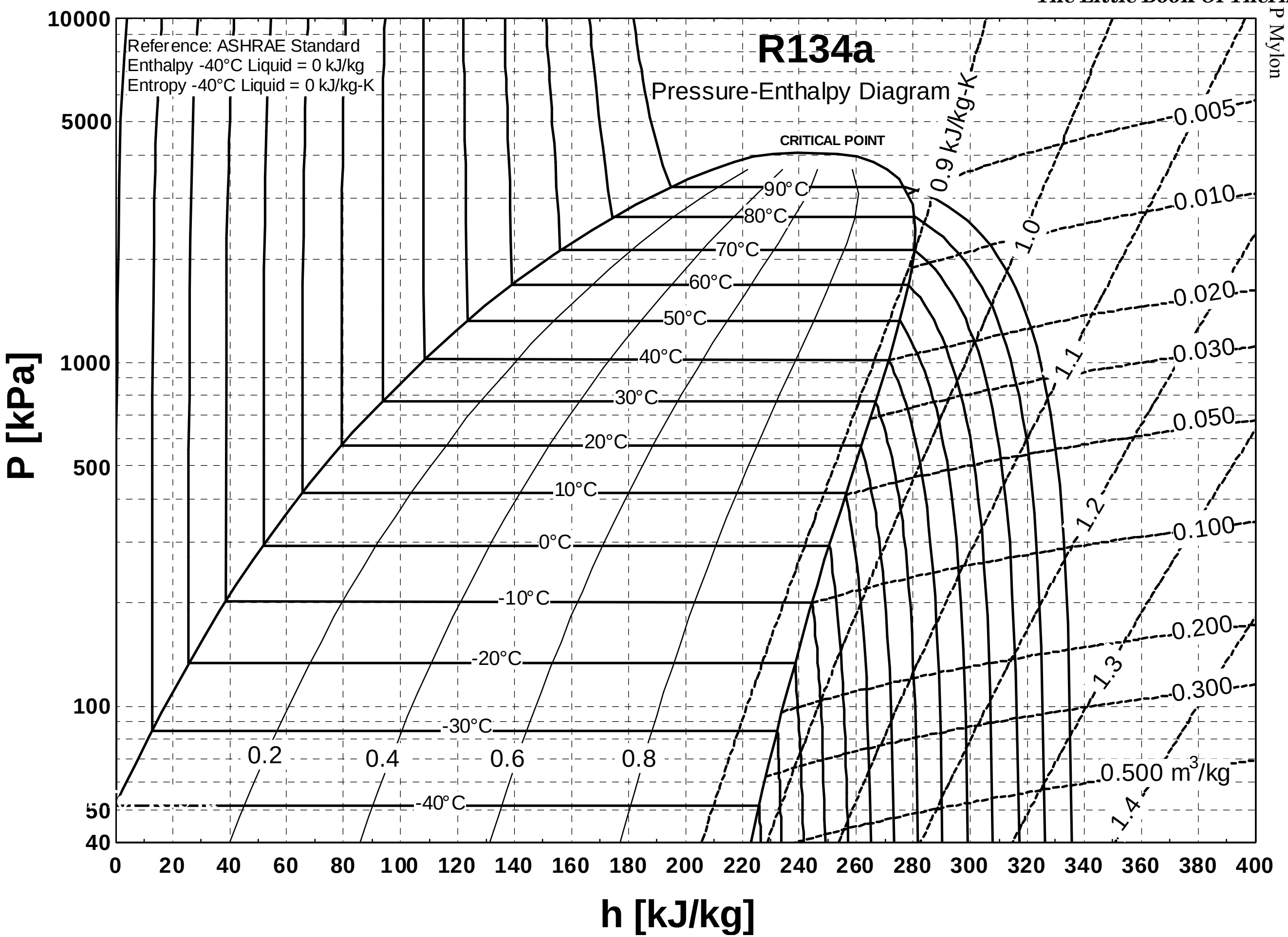
T °C	P(sat) kPa	v_f $m^3 kg^{-1}$	v_g $m^3 kg^{-1}$	h_f kJ kg^{-1}	h_g kJ kg^{-1}	s_f kJ $kg^{-1}K^{-1}$	s_g kJ $kg^{-1}K^{-1}$
-40	51.25	0.000705	0.3608	0	225.9	0	0.9687
-36	62.95	0.000711	0.2975	5.037	228.4	0.02138	0.9631
-32	76.71	0.000717	0.2471	10.10	230.9	0.04253	0.9581
-28	92.76	0.000723	0.2067	15.20	233.4	0.06344	0.9536
-26	101.7	0.000727	0.1895	17.76	234.7	0.07382	0.9514
-24	111.4	0.000730	0.1739	20.33	235.9	0.08414	0.9494
-22	121.7	0.000733	0.1600	22.91	237.2	0.09441	0.9475
-20	132.8	0.000736	0.1473	25.49	238.4	0.1046	0.9456
-18	144.7	0.000740	0.1358	28.09	239.6	0.1148	0.9439
-16	157.4	0.000743	0.1254	30.69	240.9	0.1249	0.9422
-12	185.4	0.000750	0.1074	35.92	243.3	0.1450	0.9391
-8	217.1	0.000757	0.09235	41.19	245.7	0.1650	0.9363
-4	252.9	0.000765	0.07980	46.50	248.1	0.1848	0.9337
0	293.0	0.000772	0.06925	51.86	250.5	0.2044	0.9314
4	337.9	0.000780	0.06034	57.25	252.8	0.2239	0.9293
8	387.9	0.000789	0.05276	62.69	255.0	0.2432	0.9273
12	443.3	0.000798	0.04603	68.18	257.3	0.2625	0.9255
16	504.6	0.000807	0.04075	73.73	259.5	0.2816	0.9239
20	572.1	0.000816	0.03597	79.32	261.6	0.3006	0.9223
24	646.2	0.000826	0.03183	84.98	263.7	0.3196	0.9209
26	685.8	0.000831	0.02998	87.83	264.7	0.3290	0.9202
28	727.3	0.000837	0.02824	90.69	265.7	0.3385	0.9195
30	770.6	0.000842	0.02662	93.58	266.7	0.3479	0.9188
32	815.9	0.000848	0.02511	96.48	267.6	0.3573	0.9181
34	863.1	0.000854	0.02369	99.40	268.6	0.3667	0.9174
36	912.4	0.000860	0.02236	102.3	269.5	0.3761	0.9167
38	963.7	0.000866	0.02112	105.3	270.4	0.3855	0.9161
40	1017	0.000872	0.01995	108.3	271.3	0.3949	0.9154
42	1073	0.000879	0.01885	111.3	272.1	0.4042	0.9146
44	1131	0.000885	0.01782	114.3	273.0	0.4136	0.9139
48	1254	0.000900	0.01594	120.4	274.5	0.4324	0.9124
52	1386	0.000915	0.01426	126.6	276.0	0.4513	0.9107
56	1529	0.000932	0.01277	132.9	277.3	0.4702	0.9088
60	1683	0.000950	0.01143	139.4	278.5	0.4892	0.9067
70	2118	0.001004	0.008642	156.1	280.5	0.5376	0.8998
80	2635	0.001077	0.006436	174.2	280.6	0.5880	0.8891
90	3247	0.001193	0.004599	194.8	277.1	0.6434	0.8701
100	3975	0.001527	0.002630	224.8	258.4	0.7222	0.8122

R134a superheated refrigerant – 60 to 400 kPa

	P=60 kPa, Tsat=-36.94°C			P=100 kPa, Tsat=-26.37°C			P=140 kPa, Tsat=-18.77°C		
T °C	v m^3kg^{-1}	h $kJ\,kg^{-1}$	s $kJ\,kg^{-1}K^{-1}$	v m^3kg^{-1}	h $kJ\,kg^{-1}$	s $kJ\,kg^{-1}K^{-1}$	v m^3kg^{-1}	h $kJ\,kg^{-1}$	s $kJ\,kg^{-1}K^{-1}$
-20	0.3361	240.8	1.0170	0.1984	239.5	0.9721			
-10	0.3505	248.6	1.0480	0.2074	247.5	1.0030	0.1461	246.4	0.9724
0	0.3648	256.5	1.0770	0.2163	255.6	1.0330	0.1526	254.6	1.0030
10	0.3789	264.7	1.1070	0.2251	263.8	1.0630	0.1591	262.9	1.0330
20	0.3930	272.9	1.1350	0.2337	272.2	1.0920	0.1654	271.4	1.0620
30	0.4070	281.4	1.1640	0.2423	280.7	1.1200	0.1717	280.0	1.0910
40	0.4210	290.0	1.1920	0.2509	289.3	1.1480	0.1779	288.7	1.1200
50	0.4349	298.7	1.2190	0.2594	298.2	1.1760	0.1841	297.6	1.1470
60	0.4488	307.7	1.2460	0.2678	307.1	1.2040	0.1903	306.6	1.1750
70	0.4627	316.8	1.2730	0.2763	316.3	1.2310	0.1964	315.8	1.2020
80	0.4765	326.0	1.3000	0.2847	325.5	1.2570	0.2024	325.1	1.2290
90	0.4903	335.4	1.3260	0.2930	335.0	1.2840	0.2085	334.6	1.2550
100	0.5041	345.0	1.3520	0.3014	344.6	1.3100	0.2145	344.2	1.2810
110	0.5179	354.7	1.3780	0.3097	354.4	1.3350	0.2205	354.0	1.3070
120	0.5316	364.6	1.4030	0.3180	364.3	1.3610	0.2265	363.9	1.3330
	P=180 kPa, Tsat=-12.73°C			P=200 kPa, Tsat=-10.0°C			P=240 kPa, Tsat=-5.38°C		
-10	0.1119	245.2	0.9484	0.0999	244.5	0.9380			
0	0.1172	253.6	0.9798	0.1048	253.1	0.9698	0.0862	252.0	0.9519
10	0.1224	262.0	1.0100	0.1096	261.6	1.0000	0.0903	260.6	0.9831
20	0.1275	270.6	1.0400	0.1142	270.2	1.0300	0.0942	269.4	1.0130
30	0.1325	279.3	1.0690	0.1187	278.9	1.0600	0.0981	278.2	1.0430
40	0.1374	288.0	1.0980	0.1232	287.7	1.0880	0.1019	287.1	1.0720
50	0.1423	297.0	1.1260	0.1277	296.7	1.1160	0.1057	296.1	1.1000
60	0.1471	306.0	1.1530	0.1321	305.8	1.1440	0.1094	305.2	1.1280
70	0.1520	315.3	1.1800	0.1364	315.0	1.1710	0.1131	314.5	1.1550
80	0.1567	324.6	1.2070	0.1407	324.4	1.1980	0.1168	323.9	1.1830
90	0.1615	334.1	1.2340	0.1450	333.9	1.2250	0.1204	333.5	1.2090
100	0.1662	343.8	1.2600	0.1493	343.6	1.2510	0.1240	343.2	1.2360
110	0.1709	353.6	1.2860	0.1536	353.4	1.2770	0.1276	353.1	1.2620
120	0.1756	363.6	1.3120	0.1578	363.4	1.3030	0.1311	363.1	1.2870
130	0.1803	373.7	1.3370	0.1621	373.5	1.3280	0.1347	373.2	1.3130
	P=280 kPa, Tsat=-1.25°C			P=320 kPa, Tsat=2.46°C			P=400 kPa, Tsat=8.91°C		
0	0.0728	250.8	0.9362						
10	0.0765	259.7	0.9680	0.0661	258.7	0.9544	0.0515	256.6	0.9305
20	0.0800	268.5	0.9987	0.0693	267.7	0.9856	0.0542	265.9	0.9628
30	0.0834	277.4	1.0280	0.0723	276.6	1.0160	0.0568	275.1	0.9937
40	0.0867	286.4	1.0580	0.0753	285.7	1.0450	0.0593	284.3	1.0240
50	0.0900	295.5	1.0860	0.0782	294.8	1.0740	0.0617	293.6	1.0530
60	0.0932	304.7	1.1140	0.0811	304.1	1.1020	0.0641	303.0	1.0810
70	0.0964	314.0	1.1420	0.0840	313.5	1.1300	0.0664	312.4	1.1090
80	0.0996	323.5	1.1690	0.0868	323.0	1.1570	0.0688	322.0	1.1370
90	0.1028	333.1	1.1960	0.0895	332.6	1.1840	0.0710	331.7	1.1640
100	0.1059	342.8	1.2220	0.0923	342.4	1.2110	0.0733	341.6	1.1910
110	0.1090	352.7	1.2480	0.0950	352.3	1.2370	0.0755	351.5	1.2170
120	0.1121	362.7	1.2740	0.0978	362.3	1.2630	0.0777	361.6	1.2430
130	0.1151	372.9	1.3000	0.1005	372.5	1.2880	0.0799	371.9	1.2690

R134a superheated refrigerant – 500 to 2000 kPa

	P=500 kPa,Tsat=15.71°C			P=600 kPa,Tsat=21.55°C			P=700 kPa,Tsat=26.69°C		
T °C	v m^{3}kg^{-1}	h kJ kg^{-1}	s kJ kg^{-1}K^{-1}	v m^{3}kg^{-1}	h kJ kg^{-1}	s kJ kg^{-1}K^{-1}	v m^{3}kg^{-1}	h kJ kg^{-1}	s kJ kg^{-1}K^{-1}
20	0.0421	263.5	0.9383						
30	0.0443	273.0	0.9703	0.0360	270.8	0.9499	0.0300	268.5	0.9313
40	0.0465	282.5	1.0010	0.0379	280.6	0.9816	0.0317	278.6	0.9641
50	0.0485	292.0	1.0310	0.0397	290.3	1.0120	0.0333	288.5	0.9954
60	0.0505	301.5	1.0600	0.0414	300.0	1.0420	0.0349	298.4	1.0260
70	0.0524	311.1	1.0880	0.0431	309.7	1.0710	0.0364	308.3	1.0550
80	0.0543	320.8	1.1160	0.0447	319.6	1.0990	0.0378	318.3	1.0830
90	0.0562	330.6	1.1440	0.0463	329.5	1.1260	0.0393	328.3	1.1110
100	0.0581	340.5	1.1710	0.0479	339.5	1.1540	0.0406	338.4	1.1390
110	0.0599	350.6	1.1970	0.0495	349.6	1.1800	0.0420	348.6	1.1660
120	0.0617	360.7	1.2230	0.0510	359.8	1.2070	0.0434	358.9	1.1920
130	0.0635	371.0	1.2490	0.0525	370.2	1.2330	0.0447	369.3	1.2190
140	0.0653	381.5	1.2750	0.0540	380.7	1.2580	0.0460	379.9	1.2440
150	0.0670	392.0	1.3000	0.0555	391.3	1.2840	0.0473	390.5	1.2700
160	0.0688	402.7	1.3250	0.0570	402.0	1.3090	0.0486	401.3	1.2950
	P=800 kPa,Tsat=31.31°C			P=1000 kPa,Tsat=39.37°C			P=1200 kPa, Tsat=46.29°C		
40	0.0270	276.4	0.9480	0.0204	271.7	0.9179			
50	0.0286	286.7	0.9802	0.0218	282.7	0.9525	0.0172	278.3	0.9267
60	0.0300	296.8	1.0110	0.0231	293.4	0.9850	0.0184	289.6	0.9614
70	0.0313	306.9	1.0410	0.0243	303.9	1.0160	0.0195	300.6	0.9938
80	0.0327	317.0	1.0700	0.0254	314.3	1.0460	0.0205	311.4	1.0250
90	0.0339	327.1	1.0980	0.0265	324.6	1.0750	0.0215	322.1	1.0550
100	0.0352	337.3	1.1260	0.0276	335.1	1.1030	0.0224	332.7	1.0840
110	0.0364	347.6	1.1530	0.0286	345.5	1.1310	0.0234	343.4	1.1120
120	0.0376	358.0	1.1800	0.0296	356.1	1.1580	0.0242	354.1	1.1390
130	0.0388	368.5	1.2060	0.0306	366.7	1.1850	0.0251	364.9	1.1660
140	0.0400	379.0	1.2320	0.0316	377.4	1.2110	0.0259	375.7	1.1930
150	0.0411	389.8	1.2580	0.0325	388.2	1.2370	0.0268	386.7	1.2190
160	0.0423	400.6	1.2830	0.0335	399.2	1.2620	0.0276	397.7	1.2450
170	0.0434	411.6	1.3080	0.0344	410.2	1.2880	0.0284	408.8	1.2700
180	0.0446	422.6	1.3330	0.0353	421.4	1.3120	0.0292	420.1	1.2950
	P=1400 kPa,Tsat=52.4°C			P=1600 kPa,Tsat=57.88°C			P=2000 kPa, Tsat=67.45°C		
60	0.0150	285.5	0.9389	0.0124	280.7	0.9163			
70	0.0161	297.1	0.9733	0.0134	293.2	0.9535	0.0096	283.9	0.9130
80	0.0170	308.3	1.0060	0.0144	305.1	0.9875	0.0105	297.6	0.9524
90	0.0179	319.4	1.0360	0.0152	316.5	1.0190	0.0114	310.2	0.9876
100	0.0188	330.3	1.0660	0.0160	327.8	1.0500	0.0121	322.3	1.0200
110	0.0196	341.2	1.0950	0.0168	338.9	1.0790	0.0128	334.1	1.0520
120	0.0204	352.1	1.1230	0.0175	350.0	1.1080	0.0134	345.7	1.0810
130	0.0212	363.0	1.1500	0.0182	361.1	1.1360	0.0141	357.2	1.1100
140	0.0219	374.0	1.1770	0.0189	372.3	1.1630	0.0146	368.6	1.1380
150	0.0226	385.1	1.2040	0.0196	383.4	1.1900	0.0152	380.1	1.1660
160	0.0234	396.2	1.2300	0.0202	394.7	1.2160	0.0158	391.6	1.1930
170	0.0241	407.4	1.2550	0.0208	406.0	1.2420	0.0163	403.1	1.2190
180	0.0248	418.8	1.2810	0.0215	417.4	1.2680	0.0168	414.7	1.2450


R134a
Pressure-Enthalpy Diagram
Reference: ASHRAE Standard
Enthalpy -40°C Liquid = 0 kJ/kg
Entropy -40°C Liquid = 0 kJ/kg-K
CRITICAL POINT
90°C
80°C
70°C
60°C
50°C
40°C
30°C
20°C
10°C
0°C
-10°C
-20°C
-30°C
-40°C
0.2
0.4
0.6
0.8
0.9 kJ/kg-K
1.0
1.1
1.2
1.3
1.4
0.005
0.010
0.020
0.030
0.050
0.100
0.200
0.300
0.500 m³/kg
P [kPa]
10000
5000
1000
500
100
50
40
h [kJ/kg]
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
P Mylon

Combustion Information

Enthalpy of formation

Substance	Formula	M	kJ $kmol^{-1}$
Air		28.97	0
Oxygen	O_2	32	0
Hydrogen	H_2	2	0
Nitrogen	N_2	28	0
Carbon dioxide	CO_2	44	-393,520
Carbon monoxide	CO	28	-110,530
Water (vapour)	H_2O(vap)	18	-241,820
Water (liquid)	H_2O(liq)	18	-285,830
Methane	CH_4	16	-74,850
Acetylene	C_2H_2	26	+226,730
Ethane	C_2H_6	30	-84,680
Propane	C_3H_8	44	-103,850
Butane	C_4H_{10}	58	-126,150
Octane (vapour)	C_8H_{18}	114	-208,450
Dodecane	$C_{12}H_{26}$	170	-291,010

Reactions

All species are vapour unless stated otherwise. The convention here is such that it is the heat **received** by the system. Enthalpy variation per mol of fuel (first species on the LHS). $\Delta\tilde{h}^{\ominus}$ in J mol^{-1} at standard condition T=25^{O}C.

