THE PAPUA NEW GUINEA UNIVERSITY OF TECHNOLOGY

FIRST SEMESTER EXAMINATIONS – 2022

FOOD TECHNOLOGY – SECOND YEAR DEGREE

FT 211 FOOD ENGINEERING I

MONDAY 31ST MAY – 12:50 PM

TIME ALLOWED: 3 HOURS

INFORMATION FOR CANDIDATES:

1. You have 10 minutes to read the paper. You must not begin writing in the answer book during this time.
2. **ANSWER ALL QUESTIONS**
3. All answers must be written in the answer books provided.
4. Write your name and number clearly on the front page. **Do it now.**
5. Calculators are permitted in the examination room. Notes and textbooks, laptops and mobile phones are not allowed.
6. Show all workings and calculations in the answer book.

MARKING SCHEME

Question 1	[25 marks]
Question 2	[19 marks]
Question 3	[18 marks]
Question 4	[17 marks]
Question 5	[21 marks]

ANSWER ALL QUESTIONS

1. (a) Differentiate between steady state and unsteady state heat transfer. [2 marks]

   (b) With fully labelled illustrations, compare and contrast heat transfer in fluids flowing in co-current and counter–current flow manners. [6 marks]

   (c) Calculate the radiative heat gain in by a loaf of bread at a surface temperature of 110°C. The surrounding oven surface temperature is 1020°C. The total surface area of the bread is 1500 cm^2 and the emissivity of the bread surface is 0.85. Assume that the oven is a blackbody radiator. [4 marks]

   (d) Beans are blanched by immersion in hot water at 96°C. Calculate the temperature at the thermal centre of a bean after three (3) minutes if its diameter is 8 mm, the initial temperature, 20°C and the heat transfer coefficient of the bean surface is 100 W/[m^2.°C]. Assuming that the physical properties of the beans are fixed with a density of 1050 kg/m^3, Cp = 3.7 kJ/[kg.°C] and λ = 0.5 W/[m.°C]. [13 marks]

(Total = 25 marks)

2. (a) At constant absolute humidity, how far would you reduce the temperature of a gas-water vapour mixture from 60°C before it starts losing liquid water if its initial moisture content was 2.15%? Indicate the condition when the mixture loses liquid water. [4 marks]

   (b) Define the terms;

   (i) absolute humidity, [1½ marks]
   (ii) saturated humidity, [1½ marks]
   (iii) wet bulb temperature, [1½ marks]
   (iv) humid heat. [1½ marks]

   (c) With reference to the table (below), what would be your advice, to someone wanting to create an environment that is 30%RH, so to use it for an appropriate moisture study?

Salt solutions	Temperature(°C) 30	40	50	60
LiCl (Lithium chloride)	0.113	0.112	0.111	0.110
CHC$_3$COOK (Potassium acetate)	0.216	0.204	0.192	0.180
MgCl$_2$ 6H$_2$O (Magnesium Chloride)	0.324	0.316	0.305	0.293
K$_2$CO$_3$ (Potassium carbonate)	0.431	0.433	0.427	0421
Mg(NO$_3$)$_2$ (Magnesium nitrate)	0.514	0.484	0.454	0.473
NaNO$_2$ (Sodium nitrite)	0.648	0.609	0.588	0.565
NaCl (Sodium chloride)	0.751	0.747	0.743	0.745
KaCl (Potassium chloride)	0.836	0.823	0.812	0.803

[a] (Greenspan, 1977 ; Labuza et al. , 1985)

[3 marks]

(d) In a drying operation hot exhaust air is at 46°C, 65%RH and is flowing at 28m^3/s. Ambient air at 26°C, 90%RH and flowing at 10m^3/s is to be mixed with the exhaust air before entering the drying chamber, as an attempt to save energy. Determine at least FIVE properties of the mixed air. [6 marks]

(Total = 19 marks)

3. (a) What is the ultimate aim of dehydration? [2 marks]

(b) Give the properties of a food that affects its drying rate with their correlations. [3 marks]

(c) With the aid of a well labelled diagram, describe the operating mechanism of a fluidized bed dryer. [4 marks]

(d) Turmeric was dried from one side in a dryer using air at 68 °C and absolute humidity of 0.032 kg/kg dry air and is flowing at 28,800 m/h. The bulk density of the spice material is 1152 kgm^{-3}, moisture content of 82% and spread evenly at 4.5 mm thick. If it was to be dried to 11% moisture content, then calculate the duration of constant rate drying time, when heated air is flowing parallel to the bed of spice. [9 marks]

(Total = 18 marks)

4. (a) Convective mass transfer coefficient is importantly considered in mass transfer. What does this term account for in mass transfer? [3 marks]

(b) With illustrations, FULLY explain **equi-molar counter diffusion** in mass transfer. [2 marks]

(c) The initial concentration of salt in sliced pork is 8 g/kg salt-free-pork (SFP) and the sliced pork muscle is 6mm thick, with a surface salt concentration of 550 g/kg SFP. Calculate the time for the mass average concentration to reach 300 g/kg SFP if the mass diffusivity of salt in the pork muscle is 8.64×10^{-11} m^2/s. [5 marks]

