PRINCE OF SONGKLA UNIVERSITY

FACULTY OF ENGINEERING

Final Exam	: Semester II	Academic Year	: 2013
Date	: March 01, 2014	Time	: 13:30-16:30
Subject	: Unit Operations I (231-323)	Room	: A401

Name...Student ID..............................

หมายเหตุ

1. ข้อสอบมีทั้งหมด 4 ข้อ ในกระดาษคำถามรวมภาคผนวก 15 หน้า
2. ห้ามการหยิบยืมสิ่งใด ๆ ทั้งสิ้น จากผู้อื่น ๆ เว้นแต่ผู้คุมสอบจะหยิบยืมให้
3. ห้ามนำส่วนใดส่วนหนึ่งของข้อสอบออกจากห้องสอบ
4. ผู้ที่ประสงค์จะออกจากห้องสอบก่อนหมดเวลาสอบ **แต่ต้องไม่น้อยกว่า 30 นาที** ให้ยกมือขออนุญาตจากผู้คุมสอบก่อนจะลุกจากที่นั่ง
5. เมื่อหมดเวลาสอบ ผู้เข้าสอบต้องหยุดการเขียนใด ๆ ทั้งสิ้น
6. ผู้ที่ปฏิบัติเข้าข่ายทุจริตในการสอบ ตามประกาศคณะวิศวกรรมศาสตร์ **มีโทษ คือ ปรับตกในรายวิชาที่ทุจริต และพักการเรียน 1 ภาคการศึกษา**
7. ให้ทำข้อสอบโดยใช้ ☑ ดินสอ ☑ ปากกา
8. ให้นักศึกษาสามารถนำสิ่งต่อไปนี้เข้าห้องสอบได้เท่านั้น
   - **เครื่องคิดเลข และ พจนานุกรม (หรือ** talking dictionary)

คำถามข้อที่	1	2	3	4	**รวมคะแนน**
คะแนนเต็ม	60	40	20	50	170
คะแนนที่ได้					

ดร.พรศิริ แก้วประดิษฐ์ ผู้ออกข้อสอบ

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1. (60 points)

A heat sensitive solid has been dried from an initial moisture content of 15% to a final moisture content of 0.5%, both dry basis in an adiabatic rotary dryer at a rate of 2,800 lb/h (1,270 kg/h). The solids have a specific heat of 0.52 Btu/lb.^{O}F; they enter at 80^{O}F (26.7^{O}C) and must not be heated to a temperature above 125^{O}F (51.7^{O}C). Heating air is available at 260^{O}F (126.7^{O}C) and a humidity of 0.01 lb of water per pound of dry air. The maximum allowable mass velocity of the air is 700 lb/ft^{2}.h (3,420 kg/m^{2}.h).

1.1. (10 points) Determine humid heat in Btu/^{O}F per lb dry air, and wet-bulb temperature from a given humidity chart (please draw in the chart)