$C_{solid} + O_2 \rightarrow CO_2$	-393 520	$C_8H_{18} + \frac{25}{2}O_2 \rightarrow 8CO_2 + 9H_2O$	-5 116 180
$CO + \frac{1}{2}O_2 \rightarrow CO_2$	-282 990	$CO_2 + H_2 \rightarrow CO + H_2O$	41 169
$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	-241 830	$\frac{1}{2}H_2 + OH \rightarrow H_2O$	-281 540
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	-802 310	$\frac{1}{2}N_2 + \frac{1}{2}O_2 \rightarrow NO$	90 290
$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$	-1 323 170	$H_2O(liquid) \rightarrow H_2O$	43 990
$C_2H_6 + \frac{7}{2}O_2 \rightarrow 2CO_2 + 3H_2O$	-1 427 860	$C_6H_6(liquid) \rightarrow C_6H_6$	33 800
$C_6H_6 + \frac{15}{2}O_2 \rightarrow 6CO_2 + 3H_2O$	-3 169 540	$C_8H_{18}(liquid) \rightarrow C_8H_{18}$	41 500

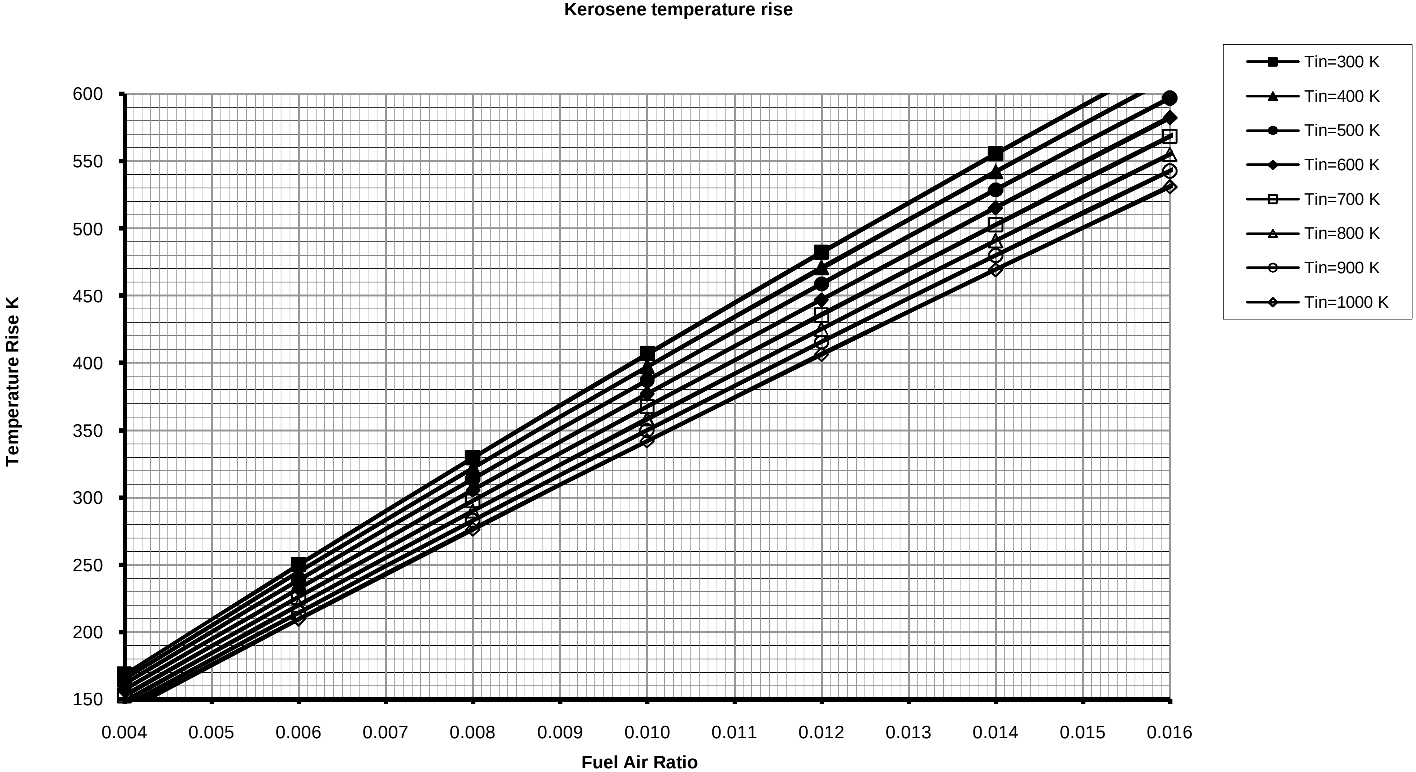
Energy values of various fuels by mass

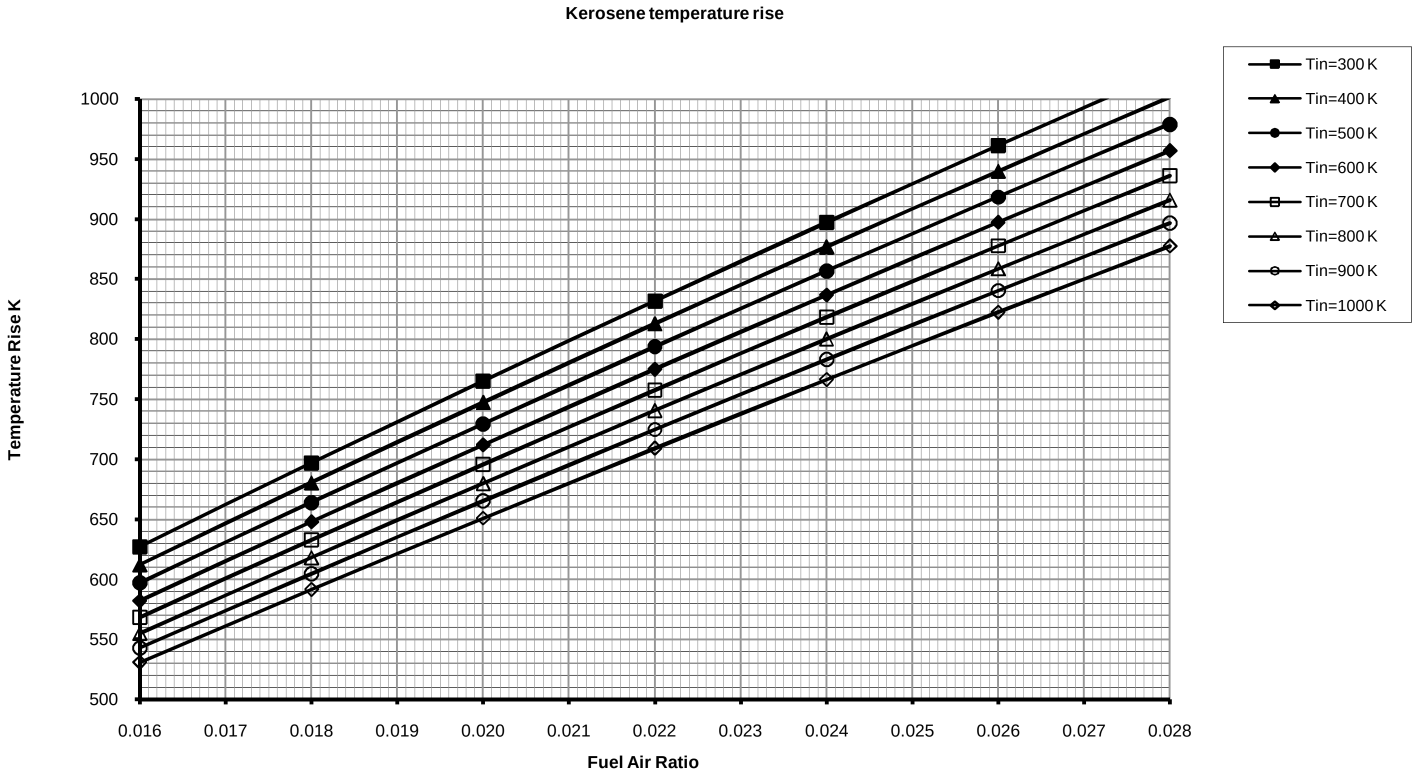
Liquid Fuels	LCV ($MJ\ kg^{-1}$)	ρ (kgm^{-3}) at 15°C	Notes
Petrol (or gasoline)	43.7	737	80 octane
Fuel oil, light	43.4	921	3.5% S (w/w)
Diesel oil	43.3	836	Medium grade (No. 7)
Fuel oil, medium	42.9	939	4.0% S (w/w)
Fuel oil, heavy	42.5	952	3.5% S (w/w)
Kerosine (or kerosene)	42.4	817	
	LCV ($MJ\ kg^{-1}$)	ρ (kgm^{-3}) at b.p.	Boiling Point (K)
Liq. Hydrogen (LH_2)	116	71	21
Liquid Methane	49	424	111
Liquid Propane	46	585	231

Gaseous Fuels	LCV ($MJ\ kg^{-1}$)	LCV ($MJ\ m^{-3}$) at 15°C and 1bar, gas phase
Hydrogen gas	119.7	10.1
Methane (CH_4)	50.0	34.0
Acetylene (C_2H_2)	48.3	53.1
Propane gas (C_3H_8)	46.4	86.5
Butane (C_4H_{10})	45.8	112.5
Iso-octane (C_8H_{18})	44.7	215.7
Ethanol	26.8	52.2

Solid Fuels	LCV ($MJ\ kg^{-1}$)	Notes
Rubber	37.7	
Coal	26.4	
Straw	18.0	
Wood pellets†	17.0	8% moisture (w/w)
Paper	16.6	
Logwood (soft) †	14.4	20% moisture (w/w)
Logwood (hard) †	13.0	25% moisture (w/w)
Wood chips (soft) †	12.3	30% moisture (w/w)
Wood chips (hard)†	10.9	35% moisture (w/w)
Municipal waste	10.7	Edmonton (1968)

†LCV refers to fresh wood, as opposed to GCV for dry mass only


Kerosene temperature rise
Tin=300 K
Tin=400 K
Tin=500 K
Tin=600 K
Tin=700 K
Tin=800 K
Tin=900 K
Tin=1000 K
Temperature Rise K
600
550
500
450
400
350
300
250
200
150
0.004
0.005
0.006
0.007
0.008
0.009
0.010
0.011
0.012
0.013
0.014
0.015
0.016
Fuel Air Ratio


Kerosene temperature rise
Temperature Rise K
Fuel Air Ratio
1000
950
900
850
800
750
700
650
600
550
500
0.016
0.017
0.018
0.019
0.020
0.021
0.022
0.023
0.024
0.025
0.026
0.027
0.028
Tin=300 K
Tin=400 K
Tin=500 K
Tin=600 K
Tin=700 K
Tin=800 K
Tin=900 K
Tin=1000 K

Equilibrium constants

	$\ln K^{\ominus}$							
T (K)	$\frac{(p_{H_2O})(p^{\ominus})^{\frac{1}{2}}}{(p_{H_2})(p_{O_2})^{\frac{1}{2}}}$	$\frac{(p_{CO_2})(p^{\ominus})^{\frac{1}{2}}}{(p_{CO})(p_{O_2})^{\frac{1}{2}}}$	$\frac{(p_{H_2O})(p_{CO})}{(p_{H_2})(p_{CO_2})}$	$\frac{(p_{H_2O})(p^{\ominus})^{\frac{1}{2}}}{(p_{OH})(p_{H_2})^{\frac{1}{2}}}$	$\frac{(p_{NO})}{(p_{N_2})^{\frac{1}{2}}(p_{O_2})^{\frac{1}{2}}}$	$\frac{(p_{H_2})(p^{\ominus})}{(p_H)^2}$	$\frac{(p_{O_2})(p^{\ominus})}{(p_O)^2}$	$\frac{(p_{N_2})(p^{\ominus})^{\frac{1}{2}}}{(p_N)^2}$
298.15	92.207	103.762	-11.554	106.329	-34.933	164.005	186.961	367.479
300	91.604	103.057	-11.453	105.626	-34.707	162.922	185.723	365.126
400	67.321	74.669	-7.348	77.360	-25.655	119.164	135.710	270.329
600	42.897	46.245	-3.348	48.956	-16.602	75.226	85.519	175.356
800	30.593	32.036	-1.444	34.670	-12.072	53.135	60.319	127.753
1000	23.162	23.528	-0.366	26.063	-9.353	39.808	45.145	99.128
1200	18.182	17.871	0.311	20.307	-7.541	30.878	35.005	80.012
1400	14.608	13.841	0.767	16.181	-6.245	24.468	27.742	66.329
1600	11.921	10.829	1.091	13.086	-5.273	19.637	22.285	56.055
1800	9.825	8.497	1.329	10.673	-4.518	15.865	18.030	48.051
2000	8.145	6.634	1.510	8.741	-3.912	12.840	14.622	41.645
2200	6.768	5.119	1.649	7.161	-3.417	10.358	11.827	36.391
2400	5.619	3.859	1.759	5.844	-3.005	8.281	9.497	32.011
2600	4.647	2.800	1.847	4.730	-2.657	6.517	7.521	28.304
2800	3.811	1.893	1.918	3.774	-2.360	5.002	5.826	25.117
3000	3.086	1.110	1.976	2.945	-2.102	3.689	4.357	22.358
3500	1.641	-0.436	2.077	1.299	-1.592	1.063	1.431	16.849
4000	0.541	-1.600	2.141	0.051	-1.207	-0.934	-0.796	12.660
4500	-0.313	-2.491	2.177	-0.914	-0.914	-2.482	-2.514	9.414
5000	-0.997	-3.198	2.201	-1.683	-0.682	-3.725	-3.895	6.807
5500	-1.561	-3.771	2.210	-2.314	-0.493	-4.743	-5.024	4.666
6000	-2.033	-4.246	2.213	-2.839	-0.338	-5.590	-5.963	2.865

Where $p^{\ominus} = 1 \text{ bar} = 10^5 \text{ Pa}$

CO - enthalpy, internal energy and entropy at atmospheric pressure

T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}	T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}
0	*0*	0	*0*	600	*17614*	12625	*218.1*
220	*6355*	4526	*188.5*	610	*17920*	12848	*218.6*
230	*6657*	4745	*189.8*	620	*18227*	13072	*219.1*
240	*6957*	4961	*191.1*	630	*18535*	13296	*219.6*
250	*7255*	5176	*192.3*	640	*18843*	13522	*220.1*
260	*7550*	5389	*193.4*	650	*19152*	13748	*220.6*
270	*7845*	5600	*194.6*	660	*19462*	13974	*221.1*
280	*8138*	5810	*195.6*	670	*19772*	14202	*221.5*
290	*8431*	6020	*196.7*	680	*20084*	14430	*222.0*
298.15	*8669*	6190	*197.5*	690	*20396*	14659	*222.4*
300	*8723*	6229	*197.6*	700	*20708*	14888	*222.9*
310	*9014*	6437	*198.6*	710	*21022*	15119	*223.3*
320	*9306*	6645	*199.5*	720	*21336*	15349	*223.8*
330	*9597*	6853	*200.4*	730	*21651*	15581	*224.2*
340	*9887*	7061	*201.3*	740	*21966*	15813	*224.6*
350	*10178*	7268	*202.1*	750	*22282*	16046	*225.1*
360	*10470*	7476	*202.9*	760	*22599*	16280	*225.5*
370	*10761*	7685	*203.7*	770	*22916*	16514	*225.9*
380	*11053*	7893	*204.5*	780	*23234*	16749	*226.3*
390	*11345*	8102	*205.3*	790	*23553*	16985	*226.7*
400	*11637*	8311	*206.0*	800	*23872*	17221	*227.1*
410	*11930*	8521	*206.7*	810	*24192*	17458	*227.5*
420	*12223*	8731	*207.5*	820	*24513*	17695	*227.9*
430	*12517*	8942	*208.1*	830	*24834*	17933	*228.3*
440	*12811*	9153	*208.8*	840	*25156*	18172	*228.7*
450	*13106*	9365	*209.5*	850	*25479*	18412	*229.1*
460	*13402*	9577	*210.1*	860	*25802*	18651	*229.4*
470	*13698*	9791	*210.8*	870	*26126*	18892	*229.8*
480	*13995*	10004	*211.4*	880	*26450*	19133	*230.2*
490	*14293*	10219	*212.0*	890	*26775*	19375	*230.6*
500	*14591*	10434	*212.6*	900	*27100*	19617	*230.9*
510	*14890*	10650	*213.2*	910	*27426*	19860	*231.3*
520	*15190*	10866	*213.8*	920	*27753*	20104	*231.6*
530	*15490*	11084	*214.4*	930	*28080*	20348	*232.0*
540	*15792*	11302	*214.9*	940	*28408*	20592	*232.3*
550	*16093*	11520	*215.5*	950	*28736*	20838	*232.7*
560	*16396*	11740	*216.0*	960	*29065*	21083	*233.0*
570	*16699*	11960	*216.6*	970	*29395*	21330	*233.4*
580	*17003*	12181	*217.1*	980	*29725*	21576	*233.7*
590	*17308*	12403	*217.6*	990	*30055*	21824	*234.0*

CO - enthalpy, internal energy and entropy at atmospheric pressure

T K	h $kJ\ kmol^{-1}$	u $kJ\ kmol^{-1}$	s $kJ\ kmol^{-1}\ K^{-1}$
1000	30386	22072	234.4
1020	31050	22569	235.0
1040	31717	23069	235.7
1060	32383	23569	236.3
1080	33052	24073	236.9
1100	33724	24578	237.6
1120	34397	25085	238.2
1140	35072	25594	238.8
1160	35749	26104	239.4
1180	36428	26617	239.9
1200	37108	27131	240.5
1220	37790	27647	241.1
1240	38474	28164	241.6
1260	39159	28683	242.2
1280	39846	29203	242.7
1300	40534	29726	243.2
1320	41224	30249	243.8
1340	41915	30774	244.3
1360	42608	31301	244.8
1380	43302	31828	245.3
1400	43998	32358	245.8
1420	44695	32888	246.3
1440	45393	33420	246.8
1460	46092	33953	247.3
1480	46793	34488	247.8
1500	47495	35023	248.2
1520	48198	35560	248.7
1540	48902	36098	249.1
1560	49608	36637	249.6
1580	50314	37178	250.1
1600	51022	37719	250.5
1620	51731	38261	250.9
1640	52441	38805	251.4
1660	53151	39349	251.8
1680	53863	39895	252.2
1700	54576	40442	252.7
1720	55290	40989	253.1
1740	56005	41537	253.5
1760	56720	42087	253.9
1780	57437	42637	254.3
1800	58154	43188	254.7
1820	58872	43740	255.1
1840	59591	44293	255.5
1860	60311	44847	255.9
1880	61033	45402	256.1
1900	61754	45956	256.3
1920	62476	46512	256.6
1940	63199	47069	257.0
1960	63923	47627	257.4
1980	64647	48185	257.8
2000	65373	48744	258.1
2050	67189	50144	258.5
2100	69009	51548	259.4
2150	70832	52956	260.3
2200	72660	54368	261.1
2250	74491	55783	262.0
2300	76325	57202	262.8
2350	78162	58623	263.6
2400	80002	60047	264.4
2450	81844	61474	265.2
2500	83689	62903	265.9
2550	85536	64335	266.7
2600	87386	65768	267.4
2650	89237	67204	268.1
2700	91091	68642	268.8
2750	92946	70081	269.5
2800	94802	71522	270.2
2850	96660	72964	270.9
2900	98520	74408	271.5
2950	100380	75853	272.2
3000	102242	77299	272.8
3050	104105	78746	273.4
3100	105969	80194	274.1
3150	107833	81643	274.7
3200	109698	83093	275.3
3250	106497	79476	275.8

For low pressures, h and u are virtually independent of pressure. If s_a is given at atmospheric pressure, then:

$$s = s_a - R_0 \ln\left(\frac{P}{P_a}\right)$$

H_2O- enthalpy, internal energy and entropy at atmospheric pressure

T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}	T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}
0	*0*	0	*0*	600	*20391*	15402	*212.8*
220	*7259*	5430	*178.3*	610	*20755*	15683	*213.4*
230	*7600*	5687	*179.9*	620	*21119*	15964	*214.0*
240	*7939*	5944	*181.3*	630	*21486*	16247	*214.6*
250	*8278*	6200	*182.7*	640	*21853*	16532	*215.2*
260	*8616*	6455	*184.0*	650	*22221*	16817	*215.8*
270	*8954*	6709	*185.3*	660	*22591*	17104	*216.3*
280	*9292*	6964	*186.5*	670	*22962*	17392	*216.9*
290	*9629*	7218	*187.7*	680	*23335*	17681	*217.4*
298.15	*9904*	7425	*188.6*	690	*23708*	17971	*218.0*
300	*9966*	7472	*188.8*	700	*24083*	18263	*218.5*
310	*10304*	7726	*190.0*	710	*24459*	18556	*219.1*
320	*10641*	7981	*191.0*	720	*24837*	18850	*219.6*
330	*10979*	8235	*192.1*	730	*25216*	19146	*220.1*
340	*11317*	8490	*193.1*	740	*25596*	19443	*220.6*
350	*11656*	8746	*194.1*	750	*25977*	19741	*221.1*
360	*11995*	9001	*195.0*	760	*26360*	20041	*221.6*
370	*12334*	9258	*195.9*	770	*26743*	20341	*222.1*
380	*12674*	9515	*196.8*	780	*27129*	20643	*222.6*
390	*13015*	9772	*197.7*	790	*27515*	20947	*223.1*
400	*13357*	10031	*198.6*	800	*27903*	21251	*223.6*
410	*13699*	10290	*199.4*	810	*28292*	21557	*224.1*
420	*14042*	10550	*200.3*	820	*28682*	21864	*224.6*
430	*14386*	10811	*201.1*	830	*29074*	22173	*225.1*
440	*14731*	11073	*201.9*	840	*29467*	22482	*225.5*
450	*15077*	11335	*202.6*	850	*29861*	22793	*226.0*
460	*15423*	11599	*203.4*	860	*30256*	23106	*226.5*
470	*15771*	11863	*204.2*	870	*30653*	23419	*226.9*
480	*16120*	12129	*204.9*	880	*31051*	23734	*227.4*
490	*16470*	12396	*205.6*	890	*31450*	24050	*227.8*
500	*16820*	12663	*206.3*	900	*31850*	24367	*228.3*
510	*17172*	12932	*207.0*	910	*32252*	24686	*228.7*
520	*17525*	13202	*207.7*	920	*32655*	25006	*229.1*
530	*17879*	13473	*208.4*	930	*33060*	25327	*229.6*
540	*18235*	13745	*209.0*	940	*33465*	25649	*230.0*
550	*18591*	14018	*209.7*	950	*33872*	25973	*230.4*
560	*18949*	14293	*210.3*	960	*34280*	26298	*230.9*
570	*19308*	14568	*211.0*	970	*34689*	26624	*231.3*
580	*19667*	14845	*211.6*	980	*35100*	26951	*231.7*
590	*20029*	15123	*212.2*	990	*35511*	27280	*232.1*

