



UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

MAIN EXAMINATIONS: MAY/ JUNE 2025

COURSE AND CODE: HEAT TRANSFER ENCH3HE

DURATION: 3 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINER/S: MRS A. SINGH
MR E.M. OBWAKA

INTERNAL MODERATOR: DR S. MOODLEY

EXTERNAL MODERATOR: MR U DEBISING

INSTRUCTIONS:

1. ALL questions should be attempted. Answer in **INK**.
2. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
3. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
4. **Two answer books are provided. Label them Book A and Book B. Answer Section A in Book A and Section B in Book B.**
5. This examination question paper, together with all associated diagrams, **MUST BE HANDED IN TOGETHER WITH YOUR SCRIPT.**

Student Number:

SECTION A

QUESTION 1

A wall built with 150 mm thick fireclay brick, is well insulated on one side. The wall, which is initially at a uniform temperature of 20°C , is exposed to hot gas at a temperature of 950°C with a convection coefficient of $100 \text{ W/m}^2\cdot\text{K}$.

- 1.1 How long will it take for the insulated surface of the wall to reach a temperature of 750°C ? (8)
- 1.2 How long will it take for that same surface of the wall to reach a temperature of 750°C if it was not insulated? Comment on your answer. (6)

Density	2600 kg/m^3
Heat Capacity	$1000 \text{ J/kg}\cdot\text{K}$
Thermal conductivity	$1.5 \text{ W/m}\cdot\text{K}$

TABLE 1: Properties of the fireclay brick

Temperature Time charts are on pages 7 & 8.

TOTAL /14/

QUESTION 2

A heating element of 5 mm diameter, and at a constant surface temperature of 350°C is immersed horizontally in water at atmospheric pressure.

Calculate the electrical power dissipation per unit heater length.

The element has an emissivity of 0.25 and is made of mechanically polished stainless steel.

Equations/ Correlations are on pages 5 & 6.

Fluid properties are on page 10. Interpolation of properties is not required, use the closest tabulated value.

TOTAL /16/

QUESTION 3

Steam at 0.14 bar is condensing in a shell and tube heat exchanger. Cooling water enters on the tube side at a temperature of 20 °C and mean velocity of 1.25 m/s. The heat exchanger configuration is such that there is one shell pass and two tube passes. There are 130 brass tubes having ^{total} length of 2 m and inner diameter of 13 mm and outer diameter of 16 mm. The heat transfer coefficient on the outer tube surface is $h_o = 13500 \text{ W/m}^2\cdot\text{K}$.

- 3.1 Use the Effectiveness-NTU method to calculate the exit temperature of the cooling water. You may assume fully developed flow. (22)
- 3.2 Calculate the rate of condensation of the steam. (3)

Thermal conductivity of Brass = 114 W/m.K

Properties of water may be evaluated at 310 K (since the exit temperature is unknown).

Fluid properties are on page 10. Interpolation of properties is not required, use the closest tabulated value.

Effectiveness-NTU relations are on page 9.

TOTAL /25/

SECTION B**QUESTION 4**

Water is to be cooled from 323 to 290 K by means of a counter-current air stream entering a cooling tower at 290 K with a relative humidity of 25 %. The flow of air is $0.6 \text{ m}^3/\text{m}^2\text{s}$ and the water throughput is $0.3 \text{ kg}/\text{m}^2\text{s}$. What is the required height of packing?

Data

$$\frac{G'_y}{sk_y a} = 6$$

Latent heat of water at 273 K = 2495 kJ/kg

Specific heat of dry air = 1.003 kJ/kg.K

Specific heat of water vapour = 2.006 kJ/kg.K

Molecular weights: water = 18 kg/kmol; dry air = 29 kg/kmol

The molar volume of an ideal gas at Standard Temperature and Pressure is 22.4 dm^3

Useful Equations

Energy balance equation for a cooling tower:

$$G'_y (H_{ya} - H_{yb}) = G_x c_L (T_{xa} - T_{xb})$$

The required height of packing can be determined from:

$$Z_T = \int_{H_{yb}}^{H_{ya}} \frac{G'_y}{sk_y a (H_y^* - H_y)} dy \approx \frac{h}{3} (f_1 + 4f_2 + 2f_3 + 4f_4 + f_5)$$

Humid heat	$c_s = c_{pB} + c_{pA}^* H$
Total enthalpy	$H_y = c_s (T - T_0) + H \lambda_0$

A psychrometric chart is provided on Page 11 and the thermophysical properties of saturated water are provided on page 10. A graph of air-enthalpy versus water temperature is provided on page 12. **This graph should be submitted together with your answer booklet.**

QUESTION 5

Heat exchange stream data for a chemical process is provided in Table 2.

