UNIVERSITY OF JOHANNESBURG

PROGRAM	:BACCALAUREUS TECHNOLGIAE *ENGINEERING: CHEMICAL*
SUBJECT	: **CHEMICAL ENGINEERING TECH NOLOGY 4B - UNIT OPERATIONS**
CODE	: **WARB432**
DATE	: WINTER EXAMINATION 10 JUNE 2014
DURATION	: (SESSION 1) 08:30 - 11:30
WEIGHT	: 40: 60
TOTAL MARKS	: 165
FULL MARKS	: 155
EXAMINERS	: PROF E MUZENDA
MODERATOR	: PROF M ONYANGO
NUMBER OF PAGES	: 4 PAGES AND 6 ANNEXURES

REQUIREMENTS : CALCULATORS ARE PERMITTED (ONLY ONE PER STUDENT)

INSTRUCTIONS TO CANDIDATES:
NUMBER AND ANSWER ALL QUESTIONS
START EACH QUESTION ON A FRESH PAGE
CLEARLY SHOW YOUR SOLUTION PROCEDURE ON THE ANSWER SHEET

QUESTION 1: DISTILLATION

A mixture of benzene (1) and toluene (2) with a mole fraction $x_{F,1} = 0.4$ should be separated in a plate column in a distillate (D) and bottoms streams (B) with mole fractions $x_{D,1} = 0.96$ and $x_{B,1} = 0.04$ respectively. The constant relative volatility α of the mixture, whose behaviour can be considered ideal is 2.42 ($\alpha_{BT} = 2.42$). The column operates with a reflux ratio $R = 1.3R_{min}$ and the feed enters the column at the boiling point (saturated liquid) and at a rate of 100kmol/hr.

1.1 Calculate the amount of distillate and bottoms products (4)
1.2 Calculate the minimum of stages N_{min} applying the Fenske equation. (4)
1.3 Minimum reflux ratio R_{min} applying Underwood equation. (10)
1.4 Determine the theoretical number of stages using the Gilliland diagram / correlation. (10)
1.5 Determine the theoretical number of stages using the Molokanov's correlation (7)

[35]

QUESTION 2: DISTILLATION

i	x_{iF}	x_{iD}	x_{iw}	K
A	0.40	0.6197	0.0011	3.12
B	0.25	0.3489	0.0704	1.38
C	0.15	0.0310	0.5068	0.60
D	0.10	0.0004	0.4217	0.28

The light and heavy keys are B and C respectively. The liquid is fed at its boiling point. The minimum number of stages at total reflux is $N_m + 1 = 5.40$. The distillate (D) and bottoms (B) compositions are 64.484 kmol/h and 35.516 kmol/hr respectively.

Calculate

2.1 Minimum reflux ratio using the Underwood Method (8)
2.2 Number of theoretical stages at an operating reflux R of 1.5 R_m using the Erbar – Maddox correlation. (6)
2.3 The location of the feed tray using the method of Kirkbridge (6)

[20]

QUESTION 3: ABSORPTION

A gas containing 88 mol % CH_4, 4% C_2H_6, 5% C_3H_8 and 3 % n-C_4H_{10} is fed to an absorber that is operated isothermally at 38^{0}C and 5 bar (abs). the tower contains 7 equilibrium stages and 85% 0f C_3H_8 must be removed. The lean oil is used as the absorbent. It contains 1% C_4H_{10} but none of the other constituents and the rest of the oil is nonvolatile. It can be assumed that the values of A and S can be based on the entering values of L and V. On a basis of 100 mol of vapour entering the absorber, calculate the amount of lean oil and the amount of n-C_4H_{10} in the exit vapour.

K values are as follows: $CH_4 = 32$; $C_2H_6 = 6.7$; $C_3H_8 = 2.4$; n-$C_4H_{10} = 0.74$

(Hint: $0.8 > A_{C3H8} > 1$ and solve the equation that the error is within 0.01%)

[25]

QUESTION 4: SOLVENT EXRACTION

To remove acetone (*C*) from an aqueous feed supplied at the rate of 1000 kg/h, it was decided to use a three-stage cross-current cascade with different amounts of the solvent TCA (trichloroethane-*B*). The solvent is pure TCA and is added in successive stages in the following amounts: 250, 300 and 350 kg. The feed contains 60 mass% acetone. Given the following LLE data; Determine the fraction of the acetone removed if the stages are ideal. (40)

Raffinate arm (mass fraction)			**Extract arm** (mass fraction)		
x_A	x_B	x_C	y_A	y_B	y_C
0.35	0.1	0.55	0.13	0.27	0.60
0.43	0.07	0.50	0.04	0.46	0.50
0.57	0.03	0.40	0.03	0.57	0.40
0.68	0.02	0.30	0.02	0.68	0.30
0.79	0.01	0.20	0.015	0.785	0.20
0.895	0.005	0.1	0.01	0.89	0.10

Tie-line data	
Extract (mass fraction acetone)	**Raffinate** (mass fraction acetone)
0.18	0.12
0.40	0.29
0.56	0.44

[40]

QUESTION 5: EVAPORATION

A double-effect forward-feed evaporator is required to give a product consisting of 30 percent crystals and a mother liquor containing 40 per cent by mass of dissolved solids. Heat transfer coefficients are 2.8 and 1.7 kW/m^2K in the first and second effects respectively. Dry saturated steam is supplied at 375 kN/m^2 and the condenser operates at 13.5 kN/m^2.

