

Tabela A-1 - Constantes Críticas*Massa molar, constante do gás e propriedades do ponto crítico*

Substance	Formula	Molar mass kg/kmol	R kJ/(kg · K)*	Temperature K	Pressure MPa	Volume m³/kmol
Ammonia	NH ₃	17.03	0.4882	405.5	11.28	0.0724
Argon	Ar	39.948	0.2081	151	4.86	0.0749
Bromine	Br ₂	159.808	0.0520	584	10.34	0.1355
Carbon dioxide	CO ₂	44.01	0.1889	304.2	7.39	0.0943
Carbon monoxide	CO	28.011	0.2968	133	3.50	0.0930
Chlorine	Cl ₂	70.906	0.1173	417	7.71	0.1242
Deuterium (normal)	D ₂	4.00	2.0785	38.4	1.66	—
Helium	He	4.003	2.0769	5.3	0.23	0.0578
Hydrogen (normal)	H ₂	2.016	4.1240	33.3	1.30	0.0649
Krypton	Kr	83.80	0.09921	209.4	5.50	0.0924
Neon	Ne	20.183	0.4119	44.5	2.73	0.0417
Nitrogen	N ₂	28.013	0.2968	126.2	3.39	0.0899
Nitrous oxide	N ₂ O	44.013	0.1889	309.7	7.27	0.0961
Oxygen	O ₂	31.999	0.2598	154.8	5.08	0.0780
Sulfur dioxide	SO ₂	64.063	0.1298	430.7	7.88	0.1217
Water	H ₂ O	18.015	0.4615	647.3	22.09	0.0568
Xenon	Xe	131.30	0.06332	289.8	5.88	0.1186
Benzene	C ₆ H ₆	78.115	0.1064	562	4.92	0.2603
n-Butane	C ₄ H ₁₀	58.124	0.1430	425.2	3.80	0.2547
Carbon tetrachloride	CCl ₄	153.82	0.05405	556.4	4.56	0.2759
Chloroform	CHCl ₃	119.38	0.06964	536.6	5.47	0.2403
Dichlorodifluoromethane (R-12)	CCl ₂ F ₂	120.91	0.06876	384.7	4.01	0.2179
Dichlorofluoromethane	CHCl ₂ F	102.92	0.08078	451.7	5.17	0.1973
Ethane	C ₂ H ₆	30.070	0.2765	305.5	4.88	0.1480
Ethyl alcohol	C ₂ H ₅ OH	46.07	0.1805	516	6.38	0.1673
Ethylene	C ₂ H ₄	28.054	0.2964	282.4	5.12	0.1242
n-Hexane	C ₆ H ₁₄	86.178	0.09647	507.9	3.03	0.3677
Methane	CH ₄	16.043	0.5182	191.1	4.64	0.0993
Methyl alcohol	CH ₃ OH	32.042	0.2595	513.2	7.95	0.1180
Methyl chloride	CH ₃ Cl	50.488	0.1647	416.3	6.68	0.1430
Propane	C ₃ H ₈	44.097	0.1885	370	4.26	0.1998
Propene	C ₃ H ₆	42.081	0.1976	365	4.62	0.1810
Propyne	C ₃ H ₄	40.065	0.2075	401	5.35	—
Trichlorofluoromethane	CCl ₃ F	137.37	0.06052	471.2	4.38	0.2478
Air	—	28.97	0.2870	—	—	—

Tabela A-2- Calores Específicos dos gases comuns: (a) a 300 K; (b) a várias temperaturas;

(a)

