Ideal Gas Model

Incompressible substance model

- Liquids and solids are often approximated as being incompressible
- v = constant
- $u = u(T)$
- $c(T) = c_v(T) = c_p(T)$
- Textbooks often have tables of specific heat values for solids and liquids.
- From the definition of the specific heats,

$$u(T_2) - u(T_1) = \int_{T_1}^{T_2} c(T)dT,$$
$$h(T_2, p_2) - h(T_1, p_1) = u(T_2) - u(T_1) + (p_2 - p_1)v$$

If c doesn't vary much with temperature (as a rule of thumb, when temperature changes are less than a few hundred Kelvin), then $c \approx$ constant and,

$$u(T_2) - u(T_1) \approx c(T_2 - T_1),$$
$$h(T_2, p_2) - h(T_1, p_1) \approx c(T_2 - T_1) + (p_2 - p_1)v$$

For example, for liquid water at 1 bar (abs):

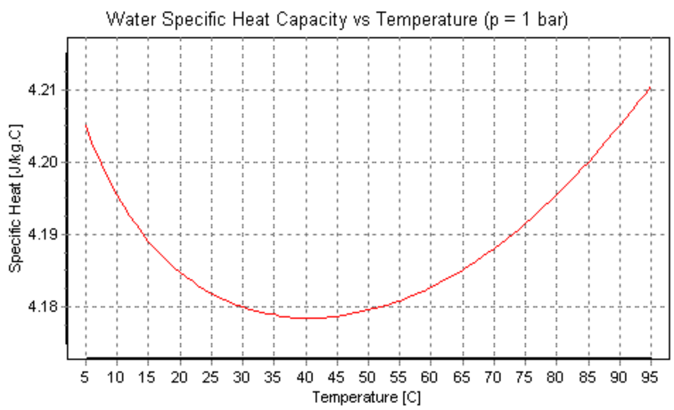


TABLE A-19

Properties of Selected Solids and Liquids: c_p, ρ, and κ

Substance	Specific Heat, c_p (kJ/kg · K)	Density, ρ (kg/m^3)	Thermal Conductivity, κ (W/m · K)
***Selected Solids*, 300K**			
Aluminum	0.903	2700	237
Coal, anthracite	1.260	1350	0.26
Copper	0.385	8930	401
Granite	0.775	2630	2.79
Iron	0.447	7870	80.2
Lead	0.129	11300	35.3
Sand	0.800	1520	0.27
Silver	0.235	10500	429
Soil	1.840	2050	0.52
Steel (AISI 302)	0.480	8060	15.1
Tin	0.227	7310	66.6
***Building Materials*, 300K**			
Brick, common	0.835	1920	0.72
Concrete (stone mix)	0.880	2300	1.4
Glass, plate	0.750	2500	1.4
Hardboard, siding	1.170	640	0.094
Limestone	0.810	2320	2.15
Plywood	1.220	545	0.12
Softwoods (fir, pine)	1.380	510	0.12
***Insulating Materials*, 300K**			
Blanket (glass fiber)	—	16	0.046
Cork	1.800	120	0.039
Duct liner (glass fiber, coated)	0.835	32	0.038
Polystyrene (extruded)	1.210	55	0.027
Vermiculite fill (flakes)	0.835	80	0.068
Saturated Liquids			
Ammonia, 300K	4.818	599.8	0.465
Mercury, 300K	0.139	13529	8.540
Refrigerant 22, 300K	1.267	1183.1	0.085
Refrigerant 134a, 300K	1.434	1199.7	0.081
Unused Engine Oil, 300K	1.909	884.1	0.145
Water, 275K	4.211	999.9	0.574
300K	4.179	996.5	0.613
325K	4.182	987.1	0.645
350K	4.195	973.5	0.668
375K	4.220	956.8	0.681
400K	4.256	937.4	0.688

Sources: Drawn from several sources, these data are only representative. Values can vary depending on temperature, purity, moisture content, and other factors.

Table A-19 from Moran et al., *Fundamentals of Engineering Thermodynamics*, 8th ed., Wiley.