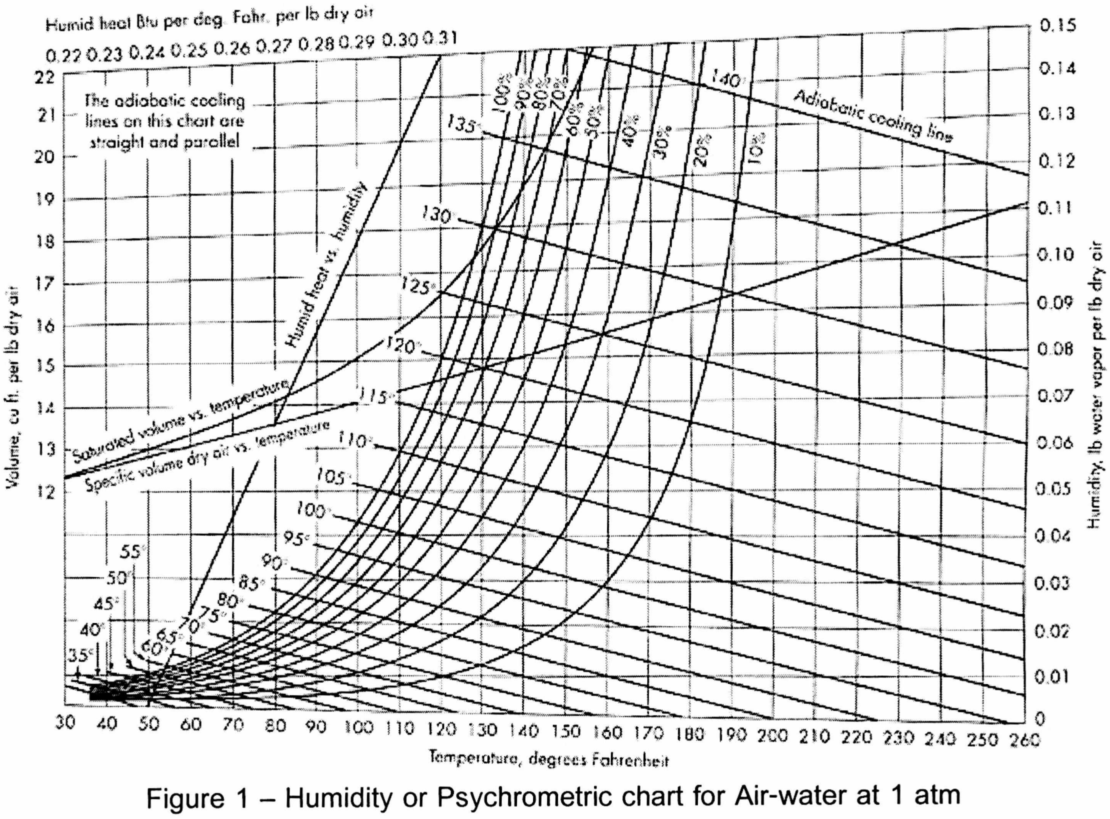


Figure 1 – Humidity or Psychrometric chart for Air-water at 1 atm

Name .... Student ID ....

1.2. **(15 points)** Determine C_{pL}, C_{pV} and λ and fulfill the table below if it is assume that the number of transfer units (N_t) is 1.5

Properties	**at Temperature (°F)**	**Value**
Liquid specific heat (C_{pL})		
Vapor specific heat (C_{pV})		
Latent heat (λ)		

1.3. **(20 points)** Determine heat transfer rate (q_T) in Btu/h

1.4. **(5 points)** Determine mass flow rate of gas in lb/h

1.5. **(15 points)** Calculate ratio of length and diameter (L/D) of the adiabatic rotary dryer

Name .... Student ID ....

2. **(40 points)**

The experimental data has been reported in the table below for water-vapor adsorption from nitrogen in a fixed bed of 4A Molecular sieves for bed depth 0.88 ft, temperature 83^{o}F, pressure 86 psia. The entering gas molar velocity is 29.6 lb-mol N_2/h.ft^2 and the entering water content is 1,440 ppm.

c_{exit}, ppm	Time, h	c_{exit}, ppm	Time, h
<1	0	808	11.0
1	9.0	1,115	11.5
33	9.6	1,330	12.0
142	10.0	1,440	12.8
365	10.4	1,440	13.0

2.1. **(15 points)** Determine length of unused bed in ft (plot breakthrough curve)

Name .... Student ID ....

2.2. **(5 points)** Determine the solute feed rate per unit area, $lb/h.ft^2$

2.3. **(20 points)** Determine total bed length in ft if breakpoint time is required at 20 h and if adsorbent has been regenerated by steam to remove 85% of the water-vapor (W_0), equilibrium loading (W_{sat}) is 0.186 lb H_2O/lb solid and bulk density of bed is 44.5 lb/ft^3 (at same conditions i.e. temperature, pressure etc.).

Name .... Student ID ....

3. **(20 points)**

Data for the equilibrium adsorption of pure methane gas on activated carbon at 296 K were obtained by Ritter and Yang.

W, cm3 (STP) of CH4/g carbon	45.5	91.5	113	121	125	126	126
P = p,psia	40	165	350	545	760	910	970

3.1. **(8 points)** Fit the data to the Freundlich isotherm

Name .... Student ID ....

3.2. **(8 points)** Fit the data to the Langmuir isotherm

3.3. **(4 points)** Which isotherm provides a better fit between Freundlich and Langmuir?

(please find the percentage of absolute error)

Name .... Student ID ....

