

Appendix 1

Properties of Fuels

Formula	Fuel	M	T_b (°C)	c_{pg} ^a (kJ/kg·K)	T_{ig} (°C)	HHV (MJ/kg)	LHV (MJ/kg)	h_{ig} ^b (kJ/kg)	AFRs	T_f (K) ^c	Δh^0 (kJ/mol)	RON ^d	MON ^e
CH ₄	Methane	16.04	-161	2.21	537	55.536	50.048	510	17.2	2,226	-74.4	120	120
C ₂ H ₂	Acetylene	26.04	-84	1.60	305	49.923	48.225	-	13.2	2,540	8.7	50	50
C ₂ H ₄	Ethylene	28.05	-104	1.54	490	50.312	47.132	-	14.7	2,380	52.4	-	-
C ₂ H ₆	Ethane	30.07	-89	1.75	472	51.902	47.611	489	16.1	2,370	-83.8	115	99
C ₃ H ₈	Propane	44.10	-42	1.62	470	50.322	46.330	432	15.7	2,334	-104.7	112	97
C ₄ H ₁₀	n-Butane	58.12	-0.5	1.64	365	49.511	45.725	386	15.5	2,270	-146.6	94	90
C ₄ H ₁₀	iso-Butane	58.12	-12	1.62	460	49.363	45.577	366	15.5	2,310	-153.5	102	98
C ₅ H ₁₂	n-Pentane	72.15	36	1.62	284	49.003	45.343	357	15.3	2,270	-173.5	62	63
C ₅ H ₁₂	iso-Pentane	72.15	28	1.60	420	48.909	45.249	342	15.3	2,310	-178.5	93	90
C ₆ H ₁₄	n-Hexane	86.18	69	1.62	233	48.674	45.099	335	15.2	2,271	-198.7	25	26
C ₆ H ₁₄	iso-Hexane	86.18	50	1.58	421	48.454	44.879	305	15.2	2,300	-207.4	104	94
C ₇ H ₁₆	n-Heptane	100.20	99	1.61	215	48.438	44.925	317	15.2	2,273	-224.2	0	0
C ₈ H ₁₈	n-Octane	114.23	126	1.61	206	48.254	44.786	301	15.1	2,275	-250.1	20	17
C ₈ H ₁₈	iso-Octane	114.23	114	1.59	418	48.119	44.651	283	15.1	2,300	-259.2	100	100
C ₉ H ₂₀	n-Nonane	128.6	151	1.61	-	48.119	44.688	295	15.1	2,274	-274.7	-	-
C ₁₀ H ₂₂	n-Decane	142.28	174	1.61	210	48.002	44.599	277	15.1	2,278	-300.9	-41	-38
C ₁₀ H ₂₂	iso-Decane	142.28	171	1.61	-	48.565	44.413	-	15.1	2,340	-	113	92
C ₁₂ H ₂₆	n-Dodecane	170.33	216	1.61	204	47.838	44.574	256	15.0	2,276	-350.9	-88	-90
CH ₄ O	Methanol	32.04	65	1.37	385	22.663	19.915	1,099	6.5	2,183	-201.5	106	92
C ₂ H ₆ O	Ethanol	46.07	78	1.42	365	29.668	26.803	836	9.0	2,144	-235.1	107	89
H ₂	Hydrogen	2.02	-253	14.47	400	141.72	119.96	451	34.3	2,345	0	-	-

^a Gas phase specific heat evaluated at 25°C^b Heat of vaporization at 1 atm^c Estimated equilibrium flame temperature^d Research octane number^e Motor octane number

Appendix 2

Properties of Air at 1 atm

Temp (K)	Specific heat c_p (kJ/kg-K)	Specific heat c_v (kJ/kg-K)	Ratio of specific heats γ , (c_p/c_v)	Viscosity, $\mu \cdot 10^5$ (kg/m-s)	Thermal conductivity, $k \cdot 10^5$ (kW/m-K)	Prandtl number ν/α	Kinematic viscosity, $\nu \cdot 10^5$ (m ² /s)	Density ρ (kg/m ³)
175	1.0023	0.7152	1.401	1.182	1.593	0.744	0.586	2.017
200	1.0025	0.7154	1.401	1.329	1.809	0.736	0.753	1.765
225	1.0027	0.7156	1.401	1.467	2.020	0.728	0.935	1.569
250	1.0031	0.716	1.401	1.599	2.227	0.720	1.132	1.412
275	1.0038	0.7167	1.401	1.725	2.428	0.713	1.343	1.284
300	1.0049	0.7178	1.400	1.846	2.624	0.707	1.568	1.177
325	1.0063	0.7192	1.400	1.962	2.816	0.701	1.807	1.086
350	1.0082	0.7211	1.398	2.075	3.003	0.697	2.056	1.009
375	1.0106	0.7235	1.397	2.181	3.186	0.692	2.317	0.9413
400	1.0135	0.7264	1.395	2.286	3.365	0.688	2.591	0.8824
450	1.0206	0.7335	1.391	2.486	3.710	0.684	3.168	0.7844
500	1.0295	0.7424	1.387	2.670	4.041	0.680	3.782	0.706
550	1.0398	0.7527	1.381	2.849	4.357	0.680	4.439	0.6418
600	1.0511	0.7540	1.376	3.017	4.661	0.680	5.128	0.5883
650	1.0629	0.7758	1.370	3.178	4.954	0.682	5.853	0.543
700	1.0750	0.7879	1.364	3.332	5.236	0.684	6.607	0.5043
750	1.0870	0.7999	1.359	3.482	5.509	0.687	7.399	0.4706
800	1.0987	0.8116	1.354	3.624	5.774	0.690	8.214	0.4412
850	1.1101	0.8230	1.349	3.763	6.030	0.693	9.061	0.4153
900	1.1209	0.8338	1.344	3.897	6.276	0.696	9.936	0.3922
950	1.1313	0.8442	1.34	4.026	6.520	0.699	10.83	0.3716
1,000	1.1411	0.8540	1.336	4.153	6.754	0.702	11.76	0.3530
1,050	1.1502	0.8631	1.333	4.276	6.985	0.704	12.72	0.3362
1,100	1.1589	0.8718	1.329	4.396	7.209	0.707	13.70	0.3209
1,150	1.1670	0.8799	1.326	4.511	7.427	0.709	14.07	0.3069
1,200	1.1746	0.8875	1.323	4.626	7.640	0.711	15.73	0.2941
1,250	1.1817	0.8946	1.321	4.736	7.849	0.713	16.77	0.2824
1,300	1.1884	0.9013	1.319	4.846	8.054	0.715	17.85	0.2715
1,350	1.1946	0.9075	1.316	4.952	8.253	0.717	18.94	0.2615

(continued)

Temp (K)	Specific heat c_p (kJ/kg-K)	Specific heat c_v (kJ/kg-K)	Ratio of specific heats γ , (c_p/c_v)	Viscosity, $\mu \cdot 10^5$ (kg/m-s)	Thermal conductivity, $k \cdot 10^5$ (kW/m-K)	Prandtl number ν/α	Kinematic viscosity, $\nu \cdot 10^5$ (m ² /s)	Density ρ (kg/m ³)
1,400	1.2005	0.9134	1.314	5.057	8.450	0.719	20.06	0.2521
1,500	1.2112	0.9241	1.311	5.262	8.831	0.722	22.36	0.2353
1,600	1.2207	0.9336	1.308	5.457	9.199	0.724	24.74	0.2206
1,700	1.2293	0.9422	1.305	5.646	9.554	0.726	27.20	0.2076
1,800	1.2370	0.9499	1.302	5.829	9.899	0.728	29.72	0.1961
1,900	1.2440	0.9569	1.300	6.008	10.233	0.730	32.34	0.1858

Appendix 3

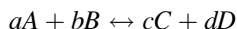
Properties of Ideal Combustion Gases

Ideal gases are assumed for combustion gases. The enthalpy, $\hat{h}(T)$, of a gaseous species consists of two parts: (1) enthalpy of formation at the standard condition (25°C and 1 atm) and (2) sensible enthalpy. Enthalpy of a species is evaluated by

$$\hat{h}(T) = \Delta\hat{h}^0 + (\hat{h}_s(T) - \hat{h}_s(T = 25^\circ\text{C})) = \Delta\hat{h}^0 + (\hat{h}_s(T) - \hat{h}_s^0)$$

This formula can be extended to include phase change from liquid to gas by including the latent heat of vaporization.

For an elementary reaction



the equilibrium constant based on concentrations, $K_c = k_f/k_b$, can be determined by thermodynamics properties as

$$K_c = \frac{k_f}{k_b} = \frac{[C]_{eq}^c [D]_{eq}^d}{[A]_{eq}^a [B]_{eq}^b} = K_p(T) \left(\frac{\hat{R}_u T}{1 \text{ atm}} \right)^{a+b-c-d}$$

where $K_p(T) = \exp \left\{ a \frac{\hat{g}_A^0}{\hat{R}_u T} + b \frac{\hat{g}_B^0}{\hat{R}_u T} - c \frac{\hat{g}_C^0}{\hat{R}_u T} - d \frac{\hat{g}_D^0}{\hat{R}_u T} \right\}$ is the equilibrium constant based on partial pressures and $\hat{g}_i^0(T) = \hat{h}_i(T) - T\hat{s}_i^0(T)$ is the Gibbs free energy at reference pressure (1 atm).

CO₂

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$\hat{g}^0 / \hat{R}_u T$
200	32.39	-3.42	199.87	-262.76
250	34.96	-1.74	207.37	-215.11
298	37.2	0	213.73	-184.46
300	37.28	0.07	213.96	-183.48
350	39.37	1.99	219.86	-161
400	41.27	4	225.25	-144.22
450	43	6.11	230.21	-131.24
500	44.57	8.3	234.82	-120.91

(continued)

CO₂ (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$\hat{g}^0 / \hat{R}_u T$
550	46	10.56	239.14	-112.51
600	47.31	12.9	243.2	-105.55
650	48.51	15.29	247.03	-99.7
700	49.61	17.75	250.67	-94.72
750	50.62	20.25	254.13	-90.43
800	51.55	22.81	257.42	-86.7
850	52.38	25.41	260.57	-83.43
900	53.13	28.05	263.59	-80.55
950	53.79	30.72	266.48	-77.99
1,000	54.36	33.42	269.25	-75.7
1,050	54.86	36.15	271.92	-73.64
1,100	55.33	38.91	274.48	-71.79
1,150	55.78	41.69	276.95	-70.11
1,200	56.2	44.49	279.33	-68.58
1,250	56.6	47.31	281.64	-67.19
1,300	56.98	50.15	283.86	-65.91
1,350	57.34	53	286.02	-64.74
1,400	57.67	55.88	288.11	-63.66
1,450	57.99	58.77	290.14	-62.67
1,500	58.29	61.68	292.11	-61.74
1,550	58.57	64.6	294.03	-60.89
1,600	58.83	67.54	295.89	-60.1
1,650	59.08	70.48	297.71	-59.36
1,700	59.31	73.44	299.47	-58.67
1,750	59.53	76.41	301.2	-58.02
1,800	59.73	79.4	302.88	-57.42
1,850	59.93	82.39	304.52	-56.86
1,900	60.11	85.39	306.12	-56.33
1,950	60.27	88.4	307.68	-55.83
2,000	60.43	91.42	309.21	-55.36
2,050	60.58	94.44	310.7	-54.92
2,100	60.71	97.47	312.16	-54.5
2,150	60.84	100.51	313.59	-54.11
2,200	60.96	103.56	314.99	-53.74
2,250	61.08	106.61	316.37	-53.39
2,300	61.18	109.66	317.71	-53.06
2,350	61.28	112.73	319.03	-52.74
2,400	61.37	115.79	320.32	-52.45
2,450	61.46	118.86	321.58	-52.16
2,500	61.55	121.94	322.83	-51.9
2,550	61.62	125.02	324.05	-51.64
2,600	61.7	128.1	325.24	-51.4
2,650	61.77	131.19	326.42	-51.17
2,700	61.84	134.28	327.57	-50.95
2,750	61.9	137.37	328.71	-50.74
2,800	61.96	140.47	329.83	-50.54

(continued)

CO₂ (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
2,850	62.02	143.57	330.92	-50.35
2,900	62.08	146.67	332	-50.17
2,950	62.14	149.78	333.06	-50
3,000	62.19	152.88	334.11	-49.83
3,050	62.25	155.99	335.14	-49.68
3,100	62.3	159.11	336.15	-49.53
3,150	62.35	162.22	337.15	-49.38
3,200	62.4	165.34	338.13	-49.25
3,250	62.45	168.46	339.1	-49.12
3,300	62.51	171.59	340.05	-48.99
3,350	62.56	174.72	340.99	-48.87
3,400	62.61	177.84	341.92	-48.76
3,450	62.66	180.98	342.83	-48.65
3,500	62.72	184.11	343.73	-48.54

H₂O

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	32.25	-3.23	175.59	-168.5
250	32.9	-1.6	182.86	-139.11
298	33.45	0	188.71	-120.26
300	33.47	0.06	188.91	-119.66
350	33.97	1.75	194.11	-105.85
400	34.44	3.46	198.68	-95.58
450	34.89	5.19	202.76	-87.64
500	35.34	6.95	206.46	-81.34
550	35.8	8.73	209.85	-76.22
600	36.29	10.53	212.98	-71.99
650	36.81	12.35	215.91	-68.43
700	37.36	14.21	218.65	-65.41
750	37.96	16.09	221.25	-62.81
800	38.59	18	223.72	-60.56
850	39.25	19.95	226.08	-58.59
900	39.93	21.93	228.34	-56.85
950	40.62	23.94	230.52	-55.31
1,000	41.31	25.99	232.62	-53.94
1,050	41.99	28.07	234.65	-52.71
1,100	42.64	30.19	236.62	-51.6
1,150	43.26	32.34	238.53	-50.6
1,200	43.87	34.52	240.39	-49.69
1,250	44.46	36.72	242.19	-48.87
1,300	45.02	38.96	243.94	-48.11

(continued)