(d) A droplet of water is falling through 25 °C air at a velocity of 40 cm/s. The diffusivity of water vapor in air is 2×10^{-5} m^2/s. estimate the mass transfer coefficient for a 95 μm diameter droplet. [7 marks]

(Total = 17 marks)

5. (a) State ALL the assumptions of Planck's equation. [5 marks]

(b) The chiller in the pilot plant is maintained at 6 °C using a vapour-compression refrigeration system that uses R-134a. The evaporator temperature is -6 °C while that of the condenser 45 °C. The refrigeration load is 25 tons. Assuming that the unit operates under saturated conditions and the compressor efficiency is 87 %, calculate:

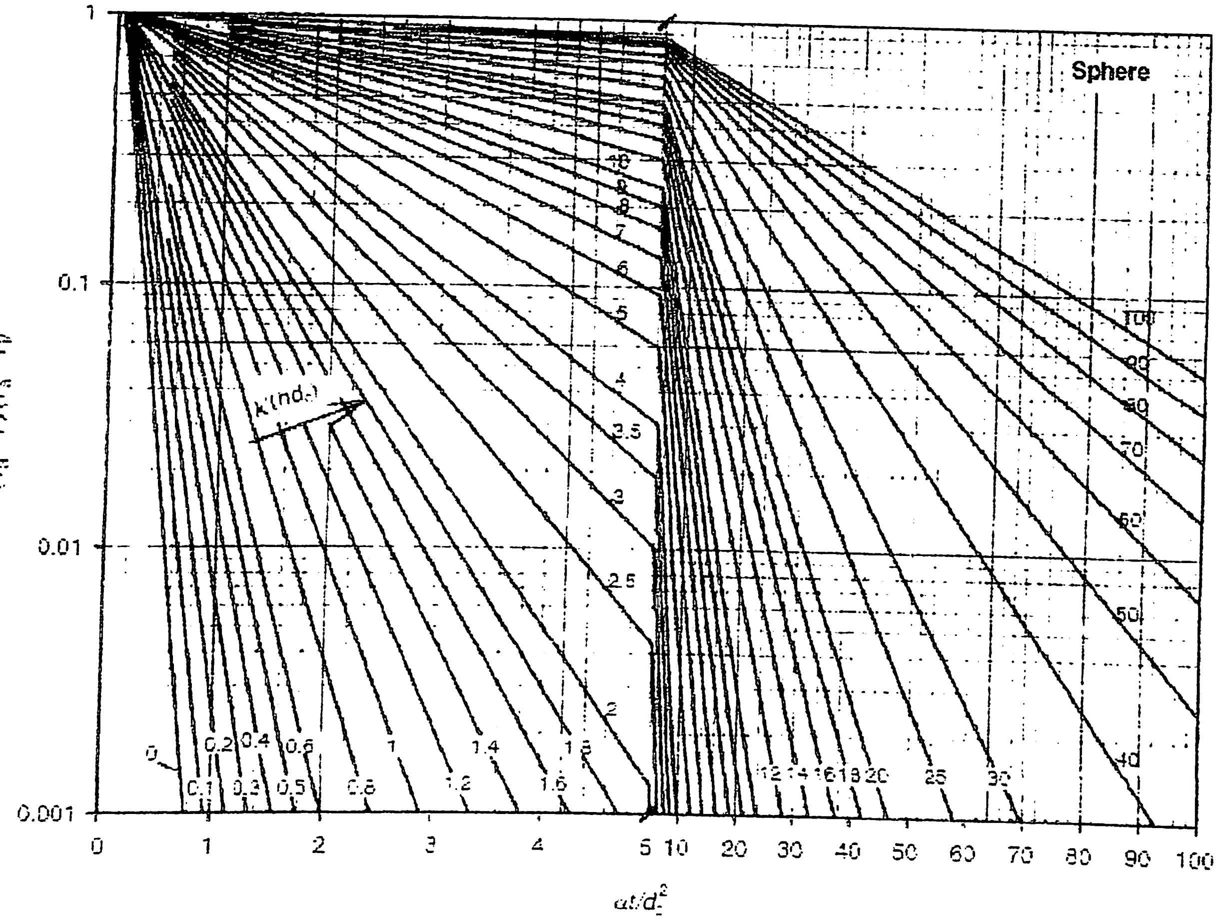
(i) The mass flow rate of the refrigerant. [2 marks]
(ii) The value of H_1, H_2 and H_3. [3 marks]
(iii) The compressor power requirement. [1½ marks]
(iv) The C.O.P. of this system. [1½ marks]