4. (50 points)

Feed to the cooling crystallizer is 1,000 lb/h of 30 wt% $MgSO_4$ in water at 120°F. This solution is cooled to 50°F to form crystals of heptahydrate.

4.1. (30 points) Please fulfill the table below by using material and/or component balance.

	lb/h		
	Feed	Mother liquor	Crystals
H_2O			
$MgSO_4$			
$MgSO_4.7H_2O$			
Total			

4.2. **(20 points)** Determine total heat removed in Btu per 1,000 lb of crystal

Name .... Student ID ....

Appendix

Drying

Transfer unit number of dryer

$$N_t = ln\frac{T_{hb} - T_{wb}}{T_{ha} - T_{wb}}$$

Heat transfer rate (q_T)

$$\frac{q_T}{\dot{m}_s} = c_{ps}(T_{sb} - T_{sa}) + X_a c_{pL}(T_v - T_{sa}) + (X_a - X_b)\lambda$$
$$+X_b c_{pL}(T_{sb} - T_v) + (X_a - X_b)c_{pv}(T_{va} - T_v)$$

$$q_T = UA\overline{\Delta T}$$

$$q_T = \dot{m}_g c_{sb}(T_{hb} - T_{ha})$$ Hot gas / air

$$q_T = 0.125\pi DLG^{0.67}\overline{\Delta T}$$ for rotary dryer

Log mean average of temperature

$$\overline{\Delta T} = \frac{(T_{hb} - T_{wb}) - (T_{ha} - T_{wa})}{ln[(T_{hb} - T_{wb})/(T_{ha} - T_{wa})]}$$

