PROPERTIES OF
CARBON DIOXIDE

UNION
ENGINEERING

Introduction

This booklet has been produced to assist customers who are interested in the physical, chemical and physiological properies of carbon dioxide.

The information provided is based on current technical knowledge. International units have been used throughout.

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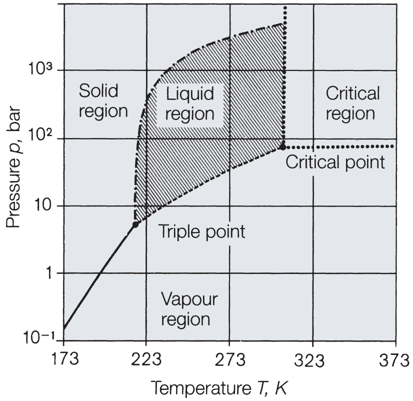
Contents

General properties of CO_2

Name	Carbon dioxide
Chemical formula	CO_2 (molecular structure: O=C=O)
English French German Spanish	Carbonic acid, dry ice Dioxyde de carbon, anhydride carbonique Kohlendioxid, Kohlensäure, Trockeneis Acido carbonico
Molecular weight	M_{CO2} = 44,011 kg/kmol
Molecular normvolume	V_{mn} = 22,263 m³/kmol
Specific gas constant	R_{CO2} = 0,1889 kJ/(kg · K)
Density of the gas (0 °C and 101.3 kPa)	ϱ_n = 1,977 kg/m³
Relative density of the gas (0 °C and 101.3 kPa, air = 1)	d = 1,529
Critical temperature	t_{crit} = 31 °C
Critical pressure	p_{crit} = 73,83 bar
Critical density	ϱ_{crit} = 466 kg/m³
Sublimation point	t_s = -78,9 °C bei 0,981 bar
Triple point	t_T = -56,6 °C bei 5,18 bar
Temperature of disintegration	more than app. 1200 °C, disintegration ratio nearly 0.032 vol %



Pressure-temperature-diagram

This phase diagram shows the three phases for carbon dioxide versus pressure and temperature.

Colour of gas	colourless
Reaction during combustion	non-combustible, fire-extinguishing agent
Reaction under normed conditions	stable molecule, used as an inert gas
Reaction with water	$CO_2 + H_2O = H_2CO_3$ Only 0.1 % of the dissolved CO_2-gas in water forms a weak acid (dissociation) named carbonic acid (H_2CO_3).The pH of carbonic acid varies with pressure and temperature from 3.7 to 3.3. This acidic nature makes CO_2 a convenient pH control medium in water treatment and neutralization of alkaline fluids.
Odour	odourless
Taste	neutral, slightly acidic
Toxicty	non toxic. In the german food directive the use of CO_2 is allowed for the production of food without declaration.
Threshold limit value	5000 ppm (In germany: The TLV is set at 5000 ppm as the maximum level wich can be tolerated over an eight hour shift, three times per shift 10000 ppm are allowed.) Consultant pertinent safety codes, standards and regulations applicable in your country.
Medical use	3 % to 5 % in breathing apparatus
Experiences with high concentrations in breathing air	3 % to 5 % CO_2: 100 % to 300 % increase in breathing rate 7 % to 10 % CO_2: Unconsciousness in cause of Oxygen deficient

Solid CO_2 (Dry ice)

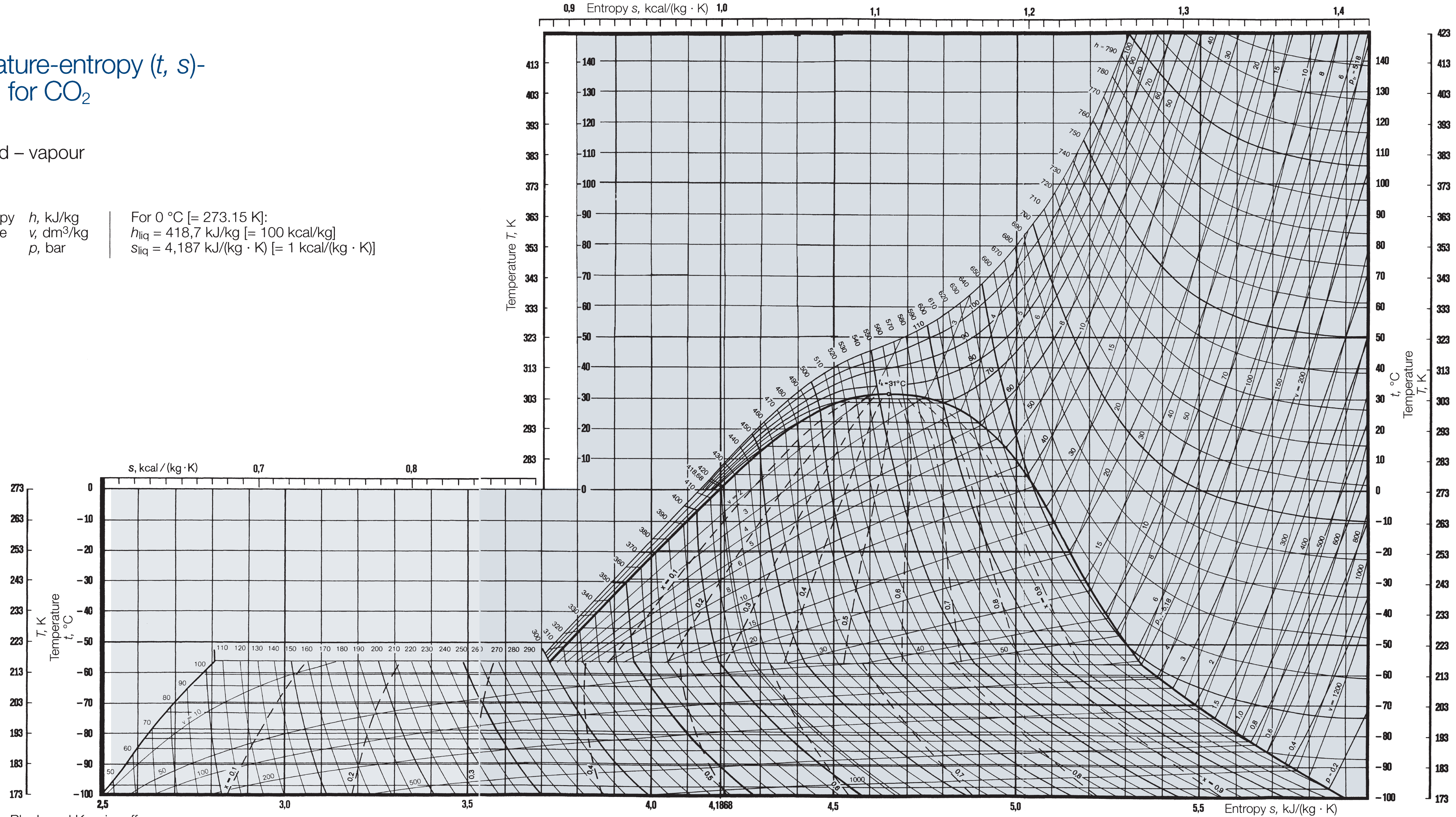
Sublimation temperature	-78.9 °C (149.25 K) at p = 0,9807 bar
Latent heat of sublimation (Enthalpy of sublimation)	r_s = 573,02 kJ/kg
Total enthalpy, increasing temperature from -78,9 °C to 0 °C	$q_o \approx$ 645 kJ/kg

PROPERTIES OF CARBON DIOXIDE

Temperature-entropy (*t, s*)-diagram for CO_2

solid – liquid – vapour

Specific enthalpy	*h*, kJ/kg	For 0 °C [= 273.15 K]:
Specific volume	*v*, dm^3/kg	h_{liq} = 418,7 kJ/kg [= 100 kcal/kg]
pressure	*p*, bar	s_{liq} = 4,187 kJ/(kg · K) [= 1 kcal/(kg · K)]



Plank and Kuprianoff

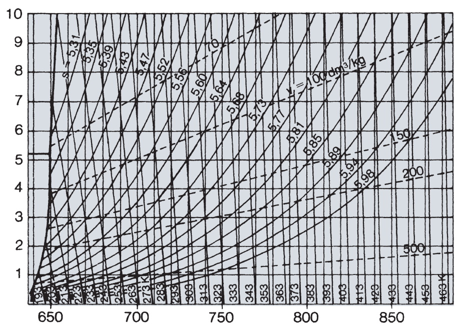
Pressure-enthalpy (*p*, *h*)-diagram for CO_2