Gas	Formula	Gas constant R kJ/(kg · K)	C_{p_0} kJ/(kg · K)	C_{v_0} kJ/(kg · K)	k
Air	—	0.2870	1.005	0.718	1.400
Argon	Ar	0.2081	0.5203	0.3122	1.667
Butane	C ₄ H ₁₀	0.1433	1.7164	1.5734	1.091
Carbon dioxide	CO ₂	0.1889	0.846	0.657	1.289
Carbon monoxide	CO	0.2968	1.040	0.744	1.400
Ethane	C ₂ H ₆	0.2765	1.7662	1.4897	1.186
Ethylene	C ₂ H ₄	0.2964	1.5482	1.2518	1.237
Helium	He	2.0769	5.1926	3.1156	1.667
Hydrogen	H ₂	4.1240	14.307	10.183	1.405
Methane	CH ₄	0.5182	2.2537	1.7354	1.299
Neon	Ne	0.4119	1.0299	0.6179	1.667
Nitrogen	N ₂	0.2968	1.039	0.743	1.400
Octane	C ₈ H ₁₈	0.0729	1.7113	1.6385	1.044
Oxygen	O ₂	0.2598	0.918	0.658	1.395
Propane	C ₃ H ₈	0.1885	1.6794	1.4909	1.126
Steam	H ₂ O	0.4615	1.8723	1.4108	1.327

(b)

Temperature K	C_{p_0} kJ/(kg · K)	C_{v_0} kJ/(kg · K)	k	C_{p_0} kJ/(kg · K)	C_{v_0} kJ/(kg · K)	k	C_{p_0} kJ/(kg · K)	C_{v_0} kJ/(kg · K)	k
	Air	Carbon dioxide, CO ₂		Carbon monoxide, CO					
250	1.003	0.716	1.401	0.791	0.602	1.314	1.039	0.743	1.400
300	1.005	0.718	1.400	0.846	0.657	1.288	1.040	0.744	1.399
350	1.008	0.721	1.398	0.895	0.706	1.268	1.043	0.746	1.398
400	1.013	0.726	1.395	0.939	0.750	1.252	1.047	0.751	1.395
450	1.020	0.733	1.391	0.978	0.790	1.239	1.054	0.757	1.392
500	1.029	0.742	1.387	1.014	0.825	1.229	1.063	0.767	1.387
550	1.040	0.753	1.381	1.046	0.857	1.220	1.075	0.778	1.382
600	1.051	0.764	1.376	1.075	0.886	1.213	1.087	0.790	1.376
650	1.063	0.776	1.370	1.102	0.913	1.207	1.100	0.803	1.370
700	1.075	0.788	1.364	1.126	0.937	1.202	1.113	0.816	1.364
750	1.087	0.800	1.359	1.148	0.959	1.197	1.126	0.829	1.358
800	1.099	0.812	1.354	1.169	0.980	1.193	1.139	0.842	1.353
900	1.121	0.834	1.344	1.204	1.015	1.186	1.163	0.866	1.343
1000	1.142	0.855	1.336	1.234	1.045	1.181	1.185	0.888	1.335
Hydrogen, H ₂				Nitrogen, N ₂			Oxygen, O ₂		
250	14.051	9.927	1.416	1.039	0.742	1.400	0.913	0.653	1.398
300	14.307	10.183	1.405	1.039	0.743	1.400	0.918	0.658	1.395
350	14.427	10.302	1.400	1.041	0.744	1.399	0.928	0.668	1.389
400	14.476	10.352	1.398	1.044	0.747	1.397	0.941	0.681	1.382
450	14.501	10.377	1.398	1.049	0.752	1.395	0.956	0.696	1.373
500	14.513	10.389	1.397	1.056	0.759	1.391	0.972	0.712	1.365
550	14.530	10.405	1.396	1.065	0.768	1.387	0.988	0.728	1.358
600	14.546	10.422	1.396	1.075	0.778	1.382	1.003	0.743	1.350
650	14.571	10.447	1.395	1.086	0.789	1.376	1.017	0.758	1.343
700	14.604	10.480	1.394	1.098	0.801	1.371	1.031	0.771	1.337
750	14.645	10.521	1.392	1.110	0.813	1.365	1.043	0.783	1.332
800	14.695	10.570	1.390	1.121	0.825	1.360	1.054	0.794	1.327
900	14.822	10.698	1.385	1.145	0.849	1.349	1.074	0.814	1.319
1000	14.983	10.859	1.380	1.167	0.870	1.341	1.090	0.830	1.313

Tabela A-2- Calores Específicos dos gases comuns: (c) como função da temperatura (**cont.**).