H₂O (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
1,350	45.57	41.23	245.65	-47.42
1,400	46.1	43.52	247.32	-46.79
1,450	46.61	45.84	248.95	-46.2
1,500	47.1	48.18	250.53	-45.66
1,550	47.58	50.55	252.09	-45.16
1,600	48.03	52.94	253.6	-44.7
1,650	48.47	55.35	255.09	-44.28
1,700	48.9	57.78	256.54	-43.88
1,750	49.31	60.24	257.97	-43.51
1,800	49.7	62.71	259.36	-43.16
1,850	50.08	65.21	260.73	-42.84
1,900	50.45	67.72	262.07	-42.54
1,950	50.8	70.25	263.38	-42.26
2,000	51.14	72.8	264.67	-42
2,050	51.47	75.37	265.94	-41.75
2,100	51.78	77.95	267.19	-41.52
2,150	52.08	80.54	268.41	-41.31
2,200	52.38	83.16	269.61	-41.1
2,250	52.66	85.78	270.79	-40.91
2,300	52.92	88.42	271.95	-40.73
2,350	53.18	91.07	273.09	-40.56
2,400	53.43	93.74	274.21	-40.4
2,450	53.67	96.42	275.32	-40.25
2,500	53.9	99.11	276.4	-40.11
2,550	54.12	101.81	277.47	-39.98
2,600	54.34	104.52	278.53	-39.85
2,650	54.54	107.24	279.56	-39.73
2,700	54.74	109.97	280.58	-39.62
2,750	54.93	112.72	281.59	-39.52
2,800	55.11	115.47	282.58	-39.42
2,850	55.29	118.23	283.56	-39.32
2,900	55.46	120.99	284.52	-39.23
2,950	55.62	123.77	285.47	-39.15
3,000	55.78	126.56	286.41	-39.07
3,050	55.93	129.35	287.33	-39
3,100	56.07	132.15	288.24	-38.92
3,150	56.21	134.96	289.14	-38.86
3,200	56.35	137.77	290.03	-38.8
3,250	56.48	140.59	290.9	-38.74
3,300	56.61	143.42	291.76	-38.68
3,350	56.73	146.25	292.62	-38.63
3,400	56.85	149.09	293.46	-38.58
3,450	56.96	151.94	294.29	-38.53
3,500	57.07	154.79	295.11	-38.49

N₂

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	28.79	-2.84	179.95	-23.35
250	28.95	-1.4	186.39	-23.09
298	29.07	0	191.5	-23.03
300	29.07	0.05	191.68	-23.03
350	29.19	1.51	196.17	-23.08
400	29.32	2.97	200.08	-23.17
450	29.46	4.44	203.54	-23.29
500	29.63	5.92	206.65	-23.43
550	29.84	7.41	209.49	-23.58
600	30.08	8.9	212.09	-23.72
650	30.37	10.42	214.51	-23.87
700	30.68	11.94	216.77	-24.02
750	31.03	13.48	218.9	-24.17
800	31.39	15.04	220.92	-24.31
850	31.76	16.62	222.83	-24.45
900	32.13	18.22	224.66	-24.59
950	32.47	19.84	226.4	-24.72
1,000	32.76	21.47	228.08	-24.85
1,050	33.01	23.11	229.68	-24.98
1,100	33.26	24.77	231.22	-25.1
1,150	33.49	26.44	232.71	-25.22
1,200	33.71	28.12	234.14	-25.34
1,250	33.91	29.81	235.52	-25.46
1,300	34.11	31.51	236.85	-25.57
1,350	34.3	33.22	238.14	-25.68
1,400	34.48	34.94	239.39	-25.79
1,450	34.64	36.67	240.6	-25.9
1,500	34.8	38.4	241.78	-26
1,550	34.95	40.15	242.92	-26.1
1,600	35.1	41.9	244.04	-26.2
1,650	35.23	43.66	245.12	-26.3
1,700	35.36	45.42	246.17	-26.4
1,750	35.48	47.19	247.2	-26.49
1,800	35.59	48.97	248.2	-26.58
1,850	35.7	50.75	249.18	-26.67
1,900	35.8	52.54	250.13	-26.76
1,950	35.9	54.33	251.06	-26.85
2,000	35.99	56.13	251.97	-26.93
2,050	36.07	57.93	252.86	-27.01
2,100	36.15	59.73	253.73	-27.1
2,150	36.23	61.54	254.58	-27.18
2,200	36.3	63.36	255.42	-27.26
2,250	36.36	65.17	256.23	-27.34
2,300	36.43	66.99	257.03	-27.41
2,350	36.49	68.82	257.82	-27.49
2,400	36.54	70.64	258.59	-27.56

(continued)

N₂ (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
2,450	36.59	72.47	259.34	-27.64
2,500	36.64	74.3	260.08	-27.71
2,550	36.69	76.13	260.81	-27.78
2,600	36.74	77.97	261.52	-27.85
2,650	36.78	79.81	262.22	-27.92
2,700	36.82	81.65	262.91	-27.98
2,750	36.86	83.49	263.58	-28.05
2,800	36.89	85.33	264.25	-28.12
2,850	36.93	87.18	264.9	-28.18
2,900	36.96	89.03	265.54	-28.25
2,950	36.99	90.88	266.17	-28.31
3,000	37.03	92.73	266.8	-28.37
3,050	37.06	94.58	267.41	-28.43
3,100	37.09	96.43	268.01	-28.49
3,150	37.11	98.29	268.61	-28.55
3,200	37.14	100.14	269.19	-28.61
3,250	37.17	102	269.77	-28.67
3,300	37.2	103.86	270.33	-28.73
3,350	37.22	105.72	270.89	-28.79
3,400	37.25	107.58	271.45	-28.84
3,450	37.27	109.45	271.99	-28.9
3,500	37.3	111.31	272.53	-28.95

O₂

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	28.47	-2.84	193.51	-24.98
250	28.9	-1.4	199.91	-24.72
298	29.31	0	205.03	-24.66
300	29.33	0.05	205.21	-24.66
350	29.77	1.53	209.77	-24.7
400	30.21	3.03	213.77	-24.8
450	30.66	4.55	217.36	-24.93
500	31.11	6.1	220.61	-25.07
550	31.57	7.66	223.6	-25.22
600	32.03	9.25	226.36	-25.37
650	32.48	10.87	228.94	-25.53
700	32.93	12.5	231.37	-25.68
750	33.35	14.16	233.65	-25.83
800	33.76	15.84	235.82	-25.98
850	34.13	17.53	237.88	-26.13
900	34.45	19.25	239.84	-26.28
950	34.73	20.98	241.71	-26.42

(continued)

O₂ (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
1,000	34.93	22.72	243.49	-26.55
1,050	35.1	24.47	245.2	-26.69
1,100	35.27	26.23	246.84	-26.82
1,150	35.43	28	248.41	-26.95
1,200	35.59	29.77	249.92	-27.08
1,250	35.75	31.56	251.38	-27.2
1,300	35.9	33.35	252.78	-27.32
1,350	36.05	35.15	254.14	-27.44
1,400	36.2	36.95	255.46	-27.55
1,450	36.35	38.77	256.73	-27.66
1,500	36.49	40.59	257.96	-27.77
1,550	36.63	42.42	259.16	-27.88
1,600	36.77	44.25	260.33	-27.99
1,650	36.9	46.09	261.46	-28.09
1,700	37.03	47.94	262.56	-28.19
1,750	37.17	49.8	263.64	-28.29
1,800	37.29	51.66	264.69	-28.38
1,850	37.42	53.53	265.71	-28.48
1,900	37.54	55.4	266.71	-28.57
1,950	37.67	57.28	267.69	-28.66
2,000	37.79	59.17	268.64	-28.75
2,050	37.9	61.06	269.58	-28.84
2,100	38.02	62.96	270.49	-28.93
2,150	38.14	64.86	271.39	-29.01
2,200	38.25	66.77	272.27	-29.1
2,250	38.36	68.69	273.13	-29.18
2,300	38.47	70.61	273.97	-29.26
2,350	38.58	72.53	274.8	-29.34
2,400	38.68	74.46	275.61	-29.42
2,450	38.79	76.4	276.41	-29.5
2,500	38.89	78.34	277.2	-29.57
2,550	38.99	80.29	277.97	-29.65
2,600	39.09	82.24	278.73	-29.72
2,650	39.19	84.2	279.47	-29.79
2,700	39.29	86.16	280.2	-29.86
2,750	39.38	88.13	280.93	-29.94
2,800	39.48	90.1	281.64	-30
2,850	39.57	92.07	282.34	-30.07
2,900	39.66	94.06	283.03	-30.14
2,950	39.75	96.04	283.7	-30.21
3,000	39.84	98.03	284.37	-30.27
3,050	39.93	100.03	285.03	-30.34
3,100	40.02	102.02	285.68	-30.4
3,150	40.11	104.03	286.32	-30.47
3,200	40.19	106.03	286.96	-30.53
3,250	40.28	108.05	287.58	-30.59

(continued)

O₂ (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0 / \hat{R}_u T$
3,300	40.36	110.06	288.2	-30.65
3,350	40.44	112.08	288.8	-30.71
3,400	40.52	114.11	289.4	-30.77
3,450	40.6	116.13	290	-30.83
3,500	40.68	118.17	290.58	-30.89

CO

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0 / \hat{R}_u T$
200	28.69	-2.84	186.01	-90.55
250	28.89	-1.4	192.43	-77
298	29.07	0	197.54	-68.35
300	29.08	0.05	197.72	-68.08
350	29.25	1.51	202.21	-61.79
400	29.43	2.98	206.13	-57.14
450	29.63	4.46	209.61	-53.57
500	29.86	5.94	212.74	-50.75
550	30.11	7.44	215.6	-48.48
600	30.41	8.95	218.23	-46.61
650	30.73	10.48	220.68	-45.06
700	31.09	12.03	222.97	-43.74
750	31.47	13.59	225.13	-42.62
800	31.86	15.17	227.17	-41.66
850	32.25	16.78	229.11	-40.82
900	32.63	18.4	230.97	-40.09
950	32.97	20.04	232.74	-39.45
1,000	33.25	21.7	234.44	-38.88
1,050	33.49	23.36	236.07	-38.38
1,100	33.72	25.04	237.63	-37.93
1,150	33.94	26.74	239.13	-37.53
1,200	34.15	28.44	240.58	-37.17
1,250	34.34	30.15	241.98	-36.84
1,300	34.53	31.87	243.33	-36.55
1,350	34.7	33.6	244.64	-36.28
1,400	34.87	35.34	245.9	-36.04
1,450	35.03	37.09	247.13	-35.82
1,500	35.18	38.85	248.32	-35.62
1,550	35.32	40.61	249.48	-35.43
1,600	35.45	42.38	250.6	-35.27
1,650	35.57	44.15	251.69	-35.11
1,700	35.69	45.93	252.76	-34.97
1,750	35.8	47.72	253.79	-34.84

(continued)

CO (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
1,800	35.91	49.51	254.8	-34.72
1,850	36.01	51.31	255.79	-34.62
1,900	36.1	53.12	256.75	-34.52
1,950	36.19	54.92	257.69	-34.42
2,000	36.27	56.73	258.6	-34.34
2,050	36.35	58.55	259.5	-34.26
2,100	36.42	60.37	260.38	-34.19
2,150	36.49	62.19	261.24	-34.13
2,200	36.55	64.02	262.08	-34.07
2,250	36.61	65.85	262.9	-34.01
2,300	36.67	67.68	263.7	-33.96
2,350	36.72	69.51	264.49	-33.91
2,400	36.77	71.35	265.27	-33.87
2,450	36.82	73.19	266.02	-33.83
2,500	36.87	75.03	266.77	-33.79
2,550	36.91	76.88	267.5	-33.76
2,600	36.95	78.72	268.22	-33.73
2,650	36.99	80.57	268.92	-33.71
2,700	37.02	82.42	269.61	-33.68
2,750	37.06	84.27	270.29	-33.66
2,800	37.09	86.13	270.96	-33.64
2,850	37.12	87.98	271.62	-33.62
2,900	37.15	89.84	272.26	-33.61
2,950	37.18	91.7	272.9	-33.59
3,000	37.21	93.56	273.52	-33.58
3,050	37.24	95.42	274.14	-33.57
3,100	37.27	97.28	274.74	-33.56
3,150	37.29	99.15	275.34	-33.55
3,200	37.32	101.01	275.93	-33.55
3,250	37.35	102.88	276.51	-33.54
3,300	37.37	104.75	277.08	-33.54
3,350	37.4	106.61	277.64	-33.53
3,400	37.42	108.49	278.19	-33.53
3,450	37.45	110.36	278.74	-33.53
3,500	37.47	112.23	279.28	-33.53

C (gas)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	20.84	-2.05	149.68	411.79
250	20.84	-1	154.33	325.78
298	20.83	0	158	270.13
300	20.83	0.04	158.13	268.35

(continued)

C (gas) (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
350	20.83	1.08	161.34	227.27
400	20.82	2.12	164.12	196.41
450	20.81	3.16	166.57	172.38
500	20.81	4.2	168.76	153.12
550	20.8	5.24	170.75	137.35
600	20.8	6.28	172.56	124.18
650	20.79	7.32	174.22	113.02
700	20.79	8.36	175.76	103.45
750	20.79	9.4	177.2	95.14
800	20.79	10.44	178.54	87.85
850	20.8	11.48	179.8	81.42
900	20.8	12.52	180.99	75.69
950	20.81	13.56	182.11	70.56
1,000	20.81	14.6	183.18	65.93
1,050	20.8	15.64	184.2	61.74
1,100	20.79	16.68	185.16	57.92
1,150	20.78	17.72	186.09	54.43
1,200	20.78	18.76	186.97	51.23
1,250	20.78	19.8	187.82	48.28
1,300	20.78	20.84	188.63	45.55
1,350	20.78	21.88	189.42	43.02
1,400	20.78	22.92	190.17	40.67
1,450	20.79	23.95	190.9	38.48
1,500	20.8	24.99	191.61	36.43
1,550	20.81	26.03	192.29	34.51
1,600	20.82	27.08	192.95	32.71
1,650	20.83	28.12	193.59	31.01
1,700	20.84	29.16	194.21	29.41
1,750	20.86	30.2	194.82	27.9
1,800	20.88	31.24	195.41	26.48
1,850	20.9	32.29	195.98	25.12
1,900	20.92	33.33	196.54	23.84
1,950	20.94	34.38	197.08	22.62
2,000	20.96	35.43	197.61	21.46
2,050	20.99	36.48	198.13	20.36
2,100	21.01	37.53	198.63	19.31
2,150	21.04	38.58	199.13	18.3
2,200	21.07	39.63	199.61	17.34
2,250	21.1	40.68	200.09	16.42
2,300	21.13	41.74	200.55	15.54
2,350	21.16	42.8	201.01	14.7
2,400	21.19	43.86	201.45	13.89
2,450	21.22	44.92	201.89	13.11
2,500	21.25	45.98	202.32	12.36
2,550	21.29	47.04	202.74	11.64
2,600	21.32	48.11	203.15	10.95

(continued)

C (gas) (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
2,650	21.36	49.17	203.56	10.28
2,700	21.39	50.24	203.96	9.63
2,750	21.43	51.31	204.35	9.01
2,800	21.47	52.39	204.74	8.41
2,850	21.5	53.46	205.12	7.83
2,900	21.54	54.54	205.49	7.27
2,950	21.58	55.61	205.86	6.73
3,000	21.62	56.69	206.22	6.2
3,050	21.66	57.78	206.58	5.7
3,100	21.69	58.86	206.93	5.2
3,150	21.73	59.95	207.28	4.72
3,200	21.77	61.03	207.62	4.26
3,250	21.81	62.12	207.96	3.81
3,300	21.85	63.21	208.3	3.37
3,350	21.89	64.31	208.62	2.95
3,400	21.93	65.4	208.95	2.54
3,450	21.96	66.5	209.27	2.13
3,500	22	67.6	209.59	1.74