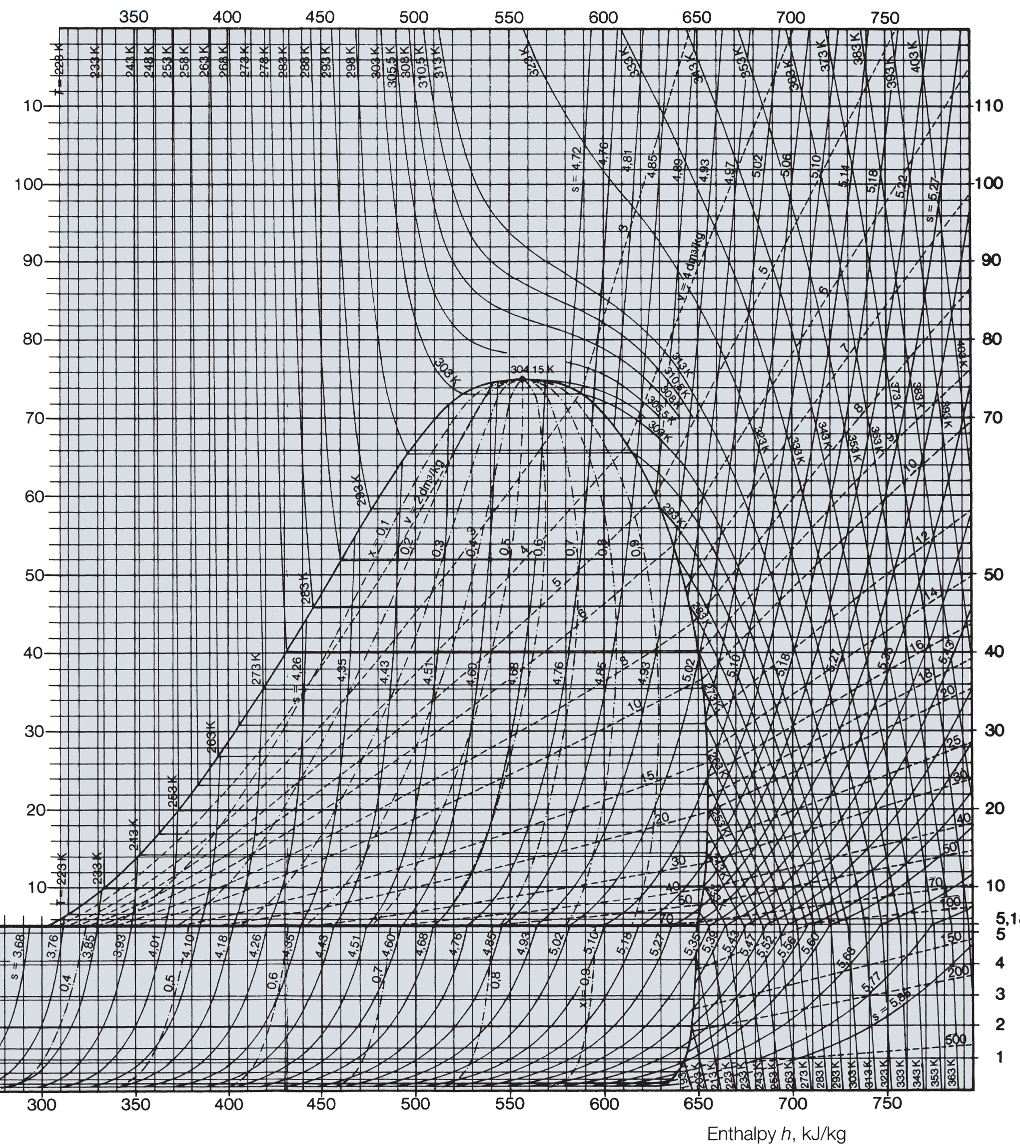
solid – liquid – vapour

according to Plank and Kuprianoff

at 273.15 K: h_{liq} = 418,7 kJ/kg
s_{liq} = 4,187 kJ/(kg · K)

For better overview in this diagram temperature is used as $T = (T_0 - 0{,}15)$ K except the critical temperature t_{crit} and the temperature of the triple point t_r.





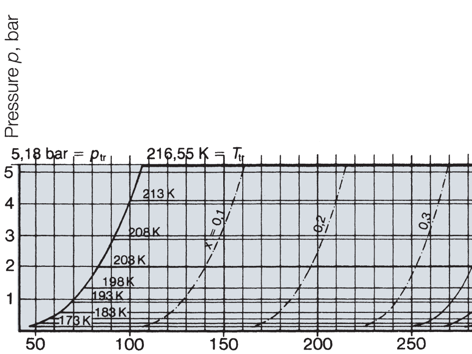


Table of properties for CO_2 liquid – vapour

(Table: CO_2-Properties of saturated solid, liquid and vapour)

t, °C	*T*, K	*p*, bar	Density, kg/m³		Enthalpy, kJ/kg		Latent heat of vaporization, kJ/kg	Entropy, kJ/(kg·K)	
			ϱ_{liq}	ϱ_{ga}	h_{liq}	h_{ga}		s_{liq}	s_{ga}
+31	304,15	73,83	466,0	466,0	558,94	558,94	0	4,6465	4,6465
+30	303,15	71,92	596,4	334,4	527,12	590,13	63,01	4,5444	4,7524
+25	298,15	64,32	705,8	240,0	497,39	616,84	119,45	4,4497	4,8504
+20	293,15	57,33	770,7	190,2	477,30	632,63	155,33	4,3827	4,9128
+15	288,15	50,93	817,9	158,0	460,97	641,29	180,32	4,3292	4,9551
+10	283,15	45,06	858,0	133,0	445,89	647,24	201,35	4,2781	4,9894
+ 5	278,15	39,72	893,1	113,0	431,66	650,84	219,18	4,2300	5,0179
0	273,15	34,85	924,8	96,3	418,68	653,69	235,01	4,1868	5,0472
−5	268,15	30,45	953,8	82,4	405,74	654,86	249,12	4,1480	5,0698
−10	263,15	26,47	980,8	70,5	393,94	655,65	261,71	4,0976	5,0924
−15	258,15	22,89	1006,1	60,2	382,84	656,07	273,23	4,0570	5,1154
−20	253,15	19,67	1029,9	51,4	372,33	656,36	284,03	4,0168	5,1380
−25	248,15	16,81	1052,6	43,8	362,28	655,95	293,67	3,9779	5,1615
−30	243,15	14,27	1074,2	37,0	352,49	655,49	303,00	3,9389	5,1854
−35	238,15	12,02	1094,9	31,2	342,82	654,77	311,95	3,8996	5,2096
−40	233,15	10,05	1115,0	26,2	333,23	653,62	320,62	3,8594	5,2348
−45	228,15	8,33	1134,5	21,8	323,64	652,68	329,04	3,8184	5,2607
−50	223,15	6,84	1153,5	18,1	314,05	651,34	337,29	3,7765	5,2883
−55	218,15	5,55	1172,1	14,8	304,46	649,88	345,42	3,7334	5,3172
−56,6	216,55	5,18	1177,9	13,8	301,32	649,33	348,01	3,7205	5,3273

at 0 °C: h_{liq} = 418,68 kJ/kg (= 100 kcal/kg) and s_{liq} = 4,1868 kJ/(kg · K)
[(= 1 kcal/(kg · K)]

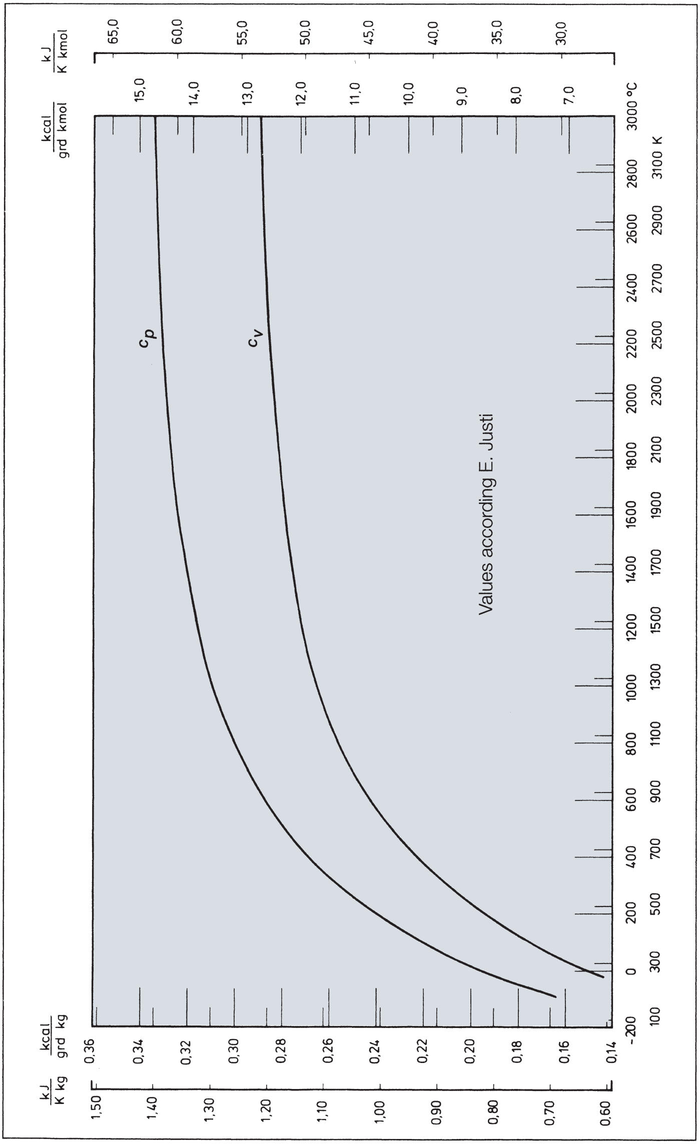
Table of properties for CO_2 solid – vapour