H_2O - enthalpy, internal energy and entropy at atmospheric pressure

T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}	T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}
1000	*35924*	27610	*232.6*	1800	*72498*	57532	*259.2*
1020	*36754*	28273	*233.4*	1820	*73490*	58358	*259.7*
1040	*37588*	28941	*234.2*	1840	*74485*	59186	*260.3*
1060	*38428*	29614	*235*	1860	*75483*	60018	*260.8*
1080	*39272*	30292	*235.8*	1880	*76484*	60853	*261.4*
1100	*40121*	30975	*236.6*	1900	*77488*	61691	*261.9*
1120	*40974*	31662	*237.3*	1920	*78495*	62531	*262.4*
1140	*41832*	32354	*238.1*	1940	*79505*	63375	*262.9*
1160	*42695*	33050	*238.8*	1960	*80518*	64222	*263.5*
1180	*43563*	33752	*239.6*	1980	*81534*	65071	*264.0*
1200	*44435*	34457	*240.3*	2000	*82553*	65924	*264.5*
1220	*45311*	35168	*241.0*	2050	*85111*	68067	*265.8*
1240	*46192*	35882	*241.7*	2100	*87687*	70227	*267.0*
1260	*47078*	36602	*242.5*	2150	*90280*	72404	*268.2*
1280	*47968*	37325	*243.2*	2200	*92887*	74596	*269.4*
1300	*48862*	38053	*243.8*	2250	*95511*	76803	*270.6*
1320	*49760*	38785	*244.5*	2300	*98148*	79025	*271.7*
1340	*50663*	39522	*245.2*	2350	*100800*	81261	*272.9*
1360	*51570*	40262	*245.9*	2400	*103465*	83510	*274.0*
1380	*52481*	41007	*246.6*	2450	*106143*	85772	*275.1*
1400	*53396*	41756	*247.2*	2500	*108833*	88047	*276.2*
1420	*54315*	42509	*247.9*	2550	*111535*	90333	*277.3*
1440	*55239*	43266	*248.5*	2600	*114248*	92631	*278.3*
1460	*56166*	44027	*249.1*	2650	*116972*	94939	*279.4*
1480	*57097*	44792	*249.8*	2700	*119707*	97258	*280.4*
1500	*58032*	45561	*250.4*	2750	*122451*	99586	*281.4*
1520	*58972*	46334	*251.0*	2800	*125204*	101924	*282.4*
1540	*59914*	47110	*251.6*	2850	*127966*	104270	*283.4*
1560	*60861*	47890	*252.3*	2900	*130737*	106625	*284.3*
1580	*61811*	48675	*252.9*	2950	*133515*	108987	*285.3*
1600	*62765*	49462	*253.5*	3000	*136300*	111357	*286.2*
1620	*63723*	50254	*254.1*	3050	*139093*	113734	*287.1*
1640	*64684*	51049	*254.6*	3100	*141892*	116117	*288.0*
1660	*65649*	51847	*255.2*	3150	*144697*	118506	*288.9*
1680	*66617*	52649	*255.8*	3200	*147507*	120901	*289.8*
1700	*67589*	53455	*256.4*	3250	*106497*	79476	*205.8*
1720	*68564*	54263	*257.0*				
1740	*69543*	55076	*257.5*				
1760	*70525*	55891	*258.1*				
1780	*71510*	56710	*258.6*				

N_2 - enthalpy, internal energy and entropy at atmospheric pressure

T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}	T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}
0	*0*	0	*0*	600	*17558*	12570	*212.0*
220	*6446*	4617	*182.8*	610	*17860*	12788	*212.5*
230	*6716*	4803	*184.0*	620	*18163*	13008	*213.0*
240	*6993*	4997	*185.2*	630	*18466*	13228	*213.5*
250	*7276*	5197	*186.3*	640	*18771*	13449	*213.9*
260	*7562*	5400	*187.4*	650	*19075*	13671	*214.4*
270	*7850*	5605	*188.5*	660	*19381*	13893	*214.9*
280	*8140*	5812	*189.6*	670	*19687*	14116	*215.3*
290	*8431*	6020	*190.6*	680	*19994*	14340	*215.8*
298.15	*8669*	6190	*191.4*	690	*20302*	14565	*216.2*
300	*8723*	6229	*191.6*	700	*20610*	14790	*216.7*
310	*9015*	6437	*192.6*	710	*20919*	15016	*217.1*
320	*9307*	6646	*193.5*	720	*21229*	15243	*217.6*
330	*9599*	6855	*194.4*	730	*21539*	15470	*218.0*
340	*9891*	7064	*195.3*	740	*21851*	15698	*218.4*
350	*10183*	7272	*196.1*	750	*22162*	15927	*218.8*
360	*10474*	7481	*196.9*	760	*22475*	16156	*219.2*
370	*10766*	7690	*197.7*	770	*22788*	16386	*219.6*
380	*11058*	7898	*198.5*	780	*23102*	16617	*220.1*
390	*11349*	8107	*199.3*	790	*23417*	16848	*220.5*
400	*11641*	8315	*200.0*	800	*23732*	17080	*220.8*
410	*11933*	8524	*200.7*	810	*24048*	17313	*221.2*
420	*12225*	8733	*201.4*	820	*24364*	17546	*221.6*
430	*12518*	8942	*202.1*	830	*24682*	17781	*222.0*
440	*12810*	9152	*202.8*	840	*24999*	18015	*222.4*
450	*13103*	9362	*203.4*	850	*25318*	18251	*222.8*
460	*13396*	9572	*204.1*	860	*25637*	18487	*223.1*
470	*13690*	9782	*204.7*	870	*25957*	18723	*223.5*
480	*13984*	9993	*205.3*	880	*26277*	18960	*223.9*
490	*14279*	10205	*205.9*	890	*26598*	19198	*224.2*
500	*14574*	10417	*206.5*	900	*26920*	19437	*224.6*
510	*14870*	10629	*207.1*	910	*27242*	19676	*225.0*
520	*15166*	10842	*207.7*	920	*27564*	19915	*225.3*
530	*15463*	11056	*208.3*	930	*27888*	20155	*225.7*
540	*15760*	11270	*208.8*	940	*28212*	20396	*226.0*
550	*16058*	11485	*209.4*	950	*28536*	20637	*226.3*
560	*16357*	11701	*209.9*	960	*28861*	20879	*226.7*
570	*16656*	11917	*210.4*	970	*29187*	21122	*227.0*
580	*16956*	12134	*211.0*	980	*29513*	21365	*227.4*
590	*17257*	12351	*211.5*	990	*29840*	21608	*227.7*

N_2 - enthalpy, internal energy and entropy at atmospheric pressure

T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}	T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}
1000	*30167*	21852	*228.0*	1800	*57640*	42674	*248.1*
1020	*30823*	22342	*228.7*	1820	*58351*	43219	*248.5*
1040	*31481*	22834	*229.3*	1840	*59063*	43764	*248.9*
1060	*32141*	23328	*229.9*	1860	*59776*	44311	*249.3*
1080	*32803*	23824	*230.6*	1880	*60488*	44857	*249.7*
1100	*33468*	24322	*231.2*	1900	*61202*	45405	*250.1*
1120	*34134*	24821	*231.8*	1920	*61917*	45953	*250.4*
1140	*34801*	25323	*232.4*	1940	*62633*	46503	*250.8*
1160	*35471*	25826	*232.9*	1960	*63349*	47053	*251.2*
1180	*36142*	26331	*233.5*	1980	*64066*	47603	*251.5*
1200	*36816*	26838	*234.1*	2000	*64784*	48155	*251.9*
1220	*37490*	27347	*234.6*	2050	*66581*	49537	*252.8*
1240	*38167*	27857	*235.2*	2100	*68383*	50923	*253.6*
1260	*38845*	28369	*235.7*	2150	*70189*	52313	*254.5*
1280	*39525*	28882	*236.3*	2200	*71998*	53707	*255.3*
1300	*40206*	29397	*236.8*	2250	*73812*	55104	*256.1*
1320	*40888*	29913	*237.3*	2300	*75628*	56505	*256.9*
1340	*41572*	30431	*237.8*	2350	*77449*	57910	*257.7*
1360	*42258*	30950	*238.3*	2400	*79272*	59318	*258.5*
1380	*42945*	31471	*238.8*	2450	*81099*	60729	*259.2*
1400	*43633*	31993	*239.3*	2500	*82928*	62142	*260.0*
1420	*44322*	32516	*239.8*	2550	*84761*	63559	*260.7*
1440	*45013*	33041	*240.3*	2600	*86596*	64979	*261.4*
1460	*45705*	33566	*240.8*	2650	*88434*	66401	*262.1*
1480	*46399*	34093	*241.3*	2700	*90275*	67826	*262.8*
1500	*47093*	34622	*241.7*	2750	*92118*	69253	*263.5*
1520	*47789*	35151	*242.2*	2800	*93963*	70683	*264.2*
1540	*48486*	35682	*242.6*	2850	*95810*	72115	*264.8*
1560	*49184*	36214	*243.1*	2900	*97660*	73549	*265.5*
1580	*49883*	36746	*243.5*	2950	*99512*	74985	*266.1*
1600	*50583*	37280	*244.0*	3000	*101366*	76423	*266.7*
1620	*51285*	37815	*244.4*	3050	*103222*	77864	*267.3*
1640	*51987*	38351	*244.8*	3100	*105080*	79306	*267.9*
1660	*52690*	38888	*245.3*	3150	*106940*	80750	*268.5*
1680	*53395*	39426	*245.7*	3200	*108802*	82196	*269.1*
1700	*54100*	39965	*246.1*				
1720	*54806*	40505	*246.5*				
1740	*55513*	41046	*246.9*				
1760	*56221*	41588	*247.3*				
1780	*56930*	42131	*247.7*				

O_2 - enthalpy, internal energy and entropy at atmospheric pressure

T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}	T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}
0	*0*	0	*0*	600	*17933*	12945	*226.3*
220	*6323*	4494	*195.8*	610	*18255*	13183	*226.8*
230	*6637*	4724	*197.2*	620	*18578*	13423	*227.3*
240	*6945*	4950	*198.5*	630	*18902*	13664	*227.8*
250	*7249*	5171	*199.7*	640	*19227*	13905	*228.4*
260	*7550*	5388	*200.9*	650	*19552*	14148	*228.9*
270	*7849*	5604	*202.0*	660	*19879*	14391	*229.4*
280	*8146*	5818	*203.1*	670	*20206*	14635	*229.8*
290	*8441*	6030	*204.1*	680	*20534*	14880	*230.3*
298.15	*8682*	6203	*205.0*	690	*20863*	15126	*230.8*
300	*8737*	6242	*205.1*	700	*21192*	15372	*231.3*
310	*9031*	6454	*206.1*	710	*21523*	15619	*231.8*
320	*9326*	6665	*207.0*	720	*21854*	15867	*232.2*
330	*9621*	6877	*207.9*	730	*22185*	16116	*232.7*
340	*9917*	7090	*208.8*	740	*22518*	16365	*233.1*
350	*10213*	7302	*209.7*	750	*22851*	16615	*233.6*
360	*10509*	7516	*210.5*	760	*23185*	16866	*234.0*
370	*10807*	7730	*211.3*	770	*23520*	17118	*234.5*
380	*11105*	7945	*212.1*	780	*23855*	17370	*234.9*
390	*11404*	8162	*212.9*	790	*24191*	17623	*235.3*
400	*11704*	8379	*213.7*	800	*24528*	17876	*235.7*
410	*12006*	8597	*214.4*	810	*24865*	18130	*236.2*
420	*12308*	8816	*215.1*	820	*25203*	18385	*236.6*
430	*12612*	9036	*215.9*	830	*25542*	18641	*237.0*
440	*12916*	9258	*216.6*	840	*25881*	18897	*237.4*
450	*13222*	9480	*217.2*	850	*26220*	19153	*237.8*
460	*13528*	9704	*217.9*	860	*26561*	19410	*238.2*
470	*13836*	9928	*218.6*	870	*26902*	19668	*238.6*
480	*14145*	10154	*219.2*	880	*27243*	19926	*239.0*
490	*14455*	10381	*219.9*	890	*27585*	20185	*239.4*
500	*14766*	10609	*220.5*	900	*27928*	20445	*239.7*
510	*15078*	10838	*221.1*	910	*28271*	20705	*240.1*
520	*15391*	11068	*221.7*	920	*28615*	20965	*240.5*
530	*15706*	11299	*222.3*	930	*28959*	21226	*240.9*
540	*16021*	11531	*222.9*	940	*29303*	21488	*241.2*
550	*16337*	11764	*223.5*	950	*29649*	21750	*241.6*
560	*16654*	11998	*224.1*	960	*29994*	22013	*242.0*
570	*16973*	12233	*224.6*	970	*30341*	22276	*242.3*
580	*17292*	12470	*225.2*	980	*30687*	22539	*242.7*
590	*17612*	12707	*225.7*	990	*31035*	22803	*243.0*

O_2 - enthalpy, internal energy and entropy at atmospheric pressure

T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}	T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}
1000	*31382*	23068	*243.4*	1800	*60356*	45390	*264.6*
1020	*32079*	23598	*244.1*	1820	*61103*	45971	*265.0*
1040	*32777*	24130	*244.8*	1840	*61852*	46554	*265.4*
1060	*33478*	24664	*245.4*	1860	*62602*	47138	*265.8*
1080	*34180*	25200	*246.1*	1880	*63352*	47721	*266.2*
1100	*34884*	25738	*246.7*	1900	*64104*	48306	*266.6*
1120	*35589*	26277	*247.4*	1920	*64856*	48892	*267.0*
1140	*36296*	26818	*248.0*	1940	*65609*	49479	*267.4*
1160	*37004*	27360	*248.6*	1960	*66364*	50067	*267.8*
1180	*37715*	27904	*249.2*	1980	*67119*	50656	*268.2*
1200	*38426*	28449	*249.8*	2000	*67875*	51246	*268.6*
1220	*39139*	28996	*250.4*	2050	*69769*	52724	*269.5*
1240	*39854*	29544	*251.0*	2100	*71669*	54208	*270.4*
1260	*40570*	30094	*251.5*	2150	*73574*	55698	*271.3*
1280	*41287*	30645	*252.1*	2200	*75484*	57193	*272.2*
1300	*42006*	31197	*252.7*	2250	*77400*	58693	*273.0*
1320	*42726*	31751	*253.2*	2300	*79321*	60198	*273.9*
1340	*43447*	32306	*253.8*	2350	*81248*	61709	*274.7*
1360	*44169*	32862	*254.3*	2400	*83180*	63225	*275.5*
1380	*44893*	33419	*254.8*	2450	*85117*	64747	*276.3*
1400	*45618*	33978	*255.3*	2500	*87059*	66273	*277.1*
1420	*46345*	34538	*255.9*	2550	*89006*	67805	*277.9*
1440	*47072*	35099	*256.4*	2600	*90959*	69341	*278.6*
1460	*47801*	35662	*256.9*	2650	*92916*	70883	*279.4*
1480	*48531*	36225	*257.4*	2700	*94879*	72430	*280.1*
1500	*49262*	36790	*257.9*	2750	*96847*	73982	*280.8*
1520	*49994*	37356	*258.3*	2800	*98820*	75539	*281.6*
1540	*50727*	37923	*258.8*	2850	*100798*	77102	*282.3*
1560	*51462*	38491	*259.3*	2900	*102780*	78669	*282.9*
1580	*52197*	39060	*259.8*	2950	*104768*	80241	*283.6*
1600	*52934*	39630	*260.2*	3000	*106762*	81818	*284.3*
1620	*53671*	40202	*260.7*	3050	*108760*	83401	*285.0*
1640	*54410*	40774	*261.1*	3100	*110763*	84988	*285.6*
1660	*55149*	41348	*261.6*	3150	*112771*	86581	*286.3*
1680	*55890*	41922	*262.0*	3200	*114784*	88178	*286.9*
1700	*56632*	42498	*262.5*				
1720	*57375*	43074	*262.9*				
1740	*58119*	43651	*263.3*				
1760	*58863*	44230	*263.8*				
1780	*59609*	44809	*264.2*				

CO_2 - enthalpy, internal energy and entropy at atmospheric pressure

T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}	T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}
0	*0*	0	*0*	600	*22261*	17273	*243.1*
220	*6637*	4808	*203.0*	610	*22735*	17664	*243.8*
230	*6967*	5055	*204.5*	620	*23212*	18057	*244.6*
240	*7302*	5307	*205.9*	630	*23691*	18453	*245.4*
250	*7644*	5565	*207.3*	640	*24172*	18851	*246.1*
260	*7991*	5829	*208.7*	650	*24655*	19251	*246.9*
270	*8343*	6099	*210.0*	660	*25141*	19653	*247.6*
280	*8701*	6373	*211.3*	670	*25629*	20058	*248.4*
290	*9064*	6653	*212.6*	680	*26118*	20465	*249.1*
298.15	*9364*	6885	*213.6*	690	*26610*	20873	*249.8*
300	*9432*	6938	*213.8*	700	*27104*	21284	*250.5*
310	*9805*	7228	*215.1*	710	*27600*	21697	*251.2*
320	*10183*	7522	*216.3*	720	*28098*	22112	*251.9*
330	*10565*	7821	*217.4*	730	*28598*	22529	*252.6*
340	*10952*	8125	*218.6*	740	*29100*	22947	*253.3*
350	*11343*	8433	*219.7*	750	*29604*	23368	*254.0*
360	*11738*	8745	*220.8*	760	*30109*	23790	*254.6*
370	*12137*	9061	*221.9*	770	*30616*	24214	*255.3*
380	*12541*	9381	*223.0*	780	*31125*	24640	*256.0*
390	*12948*	9705	*224.1*	790	*31636*	25068	*256.6*
400	*13359*	10033	*225.1*	800	*32149*	25497	*257.3*
410	*13774*	10365	*226.1*	810	*32663*	25928	*257.9*
420	*14192*	10700	*227.1*	820	*33179*	26361	*258.5*
430	*14614*	11039	*228.1*	830	*33696*	26795	*259.2*
440	*15040*	11381	*229.1*	840	*34215*	27231	*259.8*
450	*15469*	11727	*230.1*	850	*34736*	27669	*260.4*
460	*15901*	12076	*231.0*	860	*35258*	28108	*261.0*
470	*16336*	12428	*232.0*	870	*35782*	28548	*261.6*
480	*16775*	12784	*232.9*	880	*36307*	28990	*262.2*
490	*17216*	13142	*233.8*	890	*36834*	29434	*262.8*
500	*17661*	13504	*234.7*	900	*37362*	29879	*263.4*
510	*18109*	13868	*235.6*	910	*37891*	30325	*264.0*
520	*18559*	14236	*236.4*	920	*38422*	30773	*264.6*
530	*19013*	14606	*237.3*	930	*38954*	31222	*265.1*
540	*19469*	14979	*238.2*	940	*39488*	31672	*265.7*
550	*19928*	15355	*239.0*	950	*40023*	32124	*266.3*
560	*20389*	15733	*239.8*	960	*40559*	32577	*266.8*
570	*20853*	16114	*240.7*	970	*41097*	33032	*267.4*
580	*21320*	16498	*241.5*	980	*41636*	33488	*267.9*
590	*21790*	16884	*242.3*	990	*42176*	33944	*268.5*