(a) What area of heating surface is required in each effect, assuming they are both identical, if the feed rate is 0.6 kg/s of liquor, containing 20 per cent by mass of dissolved solids, and the feed temperature is 313 K?

(b) What is the pressure above the boiling liquid in the first effect?

The specific heat capacity may be taken as constant at 4.18 kJ/kg K, and the effects of boiling point rise and of hydrostatic head may be neglected.

[20]

QUESTION 6: FILTRATION

A plate and frame press gave a total of 8 m^3 of filtrate in 1800 s and 11.3 m^3 in 3600 s when filtration was stopped. Estimate the washing time if 3 m^3 of wash water is used. The resistance of the cloth may be neglected and a constant pressure is used throughout.

[10]

QUESTION 7: FLUIDISATION

Solid particles with size of 0.12mm, shape factor ϕ_s of 0.90 and a particle density of 1200kg/m^3 are to be fluidized with air at 2 bar (abs) and 25^{0}C. The bulk density of the solid material is 1000kg/m^3 and the height of the packed bed is 1.12m. The voidage at minimum fluidizing velocity is 0.40. The bed is charged with 400kg of solid material and the diameter of the empty bed is 0.64m. Take $\mu = 1.845x10^{-5}\, Ns/m^2$

Calculate

3.1 The minimum height of the fluidized bed (7)

3.2 The pressure drop at minimum fluidizing conditions (7)

3.3 The minimum fluidizing velocity (6)

[20]

FORMULAE AND CORRELATIONS

Fenske's Equation:

$$N_{\min}+1=\frac{\ln\left[\left(\frac{x_{LK}}{x_{HK}}\right)_D\left(\frac{x_{HK}}{x_{LK}}\right)_B\right]}{\log\alpha_{LK,HK}},\qquad b_i=\frac{f_i}{1+\left(\frac{d_r}{b_r}\right)\left(\alpha_{i,r}\right)_m^{N_{\min}}},\qquad d_i=\frac{f_i\left(\frac{d_r}{b_r}\right)\left(\alpha_{i,r}\right)_m^{N_{\min}}}{1+\left(\frac{d_r}{b_r}\right)\left(\alpha,r\right)_m^{N_{\min}}}$$