(Table: CO_2-Properties of saturated solid, liquid and vapour)

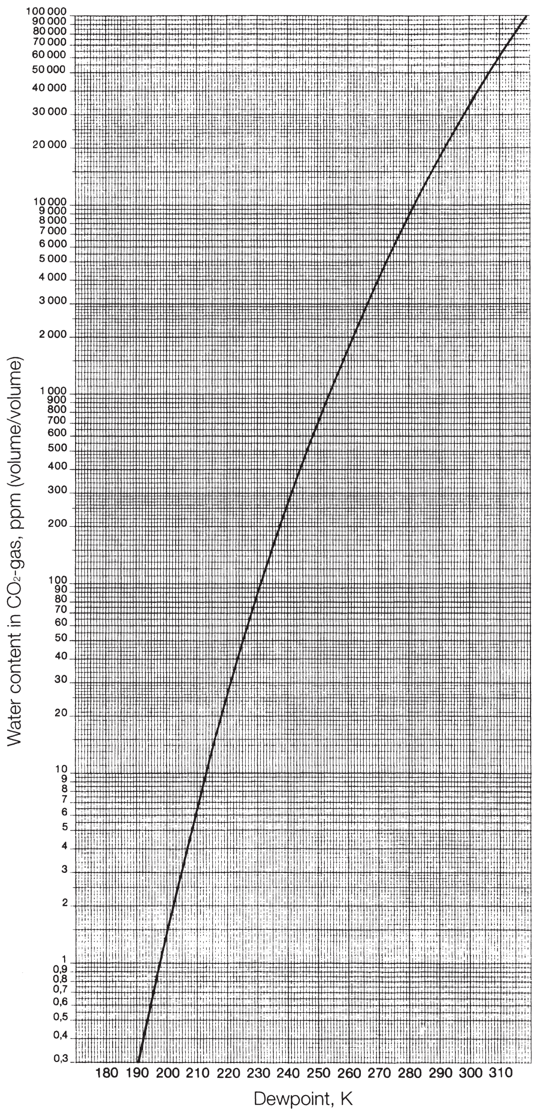
t, °C	*T*, K	*p*, bar	Density, kg/m³		Enthalpy, kJ/kg		Latent heat of vaporization, kJ/kg	Entropy, kJ/(kg·K)	
			ϱ_{sol}	ϱ_{ga}	h_{sol}	h_{ga}		s_{sol}	s_{ga}
−56,6	216,55	5,18	1512,4	13,84	105,55	649,33	543,78	2,8156	5,3273
−60	213,15	4,10	1521,9	10,97	99,27	649,21	549,94	2,7863	5,3671
−65	208,15	2,87	1534,6	7,74	89,97	648,41	558,44	2,7428	5,4261
−70	203,15	1,98	1546,1	5,39	82,02	646,94	564,92	2,7043	5,4860
−75	198,15	1,34	1556,5	3,71	75,07	645,02	569,95	2,6695	5,5467
−78,9	194,25	0,98	1564,0	2,74	70,05	643,18	573,13	2,6435	5,5948
−80	193,15	0,896	1566,1	2,51	68,71	642,63	573,92	2,6373	5,6095
−85	188,15	0,584	1574,8	1,672	62,72	639,99	577,27	2,6059	5,6748
−90	183,15	0,372	1582,2	1,087	56,90	637,06	580,16	2,5749	5,7435
−95	178,15	0,231	1588,9	0,693	51,20	633,97	582,77	2,5431	5,8150
−100	173,15	0,139	1595,2	0,428	45,55	630,74	585,19	2,5104	5,8908

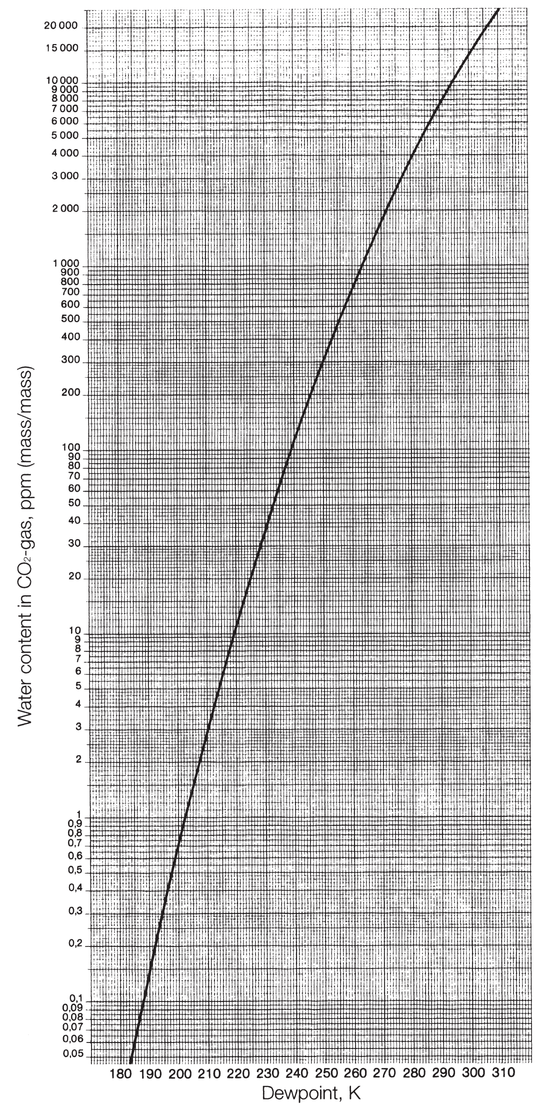
at 0 °C: h_{liq} = 418,68 kJ/kg (= 100 kcal/kg) and s_{sol} = 4,1868 kJ/(kg · K)
[(= 1 kcal/(kg · K)]

Specific heat capacity of CO_2



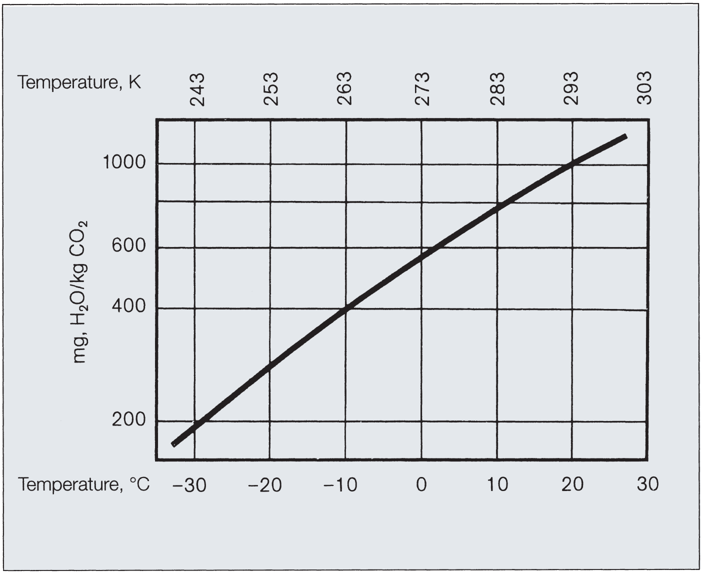
Water content in CO_2-gas, vs. dewpoint





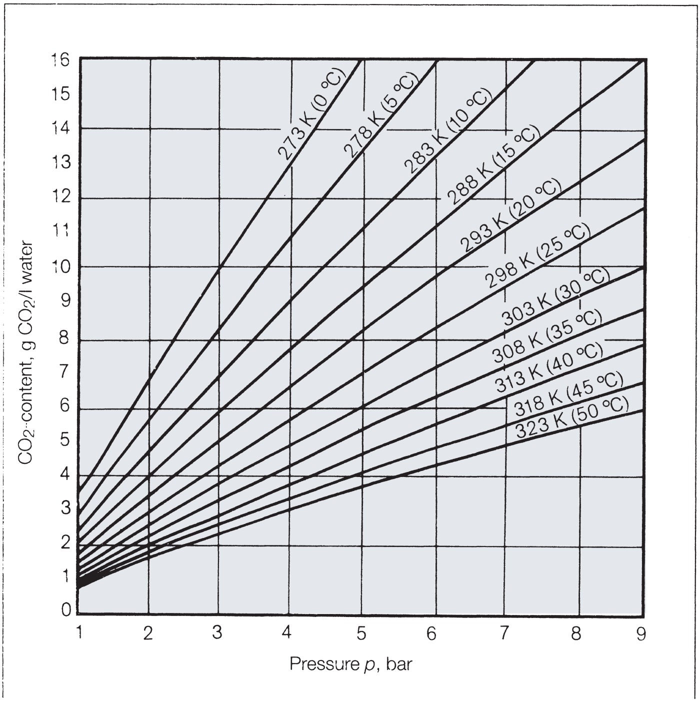
Values at 1,013 bar. Information about dew point vs. higher pressures at …