Ideal Gas Model

- Used to describe the behavior of real gases in the limit of zero pressure and infinite temperature (i.e., zero density). The model does not account for the interaction between molecules of the gas, e.g., inter-molecular forces.
- Equations of state:

  $pv = RT$

  where $R = \bar{R}_u/M$ and $\bar{R}_u$ =8.314 kJ/(kmol.K) and M is the molecular weight
  M_{air} = 28.98 kg/kmol => R_{air} = 0.287 kJ/(kg.K)

  $u = u(T)$ and $h = h(T)$
  => $u(T_2) - u(T_1) = \int_{T_1}^{T_2} c_v(T)dT$ and $h(T_2) - h(T_1) = \int_{T_1}^{T_2} c_p(T)dT$

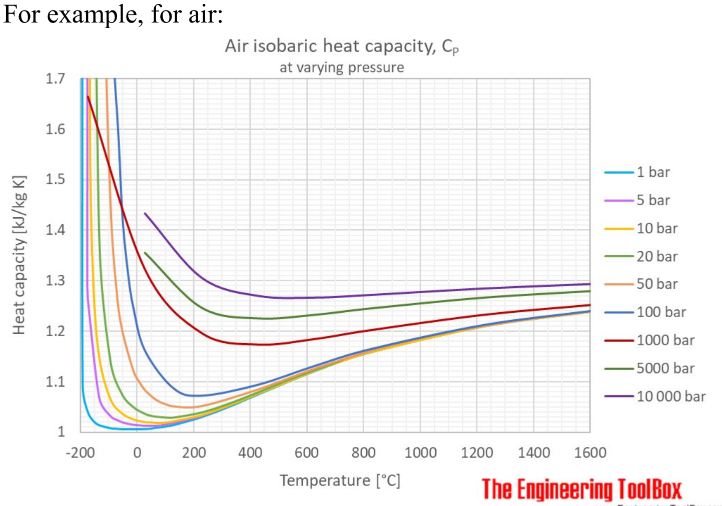
  $c_p = c_v + R$

- $c_p(T)$, $c_v(T)$, and $k(T)$ for common gases are often given in tables.
- If c_v and c_p don't vary much with temperature (as a rule of thumb, when temperature changes are less than a few hundred Kelvin at temperatures above 0 °C), then c_v and c_p may be treated as constants and,

  $u(T_2) - u(T_1) \approx c_v(T_2 - T_1)$,
  $h(T_2) - h(T_1) \approx c_p(T_2 - T_1)$

  An ideal gas with constant specific heats is known as a "perfect gas".

  For example, for air:



- Specific heat values for air and other ideal gases are often given in textbook tables.
- Property values for air, taking into account the temperature dependence of the specific heats, are frequently available in tabular form in textbooks.

TABLE A-20

Ideal Gas Specific Heats of Some Common Gases (kJ/kg · K)

Temp. K	Air c_p	Air c_v	Air k	Nitrogen, N_2 c_p	Nitrogen, N_2 c_v	Nitrogen, N_2 k	Oxygen, O_2 c_p	Oxygen, O_2 c_v	Oxygen, O_2 k	Temp. K
250	1.003	0.716	1.401	1.039	0.742	1.400	0.913	0.653	1.398	250
300	1.005	0.718	1.400	1.039	0.743	1.400	0.918	0.658	1.395	300
350	1.008	0.721	1.398	1.041	0.744	1.399	0.928	0.668	1.389	350
400	1.013	0.726	1.395	1.044	0.747	1.397	0.941	0.681	1.382	400
450	1.020	0.733	1.391	1.049	0.752	1.395	0.956	0.696	1.373	450
500	1.029	0.742	1.387	1.056	0.759	1.391	0.972	0.712	1.365	500
550	1.040	0.753	1.381	1.065	0.768	1.387	0.988	0.728	1.358	550
600	1.051	0.764	1.376	1.075	0.778	1.382	1.003	0.743	1.350	600
650	1.063	0.776	1.370	1.086	0.789	1.376	1.017	0.758	1.343	650
700	1.075	0.788	1.364	1.098	0.801	1.371	1.031	0.771	1.337	700
750	1.087	0.800	1.359	1.110	0.813	1.365	1.043	0.783	1.332	750
800	1.099	0.812	1.354	1.121	0.825	1.360	1.054	0.794	1.327	800
900	1.121	0.834	1.344	1.145	0.849	1.349	1.074	0.814	1.319	900
1000	1.142	0.855	1.336	1.167	0.870	1.341	1.090	0.830	1.313	1000