Minimum Reflux Ratio by **Underwood's Equations**: -

$$\sum\frac{\alpha_i x_{iD}}{\alpha-\theta}=R_m+1$$

$$\sum\frac{\alpha_i x_{iF}}{\alpha-\theta}=1-q$$

$$\alpha_{HK}<\theta<\alpha_{LK}$$

Erbar-Maddox correlation: -

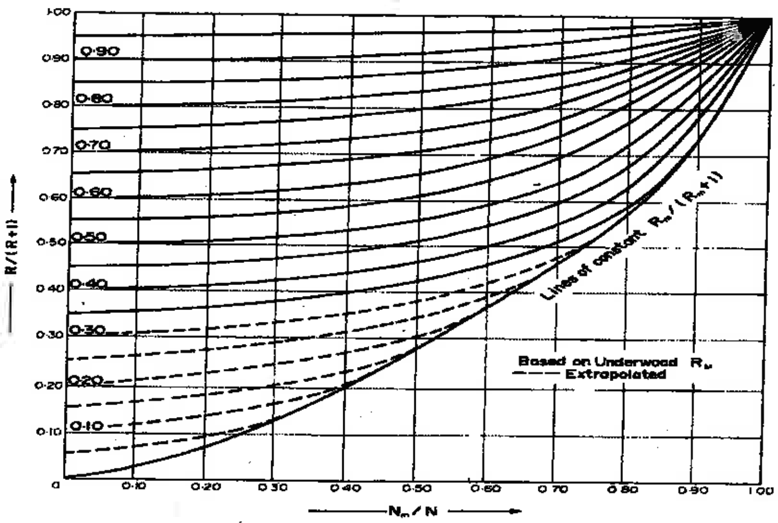


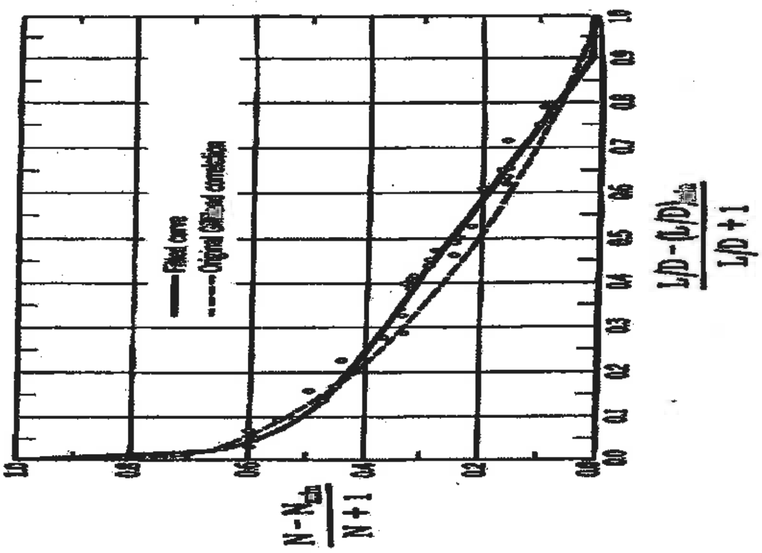
FIG. 11.11. Erbar–Maddox correlation (Erbar and Maddox, 1961)

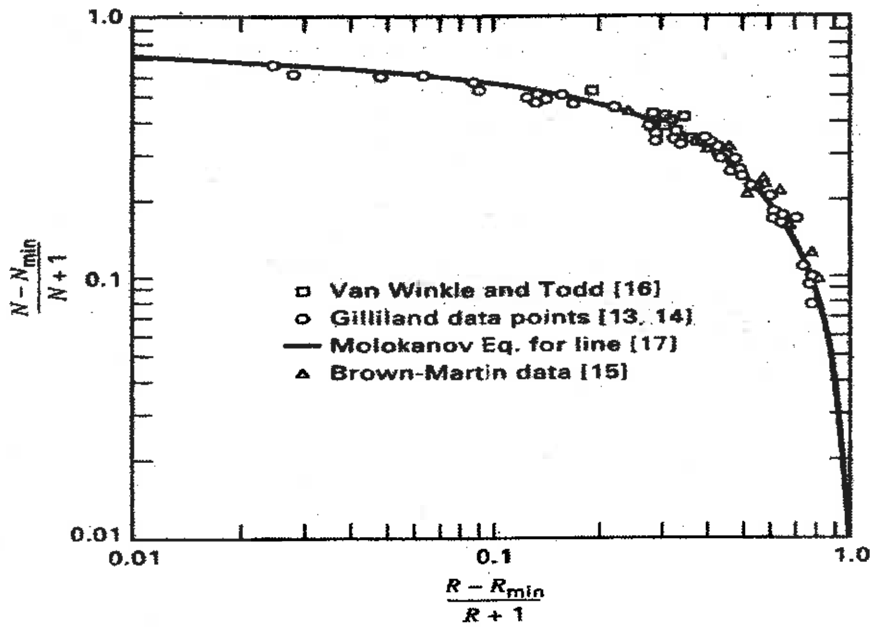
$$\frac{R}{R+1}\ \ vs\ \ \frac{N_m}{N}\ \ with\ \ \frac{R_m}{R_m+1}\ \ as\ a\ parameter$$

Feed Plate location by **Kirkbride's Equation**

$$\log\left[\frac{N_r}{N_s}\right]=0.206\log\left[\left(\frac{x_{HK}}{x_{LK}}\right)_F\left(\frac{x_{LK_W}}{x_{HK_D}}\right)^2\right],\qquad \frac{N_R}{N_S}=\left[\left(\frac{Z_{j,F}}{Z_{i,F}}\right)\left(\frac{x_{i,B}}{x_{j,D}}\right)^2\left(\frac{B}{D}\right)\right]^{0.206}$$

Gilliland correlation: Number of ideal plates at the operating reflux





$$\frac{N - N_{\min}}{N+1} = 1 - \exp\left[\left(\frac{1+54.4\Psi}{11+117{,}2\Psi}\right)\left(\frac{\psi - 1}{\psi^{0.5}}\right)\right] \text{ where } \Psi \equiv \frac{R - R_{\min}}{R+1}$$

$$Y-1-\exp(1.490+0.315X-\frac{1.805}{X^{0,1}}, \quad Y=0.75(1-X^{0.5668})=0.546$$

$$\sum y_i=\sum K_i x_i=K_c\sum \alpha_i x_i=1.0, \quad y_i=\frac{\alpha_i x_i}{\sum(\alpha_i x_1)}, \quad \sum_{i=1}^{N_C} y_1=\sum_{i=1}^{N_C} K_i x_i=1.0, \quad (K_p)Trial\ 2=\frac{(K_p)Trial\ 1}{\sum K_i x_i},$$