Solubility of water in liquid CO_2



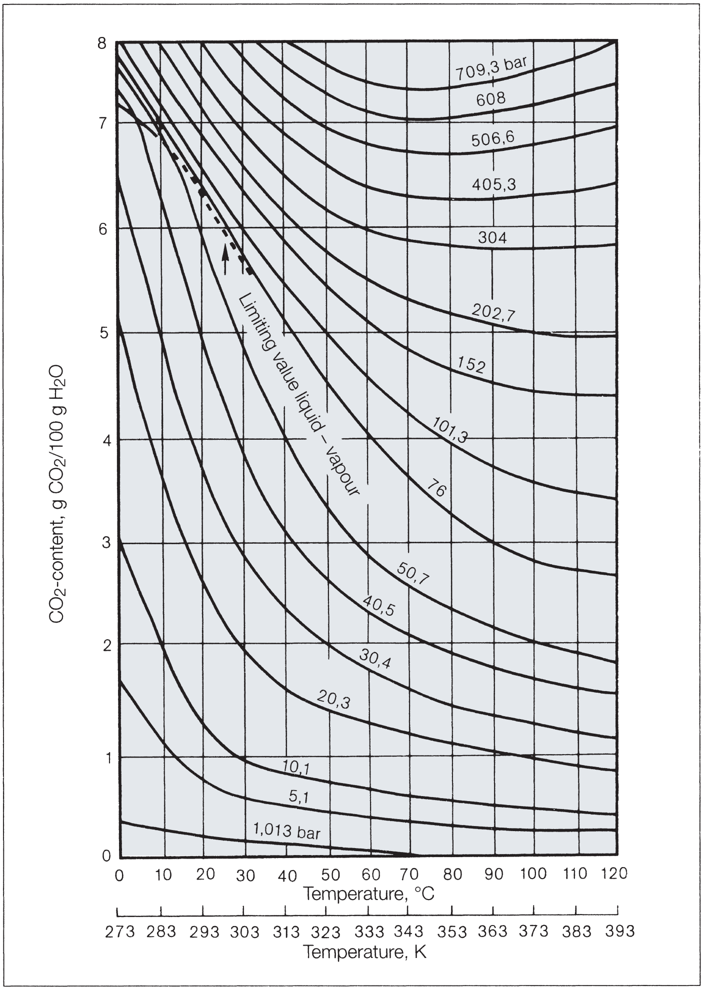
Solubility of CO_2 in water

versus temperature and pressure



Solubility of CO_2 in water

versus temperature and high pressure



Solubility of CO_2

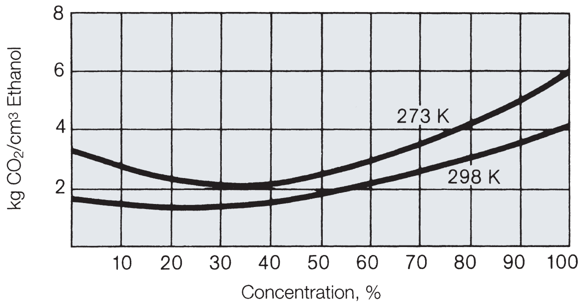
in Ethanol and other organic liquids

α_L in $\frac{\text{cm}^3 \text{ dissolved } CO_2 \text{ under normed conditions}}{\text{cm}^3 \text{ solvent} \cdot \text{bar}}$

λ_L in $\frac{\text{cm}^3 \text{ dissolved } CO_2 \text{ under normed conditions}}{\text{g solvent} \cdot \text{bar}}$

Solvent		Temperature, °C							
		−80		−60		−40		−20	
		α_L	λ_L	α_L	λ_L	α_L	λ_L	α_L	λ_L
acetone	$CH_3\ CO\ CH_3$	424	469		129,5	43,4	51		24,5
ethanol	$CH_3\ CH_2\ OH$	88,8	102	35,3	41,2	24,2	28,6		
benzene	$C_6\ H_6$								
butanol – (2)	$CH_3\ CH\ OH\ CH_2\ CH_3$								
butyric acid	$CH_3\ CH_2\ CH_2\ COOH$								
chloroform	$CH\ Cl_3$								
cumene	$C_6\ H_5\ CH\ (CH_3)_2$								
cyclohexane	$(CH_2)_6$								
decalin	$C_{10}\ H_{18}$							1,97	2,14
diethyl ether	$(C_2\ H_5)_2\ O$		306		92		36,7		17,8
1,2-dibromoethane	$(CH_2\ Br)_2$								
dimethylformamide	$(CH_3)_2\ CONH$								
d-limonene	$C_{10}\ H_{16}$								
acetic acid	$CH_3\ COOH$								
methyl acetate	$CH_3\ COOCH_3$		357		103		41,8		20,9
glycerol	$CH_2\ OHCH\ OHCH_2\ OH$								
heptane	$C_7\ H_{16}$								
methanol	$CH_3\ OH$	197	224		67	21,2	25	9,7	11,6
propionic acid	$CH_3\ CH_2\ COOH$								
carbon disulphide	CS_2								
carbon tetrachloride	$C\ Cl_4$								
toluene	$C_6\ H_5\ CH_3$		21,4	8,4	8,9	4,1	4,5	2,8	3,1
trichloroethylene	$C_2\ HCl_3$	38,5	25,5			12,8	8,2	6,4	4,3
xylol	$C_6\ H_4\ (CH_3)_2$			7,5	8,0	4,6	5	2,4	2,7