CO_2 - enthalpy, internal energy and entropy at atmospheric pressure

T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}	T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}
1000	*42717*	34403	*269.0*	1800	*88735*	73770	*302.7*
1020	*43803*	35323	*270.1*	1820	*89931*	74799	*303.4*
1040	*44894*	36247	*271.2*	1840	*91129*	75830	*304.0*
1060	*45990*	37176	*272.2*	1860	*92329*	76864	*304.7*
1080	*47089*	38110	*273.2*	1880	*93528*	77897	*305.3*
1100	*48193*	39048	*274.3*	1900	*94730*	78932	*305.9*
1120	*49302*	39990	*275.3*	1920	*95932*	79969	*306.6*
1140	*50414*	40935	*276.2*	1940	*97136*	81006	*307.2*
1160	*51530*	41885	*277.2*	1960	*98342*	82045	*307.8*
1180	*52650*	42839	*278.2*	1980	*99548*	83086	*308.4*
1200	*53773*	43796	*279.1*	2000	*100756*	84127	*309.0*
1220	*54900*	44757	*280.0*	2050	*103779*	86735	*310.5*
1240	*56031*	45721	*281.0*	2100	*106809*	89349	*312.0*
1260	*57165*	46688	*281.9*	2150	*109846*	91970	*313.4*
1280	*58302*	47659	*282.8*	2200	*112888*	94596	*314.8*
1300	*59442*	48633	*283.6*	2250	*115935*	97228	*316.2*
1320	*60585*	49610	*284.5*	2300	*118988*	99864	*317.5*
1340	*61731*	50590	*285.4*	2350	*122045*	102506	*318.8*
1360	*62880*	51572	*286.2*	2400	*125107*	105152	*320.1*
1380	*64032*	52558	*287.1*	2450	*128173*	107803	*321.4*
1400	*65186*	53546	*287.9*	2500	*131243*	110457	*322.6*
1420	*66343*	54537	*288.7*	2550	*134318*	113116	*323.8*
1440	*67503*	55530	*289.5*	2600	*137396*	115779	*325.0*
1460	*68665*	56526	*290.3*	2650	*140478*	118445	*326.2*
1480	*69829*	57524	*291.1*	2700	*143563*	121115	*327.4*
1500	*70996*	58525	*291.9*	2750	*146652*	123788	*328.5*
1520	*72165*	59527	*292.7*	2800	*149745*	126465	*329.6*
1540	*73336*	60532	*293.5*	2850	*152841*	129145	*330.7*
1560	*74510*	61539	*294.2*	2900	*155940*	131829	*331.8*
1580	*75685*	62548	*295.0*	2950	*159043*	134515	*332.8*
1600	*76863*	63560	*295.7*	3000	*162149*	137206	*333.9*
1620	*78042*	64573	*296.4*	3050	*165258*	139900	*334.9*
1640	*79223*	65588	*297.2*	3100	*168371*	142597	*335.9*
1660	*80406*	66604	*297.9*	3150	*171487*	145297	*336.9*
1680	*81591*	67623	*298.6*	3200	*174607*	148001	*337.9*
1700	*82778*	68643	*299.3*				
1720	*83966*	69665	*300.0*				
1740	*85156*	70689	*300.7*				
1760	*86348*	71714	*301.3*				
1780	*87541*	72741	*302.0*				

H_2 - enthalpy, internal energy and entropy at atmospheric pressure

T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}	T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}
0	*0*	0	*0*	600	*17265*	12276	*151.0*
220	*6329*	4500	*122.3*	610	*17557*	12485	*151.5*
230	*6585*	4673	*123.4*	620	*17850*	12695	*151.9*
240	*6849*	4853	*124.6*	630	*18142*	12904	*152.4*
250	*7118*	5040	*125.7*	640	*18435*	13113	*152.9*
260	*7393*	5231	*126.7*	650	*18727*	13323	*153.3*
270	*7671*	5426	*127.8*	660	*19020*	13532	*153.8*
280	*7952*	5624	*128.8*	670	*19313*	13742	*154.2*
290	*8235*	5824	*129.8*	680	*19606*	13952	*154.6*
298.15	*8468*	5989	*130.6*	690	*19899*	14163	*155.1*
300	*8521*	6027	*130.8*	700	*20193*	14373	*155.5*
310	*8808*	6231	*131.7*	710	*20487*	14584	*155.9*
320	*9097*	6436	*132.6*	720	*20781*	14794	*156.3*
330	*9386*	6642	*133.5*	730	*21075*	15005	*156.7*
340	*9676*	6849	*134.4*	740	*21369*	15217	*157.1*
350	*9967*	7057	*135.2*	750	*21664*	15428	*157.5*
360	*10258*	7265	*136.1*	760	*21959*	15640	*157.9*
370	*10550*	7473	*136.9*	770	*22254*	15852	*158.3*
380	*10842*	7682	*137.6*	780	*22550*	16064	*158.7*
390	*11134*	7891	*138.4*	790	*22845*	16277	*159.0*
400	*11426*	8100	*139.1*	800	*23141*	16490	*159.4*
410	*11718*	8309	*139.9*	810	*23438*	16703	*159.8*
420	*12010*	8518	*140.6*	820	*23734*	16917	*160.2*
430	*12302*	8727	*141.2*	830	*24031*	17130	*160.5*
440	*12594*	8936	*141.9*	840	*24329*	17344	*160.9*
450	*12886*	9145	*142.6*	850	*24626*	17559	*161.2*
460	*13178*	9354	*143.2*	860	*24924*	17774	*161.6*
470	*13470*	9563	*143.8*	870	*25222*	17989	*161.9*
480	*13762*	9771	*144.5*	880	*25521*	18204	*162.3*
490	*14054*	9980	*145.1*	890	*25820*	18420	*162.6*
500	*14346*	10189	*145.6*	900	*26119*	18636	*162.9*
510	*14638*	10398	*146.2*	910	*26418*	18852	*163.3*
520	*14930*	10606	*146.8*	920	*26718*	19069	*163.6*
530	*15222*	10815	*147.3*	930	*27019*	19286	*163.9*
540	*15514*	11024	*147.9*	940	*27319*	19504	*164.2*
550	*15805*	11232	*148.4*	950	*27620*	19722	*164.5*
560	*16097*	11441	*149.0*	960	*27922*	19940	*164.9*
570	*16389*	11650	*149.5*	970	*28223*	20158	*165.2*
580	*16681*	11859	*150.0*	980	*28526*	20377	*165.5*
590	*16973*	12068	*150.5*	990	*28828*	20597	*165.8*

H_2 - enthalpy, internal energy and entropy at atmospheric pressure

T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}	T K	h kJ kmol^{-1}	u kJ kmol^{-1}	s kJ kmol^{-1} K^{-1}
1000	*29131*	20817	*166.1*	1800	*54657*	39691	*184.8*
1020	*29738*	21257	*166.7*	1820	*55327*	40195	*185.1*
1040	*30346*	21699	*167.3*	1840	*55999*	40700	*185.5*
1060	*30956*	22143	*167.9*	1860	*56673*	41208	*185.9*
1080	*31568*	22588	*168.4*	1880	*57346*	41715	*186.2*
1100	*32181*	23035	*169*	1900	*58022*	42225	*186.6*
1120	*32796*	23484	*169.6*	1920	*58699*	42736	*186.9*
1140	*33412*	23934	*170.1*	1940	*59378*	43248	*187.3*
1160	*34030*	24386	*170.6*	1960	*60058*	43762	*187.6*
1180	*34650*	24839	*171.2*	1980	*60740*	44277	*188.0*
1200	*35271*	25294	*171.7*	2000	*61423*	44794	*188.3*
1220	*35894*	25751	*172.2*	2050	*63136*	46091	*189.2*
1240	*36519*	26209	*172.7*	2100	*64858*	47397	*190.0*
1260	*37145*	26669	*173.2*	2150	*66588*	48712	*190.8*
1280	*37773*	27130	*173.7*	2200	*68326*	50034	*191.6*
1300	*38402*	27593	*174.2*	2250	*70072*	51365	*192.4*
1320	*39033*	28058	*174.7*	2300	*71827*	52704	*193.2*
1340	*39666*	28525	*175.2*	2350	*73589*	54050	*193.9*
1360	*40300*	28993	*175.6*	2400	*75358*	55404	*194.7*
1380	*40936*	29462	*176.1*	2450	*77135*	56765	*195.4*
1400	*41574*	29934	*176.6*	2500	*78920*	58134	*196.1*
1420	*42213*	30407	*177*	2550	*80712*	59510	*196.8*
1440	*42854*	30881	*177.5*	2600	*82511*	60893	*197.5*
1460	*43496*	31357	*177.9*	2650	*84317*	62284	*198.2*
1480	*44140*	31835	*178.3*	2700	*86130*	63681	*198.9*
1500	*44786*	32314	*178.8*	2750	*87949*	65085	*199.6*
1520	*45433*	32795	*179.2*	2800	*89776*	66496	*200.2*
1540	*46082*	33278	*179.6*	2850	*91609*	67913	*200.9*
1560	*46732*	33762	*180.0*	2900	*93448*	69337	*201.5*
1580	*47384*	34248	*180.5*	2950	*95294*	70767	*202.1*
1600	*48038*	34735	*180.9*	3000	*97146*	72203	*202.8*
1620	*48693*	35224	*181.3*	3050	*99005*	73646	*203.4*
1640	*49349*	35714	*181.7*	3100	*100869*	75094	*204.0*
1660	*50008*	36206	*182.1*	3150	*102739*	76549	*204.6*
1680	*50667*	36699	*182.5*	3200	*104615*	78009	*205.2*
1700	*51328*	37194	*182.9*				
1720	*51991*	37690	*183.2*				
1740	*52655*	38188	*183.6*				
1760	*53321*	38688	*184.0*				
1780	*53988*	39189	*184.4*				

Specific heat of gases at constant pressure

T (K)	c_p ($kJkg^{-1}K^{-1}$)						
	CH_4	CO_2	CO	H_2	H_2O	N_2	O_2
220	2.251	0.742	1.084	12.500	1.894	0.946	0.991
230	2.230	0.756	1.074	12.900	1.888	0.978	0.972
240	2.216	0.769	1.066	13.230	1.883	1.001	0.956
250	2.210	0.782	1.059	13.490	1.879	1.016	0.945
260	2.210	0.795	1.054	13.700	1.876	1.026	0.936
270	2.215	0.807	1.049	13.870	1.874	1.033	0.930
280	2.224	0.819	1.046	14.010	1.873	1.038	0.926
290	2.237	0.831	1.043	14.120	1.872	1.040	0.923
298	2.250	0.840	1.042	14.190	1.872	1.041	0.922
300	2.253	0.842	1.041	14.210	1.872	1.042	0.922
320	2.295	0.863	1.039	14.330	1.874	1.042	0.921
340	2.345	0.884	1.039	14.410	1.878	1.042	0.924
360	2.402	0.903	1.040	14.460	1.883	1.041	0.928
380	2.464	0.921	1.042	14.480	1.890	1.041	0.934
400	2.531	0.938	1.045	14.490	1.898	1.042	0.940
420	2.600	0.955	1.048	14.490	1.907	1.043	0.947
440	2.671	0.971	1.052	14.490	1.917	1.045	0.953
460	2.743	0.986	1.057	14.490	1.927	1.048	0.960
480	2.816	1.000	1.061	14.480	1.939	1.051	0.967
500	2.890	1.014	1.066	14.480	1.950	1.054	0.974
550	3.074	1.046	1.079	14.480	1.982	1.065	0.990
600	3.255	1.075	1.092	14.490	2.015	1.077	1.005
650	3.431	1.101	1.105	14.520	2.049	1.089	1.019
700	3.601	1.125	1.118	14.570	2.085	1.102	1.031
750	3.763	1.146	1.130	14.620	2.120	1.114	1.043
800	3.918	1.166	1.141	14.690	2.156	1.126	1.053
900	4.207	1.202	1.163	14.850	2.226	1.149	1.071
1000	4.466	1.231	1.183	15.030	2.296	1.169	1.087
1100	4.698	1.257	1.200	15.230	2.362	1.187	1.101
1200	4.905	1.278	1.216	15.430	2.426	1.203	1.113
1300	5.089	1.297	1.230	15.630	2.488	1.217	1.124
1400	5.252	1.313	1.243	15.830	2.546	1.230	1.134
1500	5.396	1.327	1.254	16.030	2.601	1.241	1.143
1600	5.521	1.339	1.264	16.230	2.653	1.251	1.152
1700	5.631	1.349	1.273	16.420	2.702	1.260	1.160

Molar Gibbs function at atmospheric pressure

	$\tilde{g}^{q}$ (kJkmol^{-1})								
T (K)	CH_4	C_2H_4	CO	CO_2	H_2	H_2O	N_2	NO	O_2
220	-31354	-38311	-35122	-38047	-20597	-31995	-33786	-37519	-36762
250	-36686	-44611	-40837	-44206	-24319	-37415	-39326	-43623	-42698
298.15	-45507	-55023	-50228	-54346	-30495	-46363	-48427	-53646	-52449
300	-45852	-55430	-50594	-54742	-30737	-46712	-48782	-54036	-52828
400	-65063	-78139	-70805	-76713	-44260	-66115	-68390	-75581	-73795
500	-85297	-102174	-91757	-99722	-58519	-86382	-88736	-97882	-95522
600	-106460	-127455	-113309	-123627	-73366	-107355	-109678	-120799	-117876
700	-128494	-153911	-135373	-148321	-88703	-128937	-131124	-144240	-140767
800	-151355	-181476	-157885	-173724	-104461	-151056	-153013	-168142	-164131
900	-175001	-210088	-180798	-199769	-120589	-173661	-175296	-192454	-187917
1000	-199398	-239690	-204074	-226403	-137051	-196713	-197938	-217137	-212084

Heat Transfer

Fourier's Law $\dot{Q} = -kA\frac{\partial T}{\partial x}$

Newton's Law of Cooling $\dot{Q}_{Conv} = hA_s(T_s - T_\infty)$

Radiation heat transfer $\dot{Q}_{Emit} = \varepsilon\sigma A_s {T_s}^4$

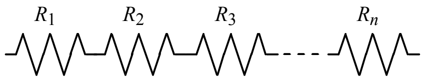
1-D heat conduction equation $\frac{1}{r^n}\frac{\partial}{\partial r}\left(r^n k\frac{\partial T}{\partial r}\right) + \dot{g} = \rho C\frac{\partial T}{\partial t}$,

where n = 0 for a flat wall, n = 1 cylinder and n = 2 sphere

Thermal resistance

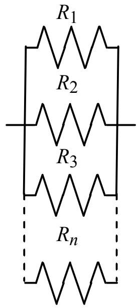
Resistors in series:

$R_{total} = R_1 + R_2 + R_3 + \cdots + R_n$



Resistors in parallel:

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n}$$

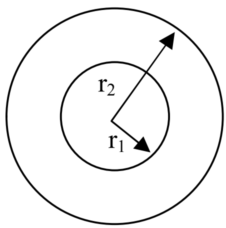


Resistance for 1D heat flow through a plate:

$$R_{total} = \frac{1}{Ah_1} + \frac{L_1}{Ak} + \frac{1}{Ah_2}$$

Resistance for 1D heat flow through a cylinder:

$$R_{total} = \frac{1}{(2\pi r_1 L)h_1} + \frac{\ln(r_2/r_1)}{2\pi Lk} + \frac{1}{(2\pi r_2 L)h_2}$$



Resistance for 1D heat flow through a sphere:

$$R_{total} = \frac{1}{(4\pi {r_1}^2)h_1} + \frac{r_2 - r_1}{4\pi r_1 r_2 k} + \frac{1}{(4\pi {r_2}^2)h_2}$$

Heat flow in multilayered cylinders and spheres:

$$\dot{Q} = \frac{T_i - T_j}{R_{total,i-j}}$$ between any two interfaces i and j

Radiative heat transfer coefficient:

$$h_{Rad} = \varepsilon\sigma\left({T_s}^2 + {T_{Surr}}^2\right)(T_s + T_{Surr})$$

Finned surfaces

$$m^2 = \frac{hp}{kA_c}$$

Temperature profile (insulated tip):

$$\frac{T(x) - T_\infty}{T_b - T_\infty} = e^{-mx}$$

Fin heat transfer:

$$\dot{Q}_{long\ fin} = \sqrt{hpkA_c}(T_b - T_\infty)$$

$$\dot{Q}_{insulated\ tip} = \sqrt{hpkA_c}(T_b - T_\infty)\tanh mL$$

Fin efficiency:

$$\eta_{long\ fin} = \frac{\dot{Q}_{fin}}{\dot{Q}_{fin,max}} = \frac{1}{mL}$$

$$\eta_{insulated\ tip} = \frac{\tanh mL}{mL}$$

Fin effectiveness:

$$\varepsilon_{long\ fin} = \frac{\dot{Q}_{fin}}{\dot{Q}_{no\ fin}} = \sqrt{\frac{kp}{hA_c}}$$

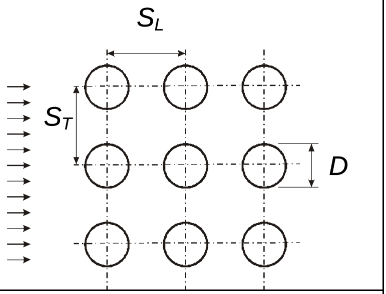
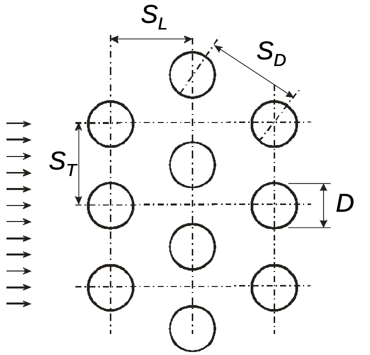
Convection heat transfer

Flow over a flat plate	Range of Re	Nusselt number
Laminar	$0 - 5 \times 10^5$	$Nu = 0.664 Re_L^{0.5} Pr^{1/3}$
Turbulent	$5 \times 10^5 - 10^7$	$Nu = 0.037 Re_L^{0.8} Pr^{1/3}$
Combined	$5 \times 10^5 \leq Re \leq 10^7$	$Nu = (0.037 Re_L^{0.8} - 871) Pr^{1/3}$

Flow across a cylinder

Fluid	Range of Re	Nusselt Number
Gas or liquid	0.4 – 4	$Nu = 0.989 Re^{0.330} Pr^{1/3}$
	4 – 40	$Nu = 0.911 Re^{0.385} Pr^{1/3}$
	40 – 4000	$Nu = 0.683 Re^{0.466} Pr^{1/3}$
	4000 – 40,000	$Nu = 0.193 Re^{0.618} Pr^{1/3}$
	40,000 – 400,000	$Nu = 0.027 Re^{0.805} Pr^{1/3}$

Flow across banks of tubes

In Line	$V_{max} = \frac{S_T}{S_T - D} V$	
Staggered	$V_{max} = \frac{S_T}{2(S_D - D)} V$ $S_D = \sqrt{S_L{}^2 + \left(S_T/2\right)^2}$	

Arrangement	Range of Re_D	Correlation
In Line	0 – 100	$Nu_D = 0.9 Re_D^{0.4} Pr^{0.36} (Pr/Pr_s)^{0.25}$
	100 – 1000	$Nu_D = 0.52 Re_D^{0.5} Pr^{0.36} (Pr/Pr_s)^{0.25}$
	1000 – 2 x 10^5	$Nu_D = 0.27 Re_D^{0.63} Pr^{0.36} (Pr/Pr_s)^{0.25}$
	2 x 10^5 – 2 x 10^6	$Nu_D = 0.033 Re_D^{0.8} Pr^{0.36} (Pr/Pr_s)^{0.25}$
Staggered	0 – 500	$Nu_D = 1.04 Re_D^{0.4} Pr^{0.36} (Pr/Pr_s)^{0.25}$
	500 – 1000	$Nu_D = 0.71 Re_D^{0.5} Pr^{0.36} (Pr/Pr_s)^{0.25}$
	1000 – 2 x 10^5	$Nu_D = 0.35 (S_T/S_L)^{0.2} Re_D^{0.5} Pr^{0.36} (Pr/Pr_s)^{0.25}$
	2 x 10^5 – 2 x 10^6	$Nu_D = 0.031 (S_T/S_L)^{0.2} Re_D^{0.8} Pr^{0.36} (Pr/Pr_s)^{0.25}$

Correction factor for less than 16 banks:

N_L	1	2	3	4	5	7	10	13
In Line	0.7	0.8	0.86	0.9	0.93	0.96	0.98	0.99
Staggered	0.64	0.76	0.84	0.89	0.93	0.96	0.98	0.99

Flow in tubes (Internal forced convection)

Constant surface heat flux:

$$\frac{dT_s}{dx} = \frac{dT_m}{dx} = \frac{\dot{q}_s p}{\dot{m}c_p} = const.$$

Constant surface temperature:

$$ln\frac{T_s - T_e}{T_s - T_i} = -\frac{hA_s}{\dot{m}c_p} \quad where \ A_s = pL$$

Laminar (Re < 2300)

Constant surface heat flux:

$$Nu = \frac{hD}{k} = 4.36$$

Constant surface temperature:

$$Nu = \frac{hD}{k} = 3.66$$

Turbulent (Re > 10,000)

Dittus–Boelter equation:

$$Nu = 0.023Re^{0.8}Pr^{n}$$

where n= 0.4 for heating the fluid, n = 0.3 for cooling the fluid.