$$\sum x_i=\sum\left(\frac{y_i}{K_i}\right)=\left(\frac{1}{K_C}\right)\sum\left(\frac{y_i}{\alpha_i}\right)=0, \quad x_i=\frac{y_i/x_i}{\sum\left(y_i/x_i\right)}, \quad \sum_{i=1}^{N_C} x_i=\sum_{i=1}^{N_C}\frac{y_i}{K_i}=1.0, \quad (K_i)Trial2=(K_i)Trial1\sum\frac{y_i}{K_i}$$

$$f=\left(\frac{c_p(t_b-t_f)_{Liquid}+\Lambda_{Feed}+\left(c_p(t_b-t_f)\right)superneatedvapour}{\Lambda}\right), \quad -\left(\frac{f}{1-f}\right)\ \text{Slope of q - line}$$

$$-\frac{\Delta P}{L}=\frac{150(1-\varepsilon_{mf})^2}{\varepsilon_{mf}^{\ 3}}\frac{\mu . u_{mf}}{d^2}+\frac{1.75(1-\varepsilon_{mf})}{\varepsilon_{mf}^{\ 3}}\frac{\rho . u_{mf}^{\ 2}}{d}, \quad (-\Delta P)=(1-e_{mf})(\rho_s-\rho)lg$$

$$(1-e_{mf})(\rho_s-\rho)g=\frac{150(1-e_{mf})^2}{e_{mf}^3}\frac{\mu u_{mf}}{d^2}+\frac{1.75(1-e_{mf})}{e_{mf}^3}\frac{\rho u_{mf}^{\ 2}}{d}$$

$$w_1=w_2+\left(y-\frac{y}{R}\right)+w_1E, \quad y=\frac{Rw_1[c_1-c_2(1-E)]}{[1-c_2(R-1)]}, \quad \frac{1}{nF}\frac{V_W}{V_L}=\ln\frac{1-F}{F}$$

$$\{m_{steam}xh_{fg}\}=\{m_{feed}C_p\Delta T\}+\{m_v xh_{fg}\}+\{m_L C_p\Delta T\}$$

$$Q=m_{steam}h_{fg}=m_{feed}C_p\Delta T+m_v h_{fg}, \quad Q=m_{feed}C_p\Delta T+m_{v1}h_{fg},$$

$$\frac{t-t_s}{V-V_s}=\frac{K_1(V+V_s)}{2P}+\frac{K_2}{P}$$

For the rotary filter

$$\theta_f=k_f\theta_c \qquad \theta_f=\frac{K_1V_f^2}{2P}+\frac{K_2V_f}{P}, \quad A=\left(\frac{V_f}{\theta_c}\right)\sqrt{\left(\frac{s\rho\mu\alpha_{ave}\theta_c}{2Pk_f(1-ms)}\right)}$$

$$v_1=V_N+1\phi_A, \quad \phi_A=\frac{V_1}{V_{N+1}}=\frac{A_{e-1}}{A_e^{N+1}-1}, \quad A_e=\frac{L}{KV}$$

$$\phi_{i,s}=\frac{S_i-1}{S_i^{N+1}-1}, \quad S_i=\frac{KV_i}{L}=\frac{1}{A_i}, \quad v_{i,1}=v+1\phi_{i,A}+l_{i,o}(1-\phi_{i,s})$$