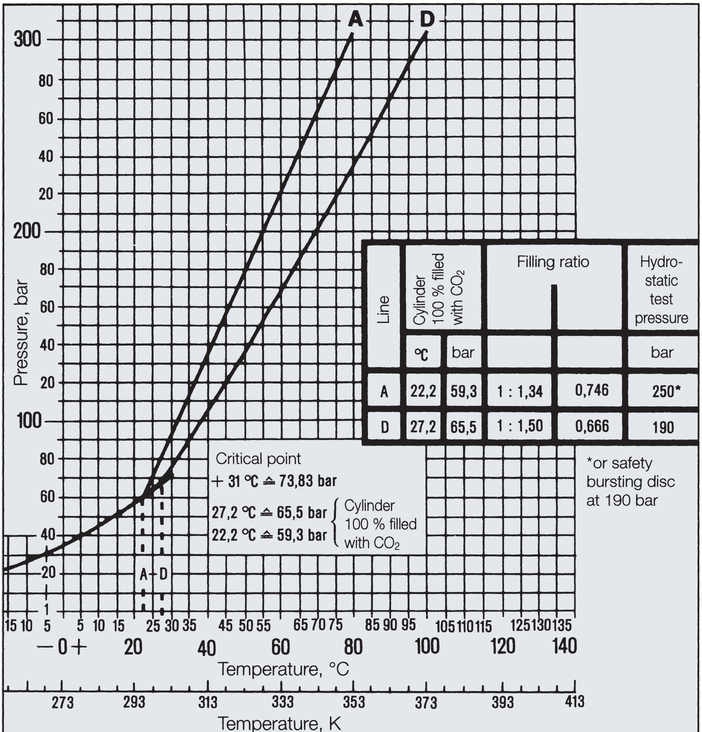
Solubility of CO_2 in Ethanol



Temperature, °C															
0		10		15		20		25		30		35		40	
α_L	λ_L	α_L	λ_L	α_L	λ_L	α_L	λ_L	α_L	λ_L	α_L	λ_L	α_L	λ_L	α_L	λ_L
10,9	13,3	8,6	10,7		6,6		8,4				6,7			4,2	5,5
4,3	5,4	3,6	4,4			2,91	3,7			2,6	3,3				
		2,6	4	2,54	2,87	2,34	2,66	2,4	2,74	2,30	2,64	2,14	2,48		
				1,95	2,42	1,80	2,24	1,67	2,09						
				3,82	3,97	3,46	3,61	3,15	3,29						
				3,70	2,47	3,39	2,27	3,10	2,09		1,90		1,5		
				1,86	2,13	1,73	2,01	1,61	1,88						
								1,56	2,01						
1,4	1,5					1,11	1,25	1,0		0,94		0,88		0,81	0,94
	9,8		8				6,4								
				2,27	1,03	2,11	0,97	1,95	0,90	1,81	0,84	1,62	0,75		
								4,5	4,8						
				1,90	2,24	1,77	2,09	1,63	1,94						
				5,25	4,99	4,72	4,49	4,23	4,05		3,8		3,4		
	11,7		9,4				7,5				6,1				
								0,03	0,02						
						1,95	2,86	1,83	2,68			1,60	2,39		
5,2	6,4		5,1			3,3	4,2				3,7			2,5	3,3
				4,48	4,48	4,07	4,09	3,69	3,72						
				0,89	0,69	0,82	0,64	0,79	0,62						
								2,44	1,54					2,3	1,4
3,21	3,6	3,02	3,5	2,40	2,75	2,7	3,1	2,18	2,53	2,5	2,9				
3,8	2,5														
1,7	1,9			2,20	2,53	2,04	2,36	1,89	2,19						

Pressure in cylinders filled with CO_2

vs. temperature and filling ratio



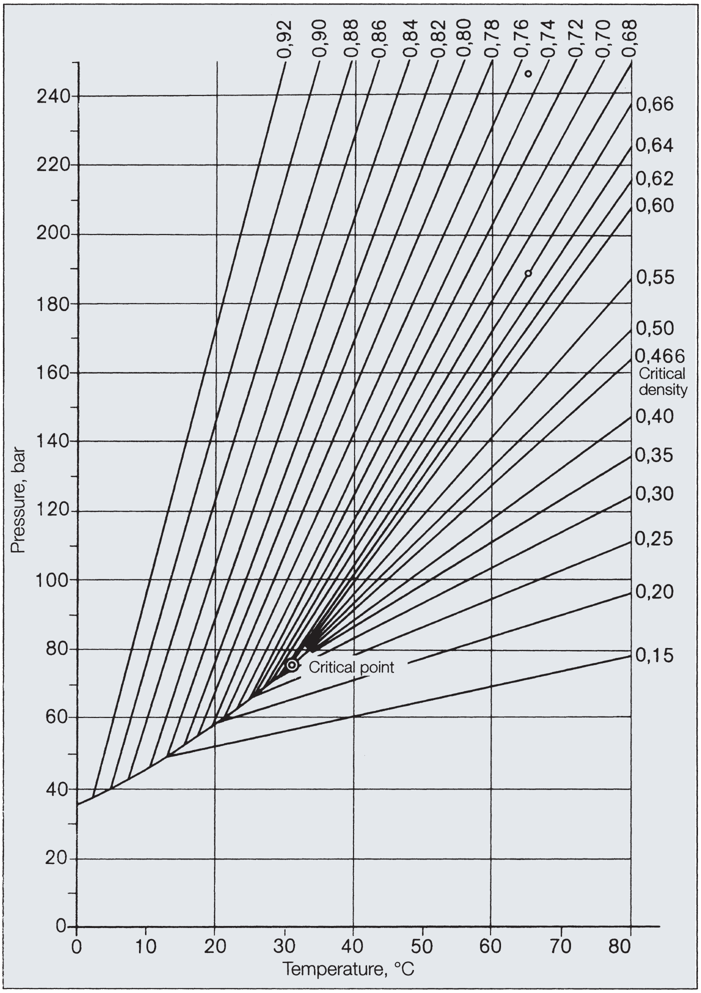
Line	Cylinder 100 % filled with CO_2		Filling ratio		Hydro-static test pressure
	°C	bar			bar
A	22,2	59,3	1 : 1,34	0,746	250*
D	27,2	65,5	1 : 1,50	0,666	190

*or safety bursting disc at 190 bar

The pressure in cylinders is not proportional to the weight of the contents. Under low temperature conditions (winter) the pressure in CO_2-cylinders will decrease significantly. Measurement of contents is only possible by weighing.

Isochores for CO_2

(equal level of density)



Specific volume of CO_2

in dm^3 vs. different temperature and pressure

Temperature		Pressure, bar								
°C	K	1	2	3	4	5	6	7	8	9
−30	243,15	455	225	149	110	87,2	71,8	60,8	52,6	46,2
−20	253,15	474	235	155	115	91,4	75,4	64,0	55,4	48,7
−15	258,15	484	240	159	118	93,5	77,2	65,6	56,8	50,0
−10	263,15	494	245	162	120	95,6	79,0	67,1	58,2	51,3
− 5	268,15	503	250	165	123	97,6	80,7	68,6	59,6	52,5
0	273,15	513	255	169	125	100	82,4	70,1	60,9	53,7
5	278,15	522	259	172	128	102	84,2	71,6	62,2	54,9
10	283,15	532	264	175	131	104	85,9	73,1	63,6	56,1
15	288,15	541	269	178	133	106	87,6	74,6	64,9	57,3
20	293,15	551	274	182	135	108	89,3	76,1	66,2	58,5
25	298,15	561	279	185	138	110	91,0	77,6	67,5	59,7
30	303,15	570	284	188	140	112	92,7	79,0	68,8	60,8
35	308,15	580	289	191	143	114	94,4	80,5	70,1	62,0
40	313,15	589	293	195	145	116	96,0	82,0	71,4	63,2
45	318,15	599	298	198	148	118	97,7	83,4	72,7	64,3
50	323,15	608	303	201	150	120	99,4	84,8	73,9	65,4

Temperature		Pressure, bar								
°C	K	55	60	65	70	75	80	85	90	95
−30	243,15	0,92	0,92	0,92	0,91	0,91	0,91	0,91	0,91	0,91
−20	253,15	0,96	0,95	0,95	0,95	0,95	0,95	0,95	0,94	0,94
−15	258,15	0,98	0,98	0,97	0,97	0,97	0,97	0,97	0,96	0,96
−10	253,15	1,00	1,00	1,00	0,99	0,99	0,99	0,99	0,98	0,98
− 5	268,15	1,03	1,03	1,02	1,02	1,02	1,02	1,01	1,01	1,01
0	273,15	1,06	1,06	1,05	1,05	1,05	1,04	1,04	1,04	1,03
5	278,15	1,10	1,09	1,09	1,08	1,08	1,07	1,07	1,06	1,06
10	283,15	1,15	1,14	1,13	1,13	1,12	1,11	1,11	1,10	1,09
15	288,15	1,21	1,20	1,19	1,17	1,16	1,16	1,15	1,14	1,13
20	293,15	5,72	1,29	1,33	1,26	1,24	1,22	1,21	1,19	1,18
25	298,15	6,24	5,19	4,44	1,38	1,33	1,30	1,28	1,26	1,24
30	303,15	6,85	5,78	4,72	3,52	2,17	1,86	1,50	1,39	1,34
35	308,15	7,29	6,27	5,33	4,41	3,46	2,71	1,82	1,56	1,47
40	313,15	7,67	6,68	5,81	5,01	4,24	3,43	2,50	2,16	1,88
45	318,15	8,03	7,05	6,19	5,43	4,74	4,07	3,40	2,90	2,45
50	323,15	8,36	7,38	6,54	5,80	5,14	4,53	3,98	3,45	2,96

Values under the line for gas, above the line for condensate.