C (Solid)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	4.63	-0.65	3.14	-0.77
250	6.69	-0.37	4.4	-0.7
298	8.51	0	5.74	-0.69
300	8.57	0.02	5.79	-0.69
350	10.3	0.49	7.24	-0.7
400	11.87	1.04	8.72	-0.73
450	13.29	1.67	10.2	-0.78
500	14.58	2.37	11.67	-0.83
550	15.74	3.13	13.12	-0.89
600	16.79	3.94	14.53	-0.96
650	17.72	4.81	15.91	-1.02
700	18.55	5.71	17.26	-1.09
750	19.28	6.66	18.56	-1.16
800	19.92	7.64	19.83	-1.24
850	20.47	8.65	21.05	-1.31
900	20.94	9.68	22.23	-1.38
950	21.33	10.74	23.38	-1.45
1,000	21.65	11.82	24.48	-1.52
1,050	21.92	12.91	25.54	-1.59
1,100	22.18	14.01	26.57	-1.66
1,150	22.43	15.12	27.56	-1.73
1,200	22.66	16.25	28.52	-1.8
1,250	22.89	17.39	29.45	-1.87

(continued)

C (Solid) (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
1,300	23.1	18.54	30.35	-1.94
1,350	23.3	19.7	31.23	-2
1,400	23.49	20.87	32.08	-2.07
1,450	23.67	22.05	32.9	-2.13
1,500	23.84	23.24	33.71	-2.19
1,550	24.01	24.43	34.49	-2.25
1,600	24.16	25.64	35.26	-2.31
1,650	24.31	26.85	36	-2.37
1,700	24.45	28.07	36.73	-2.43
1,750	24.58	29.29	37.44	-2.49
1,800	24.71	30.52	38.14	-2.55
1,850	24.82	31.76	38.82	-2.6
1,900	24.94	33.01	39.48	-2.66
1,950	25.05	34.26	40.13	-2.71
2,000	25.15	35.51	40.76	-2.77
2,050	25.25	36.77	41.39	-2.82
2,100	25.34	38.04	42	-2.87
2,150	25.43	39.3	42.59	-2.92
2,200	25.52	40.58	43.18	-2.97
2,250	25.6	41.86	43.75	-3.02
2,300	25.68	43.14	44.32	-3.07
2,350	25.75	44.42	44.87	-3.12
2,400	25.83	45.71	45.41	-3.17
2,450	25.9	47.01	45.95	-3.22
2,500	25.97	48.3	46.47	-3.27
2,550	26.03	49.6	46.98	-3.31
2,600	26.1	50.91	47.49	-3.36
2,650	26.16	52.21	47.99	-3.4
2,700	26.23	53.52	48.48	-3.45
2,750	26.29	54.84	48.96	-3.49
2,800	26.35	56.15	49.43	-3.53
2,850	26.41	57.47	49.9	-3.58
2,900	26.47	58.79	50.36	-3.62
2,950	26.53	60.12	50.81	-3.66
3,000	26.59	61.45	51.26	-3.7
3,050	26.65	62.78	51.7	-3.74
3,100	26.7	64.11	52.13	-3.78
3,150	26.76	65.45	52.56	-3.82
3,200	26.82	66.79	52.98	-3.86
3,250	26.88	68.13	53.4	-3.9
3,300	26.94	69.47	53.81	-3.94
3,350	27	70.82	54.22	-3.98
3,400	27.06	72.17	54.62	-4.02
3,450	27.12	73.53	55.01	-4.05
3,500	27.18	74.89	55.4	-4.09

CH₄

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	28.14	-3.12	173.46	-67.78
250	31.9	-1.62	180.15	-58.48
298	35.14	0	186.05	-52.59
300	35.26	0.07	186.27	-52.4
350	38.33	1.91	191.94	-48.17
400	41.19	3.89	197.24	-45.07
450	43.93	6.02	202.25	-42.73
500	46.61	8.29	207.02	-40.92
550	49.26	10.68	211.59	-39.49
600	51.93	13.21	215.99	-38.34
650	54.62	15.88	220.25	-37.41
700	57.33	18.67	224.4	-36.65
750	60.05	21.61	228.45	-36.02
800	62.75	24.68	232.41	-35.5
850	65.38	27.88	236.29	-35.07
900	67.88	31.22	240.1	-34.72
950	70.17	34.67	243.83	-34.42
1,000	72.16	38.23	247.48	-34.18
1,050	73.92	41.88	251.05	-33.98
1,100	75.6	45.62	254.52	-33.81
1,150	77.19	49.44	257.92	-33.68
1,200	78.71	53.34	261.24	-33.58
1,250	80.15	57.31	264.48	-33.5
1,300	81.52	61.35	267.65	-33.45
1,350	82.82	65.46	270.75	-33.41
1,400	84.05	69.63	273.79	-33.38
1,450	85.22	73.86	276.76	-33.37
1,500	86.32	78.15	279.66	-33.38
1,550	87.36	82.49	282.51	-33.39
1,600	88.35	86.89	285.3	-33.41
1,650	89.29	91.33	288.03	-33.45
1,700	90.17	95.81	290.71	-33.49
1,750	91	100.34	293.34	-33.53
1,800	91.78	104.91	295.91	-33.59
1,850	92.52	109.52	298.44	-33.64
1,900	93.22	114.16	300.92	-33.71
1,950	93.87	118.84	303.35	-33.78
2,000	94.49	123.55	305.73	-33.85
2,050	95.07	128.29	308.07	-33.92
2,100	95.62	133.06	310.37	-34
2,150	96.13	137.85	312.62	-34.08
2,200	96.61	142.67	314.84	-34.16
2,250	97.06	147.51	317.02	-34.25
2,300	97.49	152.38	319.15	-34.34
2,350	97.88	157.26	321.25	-34.42
2,400	98.26	162.16	323.32	-34.51

(continued)

CH₄ (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
2,450	98.61	167.09	325.35	-34.61
2,500	98.94	172.02	327.34	-34.7
2,550	99.25	176.98	329.31	-34.79
2,600	99.54	181.95	331.24	-34.89
2,650	99.82	186.93	333.14	-34.98
2,700	100.08	191.93	335	-35.08
2,750	100.32	196.94	336.84	-35.18
2,800	100.55	201.96	338.65	-35.27
2,850	100.77	207	340.43	-35.37
2,900	100.98	212.04	342.19	-35.47
2,950	101.18	217.09	343.92	-35.57
3,000	101.37	222.16	345.62	-35.67
3,050	101.55	227.23	347.3	-35.76
3,100	101.72	232.31	348.95	-35.86
3,150	101.89	237.4	350.58	-35.96
3,200	102.05	242.5	352.18	-36.06
3,250	102.2	247.61	353.77	-36.16
3,300	102.35	252.72	355.33	-36.26
3,350	102.5	257.84	356.87	-36.35
3,400	102.64	262.97	358.39	-36.45
3,450	102.78	268.11	359.89	-36.55
3,500	102.92	273.25	361.37	-36.65

H₂

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	28.52	-2.82	119.13	-16.02
250	28.71	-1.39	125.52	-15.76
298	28.87	0	130.59	-15.71
300	28.88	0.05	130.77	-15.71
350	29.01	1.5	135.23	-15.75
400	29.12	2.95	139.11	-15.84
450	29.21	4.41	142.54	-15.97
500	29.27	5.87	145.63	-16.1
550	29.33	7.34	148.42	-16.25
600	29.37	8.81	150.97	-16.39
650	29.42	10.28	153.32	-16.54
700	29.46	11.75	155.51	-16.69
750	29.51	13.22	157.54	-16.83
800	29.58	14.7	159.45	-16.97
850	29.67	16.18	161.24	-17.1
900	29.79	17.67	162.94	-17.24
950	29.95	19.16	164.56	-17.37

(continued)

H₂ (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
1,000	30.16	20.66	166.1	-17.49
1,050	30.39	22.18	167.58	-17.62
1,100	30.62	23.7	168.99	-17.73
1,150	30.85	25.24	170.36	-17.85
1,200	31.08	26.79	171.68	-17.96
1,250	31.3	28.35	172.95	-18.07
1,300	31.51	29.92	174.18	-18.18
1,350	31.73	31.5	175.38	-18.29
1,400	31.94	33.09	176.53	-18.39
1,450	32.15	34.69	177.66	-18.49
1,500	32.35	36.3	178.75	-18.59
1,550	32.56	37.93	179.82	-18.68
1,600	32.76	39.56	180.85	-18.78
1,650	32.95	41.2	181.86	-18.87
1,700	33.14	42.86	182.85	-18.96
1,750	33.33	44.52	183.81	-19.05
1,800	33.52	46.19	184.76	-19.14
1,850	33.7	47.87	185.68	-19.22
1,900	33.88	49.56	186.58	-19.3
1,950	34.06	51.26	187.46	-19.39
2,000	34.23	52.97	188.33	-19.47
2,050	34.41	54.68	189.17	-19.55
2,100	34.57	56.41	190	-19.62
2,150	34.74	58.14	190.82	-19.7
2,200	34.9	59.88	191.62	-19.77
2,250	35.06	61.63	192.41	-19.85
2,300	35.21	63.39	193.18	-19.92
2,350	35.37	65.15	193.94	-19.99
2,400	35.52	66.92	194.68	-20.06
2,450	35.66	68.7	195.42	-20.13
2,500	35.81	70.49	196.14	-20.2
2,550	35.95	72.28	196.85	-20.27
2,600	36.09	74.08	197.55	-20.33
2,650	36.23	75.89	198.24	-20.4
2,700	36.36	77.71	198.92	-20.46
2,750	36.49	79.53	199.58	-20.53
2,800	36.62	81.35	200.24	-20.59
2,850	36.75	83.19	200.89	-20.65
2,900	36.87	85.03	201.53	-20.71
2,950	36.99	86.88	202.16	-20.77
3,000	37.11	88.73	202.79	-20.83
3,050	37.23	90.59	203.4	-20.89
3,100	37.34	92.45	204.01	-20.95
3,150	37.45	94.32	204.61	-21.01
3,200	37.56	96.2	205.2	-21.06
3,250	37.67	98.08	205.78	-21.12

(continued)

H₂ (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
3,300	37.78	99.96	206.36	-21.18
3,350	37.88	101.86	206.92	-21.23
3,400	37.99	103.75	207.49	-21.29
3,450	38.09	105.65	208.04	-21.34
3,500	38.19	107.56	208.59	-21.39

H

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	20.79	-2.04	106.3	117.07
250	20.79	-1	110.94	91.04
298	20.79	0	114.6	74.15
300	20.79	0.04	114.73	73.61
350	20.79	1.08	117.93	61.09
400	20.79	2.12	120.71	51.66
450	20.79	3.16	123.16	44.29
500	20.79	4.2	125.35	38.37
550	20.79	5.23	127.33	33.5
600	20.79	6.27	129.13	29.42
650	20.79	7.31	130.8	25.95
700	20.79	8.35	132.34	22.97
750	20.79	9.39	133.77	20.37
800	20.79	10.43	135.11	18.09
850	20.79	11.47	136.37	16.06
900	20.79	12.51	137.56	14.26
950	20.79	13.55	138.69	12.63
1,000	20.79	14.59	139.75	11.16
1,050	20.79	15.63	140.77	9.83
1,100	20.79	16.67	141.73	8.61
1,150	20.79	17.71	142.66	7.49
1,200	20.79	18.74	143.54	6.46
1,250	20.79	19.78	144.39	5.51
1,300	20.79	20.82	145.21	4.63
1,350	20.79	21.86	145.99	3.81
1,400	20.79	22.9	146.75	3.04
1,450	20.79	23.94	147.48	2.33
1,500	20.79	24.98	148.18	1.66
1,550	20.79	26.02	148.86	1.03
1,600	20.79	27.06	149.52	0.44
1,650	20.79	28.1	150.16	-0.12
1,700	20.79	29.14	150.78	-0.65
1,750	20.79	30.18	151.38	-1.15
1,800	20.79	31.22	151.97	-1.63

(continued)

H (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
1,850	20.79	32.26	152.54	-2.08
1,900	20.79	33.29	153.09	-2.51
1,950	20.79	34.33	153.63	-2.92
2,000	20.79	35.37	154.16	-3.31
2,050	20.79	36.41	154.67	-3.68
2,100	20.79	37.45	155.17	-4.03
2,150	20.79	38.49	155.66	-4.38
2,200	20.79	39.53	156.14	-4.7
2,250	20.79	40.57	156.61	-5.02
2,300	20.79	41.61	157.06	-5.32
2,350	20.79	42.65	157.51	-5.61
2,400	20.79	43.69	157.95	-5.88
2,450	20.79	44.73	158.38	-6.15
2,500	20.79	45.77	158.8	-6.41
2,550	20.79	46.8	159.21	-6.66
2,600	20.79	47.84	159.61	-6.9
2,650	20.79	48.88	160.01	-7.13
2,700	20.79	49.92	160.4	-7.36
2,750	20.79	50.96	160.78	-7.58
2,800	20.79	52	161.15	-7.79
2,850	20.79	53.04	161.52	-7.99
2,900	20.79	54.08	161.88	-8.19
2,950	20.79	55.12	162.24	-8.38
3,000	20.79	56.16	162.59	-8.57
3,050	20.79	57.2	162.93	-8.75
3,100	20.79	58.24	163.27	-8.92
3,150	20.79	59.28	163.6	-9.09
3,200	20.79	60.31	163.93	-9.26
3,250	20.79	61.35	164.25	-9.42
3,300	20.79	62.39	164.57	-9.58
3,350	20.79	63.43	164.88	-9.73
3,400	20.79	64.47	165.19	-9.88
3,450	20.79	65.51	165.49	-10.02
3,500	20.79	66.55	165.79	-10.16

O

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	22.48	-2.18	152.08	130.26
250	22.15	-1.06	157.06	100.49
298	21.9	0	160.94	81.17
300	21.89	0.04	161.07	80.55
350	21.67	1.13	164.43	66.24

(continued)

O (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
400	21.5	2.21	167.31	55.47
450	21.36	3.28	169.84	47.05
500	21.26	4.35	172.08	40.29
550	21.17	5.41	174.1	34.74
600	21.11	6.46	175.94	30.09
650	21.07	7.52	177.63	26.14
700	21.03	8.57	179.19	22.74
750	21.01	9.62	180.64	19.78
800	20.99	10.67	182	17.18
850	20.97	11.72	183.27	14.88
900	20.95	12.77	184.46	12.82
950	20.93	13.81	185.6	10.97
1,000	20.91	14.86	186.67	9.31
1,050	20.91	15.91	187.69	7.79
1,100	20.9	16.95	188.66	6.41
1,150	20.89	18	189.59	5.14
1,200	20.88	19.04	190.48	3.97
1,250	20.87	20.08	191.33	2.9
1,300	20.87	21.13	192.15	1.9
1,350	20.86	22.17	192.94	0.97
1,400	20.85	23.21	193.7	0.1
1,450	20.85	24.26	194.43	-0.7
1,500	20.84	25.3	195.14	-1.46
1,550	20.84	26.34	195.82	-2.17
1,600	20.83	27.38	196.48	-2.84
1,650	20.83	28.42	197.12	-3.47
1,700	20.83	29.46	197.74	-4.07
1,750	20.82	30.51	198.35	-4.63
1,800	20.82	31.55	198.93	-5.17
1,850	20.82	32.59	199.5	-5.68
1,900	20.82	33.63	200.06	-6.16
1,950	20.82	34.67	200.6	-6.62
2,000	20.82	35.71	201.13	-7.06
2,050	20.82	36.75	201.64	-7.48
2,100	20.82	37.79	202.14	-7.88
2,150	20.82	38.83	202.63	-8.26
2,200	20.82	39.87	203.11	-8.63
2,250	20.83	40.92	203.58	-8.98
2,300	20.83	41.96	204.04	-9.32
2,350	20.83	43	204.48	-9.64
2,400	20.84	44.04	204.92	-9.95
2,450	20.84	45.08	205.35	-10.25
2,500	20.85	46.13	205.77	-10.54
2,550	20.86	47.17	206.19	-10.82
2,600	20.86	48.21	206.59	-11.09
2,650	20.87	49.25	206.99	-11.35