Stream Number	Stream Name	Supply Temperature, (°C)	Target Temperature, (°C)	Heat Capacity Flowrate, CP, (kW/°C)
1	Reactor 1 Feed	20	180	200
2	Reactor 1 Product	240	40	160
3	Reactor 2 Feed	140	220	300
4	Reactor 2 Product	200	80	250

TABLE 2: Heat exchange stream data

5.1 Given $\Delta T_{\min} = 20^\circ\text{C}$, use the Problem Table Algorithm method to determine the required interval temperatures.

(5)

5.2 Using the required interval temperatures determined in 5.1, set up and fill a Problem Table with the following column headings: Required intervals; ΔT (°C); $\Sigma CP_C - \Sigma CP_H$ (MW/°C); ΔH (MW); Heat Cascade; Corrected Heat Cascade; Stream lines.

(11)

5.3 Hence determine the following:

5.3.1 Minimum hot utility required (1)

5.3.2 Minimum cold utility required (1)

5.3.2 Hot pinch temperature (1)

5.3.4 Cold pinch temperature (1)

TOTAL /20/

CONVECTION CORRELATIONS

FORCED CONVECTION: INTERNAL FLOW

Fully developed Turbulent flow in smooth circular tubes: Dittus-Boelter correlation

$$Nu_D = 0.023 Re^{4/5} Pr^n$$
$$n = 0.4 \text{ if } T_s > T_m$$
$$n = 0.3 \text{ if } T_s < T_m$$

Valid if: $0.7 \leq Pr \leq 160$
 $Re_D \geq 10\,000$
 $L/D \geq 10$
(Properties evaluated at T_m)

FORCED CONVECTION: EXTERNAL FLOW

Horizontal cylinder in cross flow

$$Nu_D = 0.3 + \frac{0.62 Re_D^{0.5} Pr^{1/3}}{\left[1 + (0.4/Pr)^{2/3}\right]^{1/4}} \left[1 + (Re_D/282000)^{5/8}\right]^{4/5}$$

Properties evaluated at T_f
For all Re , $RePr \geq 0.2$

CORRELATIONS: BOILING

Rohsenow correlation for nucleate pool boiling ($5 \leq \Delta T_e \leq 30$)

$$q_s'' = \mu_l h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma} \right]^{1/2} \left(\frac{C_{p,l} \Delta T_e}{C_{s,f} h_{fg} \text{Pr}_l^n} \right)^3$$

Values of $C_{s,f}$ and n may be found from Table 3

Film pool boiling ($120 \leq \Delta T_e \leq 1100$)

$$\overline{Nu_D} = C \left[\frac{g(\rho_l - \rho_v) h'_{fg} D^3}{v_v k_v (T_s - T_{sat})} \right]^{1/4}$$

$C = 0.62$ for horizontal cylinders

$C = 0.67$ for spheres

$$h'_{fg} = h_{fg} + 0.80 C_{p,v} (T_s - T_{sat})$$

$$\bar{h}^{4/3} = \bar{h}_{conv}^{4/3} + \bar{h}_{rad} \bar{h}^{1/3}$$

$$\bar{h} = \bar{h}_{conv} + \frac{3}{4} \bar{h}_{rad} \text{ if } \bar{h}_{rad} < \bar{h}_{conv}$$

Stefan Boltzmann constant = $5.676 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$

Surface-Fluid Combination	$C_{s,f}$	n
Water-copper		
Scored	0.0068	1.0
Polished	0.0120	1.0
Water- stainless steel		
Chemically etched	0.0130	1.0
Mechanically polished	0.0130	1.0
Ground and polished	0.0060	1.0