Maximum mass velocity of air $G = \dot{m}_g/S$ where, S = Surface area of dryer

Adsorption

For a unit area of bed cross section, the solute feed rate

$$F_A = u_0 c_0$$

For ideal breakthrough curve, ideal adsorption time

$$t^* = \frac{L\rho_b(W_{sat} - W_0)}{u_0 c_0}$$

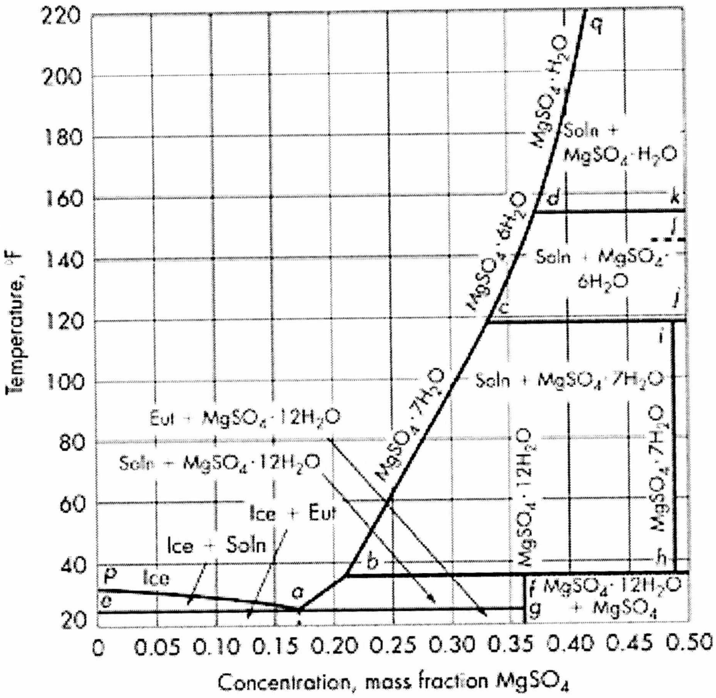
Break point time,

$$t_b = t^*\left[1 - \frac{LUB}{L}\right]$$

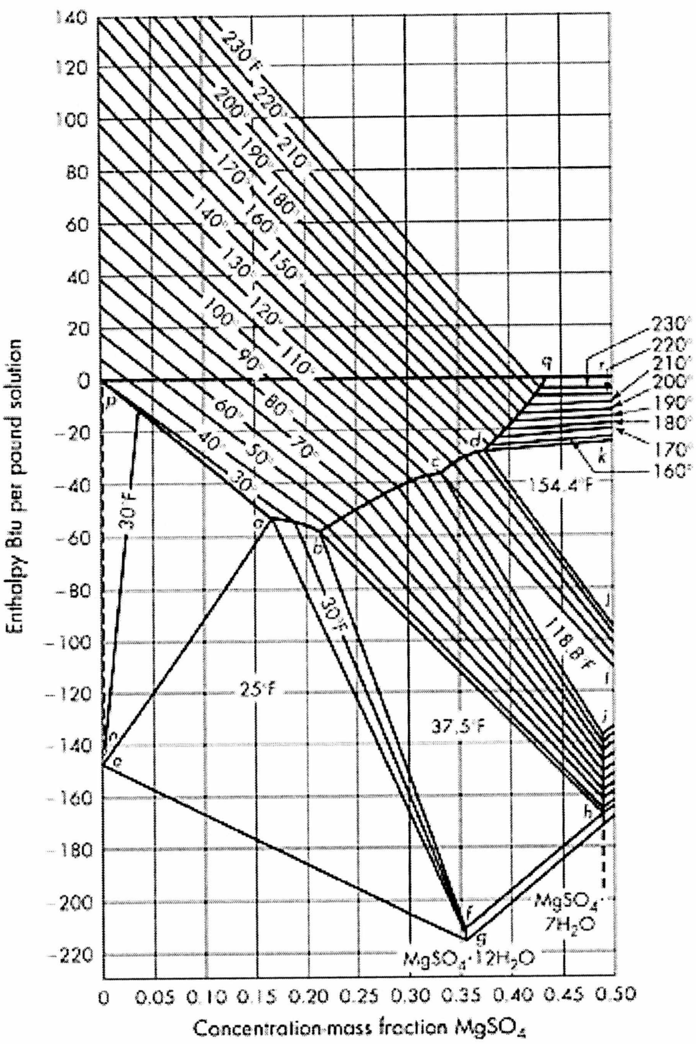
Langmuir isotherm $W = W_{max}\left[\frac{Kc}{1+Kc}\right]$

Empirical Freundlich isotherm $W = bc^m$

Name .... Student ID ....



Phase diagram of $MgSO_4$



Enthalpy-Concentration diagram

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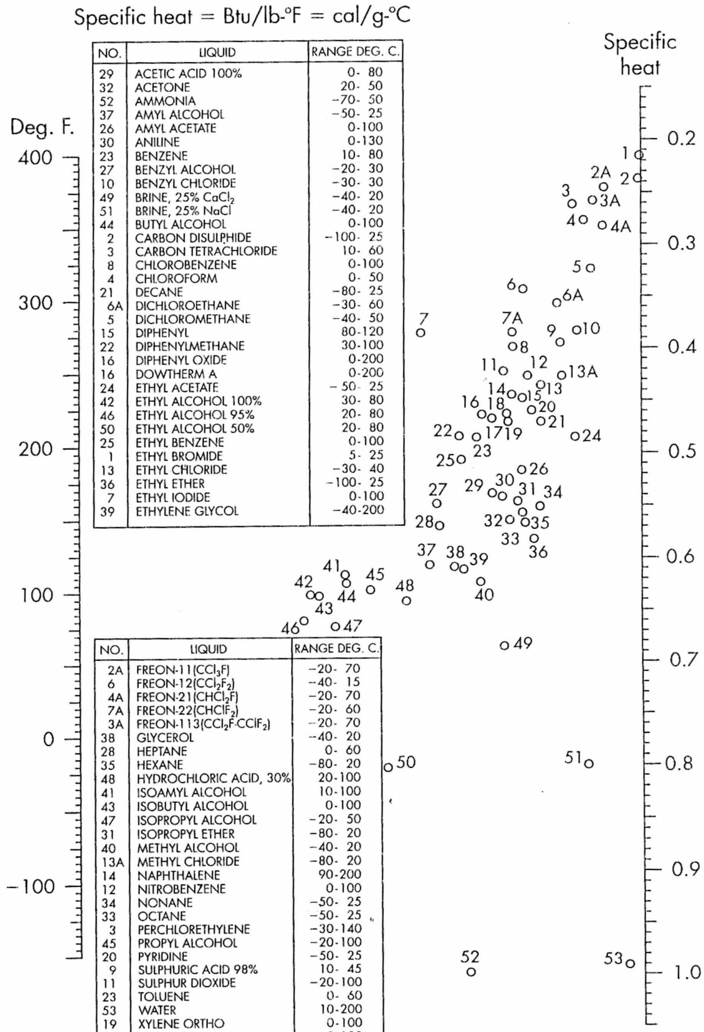
Specific heats of Liquids

