NOTATION

A = cross-sectional area, L
a = surface area per unit volume, L^{-1}
b_1, b_2, etc. = constants
c = fractional concentration of aromatics in raffinate
c' = fractional concentration of aromatics in extract
D = drop diameter, L
E = extract oil flow, L^3/θ
f = fractional holdup of oil in mixing zone
G = oil flow per unit cross section, L/θ
g = acceleration of gravity, L/θ^2
I = raffinate-oil refractive index
I' = extract-oil refractive index
K = over-all mass transfer coefficient
k = individual film mass transfer coefficient
L = mixing section length or distance, L
m = equilibrium line slope
R = raffinate oil flow, L^3/θ
$R_s = S_x/S_y$ = phase solubility ratio
S = fraction of oil in phase
s = operating line slope in extraction
X = raffinate-phase flow, L^3/θ
Y = extract-phase flow, L^3/θ
ε_x = entrainment of raffinate phase in extract phase, L^3/L^3
ε_y = entrainment of extract phase in raffinate phase, L^3/L^3
ε_f = entrainment factor
η_a = apparent efficiency
η_c = cocurrent efficiency
η_M = Murphree efficiency
η_o = over-all efficiency
μ = absolute viscosity, $M/L\theta$
υ = kinematic viscosity, L^2/θ
ρ = density, M/L^3
θ = time

Subscripts

E = extract
F = feed
R = raffinate
o, x = raffinate phase
y = extract phase

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Thermodynamic Properties of Air

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In recent years the development of new sources and uses for high pressure air has emphasized the need for thermodynamic charts covering a wider pressure range than do the published charts. To fill this need, the chart by Williams (*9*) has been extended to cover pressures from 1 to 1,000 atm. in the temperature range of 300° to 675°R. Previously published temperature-entropy charts for air, all including isoenthalpic lines, are those of

	Temp., °R.	Press., atm.
Gerhart (*2*)..	460 to 1,010	1 to 238
N.D.R.C. (*8*).	140 to 760	1 to 238
Williams (*9*).	125 to 500	1 to 220

The charts of both Gerhart (*2*) and Williams (*9*) were calculated from Joule-Thompson expansion data; the values obtained are also given in tabular form. The method for determining the values for the N.D.R.C. (*8*) chart is not reported; this chart is small and difficult to use and tabular results are not given.

The additional values required for the chart presented here were calculated by the thermodynamic techniques outlined below and serve as an independent check on the calculations of both Williams (*9*) and Gerhart (*2*), which differ by less than 0.5% from those given in this paper.

The sources of the data utilized and the range over which each source applied are as follows:

	Temperature, °R.	Pressure, atm.
Amagat (*1*)	460 to 675	100 to 1,000
Holborn and Otto (*4, 5*)	492 to 675	1 to 100
Nelson, Obert "Z" charts (*7*)	300 to 500	220 to 1,000
Williams (*9*)	125 to 500	1 to 220

There are some P.V. data by Koch (*6*) and Witkowski (*10*) in the range 300° to 492°R. and 1 to 220 atm. but they are not of sufficient quantity to be usable. The data which were available, as P.V. data or as Z charts, required calculations and graphical solutions to give the required enthalpy and entropy values (*3*). As a basis for construction of the chart the value of zero entropy has been arbitrarily assigned to saturated liquid air at 1-atm. pressure, and an enthalpy value of 100 B.t.u./lb. has been arbitrarily assigned to gaseous air at zero pressure and 0°R.

The enthalpy of the air at any pressure and temperature is obtained from Equations (1), (2), (3), and (4).

$$H_{PT} = H^*_T - (H^* - H_P)_T \qquad (1)$$

$$H^*_T = \int_0^T C^*_p \, dT + 100 \qquad (2)$$

$$(H^* - H_P)_T = \int_0^P \frac{RT^2}{P}\left(\frac{\partial Z}{\partial T}\right)_P dP \qquad (3)$$

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Note: Figure 1, measuring 17 by 22 in., is available from the authors at a cost of 25 cents for handling and mailing.