(c)

$$\bar{C}_{p0} = a + bT + cT^2 + dT^3$$

[T in K, \bar{C}_{p0} in kJ/(kmol · K)]

Substance	Formula	a	b	c	d	Temperature range K	% error	Max.	Avg.
Nitrogen	N ₂	28.90	-0.1571 × 10 ⁻²	0.8081 × 10 ⁻⁵	-2.873 × 10 ⁻⁹	273–1800	0.59	0.34	
Oxygen	O ₂	25.48	1.520 × 10 ⁻²	-0.7155 × 10 ⁻⁵	1.312 × 10 ⁻⁹	273–1800	1.19	0.28	
Air		28.11	0.1967 × 10 ⁻²	0.4802 × 10 ⁻⁵	-1.966 × 10 ⁻⁹	273–1800	0.72	0.33	
Hydrogen	H ₂	29.11	-0.1916 × 10 ⁻²	0.4003 × 10 ⁻⁵	-0.8704 × 10 ⁻⁹	273–1800	1.01	0.26	
Carbon monoxide	CO	28.16	0.1675 × 10 ⁻²	0.5372 × 10 ⁻⁵	-2.222 × 10 ⁻⁹	273–1800	0.89	0.37	
Carbon dioxide	CO ₂	22.26	5.981 × 10 ⁻²	-3.501 × 10 ⁻⁵	7.469 × 10 ⁻⁹	273–1800	0.67	0.22	
Water vapor	H ₂ O	32.24	0.1923 × 10 ⁻²	1.055 × 10 ⁻⁵	-3.595 × 10 ⁻⁹	273–1800	0.53	0.24	
Nitric oxide	NO	29.34	-0.09395 × 10 ⁻²	0.9747 × 10 ⁻⁵	-4.187 × 10 ⁻⁹	273–1500	0.97	0.36	
Nitrous oxide	N ₂ O	24.11	5.8632 × 10 ⁻²	-3.562 × 10 ⁻⁵	10.58 × 10 ⁻⁹	273–1500	0.59	0.26	
Nitrogen dioxide	NO ₂	22.9	5.715 × 10 ⁻²	-3.52 × 10 ⁻⁵	7.87 × 10 ⁻⁹	273–1500	0.46	0.18	
Ammonia	NH ₃	27.568	2.5630 × 10 ⁻²	0.99072 × 10 ⁻⁵	-6.6909 × 10 ⁻⁹	273–1500	0.91	0.36	
Sulfur	S ₂	27.21	2.218 × 10 ⁻²	-1.628 × 10 ⁻⁵	3.986 × 10 ⁻⁹	273–1800	0.99	0.38	
Sulfur dioxide	SO ₂	25.78	5.795 × 10 ⁻²	-3.812 × 10 ⁻⁵	8.612 × 10 ⁻⁹	273–1800	0.45	0.24	