Saturated Water and Steam

p [bar]	T_s [°C]	v_g [m³/kg]	u_f [kJ/kg]	u_g [kJ/kg]	h_f [kJ/kg]	h_{fg} [kJ/kg]	h_g [kJ/kg]	s_f [kJ/kg K]	s_{fg} [kJ/kg K]	s_g [kJ/kg K]
1.0	99.6	1.694	417	2506	417	2258	2675	1.303	6.056	7.359
1.1	102.3	1.549	429	2510	429	2251	2680	1.333	5.994	7.327
1.2	104.8	1.428	439	2512	439	2244	2683	1.361	5.937	7.298
1.3	107.1	1.325	449	2515	449	2238	2687	1.387	5.884	7.271
1.4	109.3	1.236	458	2517	458	2232	2690	1.411	5.835	7.246
1.5	111.4	1.159	467	2519	467	2226	2693	1.434	5.789	7.223
1.6	113.3	1.091	475	2521	475	2221	2696	1.455	5.747	7.202
1.7	115.2	1.031	483	2524	483	2216	2699	1.475	5.707	7.182
1.8	116.9	0.9774	491	2526	491	2211	2702	1.494	5.669	7.163
1.9	118.6	0.9292	498	2528	498	2206	2704	1.513	5.632	7.145
2.0	120.2	0.8856	505	2530	505	2202	2707	1.530	5.597	7.127
2.1	121.8	0.8461	511	2531	511	2198	2709	1.547	5.564	7.111
2.2	123.3	0.8100	518	2533	518	2193	2711	1.563	5.533	7.096
2.3	124.7	0.7770	524	2534	524	2189	2713	1.578	5.503	7.081
2.4	126.1	0.7466	530	2536	530	2185	2715	1.593	5.474	7.067
2.5	127.4	0.7186	535	2537	535	2182	2717	1.607	5.446	7.053
2.6	128.7	0.6927	541	2539	541	2178	2719	1.621	5.419	7.040
2.7	130.0	0.6686	546	2540	546	2174	2720	1.634	5.393	7.027
2.8	131.2	0.6462	551	2541	551	2171	2722	1.647	5.368	7.015
2.9	132.4	0.6253	556	2543	556	2168	2724	1.660	5.344	7.004
3.0	133.5	0.6057	561	2544	561	2164	2725	1.672	5.321	6.993
3.5	138.9	0.5241	584	2549	584	2148	2732	1.727	5.214	6.941
4.0	143.6	0.4623	605	2554	605	2134	2739	1.776	5.121	6.897
4.5	147.9	0.4139	623	2558	623	2121	2744	1.820	5.037	6.857
5.0	151.8	0.3748	639	2562	640	2109	2749	1.860	4.962	6.822
5.5	155.5	0.3427	655	2565	656	2097	2753	1.897	4.893	6.790
6	158.8	0.3156	669	2568	670	2087	2757	1.931	4.830	6.761
7	165.0	0.2728	696	2573	697	2067	2764	1.992	4.717	6.709
8	170.4	0.2403	720	2577	721	2048	2769	2.046	4.617	6.663
9	175.4	0.2149	742	2581	743	2031	2774	2.094	4.529	6.623
10	179.9	0.1944	762	2584	763	2015	2778	2.138	4.448	6.586
11	184.1	0.1774	780	2586	781	2000	2781	2.179	4.375	6.554
12	188.0	0.1632	797	2588	798	1986	2784	2.216	4.307	6.523
13	191.6	0.1512	813	2590	815	1972	2787	2.251	4.244	6.495
14	195.0	0.1408	828	2593	830	1960	2790	2.284	4.185	6.469
15	198.3	0.1317	843	2595	845	1947	2792	2.315	4.130	6.445
16	201.4	0.1237	857	2596	859	1935	2794	2.344	4.078	6.422
17	204.3	0.1167	870	2597	872	1923	2795	2.372	4.028	6.400
18	207.1	0.1104	883	2598	885	1912	2797	2.398	3.981	6.379
19	209.8	0.1047	895	2599	897	1901	2798	2.423	3.936	6.359
20	212.4	0.09957	907	2600	909	1890	2799	2.447	3.893	6.340
22	217.2	0.09069	928	2601	931	1870	2801	2.492	3.813	6.305
24	221.8	0.08323	949	2602	952	1850	2802	2.534	3.738	6.272
26	226.0	0.07689	969	2603	972	1831	2803	2.574	3.668	6.242
28	230.0	0.07142	988	2603	991	1812	2803	2.611	3.602	6.213
30	233.8	0.06665	1004	2603	1008	1795	2803	2.645	3.541	6.186
32	237.4	0.06246	1021	2603	1025	1778	2803	2.679	3.482	6.161
34	240.9	0.05875	1038	2603	1042	1761	2803	2.710	3.426	6.136
36	244.2	0.05544	1054	2602	1058	1744	2802	2.740	3.373	6.113
38	247.3	0.05246	1068	2602	1073	1729	2802	2.769	3.322	6.091
40	250.3	0.04977	1082	2602	1087	1714	2801	2.797	3.273	6.070