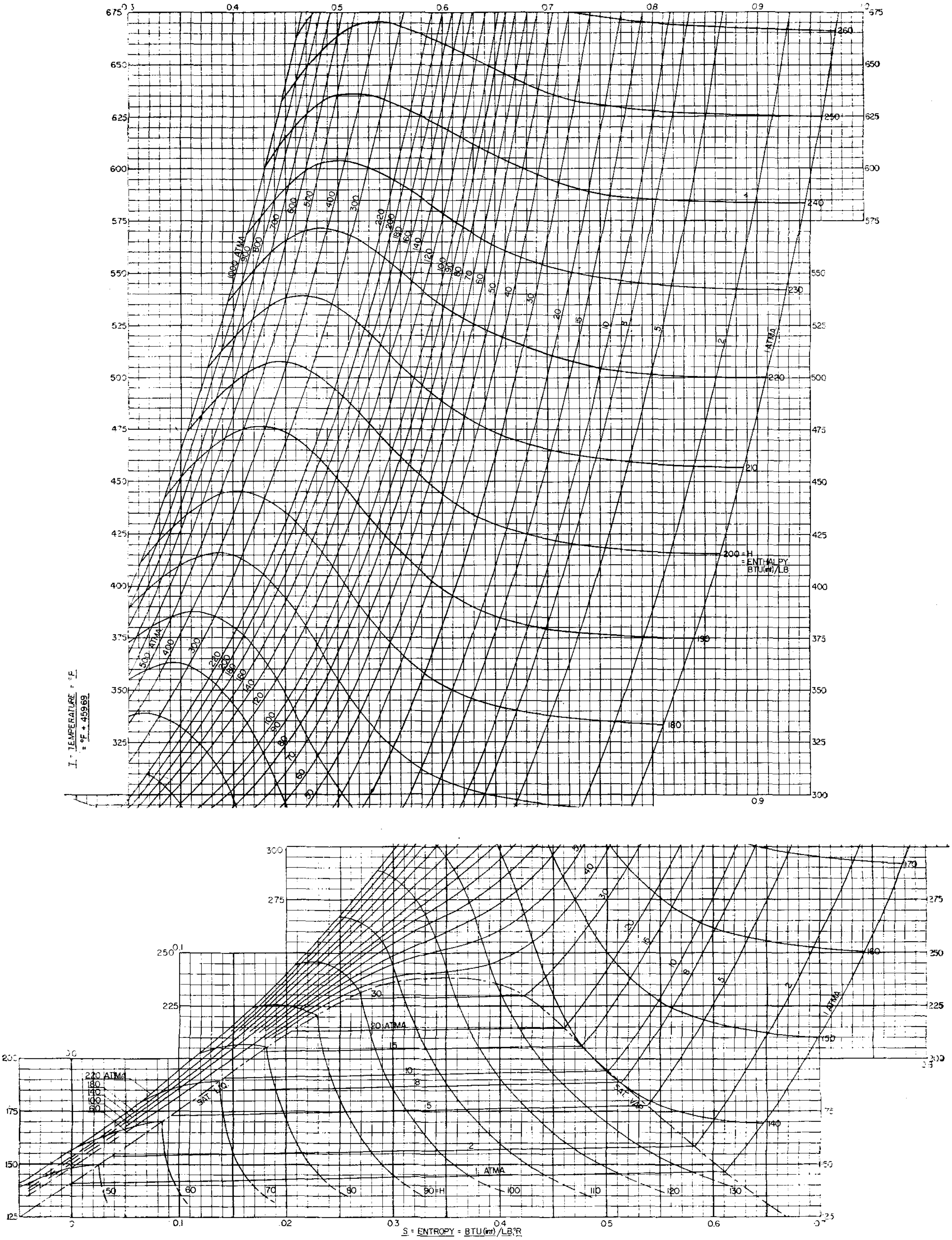

Fig. 1. Air-temperature chart: upper, 50 to 500 atm.; lower, 1 to 50 atm.

TABLE 1.—THERMODYNAMIC PROPERTIES OF AIR

T = °F.
P = pressure, atm.
H = enthalpy, B.t.u. (int.)/lb.
S = entropy, B.t.u. (int.)/(lb.) (°R.)