Heat exchangers

Heat transfer in a well insulated heat exchanger is given by the heat transfer from the hot or to the cold fluids:

$$\dot{Q} = C_c(T_{c,out} - T_{c,in}) = C_h(T_{h,in} - T_{h,out}) \text{ where } C = \dot{m}c_p$$

It can also be determined using:

$$\dot{Q} = UA\Delta T_{lm} \text{ where } \Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{ln(\Delta T_1/\Delta T_2)}$$

Counter-flow:

$$\Delta T_1 = T_{h,in} - T_{c,out}; \Delta T_2 = T_{h,out} - T_{c,in}$$

Parallel-flow:

$$\Delta T_1 = T_{h,in} - T_{c,in}; \Delta T_2 = T_{h,out} - T_{c,out}$$

Heat exchanger effectiveness

Heat exchanger effectiveness:

$$\varepsilon = \frac{\dot{Q}}{Q_{max}}$$

Double pipe parallel flow

$$\varepsilon = \frac{1 - e^{-NTU(1+c)}}{1 + c}$$

Double pipe counter flow

$$\varepsilon = \frac{1 - e^{-NTU(1-c)}}{1 - ce^{-NTU(1-c)}}$$

$$NTU = \frac{UA_s}{C_{min}} = \frac{UA_s}{\left(\dot{m}c_p\right)_{min}} \text{ and } c = \frac{C_{min}}{C_{max}}$$

Radiation

Stefan-Boltzmann law:

$$E_b(T) = \sigma T^4 \; W/m^2$$

View factor relationships

Reciprocity:

$$A_i F_{ij} = A_j F_{ji}$$

Summation:

$$\sum_{j=1}^{N} F_{ij} = 1$$

Superposition:

$$F_{1\to(2,3)} = F_{1\to 2} + F_{1\to 3}$$

Symmetry: if the surfaces *j* and *k* are symmetric about surface *i* then:

$$F_{i\to j} = F_{i\to k}$$

Net radiation heat transfer from 1 surface:

$$\dot{Q}_i = \frac{E_{bi} - J_i}{R_i}, \text{where } R_i = \frac{1-\varepsilon_i}{A_i \varepsilon_i}$$

Direct Method:

$$\dot{Q}_i = A_i \sum_{j=1}^{N} F_{ij}\left(J_i - J_j\right)$$

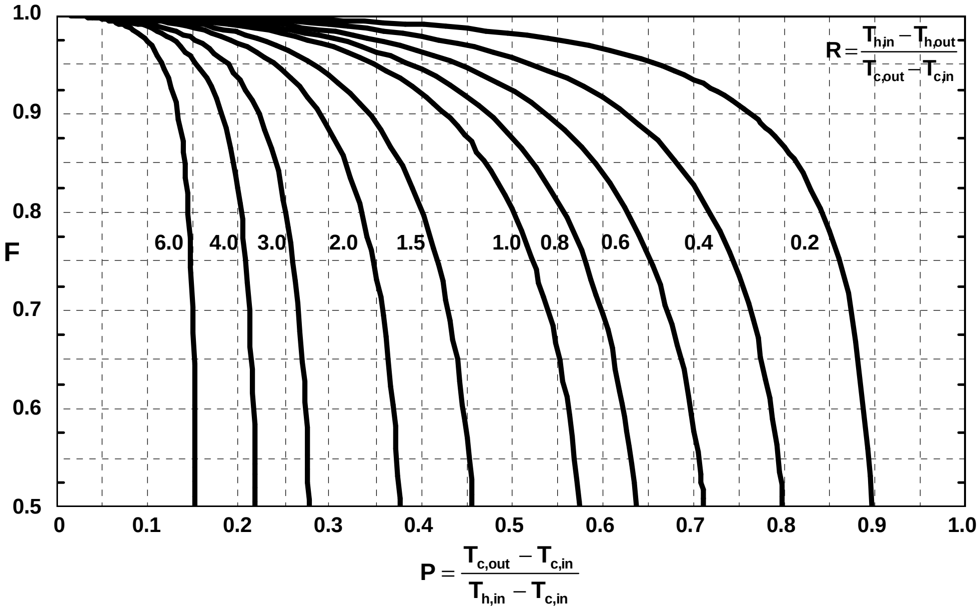
$$\sigma T_i^4 = J_i + \frac{1-\varepsilon_i}{\varepsilon_i} \sum_{j=1}^{N} F_{ij}\left(J_i - J_j\right)$$

Network Method – radiation between two surfaces:

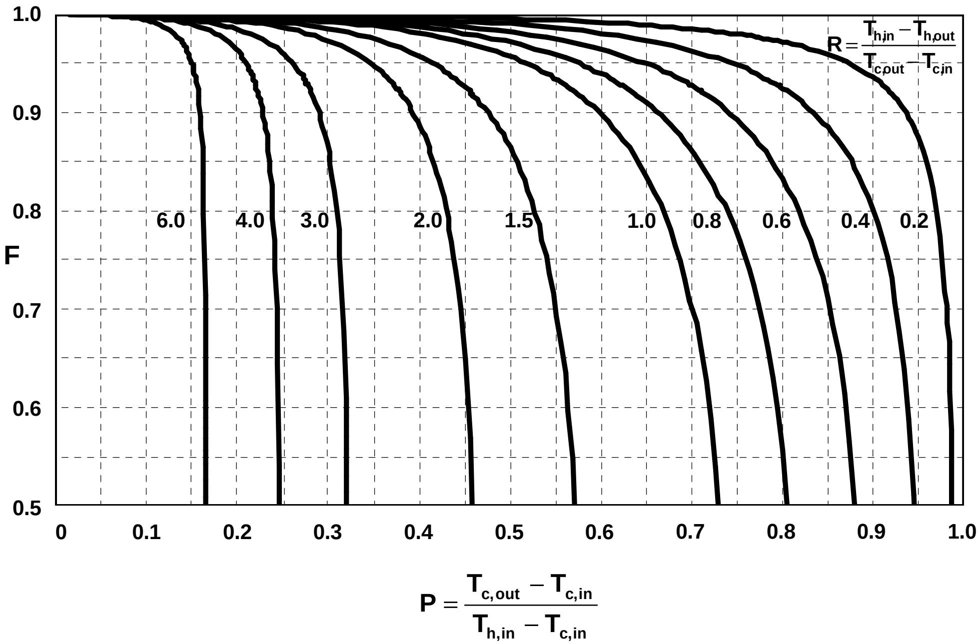
$$\dot{Q}_{12} = \frac{E_{b1} - E_{b2}}{R_1 + R_{12} + R_2} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{A_1\varepsilon_1} + \frac{1}{A_1 F_{12}} + \frac{1-\varepsilon_2}{A_2\varepsilon_2}}$$

Correction factors for LMTD method

Shell-and-tube heat exchanger with *one* shell pass and *2n* tube passes (n=1,2,3,..)

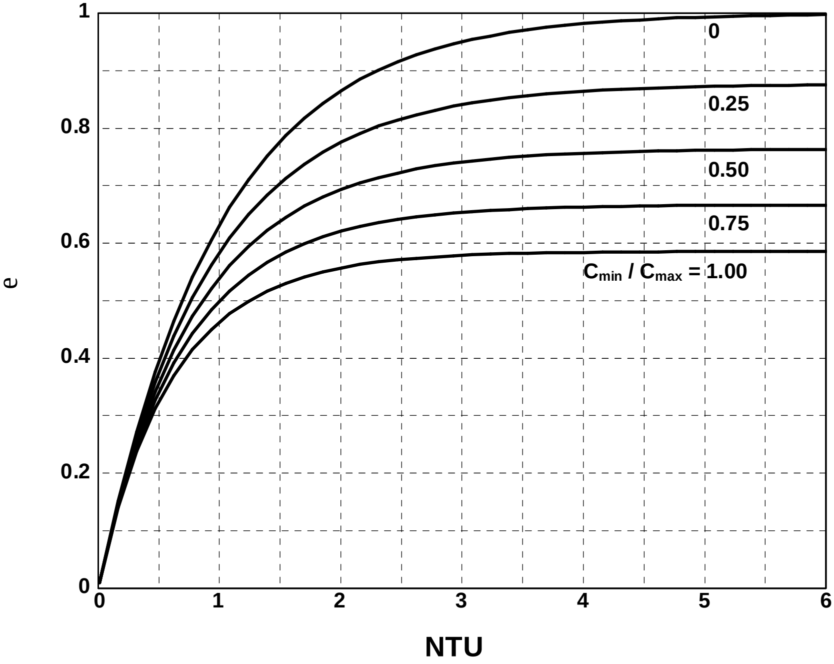


Shell-and-tube heat exchanger with *two* shell passes and *4n* tube passes (n=1,2,3,..)

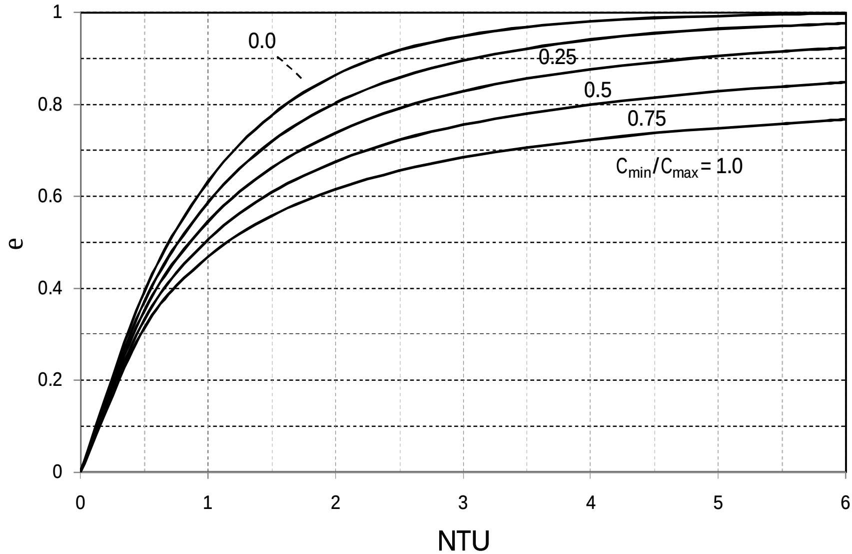


NTU-effectiveness

Shell-and-tube heat exchanger with *one* shell pass and *2n* tube passes (n=1,2,3,..)



Cross-flow heat exchanger with both fluids unmixed



Thermodynamic Properties of Gases, Liquids and Solids

Properties of various gases (100 kPa and 300K)

	Molar Mass kg kmol $^{-1}$	C_v kJkg^{-1}K^{-1}	C_p kJkg^{-1}K^{-1}	γ	k Wm^{-1}K^{-1}	$\mu \times 10^5$ kgm^{-1}s^{-1}	P_c MPa	T_c K
Air	28.97	0.7197	1.007	1.399	0.02565	1.857	3.786	132.5
Ammonia	17.03	1.661	2.180	1.313	0.02486	1.031	11.30	405.4
Argon	39.95	0.3124	0.5215	1.669	0.01787	2.285	4.863	150.7
Carbon Dioxide	44.01	0.6593	0.8525	1.293	0.01677	1.502	7.377	304.1
Helium	4.003	3.116	5.193	1.667	0.1572	2.027	0.2275	5.195
Hydrogen	2.016	10.19	14.31	1.405	0.1779	0.9093	1.315	33.19
Methane	16.04	1.713	2.236	1.305	0.03438	1.125	4.599	190.6
Isobutane	58.12	1.701	1.541	1.104	0.01712	0.7561	36.40	407.8
Nitrogen	28.01	0.7441	1.042	1.401	0.02588	1.823	3.398	126.2
Oxygen	32.00	0.6581	0.9193	1.397	0.02669	2.099	5.043	154.6
Propane	44.10	1.698	1.496	1.135	0.01852	0.8295	42.47	369.8
Steam	18.02	-	-	-	0.01867	0.9815	22.06	647.1

Note: the actual values of μ are 10^5 times smaller than the figures given e.g. $\mu_{air} = 0.00001857$ kgm^{-1}s^{-1}.

Transport properties of various liquids

Name	Temp (°C)	Density kg m^{-3}	C_v kJkg^{-1}K^{-1}	k Wm^{-1}K^{-1}	μ kgm^{-1}s^{-1}
Water	10	1000	4.182	0.5672	0.001312
Glycerine	10	1270	2.319	0.2846	4.293
Engine Oil-SAE60	10	893.7	1.839	0.1443	1.819
Engine Oil-SAE60	100	840	2.22	0.1367	0.01718
Mercury	10	13571	0.14	8.313	0.001627
Sodium	400	846.5	1.293	70.18	0.0002637
Ethanol	25	783	0.977	-	0.001144
R134a (1MPa)	0	1298	0.8787	0.09522	0.0002686
n-butane (2MPa)	10	592.7	1.669	0.1123	0.0001886

Thermodynamic properties of various metals at 300K (unless stated)

Name	ρ kg m^{-3}	C_v kJkg^{-1}K^{-1}	k Wm^{-1}K^{-1}	ε (polished) Wm^{-2}K^{-4}	ε (oxidised) W m^{-2} K^{-4}
Aluminium	2702	0.903	237	0.07	0.82 (anodised)
Carbon steel	7854	0.434	60.5	0.066	0.90
Copper	8933	0.385	401	0.03	0.50 (600K)
Gold	19300	0.129	317	0.07	0.025
Iron and steel	7870	0.447	80.2	0.3	0.61 (rusted)
Lead	11340	0.129	35.3	0.28 (grey)	0.63
Magnesium	1740	1.024	156	0.55	0.20
Stainless steel	8053	0.4815	15.2	0.17	0.33 (800K)
Titanium	4500	0.522	21.9	0.12	0.49 (800K)

Thermodynamic properties of various solids at 300K

Name	ρ kg m^{-3}	C_v $kJkg^{-1}K^{-1}$	k $Wm^{-1}K^{-1}$	ε $W m^{-2} K^{-4}$
Al-silica blanket	64	0.903	0.003	0.40
Brick-common	1920	0.4593	0.72	0.95
Cement mortar	1860	0.78	0.72	0.90
Concrete and stone mix	2100	0.88	1.38	0.90
Glass fibre duct liner	32	0.835	0.038	-
Glass-soda lime	2500	0.75	1.4	0.90
Gypsum plaster	1440	0.85	0.48	0.91
Hardwoods (oak, maple)	720	1.255	0.16	0.82
Ice (<273K)	920	2.168	1.678	0.96
Particle board-high density	1000	1.3	0.17	-
Polyethylene	960	2.1	0.33	-
Polystyrene moulded beads	16	1.21	0.04	
PVC (poly vinyl chloride)	1700	1.1	0.09	-
Rock-granite	2630	0.775	2.79	0.88
Rock-limestone	2320	0.81	2.15	0.95
Rockwool Loosely packed	64	-	0.067	-
Rubber-vulcanized soft	1100	2.01	0.13	-
Silicon Carbide	3150	0.68	490	0.87
Softwoods (fir, pine)	510	1.38	0.12	0.92
Soil	2050	1.84	0.52	0.95
Urethane (two part, rigid)	70	1.04	0.026	-
Vermiculite flakes	120	0.065	900	-

Emissivities of various surfaces at 300K

Name	ε $W m^{-2} K^{-4}$
Aluminium paint	0.50
Asphalt	0.88
Enamel (white)	0.90
Paint (black)	0.98
Paint (white)	0.90
Paper (white)	0.95
Snow (<273K)	0.86
Zinc (galvanised surface)	0.23

Thermodynamic properties of gaseous steam and R134a, and air

Gaseous steam at low pressure

T (°C)	C_p $kJkg^{-1}K^{-1}$	k $Wm^{-1}K^{-1}$	$\mu \times 10^5$ $kgm^{-1}s^{-1}$	Pr
0	1.858	*0.01707*	0.9216	*1.003*
20	1.866	*0.01823*	0.9727	*0.995*
40	1.874	*0.01960*	1.031	*0.986*
60	1.882	*0.02119*	1.093	*0.971*
80	1.891	*0.02301*	1.159	*0.953*
100	1.900	*0.02508*	1.227	*0.930*
150	1.924	*0.02886*	1.418	*0.945*
200	1.950	*0.03328*	1.618	*0.948*
250	1.977	*0.03817*	1.822	*0.944*
300	2.005	*0.04342*	2.029	*0.937*
350	2.035	*0.04897*	2.237	*0.929*
400	2.065	*0.05476*	2.445	*0.922*
450	2.097	*0.06077*	2.652	*0.915*
500	2.129	*0.06698*	2.857	*0.908*
600	2.196	*0.07990*	3.262	*0.896*
700	2.264	*0.09338*	3.655	*0.886*
800	2.331	*0.10730*	4.038	*0.877*

Gaseous R134a at low pressure

T (°C)	C_p $kJkg^{-1}K^{-1}$	k $Wm^{-1}K^{-1}$	$\mu \times 10^5$ $kgm^{-1}s^{-1}$	Pr
-40	0.6703	*0.008113*	0.9335	*0.771*
-30	0.7006	*0.009131*	0.9727	*0.746*
-20	0.7324	*0.01009*	1.012	*0.735*
-10	0.7654	*0.011000*	1.051	*0.731*
0	0.7995	*0.01188*	1.089	*0.733*
10	0.8349	*0.01273*	1.128	*0.740*
20	0.8712	*0.01354*	1.166	*0.750*
30	0.9089	*0.01432*	1.205	*0.765*
40	0.9478	*0.01507*	1.243	*0.782*
50	0.9879	*0.01579*	1.281	*0.801*
60	1.0287	*0.01647*	1.319	*0.824*
70	1.0719	*0.01712*	1.357	*0.850*
80	1.1159	*0.01774*	1.395	*0.877*
90	1.1611	*0.01832*	1.433	*0.908*

Note: the actual values of μ are 10^5 times smaller than the figures given. For example, the viscosity of gaseous R134a at 0°C is 0.00001089 $kgm^{-1}s^{-1}$.

Air tables (100 kPa, but usable for most pressures)

T (K)	C_p $kJkg^{-1}K^{-1}$	C_v $kJkg^{-1}K^{-1}$	γ	k $Wm^{-1}K^{-1}$	$\mu \times 10^5$ $kgm^{-1}s^{-1}$	Pr
150	0.9432	0.6562	1.437	*0.01393*	1.045	*0.7076*
200	0.9882	0.7012	1.409	*0.01797*	1.346	*0.7406*
250	1.005	0.7176	1.400	*0.02187*	1.614	*0.7414*
260	1.006	0.7185	1.399	*0.02264*	1.664	*0.7394*
280	1.006	0.7194	1.399	*0.02415*	1.763	*0.7345*
300	1.007	0.7197	1.399	*0.02565*	1.857	*0.7290*
320	1.007	0.7199	1.399	*0.02712*	1.949	*0.7236*
340	1.007	0.7203	1.398	*0.02858*	2.038	*0.7185*
350	1.008	0.7207	1.398	*0.02930*	2.082	*0.7161*
400	1.012	0.7246	1.396	*0.03283*	2.292	*0.7062*
450	1.019	0.7316	1.392	*0.03625*	2.489	*0.6996*
500	1.028	0.7409	1.387	*0.03955*	2.676	*0.6956*
600	1.051	0.7636	1.376	*0.04582*	3.024	*0.6935*
700	1.075	0.7880	1.364	*0.05168*	3.344	*0.6956*
800	1.099	0.8117	1.354	*0.05716*	3.641	*0.6999*
1000	1.140	0.8532	1.336	*0.06706*	4.180	*0.7108*
1200	1.173	0.8863	1.324	*0.07576*	4.662	*0.7220*
1400	1.199	0.9122	1.315	*0.08347*	5.098	*0.7325*
1600	1.220	0.9326	1.308	*0.09042*	5.497	*0.7415*
1800	1.236	0.9489	1.302	*0.09682*	5.865	*0.7486*
2000	1.249	0.9621	1.298	*0.1029*	6.204	*0.7531*
2500	1.274	0.9866	1.291	*0.1182*	6.953	*0.7491*
3000	1.291	1.004	1.286	*0.1364*	7.582	*0.7177*

International standard atmosphere

z	*p*	*T*	*r*
m	kPa	K	kg m^{-3}
-2500	*135.21*	304.4	*1.5473*
-2000	*127.78*	301.2	*1.4782*
-1500	*120.70*	297.9	*1.4114*
-1000	*113.93*	294.7	*1.3470*
-500	*107.48*	291.4	*1.2849*
0	*101.33*	288.2	*1.2250*
500	*95.46*	284.9	*1.1673*
1000	*89.88*	281.7	*1.1117*
1500	*84.56*	278.4	*1.0582*
2000	*79.50*	275.2	*1.0066*
2500	*74.69*	271.9	*0.9570*
3000	*70.12*	268.7	*0.9093*
3500	*65.78*	265.4	*0.8634*
4000	*61.66*	262.2	*0.8194*
4500	*57.75*	258.9	*0.7770*
5000	*54.05*	255.7	*0.7365*
5500	*50.54*	252.4	*0.6975*
6000	*47.22*	249.2	*0.6602*
6500	*44.08*	245.9	*0.6243*
7000	*41.11*	242.7	*0.5901*
7500	*38.30*	239.5	*0.5573*
8000	*35.65*	236.2	*0.5258*
8500	*33.15*	233.0	*0.4958*
9000	*30.80*	229.7	*0.4671*
9500	*28.58*	226.5	*0.4397*
10000	*26.50*	223.3	*0.4136*

z	*p*	*T*	*r*
m	kPa	K	kg m^{-3}
10500	*24.54*	220.0	*0.3886*
11000	*22.70*	216.8	*0.3648*
11500	*20.98*	216.7	*0.3375*
12000	*19.40*	216.7	*0.3119*
12500	*17.93*	216.7	*0.2884*
13000	*16.58*	216.7	*0.2666*
13500	*15.33*	216.7	*0.2465*
14000	*14.17*	216.7	*0.2279*
14500	*13.10*	216.7	*0.2107*
15000	*12.11*	216.7	*0.1948*
15500	*11.20*	216.7	*0.1801*
16000	*10.35*	216.7	*0.1665*
16500	*9.57*	216.7	*0.1539*
17000	*8.85*	216.7	*0.1423*
17500	*8.18*	216.7	*0.1316*
18000	*7.57*	216.7	*0.1216*
18500	*7.00*	216.7	*0.1125*
19000	*6.47*	216.7	*0.1040*
19500	*5.98*	216.7	*0.0962*
20000	*5.53*	216.7	*0.0889*
22000	*4.05*	218.6	*0.0645*
24000	*2.97*	220.6	*0.0469*
26000	*2.19*	222.5	*0.0343*
28000	*1.62*	224.5	*0.0251*
30000	*1.20*	226.5	*0.0184*
32000	*0.89*	228.5	*0.0136*

Temperature lapse rates are based on the US standard atmosphere 1976.