(continued)

O (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
2,700	20.88	50.3	207.38	-11.6
2,750	20.89	51.34	207.76	-11.85
2,800	20.9	52.39	208.14	-12.08
2,850	20.91	53.43	208.51	-12.31
2,900	20.92	54.48	208.87	-12.53
2,950	20.93	55.52	209.23	-12.74
3,000	20.94	56.57	209.58	-12.95
3,050	20.96	57.62	209.93	-13.15
3,100	20.97	58.67	210.27	-13.35
3,150	20.98	59.72	210.61	-13.54
3,200	21	60.76	210.94	-13.72
3,250	21.01	61.81	211.26	-13.9
3,300	21.03	62.87	211.58	-14.08
3,350	21.04	63.92	211.9	-14.25
3,400	21.06	64.97	212.21	-14.41
3,450	21.08	66.02	212.52	-14.57
3,500	21.09	67.08	212.82	-14.73

OH

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	30.14	-2.95	171.6	1.03
250	30.04	-1.44	178.31	-3.39
298	29.93	0	183.6	-6.36
300	29.93	0.06	183.78	-6.45
350	29.82	1.55	188.39	-8.73
400	29.72	3.04	192.36	-10.5
450	29.63	4.52	195.86	-11.93
500	29.57	6	198.97	-13.11
550	29.53	7.48	201.79	-14.11
600	29.53	8.95	204.36	-14.97
650	29.55	10.43	206.72	-15.72
700	29.61	11.91	208.92	-16.38
750	29.71	13.39	210.96	-16.97
800	29.84	14.88	212.88	-17.51
850	30.01	16.38	214.7	-17.99
900	30.21	17.88	216.42	-18.43
950	30.43	19.4	218.06	-18.84
1,000	30.68	20.93	219.62	-19.21
1,050	30.94	22.47	221.13	-19.56
1,100	31.18	24.02	222.57	-19.88
1,150	31.43	25.59	223.96	-20.18
1,200	31.66	27.16	225.31	-20.47
1,250	31.89	28.75	226.6	-20.74

(continued)

OH (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
1,300	32.11	30.35	227.86	-20.99
1,350	32.33	31.96	229.07	-21.23
1,400	32.54	33.58	230.25	-21.46
1,450	32.74	35.22	231.4	-21.68
1,500	32.94	36.86	232.51	-21.88
1,550	33.13	38.51	233.6	-22.08
1,600	33.32	40.17	234.65	-22.27
1,650	33.5	41.84	235.68	-22.46
1,700	33.68	43.52	236.68	-22.63
1,750	33.85	45.21	237.66	-22.8
1,800	34.02	46.91	238.62	-22.96
1,850	34.18	48.61	239.55	-23.12
1,900	34.34	50.33	240.46	-23.27
1,950	34.49	52.05	241.36	-23.42
2,000	34.63	53.77	242.23	-23.56
2,050	34.78	55.51	243.09	-23.69
2,100	34.91	57.25	243.93	-23.83
2,150	35.05	59	244.75	-23.96
2,200	35.18	60.76	245.56	-24.08
2,250	35.3	62.52	246.35	-24.2
2,300	35.42	64.29	247.13	-24.32
2,350	35.54	66.06	247.89	-24.44
2,400	35.65	67.84	248.64	-24.55
2,450	35.76	69.63	249.38	-24.66
2,500	35.87	71.42	250.1	-24.77
2,550	35.97	73.21	250.81	-24.88
2,600	36.07	75.01	251.51	-24.98
2,650	36.17	76.82	252.2	-25.08
2,700	36.26	78.63	252.88	-25.18
2,750	36.35	80.45	253.54	-25.27
2,800	36.44	82.27	254.2	-25.37
2,850	36.52	84.09	254.85	-25.46
2,900	36.6	85.92	255.48	-25.55
2,950	36.68	87.75	256.11	-25.64
3,000	36.76	89.59	256.72	-25.72
3,050	36.83	91.43	257.33	-25.81
3,100	36.9	93.27	257.93	-25.89
3,150	36.97	95.12	258.52	-25.97
3,200	37.04	96.97	259.11	-26.06
3,250	37.1	98.82	259.68	-26.13
3,300	37.16	100.68	260.25	-26.21
3,350	37.22	102.54	260.81	-26.29
3,400	37.28	104.4	261.36	-26.36
3,450	37.34	106.26	261.9	-26.44
3,500	37.4	108.13	262.44	-26.51

N

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	20.79	-2.04	144.88	265.57
250	20.79	-1	149.52	208.91
298	20.79	0	153.18	172.23
300	20.79	0.04	153.31	171.06
350	20.78	1.08	156.51	143.96
400	20.78	2.12	159.29	123.59
450	20.78	3.16	161.74	107.71
500	20.78	4.2	163.93	94.98
550	20.79	5.23	165.91	84.54
600	20.79	6.27	167.72	75.83
650	20.79	7.31	169.38	68.43
700	20.79	8.35	170.92	62.08
750	20.79	9.39	172.35	56.57
800	20.79	10.43	173.7	51.73
850	20.78	11.47	174.96	47.46
900	20.78	12.51	176.14	43.65
950	20.78	13.55	177.27	40.23
1,000	20.78	14.59	178.33	37.15
1,050	20.79	15.63	179.35	34.36
1,100	20.79	16.67	180.32	31.81
1,150	20.79	17.71	181.24	29.48
1,200	20.79	18.75	182.13	27.34
1,250	20.79	19.79	182.97	25.37
1,300	20.79	20.83	183.79	23.55
1,350	20.79	21.87	184.57	21.85
1,400	20.79	22.9	185.33	20.28
1,450	20.79	23.94	186.06	18.81
1,500	20.79	24.98	186.76	17.44
1,550	20.79	26.02	187.45	16.15
1,600	20.79	27.06	188.11	14.94
1,650	20.78	28.1	188.75	13.8
1,700	20.78	29.14	189.37	12.72
1,750	20.78	30.18	189.97	11.71
1,800	20.78	31.22	190.55	10.75
1,850	20.78	32.26	191.12	9.84
1,900	20.78	33.3	191.68	8.97
1,950	20.78	34.34	192.22	8.15
2,000	20.78	35.37	192.74	7.37
2,050	20.78	36.41	193.26	6.62
2,100	20.78	37.45	193.76	5.91
2,150	20.78	38.49	194.25	5.23
2,200	20.78	39.53	194.72	4.58
2,250	20.79	40.57	195.19	3.96
2,300	20.79	41.61	195.65	3.36
2,350	20.79	42.65	196.09	2.79
2,400	20.8	43.69	196.53	2.24

(continued)

N (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
2,450	20.81	44.73	196.96	1.71
2,500	20.82	45.77	197.38	1.2
2,550	20.83	46.81	197.79	0.71
2,600	20.84	47.85	198.2	0.24
2,650	20.85	48.89	198.6	-0.22
2,700	20.86	49.94	198.99	-0.66
2,750	20.88	50.98	199.37	-1.08
2,800	20.89	52.02	199.74	-1.49
2,850	20.91	53.07	200.11	-1.88
2,900	20.93	54.11	200.48	-2.27
2,950	20.95	55.16	200.84	-2.64
3,000	20.97	56.21	201.19	-3
3,050	21	57.26	201.54	-3.34
3,100	21.02	58.31	201.88	-3.68
3,150	21.05	59.36	202.21	-4.01
3,200	21.08	60.41	202.55	-4.33
3,250	21.11	61.47	202.87	-4.64
3,300	21.14	62.53	203.2	-4.94
3,350	21.18	63.58	203.51	-5.23
3,400	21.21	64.64	203.83	-5.51
3,450	21.25	65.71	204.14	-5.79
3,500	21.29	66.77	204.44	-6.05

NO

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	29.37	-2.9	198.85	28.64
250	29.56	-1.43	205.42	18.05
298	29.73	0	210.64	11.09
300	29.73	0.06	210.83	10.87
350	29.91	1.55	215.42	5.65
400	30.1	3.05	219.43	1.67
450	30.32	4.56	222.99	-1.47
500	30.57	6.08	226.19	-4.02
550	30.85	7.61	229.12	-6.15
600	31.17	9.16	231.82	-7.95
650	31.53	10.73	234.33	-9.49
700	31.91	12.32	236.68	-10.84
750	32.31	13.92	238.89	-12.02
800	32.71	15.55	240.99	-13.07
850	33.11	17.19	242.99	-14.02
900	33.49	18.86	244.89	-14.87
950	33.82	20.54	246.71	-15.64

(continued)

NO (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
1,000	34.07	22.24	248.45	-16.35
1,050	34.28	23.95	250.12	-17
1,100	34.48	25.67	251.72	-17.6
1,150	34.67	27.4	253.25	-18.15
1,200	34.85	29.13	254.73	-18.67
1,250	35.02	30.88	256.16	-19.15
1,300	35.18	32.64	257.54	-19.6
1,350	35.33	34.4	258.87	-20.03
1,400	35.47	36.17	260.15	-20.43
1,450	35.61	37.95	261.4	-20.8
1,500	35.74	39.73	262.61	-21.16
1,550	35.86	41.52	263.78	-21.5
1,600	35.97	43.32	264.92	-21.82
1,650	36.08	45.12	266.03	-22.13
1,700	36.18	46.92	267.11	-22.42
1,750	36.27	48.73	268.16	-22.7
1,800	36.36	50.55	269.18	-22.97
1,850	36.45	52.37	270.18	-23.22
1,900	36.53	54.19	271.15	-23.47
1,950	36.6	56.02	272.1	-23.7
2,000	36.67	57.85	273.03	-23.93
2,050	36.73	59.69	273.94	-24.15
2,100	36.8	61.53	274.82	-24.36
2,150	36.85	63.37	275.69	-24.56
2,200	36.91	65.21	276.54	-24.76
2,250	36.96	67.06	277.37	-24.95
2,300	37.01	68.91	278.18	-25.13
2,350	37.05	70.76	278.98	-25.31
2,400	37.09	72.61	279.76	-25.48
2,450	37.13	74.47	280.52	-25.65
2,500	37.17	76.33	281.27	-25.82
2,550	37.21	78.19	282.01	-25.97
2,600	37.24	80.05	282.73	-26.13
2,650	37.27	81.91	283.44	-26.28
2,700	37.3	83.78	284.14	-26.42
2,750	37.33	85.64	284.82	-26.56
2,800	37.36	87.51	285.5	-26.7
2,850	37.39	89.38	286.16	-26.84
2,900	37.41	91.25	286.81	-26.97
2,950	37.44	93.12	287.45	-27.1
3,000	37.46	94.99	288.08	-27.22
3,050	37.49	96.86	288.7	-27.34
3,100	37.51	98.74	289.31	-27.46
3,150	37.53	100.62	289.91	-27.58
3,200	37.55	102.49	290.5	-27.69
3,250	37.58	104.37	291.08	-27.81

(continued)

NO (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
3,300	37.6	106.25	291.66	-27.92
3,350	37.62	108.13	292.22	-28.02
3,400	37.64	110.01	292.78	-28.13
3,450	37.66	111.89	293.33	-28.23
3,500	37.68	113.78	293.87	-28.33

NO₂

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	32.93	-3.43	226.01	-9.34
250	35.03	-1.73	233.58	-13.01
298	36.88	0	239.91	-15.51
300	36.95	0.07	240.14	-15.59
350	38.71	1.96	245.97	-17.54
400	40.33	3.94	251.25	-19.08
450	41.83	5.99	256.09	-20.35
500	43.23	8.12	260.57	-21.43
550	44.52	10.31	264.75	-22.35
600	45.73	12.57	268.67	-23.16
650	46.86	14.88	272.38	-23.88
700	47.91	17.25	275.89	-24.53
750	48.88	19.67	279.23	-25.12
800	49.76	22.14	282.41	-25.66
850	50.55	24.65	285.45	-26.16
900	51.24	27.19	288.36	-26.63
950	51.82	29.77	291.15	-27.06
1,000	52.27	32.37	293.82	-27.47
1,050	52.64	35	296.38	-27.85
1,100	52.99	37.64	298.84	-28.21
1,150	53.31	40.29	301.2	-28.55
1,200	53.62	42.97	303.47	-28.88
1,250	53.91	45.66	305.67	-29.19
1,300	54.18	48.36	307.79	-29.48
1,350	54.44	51.07	309.84	-29.77
1,400	54.68	53.8	311.82	-30.04
1,450	54.9	56.54	313.75	-30.3
1,500	55.11	59.29	315.61	-30.55
1,550	55.3	62.05	317.42	-30.8
1,600	55.48	64.82	319.18	-31.03
1,650	55.65	67.6	320.89	-31.26
1,700	55.8	70.39	322.55	-31.47
1,750	55.95	73.18	324.17	-31.69
1,800	56.08	75.98	325.75	-31.89

(continued)

NO₂ (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
1,850	56.2	78.79	327.29	-32.09
1,900	56.31	81.6	328.79	-32.29
1,950	56.42	84.42	330.25	-32.47
2,000	56.51	87.24	331.68	-32.66
2,050	56.6	90.07	333.08	-32.84
2,100	56.68	92.9	334.44	-33.01
2,150	56.76	95.74	335.78	-33.18
2,200	56.82	98.58	337.08	-33.35
2,250	56.88	101.42	338.36	-33.51
2,300	56.94	104.27	339.61	-33.66
2,350	56.99	107.11	340.84	-33.82
2,400	57.04	109.97	342.04	-33.97
2,450	57.08	112.82	343.21	-34.12
2,500	57.12	115.67	344.37	-34.26
2,550	57.15	118.53	345.5	-34.4
2,600	57.18	121.39	346.61	-34.54
2,650	57.21	124.25	347.7	-34.68
2,700	57.24	127.11	348.77	-34.81
2,750	57.27	129.97	349.82	-34.94
2,800	57.29	132.84	350.85	-35.07
2,850	57.31	135.7	351.87	-35.2
2,900	57.33	138.57	352.86	-35.32
2,950	57.35	141.43	353.84	-35.44
3,000	57.37	144.3	354.81	-35.56
3,050	57.39	147.17	355.76	-35.68
3,100	57.4	150.04	356.69	-35.8
3,150	57.42	152.91	357.61	-35.91
3,200	57.44	155.78	358.51	-36.02
3,250	57.45	158.66	359.4	-36.13
3,300	57.47	161.53	360.28	-36.24
3,350	57.49	164.4	361.14	-36.35
3,400	57.51	167.28	362	-36.45
3,450	57.52	170.15	362.84	-36.56
3,500	57.54	173.03	363.66	-36.66