Specific heat = Btu/lb-°F = cal/g-°C



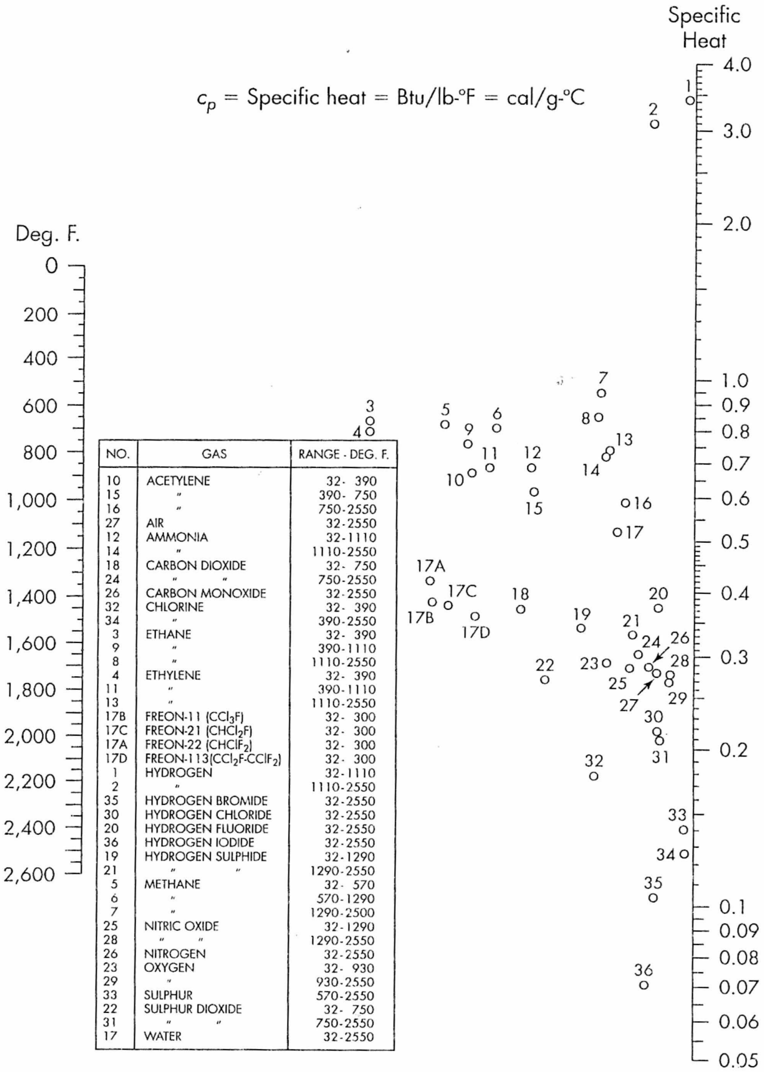
NO.	LIQUID	RANGE DEG. C.
29	ACETIC ACID 100%	0- 80
32	ACETONE	20- 50
52	AMMONIA	-70- 50
37	AMYL ALCOHOL	-50- 25
26	AMYL ACETATE	0-100
30	ANILINE	0-130
23	BENZENE	10- 80
27	BENZYL ALCOHOL	-20- 30
10	BENZYL CHLORIDE	-30- 30
49	BRINE, 25% $CaCl_2$	-40- 20
51	BRINE, 25% NaCl	-40- 20
44	BUTYL ALCOHOL	0-100
2	CARBON DISULPHIDE	-100- 25
3	CARBON TETRACHLORIDE	10- 60
8	CHLOROBENZENE	0-100
4	CHLOROFORM	0- 50
21	DECANE	-80- 25
6A	DICHLOROETHANE	-30- 60
5	DICHLOROMETHANE	-40- 50
15	DIPHENYL	80-120
22	DIPHENYLMETHANE	30-100
16	DIPHENYL OXIDE	0-200
16	DOWTHERM A	0-200
24	ETHYL ACETATE	- 50- 25
42	ETHYL ALCOHOL 100%	30- 80
46	ETHYL ALCOHOL 95%	20- 80
50	ETHYL ALCOHOL 50%	20- 80
25	ETHYL BENZENE	0-100
1	ETHYL BROMIDE	5- 25
13	ETHYL CHLORIDE	-30- 40
36	ETHYL ETHER	-100- 25
7	ETHYL IODIDE	0-100
39	ETHYLENE GLYCOL	-40-200