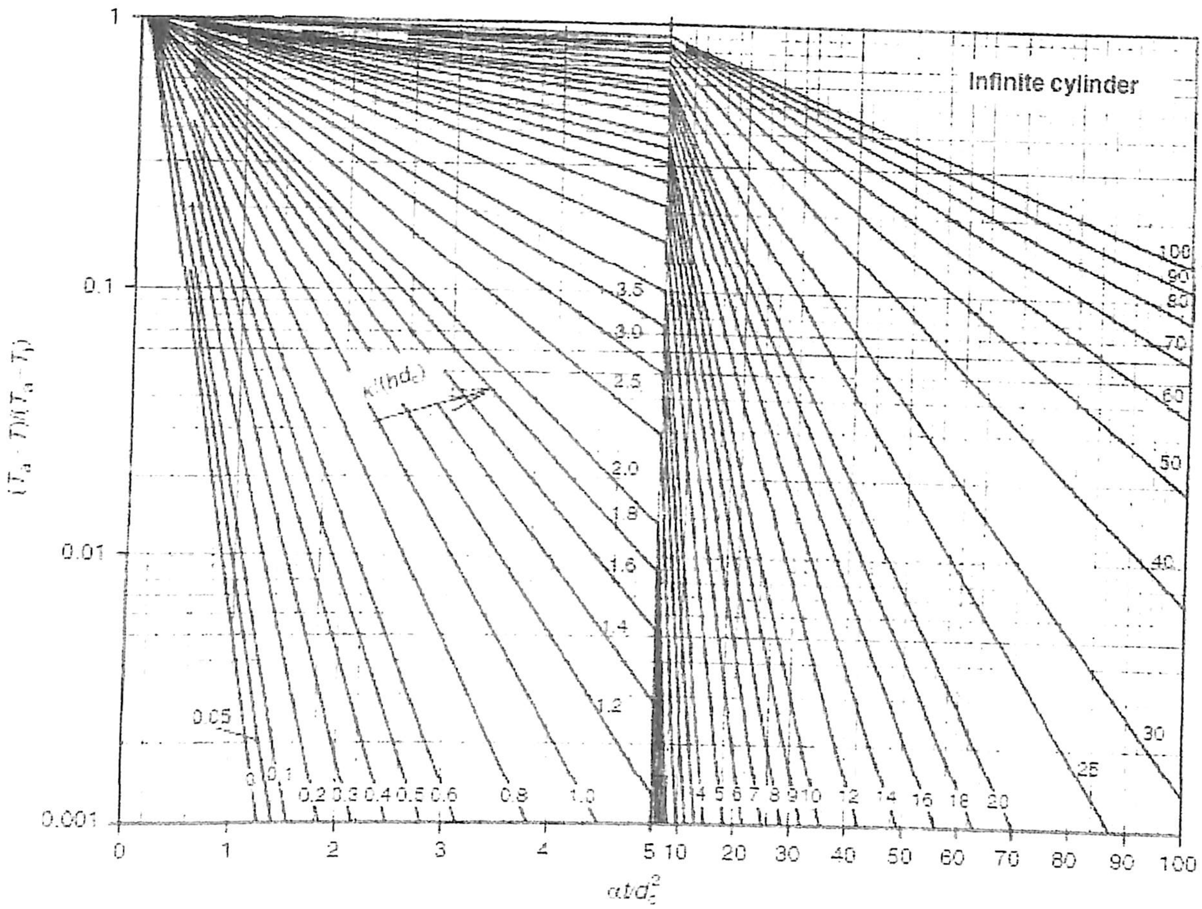
(c) An apple (assumed to be spherical) is being frozen in an air-blast freezer. The initial product temperature is 10 °C and the cold air is at -25°C. The diameter and density are 5.5 cm and 1000 kg/m³ respectively. The freezing temperature is -1.5 °C and the thermal conductivity of the frozen product is 1.5 W/[m.°C] while its latent heat of fusion is 250 kJ/kg and the surface film heat transfer coefficient is 60 W/[m².°C]. Compute the freezing time of the apple. [8 marks]

(Total = 21 marks)