Temp. K	Carbon Dioxide, CO_2 c_p	Carbon Dioxide, CO_2 c_v	Carbon Dioxide, CO_2 k	Carbon Monoxide, CO c_p	Carbon Monoxide, CO c_v	Carbon Monoxide, CO k	Hydrogen, H_2 c_p	Hydrogen, H_2 c_v	Hydrogen, H_2 k	Temp. K
250	0.791	0.602	1.314	1.039	0.743	1.400	14.051	9.927	1.416	250
300	0.846	0.657	1.288	1.040	0.744	1.399	14.307	10.183	1.405	300
350	0.895	0.706	1.268	1.043	0.746	1.398	14.427	10.302	1.400	350
400	0.939	0.750	1.252	1.047	0.751	1.395	14.476	10.352	1.398	400
450	0.978	0.790	1.239	1.054	0.757	1.392	14.501	10.377	1.398	450
500	1.014	0.825	1.229	1.063	0.767	1.387	14.513	10.389	1.397	500
550	1.046	0.857	1.220	1.075	0.778	1.382	14.530	10.405	1.396	550
600	1.075	0.886	1.213	1.087	0.790	1.376	14.546	10.422	1.396	600
650	1.102	0.913	1.207	1.100	0.803	1.370	14.571	10.447	1.395	650
700	1.126	0.937	1.202	1.113	0.816	1.364	14.604	10.480	1.394	700
750	1.148	0.959	1.197	1.126	0.829	1.358	14.645	10.521	1.392	750
800	1.169	0.980	1.193	1.139	0.842	1.353	14.695	10.570	1.390	800
900	1.204	1.015	1.186	1.163	0.866	1.343	14.822	10.698	1.385	900
1000	1.234	1.045	1.181	1.185	0.888	1.335	14.983	10.859	1.380	1000

Source: Adapted from K. Wark, *Thermodynamics*, 4th ed., McGraw-Hill, New York, 1983, as based on "Tables of Thermal Properties of Gases," NBS Circular 564, 1955.

Table A-20 from Moran et al., *Fundamentals of Engineering Thermodynamics*, 8th ed., Wiley.

Ideal Gas Table for air.

Temp. [K]	h [kJ/kg]	u [kJ/kg]	s° [kJ/kg/K]	p_r	v_r
200	200.0	142.5	1.309	0.3363	1707.0
210	210.0	149.7	1.352	0.3987	1512.0
220	220.0	156.8	1.395	0.4690	1346.0
230	230.0	164.0	1.437	0.5477	1205.0
240	240.0	171.1	1.479	0.6355	1084.0
250	250.0	178.3	1.520	0.7329	979.0
260	260.0	185.4	1.559	0.8405	887.8
270	270.0	192.6	1.597	0.9590	808.0
280	280.1	199.8	1.633	1.0889	738.0
285	285.1	203.3	1.651	1.1584	706.1
290	290.1	206.9	1.669	1.2311	676.1
295	295.1	210.5	1.686	1.3068	647.9
300	300.1	214.1	1.703	1.3860	621.2
305	305.2	217.7	1.719	1.4686	596.0
310	310.2	221.2	1.736	1.5546	572.3
315	315.2	224.8	1.752	1.6442	549.8
320	320.2	228.4	1.768	1.7375	528.6
325	325.3	232.0	1.783	1.8345	508.4
330	330.3	235.6	1.799	1.9352	489.4

Carbon Dioxide (CO_2)

Temp. [K]	h [kJ/kmol]	u [kJ/kmol]	s° [kJ/kmol/K]
0	0.0	0.0	0.000
220	6601.0	4772.0	203.100
230	6937.0	5026.0	204.600
240	7278.0	5284.0	206.000
250	7625.0	5547.0	207.400
260	7976.0	5815.0	208.800
270	8332.0	6088.0	210.200
280	8693.0	6366.0	211.500
285	8875.0	6506.0	212.100
290	9058.0	6648.0	212.800
295	9242.0	6791.0	213.400
300	9428.0	6935.0	214.000
305	9615.0	7080.0	214.600
310	9802.0	7226.0	215.200
315	9991.0	7373.0	215.800

Note: To convert from kJ/kmol to kJ/kg, divide by the molecular mass of the gas, e.g., M_C = 12.0107 kg/kmol and M_O = 15.999 kg/kmol => M_{CO2} = 12.0107 + 2*15.999 kg/kmol = 44.01 kg/kmol,

$$h_{@220\,K} = \frac{6601.0\,\frac{kJ}{kmol}}{44.01\,\frac{kg}{kmol}} = 149.99\,\frac{kJ}{kg}$$