Saturated Water and Steam

p [bar]	T_s [°C]	v_g [m³/kg]	u_f [kJ/kg]	u_g [kJ/kg]	h_f [kJ/kg]	h_{fg} [kJ/kg]	h_g [kJ/kg]	s_f [kJ/kg K]	s_{fg} [kJ/kg K]	s_g [kJ/kg K]
40	250.3	0.04977	1082	2602	1087	1714	2801	2.797	3.273	6.070
42	253.2	0.04732	1097	2601	1102	1698	2800	2.823	3.226	6.049
44	256.0	0.04509	1109	2600	1115	1683	2798	2.849	3.180	6.029
46	258.8	0.04305	1123	2599	1129	1668	2797	2.874	3.136	6.010
48	261.4	0.04117	1136	2598	1142	1654	2796	2.897	3.094	5.991
50	263.9	0.03944	1149	2597	1155	1639	2794	2.921	3.052	5.973
55	269.9	0.03563	1178	2594	1185	1605	2790	2.976	2.955	5.931
60	275.6	0.03244	1206	2590	1214	1570	2784	3.027	2.863	5.890
65	280.8	0.02972	1232	2586	1241	1538	2779	3.076	2.775	5.851
70	285.8	0.02737	1258	2581	1267	1505	2772	3.122	2.692	5.814
75	290.5	0.02532	1283	2576	1293	1473	2766	3.166	2.613	5.779
80	295.0	0.02352	1306	2570	1317	1441	2758	3.207	2.537	5.744
85	299.2	0.02192	1329	2565	1341	1410	2751	3.248	2.463	5.711
90	303.3	0.02048	1351	2559	1364	1379	2743	3.286	2.393	5.679
95	307.2	0.01919	1372	2552	1386	1348	2734	3.324	2.323	5.647
100	311.0	0.01802	1393	2545	1408	1317	2725	3.360	2.255	5.615
105	314.6	0.01696	1414	2537	1429	1286	2715	3.395	2.189	5.584
110	318.0	0.01598	1434	2529	1450	1255	2705	3.430	2.123	5.553
115	321.4	0.01508	1454	2522	1471	1224	2695	3.463	2.060	5.523
120	324.6	0.01426	1473	2514	1491	1194	2685	3.496	1.997	5.493
125	327.8	0.01349	1492	2505	1511	1163	2674	3.529	1.934	5.463
130	330.8	0.01278	1511	2496	1531	1131	2662	3.561	1.872	5.433
135	333.8	0.01211	1530	2487	1551	1099	2650	3.592	1.811	5.403
140	336.6	0.01149	1548	2477	1571	1067	2638	3.623	1.750	5.373
145	339.4	0.01090	1567	2467	1591	1034	2625	3.654	1.689	5.343
150	342.1	0.01035	1585	2456	1610	1001	2611	3.685	1.627	5.312
155	344.8	0.00982	1604	2445	1630	967	2597	3.715	1.565	5.280
160	347.3	0.00932	1623	2433	1650	932	2582	3.746	1.502	5.248
165	349.8	0.00884	1641	2420	1670	895	2565	3.777	1.437	5.214
170	352.3	0.00838	1660	2406	1690	858	2548	3.808	1.373	5.181
175	354.6	0.00794	1679	2391	1711	819	2530	3.839	1.305	5.144
180	357.0	0.00751	1699	2375	1732	778	2510	3.872	1.236	5.108
185	359.2	0.00709	1719	2358	1754	735	2489	3.905	1.163	5.068
190	361.4	0.00668	1740	2339	1777	689	2466	3.941	1.086	5.027
195	363.6	0.00627	1762	2318	1801	639	2440	3.977	1.004	4.981
200	365.7	0.00585	1786	2294	1827	584	2411	4.014	0.914	4.928
202	366.5	0.00569	1796	2283	1838	560	2398	4.031	0.875	4.906
204	367.4	0.00552	1806	2271	1849	535	2384	4.049	0.835	4.884
206	368.2	0.00534	1817	2259	1861	508	2369	4.067	0.792	4.859
208	369.0	0.00517	1829	2245	1874	479	2353	4.087	0.745	4.832
210	369.8	0.00498	1842	2231	1889	447	2336	4.108	0.695	4.803
212	370.6	0.00479	1856	2214	1904	412	2316	4.131	0.640	4.771
214	371.4	0.00458	1871	2196	1921	373	2294	4.157	0.579	4.736
216	372.1	0.00436	1888	2174	1940	328	2268	4.186	0.508	4.694
218	372.9	0.00409	1911	2146	1965	270	2235	4.224	0.417	4.641
220	373.7	0.00368	1949	2097	2008	170	2178	4.289	0.263	4.552
221.2	374.15	0.00317	2014	2014	2084	0	2084	4.406	0.000	4.406