Useful Data

1.	H = $\frac{18\,Pwv}{29(P-Pwv)}$	22	$\%RH = \frac{H}{Hs}x100$
2.	% RH = $\frac{P_{wvs}}{P_{wv}}$	23	$Q = G_A(EB - E_A)$ $Q = VF_A(E_B - E_A)$
3.	$H_3 = \frac{M_AH_A+M_BH_B}{M_A+M_B}$	24	$\left[\frac{dw}{dt}\right] = -KA\ (Hs\ - H)$
4.	$t_c = \frac{(M_o-M_c)\rho Lx}{h_c(\theta_a-\theta_s)}$	25	$tc = \frac{r2\rho lL}{3hc.(\theta a-\theta s)}\frac{(Mo-Mf)}{1+Mo}$
5.	$tfd = \frac{4x2}{D\pi 2}\ln[\frac{(Mc-Me)}{(M-Me)} - \ln\frac{8}{\pi 2}]$	26	For perpendicular flow $h_c = 413.5G^{0.37}$
6.	For parallel flow $h_c = 14.305G^{0.8}$	27	G = vρ (Velocity x density) of hot air
7.	$A = 4\pi r^2$	28	$q_c = H_2 - H_1$
8.	$q_w = H_3 - H_2$	29	$N = -D\frac{\Delta C}{\Delta x}$
9.	$q_c = H_3 - H_1$	30	$k_m = \frac{ShD}{d_c}$
10.	$C.O.P = \frac{H_2 - H_1}{H_3 - H_2}$	31	$T_F = \frac{\rho_f L_f}{T_F - T_a}\left[\frac{P r a}{h} + \frac{R'a^2}{k_f}\right]$
11.	$J = DA\frac{(C1-C2)}{x}$	32	$J = DA\frac{H(P_1-P_2)}{x}$
12.	$B = \frac{Jx}{A(P_1-P_2)}$	33	$J_{solvent} = K_{solvent}(\Delta P-Л)$
13.	$Re = \frac{\rho vd}{\mu}$	34	$y-y_1 = \frac{y_2-y_1}{x_2-x_1}[x - x_1]$
14.	$Sh = \frac{k_m x}{D_{AB}}$	35	$Sc = \frac{\mu}{\rho D}$
15.	$Sh = 2 + 0.6Re^{1/2}Sc^{1/3}$	36	$N_A = \frac{D_W}{RT_X}\frac{P_T}{P_{AM}}(P_{w1} - P_{w2})$
16.	$\frac{C_{ma} - C_m}{C_i - C_m}$	37	$Sh = 0.023Re^{0.8}Sc^{1/3}$
17.	Sphere P = 1/6, R = 1/24	38	Slab P = 1/2 , R = 1/8
18.	1 Ton Refrigerant= 303,852 kJ/24hrs for R-134a	39	$q = \frac{4\pi k(T_1-T_2)}{\frac{1}{r_1}-\frac{1}{r_2}}$
19.	$q = -kA\frac{\Delta T}{\Delta x}$	40	$F_o = \frac{\alpha t}{d^2}, \qquad \alpha = \frac{k}{Cp\rho}$
20.	$q = \frac{T_1-T_4}{\frac{x_a}{k_aA}+\frac{x_b}{k_bA}+\frac{x_c}{k_cA}}$	41	$Bi = \frac{hd}{k}, \qquad T_f = \frac{T_b-T_F}{T_b-T_i}$
21.	$q = \frac{2\pi L[T_1-T_4]}{\frac{ln\left(\frac{r_2}{r_1}\right)}{k_a}+\frac{ln\left(\frac{r_3}{r_2}\right)}{k_b}+\frac{ln\left(\frac{r_4}{r_3}\right)}{k_c}}$	42	$q = \varepsilon\sigma A(T_1^4 - T_2^4)$ $\sigma = 5.7 \times 10^{-8}\ Js^{-1}m^{-2}K^{-4}$