FLOW OF FLUIDS

Nomenclature

b	wingspan	m
c	speed of sound	ms^{-1}
C	velocity	ms^{-1}
C_f	skin friction coefficient	-
D	diameter	m
D	drag force (p. 62)	N
f	force, body force	N
g	gravity	ms^{-2}
l	reference length (usually mean chord)	m
L	lift force	N
L_e	flow development length	m
P	pressure	Nm^{-2}
q	dynamic pressure	Nm^{-2}
$\dot{Q}$	heat transfer rate (heat in)	W
Q	volume flow rate	m^3s^{-1}
r	radial distance	m
R	radius	m
R	gas constant	$kJkg^{-1}k^{-1}$
Re	Reynolds number	-
S	reference area (usually wing area)	m^2
u, v, w	velocity components in the x, y, z directions, respectively	ms^{-1}
U_∞	free stream velocity	ms^{-1}
V	1D velocity	ms^{-1}
$\dot{W}$	power (work out)	W
x	axial distance	m
z	elevation from a datum	m
δ^*	displacement thickness	m
γ	ratio of specific heats	-
Λ	aspect ratio	-
μ	dynamic viscosity	Pas
θ	momentum thickness	m
ρ	density	m^3kg^{-1}
τ	shear stress	Nm^{-2}
υ	kinematic viscosity	Nms^{-1}

$_w$	conditions at the wall
$_\infty$	free stream conditions

Bernoulli's equation:

$$P + \frac{1}{2}\rho C^2 + \rho g z = \text{constant}$$

Bernoulli's equation with losses:

$$\frac{1}{2}\rho(C_2^2 - C_1^2) + \rho g(z_2 - z_1) + P_2 - P_1 + P_{loss} = 0$$

Steady flow energy equation:

$$\frac{1}{2}\rho(C_2^2 - C_1^2) + \rho g(z_2 - z_1) + P_{loss} = \frac{\dot{Q} - \dot{W}}{Q} = \frac{\dot{Q} - \dot{W}}{C_1 A_1}$$

Newton's law of viscosity:

$$\tau = \mu \frac{du}{dy}$$

Laminar flow

For a horizontal tube (Poiseuille Flow):

$$u = -\frac{dP}{dx}\frac{1}{4\mu}(R^2 - r^2)$$

$$Q = -\frac{dP}{dx}\frac{\pi R^4}{8\mu} = \frac{\pi R^4 \Delta P}{8\mu l} = \frac{\pi d^4 \Delta P}{128\mu l}$$

For flow between parallel plates:

$$Q = -\frac{dP}{dx}\frac{\mathrm{bc}^3}{12\mu} = \frac{bc^3 \Delta P}{12\mu l}$$

Mean hydraulic diameter:

$$\frac{4 \times Area}{Perimeter}$$

Force momentum equation (FME) about axis *x*:

$$\sum F_x = \sum(\dot{m}C)_{out} - \sum(\dot{m}C)_{in}$$

Torque momentum equation (TME)
General:

$$\sum T_A = \left(\sum \dot{O}_{out} - \sum \dot{O}_{in}\right)_{\mathrm{A}}$$

where $\dot{O} = \dot{m}rC$ (for a liquid $\dot{O} = \rho A r C^2$)

1D:

$$\sum T_A = \dot{m}(r_{out}C_{out} - r_{in}C_{in})$$

Speed of sound (in a perfect gas):

$$a = \sqrt{\gamma R T}$$

Pressure loss coefficients

Pressure loss coefficient in circular pipes:

$$\Delta P = \frac{1}{2}\rho C^2 \frac{4fl}{d}$$

f is taken from the Moody Diagram (page 63) or:

Laminar flow	Colebrook-White (implicit)	Swami and Jaine (explicit)
$f = \frac{16}{Re}$	$\frac{1}{\sqrt{f}} = \log_{10}\left(\frac{\varepsilon}{3.7d} + \frac{1.255}{Re \times \sqrt{f}}\right)$	$\sqrt{f} = \frac{0.25}{\log_{10}\left(\frac{\varepsilon}{3.7d} + \frac{5.745}{Re^{0.9}}\right)}$

Pressure losses in expansions and contractions: k = loss coefficient:

Sudden expansion

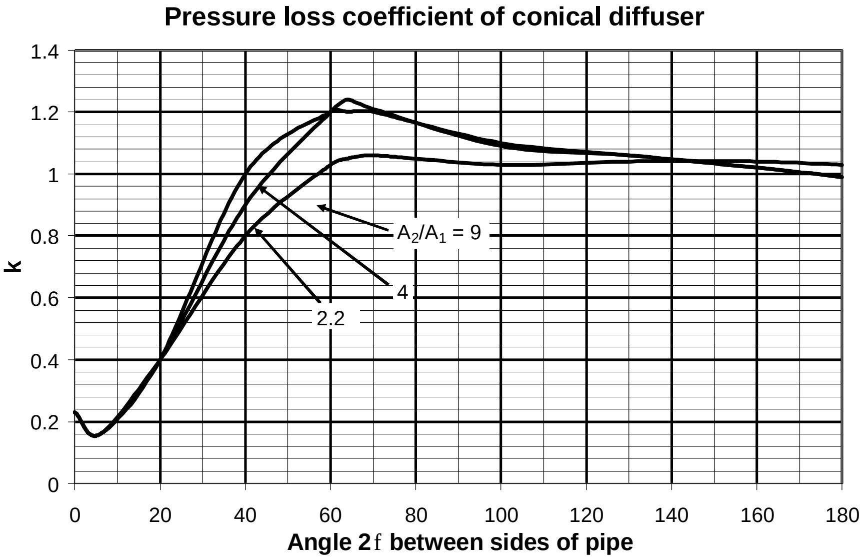
$$\Delta P = k \times \frac{1}{2}\rho {C_1}^2$$

where $k = \left(1 - \frac{A_1}{A_2}\right)^2$

Sudden contraction

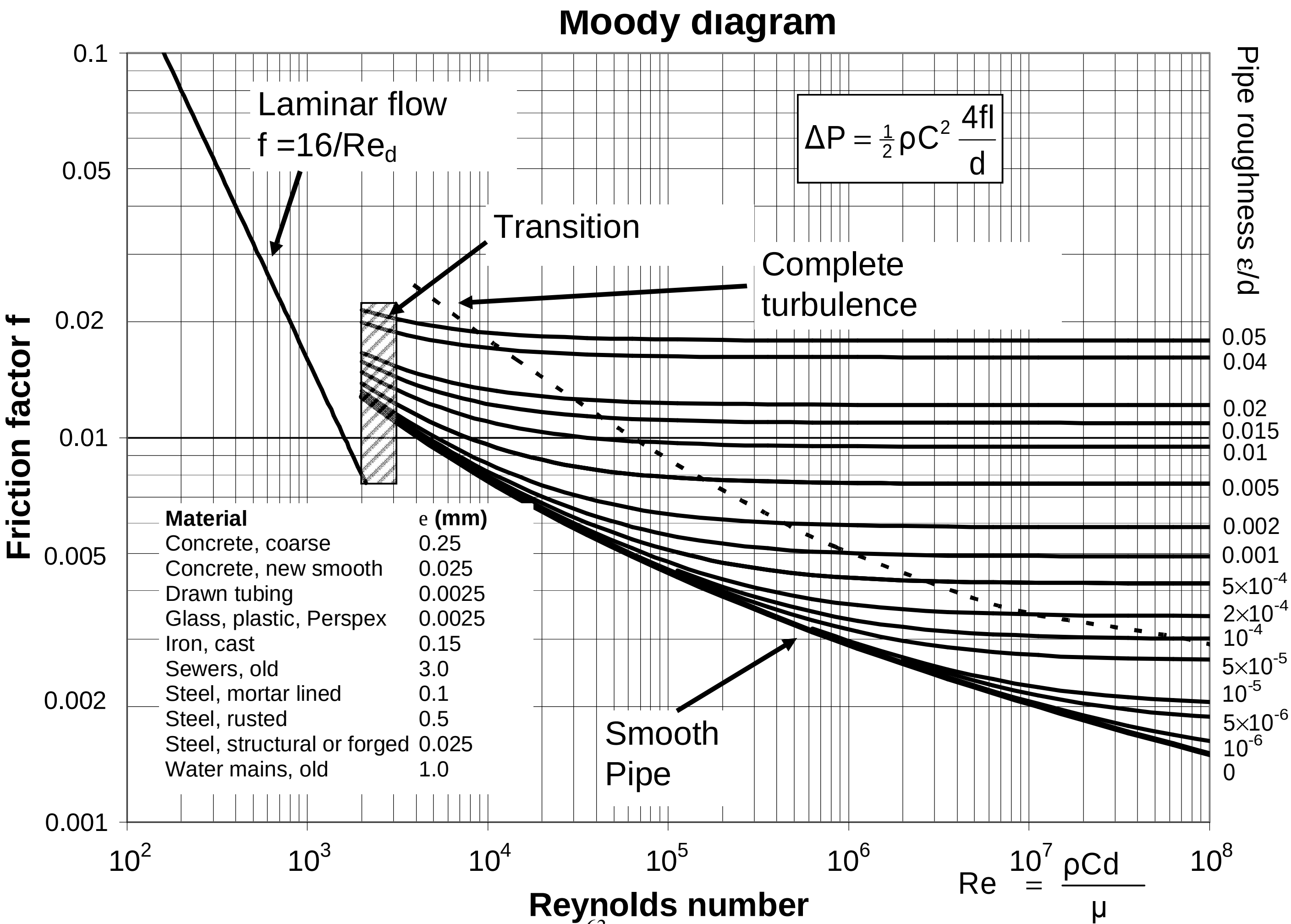
$$\Delta P = k \times \frac{1}{2}\rho {C_2}^2$$

d_2/d_1	0	0.2	0.4	0.6	0.8	1.0
k	0.50	0.45	0.38	0.28	0.14	0



Loss coefficients for pipe fittings (smooth pipe). Tees assume equal flows.

90º Elbow (Sharp)	1.0	90º Elbow (Gradual)	0.2
45º Elbow (Sharp)	0.3	45º Elbow (Gradual)	0.1
90º Combining Tee (line flow)	0.5	90º Combining Tee (branch flow)	0.5
45º Combining Tee (line flow)	0.15	45º Combining Tee (branch flow)	0.15
90º Dividing Tee (line flow)	0.0	90º Dividing Tee (branch flow)	0.85
45º Dividing Tee (line flow)	0.0	45º Dividing Tee (branch flow)	0.45



Material	e (mm)
Concrete, coarse	0.25
Concrete, new smooth	0.025
Drawn tubing	0.0025
Glass, plastic, Perspex	0.0025
Iron, cast	0.15
Sewers, old	3.0
Steel, mortar lined	0.1
Steel, rusted	0.5
Steel, structural or forged	0.025
Water mains, old	1.0

Boundary layers

Boundary layer on a flat-plate with zero pressure gradient

Boundary conditions $y = 0: \quad u = v = 0 \qquad y = \infty: \quad u = U_{¥}$

Blasius solution

$\eta = y\sqrt{\frac{U_\infty}{\upsilon x}}$	f	$f' = \frac{u}{U_\infty}$	f''	$\eta = y\sqrt{\frac{U_\infty}{\upsilon x}}$	f	$f' = \frac{u}{U_\infty}$	f''
0	0	0	0.33206	4.6	2.88826	0.98269	0.02948
0.2	0.00664	0.06641	0.33199	4.8	3.08534	0.98779	0.02187
0.4	0.02656	0.13277	0.33147	5.0	3.28329	0.99155	0.01591
0.6	0.05974	0.19894	0.33008	5.2	3.48189	0.99425	0.01134
0.8	0.10611	0.26471	0.32739	5.4	3.68094	0.99616	0.00793
1.0	0.16557	0.32979	0.32301	5.6	3.88031	0.99748	0.00543
1.2	0.23795	0.39378	0.31659	5.8	4.07990	0.99838	0.00365
1.4	0.32298	0.45627	0.30787	6.0	4.27964	0.99898	0.00240
1.6	0.42032	0.51676	0.29667	6.2	4.47946	0.99937	0.00155
1.8	0.52952	0.57477	0.28293	6.4	4.67938	0.99961	0.00098
2.0	0.65003	0.62977	0.26675	6.6	4.87931	0.99977	0.00061
2.2	0.78120	0.68132	0.24835	6.8	5.07928	0.99987	0.00037
2.4	0.92230	0.72899	0.22809	7.0	5.27926	0.99992	0.00022
2.6	1.07252	0.77246	0.20646	7.2	5.47925	0.99996	0.00013
2.8	1.23099	0.81152	0.18401	7.4	5.67924	0.99998	0.00007
3.0	1.39682	0.84605	0.16136	7.6	5.87924	0.99999	0.00004
3.2	1.56911	0.87609	0.13913	7.8	6.07923	1.00000	0.00002
3.4	1.74696	0.90177	0.11788	8.0	6.27923	1.00000	0.00001
3.6	1.92954	0.92333	0.09809	8.2	6.47923	1.00000	0.00001
3.8	2.11605	0.94112	0.08013	8.4	6.67923	1.00000	0.00000
4.0	2.30576	0.95552	0.06424	8.6	6.87923	1.00000	0.00000
4.2	2.49806	0.96696	0.05052	8.8	7.07923	1.00000	0.00000
4.4	2.69238	0.97587	0.03897				

Displacement: thickness: $\delta^* = 1.7208\sqrt{\frac{\upsilon x}{U_\infty}}$

Momentum: thickness: $\theta = 0.664\sqrt{\frac{\upsilon x}{U_\infty}}$

Skin friction coefficient: $C_f = \frac{\tau_w}{\frac{1}{2}\rho U_\infty^2} = \frac{0.664}{\sqrt{Re_x}} = 2\frac{d\theta}{dx}$

Flow development length

Laminar flow: $L_e/D = 0.06Re_D$

Turbulent flow: $L_e/D = 4.4(Re_D)^{1/6}$

Equations of Motion in Cartesian Coordinates

Local energy conservation equation:

$$\frac{\partial(\rho u)}{\partial t} + div(pu.\vec{V}) = -div(p.\vec{V}) + \rho(\bar{g}.\vec{V}) + div(\bar{\bar{\tau}}.\vec{V}) - div(\vec{q}) + \dot{q}_{prod}$$

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \left[\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z}\right] = 0$$

Navier Stokes equations

x-direction : velocity component u

$$\frac{\partial \rho u}{\partial t} + \frac{\partial(\rho u)u}{\partial x} + \frac{\partial(\rho v)u}{\partial y} + \frac{\partial(\rho w)u}{\partial z} =$$

$$\frac{\partial}{\partial x}\left[\mu\left(2\frac{\partial u}{\partial x} - \frac{2}{3}(\nabla \bullet \vec{V})\right)\right] + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)\right] - \frac{\partial P}{\partial x} + \rho f_x$$

y-direction : velocity component v

$$\frac{\partial \rho v}{\partial t} + \frac{\partial(\rho u)v}{\partial x} + \frac{\partial(\rho v)v}{\partial y} + \frac{\partial(\rho w)v}{\partial z} =$$

$$\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)\right] + \frac{\partial}{\partial y}\left[\mu\left(2\frac{\partial v}{\partial y} - \frac{2}{3}(\nabla \bullet \vec{V})\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)\right] - \frac{\partial P}{\partial x} + \rho f_y$$

z-direction : velocity component w

$$\frac{\partial \rho w}{\partial t} + \frac{\partial(\rho u)w}{\partial x} + \frac{\partial(\rho v)w}{\partial y} + \frac{\partial(\rho w)w}{\partial z} =$$

$$\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)\right] + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(2\frac{\partial w}{\partial z} - \frac{2}{3}(\nabla \bullet \vec{V})\right)\right] - \frac{\partial P}{\partial z} + \rho f_z$$

Divergence of a vector in Cartesian coordinates:

$$div\vec{A} = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}$$

Equations of Motion in Cylindrical Coordinates

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{1}{r}\frac{\partial \rho v_r}{\partial dr} + \frac{1}{r}\frac{\partial \rho v_\theta}{\partial d\theta} + \frac{\partial \rho v_z}{\partial dz} = 0$$

Navier Stokes equation

r-direction : velocity component, v_r

$$\frac{\partial v_r}{\partial t} + v_r\frac{\partial v_r}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta} + v_z\frac{\partial v_r}{\partial z} - \frac{{v_\theta}^2}{r} =$$

$$\frac{1}{3}\upsilon\frac{\partial}{\partial r}(\nabla \bullet \vec{V}) + \upsilon\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_r}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 v_r}{\partial \theta^2} + \frac{\partial^2 v_r}{\partial z^2} - \frac{v_r}{r^2} - \frac{2}{r^2}\frac{\partial v_\theta}{\partial \theta}\right] - \frac{1}{\rho}\frac{\partial P}{\partial r} + \rho f_r$$

θ-direction : velocity component, v_θ

$$\frac{\partial v_\theta}{\partial t} + v_r\frac{\partial v_\theta}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta} + v_z\frac{\partial v_r}{\partial z} + \frac{v_r v_\theta}{r} =$$

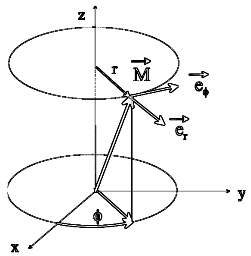
$$\frac{1}{3}\upsilon\frac{\partial}{r\partial \theta}(\nabla \bullet \vec{V}) + \upsilon\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_\theta}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 v_\theta}{\partial \theta^2} + \frac{\partial^2 v_\theta}{\partial z^2} - \frac{v_\theta}{r^2} + \frac{2}{r^2}\frac{\partial v_r}{\partial \theta}\right] - \frac{1}{\rho}\frac{\partial P}{r\partial \theta} + \rho f_\theta$$

z-direction : velocity component, v_z

$$\frac{\partial v_z}{\partial t} + v_r\frac{\partial v_z}{\partial r} + \frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta} + v_z\frac{\partial v_z}{\partial z} =$$

$$\frac{1}{3}\upsilon\frac{\partial}{\partial z}(\nabla \bullet \vec{V}) + \upsilon\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 v_z}{\partial \theta^2} + \frac{\partial^2 v_r}{\partial z^2}\right] - \frac{1}{\rho}\frac{\partial P}{r\partial \theta} + \rho f_\theta$$

Divergence of a vector in cylindrical coordinates.