ANNEXTURE

Saturated Water and Steam

T [°C]	p_s [bar]	v_g [m³/kg]	h_f [kJ/kg]	h_{fg} [kJ/kg]	h_g [kJ/kg]	s_f [kJ/kg K]	s_{fg} [kJ/kg K]	s_g [kJ/kg K]
0.01	0.006112	206.1	0*	2500.8	2500.8	0†	9.155	9.155
1	0.006566	192.6	4.2	2498.3	2502.5	0.015	9.113	9.128
2	0.007054	179.9	8.4	2495.9	2504.3	0.031	9.071	9.102
3	0.007575	168.2	12.6	2493.6	2506.2	0.046	9.030	9.076
4	0.008129	157.3	16.8	2491.3	2508.1	0.061	8.989	9.050
5	0.008719	147.1	21.0	2488.9	2509.9	0.076	8.948	9.024
6	0.009346	137.8	25.2	2486.6	2511.8	0.091	8.908	8.999
7	0.01001	129.1	29.4	2484.3	2513.7	0.106	8.868	8.974
8	0.01072	121.0	33.6	2481.9	2515.5	0.121	8.828	8.949
9	0.01147	113.4	37.8	2479.6	2517.4	0.136	8.788	8.924
10	0.01227	106.4	42.0	2477.2	2519.2	0.151	8.749	8.900
11	0.01312	99.90	46.2	2474.9	2521.1	0.166	8.710	8.876
12	0.01401	93.83	50.4	2472.5	2522.9	0.180	8.671	8.851
13	0.01497	88.17	54.6	2470.2	2524.8	0.195	8.633	8.828
14	0.01597	82.89	58.8	2467.8	2526.6	0.210	8.594	8.804
15	0.01704	77.97	62.9	2465.5	2528.4	0.224	8.556	8.780
16	0.01817	73.38	67.1	2463.1	2530.2	0.239	8.518	8.757
17	0.01936	69.09	71.3	2460.8	2532.1	0.253	8.481	8.734
18	0.02063	65.08	75.5	2458.4	2533.9	0.268	8.444	8.712
19	0.02196	61.34	79.7	2456.0	2535.7	0.282	8.407	8.689
20	0.02337	57.84	83.9	2453.7	2537.6	0.296	8.370	8.666
21	0.02486	54.56	88.0	2451.4	2539.4	0.310	8.334	8.644
22	0.02642	51.49	92.2	2449.0	2541.2	0.325	8.297	8.622
23	0.02808	48.62	96.4	2446.6	2543.0	0.339	8.261	8.600
24	0.02982	45.92	100.6	2444.2	2544.8	0.353	8.226	8.579
25	0.03166	43.40	104.8	2441.8	2546.6	0.367	8.190	8.557
26	0.03360	41.03	108.9	2439.5	2548.4	0.381	8.155	8.536
27	0.03564	38.81	113.1	2437.2	2550.3	0.395	8.120	8.515
28	0.03778	36.73	117.3	2434.8	2552.1	0.409	8.085	8.494
29	0.04004	34.77	121.5	2432.4	2553.9	0.423	8.050	8.473
30	0.04242	32.93	125.7	2430.0	2555.7	0.436	8.016	8.452
32	0.04754	29.57	134.0	2425.3	2559.3	0.464	7.948	8.412
34	0.05318	26.60	142.4	2420.5	2562.9	0.491	7.881	8.372
36	0.05940	23.97	150.7	2415.8	2566.5	0.518	7.814	8.332
38	0.06624	21.63	159.1	2411.0	2570.1	0.545	7.749	8.294
40	0.07375	19.55	167.5	2406.2	2573.7	0.572	7.684	8.256
42	0.08198	17.69	175.8	2401.4	2577.2	0.599	7.620	8.219
44	0.09100	16.03	184.2	2396.6	2580.8	0.625	7.557	8.182
46	0.1009	14.56	192.5	2391.8	2584.3	0.651	7.494	8.145
48	0.1116	13.23	200.9	2387.0	2587.9	0.678	7.433	8.111
50	0.1233	12.04	209.3	2382.1	2591.4	0.704	7.371	8.075
55	0.1574	9.578	230.2	2370.1	2600.3	0.768	7.223	7.991
60	0.1992	7.678	251.1	2357.9	2609.0	0.831	7.078	7.909
65	0.2501	6.201	272.0	2345.7	2617.7	0.893	6.937	7.830
70	0.3116	5.045	293.0	2333.3	2626.3	0.955	6.800	7.755
75	0.3855	4.133	313.9	2320.8	2634.7	1.015	6.666	7.681
80	0.4736	3.408	334.9	2308.3	2643.2	1.075	6.536	7.611
85	0.5780	2.828	355.9	2295.6	2651.5	1.134	6.410	7.544
90	0.7011	2.361	376.9	2282.8	2659.7	1.192	6.286	7.478
95	0.8453	1.982	398.0	2269.8	2667.8	1.250	6.166	7.416
100	1.01325	1.673	419.1	2256.7	2675.8	1.307	6.048	7.355

† u and s are chosen to be zero for saturated liquid at the triple point.

Note: values of v_f can be found on p. 10.