Sphere
$(T_a - T)/(T_a - T_i)$
$k'(nd_c)$
$\alpha t/d_c^2$


Infinite cylinder
$(T_a - T)/(T_a - T_i)$
$\alpha t/d_c^2$
$k/(hd_c)$
1
0.1
0.01
0.001
0
1
2
3
4
5
10
20
30
40
50
60
70
80
90
100
0.05
0.1
0.2
0.3
0.4
0.5
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
3.5
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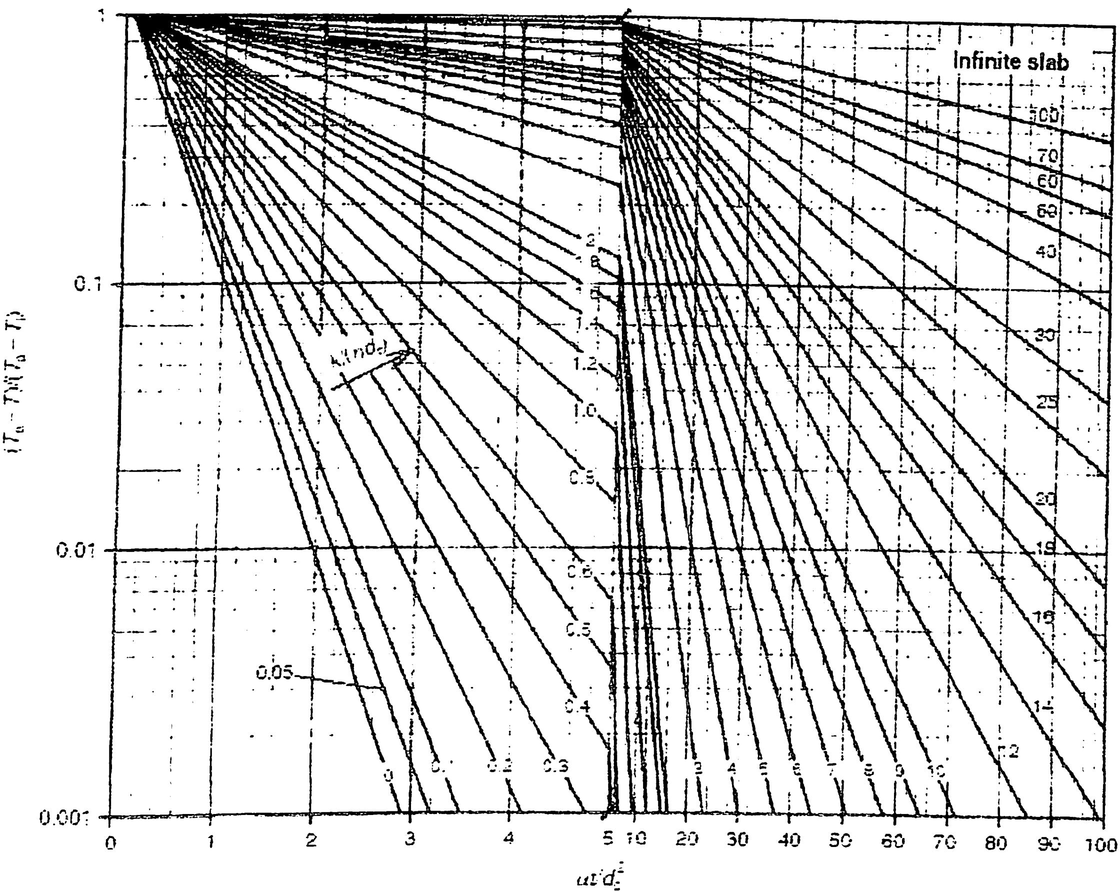
Infinite slab
100
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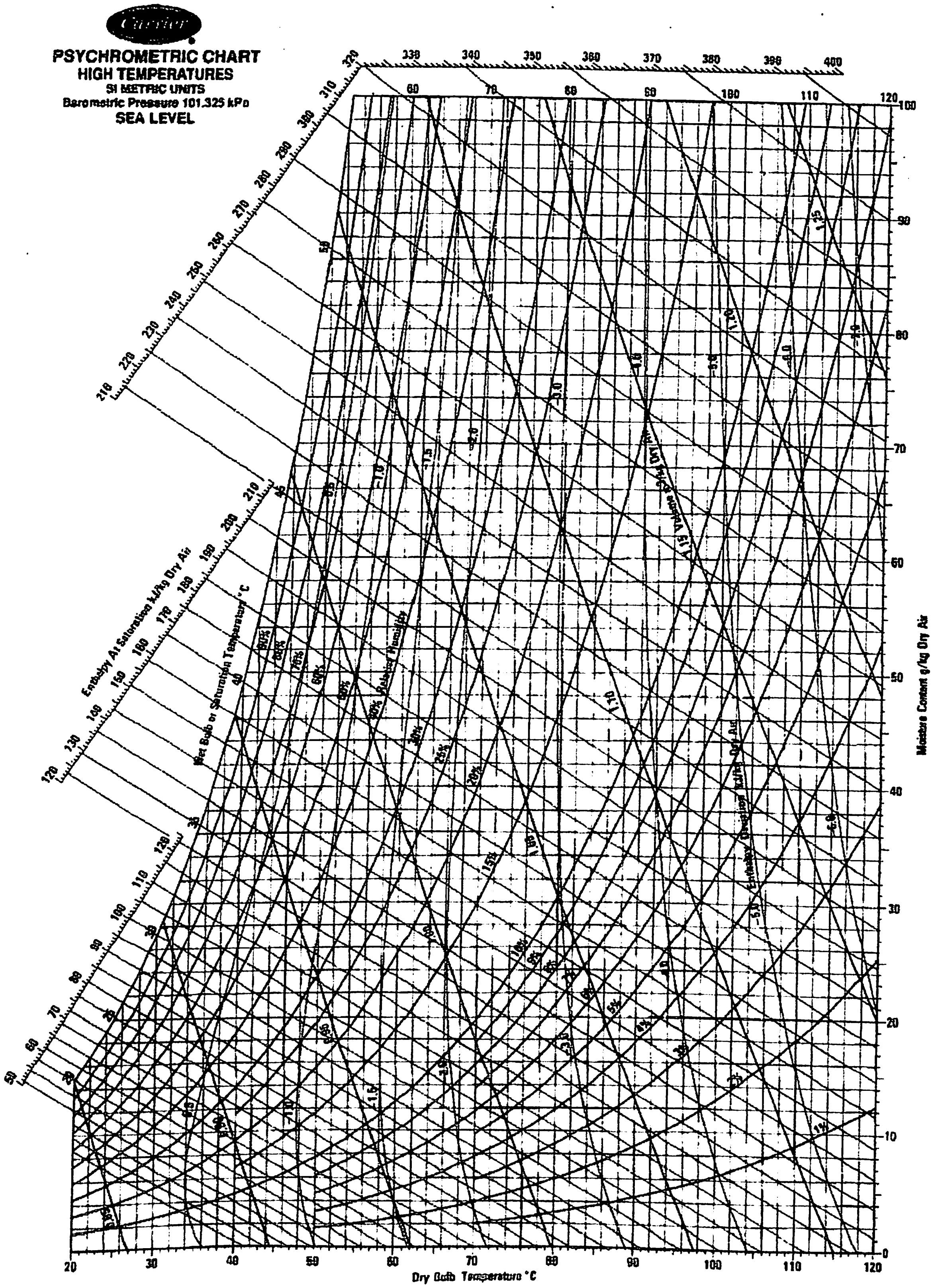
Table C.1aSI Saturation Temperature Table for Steam in SI Units