NO.	LIQUID	RANGE DEG. C.
2A	FREON-11(CCl_3F)	-20- 70
6	FREON-12(CCl_2F_2)	-40- 15
4A	FREON-21($CHCl_2F$)	-20- 70
7A	FREON-22($CHClF_2$)	-20- 60
3A	FREON-113(CCl_2F-$CClF_2$)	-20- 70
38	GLYCEROL	-40- 20
28	HEPTANE	0- 60
35	HEXANE	-80- 20
48	HYDROCHLORIC ACID, 30%	20-100
41	ISOAMYL ALCOHOL	10-100
43	ISOBUTYL ALCOHOL	0-100
47	ISOPROPYL ALCOHOL	-20- 50
31	ISOPROPYL ETHER	-80- 20
40	METHYL ALCOHOL	-40- 20
13A	METHYL CHLORIDE	-80- 20
14	NAPHTHALENE	90-200
12	NITROBENZENE	0-100
34	NONANE	-50- 25
33	OCTANE	-50- 25
3	PERCHLORETHYLENE	-30-140
45	PROPYL ALCOHOL	-20-100
20	PYRIDINE	-50- 25
9	SULPHURIC ACID 98%	10- 45
11	SULPHUR DIOXIDE	-20-100
23	TOLUENE	0- 60
53	WATER	10-200
19	XYLENE ORTHO	0-100
18	XYLENE META	0-100
17	XYLENE PARA	0-100

Name .... Student ID ....

Specific heats of Gases

c_p = Specific heat = Btu/lb-°F = cal/g-°C



NO.	GAS	RANGE - DEG. F.
10	ACETYLENE	32- 390
15	"	390- 750
16	"	750-2550
27	AIR	32-2550
12	AMMONIA	32-1110
14	"	1110-2550
18	CARBON DIOXIDE	32- 750
24	" "	750-2550
26	CARBON MONOXIDE	32-2550
32	CHLORINE	32- 390
34	"	390-2550
3	ETHANE	32- 390
9	"	390-1110
8	"	1110-2550
4	ETHYLENE	32- 390
11	"	390-1110
13	"	1110-2550
17B	FREON-11 (CCl_3F)	32- 300
17C	FREON-21 ($CHCl_2F$)	32- 300
17A	FREON-22 ($CHClF_2$)	32- 300
17D	FREON-113(CCl_2F-$CClF_2$)	32- 300
1	HYDROGEN	32-1110
2	"	1110-2550
35	HYDROGEN BROMIDE	32-2550
30	HYDROGEN CHLORIDE	32-2550
20	HYDROGEN FLUORIDE	32-2550
36	HYDROGEN IODIDE	32-2550
19	HYDROGEN SULPHIDE	32-1290
21	" "	1290-2550
5	METHANE	32- 570
6	"	570-1290
7	"	1290-2500
25	NITRIC OXIDE	32-1290
28	" "	1290-2550
26	NITROGEN	32-2550
23	OXYGEN	32- 930
29	"	930-2550
33	SULPHUR	570-2550
22	SULPHUR DIOXIDE	32- 750
31	" "	750-2550
17	WATER	32-2550

Name .... Student ID ....