SO₂

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	35.59	-3.71	233.08	-208.79
250	37.86	-1.87	241.27	-172.74
298	39.86	0	248.11	-149.6
300	39.94	0.07	248.35	-148.86
350	41.83	2.12	254.66	-131.92
400	43.55	4.25	260.36	-119.3

(continued)

SO₂ (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$\hat{g}^0 / \hat{R}_u T$
450	45.12	6.47	265.58	-109.56
500	46.54	8.76	270.4	-101.83
550	47.83	11.12	274.9	-95.55
600	48.99	13.54	279.11	-90.37
650	50.03	16.02	283.08	-86.02
700	50.97	18.54	286.82	-82.32
750	51.8	21.11	290.36	-79.15
800	52.53	23.72	293.73	-76.39
850	53.17	26.37	296.94	-73.99
900	53.71	29.04	299.99	-71.87
950	54.17	31.74	302.91	-70
1,000	54.53	34.45	305.7	-68.33
1,050	54.84	37.19	308.36	-66.83
1,100	55.14	39.94	310.92	-65.49
1,150	55.41	42.7	313.38	-64.28
1,200	55.67	45.48	315.74	-63.17
1,250	55.92	48.27	318.02	-62.17
1,300	56.16	51.07	320.22	-61.26
1,350	56.38	53.88	322.34	-60.42
1,400	56.58	56.71	324.4	-59.65
1,450	56.78	59.54	326.39	-58.94
1,500	56.96	62.39	328.31	-58.29
1,550	57.14	65.24	330.18	-57.69
1,600	57.3	68.1	332	-57.13
1,650	57.45	70.97	333.77	-56.61
1,700	57.6	73.85	335.48	-56.13
1,750	57.73	76.73	337.16	-55.68
1,800	57.86	79.62	338.78	-55.26
1,850	57.98	82.51	340.37	-54.87
1,900	58.09	85.42	341.92	-54.51
1,950	58.2	88.32	343.43	-54.17
2,000	58.3	91.24	344.9	-53.85
2,050	58.39	94.15	346.34	-53.55
2,100	58.48	97.07	347.75	-53.27
2,150	58.56	100	349.13	-53.01
2,200	58.63	102.93	350.48	-52.76
2,250	58.71	105.86	351.79	-52.52
2,300	58.78	108.8	353.09	-52.3
2,350	58.84	111.74	354.35	-52.1
2,400	58.9	114.68	355.59	-51.9
2,450	58.96	117.63	356.81	-51.71
2,500	59.02	120.58	358	-51.54
2,550	59.07	123.53	359.17	-51.38
2,600	59.12	126.49	360.31	-51.22
2,650	59.17	129.45	361.44	-51.07
2,700	59.22	132.41	362.55	-50.93

(continued)

SO₂ (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
2,750	59.27	135.37	363.63	-50.8
2,800	59.31	138.33	364.7	-50.68
2,850	59.36	141.3	365.75	-50.56
2,900	59.4	144.27	366.79	-50.45
2,950	59.44	147.24	367.8	-50.34
3,000	59.49	150.21	368.8	-50.24
3,050	59.53	153.19	369.78	-50.14
3,100	59.57	156.17	370.75	-50.05
3,150	59.61	159.14	371.71	-49.97
3,200	59.66	162.13	372.65	-49.89
3,250	59.7	165.11	373.57	-49.81
3,300	59.74	168.1	374.48	-49.74
3,350	59.78	171.08	375.38	-49.67
3,400	59.83	174.07	376.27	-49.6
3,450	59.87	177.07	377.14	-49.54
3,500	59.92	180.06	378	-49.48

SO₃

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	42.79	-4.6	238.07	-269.42
250	47.05	-2.36	248.08	-221.39
298	50.78	0	256.7	-190.54
300	50.91	0.09	257.01	-189.55
350	54.42	2.73	265.13	-166.96
400	57.58	5.53	272.6	-150.13
450	60.42	8.48	279.55	-137.14
500	62.96	11.57	286.05	-126.83
550	65.23	14.77	292.16	-118.46
600	67.23	18.09	297.92	-111.55
650	68.99	21.49	303.38	-105.75
700	70.52	24.98	308.55	-100.82
750	71.86	28.54	313.46	-96.6
800	73	32.16	318.13	-92.93
850	73.97	35.84	322.59	-89.73
900	74.78	39.56	326.84	-86.92
950	75.45	43.31	330.9	-84.43
1,000	76	47.1	334.79	-82.21
1,050	76.47	50.91	338.51	-80.22
1,100	76.91	54.75	342.07	-78.43
1,150	77.33	58.6	345.5	-76.82
1,200	77.72	62.48	348.8	-75.36
1,250	78.08	66.37	351.98	-74.03

(continued)

SO₃ (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$\hat{g}^0 / \hat{R}_u T$
1,300	78.42	70.29	355.05	-72.82
1,350	78.74	74.22	358.02	-71.71
1,400	79.04	78.16	360.89	-70.69
1,450	79.31	82.12	363.66	-69.76
1,500	79.57	86.09	366.36	-68.9
1,550	79.81	90.08	368.97	-68.1
1,600	80.03	94.07	371.51	-67.36
1,650	80.23	98.08	373.97	-66.68
1,700	80.42	102.1	376.37	-66.05
1,750	80.59	106.12	378.71	-65.46
1,800	80.75	110.15	380.98	-64.91
1,850	80.9	114.2	383.19	-64.4
1,900	81.03	118.24	385.35	-63.92
1,950	81.16	122.3	387.46	-63.47
2,000	81.27	126.36	389.51	-63.05
2,050	81.37	130.43	391.52	-62.66
2,100	81.46	134.5	393.48	-62.29
2,150	81.54	138.57	395.4	-61.95
2,200	81.62	142.65	397.28	-61.62
2,250	81.69	146.73	399.11	-61.32
2,300	81.75	150.82	400.91	-61.03
2,350	81.8	154.91	402.67	-60.76
2,400	81.85	159	404.39	-60.51
2,450	81.9	163.09	406.08	-60.27
2,500	81.94	167.19	407.73	-60.04
2,550	81.97	171.29	409.36	-59.83
2,600	82	175.39	410.95	-59.62
2,650	82.03	179.49	412.51	-59.43
2,700	82.06	183.59	414.04	-59.25
2,750	82.08	187.69	415.55	-59.08
2,800	82.11	191.8	417.03	-58.92
2,850	82.13	195.9	418.48	-58.77
2,900	82.15	200.01	419.91	-58.63
2,950	82.17	204.12	421.32	-58.49
3,000	82.18	208.23	422.7	-58.36
3,050	82.2	212.34	424.05	-58.24
3,100	82.22	216.45	425.39	-58.12
3,150	82.24	220.56	426.71	-58.01
3,200	82.26	224.67	428	-57.91
3,250	82.28	228.78	429.28	-57.81
3,300	82.29	232.9	430.53	-57.72
3,350	82.31	237.01	431.77	-57.63
3,400	82.34	241.13	432.99	-57.55
3,450	82.36	245.25	434.19	-57.47
3,500	82.38	249.37	435.38	-57.4

C_3H_8

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
200	52.35	-6.19	245.27	-95.68
250	63.29	-3.3	258.13	-82.6
298	73.55	0	270.16	-74.39
300	73.94	0.14	270.62	-74.13
350	84.23	4.09	282.8	-68.3
400	94.1	8.55	294.69	-64.1
450	103.5	13.49	306.32	-60.99
500	112.4	18.89	317.69	-58.65
550	120.79	24.73	328.8	-56.85
600	128.63	30.96	339.65	-55.46
650	135.95	37.58	350.24	-54.39
700	142.74	44.55	360.57	-53.56
750	149.03	51.85	370.63	-52.92
800	154.86	59.44	380.44	-52.44
850	160.26	67.32	389.99	-52.08
900	165.31	75.47	399.3	-51.82
950	170.06	83.85	408.36	-51.65
1,000	174.61	92.47	417.2	-51.55
1,050	178.22	101.29	425.81	-51.51
1,100	181.68	110.29	434.18	-51.52
1,150	184.99	119.45	442.33	-51.57
1,200	188.16	128.78	450.27	-51.66
1,250	191.18	138.27	458.01	-51.78
1,300	194.07	147.9	465.57	-51.92
1,350	196.82	157.67	472.95	-52.09
1,400	199.45	167.58	480.15	-52.28
1,450	201.95	177.61	487.19	-52.48
1,500	204.33	187.77	494.08	-52.7
1,550	206.59	198.05	500.82	-52.93
1,600	208.74	208.43	507.41	-53.17
1,650	210.79	218.92	513.87	-53.42
1,700	212.72	229.51	520.19	-53.68
1,750	214.56	240.19	526.38	-53.94
1,800	216.3	250.96	532.45	-54.21
1,850	217.94	261.82	538.4	-54.49
1,900	219.5	272.75	544.23	-54.77
1,950	220.96	283.77	549.95	-55.05
2,000	222.35	294.85	555.56	-55.34
2,050	223.65	306	561.07	-55.62
2,100	224.88	317.21	566.47	-55.91
2,150	226.03	328.48	571.78	-56.21
2,200	227.11	339.81	576.99	-56.5
2,250	228.12	351.19	582.1	-56.79
2,300	229.07	362.63	587.13	-57.09
2,350	229.96	374.1	592.06	-57.38
2,400	230.79	385.62	596.91	-57.68

(continued)

C_3H_8 (continued)

T (K)	$\hat{c}_p$ (kJ/kmol-K)	$\hat{h} - \hat{h}^0$ (MJ/kmol)	$\hat{s}$ (kJ/kmol-K)	$g^0/\hat{R}_u T$
2,450	231.57	397.18	601.68	-57.97
2,500	232.29	408.78	606.37	-58.26
2,550	232.96	420.41	610.97	-58.56
2,600	233.58	432.07	615.5	-58.85
2,650	234.16	443.77	619.96	-59.14
2,700	234.7	455.49	624.34	-59.43
2,750	235.2	467.23	628.65	-59.72
2,800	235.66	479.01	632.89	-60.01
2,850	236.08	490.8	637.07	-60.3
2,900	236.48	502.61	641.18	-60.58
2,950	236.84	514.45	645.22	-60.87
3,000	237.17	526.3	649.21	-61.15
3,050	237.48	538.16	653.13	-61.43
3,100	237.77	550.05	656.99	-61.71
3,150	238.03	561.94	660.8	-61.99
3,200	238.28	573.85	664.55	-62.27
3,250	238.5	585.77	668.25	-62.54
3,300	238.71	597.7	671.89	-62.81
3,350	238.91	609.64	675.48	-63.09
3,400	239.09	621.59	679.02	-63.36
3,450	239.27	633.55	682.51	-63.62
3,500	239.43	645.52	685.96	-63.89

Appendix 4

Elementary Reaction Mechanisms

Table A Elementary reactions for hydrogen combustion $k = A_o T^b \exp\left(-\frac{E_a}{R_u T}\right)$

#	Reaction	A_o	b	E_a (cal/mol)
1	$\text{H} + \text{O}_2 = \text{O} + \text{OH}$	$1.92 \cdot 10^{14}$	0.0	16,440.0
2	$\text{O} + \text{H}_2 = \text{H} + \text{OH}$	$5.08 \cdot 10^4$	2.7	6,292.0
3	$\text{OH} + \text{H}_2 = \text{H} + \text{H}_2\text{O}$	$2.16 \cdot 10^8$	1.5	3,430.0
4	$\text{O} + \text{H}_2\text{O} = \text{OH} + \text{OH}$	$2.97 \cdot 10^6$	2.0	13,400.0
5	$\text{H}_2 + \text{M} = \text{H} + \text{H} + \text{M}$	$4.58 \cdot 10^{19}$	-1.4	104,400.0
6	$\text{O}_2 + \text{M} = \text{O} + \text{O} + \text{M}$	$4.52 \cdot 10^{17}$	-0.6	118,900.0
7	$\text{OH} + \text{M} = \text{O} + \text{H} + \text{M}$	$9.88 \cdot 10^{17}$	-0.7	102,100.0
8	$\text{H}_2\text{O} + \text{M} = \text{H} + \text{OH} + \text{M}$	$1.91 \cdot 10^{23}$	-1.8	118,500.0
9	$\text{H} + \text{O}_2(+\text{M}) = \text{HO}_2(+\text{M})$	$1.48 \cdot 10^{12}$	0.6	0.0
	Low pressure limit:	$3.48 \cdot 10^{16}$	-0.41	-11,150.0
	Troe centering:	0.5	0	$10^{31} 10^{100}$
10	$\text{HO}_2 + \text{H} = \text{H}_2 + \text{O}_2$	$1.66 \cdot 10^{13}$	0	823.
11	$\text{HO}_2 + \text{H} = \text{OH} + \text{OH}$	$7.08 \cdot 10^{13}$	0	295.0
12	$\text{HO}_2 + \text{O} = \text{OH} + \text{O}_2$	$3.25 \cdot 10^{13}$	0	0
13	$\text{HO}_2 + \text{OH} = \text{H}_2\text{O} + \text{O}_2$	$2.89 \cdot 10^{13}$	0	-497.0
14	$\text{H}_2\text{O}_2 + \text{O}_2 = \text{HO}_2 + \text{HO}_2$	$4.63 \cdot 10^{16}$	-0.3	50,670.0
15	$\text{H}_2\text{O}_2 + \text{O}_2 = \text{HO}_2 + \text{HO}_2$	$1.43 \cdot 10^{13}$	-0.3	37,060.0
16	$\text{H}_2\text{O}_2(+\text{M}) = \text{OH} + \text{OH}(+\text{M})$	$2.95 \cdot 10^{14}$	0	48,430.0
	Low pressure limit ^a :	$1.20 \cdot 10^{17}$	0	45,500.0
	Troe centering:	0.5	0	$10^{31} 10^{100}$
17	$\text{H}_2\text{O}_2 + \text{H} = \text{H}_2\text{O} + \text{OH}$	$2.41 \cdot 10^{13}$	0	3,970.0
18	$\text{H}_2\text{O}_2 + \text{H} = \text{H}_2 + \text{HO}_2$	$6.02 \cdot 10^{13}$	0	7,950.0
19	$\text{H}_2\text{O}_2 + \text{O} = \text{OH} + \text{HO}_2$	$9.55 \cdot 10^6$	2.0	3,970.0
20	$\text{H}_2\text{O}_2 + \text{OH} = \text{H}_2\text{O} + \text{HO}_2$	$1.00 \cdot 10^{12}$	0	0
21	$\text{H}_2\text{O}_2 + \text{OH} = \text{H}_2\text{O} + \text{HO}_2$	$5.80 \cdot 10^{14}$	0	9,557.0

Note: E_a units cal/mol, A_o units mol-cm-s-K

^a At high pressures, the concentration of third body becomes high enough so that the three-body reaction becomes a two-body reaction. A high pressure rate is then modeled through a different model such as that proposed by Troe

Table B Elementary reactions for methane-air combustion $k = A_o T^b \exp\left(-\frac{E_a}{R_u T}\right)$