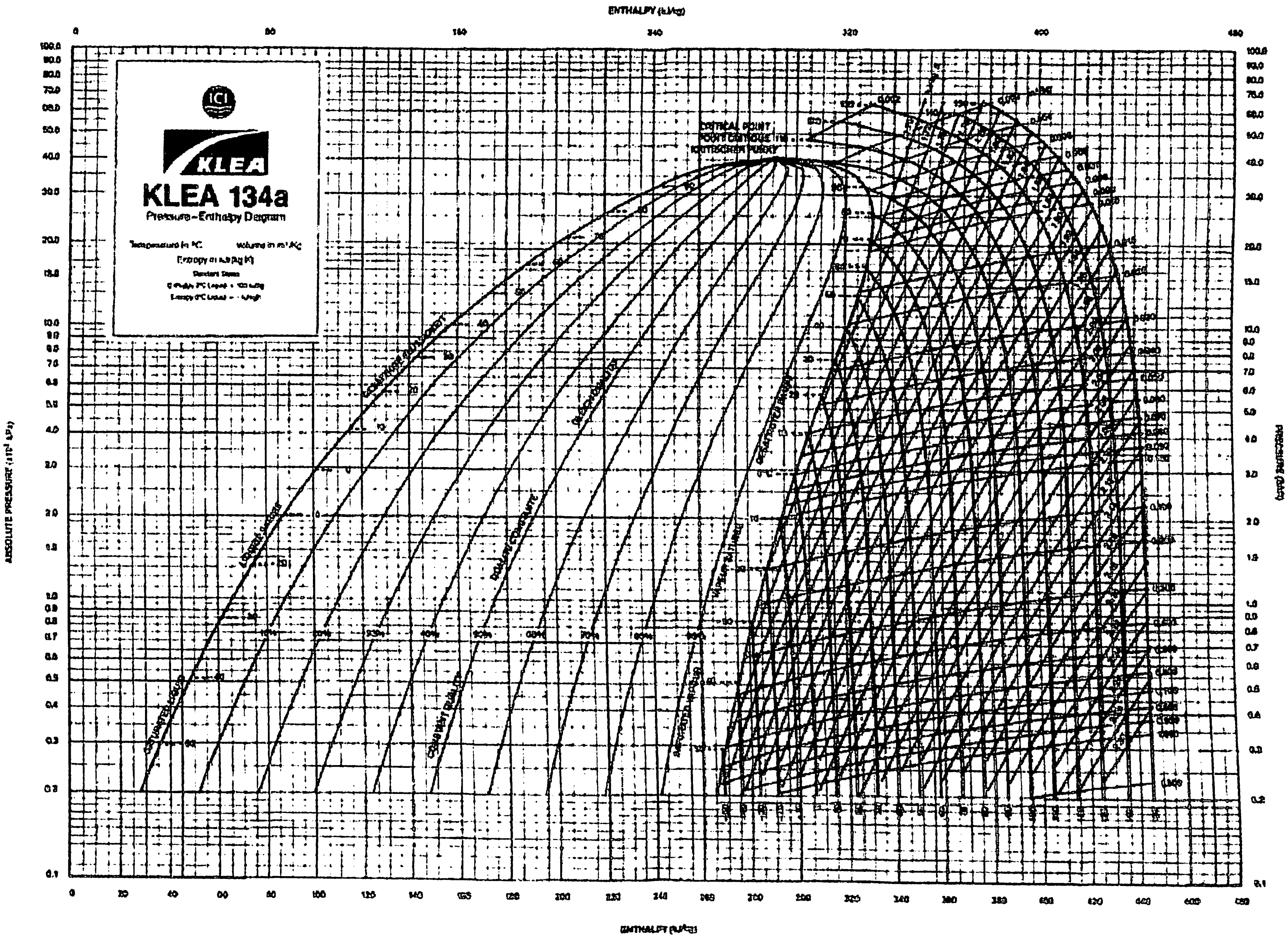
T C	P_{sat} kPa	v_f m3/kg	v_g m3/kg	v_{fg} m3/kg	h_f kJ/kg	h_g kJ/kg	h_{fg} kJ/kg	u_f kJ/kg	u_g kJ/kg	u_{fg} kJ/kg	s_f kJ/kg K	s_g kJ/kg K	s_{fg} kJ/kg K
0	0.6119	0.000995	205.94	205.93	0.9007	2500.02	2499.12	0.9001	2374.02	2373.12	-0.0013	9.1582	9.1595
2	0.7066	0.000995	179.63	179.63	9.2488	2504.40	2495.15	9.2481	2377.48	2368.24	0.0297	9.1052	9.0755
4	0.8140	0.000996	157.04	157.04	17.5909	2508.60	2491.01	17.5901	2380.76	2363.17	0.0604	9.0531	8.9928
6	0.9357	0.000996	137.59	137.59	25.9279	2512.64	2486.72	25.9269	2383.90	2357.97	0.0908	9.0020	8.9113
8	1.0732	0.000997	120.82	120.82	34.2606	2516.58	2482.31	34.2595	2386.91	2352.66	0.1209	8.9519	8.8309
10	1.2282	0.000997	106.31	106.31	42.5897	2520.42	2477.83	42.5885	2389.84	2347.25	0.1508	8.9026	8.7518
12	1.4026	0.000998	93.74	93.74	50.9160	2524.19	2473.27	50.9146	2392.70	2341.79	0.1804	8.8542	8.6738
14	1.5985	0.000999	82.83	82.83	59.2401	2527.90	2468.66	59.2385	2395.51	2336.27	0.2098	8.8066	8.5969
16	1.8180	0.000999	73.33	73.33	67.5625	2531.58	2464.02	67.5607	2398.27	2330.71	0.2389	8.7599	8.5211
18	2.0635	0.001000	65.04	65.04	75.8837	2535.23	2459.34	75.8817	2401.01	2325.13	0.2678	8.7141	8.4463
20	2.3376	0.001000	57.80	57.80	84.2043	2538.85	2454.65	84.2020	2403.73	2319.53	0.2964	8.6690	8.3725
22	2.6431	0.001001	51.47	51.46	92.5247	2542.46	2449.94	92.5220	2406.43	2313.91	0.3249	8.6247	8.2998
24	2.9830	0.001002	45.90	45.90	100.845	2546.06	2445.21	100.842	2409.12	2308.28	0.3531	8.5811	8.2280