Properties of Saturated Steam and water

Temperature T, °F	Vapor pressure p_A, $lb_f/in.^2$	Specific volume, ft^3/lb: Liquid v_x	Specific volume, ft^3/lb: Saturated vapor v_y	Enthalpy, Btu/lb: Liquid H_x	Enthalpy, Btu/lb: Vaporization λ	Enthalpy, Btu/lb: Saturated vapor H_y
32	0.08859	0.016022	3,305	0	1,075.4	1,075.4
35	0.09992	0.016021	2,948	3.00	1,073.7	1,076.7
40	0.12166	0.016020	2,445	8.02	1,070.9	1,078.9
45	0.14748	0.016021	2,037	13.04	1,068.1	1,081.1
50	0.17803	0.016024	1,704.2	18.06	1,065.2	1,083.3
55	0.2140	0.016029	1,431.4	23.07	1,062.4	1,085.5
60	0.2563	0.016035	1,206.9	28.08	1,059.6	1,087.7
65	0.3057	0.016042	1,021.5	33.09	1,056.8	1,089.9
70	0.3632	0.016051	867.7	38.09	1,054.0	1,092.0
75	0.4300	0.016061	739.7	43.09	1,051.1	1,094.2
80	0.5073	0.016073	632.8	48.09	1,048.3	1,096.4
85	0.5964	0.016085	543.1	53.08	1,045.5	1,098.6
90	0.6988	0.016099	467.7	58.07	1,042.7	1,100.7
95	0.8162	0.016114	404.0	63.06	1,039.8	1,102.9
100	0.9503	0.016130	350.0	68.05	1,037.0	1,105.0
110	1.2763	0.016166	265.1	78.02	1,031.4	1,109.3
120	1.6945	0.016205	203.0	88.00	1,025.5	1,113.5
130	2.225	0.016247	157.17	97.98	1,019.8	1,117.8
140	2.892	0.016293	122.88	107.96	1,014.0	1,121.9
150	3.722	0.016343	96.99	117.96	1,008.1	1,126.1
160	4.745	0.016395	77.23	127.96	1,002.2	1,130.1
170	5.996	0.016450	62.02	137.97	996.2	1,134.2
180	7.515	0.016509	50.20	147.99	990.2	1,138.2
190	9.343	0.016570	40.95	158.03	984.1	1,142.1
200	11.529	0.016634	33.63	168.07	977.9	1,145.9
210	14.125	0.016702	27.82	178.14	971.6	1,149.7
212	14.698	0.016716	26.80	180.16	970.3	1,150.5

Temperature T, °F	Vapor pressure p_A, $lb_f/in.^2$	Specific volume, ft^3/lb: Liquid v_x	Specific volume, ft^3/lb: Saturated vapor v_y	Enthalpy, Btu/lb: Liquid H_x	Enthalpy, Btu/lb: Vaporization λ	Enthalpy, Btu/lb: Saturated vapor H_y
220	17.188	0.016772	23.15	188.22	965.3	1,153.5
230	20.78	0.016845	19.386	198.32	958.8	1,157.1
240	24.97	0.016922	16.327	208.44	952.3	1,160.7
250	29.82	0.017001	13.826	218.59	945.6	1,164.2
260	35.42	0.017084	11.768	228.76	938.8	1,167.6
270	41.85	0.017170	10.066	238.95	932.0	1,170.9
280	49.18	0.017259	8.650	249.18	924.9	1,174.1
290	57.53	0.017352	7.467	259.44	917.8	1,177.2
300	66.98	0.017448	6.472	269.73	910.4	1,180.2
310	77.64	0.017548	5.632	280.06	903.0	1,183.0
320	89.60	0.017652	4.919	290.43	895.3	1,185.8
340	117.93	0.017872	3.792	311.30	879.5	1,190.8
350	134.53	0.017988	3.346	321.80	871.3	1,193.1
360	152.92	0.018108	2.961	332.35	862.9	1,195.2
370	173.23	0.018233	2.628	342.96	854.2	1,197.2
380	195.60	0.018363	2.339	353.62	845.4	1,199.0
390	220.2	0.018498	2.087	364.34	836.2	1,200.6
400	247.1	0.018638	1.8661	375.12	826.8	1,202.0
410	276.5	0.018784	1.6726	385.97	817.2	1,203.1
420	308.5	0.018936	1.5024	396.89	807.2	1,204.1
430	343.3	0.019094	1.3521	407.89	796.9	1,204.8
440	381.2	0.019260	1.2192	418.98	786.3	1,205.3
450	422.1	0.019433	1.1011	430.2	775.4	1,205.6

†Abstracted from *Steam Tables*, by Joseph H. Keenan, Frederick G. Keyes, Philip G. Hill, and Joan G. Moore, John Wiley & Sons, New York, 1969, with the permission of the publisher.