#	Reaction	A_o	b	E_a (cal/mol)
1 ^a	$\text{CH}_4(+\text{M}) = \text{CH}_3 + \text{H}(+\text{M})$	$6.3 \cdot 10^{14}$	0.0	104,000
2	$\text{CH}_4 + \text{O}_2 = \text{CH}_3 + \text{HO}_2$	$7.9 \cdot 10^{13}$	0.0	56,000.0
3 ^b	$\text{CH}_4 + \text{H} = \text{CH}_3 + \text{H}_2$	$2.2 \cdot 10^4$	3.0	8,750.0
4 ^c	$\text{CH}_4 + \text{O} = \text{CH}_3 + \text{OH}$	$1.6 \cdot 10^6$	2.36	7,400.0
5 ^a	$\text{CH}_4 + \text{OH} = \text{CH}_3 + \text{H}_2\text{O}$	$1.6 \cdot 10^6$	2.1	2,460.0
6 ^b	$\text{CH}_3 + \text{O} = \text{CH}_2\text{O} + \text{H}$	$6.8 \cdot 10^{13}$	0.0	0.0
7 ^a	$\text{CH}_3 + \text{OH} = \text{CH}_2\text{O} + \text{H}_2$	$1.0 \cdot 10^{12}$	0.0	0.0
8 ^a	$\text{CH}_3 + \text{OH} = \text{CH}_2 + \text{H}_2\text{O}$	$1.5 \cdot 10^{13}$	0.0	5,000.0
9	$\text{CH}_3 + \text{H} = \text{CH}_2 + \text{H}_2$	$9.0 \cdot 10^{13}$	0.0	15,100.0
10	$\text{CH}_2 + \text{H} = \text{CH} + \text{H}_2$	$1.4 \cdot 10^{19}$	-2.0	0.0
11 ^a	$\text{CH}_2 + \text{OH} = \text{CH}_2\text{O} + \text{H}$	$2.5 \cdot 10^{13}$	0.0	0.0
12 ^a	$\text{CH}_2 + \text{OH} = \text{CH} + \text{H}_2\text{O}$	$4.5 \cdot 10^{13}$	0.0	3,000.0
13 ^a	$\text{CH} + \text{O}_2 = \text{HCO} + \text{O}$	$3.3 \cdot 10^{13}$	0.0	0.0
14	$\text{CH} + \text{O} = \text{CO} + \text{H}$	$5.7 \cdot 10^{13}$	0.0	0.0
15	$\text{CH} + \text{OH} = \text{HCO} + \text{H}$	$3.0 \cdot 10^{13}$	0.0	0.0
16 ^c	$\text{CH} + \text{CO}_2 = \text{HCO} + \text{CO}$	$3.4 \cdot 10^{12}$	0.0	690.0
17	$\text{CH}_2 + \text{CO}_2 = \text{CH}_2\text{O} + \text{CO}$	$1.1 \cdot 10^{11}$	0.0	1,000.0
18	$\text{CH}_2 + \text{O} = \text{CO} + \text{H} + \text{H}$	$3.0 \cdot 10^{13}$	0.0	0.0
19	$\text{CH}_2 + \text{O} = \text{CO} + \text{H}_2$	$5.0 \cdot 10^{13}$	0.0	0.0
20	$\text{CH}_2 + \text{O}_2 = \text{CO}_2 + \text{H} + \text{H}$	$1.6 \cdot 10^{12}$	0.0	1,000.0
21 ^a	$\text{CH}_2 + \text{O}_2 = \text{CH}_2\text{O} + \text{O}$	$5.0 \cdot 10^{13}$	0.0	9,000.0
22	$\text{CH}_2 + \text{O}_2 = \text{CO}_2 + \text{H}_2$	$6.9 \cdot 10^{11}$	0.0	500.0
23	$\text{CH}_2 + \text{O}_2 = \text{CO} + \text{H}_2\text{O}$	$1.9 \cdot 10^{10}$	0.0	-1,000.0
24	$\text{CH}_2 + \text{O}_2 = \text{CO} + \text{OH} + \text{H}$	$8.6 \cdot 10^{10}$	0.0	-500.0
25	$\text{CH}_2 + \text{O}_2 = \text{HCO} + \text{OH}$	$4.3 \cdot 10^{10}$	0.0	-500.0
26 ^a	$\text{CH}_2\text{O} + \text{OH} = \text{HCO} + \text{H}_2\text{O}$	$3.43 \cdot 10^9$	1.18	-447.0
27 ^b	$\text{CH}_2\text{O} + \text{H} = \text{HCO} + \text{H}_2$	$2.19 \cdot 10^8$	1.77	3,000.0
28	$\text{CH}_2\text{O} + \text{M} = \text{HCO} + \text{H} + \text{M}$	$3.31 \cdot 10^{16}$	0.0	81,000.0
29	$\text{CH}_2\text{O} + \text{O} = \text{HCO} + \text{OH}$	$1.81 \cdot 10^{13}$	0.0	3,082.0
30	$\text{HCO} + \text{OH} = \text{CO} + \text{H}_2\text{O}$	$5.0 \cdot 10^{12}$	0.0	0.0
31 ^a	$\text{HCO} + \text{M} = \text{H} + \text{CO} + \text{M}$	$1.6 \cdot 10^{14}$	0.0	14,700.0
32	$\text{HCO} + \text{H} = \text{CO} + \text{H}_2$	$4.00 \cdot 10^{13}$	0.0	0.0
33	$\text{HCO} + \text{O} = \text{CO}_2 + \text{H}$	$1.0 \cdot 10^{13}$	0.0	0.0
34	$\text{HCO} + \text{O}_2 = \text{HO}_2 + \text{CO}$	$3.3 \cdot 10^{13}$	-0.4	0.0
35	$\text{CO} + \text{O} + \text{M} = \text{CO}_2 + \text{M}$	$3.20 \cdot 10^{13}$	0.0	-4,200.0
36 ^b	$\text{CO} + \text{OH} = \text{CO}_2 + \text{H}$	$1.51 \cdot 10^7$	1.3	-758.0
37	$\text{CO} + \text{O}_2 = \text{CO}_2 + \text{O}$	$1.6 \cdot 10^{13}$	0.0	41,000.0
38	$\text{HO}_2 + \text{CO} = \text{CO}_2 + \text{OH}$	$5.80 \cdot 10^{13}$	0.0	22,934.0
39	$\text{H}_2 + \text{O}_2 = 2\text{OH}$	$1.7 \cdot 10^{13}$	0.0	47,780.0
40 ^b	$\text{OH} + \text{H}_2 = \text{H}_2\text{O} + \text{H}$	$1.17 \cdot 10^9$	1.3	3,626.0
41 ^b	$\text{H} + \text{O}_2 = \text{OH} + \text{O}$	$5.13 \cdot 10^{16}$	-0.816	16,507.0
42 ^a	$\text{O} + \text{H}_2 = \text{OH} + \text{H}$	$1.8 \cdot 10^{10}$	1.0	8,826.0
43 ^b	$\text{H} + \text{O}_2 + \text{M} = \text{HO}_2 + \text{M}$	$3.61 \cdot 10^{17}$	-0.72	0.0
44 ^c	$\text{OH} + \text{HO}_2 = \text{H}_2\text{O} + \text{O}_2$	$7.5 \cdot 10^{12}$	0.0	0.0
45 ^b	$\text{H} + \text{HO}_2 = 2\text{OH}$	$1.4 \cdot 10^{14}$	0.0	1,073.0

(continued)

Table B (continued)

#	Reaction	A_o	b	E_a (cal/mol)
46	$O + HO_2 = O_2 + OH$	$1.4 \cdot 10^{13}$	0.0	1,073.0
47 ^b	$2OH = O + H_2O$	$6.0 \cdot 10^8$	1.3	0.0
48	$H + H + M = H_2 + M$	$1.0 \cdot 10^{18}$	-1.0	0.0
49	$H + H + H_2 = H_2 + H_2$	$9.2 \cdot 10^{16}$	-0.6	0.0
50	$H + H + H_2O = H_2 + H_2O$	$6.0 \cdot 10^{19}$	-1.25	0.0
51	$H + H + CO_2 = H_2 + CO_2$	$5.49 \cdot 10^{20}$	-2.0	0.0
52	$H + OH + M = H_2O + M$	$1.6 \cdot 10^{22}$	-2.0	0.0
53	$H + O + M = OH + M$	$6.2 \cdot 10^{16}$	-0.6	0.0
54	$H + HO_2 = H_2 + O_2$	$1.25 \cdot 10^{13}$	0.0	0.0
55 ^c	$HO_2 + HO_2 = H_2O_2 + O_2$	$2.0 \cdot 10^{12}$	0.0	0.0
56 ^c	$H_2O_2 + M = OH + OH + M$	$1.3 \cdot 10^{17}$	0.0	45,500.0
57	$H_2O_2 + H = HO_2 + H_2$	$1.6 \cdot 10^{12}$	0.0	3,800.0
58 ^c	$H_2O_2 + OH = H_2O + HO_2$	$1.0 \cdot 10^{13}$	0.0	1,800.0

^a Subsidiary reaction path^b Main reaction path^c Additional reaction important for minor species**Table C** Elementary reactions for formation of nitrogen oxides $k = A_o T^b \exp\left(-\frac{E_a}{R_u T}\right)$

#	Reaction	A_o	b	E_a (cal/mol)
1	$O + N_2 = N + NO$	$1.82 \cdot 10^{14}$	0.0	76,213.9
2	$O + NO = N + O_2$	$3.80 \cdot 10^9$	1.0	41,356.0
3	$H + NO = N + OH$	$2.63 \cdot 10^{14}$	0.0	50,393.6
4	$NO + M = N + O + M$	$3.98 \cdot 10^{20}$	-1.5	149,945.6
5	$N_2O + M = N_2 + O + M$	$1.60 \cdot 10^{14}$	0.0	51,600.0
6	$N_2O + O = NO + NO$	$6.92 \cdot 10^{13}$	0.0	26,615.8
7	$N_2O + O = N_2 + O_2$	$1.00 \cdot 10^{14}$	0.0	28,006.2
8	$N_2O + N = N_2 + NO$	$1.00 \cdot 10^{13}$	0.0	19,862.1
9	$N + HO_2 = NO + OH$	$1.00 \cdot 10^{13}$	0.0	1,985.3
10	$N_2O + H = N_2 + OH$	$7.60 \cdot 10^{13}$	0.0	15,096.1
11	$HNO + O = NO + OH$	$5.01 \cdot 10^{11}$	0.5	1,985.3
12	$HNO + OH = NO + H_2O$	$1.26 \cdot 10^{12}$	0.5	1,985.3
13	$NO + HO_2 = HNO + O_2$	$2.00 \cdot 10^{11}$	0	1,985.3
14	$HNO + HO_2 = NO + H_2O_2$	$3.16 \cdot 10^{11}$	0.5	1,985.3
15	$HNO + H = NO + H_2$	$1.26 \cdot 10^{13}$	0.0	3,972.9
16	$HNO + M = H + NO + M$	$1.78 \cdot 10^{16}$	0.0	48,663.9
17	$HO_2 + NO = NO_2 + OH$	$2.11 \cdot 10^{12}$	0.0	-479.0
18	$NO_2 + H = NO + OH$	$3.50 \cdot 10^{14}$	0.0	1,500.0
19	$NO_2 + O = NO + O_2$	$1.00 \cdot 10^{13}$	0.0	600.0
20	$NO_2 + M = NO + O + M$	$1.10 \cdot 10^{16}$	0.0	66,000.0

Note: E_a units cal/mol, A_o units mol-cm-s-K

Appendix 5

Summary of Limits of Flammability¹

Gas or vapor ^a	In air (%)		In air (%)		In O ₂ (%)		In O ₂ (%)	
	Lower		Higher		Lower		Higher	
	M1	M2	M1	M2	M1	M2	M1	M2
<i>Inorganic</i>								
Hydrogen	4.0	4.0	75	75	–	4.0	94	–
Deuterium	–	5	–	75	–	5	–	95
Ammonia	–	15	–	28	–	15	–	79
Hydrazine	–	4.7	–	100	–	–	–	–
Hydrogen sulfide	–	4.3	–	45	–	–	–	–
Hydrogen cyanide	–	6	–	41	–	–	–	–
Cyanogen	–	6	–	32	–	–	–	–
Carbon disulfide	1.25	–	44	50	–	–	–	–
Carbon oxysulfide	–	12	–	29	–	–	–	–
Carbon monoxide	12.5	–	74	–	–	15.5	–	94
Chlorine monoxide	–	23.5	–	100	–	–	–	–
<i>Hydrocarbons</i>								
Methane	5.3	5.0	14	15	5.1	–	61	–
Ethane	3.0	–	12.5	15	3.0	–	66	–
Propane	2.2	–	9.5	–	2.3	–	55	–
Butane	1.9	–	8.5	–	1.8	–	49	–
Isobutane	1.8	–	8.4	–	1.8	–	48	–
Pentane	1.5	1.4	7.8	–	–	–	–	–
Isopentane	1.4	–	7.6	–	–	–	–	–
2,2-Dimethyl propane	1.4	–	7.5	–	–	–	–	–
Dimethyl butane	1.2	–	7.0	–	–	–	–	–
2-Methyl pentane	1.2	–	7.0	–	–	–	–	–
Heptane	1.2	1.1	6.7	–	–	–	–	–
2,3-Dimethyl pentane	1.1	–	6.7	–	–	–	–	–
Octane	1.0	–	–	–	–	–	–	–

(continued)

¹H.F. Coward and G.W. Jones, “Limits of Flammability of Gases and Vapors,” Bulletin 503, Bureau of Mines, (1952) US Government of Printing Office, Washington DC.