26	3.3604	0.001002	41.02	41.02	109.166	2549.65	2440.48	109.163	2411.81	2302.65	0.3811	8.5384	8.1572
28	3.7789	0.001003	36.72	36.71	117.488	2553.23	2435.74	117.484	2414.49	2297.01	0.4090	8.4963	8.0874
30	4.2420	0.001004	32.92	32.92	125.811	2556.81	2431.00	125.807	2417.17	2291.36	0.4366	8.4550	8.0184
32	4.7536	0.001005	29.57	29.56	134.136	2560.39	2426.25	134.131	2419.84	2285.71	0.4640	8.4143	7.9503
34	5.3181	0.001005	26.60	26.60	142.462	2563.96	2421.50	142.456	2422.52	2280.06	0.4913	8.3744	7.8831
36	5.9398	0.001006	23.96	23.96	150.790	2567.53	2416.74	150.784	2425.19	2274.40	0.5183	8.3351	7.8168
38	6.6235	0.001007	21.62	21.62	159.120	2571.09	2411.97	159.113	2427.86	2268.74	0.5452	8.2964	7.7512
40	7.3743	0.001008	19.54	19.54	167.452	2574.65	2407.20	167.444	2430.52	2263.08	0.5719	8.2584	7.6865
42	8.1975	0.001009	17.69	17.69	175.786	2578.20	2402.41	175.778	2433.18	2257.41	0.5985	8.2210	7.6226
44	9.0987	0.001009	16.04	16.03	184.123	2581.75	2397.63	184.114	2435.84	2251.73	0.6248	8.1843	7.5594
46	10.084	0.001010	14.56	14.56	192.463	2585.29	2392.83	192.452	2438.50	2246.04	0.6510	8.1481	7.4970
48	11.160	0.001011	13.23	13.23	200.805	2588.82	2388.02	200.794	2441.14	2240.35	0.6771	8.1125	7.4354
50	12.333	0.001012	12.05	12.04	209.150	2592.34	2383.19	209.137	2443.78	2234.65	0.7030	8.0775	7.3745
52	13.610	0.001013	10.98	10.98	217.498	2595.86	2378.36	217.484	2446.42	2228.93	0.7287	8.0430	7.3143