P	T	−126	−76	−40	−4	32	78	104	140	176
1	H	....	....	....	....	217.84	226.47	235.23	243.82	252.51
	S	....	....	....	....	0.9037	0.9226	0.9361	0.9507	0.9644
5	H	....	....	....	....	217.49	226.19	234.96	243.70	252.39
	S	....	....	....	....	0.7925	0.8115	0.8251	0.8398	0.8542
10	H	....	....	....	....	216.88	225.70	234.59	243.38	252.69
	S	....	....	....	....	0.7438	0.7630	0.7768	0.7916	0.8054
20	H	....	....	....	....	215.02	224.15	233.28	242.13	251.02
	S	....	....	....	....	0.6929	0.7127	0.7270	0.7419	0.7561
50	H	....	....	....	....	212.25	221.68	230.97	240.05	249.12
	S	....	....	....	....	0.6254	0.6457	0.6603	0.6756	0.6902
100	H	153.10	174.97	187.46	198.14	207.45	217.39	227.00	236.65	246.49
	S	0.436	0.491	0.520	0.543	0.5693	0.5908	0.6058	0.6221	0.6378
200	H	141.50	163.54	175.41	189.30	200.54	211.08	221.45	232.14	242.87
	S	0.359	0.418	0.451	0.479	0.5085	0.5313	0.5476	0.5657	0.5828
300	H	138.27	159.67	170.96	185.00	196.54	207.54	218.55	229.83	240.93
	S	0.324	0.381	0.414	0.441	0.4712	0.4950	0.5125	0.5316	0.5492
400	H	137.95	159.07	169.88	183.90	195.12	206.30	217.58	229.03	240.42
	S	0.301	0.358	0.389	0.417	0.4457	0.4697	0.4878	0.5073	0.5270
500	H	139.12	160.02	170.15	184.50	195.43	206.61	217.94	229.42	240.93
	S	0.284	0.340	0.370	0.398	0.4269	0.4508	0.4691	0.4885	0.5067
600	H	141.05	161.67	172.13	185.78	196.79	207.87	219.19	230.59	242.18
	S	0.271	0.326	0.357	0.384	0.4121	0.4359	0.4540	0.4733	*0.4917*
700	H	143.32	163.87	174.21	187.63	198.78	209.79	221.01	232.36	243.99
	S	0.260	0.315	0.343	0.371	0.4000	0.4236	0.4415	0.4607	0.4792
800	H	145.85	166.50	176.64	189.90	201.16	212.09	223.24	234.63	246.20
	S	0.250	0.305	0.333	0.361	0.3895	0.4131	0.4308	0.4499	0.4682
900	H	148.57	169.33	179.37	192.53	203.75	214.65	225.73	237.00	248.72
	S	0.241	0.297	0.325	0.352	0.3803	0.4037	0.4213	0.4404	0.4590
1000	H	151.46	172.08	182.31	195.45	206.49	217.42	228.36	239.67	251.45
	S	0.233	0.289	0.320	0.344	0.3719	0.3954	0.4128	0.4319	0.4507

$$Z = Z_s \frac{PV}{P_sV_s} \times \frac{T_s}{T} = 0.99941 \frac{PV}{T} \times \frac{459.69}{1.0} \qquad (4)$$

The solution of Equation (3), which is necessary to solve Equation (1), is accomplished graphically from a plot of $RT^2\ (\partial Z/\partial T)_P$ vs. P or a plot of $(\partial Z/\partial T)_P$ vs. P. The value of $(\partial Z/\partial T)_P$ is obtained from a plot of Z vs. T at constant pressure. Smoothed values of $(\partial Z/\partial T)_P$ are obtained by plotting the observed slopes against temperature and using values obtained from the resulting curve.

The entropy of the air at any pressure and temperature is obtained from Equations (5), (6), and (7).

$$S_{PT} = S^*_{PT} - (S^*_P - S_P)_T \qquad (5)$$

$$S^*_{PT} = \int_{492^\circ \mathrm{R.}}^{T} C^*_p \frac{dT}{T} - R \ln\left(\frac{P}{1}\right) + 0.9045 \qquad (6)$$

$$(S^*_P - S_P)_T = \frac{(H^* - H_P)_T}{T} - \int_0^P \frac{R\,(1 - Z)}{P}\, dP \qquad (7)$$

The value of 0.9045 is the entropy of air at 492°R. and 1 atm. referred to zero entropy for saturated liquid air at 1 atm. The value of the group $(H^* - H_P)_T$ had been previously determined (*see* above), and the value of the integral of Equation (7) was determined graphically from a plot of $(1 - Z)/P$ vs. P.

Calculations carried out according to the foregoing procedures resulted in the values given in Table 1. These values plus additional values (*9*) served as the basis for construction of Figure 1.

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NOTATION

C_p = heat capacity at constant pressure
H_{PT} = enthalpy at a given temperature, T, and pressure P
H^*_T = enthalpy of an ideal gas at a temperature, T
P = pressure
P_s = pressure, standard condition
R = gas constant
S_{PT} = entropy at a given temperature, T, and pressure, P
S^*_{PT} = entropy of an ideal gas at a given temperature, T, and pressure, P
T = temperature
T_s = temperature, standard condition
V = volume
V_s = volume, standard condition
Z = compressibility factor
Z_s = compressibility factor at standard conditions (0.99941)

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