Gas or vapor ^a	In air (%)		In air (%)		In O ₂ (%)		In O ₂ (%)	
	Lower		Higher		Lower		Higher	
	M1	M2	M1	M2	M1	M2	M1	M2
Isooctane	1.1	1.0	—	6.0	—	—	—	—
Nonane	—	0.8	—	—	—	—	—	—
Tetramethyl pentane	0.8	—	4.9	—	—	—	—	—
Diethyl pentane	—	0.7	—	5.7	—	—	—	—
Decane	0.8	—	—	5.4	—	—	—	—
Ethylene	3.1	2.7	32	34	3.0	—	80	—
Propylene	2.4	2.0	10.3	11	2.1	—	53	—
Butylene	2.0	—	9.6	—	—	—	—	—
Butene-1	1.6	—	9.3	—	1.8	—	58	—
Butene-2	1.8	—	9.7	—	1.7	—	55	—
Isobutylene	1.8	—	8.8	—	—	—	—	—
b-n-Amylene	1.5	1.4	8.7	—	—	—	—	—
Butadiene	2.0	—	11.5	—	—	—	—	—
Acetylene	2.5	2.3	—	81	—	—	—	—
Benzene	1.4	—	7.1	—	—	—	—	—
Toluene	1.4	1.3	—	6.7	—	—	—	—
o-Xylene	—	1.0	—	6.0	—	—	—	—
Ethyl benzene	1.0	—	—	—	—	—	—	—
Styrene	—	1.1	—	6.1	—	—	—	—
Butyl benzene	—	0.8	—	5.8	—	—	—	—
Naphthalence	—	0.9	—	5.9	—	—	—	—
Cyclopropane	2.4	—	10.4	—	2.5	—	60	—
Ethyl cyclobutane	1.2	—	7.7	—	—	—	—	—
Ethyl cyclopentane	1.1	—	6.7	—	—	—	—	—
Cyclohexane	1.3	—	8.0	—	—	—	—	—
Methyl cyclohexane	1.2	—	—	—	—	—	—	—
Ethyl cyclohexane	0.9	—	6.6	—	—	—	—	—
<i>Alcohols</i>								
Methyl alcohol	7.3	6.7	—	36	—	—	—	—
Ethyl alcohol	4.3	3.3	—	19	—	—	—	—
n-propyl alcohol	—	2.1	—	13.5	—	—	—	—
Isoproyl alcohol	—	2.0	—	12	—	—	—	—
n-Butyl alcohol	—	1.4	—	11.2	—	—	—	—
Amyl alcohol	—	1.2	—	—	—	—	—	—
Furfuryl alcohol	—	1.8	—	16.3	—	—	—	—
Allyl alcohol	—	2.5	—	18.0	—	—	—	—
Propylene glycol	—	2.6	—	12.5	—	—	—	—
Triethylene glycol	—	0.9	—	9.2	—	—	—	—
<i>Ethers</i>								
Methyl ether	3.4	—	18	27	—	3.9	—	61
Ethyl ether	1.9	1.7	48	—	2.0	2.1	—	82
Ethyl n-propyl ether	1.9	—	24	—	2.0	—	78	—
Isopropyl ether	1.4	1.3	21	—	—	—	69	—
Vinyl ether	—	1.7	27	28	—	1.8	—	85

(continued)

Gas or vapor ^a	In air (%)		In air (%)		In O ₂ (%)		In O ₂ (%)	
	Lower		Higher		Lower		Higher	
	M1	M2	M1	M2	M1	M2	M1	M2
Ethylene oxide	3.0	3.6	80	100	—	—	—	—
Propylene oxide	2.1	—	21.6	—	—	—	—	—
Dioxane	—	2.0	—	22	—	—	—	—
Trioxane	—	3.6	—	29	—	—	—	—
Acetal	1.6	—	10.4	—	—	—	—	—
Methyl cellosolve	—	2.5	—	19.8	—	—	—	—
Ethyl cellosolve	—	1.8	—	14.0	—	—	—	—
Butyl cellosolve	—	1.1	—	10.6	—	—	—	—
Diethyl peroxide	—	2.3	—	—	—	—	—	—
<i>Aldehydes</i>								
Acetaldehyde	4.1	—	55	—	—	4	—	93
Paraldehyde	—	1.3	—	—	—	—	—	—
Butyraldehyde	2.5	—	—	—	—	—	—	—
Acrolein	2.8	—	31	—	—	—	—	—
Croton aldehyde	—	2.1	—	15.5	—	—	—	—
Furfural	2.1	—	—	—	—	—	—	—
<i>Ketones</i>								
Acetone	3.0	2.5	11	13	—	—	—	—
Methyl ethyl ketone	—	1.8	—	10	—	—	—	—
Methyl propyl ketone	—	1.5	—	8	—	—	—	—
Methyl butyl ketone	—	1.3	—	8	—	—	—	—
Methyl isobutyl ketone	—	1.4	—	7.5	—	—	—	—
Cyclohexanone	—	1.1	—	—	—	—	—	—
Isophorone	—	0.8	—	3.8	—	—	—	—
<i>Acid; anhydrides</i>								
Acetic acid	—	5.4	—	—	—	—	—	—
Acetic anhydride	—	2.7	—	10	—	—	—	—
Phthalic anhydride	—	1.7	—	10.5	—	—	—	—
<i>Esters</i>								
Methyl formate	5.9	5.0	20	23	—	—	—	—
Ethyl formate	2.7	—	13.5	16.4	—	—	—	—
Butyl formate	—	1.7	—	8	—	—	—	—
Methyl acetate	—	3.1	—	16	—	—	—	—
Ethyl acetate	2.5	2.2	9	11	—	—	—	—
Vinyl acetate	2.6	—	13.4	—	—	—	—	—
Propyl acetate	2.0	1.8	—	8	—	—	—	—
Isopropyl acetate	—	1.8	—	8	—	—	—	—
Butyl acetate	1.7	1.4	—	7.6	—	—	—	—
Amyl acetate	—	1.1	—	—	—	—	—	—
Methyl cellosolve acetate	—	1.7	—	8.2	—	—	—	—
Methyl propionate	2.45	—	13	—	—	—	—	—
Ethyl propionate	1.85	—	11	—	—	—	—	—
Methyl lactate	—	2.2	—	—	—	—	—	—
Ethyl lactate	—	1.5	—	—	—	—	—	—

(continued)

Gas or vapor ^a	In air (%)		In air (%)		In O ₂ (%)		In O ₂ (%)	
	Lower		Higher		Lower		Higher	
	M1	M2	M1	M2	M1	M2	M1	M2
Ethyl nitrate	4.0	—	—	—	—	—	—	—
Ethyl nitrite	4.1	3.0	—	—	—	—	—	—
Phenols								
Cresol	—	1.1	—	—	—	—	—	—
<i>Amines & imines</i>								
Methylamine	4.9	—	20.7	—	—	—	—	—
Dimethylamine	2.8	—	14.4	—	—	—	—	—
Trimethylamine	2.0	—	11.6	—	—	—	—	—
Ethylamine	3.5	—	14.0	—	—	—	—	—
Diethylamine	1.8	—	10.1	—	—	—	—	—
Triethylamine	1.2	—	—	8.0	—	—	—	—
Propylamine	2.0	—	10.4	—	—	—	—	—
n-Butyl amine	1.7	—	9.8	—	—	—	—	—
Allylamine	2.2	—	22.	—	—	—	—	—
Ethylene imine	3.6	—	46	—	—	—	—	—
Other nitrogen compounds								
Acrylonitrile	3.0	—	—	17	—	—	—	—
Pyridine	—	1.8	—	12.4	—	—	—	—
Nicotine	—	0.7	—	4.0	—	—	—	—
<i>Halogen derivatives</i>								
Methyl chloride	10.7	7.6	17.4	19	—	8	—	66
Methyl bromide	—	13.5	—	14.5	14	—	19	—
Methylene chloride	—	—	—	—	15.5	—	—	66
Ethyl chloride	3.8	—	15.4	—	4.0	—	67	—
Ethyl bromide	—	6.7	—	11.3	6.7	—	44	—
Ethylene dichloride	6.2	—	16	—	—	—	—	—
Vinyl chloride	4.0	—	22	—	4.0	—	70	—
Dichloroethylene	9.7	—	12.8	—	10	—	26	—
Trichloroethylene	—	—	—	—	—	10	—	65
Ethylene chlorohydrin	—	4.9	—	15.9	—	—	—	—
Propyl chloride	—	2.6	—	11.1	—	—	—	—
Propylene dichloride	—	3.4	—	14.5	—	—	—	—
Allyl chloride	3.3	—	11.1	—	—	—	—	—
Allyl bromide	4.4	—	7.3	—	—	—	—	—
2-Chloropropene	4.5	—	16.0	—	4.5	—	54	—
n-Butyl chloride	—	1.8	—	10.1	—	—	—	—
Isobutyl chloride	—	2.0	—	8.8	—	—	—	—
Butyl bromide	—	5.2	—	5.6	—	—	—	—
Chlorobutene	2.2	—	9.3	—	—	—	—	—
Isocrotyl chloride	4.2	—	19.	—	4.2	—	66	—
Isocrotyl bromide	6.4	—	12	—	6.4	—	50	—
n-Amyl chloride	—	1.6	—	8.6	—	—	—	—
tert-Amyl chloride	—	1.5	—	7.4	—	—	—	—
Chlorobenzene	—	1.3	—	7.1	—	—	—	—

(continued)

Gas or vapor ^a	In air (%)		In air (%)		In O ₂ (%)		In O ₂ (%)	
	Lower		Higher		Lower		Higher	
	M1	M2	M1	M2	M1	M2	M1	M2
Dichlorobenzene	—	2.2	—	9.2	—	—	—	—
Miscellaneous								
Dimethyl sulfide	2.2	—	19.7	—	—	—	—	—
Ethyl mercaptan	2.8	—	18.0	—	—	—	—	—
Diethyl selenide	—	2.5	—	—	—	—	—	—
Dimethyldichloro-silane	3.4	—	—	—	—	—	—	—
Methyltrichloro-silane	7.6	—	—	—	—	—	—	—
Tin tetramethyl	—	1.9	—	—	—	—	—	—
Lead tetramethyl	—	1.8	—	—	—	—	—	—
Water gas	7.0	—	72	—	—	—	—	—
Carbureted water gas	5.5	—	36	—	—	—	—	—
Pittsburgh natural gas	4.8	—	13.5	—	—	—	—	—
Other natural gas	3.8—6.5	—	13—17	—	—	—	—	—
Benzine	1.1	—	—	—	—	—	—	—
Gasoline	1.4	—	7.6	—	—	—	—	—
Naphtha	—	0.8	—	5	—	—	—	—
Kerosine	—	0.7	—	5	—	—	—	—
Coal gas	5.3	—	32	—	—	7	—	70
Coke-oven gas	4.4	—	34	—	—	—	—	—
Blast furnace gas	35	—	74	—	—	—	—	—
Producer gas	17	20—35	70	70—80	—	—	—	—
Oil gas	4.7	—	33	—	—	—	—	—

^a Ordinary temperatures and pressures

M1: upward propagation of flame in large vessels, open at their lower ends.

M2: mixtures contained in closed or small vessels.

Appendix 6

Minimum Ignition Energy

Substance	MIE (mJ)	Ref.	Substance	MIE (mJ)	Ref.
ABS	30	3	Carbon monoxide	<0.3	2
Acetaldehyde	0.37	1	Carbon disulphide	0.009	1
	0.36	3		0.015	3
Acetone	1.15	1	Casein	60	1
Acetyl cellulose	15	1	Cellulose	35	1
Acetylene	0.017	1	Cellulose acetate	20–50	3
Acrolein	0.13	1	Charcoal	20	3
Acrolonitrile	0.16	1	Chromium	140	3
Adicpic acid	60	1	Cinnamon	30	1
Alfalfa meal	32–5100	3	Coal	40	1
Allyl chloride	0.78	3	Coal pittsburgh	250	3
Aluminum	50	1	Cocoa	100	1
Aluminum stearate	15	1		100–180	3
Ammonia	680	2	Coffee	160	3
Antimony	1920	3	Copal	30	1
Aspirin	25–30	3	Cork powder	45	1
Aziridine	0.48	2		35–100	3
Benzene	0.20	1	Corn meal	40	1
Bisphenol-A	1.8	4	Corn flour	20	1
Black Power	320	3	Corn starch	30–60	3
Boron	60	3	Cotton (filler)	25	1
1,3-butadiene	0.13	1	Cotton linters	1920	3
Butane	0.25	1	Cyclohexane	0.22	1
	0.26	3	Cyclopentane	0.54	1
n-Butyl chloride	0.33	3		0.24	3
Cadmium	4000	3	1,3-Cyclopentadiene	0.67	1

(continued)

Substance	MIE (mJ)	Ref.	Substance	MIE (mJ)	Ref.
Cyclopropane	0.17	1	Grain dust	30	3
	0.18	3	Grass seed	60–260	3
Dextrine	40	1	Hemp	30	1
Dichlorosilane	0.015	3	Heptane	0.24	1
Diethyl ether	0.19	1	Hexamethylene-tetramine	10	1
	0.2	3			
2,3-Dihydropyran	0.36	1	Hexane	0.24	1
Diisobutylene	0.96	1		0.29	3
Diisopropyl ether	1.14	1	Hydrogen	0.011	1
Dimethoxymethane	0.42	3		0.017	3
Dimethyl amine	<0.3	2	Hydrogen sulphide	0.068	1
2,2-dimethyl butane	0.25	1		0.077	3
Dimethyl ether	0.29	1	Isooctane	1.35	1
2,2-Dimethyl propane	1.57	1	Isopentane	0.21	1
Dimethyl sulphide	0.5	2		0.25	3
	0.48	3	Isopropyl alcohol	0.65	1
Dinitrobenzamide	45	3	Isopropyl amine	2.0	1
Dinitrobenzoic acid	45	3	Isopropyl chloride	1.55	1
Dinitro-sym-diphenylurea	60	3		1.08	3
Dinitrotoluamide	15	3	Isopropyl ether	1.14	2
Dioxane	<0.3	2	Isopropyl mercaptan	0.53	1
Di-ter-butylperoxide	0.5	2	Lignin	20	1
	0.41	3	Lycopodium	50	3
Epoxy resin	15	1	Magnesium	80	1
Ethane	0.24	1		40	3
	0.26	3	Manganese	305	3
Ethene	0.07	2	Melamine formaldehyde	50320	3
Ether	0.19	2			
Ethyl acetate	1.42	1	Methane	0.28	1
Ethyl amine	2.4	1		0.3	3
Ethyl cellulose	10	1	Methanol	0.14	1
Ethyl chloride	<0.3	2	Methyl acetylene	0.11	1
Ethylene	0.07	3		0.115	3
Ethylene oxide	0.06	1	Methylal	0.5	2
	0.065	2	Methyl cyclohexane	0.27	1
	0.062	3	Methylene chloride	10000	1
Flour, cake	25–80	3	Methyl ethyl ketone	0.53	1
Furan	0.22	1	Methylformate	0.5	2
Gasoline	0.8	3	Methylmethacrylate	15	1

(continued)

Substance	MIE (mJ)	Ref.	Substance	MIE (mJ)	Ref.
Nitrostarch	40	3	Rubber (hard)	30	1
Nylon	20	1	SAN	30	3
	20–30	3	Shellac	10	1
Paper dust	20–60	3	Silicon	100	3
Paraformaldehyde	20	1	Soap	60	1
Pentaerythritol	10	1		60–120	3
Pentane	0.22	1	Soy flour	100–460	3
2-Pentane	0.18	1	Sugar	30	1
Petroleum ether (benzene)	0.25	3	Sulphur	15	1
			Tantalum	120	3
Phenol formaldehyde	10–6000	3	Tetrafluoroethylene	3.5	3
Phosphorus (red)	0.2	1	Tetrahydrofuran	0.54	1
Phthalic anhydride	15	1	Tetrahydropyran	0.22	1
PMMA	15–20	3	Thiophene	0.39	1
Polyacrylonitrile	20	3	Thorium	5	1
Polycarbonate	25	1	Tin	80	3
Polyethylene	10	1	Titanium	40	1
	70	3		25	3
Polyethylene teraphthalate	35	3	TNT	75	3
			Toluene	0.24	3
Ploypropylene	25–400	3	Trichloroethylene	295	3
Polystyrene	40–120	3	Triethyl amine	0.75	1
Polyvinyl acetate	160	3		1.15	3
			2,2,3-Trimethylbutane	1.0	1
Polyvinyl acetate alcohol	120	3	Uranium	45	1
			Urea formaldehyde	80–1280	3
Polyvinlyl butyral	10	3	Vanadium	60	3
Potato starch	20	1	Vinyl acetate	0.7	1
	25	3	Vinyl acetylene	0.082	1
Propane	0.25	1	Vinyl chloride	<0.3	2
	0.26	3	Wheat flour	50	1
Propene	0.28	2	Wheat starch	20	1
Propionaldehyde	0.4	2		25–60	3
Propylchloride	1.08	1	Wood bark	40–60	3
Propylene	0.28	1	Wood (filler)	20	1
Propylene oxide	0.13	1	Wood flour	30–40	3
	0.14	3	m-,o-,& p-xylene	0.2	3
Pyrethrum	80	3	Yeast	50	3
Rayon	240	3	Zinc	960	3
Rice	40	1	Zirconium	5	1
	40–120	3		15	3

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Appendix 7

Antoine Equation

$$\ln P = A - \frac{B}{T + C}$$

where P is in kPa and T is in K. The calculations are based on the Antoine correlation and the Peng-Robinson equation of state. For convenience the appropriate Antoine parameters are given for the calculation.