Sulfur trioxide	SO ₃	16.40	14.58 × 10 ⁻²	-11.20 × 10 ⁻⁵	32.42 × 10 ⁻⁹	273–1300	0.29	0.13	
Acetylene	C ₂ H ₂	21.8	9.2143 × 10 ⁻²	-6.527 × 10 ⁻⁵	18.21 × 10 ⁻⁹	273–1500	1.46	0.59	
Benzene	C ₆ H ₆	-36.22	48.475 × 10 ⁻²	-31.57 × 10 ⁻⁵	77.62 × 10 ⁻⁹	273–1500	0.34	0.20	
Methanol	CH ₃ OH	19.0	9.152 × 10 ⁻²	-1.22 × 10 ⁻⁵	-8.039 × 10 ⁻⁹	273–1000	0.18	0.08	
Ethanol	C ₂ H ₆ O	19.9	20.96 × 10 ⁻²	-10.38 × 10 ⁻⁵	20.05 × 10 ⁻⁹	273–1500	0.40	0.22	
Hydrogen chloride	HCl	30.33	-0.7620 × 10 ⁻²	1.327 × 10 ⁻⁵	-4.338 × 10 ⁻⁹	273–1500	0.22	0.08	
Methane	CH ₄	19.89	5.024 × 10 ⁻²	1.269 × 10 ⁻⁵	-11.01 × 10 ⁻⁹	273–1500	1.33	0.57	
Ethane	C ₂ H ₆	6.900	17.27 × 10 ⁻²	-6.406 × 10 ⁻⁵	7.285 × 10 ⁻⁹	273–1500	0.83	0.28	
Propane	C ₃ H ₈	-4.04	30.48 × 10 ⁻²	-15.72 × 10 ⁻⁵	31.74 × 10 ⁻⁹	273–1500	0.40	0.12	
n-Butane	C ₄ H ₁₀	3.96	37.15 × 10 ⁻²	-18.34 × 10 ⁻⁵	35.00 × 10 ⁻⁹	273–1500	0.54	0.24	
i-Butane	C ₄ H ₁₀	-7.913	41.60 × 10 ⁻²	-23.01 × 10 ⁻⁵	49.91 × 10 ⁻⁹	273–1500	0.25	0.13	
n-Pentane	C ₅ H ₁₂	6.774	45.43 × 10 ⁻²	-22.46 × 10 ⁻⁵	42.29 × 10 ⁻⁹	273–1500	0.56	0.21	
n-Hexane	C ₆ H ₁₄	6.938	55.22 × 10 ⁻²	-28.65 × 10 ⁻⁵	57.69 × 10 ⁻⁹	273–1500	0.72	0.20	
Ethylene	C ₂ H ₄	3.95	15.64 × 10 ⁻²	-8.344 × 10 ⁻⁵	17.67 × 10 ⁻⁹	273–1500	0.54	0.13	
Propylene	C ₃ H ₆	3.15	23.83 × 10 ⁻²	-12.18 × 10 ⁻⁵	24.62 × 10 ⁻⁹	273–1500	0.73	0.17	