Temperature		Pressure, bar								
°C	K	10	15	20	25	30	35	40	45	50
−30	243,15	41,0	0,96	0,93	0,93	0,93	0,92	0,92	0,92	0,92
−20	253,15	43,4	27,2	0,97	0,97	0,97	0,96	0,96	0,96	0,96
−15	258,15	44,6	28,1	20,4	0,99	0,99	0,99	0,99	0,98	0,98
−10	263,15	45,7	29,0	20,5	15,3	1,05	1,01	1,01	1,01	1,01
− 5	268,15	46,9	29,8	21,2	16,0	12,3	1,04	1,04	1,04	1,03
0	273,15	48,0	30,7	21,9	16,6	12,9	1,08	1,08	1,07	1,07
5	278,15	49,1	31,5	22,6	17,2	13,5	10,8	1,12	1,11	1,11
10	283,15	50,2	32,3	23,2	17,8	14,1	11,3	9,19	1,16	1,21
15	288,15	51,3	33,0	23,9	18,3	14,6	11,9	10,2	8,01	6,48
20	293,15	52,3	33,8	24,5	18,9	15,1	12,4	10,7	8,53	7,06
25	298,15	53,4	34,6	25,1	19,4	15,6	12,8	11,1	9,18	7,59
30	303,15	54,5	35,3	25,7	19,9	16,1	13,3	11,5	9,44	8,04
35	308,15	55,5	36,1	26,3	20,5	16,5	13,7	11,9	9,84	8,45
40	313,15	56,6	36,8	26,9	21,0	17,0	14,1	12,3	10,2	8,83
45	318,15	57,6	37,5	27,5	21,4	17,4	14,5	12,7	10,6	9,19
50	323,15	58,6	38,3	28,1	21,9	17,8	14,9	13,4	10,9	9,52

Temperature		Pressure, bar								
°C	K	100	150	200	250	300	350	400	450	500
−30	243,15	0,91	0,90	0,89	0,88	0,87	0,86	0,86	0,85	0,84
−20	253,15	0,94	0,93	0,91	0,90	0,89	0,88	0,88	0,87	0,86
−15	258,15	0,96	0,94	0,93	0,92	0,91	0,90	0,89	0,88	0,87
−10	253,15	0,98	0,96	0,95	0,93	0,92	0,91	0,90	0,89	0,88
− 5	268,15	1,00	0,98	0,96	0,94	0,93	0,92	0,91	0,90	0,89
0	273,15	1,03	1,00	0,98	0,96	0,95	0,94	0,92	0,91	0,91
5	278,15	1,06	1,02	1,00	0,98	0,96	0,95	0,94	0,93	0,92
10	283,15	1,09	1,05	1,02	1,00	0,98	0,97	0,95	0,94	0,93
15	288,15	1,13	1,08	1,04	1,02	1,00	0,98	0,97	0,95	0,94
20	293,15	1,17	1,11	1,07	1,04	1,02	1,00	0,98	0,97	0,95
25	298,15	1,23	1,14	1,09	1,06	1,03	1,01	1,00	0,98	0,97
30	303,15	1,31	1,18	1,12	1,08	1,06	1,03	1,01	1,00	0,98
35	308,15	1,42	1,23	1,16	1,11	1,08	1,05	1,03	1,01	0,99
40	313,15	1,70	1,29	1,19	1,14	1,10	1,07	1,05	1,03	1,01
45	318,15	2,08	1,35	1,23	1,17	1,12	1,09	1,06	1,04	1,02
50	323,15	2,54	1,44	1,28	1,20	1,15	1,11	1,08	1,06	1,04

Density of CO_2

in kg/m³ at different temperatures and pressures

t, °C / p, bar	-50	-40	-30	-20	-10	0	10
(K)	223,15	233,15	243,15	253,15	263,15	273,15	283,15
1	2,403	2,296	2,198	2,109	2,026	1,951	1,880
2	4,873	4,646	4,442	4,255	4,085	3,928	3,784
3	7,414	7,055	6,733	6,442	6,177	5,934	5,711
4	10,034	9,526	9,075	8,669	8,303	7,969	7,663
5	12,739	12,064	11,470	10,941	10,465	10,033	9,640
6	15,538	14,675	13,923	13,258	12,665	12,129	11,643
7	1155,755	17,364	16,437	15,625	14,904	14,258	13,673
8	1155,992	20,139	19,016	18,043	17,184	16,419	15,731
9	1156,230	23,008	21,667	20,515	19,509	18,617	17,818
10	1156,467	25,982	24,394	23,046	21,879	20,851	19,934
20	1158,813	1119,813	1078,048	1032,125	48,795	45,648	43,035
30	1161,118	1122,604	1081,518	1036,625	985,771	77,333	71,056
40	1163,384	1125,334	1084,890	1040,948	991,661	933,318	108,323
50	1165,612	1128,007	1088,171	1045,111	997,231	941,517	870,489
60	1167,805	1130,627	1091,366	1049,128	1002,523	949,064	883,203
70	1169,963	1133,194	1094,480	1053,011	1007,569	956,075	894,280
80	1172,089	1135,713	1097,519	1056,770	1012,393	962,634	904,154
90	1174,182	1138,185	1100,487	1060,416	1017,020	968,806	913,099
100	1176,244	1140,613	1103,388	1063,955	1021,468	974,642	921,302
200	1195,392	1162,802	1129,374	1094,812	1058,791	1020,927	980,760
300	1212,373	1182,053	1151,308	1119,963	1087,853	1054,818	1020,700
400		1199,169	1170,456	1141,446	1112,039	1082,149	1051,709
500		1214,648	1187,545	1160,335	1132,943	1105,317	1077,420

t, °C / p, bar	20	30	40	50	60	70	80
(K)	293,15	303,15	313,15	323,15	333,15	343,15	353,15
1	1,815	1,754	1,697	1,644	1,594	1,5474	1,5031
2	3,650	3,525	3,409	3,301	3,200	3,1047	3,0150
3	5,505	5,314	5,137	4,971	4,817	4,6719	4,5355
4	7,381	7,121	6,880	6,655	6,445	6,2493	6,0650
5	9,279	8,946	8,638	8,352	8,086	7,8369	7,6034
6	11,198	10,790	10,413	10,063	9,738	9,4348	9,1508
7	13,140	12,653	12,203	11,788	11,402	11,0433	10,7074
8	15,106	14,535	14,011	13,527	13,079	12,6624	12,2733
9	17,095	16,438	15,836	15,281	14,768	14,2923	13,8485
10	19,110	18,361	17,678	17,050	16,470	15,9332	15,4332
20	40,806	38,866	37,153	35,621	34,238	32,9802	31,8283
30	66,202	62,250	58,925	56,060	53,548	51,3167	49,3119
40	97,510	89,782	83,774	78,869	74,734	71,1683	68,0394
50	140,532	123,995	113,019	104,805	98,258	92,8294	88,2032
60	784,972	171,486	149,201	135,098	124,789	116,6919	110,0440
70	810,026	268,984	* 198,315	171,921	155,337	143,2873	133,8636
80	828,801	699,939	281,328	219,584	191,481	173,3417	160,0380
90	844,105	743,739	484,090	287,528	235,732	207,8317	189,0221
100	857,159	771,414	622,640	389,912	291,658	247,9632	221,3241
200	937,723	891,127	840,193	784,233	723,192	658,6143	594,1590
300	985,353	948,648	910,500	870,900	829,966	788,0056	745,5433
400	1020,670	989,008	956,729	923,879	890,554	856,9055	823,1460
500	1049,235	1020,764	992,028	963,072	933,967	904,8086	875,7146

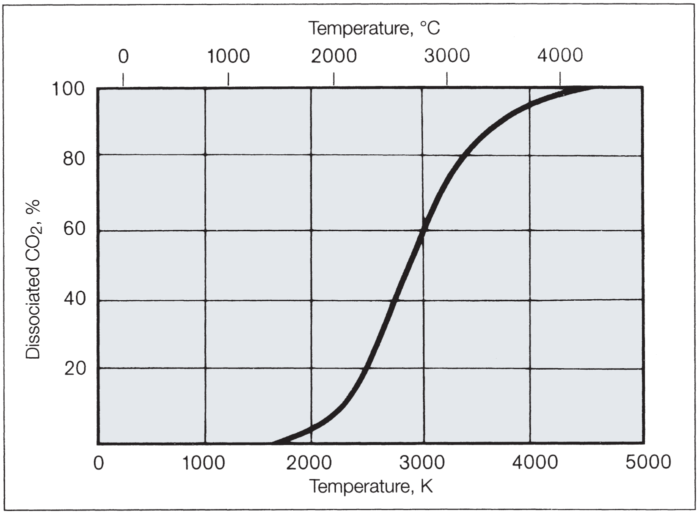
*) Critical point

p, bar \ t, °C (K)	90 (363,15)	100 (373,15)	200 (473,15)	300 (573,15)	400 (673,15)	500 (733,15)	600 (873,15)
1	1,4613	1,4218	1,1198	0,9238	0,7864	0,6846	0,6061
2	2,9304	2,8505	2,2417	1,8484	1,5729	1,3691	1,2121
3	4,4071	4,2859	3,3658	2,7737	2,3596	2,0535	1,8179
4	5,8916	5,7282	4,4920	3,6996	3,1464	2,7378	2,4235
5	7,3840	7,1775	5,6204	4,6262	3,9334	3,4221	3,0289
6	8,8843	8,6336	6,7508	5,5534	4,7205	4,1063	3,6342
7	10,3926	10,0969	7,8835	6,4813	5,5077	4,7904	4,2393
8	11,9090	11,5672	9,0182	7,4099	6,2950	5,4743	4,8442
9	13,4336	13,0446	10,1551	8,3391	7,0824	6,1582	5,4490
10	14,9664	14,5293	11,2941	9,2690	7,8699	6,84,20	6,0535
20	30,7677	29,7863	22,8004	18,6020	15,7509	13,6742	12,0890
30	47,4953	45,8372	34,5165	27,9944	23,6399	20,4949	18,1054
40	65,2574	62,7575	46,4390	37,4412	31,5339	27,3023	24,1020
50	84,1821	80,6331	58,5641	46,9375	39,4300	34,0948	30,0777
60	104,4213	99,5619	70,8868	56,4783	47,3253	40,8710	36,0318
70	126,1549	119,6536	83,4016	66,0585	55,2170	47,6293	41,9636
80	149,5915	141,0290	96,1015	75,6728	63,1022	54,3682	47,8721
90	174,9649	163,8144	108,9786	85,3160	70,9783	61,0864	53,7568
100	202,5164	188,1318	122,0235	94,9826	78,8425	67,7824	59,6169
200	534,2812	482,0222	258,4521	191,6980	156,2715	133,2510	116,7296
300	703,3082	662,1336	389,9362	284,4402	229,9006	195,2833	170,7922
400	789,5420	756,3960	497,5657	368,2514	297,9378	253,1158	221,4635
500	846,8254	818,2952	580,2124	440,8542	359,4118	306,3397	268,5790