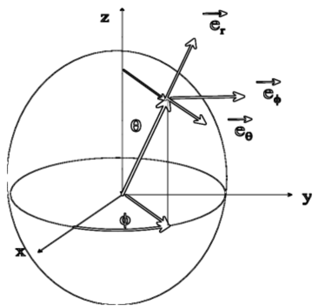
In cylindrical (polar) coordinates a vector, $\vec{A}$, is known by its components $\left(A_r, A_\phi, A_z\right)$ such that:

$$\vec{A} = A_r\vec{e}_r + A_\phi\vec{e}_\phi + A_z\vec{e}_z$$

In this system of coordinates but the divergence of a vector is:

$$div\vec{A} = \frac{1}{r}\frac{\partial}{\partial r}(rA_r) + \frac{1}{r}\frac{\partial}{\partial \phi}(A_\phi) + \frac{\partial}{\partial z}(A_z)$$

Divergence of a vector in spherical coordinates



In spherical coordinates a vector, $\vec{A}$, is known by its components $\left(A_r, A_\phi, A_q\right)$ such that:

$$\vec{A} = A_r\vec{e}_r + A_\phi\vec{e}_\phi + A_\theta\vec{e}_\theta$$

And:

$$div\vec{A} = \frac{1}{r^2}\frac{\partial}{\partial r}(r^2 A_r) + \frac{1}{r\sin\theta}\frac{\partial}{\partial \phi}(A_\phi) + \frac{1}{r\sin\theta}\frac{\partial}{\partial \theta}(\sin\theta\, A_\theta)$$

Turbulence

Integral length scale (m):

$$L = \frac{3\pi}{4}\frac{\int E(k)k^{-1}\,dk}{\int E(k)dk}$$

The rms velocity u' associated to the energy spectrum *E(k)* is defined as:

$$u'^2 = \frac{2}{3}\int E(k)\,dk$$

Kolmogorov length scale (m):

$$\eta \approx \varepsilon^{-\frac{1}{4}}\nu^{\frac{3}{4}}$$

Kolmogorov velocity (ms^{-1}):

$$v_k \approx \varepsilon^{\frac{1}{4}}\nu^{\frac{1}{4}}$$

Turbulence dissipation (m^2s^{-3}):

$$\varepsilon \approx \frac{u'^3}{L}$$

Reynolds number:

$$Re_L = \frac{u'L}{\nu} = \left(\frac{L}{\eta}\right)^{\frac{4}{3}}$$

where

$E(k)$	=	energy spectrum (m^3s^{-2})
u'	=	rms value of the turbulence velocity fluctuation (ms^{-1})
v_k	=	Kolmogorov velocity (ms^{-1})
ν	=	kinematic viscosity (m^2s^{-1})

so that:

$$Re_\eta = \frac{\eta v_k}{\nu} = 1$$

Aerodynamics and High-Speed Flow

Also see 'Some Dimensionless Groups' (page 8).

3D coefficients for wings

Pressure coefficient:

$$C_p = \frac{p - p_\infty}{q_\infty}$$

Skin friction coefficient:

$$C_f = \frac{\tau}{q_\infty}$$

Lift coefficient:

$$C_L = \frac{L}{q_\infty S}$$

Drag coefficient:

$$C_D = \frac{D}{q_\infty S}$$

Moment coefficient:

$$C_M = \frac{M}{q_\infty S l}$$

Induced drag coefficient:

$$C_{Di} = \frac{{C_L}^2}{\pi \Lambda}$$

where $q = \frac{1}{2}\rho V^2 \; and \; \Lambda = \frac{b^2}{S}$

Velocity potential

Velocity potential function:

$$\mathbf{V} = \nabla \phi$$

Laplace equation for velocity potential:

$$\nabla^2 \phi = \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} = 0$$

Shock waves

Dynamic relations for gas

$$e = c_v T$$

$$h = c_p T$$

$$c_p - c_v = R$$

$$\gamma = \frac{c_p}{c_v}$$

Isentropic flow properties

γ	=	1.400
$(\gamma - 1)/2$	=	0.200
$(\gamma + 1)/2(\gamma - 1)$	=	3

$$\frac{A}{A^*} = \frac{1}{M}\left[\frac{1 + \frac{\gamma - 1}{2}M^2}{1 + \frac{\gamma - 1}{2}}\right]^{\frac{\gamma+1}{2(\gamma-1)}}$$

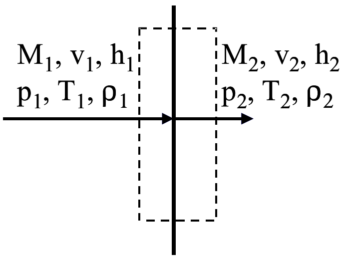
$$\frac{\rho_o}{\rho} = \left[1 + \frac{\gamma - 1}{2}M^2\right]^{\frac{1}{\gamma-1}}$$

$$\frac{T_o}{T} = 1 + \frac{\gamma - 1}{2}M^2$$

$$\frac{P_o}{P} = \left[1 + \frac{\gamma - 1}{2}M^2\right]^{\frac{\gamma}{\gamma-1}}$$

Normal shock properties

γ	=	1.400
$(\gamma - 1)/2$	=	0.200
$2/(\gamma - 1)$	=	5.000
$2\gamma/(\gamma - 1)$	=	7.000
$\gamma/(\gamma - 1)$	=	3.5



Normal shock

$$\frac{P_2}{P_1} = \frac{1 + \gamma M_1^2}{1 + \gamma M_2^2}$$

$$\frac{\rho_2}{\rho_1} = \frac{M_1}{M_2}\left[\frac{1 + \frac{\gamma - 1}{2}M_2^2}{1 + \frac{\gamma - 1}{2}M_1^2}\right]^{0.5}$$

$$\frac{T_2}{T_1} = \frac{1 + \frac{\gamma - 1}{2}M_1^2}{1 + \frac{\gamma - 1}{2}M_2^2}$$

$$\frac{P_{o2}}{P_{o1}} = \frac{P_2}{P_1}\left[\frac{1 + \frac{\gamma - 1}{2}M_2^2}{1 + \frac{\gamma - 1}{2}M_1^2}\right]^{\frac{\gamma}{\gamma-1}}$$

$$\frac{P_{o2}}{P_{o1}} = \frac{P_{o2}}{P_{o1}}\frac{P_{o1}}{P_1}$$

Isentropic flow properties for g = 1.4

M	A/A*	P_o/P	T_o/T	ρ_o/ρ	M	A/A*	P_o/P	T_o/T	ρ_o/ρ	M	A/A*	P_o/P	T_o/T	ρ_o/ρ
0.02	28.942	1.000	1.000	1.000	0.62	1.166	1.296	1.077	1.203	1.22	1.037	2.489	1.298	1.918
0.04	14.481	1.001	1.000	1.001	0.64	1.145	1.317	1.082	1.218	1.24	1.043	2.556	1.308	1.955
0.06	9.666	1.003	1.001	1.002	0.66	1.127	1.340	1.087	1.232	1.26	1.050	2.625	1.318	1.992
0.08	7.262	1.004	1.001	1.003	0.68	1.110	1.363	1.092	1.247	1.28	1.058	2.697	1.328	2.031
0.10	5.822	1.007	1.002	1.005	0.70	1.094	1.387	1.098	1.263	1.30	1.066	2.771	1.338	2.071
0.12	4.864	1.010	1.003	1.007	0.72	1.081	1.412	1.104	1.280	1.32	1.075	2.847	1.348	2.112
0.14	4.182	1.014	1.004	1.010	0.74	1.068	1.439	1.110	1.297	1.34	1.084	2.927	1.359	2.153
0.16	3.673	1.018	1.005	1.013	0.76	1.057	1.466	1.116	1.314	1.36	1.094	3.009	1.370	2.197
0.18	3.278	1.023	1.006	1.016	0.78	1.047	1.495	1.122	1.333	1.38	1.104	3.094	1.381	2.241
0.20	2.964	1.028	1.008	1.020	0.80	1.038	1.524	1.128	1.351	1.40	1.115	3.182	1.392	2.286
0.22	2.708	1.034	1.010	1.024	0.82	1.030	1.555	1.134	1.371	1.42	1.126	3.273	1.403	2.333
0.24	2.496	1.041	1.012	1.029	0.84	1.024	1.587	1.141	1.391	1.44	1.138	3.368	1.415	2.381
0.26	2.317	1.048	1.014	1.034	0.86	1.018	1.621	1.148	1.412	1.46	1.150	3.465	1.426	2.430
0.28	2.166	1.056	1.016	1.040	0.88	1.013	1.655	1.155	1.433	1.48	1.163	3.566	1.438	2.480
0.30	2.035	1.064	1.018	1.046	0.90	1.009	1.691	1.162	1.456	1.50	1.176	3.671	1.450	2.532
0.32	1.922	1.074	1.020	1.052	0.92	1.006	1.729	1.169	1.478	1.52	1.190	3.779	1.462	2.585
0.34	1.823	1.083	1.023	1.059	0.94	1.003	1.767	1.177	1.502	1.54	1.204	3.891	1.474	2.639
0.36	1.736	1.094	1.026	1.066	0.96	1.001	1.808	1.184	1.526	1.56	1.219	4.007	1.487	2.695
0.38	1.659	1.105	1.029	1.074	0.98	1.000	1.850	1.192	1.552	1.58	1.234	4.127	1.499	2.752
0.40	1.590	1.117	1.032	1.082	1.00	1.000	1.893	1.200	1.577	1.60	1.250	4.250	1.512	2.811
0.42	1.529	1.129	1.035	1.091	1.02	1.000	1.938	1.208	1.604	1.62	1.267	4.378	1.525	2.871
0.44	1.474	1.142	1.039	1.100	1.04	1.001	1.985	1.216	1.632	1.64	1.284	4.511	1.538	2.933
0.46	1.425	1.156	1.042	1.109	1.06	1.003	2.033	1.225	1.660	1.66	1.301	4.648	1.551	2.996
0.48	1.380	1.171	1.046	1.119	1.08	1.005	2.083	1.233	1.689	1.68	1.319	4.790	1.564	3.061
0.50	1.340	1.186	1.050	1.130	1.10	1.008	2.135	1.242	1.719	1.70	1.338	4.936	1.578	3.128
0.52	1.303	1.202	1.054	1.141	1.12	1.011	2.189	1.251	1.750	1.72	1.357	5.087	1.592	3.196
0.54	1.270	1.219	1.058	1.152	1.14	1.015	2.245	1.260	1.782	1.74	1.376	5.244	1.606	3.266
0.56	1.240	1.237	1.063	1.164	1.16	1.020	2.303	1.269	1.814	1.76	1.397	5.406	1.620	3.338
0.58	1.213	1.256	1.067	1.177	1.18	1.025	2.363	1.278	1.848	1.78	1.418	5.573	1.634	3.411
0.60	1.188	1.276	1.072	1.190	1.20	1.030	2.425	1.288	1.883	1.80	1.439	5.746	1.648	3.487

Isentropic flow properties for g = 1.4

M	A/A*	P_o/P	T_o/T	ρ_o/ρ	M	A/A*	P_o/P	T_o/T	ρ_o/ρ	M	A/A*	P_o/P	T_o/T	ρ_o/ρ
1.82	1.461	5.924	1.662	3.564	2.42	2.448	15.08	2.171	6.947	3.05	4.441	39.59	2.861	13.84
1.84	1.484	6.109	1.677	3.643	2.44	2.494	15.56	2.191	7.103	3.10	4.657	42.65	2.922	14.59
1.86	1.507	6.300	1.692	3.723	2.46	2.540	16.05	2.210	7.263	3.15	4.884	45.93	2.985	15.39
1.88	1.531	6.497	1.707	3.806	2.48	2.588	16.56	2.230	7.427	3.20	5.121	49.44	3.048	16.22
1.90	1.555	6.701	1.722	3.891	2.50	2.637	17.09	2.250	7.594	3.25	5.369	53.20	3.113	17.09
1.92	1.580	6.911	1.737	3.978	2.52	2.686	17.63	2.270	7.764	3.30	5.629	57.22	3.178	18.00
1.94	1.606	7.128	1.753	4.067	2.54	2.737	18.18	2.290	7.939	3.35	5.900	61.52	3.245	18.96
1.96	1.633	7.353	1.768	4.158	2.56	2.789	18.75	2.311	8.116	3.40	6.184	66.12	3.312	19.96
1.98	1.660	7.585	1.784	4.251	2.58	2.842	19.35	2.331	8.298	3.45	6.480	71.03	3.381	21.01
2.00	1.688	7.824	1.800	4.347	2.60	2.896	19.95	2.352	8.484	3.50	6.790	76.27	3.450	22.11
2.02	1.716	8.072	1.816	4.445	2.62	2.951	20.58	2.373	8.673	3.60	7.450	87.84	3.592	24.45
2.04	1.745	8.327	1.832	4.545	2.64	3.007	21.23	2.394	8.867	3.70	8.169	101.0	3.738	27.01
2.06	1.775	8.591	1.849	4.647	2.66	3.065	21.89	2.415	9.065	3.80	8.951	115.9	3.888	29.81
2.08	1.806	8.863	1.865	4.752	2.68	3.123	22.58	2.436	9.266	3.90	9.799	132.8	4.042	32.85
2.10	1.837	9.145	1.882	4.859	2.70	3.183	23.28	2.458	9.472	4.00	10.72	151.8	4.200	36.15
2.12	1.869	9.435	1.899	4.969	2.72	3.244	24.01	2.480	9.683	4.10	11.71	173.3	4.362	39.74
2.14	1.902	9.735	1.916	5.081	2.74	3.306	24.76	2.502	9.897	4.20	12.79	197.5	4.528	43.63
2.16	1.935	10.04	1.933	5.196	2.76	3.370	25.53	2.524	10.12	4.30	13.95	224.7	4.698	47.84
2.18	1.970	10.36	1.950	5.313	2.78	3.434	26.32	2.546	10.34	4.40	15.21	255.3	4.872	52.39
2.20	2.005	10.69	1.968	5.433	2.80	3.500	27.14	2.568	10.57	4.50	16.56	289.4	5.050	57.31
2.22	2.041	11.03	1.986	5.556	2.82	3.567	27.98	2.590	10.80	4.75	20.41	393.3	5.513	71.35
2.24	2.078	11.38	2.004	5.682	2.84	3.636	28.84	2.613	11.04	5.00	25.00	529.1	6.000	88.18
2.26	2.115	11.75	2.022	5.810	2.86	3.706	29.73	2.636	11.28	5.25	30.45	704.9	6.513	108.2
2.28	2.154	12.12	2.040	5.942	2.88	3.777	30.65	2.659	11.53	5.50	36.87	930.4	7.050	132.0
2.30	2.193	12.50	2.058	6.076	2.90	3.850	31.59	2.682	11.78	5.75	44.40	1217	7.613	159.9
2.32	2.233	12.90	2.076	6.213	2.92	3.924	32.56	2.705	12.04	6.00	53.18	1579	8.200	192.5
2.34	2.274	13.31	2.095	6.354	2.94	3.999	33.56	2.729	12.30	6.25	63.37	2032	8.813	230.5
2.36	2.316	13.73	2.114	6.497	2.96	4.076	34.59	2.752	12.57	6.50	75.13	2594	9.450	274.5
2.38	2.359	14.17	2.133	6.644	2.98	4.155	35.65	2.776	12.84	6.75	88.66	3289	10.11	325.2
2.40	2.403	14.62	2.152	6.794	3.00	4.235	36.73	2.800	13.12	7.00	104.1	4140	10.80	383.3

Normal shock properties

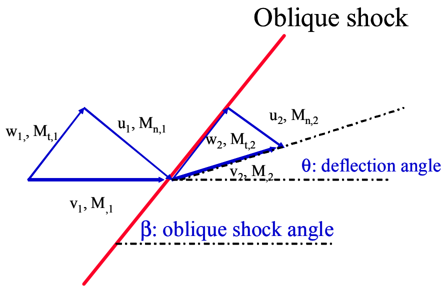
M_1	P_2/P_1	ρ_2/ρ_1	T_2/T_1	P_{o2}/P_{o1}	P_{o2}/P_1	M_2	M_1	P_2/P_1	ρ_2/ρ_1	T_2/T_1	P_{o2}/P_{o1}	P_{o2}/P_1	M_2
1.00	1.000	1.000	1.000	1.000	1.893	1.000	1.60	2.820	2.032	1.388	0.895	3.805	0.668
1.02	1.047	1.033	1.013	1.000	1.938	0.981	1.62	2.895	2.065	1.402	0.888	3.887	0.663
1.04	1.095	1.067	1.026	1.000	1.984	0.962	1.64	2.971	2.099	1.416	0.880	3.969	0.657
1.06	1.144	1.101	1.039	1.000	2.032	0.944	1.66	3.048	2.132	1.430	0.872	4.053	0.651
1.08	1.194	1.135	1.052	0.999	2.082	0.928	1.68	3.126	2.165	1.444	0.864	4.138	0.646
1.10	1.245	1.169	1.065	0.999	2.133	0.912	1.70	3.205	2.198	1.458	0.856	4.224	0.641
1.12	1.297	1.203	1.078	0.998	2.185	0.897	1.72	3.285	2.230	1.473	0.847	4.311	0.635
1.14	1.350	1.238	1.090	0.997	2.239	0.882	1.74	3.366	2.263	1.487	0.839	4.399	0.631
1.16	1.403	1.272	1.103	0.996	2.294	0.868	1.76	3.447	2.295	1.502	0.830	4.488	0.626
1.18	1.458	1.307	1.115	0.995	2.350	0.855	1.78	3.530	2.327	1.517	0.822	4.578	0.621
1.20	1.513	1.342	1.128	0.993	2.408	0.842	1.80	3.613	2.359	1.532	0.813	4.670	0.617
1.22	1.570	1.376	1.141	0.991	2.466	0.830	1.82	3.698	2.391	1.547	0.804	4.762	0.612
1.24	1.627	1.411	1.153	0.988	2.526	0.818	1.84	3.783	2.422	1.562	0.795	4.855	0.608
1.26	1.686	1.446	1.166	0.986	2.588	0.807	1.86	3.870	2.454	1.577	0.786	4.950	0.604
1.28	1.745	1.481	1.178	0.983	2.650	0.796	1.88	3.957	2.485	1.592	0.777	5.045	0.600
1.30	1.805	1.516	1.191	0.979	2.714	0.786	1.90	4.045	2.516	1.608	0.767	5.142	0.596
1.32	1.866	1.551	1.204	0.976	2.778	0.776	1.92	4.134	2.546	1.624	0.758	5.239	0.592
1.34	1.928	1.585	1.216	0.972	2.844	0.766	1.94	4.224	2.577	1.639	0.749	5.338	0.588
1.36	1.991	1.620	1.229	0.968	2.912	0.757	1.96	4.315	2.607	1.655	0.740	5.438	0.584
1.38	2.055	1.655	1.242	0.963	2.980	0.748	1.98	4.407	2.637	1.671	0.730	5.539	0.581
1.40	2.120	1.690	1.255	0.958	3.049	0.740	2.00	4.500	2.667	1.688	0.721	5.640	0.577
1.42	2.186	1.724	1.268	0.953	3.120	0.731	2.05	4.736	2.740	1.729	0.698	5.900	0.569
1.44	2.253	1.759	1.281	0.948	3.191	0.723	2.10	4.978	2.812	1.770	0.674	6.165	0.561
1.46	2.320	1.793	1.294	0.942	3.264	0.716	2.15	5.226	2.882	1.813	0.651	6.438	0.554
1.48	2.389	1.828	1.307	0.936	3.338	0.708	2.20	5.480	2.951	1.857	0.628	6.716	0.547
1.50	2.458	1.862	1.320	0.930	3.413	0.701	2.25	5.740	3.019	1.901	0.606	7.002	0.541
1.52	2.529	1.896	1.334	0.923	3.489	0.694	2.30	6.005	3.085	1.947	0.583	7.294	0.534
1.54	2.600	1.930	1.347	0.917	3.567	0.687	2.35	6.276	3.149	1.993	0.561	7.592	0.529
1.56	2.673	1.964	1.361	0.910	3.645	0.681	2.40	6.553	3.212	2.040	0.540	7.897	0.523
1.58	2.746	1.998	1.374	0.903	3.724	0.675	2.45	6.836	3.273	2.088	0.519	8.208	0.518