Tabela A-3 – Calores Específicos dos sólidos e líquidos: (a) a 25 °C, (b) a várias temperaturas.

(a)

Solid	C_p kJ/(kg · K)	ρ kg/m³	Liquid	C_p kJ/(kg · K)	ρ kg/m³
Aluminum	0.900	2,700	Ammonia	4.800	602
Copper	0.386	8,900	Ethanol	2.456	783
Granite	1.017	2,700	Refrigerant-12	0.977	1,310
Graphite	0.711	2,500	Mercury	0.139	13,560
Iron	0.450	7,840	Methanol	2.550	787
Lead	0.128	11,310	Oil (light)	1.800	910
Rubber (soft)	1.840	1,100	Water	4.184	997
Silver	0.235	10,470			
Tin	0.217	5,730			
Wood (most)	1.760	350–700			

(b)

Solids					
Substance	Temp.	C_p kJ/(kg · K)	Substance	Temp.	C_p kJ/(kg · K)
Ice	200 K	1.56	Silver	20°C	0.233
	220 K	1.71		200°C	0.243
	240 K	1.86	Lead	-173°C	0.118
	260 K	2.01		-50°C	0.126
	270 K	2.08		27°C	0.129
	273 K	2.11		100°C	0.131
	200 K	0.797		200°C	0.136
Aluminum	250 K	0.859	Copper	-173°C	0.254
	300 K	0.902		-100°C	0.342
	350 K	0.929		-50°C	0.367
	400 K	0.949		0°C	0.381
	450 K	0.973		27°C	0.386
	500 K	0.997		100°C	0.393
Iron	20°C	0.448		200°C	0.403
Liquids					
Substance	State	C_p kJ/(kg · K)	Substance	State	C_p kJ/(kg · K)
Water	1 atm, 273 K	4.217	Benzene	1 atm, 15°C	1.80
	1 atm, 280 K	4.198		1 atm, 65°C	1.92
	1 atm, 300 K	4.179	Glycerin	1 atm, 10°C	2.32
	1 atm, 320 K	4.180		1 atm, 50°C	2.58
	1 atm, 340 K	4.188	Mercury	1 atm, 10°C	0.138
	1 atm, 360 K	4.203		1 atm, 315°C	0.134
	1 atm, 373 K	4.218	Sodium	1 atm, 95°C	1.38
Ammonia	Sat., -20°C	4.52		1 atm, 540°C	1.26
	Sat., 50°C	5.10	Propane	1 atm, 0°C	2.41
Refrigerant-12	Sat., -40°C	0.883	Bismuth	1 atm, 425°C	0.144
	Sat., -20°C	0.908		1 atm, 760°C	0.164
	Sat., 50°C	1.02	Ethyl alcohol	1 atm, 25°C	2.43

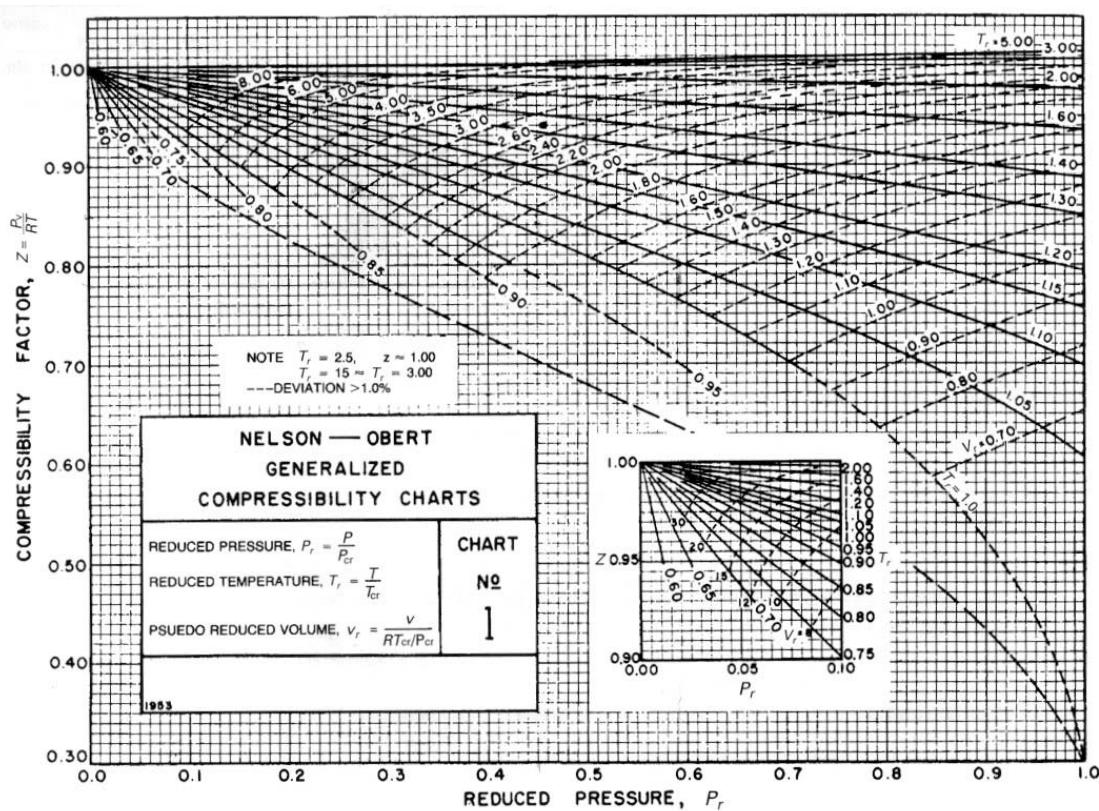
Tabela A-8 - Propriedades do ar como gás ideal