Species	A	B	C
Ammonia	15.494	2363.24	−22.6207
Aniline	15.0205	4103.52	−62.7983
Acetone	14.7171	2975.95	−34.5228
Ammonia	15.494	2363.24	−22.6207
Acetonitrile	14.8766	3366.49	−26.6513
Acetylene	14.8321	1836.66	−8.4521
Benzene	14.1603	2948.78	−44.5633
Biphenyl	14.4481	4415.36	−79.1919
Carbon disulfide	15.2388	3549.9	15.1796
Carbon tet	14.6247	3394.46	−10.2163
Chlorobenzene	14.305	3457.17	−48.5524
cis-2-Butene	13.8005	2209.76	−36.08
Cyclohexane	13.7865	2794.58	−49.1081
Cyclopentane	13.844	2590.03	−41.6716
Diethyl ether	14.1675	2563.73	−39.3707
Diethyl ketone	14.3864	3128.36	−54.4122
Dimethyl ether	14.3448	2176.84	−24.6733
Ethane	13.8797	1582.18	−13.7622
Ethanol	16.1952	3423.53	−55.7152
Ethyl benzene	13.9698	3257.17	−61.0096
Ethyl formate	14.4017	2758.61	−45.7813
Ethyl amine	14.4758	2407.6	−45.7539
Ethylene	13.8182	1427.22	−14.308
Formaldehyde	14.3483	2161.33	−31.9756
Hydrogen chloride	14.7081	1802.24	−9.6678
Hydrogen cyanide	15.4856	3151.53	−8.8383
Hydrogen sulfide	14.5513	1964.37	−15.2417

(continued)

Species	A	B	C
iso-Butane	13.8137	2150.23	-27.6228
iso-Butene	13.9102	2196.49	-29.863
iso-Butanol	15.4994	3246.51	-826.994
iso-Pentane	13.6106	2345.09	-40.2128
Iso-Propanol	15.6491	3109.34	-73.5459
n-Butane	13.9836	2292.44	-27.8623
n-Butanol	14.6961	2902.96	-102.912
n-Butylbenzene	14.0579	3630.48	-71.8524
n-Butylcyclohexane	13.8938	3538.87	-72.5651
nHexane	14.0568	2825.42	-42.7089
n-Decane	13.9899	3452.22	-78.8993
n-Octane	14.2368	3304.16	-55.2278
n-Propylbenzene	13.9908	3433.51	-66.0278
n-Pentane	13.9778	2554.6	-36.2529
n-Propanol	15.2175	3008.31	-86.4909
Nitric oxide	16.9196	1319.11	-14.1427
Nitrogen	13.4477	658.22	-2.854
Nitrogen dioxide	21.9837	6615.36	86.878
m-Xylene	14.1146	3360.81	-58.3463
Methyl ethyl ketone	14.2173	2831.82	-57.3831
Methane	13.584	968.13	-3.72
Methyl acetate	14.7074	2917.7	-41.3724
Methanol	16.4948	3593.39	-35.2249
Methyl amine	14.8909	2342.65	-38.7081
Methylcyclohexane	13.763	2965.76	-49.7775
Methylcyclopentane	13.8064	2742.47	-46.5148
o-Dichlorobenzene	14.3011	3776.97	-63.6069
o-Xylene	14.1257	3412.02	-58.6824
Oxygen	13.6835	780.26	-4.1758
p-Xylene	14.0891	3351.69	-57.6
Phenol	15.2767	4027.98	-76.7014
Propane	13.7097	1872.82	-25.1011
Propionic acid	15.4276	3761.14	-66.0009
Propylene	13.8782	1875.25	-22.9101
Styrene	14.3284	3516.43	-56.1529
Toluene	14.2515	3242.38	-67.1806
Trimethylamine	13.865	2239.1	-33.8347
Vinyl chloride	13.6163	2027.8	-33.5344
1-Butene	13.8817	2189.45	-30.5161
1-Heptene	13.8747	2895.9	-53.9388
1-Hexene	13.7987	2657.34	-47.1749
1-Pentene	13.7564	2409.11	-39.4834
1,1-Dichloroethane	13.8796	2607.81	-48.9442
1,2-Butadiene	14.4754	2580.48	-22.2012
1,2-Dichloroethane	14.3572	3069.08	-42.3468
1,3-Butadiene	14.0719	2280.96	-27.5956
Water	16.5362	3985.44	-38.9974

Appendix 8

Flash Points for Common Fuels

Fuel	Formula	T_L (K) Closed	T_L (K) Open	T_b (K)	T_a (K)	$T_{f,ad}$ ^a (K)	LFL (%)	h_{fg} (kJ/g)	Q_c ^b (kJ/g)
Methane	CH ₄	—	—	111	910	2,226	5.3	0.59	50.2
Propane	C ₃ H ₈	—	169	231	723	2,334	2.2	0.43	46.4
n-Butane	C ₄ H ₁₀	—	213	273	561	2,270	1.9	0.39	45.9
n-Hexane	C ₆ H ₁₄	251	247	342	498	2,273	1.2	0.35	45.1
n-Heptane	C ₇ H ₁₆	269	—	371	533	2,274	1.2	0.32	44.9
n-Octane	C ₈ H ₁₈	286	—	398	479	2,275	0.8	0.3	44.8
n-Decane	C ₁₀ H ₂₂	317	—	447	474	2,277	0.6	0.28	44.6
Kerosene	≈C ₁₄ H ₃₀	322	—	505	533	—	0.6	0.29	44.0
Benzene	C ₆ H ₆	262	—	353	771	2,342	1.2	0.39	40.6
Toluene	C ₇ H ₈	277	280	383	753	2,344	1.3	0.36	41.0
Naphthalene	C ₁₀ H ₈	352	361	491	799	—	0.9	0.32	40.3
Methanol	CH ₃ OH	285	289	337	658	2,183	6.7	1.10	20.8
Ethanol	C ₂ H ₅ OH	286	295	351	636	2,144	3.3	0.84	27.8
n-Butanol	C ₄ H ₉ OH	302	316	390	616	2,262	11.3	0.62	36.1
Formaldehyde	CH ₂ O	366	—	370	703	2,334	7.0	0.83	18.7
Acetone	C ₃ H ₆ O	255	264	329	738	2,121	2.6	0.52	29.1
Gasoline	≈ C _{8.26} H _{15.5}	228	—	306	644	—	1.4	0.34	44.1

T_L = flash point; T_a = autoignition; T_b = boiling point; $T_{f,ad}$ = adiabatic flame temperature;
LFL = lean flammability limit; h_{fg} = heat of vaporization; Q_c = heat of combustion

^a Based on stoichiometric combustion with air

^b Water and fuel in gaseous state

Appendix 9

Properties of Some Alcohol Fuels and Ammonia

Methanol

Critical temperature: 513.15 K

Chemical formula: CH₃OH

Critical pressure: 7,950 kPa

Molecular weight: 32.0

Critical density: 275 kg/m³

T _{sat} (K)	337.85	353.2	373.2	393.2	413.2	433.2	453.2	473.2	493.2	511.7
P _{sat} (kPa)	101.3	178.4	349.4	633.3	1,076	1,736	2,678	3,970	5,675	7,775
ρ _l (kg/m ³)	751.0	735.5	714.0	690.0	664.0	634.0	598.0	533.0	490.0	363.5
ρ _v (kg/m ³)	1.222	2.084	3.984	7.142	12.16	19.94	31.86	50.75	86.35	178.9
h _{lv} (kJ/kg)	1,101	1,070	1,022	968	922	843	756	645	482	
c _{pl} (kJ/kg-K)	2.88	3.03	3.26	3.52	3.80	4.11	4.45	4.81		
c _{pv} (kJ/kg-K)	1.55	1.61	1.69	1.83	1.99	2.20	2.56	3.65	5.40	
μ _l (μNs/m ²)	326	271	214	170	136	109	88.3	71.6	58.3	41.6
μ _v (μNs/m ²)	11.1	11.6	12.4	13.1	14.0	14.9	16.0	17.4	20.1	26.0
k _l (mW/m-K)	191.4	187.0	181.3	178.5	170.0	164.0	158.7	153.0	147.3	142.0
k _v (mW/m-K)	18.3	20.6	23.2	26.2	29.7	33.8	39.4	46.9	60.0	98.7
Pr _l	5.13	4.67	4.15	3.61	3.34	2.82	2.56	2.42		
Pr _v	0.94	0.91	0.90	0.92	0.94	0.97	1.04	1.35	1.81	
σ (mN/m)	18.75	17.5	15.7	13.6	11.5	9.3	6.9	4.5	2.1	0.09

Ethanol

Critical temperature: 516.25K
 Chemical formula: CH₃CH₂OH
 Critical pressure: 6,390 kPa
 Molecular weight: 46.1
 Critical density: 280 kg/m³

T _{sat} (K)	351.45	373	393	413	433	453	473	483	503	513
P _{sat} (kPa)	101.3	226	429	753	1,256	1,960	2,940	3,560	5,100	6,020
ρ _l (kg/m ³)	757.0	733.7	709.0	680.3	648.5	610.5	564.0	537.6	466.2	420.3
ρ _v (kg/m ³)	1.435	3.175	5.841	10.25	17.15	27.65	44.40	56.85	101.1	160.2
h _{lv} (kJ/kg)	963.0	927.0	885.5	834.0	772.9	698.9	598.3	536.7	387.3	280.5
c _{pl} (kJ/kg-K)	3.00	3.30	3.61	3.96	4.65	5.51	6.16	6.61		
c _{pv} (kJ/kg-K)	1.83	1.92	2.02	2.11	2.31	2.80	3.18	3.78	6.55	
μ _l (μNs/m ²)	428.7	314.3	240.0	185.5	144.6	113.6	89.6	79.7	63.2	56.3
μ _v (μNs/m ²)	10.4	11.1	11.7	12.3	12.9	13.7	14.5	15.1	16.7	18.5
k _l (mW/m-K)	153.6	150.7	146.5	141.9	137.2	134.8	129.1	125.6	108.0	79.11
k _v (mW/m-K)	19.9	22.4	24.5	26.8	29.3	32.1	35.3	37.8	43.9	50.7
Pr _l	8.37	6.88	5.91	5.18	4.90	4.64	4.28	4.19		
Pr _v	0.96	0.95	0.96	0.97	1.02	1.20	1.31	1.51	2.49	
σ (mN/m)	17.7	15.7	13.6	11.5	9.3	6.9	4.5	3.3	0.9	0.34

1-Propanol

Critical temperature: 536.85K
 Chemical formula: CH₃CH₂CH₂OH
 Critical pressure: 5,050 kPa
 Molecular weight: 60.1
 Critical density: 273 kg/m³

T _{sat} (K)	373.2	393.2	413.2	433.2	453.2	473.2	493.2	513.2	523.2	533.1
P _{sat} (kPa)	109.4	218.5	399.2	683.6	1,089	1,662	2,426	3,402	3,998	4,689
ρ _l (kg/m ³)	732.5	711	687.5	660	628.5	592.0	548.5	492.0	452.5	390.5
ρ _v (kg/m ³)	2.26	4.43	8.05	13.8	22.5	35.3	55.6	90.4	118.0	161.0
h _{lv} (kJ/kg)	687	645	594	544	486	427	356	264	209	138
c _{pl} (kJ/kg-K)	3.21	3.47	3.86	4.36	5.02	5.90	6.78	7.79		
c _{pv} (kJ/kg-K)	1.65	1.82	1.93	2.05	2.20	2.36	2.97	3.94		
μ _l (μNs/m ²)	447	337	250	188	148	119	90.6	70.0	61.4	53.9
μ _v (μNs/m ²)	9.61	10.3	10.9	11.5	12.2	12.9	14.2	15.7	17.0	19.3
k _l (mW/m-K)	142.4	139.2	138.4	133.5	127.9	120.7	111.8	100.6	94.1	89.3
k _v (mW/m-K)	20.9	23.	26.2	28.9	31.4	34.7	38.0	43.9	47.5	53.5
Pr _l	10.1	8.40	6.97	5.14	5.81	5.82	5.50	5.42		
Pr _v	0.76	0.82	0.80	0.82	0.85	0.88	1.11	1.41		
σ (mN/m)	17.6	16.15	14.42	12.7	10.77	8.85	6.35	4.04	2.6	0.96

Ammonia

Critical temperature: 405.55K

Chemical formula: NH₃

Critical pressure: 11,290 kPa

Molecular weight: 17.03

Critical density: 235 kg/m³

T _{sat} (K)	239.75	250	270	290	310	330	350	370	390	400
P _{sat} (kPa)	101.3	165.4	381.9	775.3	1,425	2,422	3,870	5,891	8,606	10,280
ρ _l (kg/m ³)	682	669	643	615	584	551	512	466	400	344
ρ _v (kg/m ³)	0.86	1.41	3.09	6.08	11.0	18.9	31.5	52.6	93.3	137
h _{lv} (kJ/kg)	1,368	1,338	1,273	1,200	1,115	1,019	899	744	508	307
c _{pl} (kJ/kg-K)	4.472	4.513	4.585	4.649	4.857	5.066	5.401	5.861	7.74	
c _{pv} (kJ/kg-K)	2.12	2.32	2.69	3.04	3.44	3.90	4.62	6.21	8.07	
μ _l (μNs/m ²)	285	246	190	152	125	105	88.5	70.2	50.7	39.5
μ _v (μNs/m ²)	9.25	9.59	10.30	11.05	11.86	12.74	13.75	15.06	17.15	19.5
k _l (mW/m-K)	614	592	569	501	456	411	365	320	275	252
k _v (mW/m-K)	18.8	19.8	22.7	25.2	28.9	34.3	39.5	50.4	69.2	79.4
Pr _l	2.06	1.88	1.58	1.39	1.36	1.32	1.34	1.41	1.43	
Pr _v	1.04	1.11	1.17	1.25	1.31	1.34	1.49	1.70	1.86	
σ (mN/m)	33.9	31.5	26.9	22.4	18.0	13.7	9.60	5.74	2.21	0.68

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