Normal shock properties

M_1	P_2/P_1	ρ_2/ρ_1	T_2/T_1	P_{o2}/P_{o1}	P_{o2}/P_1	M_2
2.50	7.125	3.333	2.138	0.499	8.526	0.513
2.55	7.420	3.392	2.187	0.479	8.850	0.508
2.60	7.720	3.449	2.238	0.460	9.181	0.504
2.65	8.026	3.505	2.290	0.442	9.519	0.500
2.70	8.338	3.559	2.343	0.424	9.862	0.496
2.75	8.656	3.612	2.397	0.406	10.21	0.492
2.80	8.980	3.664	2.451	0.389	10.57	0.488
2.85	9.310	3.714	2.507	0.373	10.93	0.485
2.90	9.645	3.763	2.563	0.358	11.30	0.481
2.95	9.986	3.811	2.621	0.343	11.68	0.478
3.00	10.33	3.857	2.679	0.328	12.06	0.475
3.05	10.69	3.902	2.738	0.315	12.45	0.472
3.10	11.05	3.947	2.799	0.301	12.85	0.470
3.15	11.41	3.990	2.860	0.288	13.25	0.467
3.20	11.78	4.031	2.922	0.276	13.66	0.464
3.25	12.16	4.072	2.985	0.265	14.07	0.462
3.30	12.54	4.112	3.049	0.253	14.49	0.460
3.35	12.93	4.151	3.114	0.243	14.92	0.457
3.40	13.32	4.188	3.180	0.232	15.35	0.455
3.45	13.72	4.225	3.247	0.222	15.79	0.453
3.50	14.13	4.261	3.315	0.213	16.24	0.451
3.55	14.54	4.296	3.384	0.204	16.70	0.449
3.60	14.95	4.330	3.454	0.195	17.16	0.447
3.65	15.38	4.363	3.525	0.187	17.62	0.446
3.70	15.81	4.395	3.596	0.179	18.10	0.444
3.75	16.24	4.426	3.669	0.172	18.57	0.442
3.80	16.68	4.457	3.743	0.164	19.06	0.441
3.85	17.13	4.487	3.817	0.158	19.55	0.439
3.90	17.58	4.516	3.893	0.151	20.05	0.438
3.95	18.04	4.544	3.969	0.145	20.56	0.436
4.00	18.50	4.571	4.047	0.139	21.07	0.435
4.10	19.45	4.624	4.205	0.128	22.11	0.432
4.20	20.41	4.675	4.367	0.117	23.18	0.430
4.30	21.41	4.723	4.532	0.108	24.27	0.428
4.40	22.42	4.768	4.702	0.099	25.39	0.426
4.50	23.46	4.812	4.875	0.092	26.54	0.424
4.60	24.52	4.853	5.052	0.085	27.71	0.422
4.70	25.61	4.893	5.233	0.078	28.91	0.420
4.80	26.71	4.930	5.418	0.072	30.13	0.418
4.90	27.85	4.966	5.607	0.067	31.38	0.417
5.00	29.00	5.000	5.800	0.062	32.65	0.415
5.10	30.18	5.033	5.997	0.057	33.95	0.414
5.20	31.38	5.064	6.197	0.053	35.28	0.413
5.30	32.61	5.093	6.401	0.049	36.63	0.411
5.40	33.85	5.122	6.610	0.046	38.01	0.410
5.50	35.13	5.149	6.822	0.042	39.41	0.409
5.60	36.42	5.175	7.038	0.039	40.84	0.408
5.70	37.74	5.200	7.258	0.037	42.30	0.407
5.80	39.08	5.224	7.481	0.034	43.78	0.406
5.90	40.45	5.246	7.709	0.032	45.28	0.405
6.00	41.83	5.268	7.941	0.030	46.82	0.404
6.10	43.25	5.289	8.176	0.028	48.37	0.403
6.20	44.68	5.309	8.415	0.026	49.96	0.403
6.30	46.14	5.329	8.658	0.024	51.57	0.402
6.40	47.62	5.347	8.905	0.023	53.20	0.401
6.50	49.13	5.365	9.156	0.021	54.86	0.400
6.60	50.65	5.382	9.411	0.020	56.55	0.400
6.70	52.21	5.399	9.670	0.019	58.26	0.399
6.80	53.78	5.415	9.933	0.017	60.00	0.398
6.90	55.38	5.430	10.20	0.016	61.76	0.398
7.00	57.00	5.444	10.47	0.015	63.55	0.397

Oblique shocks

Flow can be decomposed into normal and tangential components.
The tangential velocity component is constant across a oblique shock (tangential momentum equation), $w_1=w_2$.
The three equations for the normal component are the same as the normal shock case.
The normal shock relations are therefore applicable to the normal component of the velocity.
Normal shock is a special case for $\beta=\pi/2$.



$$\sin b = \frac{u_1}{v_1}$$

$$\sin(b-q) = \frac{u_2}{v_2}$$

Oblique shock relations

Flow downstream of a oblique shock is defined by M_1 and β.
Mach number downstream of shock can be either supersonic(mostly) or subsonic
You can use the normal shock table for M_{n1}.

$$w_2 = w_1$$

$$M_{n1} = M_1 \sin\beta$$

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma+1){M_{n1}}^2}{2+(\gamma-1){M_{n1}}^2}$$

$$\frac{T_2}{T_1} = \frac{h_2}{h_1} = \frac{p_2}{p_1}\frac{\rho_1}{\rho_2} = \left[1+\frac{2\gamma}{\gamma+1}\left({M_{n1}}^2-1\right)\right]\frac{2+(\gamma-1){M_{n1}}^2}{(\gamma+1){M_{n1}}^2}$$

$${M_{n2}}^2 = \frac{1+[(\gamma-1)/2]{M_{n1}}^2}{\gamma {M_{n1}}^2-(\gamma-1)/2}$$

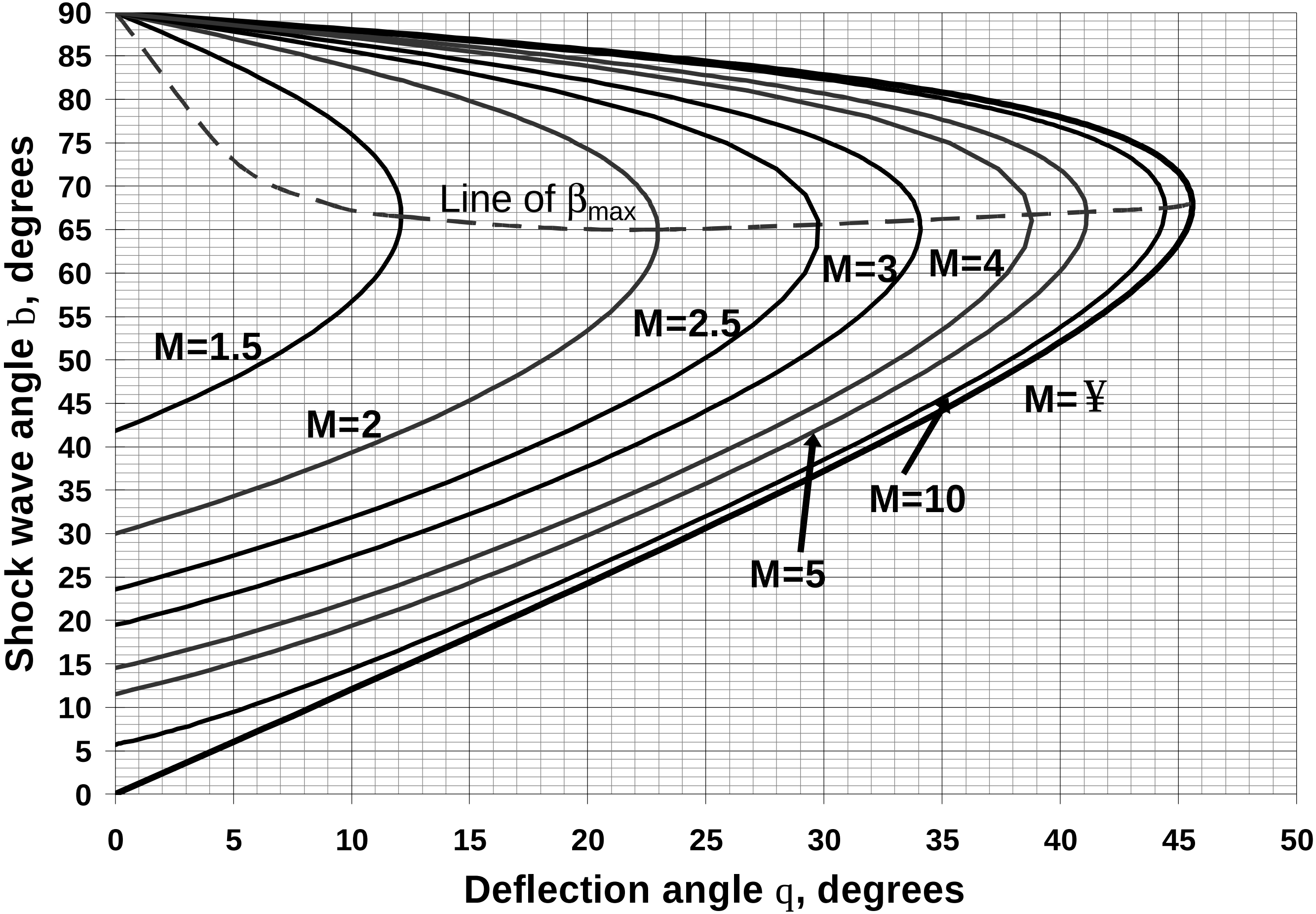
$$M_2 = \frac{M_{n2}}{\sin(\beta-\theta)}$$

Angle of oblique shock for q-b-M chart

There is a maximum deflection for a given Mach number. There is no straight oblique shock solution for larger dynamic pressures, because the shock wave has become detached.

$$\tan\theta = 2\cot\beta\left[\frac{{M_1}^2\sin^2\beta-1}{{M_1}^2(\gamma+\cos 2\beta)+2}\right]$$

For a given dynamic pressure, there is both a weak and a strong shock solution. The weaker one is naturally favoured as this flow is generally supersonic.
When the dynamic pressure is zero, there is either a normal shock or a Mach wave.


Line of βmax
M=1.5
M=2
M=2.5
M=3
M=4
M=5
M=10
M= ¥
Shock wave angle b, degrees
Deflection angle q, degrees
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
0
5
10
15
20
25
30
35
40
45
50

Renewable Energy Data

Flat plate collector efficiency

$$\eta = \frac{GAF'^{(\tau\alpha)} - AU'\Delta t}{AG}$$

$$\Delta t = \frac{(t_{cout} + t_{cin})}{2} - (t_o - 3)$$

Heat rise across plate:

$$\Delta T = \frac{\dot{Q}}{\dot{m}C_v}$$

Assume environmental temperature = $t_o - 3$

Hydroelectricity

$$v = \sqrt{2gH} = \sqrt{2gh\eta_h}, \text{and } Q = v \times A$$

Ideal energy flow rate:

$$Power = Q \times h \times g \times r \qquad \text{(W)}$$

With energy losses and the 'effective' head.

Power	=	$(\rho \times g \times h \times \eta_h) \times (A \times v) \times \eta_f$	(W)
h	=	head	(m)
η_f	=	turbine efficiency	
η_h	=	efficiency	
v	=	fluid velocity	($m\ s^{-1}$)
A	=	cross sectional area	(m^2)
Q	=	volume flow rate	($m^3\ s^{-1}$)

Tidal power

Available Energy:

$$\frac{\rho A R^2 g}{2}$$

Ground source heat pumps

kW Work (electricity) required per kW heat:

$$\frac{1}{COP_R + 1}$$

Calculations for vertical coils:

$$Length\,(m) = \frac{Heat\ Evaporator\ Capacity\ (W)}{Specific\ Heat\ Extraction\ Rate\ (W/m)}$$

Typical values of SHER range between 40-70 W/m

Or from ASHRAE's GSHP Engineering Manual:

$$Length\,(m) = \frac{0.05506 \times Annual\ energy\ rejected\ to\ the\ ground\ (MJ)}{Deep\ ground\ temp.\,(°C) - Maximum\ entering\ liquid\ temp.\,(°C)}$$

Calculations for horizontal coils:

$$Area\,(m^2) = \frac{Evaporator\ capacity\ (W)}{Average\ solar\ energy\ (W/m^2)}$$

Wind power

Weibull Distribution (H = hours/year during which V is exceeded):

$$H = 8760\,exp\left[-\left(\frac{V}{C}\right)^k\right]$$

Total energy in wind per m^2 per year:

$$E = 0.043{V_{50}}^3 (GJm^{-2}yr^{-1})$$

Power coefficient:

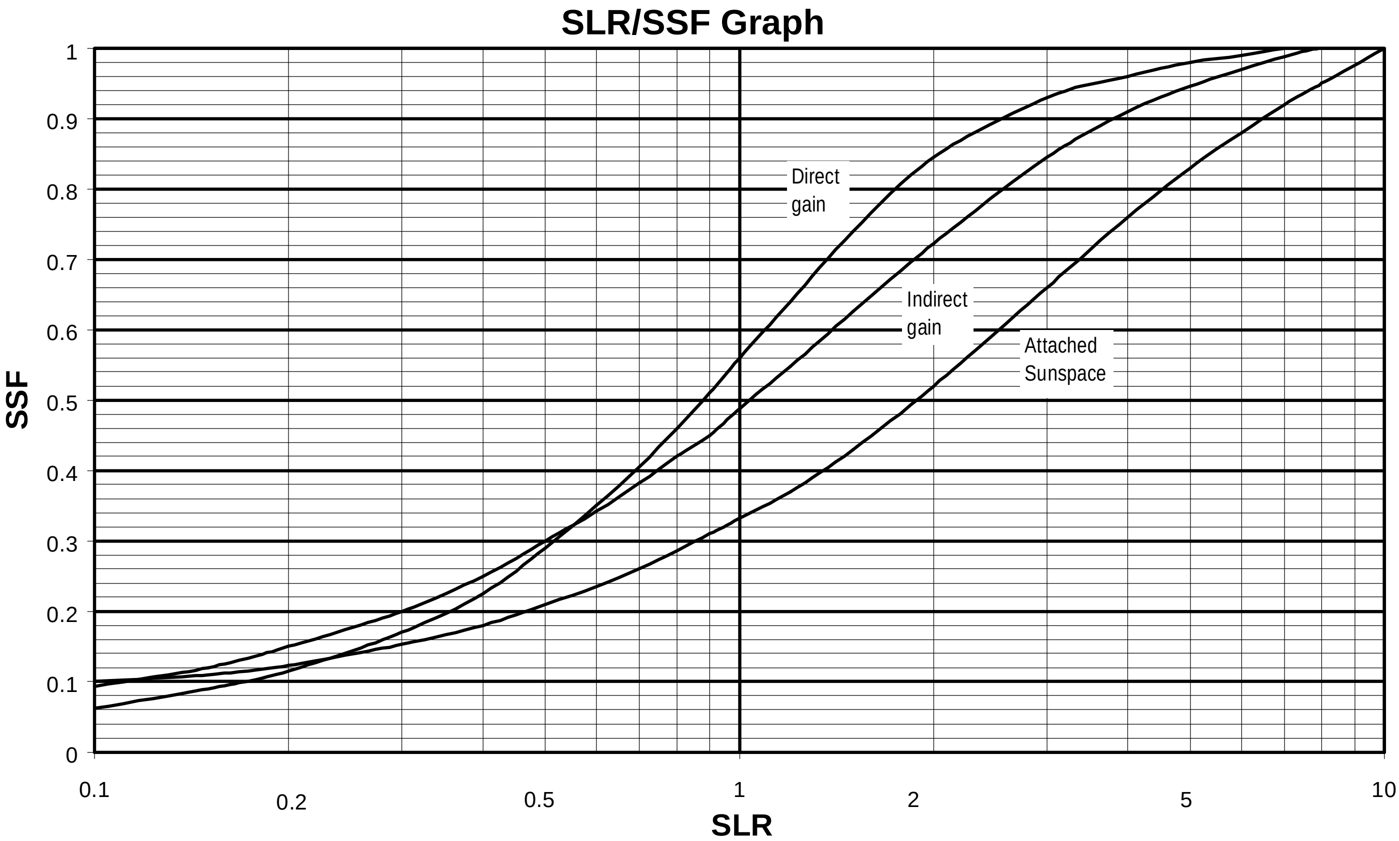
$$C_P = \frac{P}{\dot{E}} = \frac{P}{\frac{1}{2}\rho A V^3}$$

Tip speed ratio:

$$\mu = \frac{Speed\ of\ blade\ tip}{Wind\ speed} = \frac{\omega R}{V}$$

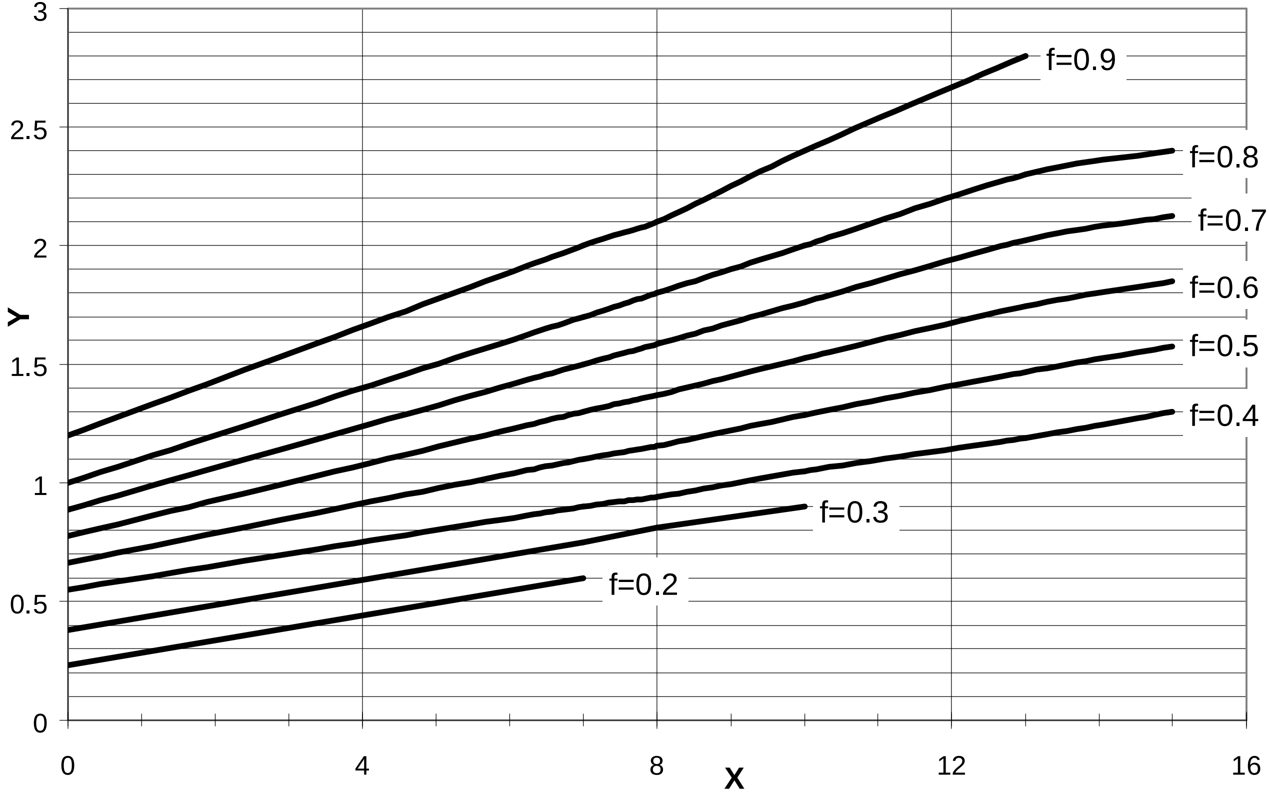
Solidity:

$$\frac{Total\ blade\ area}{Flow\ area\ swept\ by\ rotor} = \frac{A_b}{A}$$


SLR/SSF Graph
SSF
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.5
1
2
5
10
SLR
Direct gain
Indirect gain
Attached Sunspace

f Chart

$$X = F_R . U^1 . \frac{F_R{}^1}{F_R}\left(T_{ref} - \overline{T_a}\right) . N_S . \frac{A}{L} \qquad Y = F_R . (\tau\alpha)_\eta . \frac{F_R{}^1}{F_R} . \frac{(\overline{\tau\alpha})}{(\overline{\tau\alpha})_n} . \overline{H_T} . N_D . \frac{A}{L}$$



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GENERAL INFORMATION

Useful data

Acceleration due to gravity	g	9.81 m s^{-2}
Avogadro constant	N_a	6.022×10^{26} kmol^{-1}
Boltzmann's constant:	k	1.381×10^{-23} JK^{-1}
Charge on electron:	e	-1.602×10^{-19} C
Molar gas constant	R_u	8.314 kJ kmol^{-1} K^{-1}
Molar volume of ideal gas (273.15 K, 100 kPa)	V_m	22.4 m^3 kmol^{-1}
Planck's constant:	h	6.626×10^{-34} Js
Speed of light in vacuum	c	2.998×10^{8} m s^{-1}
Stefan-Boltzmann constant	σ	56.7×10^{-9} W m^{-2} K^{-4}
Standard atmospheric pressure	p_a	101.325 kPa

Composition of air by volume

Nitrogen	N_2	78.084 %
Oxygen	O_2	20.9476 %
Argon	Ar	0.934 %
Carbon Dioxide	CO_2	0.0314 %

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