T K	h kJ/kg	P_r	u kJ/kg	v_r	s° kJ/(kg · K)	T K	h kJ/kg	P_r	u kJ/kg	v_r	s° kJ/(kg · K)
200	199.97	0.3363	142.56	1707.0	1.295 59	580	586.04	14.38	419.55	115.7	2.373 48
210	209.97	0.3987	149.69	1512.0	1.344 44	590	596.52	15.31	427.15	110.6	2.391 40
220	219.97	0.4690	156.82	1346.0	1.391 05	600	607.02	16.28	434.78	105.8	2.409.02
230	230.02	0.5477	164.00	1205.0	1.435 57	610	617.53	17.30	442.42	101.2	2.426 44
240	240.02	0.6355	171.13	1084.0	1.478 24	620	628.07	18.36	450.09	96.92	2.443 56
250	250.05	0.7329	178.28	979.0	1.519 17	630	638.63	19.84	457.78	92.84	2.460 48
260	260.09	0.8405	185.45	887.8	1.558 48	640	649.22	20.64	465.50	88.99	2.477 16
270	270.11	0.9590	192.60	808.0	1.596 34	650	659.84	21.86	473.25	85.34	2.493 64
280	280.13	1.0889	199.75	738.0	1.632 79	660	670.47	23.13	481.01	81.89	2.509 85
285	285.14	1.1584	203.33	706.1	1.650 55	670	681.14	24.46	488.81	78.61	2.525 89
290	290.16	1.2311	206.91	676.1	1.668 02	680	691.82	25.85	496.62	75.50	2.541 75
295	295.17	1.3068	210.49	647.9	1.685 15	690	702.52	27.29	504.45	72.56	2.557 31
300	300.19	1.3860	214.07	621.2	1.702 03	700	713.27	28.80	512.33	69.76	2.572 77
305	305.22	1.4686	217.67	596.0	1.718 65	710	724.04	30.38	520.23	67.07	2.588 10
310	310.24	1.5546	221.25	572.3	1.734 98	720	734.82	32.02	528.14	64.53	2.603 19
315	315.27	1.6442	224.85	549.8	1.751 06	730	745.62	33.72	536.07	62.13	2.618 03
320	320.29	1.7375	228.42	528.6	1.766 90	740	756.44	35.50	544.02	59.82	2.632 80
325	325.31	1.8345	232.02	508.4	1.782 49	750	767.29	37.35	551.99	57.63	2.647 37
330	330.34	1.9352	235.61	489.4	1.797 83	760	778.18	39.27	560.01	55.54	2.661 76
340	340.42	2.149	242.82	454.1	1.827 90	780	800.03	43.35	576.12	51.64	2.690 13
350	350.49	2.379	250.02	422.2	1.857 08	800	821.95	47.75	592.30	48.08	2.717 87
360	360.58	2.626	257.24	393.4	1.885 43	820	843.98	52.59	608.59	44.84	2.745 04
370	370.67	2.892	264.46	367.2	1.913 13	840	866.08	57.60	624.95	41.85	2.771 70
380	380.77	3.176	271.69	343.4	1.940 01	860	888.27	63.09	641.40	39.12	2.797 83
390	390.88	3.481	278.93	321.5	1.966 33	880	910.56	68.98	657.95	36.61	2.823 44
400	400.98	3.806	286.16	301.6	1.991 94	900	932.93	75.29	674.58	34.31	2.848 56
410	411.12	4.153	293.43	283.3	2.016 99	920	955.38	82.05	691.28	32.18	2.873 24
420	421.26	4.522	300.69	266.6	2.041 42	940	977.92	89.28	708.08	30.22	2.897 48
430	431.43	4.915	307.99	251.1	2.065 33	960	1000.55	97.00	725.02	28.40	2.921 28
440	441.61	5.332	315.30	236.8	2.088 70	980	1023.25	105.2	741.98	26.73	2.944 68
450	451.80	5.775	322.62	223.6	2.111 61	1000	1046.04	114.0	758.94	25.17	2.967 70
460	462.02	6.245	329.97	211.4	2.134 07	1020	1068.89	123.4	776.10	23.72	2.990 34
470	472.24	6.742	337.32	200.1	2.156 04	1040	1091.85	133.3	793.36	22.39	3.012 60
480	482.49	7.268	344.70	189.5	2.177 60	1060	1114.86	143.9	810.62	21.14	3.034 49
490	492.74	7.824	352.08	179.7	2.198 76	1080	1137.89	155.2	827.88	19.98	3.056 08
500	503.02	8.411	359.49	170.6	2.219 52	1100	1161.07	167.1	845.33	18.896	3.077 32
510	513.32	9.031	366.92	162.1	2.239 93	1120	1184.28	179.7	862.79	17.886	3.098 25
520	523.63	9.684	374.36	154.1	2.259 97	1140	1207.57	193.1	880.35	16.946	3.118 83
530	533.98	10.37	381.84	146.7	2.279 67	1160	1230.92	207.2	897.91	16.064	3.139 16
540	544.35	11.10	389.34	139.7	2.299 06	1180	1254.34	222.2	915.57	15.241	3.159 16
550	554.74	11.86	396.86	133.1	2.318 09	1200	1277.79	238.0	933.33	14.470	3.178 88
560	565.17	12.66	404.42	127.0	2.336 85	1220	1301.31	254.7	951.09	13.747	3.198 34
570	575.59	13.50	411.97	121.2	2.355 31	1240	1324.93	272.3	968.95	13.069	3.217 51