Saturated Water and Steam

p [bar]	T_s [°C]	v_g [m³/kg]	u_f [kJ/kg]	u_g [kJ/kg]	h_f [kJ/kg]	h_{fg} [kJ/kg]	h_g [kJ/kg]	s_f [kJ/kg K]	s_{fg} [kJ/kg K]	s_g [kJ/kg K]
0.006112	0.01	206.1	0†	2375	0*	2501	2501	0†	9.155	9.155
0.010	7.0	129.2	29	2385	29	2485	2514	0.106	8.868	8.974
0.015	13.0	87.98	55	2393	55	2470	2525	0.196	8.631	8.827
0.020	17.5	67.01	73	2399	73	2460	2533	0.261	8.462	8.723
0.025	21.1	54.26	88	2403	88	2451	2539	0.312	8.330	8.642
0.030	24.1	45.67	101	2408	101	2444	2545	0.354	8.222	8.576
0.035	26.7	39.48	112	2412	112	2438	2550	0.391	8.130	8.521
0.040	29.0	34.80	121	2415	121	2433	2554	0.422	8.051	8.473
0.045	31.0	31.14	130	2418	130	2428	2558	0.451	7.980	8.431
0.050	32.9	28.20	138	2420	138	2423	2561	0.476	7.918	8.394
0.055	34.6	25.77	145	2422	145	2419	2564	0.500	7.860	8.360
0.060	36.2	23.74	152	2425	152	2415	2567	0.521	7.808	8.329
0.065	37.7	22.02	158	2427	158	2412	2570	0.541	7.760	8.301
0.070	39.0	20.53	163	2428	163	2409	2572	0.559	7.715	8.274
0.075	40.3	19.24	169	2430	169	2405	2574	0.576	7.674	8.250
0.080	41.5	18.10	174	2432	174	2402	2576	0.593	7.634	8.227
0.085	42.7	17.10	179	2434	179	2400	2579	0.608	7.598	8.206
0.090	43.8	16.20	183	2435	183	2397	2580	0.622	7.564	8.186
0.095	44.8	15.40	188	2436	188	2394	2582	0.636	7.531	8.167
0.100	45.8	14.67	192	2437	192	2392	2584	0.649	7.500	8.149
0.12	49.4	12.36	207	2442	207	2383	2590	0.696	7.389	8.085
0.14	52.6	10.69	220	2446	220	2376	2596	0.737	7.294	8.031
0.16	55.3	9.432	232	2450	232	2369	2601	0.772	7.213	7.985
0.18	57.8	8.444	242	2453	242	2363	2605	0.804	7.140	7.944
0.20	60.1	7.648	251	2456	251	2358	2609	0.832	7.075	7.907
0.22	62.2	6.994	260	2459	260	2353	2613	0.858	7.016	7.874
0.24	64.1	6.445	268	2461	268	2348	2616	0.882	6.962	7.844
0.26	65.9	5.979	276	2464	276	2343	2619	0.904	6.913	7.817
0.28	67.5	5.578	283	2466	283	2339	2622	0.925	6.866	7.791
0.30	69.1	5.228	289	2468	289	2336	2625	0.944	6.823	7.767
0.32	70.6	4.921	295	2470	295	2332	2627	0.962	6.783	7.745
0.34	72.0	4.649	302	2472	302	2328	2630	0.980	6.745	7.725
0.36	73.4	4.407	307	2473	307	2325	2632	0.996	6.709	7.705
0.38	74.7	4.189	312	2475	312	2322	2634	1.011	6.675	7.686
0.40	75.9	3.992	318	2476	318	2318	2636	1.026	6.643	7.669
0.42	77.1	3.814	323	2478	323	2315	2638	1.040	6.612	7.652
0.44	78.2	3.651	327	2479	327	2313	2640	1.054	6.582	7.636
0.46	79.3	3.502	332	2481	332	2310	2642	1.067	6.554	7.621
0.48	80.3	3.366	336	2482	336	2308	2644	1.079	6.528	7.607
0.50	81.3	3.239	340	2483	340	2305	2645	1.091	6.502	7.593
0.55	83.7	2.964	351	2486	351	2298	2649	1.119	6.442	7.561
0.60	86.0	2.731	360	2489	360	2293	2653	1.145	6.386	7.531
0.65	88.0	2.535	369	2492	369	2288	2657	1.169	6.335	7.504
0.70	90.0	2.364	377	2494	377	2283	2660	1.192	6.286	7.478
0.75	91.8	2.217	384	2496	384	2278	2662	1.213	6.243	7.456
0.80	93.5	2.087	392	2498	392	2273	2665	1.233	6.201	7.434
0.85	95.2	1.972	399	2500	399	2269	2668	1.252	6.162	7.414
0.90	96.7	1.869	405	2502	405	2266	2671	1.270	6.124	7.394
0.95	98.2	1.777	411	2504	411	2262	2673	1.287	6.089	7.376
1.00	99.6	1.694	417	2506	417	2258	2675	1.303	6.056	7.359

$$* \frac{h_f}{[\text{kJ/kg}]} = \frac{pv_f}{[\text{kJ/kg}]} = \frac{p}{[\text{bar}]} \times \frac{10^5[\text{N}]}{[\text{m}^2]} \times \frac{v_f}{[\text{m}^3/\text{kg}]} \times \left[\frac{\text{m}^3}{\text{kg}}\right] \times \frac{[\text{kJ}]}{10^3[\text{N m}]} \times \frac{1}{[\text{kJ/kg}]}$$

$$= \frac{p}{[\text{bar}]} \times \frac{v_f}{[\text{m}^3/\text{kg}]} \times 10^2 = 0.006112 \times 0.0010002 \times 10^2 = 0.0006112$$