p, bar \ t, °C (K)	700 (973,15)	800 (1073,15)	900 (1173,15)	1000 (1273,15)
1	0,5438	0,4931	0,4511	0,4156
2	1,0874	0,9860	0,9019	0,8311
3	1,6308	1,4787	1,3526	1,2464
4	2,1740	1,9713	1,8031	1,6614
5	2,7171	2,4636	2,2534	2,0763
6	3,2599	2,9556	2,7035	2,4910
7	3,8025	3,4475	3,1533	2,9055
8	4,3448	3,9392	3,6030	3,3198
9	4,8870	4,4306	4,0524	3,7339
10	5,4290	4,9218	4,5017	4,1478
20	10,8371	9,8224	8,9827	8,2762
30	16,2238	14,7013	13,4431	12,3850
40	21,5886	19,5585	17,8825	16,4743
50	26,9311	24,3937	22,3011	20,5441
60	32,2508	29,2067	26,6988	24,5945
70	37,5474	33,9973	31,0754	28,6253
80	42,8205	38,7654	35,4310	32,6367
90	48,0698	43,5108	38,7655	36,6287
100	53,2947	48,2334	44,0788	40,6012
100	104,1472	94,1756	86,0431	79,2641
300	152,3009	137,7244	125,8751	116,0176
400	197,6135	178,8381	163,5865	150,9017
500	240,0348	217,5232	199,2124	183,9660

Dissociation of CO_2

Normed pressure



Different pressures (in %)

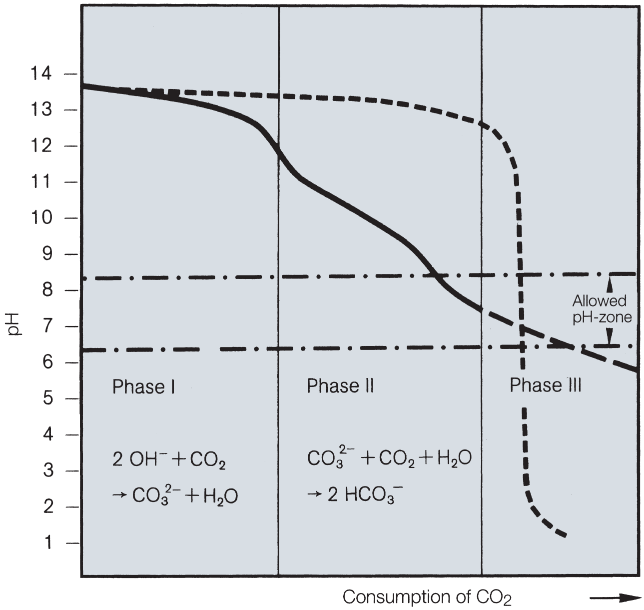
Temperature	Pressure			
K	0,1 bar	1 bar	10 bar	100 bar
1000	$5,31 \times 10^{-5}$	$2,47 \times 10^{-5}$	$1,14 \times 10^{-5}$	$5,31 \times 10^{-6}$
1500	$1,04 \times 10^{-1}$	$4,83 \times 10^{-2}$	$2,24 \times 10^{-2}$	$1,04 \times 10^{-2}$
2000	4,35	2,05	$9,60 \times 10^{-1}$	$4,45 \times 10^{-1}$
2500	33,5	17,6	8,63	4,09
3000	77,1	54,8	32,2	16,9
3500	93,7	83,2	63,4	39,8

From a chemical point of view CO_2 is a stable molecule. Disintegration starts at high temperatures above 1200 °C and Carbon monoxide and Oxygen are produced.

$$CO_2 + 283\ kJ \rightleftharpoons CO + 1/2\ O_2$$

Neutralisation

——— pure KOH with CO_2
- - - - - - pure KOH with mineral acid



The control limits in the diagram above indicate typical pH discharge consent levels for industrial effluent water.

The reaction formula with alkali (NaOH) are as follow (2 steps):

1. step: $2NaOH + CO_2 \rightleftharpoons Na_2CO_3 + H_2O$

2. step: $Na_2CO_3 + CO_2 + H_2O \rightleftharpoons 2NaHCO_3$

Definitions

Thermodynamic

The study of relationships between various forms of energy is called thermodynamics. All processes involve the conversion of energy from one form to another. Within chemistry, the most important purpose of thermodynamics to determine the equilibrium point of a chemical reaction and to predict whether a reaction is spontaneous under defined conditions. Thermodynamics cannot supply any information on the rate at which the reaction takes place.

General information

Every substance is described with the three thermodynamic functions: Volume, pressure and temperature. For every aggregate state, solid, liquid and vapour; if two states are known the third can be determined. The pressure-temperature-diagram shows the aggregate states for CO_2. Near the limiting value lines two states exist at the same time. At the triple point three phases can exist in an equilibrium at a given temperature and a given pressure. Above the critical point liquid and vapour state cannot be differentiated. Above it's critical temperature, a gas cannot liquefy and a liquid cannot continue to exist.

Enthalpy

Heat function at constant pressure. Enthalpy is sometimes also called the heat content of the system.

Symbol *H*, Unit kJ

As specific enthalpy:

Symbol *h*, Unit kJ/kg

Entropy

A measure of the degree of disorder in a system, where every change that occurs and results in an increase of disorder is said to be a positive change in entropy.
All spontaneous processes are accompanied by an increase in entropy („second law of thermodynamics").

Symbol *S*, Unit kJ/K

As specific entropy:

Symbol *s*, Unit kJ/(kg · K)

Molecular mass

The sum total of the individual atomic masses (see IUPAC-Definition of „1u“) of each atom in the molecule. For example CO_2:

C		12.011
O (2x)	15.999	31.998
		44.009

Density

The ratio of the mass of a substance to its volume, as quotient of mass and volume.

Symbol, Unit kg/m^3

Thermal capacity

The quantity of heat required to raise the temperature of the system one degree. Heat capacity is always a positive quantity. The quantity of heat added to a gaseous system is dependent upon whether heating has taken place at constant volume (C_v) or constant pressure (C_p).

Symbol C_p, C_v; Unit kJ/K

As specific thermal capacity

The amount of heat required to raise the temperature of 1 kg of a substance by 1 K. For ideal gases the quotient of c_p to c_v is constant.

Symbol c_p, c_v; Unit kJ/(kg · K)

Thermal conductivity

In a stationary gas all heat transfer is conductive. An example of this is the boundary layer immediately adjacent to a wall surface, such as a heat exchanger surface. The thermal conductivity of a gas is, in principle, independent of pressure but increases with rising temperature.

Symbol, Unit W/(m · K)

TLV

The TLV (threshold limit value) is the maximum level of air concentration of a gas which can be reasonable be tolerated over an eight hour shift for 40 hours a week. Consultant pertinent safety codes, standards and regulations applicable in your country.