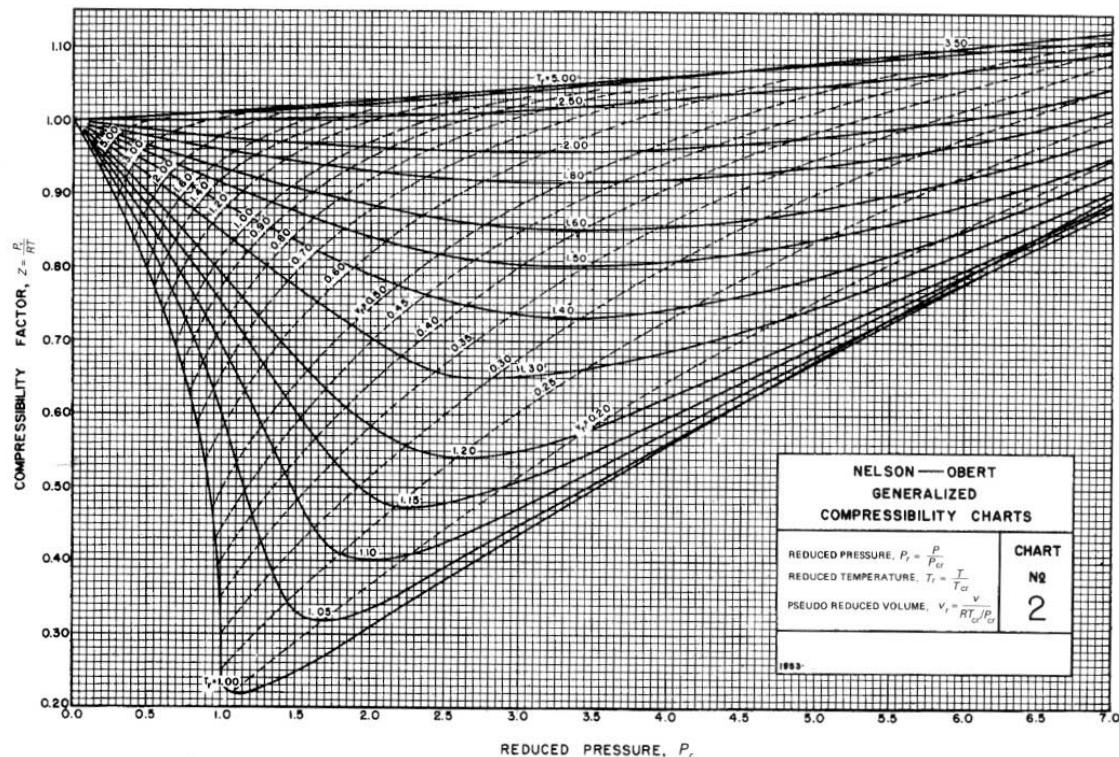
Tabela A-8 - Propriedades do ar como gás ideal (**continuação**)