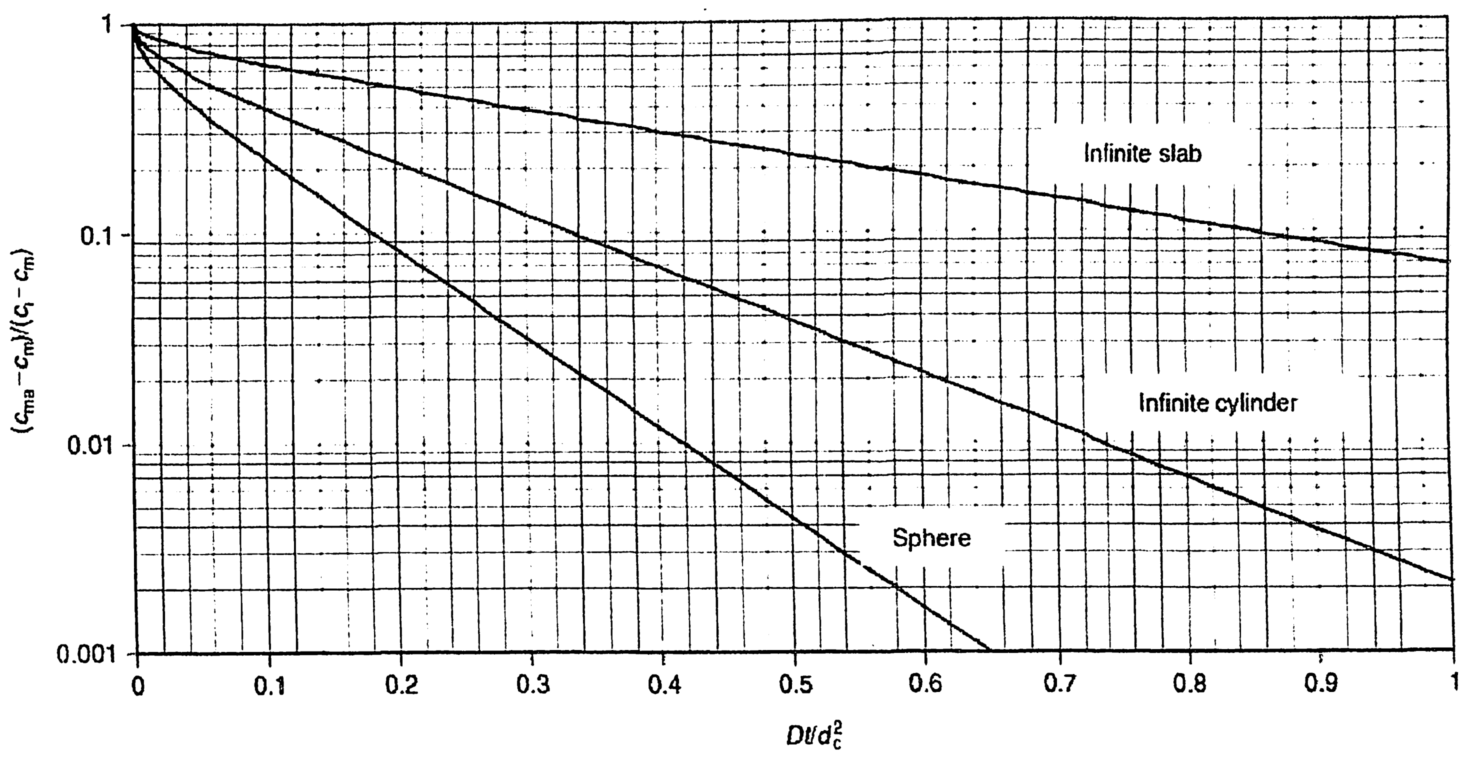
PSYCHROMETRIC CHARTS



Physical Properties of Dry Air at Atmospheric Pressure

Temperature t (°C)	T (K)	Density (ρ) (kg/m^3)	Volumetric coefficient of expansion (β) ($\times 10^{-3}$ K^{-1})	Specific heat (c_p) (kJ/[kg K])	Thermal conductivity (k) (W/[m K])	Thermal diffusivity (α) ($\times 10^{-6}$ m^2/s)	Viscosity (μ) ($\times 10^{-6}$ N s/m^2)	Kinematic viscosity (ν) ($\times 10^{-6}$ m^2/s)	Prandtl number (N_{Pr})
−20	253.15	1.365	3.97	1.005	0.0226	16.8	16.279	12.0	0.71
0	273.15	1.252	3.65	1.011	0.0237	19.2	17.456	13.9	0.71
10	283.15	1.206	3.53	1.010	0.0244	20.7	17.848	14.66	0.71
20	293.15	1.164	3.41	1.012	0.0251	22.0	18.240	15.7	0.71
30	303.15	1.127	3.30	1.013	0.0258	23.4	18.682	16.58	0.71
40	313.15	1.092	3.20	1.014	0.0265	24.8	19.123	17.6	0.71
50	323.15	1.057	3.10	1.016	0.0272	26.2	19.515	18.58	0.71
60	333.15	1.025	3.00	1.017	0.0279	27.6	19.907	19.4	0.71
70	343.15	0.996	2.91	1.018	0.0286	29.2	20.398	20.65	0.71
80	353.15	0.968	2.83	1.019	0.0293	30.6	20.790	21.5	0.71
90	363.15	0.942	2.76	1.021	0.0300	32.2	21.231	22.82	0.71
100	373.15	0.916	2.69	1.022	0.0307	33.6	21.673	23.6	0.71
120	393.15	0.870	2.55	1.025	0.0320	37.0	22.555	25.9	0.71
140	413.15	0.827	2.43	1.027	0.0333	40.0	23.340	28.2	0.71
150	423.15	0.810	2.37	1.028	0.0336	41.2	23.732	29.4	0.71
160	433.15	0.789	2.31	1.030	0.0344	43.3	24.124	30.6	0.71
180	453.15	0.755	2.20	1.032	0.0357	47.0	24.909	33.0	0.71
200	473.15	0.723	2.11	1.035	0.0370	49.7	25.693	35.5	0.71
250	523.15	0.653	1.89	1.043	0.0400	60.0	27.557	42.2	0.71


KLEA
KLEA 134a
Pressure–Enthalpy Diagram
ENTHALPY (kJ/kg)
ABSOLUTE PRESSURE
CRITICAL POINT
SATURATED LIQUID
SATURATED VAPOUR
CONSTANT QUALITY


1
0.1
0.01
0.001
$(c_{ma} - c_m)/(c_i - c_m)$
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dt/d_c^2
Infinite slab
Infinite cylinder
Sphere