Technical units and conversion tables

Decimal multiples and subdivisons of units

	Prefix	Symbol
10^{18}	Exa	E
10^{15}	Peta	P
10^{12}	Tera	T
10^{9}	Giga	G
10^{6}	Mega	M
10^{3}	Kilo	k
10^{2}	Hekto	h
10^{1}	Deka	da
10^{-1}	Dezi	d
10^{-2}	Zenti	s
10^{-3}	Milli	m
10^{-6}	Mikro	μ
10^{-9}	Nano	n
10^{-12}	Piko	p
10^{-15}	Femto	f
10^{-18}	Atto	a

Important constants

Avogadro constant	$N_A = 6{,}02252 \cdot 10^{26}$ kmol^{-1}
Universal gas constant	$R = 8{,}3143$ kJ/(kmol · K)
Molar gas constant	$V_o = 22{,}41383$ m^3/kmol
Normed pressure	$p_n = 101325$ Pa $= 1{,}01325$ bar
	$=$ (1 atm $=$ 760 Torr)
Normed temperature	$T_n = 273{,}15$ K $= 0$ °C

Important conversions

Temperature

From Temperature to Kelvin	T in K	$T = t + 273{,}15$
From Temperature to degree Celsius	t in °C	$t = {}^{5}/9\ (t_F - 32)$
From Temperature to degree Fahrenheit	t_F in °F	$t_F = {}^{9}/5\ t + 32$
From Temperature to degree Rankine	T_R in °R	$T_R = t_F + 459{,}69$

Pressure p

	Pa	bar	atm	Torr	at
1 Pa = 1 N/m² =	1	10^{-5}	$0{,}986923 \cdot 10^{-5}$	$0{,}750062 \cdot 10^{-2}$	$1{,}01972 \cdot 10^{-5}$
1 bar = 10^6 dyn/cm² =	10^5	1	0,986923	750,062	1,01972
1 atm = 760 Torr =	$1{,}01325 \cdot 10^5$	1,01325	1	760	1,033227
1 Torr =	$1{,}333224 \cdot 10^2$	$1{,}333224 \cdot 10^{-3}$	$1{,}315789 \cdot 10^{-3}$	1	$1{,}35951 \cdot 10^{-3}$
1 at = 1 kp/cm² = 10^4 kp/m² = 10 m WS =	$9{,}80665 \cdot 10^4$	0,980665	0,967841	735,559	1

1 lb/in² = 0,68948 η Pa = 68,948 mbar   1 mm Hg (Mercury column) = 133,322 Pa = 1,33322 mbar

Energy E

	J	kp m	kcal	kW h	PS h
1 J = 1 W s = 1 N m = 1 kg m²/s² = 10^7 erg =	1	0,101972	$2{,}38844 \cdot 10^{-4}$	$2{,}77778 \cdot 10^{-7}$	$3{,}77673 \cdot 10^{-7}$
1 kp m =	9,80665	1	$2{,}34228 \cdot 10^{-3}$	$2{,}72407 \cdot 10^{-6}$	$3{,}70370 \cdot 10^{-6}$
1 kcal =	$4{,}1868 \cdot 10^3$	426,935	1	$1{,}163 \cdot 10^{-3}$	$1{,}58124 \cdot 10^{-3}$
1 kW h =	$3{,}6 \cdot 10^6$	$3{,}670978 \cdot 10^5$	859,845	1	1,35962
1 PS h =	$2{,}647796 \cdot 10^6$	$2{,}7 \cdot 10^5$	632,416	0,735499	1

1 Btu = 0,251996 kcal = 1,055056 kJ (according international vapour table)

Power P

	W	kW	PS	HP	kcal/h
1 W = 1 J/s = 1 N m/s =	1	10^{-3}	$1{,}35962 \cdot 10^{-3}$	$1{,}34102 \cdot 10^{-3}$	0,859845
1 kW =	10^3	1	1,35962	1,34102	859,845
1 PS =	735,499	0,735499	1	0,986	632,416
1 HP = 550 lbf · ft/s =	745,7	0,7457	1,0138	1	641,197
1 kcal/h =	1,1630	$1{,}1630 \cdot 10^{-3}$	$1{,}58124 \cdot 10^{-3}$	$1{,}55958 \cdot 10^{-3}$	1

Specific thermal capacity *c*

	J/(kg · K)	kW h/(kg · K)	kcal/(kg · K)	cal/(g · K)	Btu/(lb · °F)
1 J/(kg · K) =	1	$2{,}7778 \cdot 10^{-7}$	$2{,}3885 \cdot 10^{-4}$	$2{,}3885 \cdot 10^{-4}$	$2{,}3885 \cdot 10^{-4}$
1 kW h/(kg · K) =	$3{,}6 \cdot 10^{6}$	1	859,845	859,845	859,845
1 kcal/(kg · K) =	$4{,}1868 \cdot 10^{3}$	$1{,}1630 \cdot 10^{-3}$	1	1	1
1 cal/(g · K) =	$4{,}1868 \cdot 10^{3}$	$1{,}1630 \cdot 10^{-3}$	1	1	1
1 Btu/(lb · °F) =	$4{,}1868 \cdot 10^{3}$	$1{,}1630 \cdot 10^{-3}$	1	1	1

Dynamic viscosity η

	Pa s	kg/(m · h)	kp s/m²	kp h/m²	lb - mass/(ft · s)
1 Pa s = 1 N s/m² =	1	3600	0,10197	$2{,}833 \cdot 10^{-5}$	0,6721
1 kg/(m · h) =	$2{,}778 \cdot 10^{-4}$	1	$2{,}833 \cdot 10^{-5}$	$78{,}68 \cdot 10^{-10}$	$18{,}67 \cdot 10^{-5}$
1 kp s/m² =	9,807	$3{,}5304 \cdot 10^{4}$	1	$2{,}778 \cdot 10^{-4}$	6,5919
1 kp h/m² =	$353{,}04 \cdot 10^{2}$	$127{,}09 \cdot 10^{6}$	3600	1	23730
1 lb - mass/(ft · s) =	1,488	5357	0,15175	$4{,}214 \cdot 10^{-5}$	1

1 lb - mass/fts = 0,03108 lb · force s/ft²

Kinematic viscosity ν

	St (Stokes)	m²/s	m²/h	ft²/s	ft²/h
1 St = 1 cm²/s (Stokes) =	1	10^{-4}	0,36	$1{,}0764 \cdot 10^{-3}$	3,875
1 m²/s =	10^{4}	1	3600	10,764	$3{,}875 \cdot 10^{4}$
1 m²/h =	2,778	$2{,}778 \cdot 10^{-4}$	1	$29{,}9 \cdot 10^{-4}$	10,764
1 ft²/s =	929;03	$9{,}2903 \cdot 10^{-2}$	334,45	1	3600
1 ft²/h =	0,25806	$25{,}806 \cdot 10^{-6}$	$9{,}2903 \cdot 10^{-2}$	$2{,}778 \cdot 10^{-4}$	1

This table can also be used for temperature conductivity *a* and diffusions coefficient *D*.

Thermal conductivity λ

	W/(m · K)	kcal/(m · h · K)	kJ/(m · h · K)	Btu · in/(ft² · h · °F)	Btu/(ft · h · °F)
1 W/(m · K) =	1	0,859845	3,6000	6,9335	0,5778
1 kcal/(m · h · K) =	1,163	1	4,1868	8,064	0,6719
1 kJ/(m · h · K) =	0,2778	0,23885	1	1,9262	0,1605
1 Btu · in/(ft² · h · °F) =	0,14423	0,1240	0,5192	1	0,08333
1 Btu/(ft · h · °F) =	1,73071	1,488	6,2300	12	1

Heat conducting coefficient α and heat-transmission coefficient k

	W/(m² · K)	W/(cm² · K)	kcal/(m² · h · K)	kJ/(m² · h · K)	Btu/(ft² · h · °F)
1 W/(m² · K) =	1	10^{-4}	0,859845	3,600	0,1761
1 W/(cm² · K) =	10^{4}	1	8598,45	3600	$0,1761 \cdot 10^{4}$
1 kcal/(m² · h · K) =	1,163	$1,163 \cdot 10^{-4}$	1	4,1868	0,2048
1 kJ/(m² · h · K) =	0,2778	$0,2778 \cdot 10^{-4}$	0,23885	1	0,4893
1 Btu/(ft² · h · °F) =	5,678	$5,678 \cdot 10^{-4}$	4,8823	2,0438	1

Heat flow q

	W/m²	kcal/(m² · h)	kJ/(m² · h)	Btu/(in² · s)	Btu/(ft² · h)
1 W/m² = 1 J (s · m²) =	1	0,859845	3,600	$6,1151 \cdot 10^{-7}$	0,317
1 kcal/(m² · h) =	1,163	1	4,1868	$71,119 \cdot 10^{-8}$	0,36868
1 kJ/(m² · h) =	0,2778	0,23885	1	$1,699 \cdot 10^{-7}$	0,08806
1 Btu/(in² · s) =	$1,635 \cdot 10^{6}$	$1,405 \cdot 10^{6}$	$5,8858 \cdot 10^{6}$	1	$51,84 \cdot 10^{4}$
1 Btu/(ft² · h) =	3,15454	2,713	11,356	$1,929 \cdot 10^{-6}$	1

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Special regulations are given for the use of Carbon dioxide in each country. This document should not be confused with federal or national regulations, insurance requirements or national safety codes. For handling, transportation and storage, consultant pertinent safety codes, standards, and regulations in your country. Further informations will be given from Union Engineering A/S.

Informations from editor

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