<i>T</i> K	<i>h</i> kJ/kg	<i>P_r</i>	<i>u</i> kJ/kg	<i>v_r</i>	<i>s°</i> kJ/(kg · K)	<i>T</i> K	<i>h</i> kJ/kg	<i>P_r</i>	<i>u</i> kJ/kg	<i>v_r</i>	<i>s°</i> kJ/(kg · K)
1260	1348.55	290.8	986.90	12.435	3.236 38	1600	1757.57	791.2	1298.30	5.804	3.523 64
1280	1372.24	310.4	1004.76	11.835	3.255 10	1620	1782.00	834.1	1316.96	5.574	3.538 79
1300	1395.97	330.9	1022.82	11.275	3.273 45	1640	1806.46	878.9	1335.72	5.355	3.553 81
1320	1419.76	352.5	1040.88	10.747	3.291 60	1660	1830.96	925.6	1354.48	5.147	3.568 67
1340	1443.60	375.3	1058.94	10.247	3.309 59	1680	1855.50	974.2	1373.24	4.949	3.583 35
1360	1467.49	399.1	1077.10	9.780	3.327 24	1700	1880.1	1025	1392.7	4.761	3.5979
1380	1491.44	424.2	1095.26	9.337	3.344 74	1750	1941.6	1161	1439.8	4.328	3.6336
1400	1515.42	450.5	1113.52	8.919	3.362 00	1800	2003.3	1310	1487.2	3.944	3.6684
1420	1539.44	478.0	1131.77	8.526	3.379 01	1850	2065.3	1475	1534.9	3.601	3.7023
1440	1563.51	506.9	1150.13	8.153	3.395 86	1900	2127.4	1655	1582.6	3.295	3.7354
1460	1587.63	537.1	1168.49	7.801	3.412 47	1950	2189.7	1852	1630.6	3.022	3.7677
1480	1611.79	568.8	1186.95	7.468	3.428 92	2000	2252.1	2068	1678.7	2.776	3.7994
1500	1635.97	601.9	1205.41	7.152	3.445 16	2050	2314.6	2303	1726.8	2.555	3.8303
1520	1660.23	636.5	1223.87	6.854	3.461 20	2100	2377.4	2559	1775.3	2.356	3.8605
1540	1684.51	672.8	1242.43	6.569	3.477 12	2150	2440.3	2837	1823.8	2.175	3.8901
1560	1708.82	710.5	1260.99	6.301	3.492 76	2200	2503.2	3138	1872.4	2.012	3.9191
1580	1733.17	750.0	1279.65	6.046	3.508 29	2250	2566.4	3464	1921.3	1.864	3.9474

Carta da Compressibilidade Generalizada – Pressões Baixas ($0 < P_r < 1,0$)



Carta da Compressibilidade Generalizada – Pressões Intermédias ($0 < P_r < 7$)



Carta da Compressibilidade Generalizada – Pressões Altas ($0 < P_r < 40$)