Table 3: Values of constants for various surface-fluid combinations

2257

TEMPERATURE TIME CHARTS

Dimensionless Ratios for Temperature Time charts

$$Y = \frac{T_{\infty} - T}{T_{\infty} - T_0}$$

$$X = \frac{\alpha t}{x_1^2}$$

$$n = \frac{x}{x_1}$$

$$m = \frac{k}{hx_1}$$

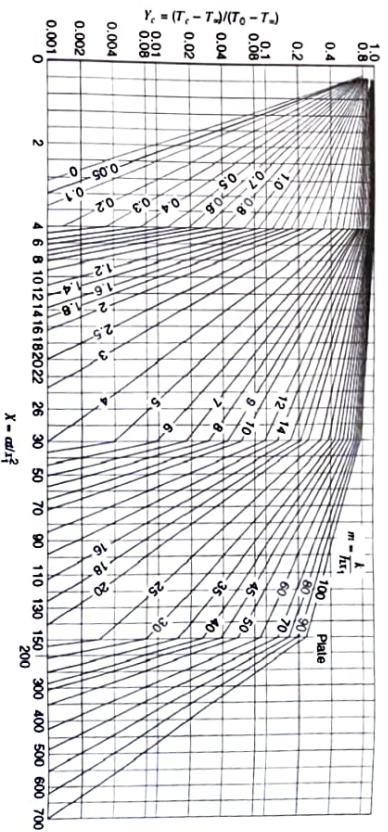
 x_1 = radius/ semi-thickness of conducting mediumFIGURE 2: CENTRE TEMPERATURE HISTORY FOR UNSTEADY STATE
TRANSPORT: FLAT PLATE

FIGURE 2: TEMPERATURE TIME HISTORY FOR UNSTEADY STATE
TRANSPORT: FLAT PLATE

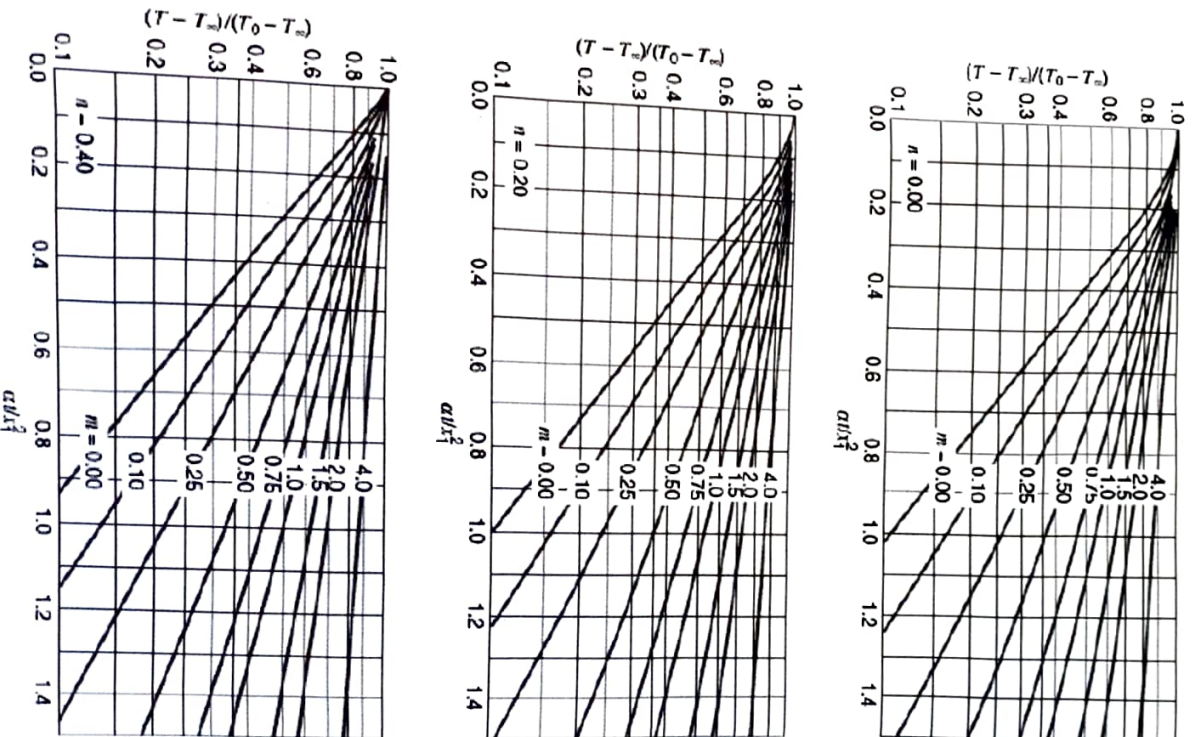


TABLE 4: HEAT EXCHANGER EFFECTIVENESS RELATIONS

Flow Arrangement	Relation
Concentric Tube	
Parallel flow	$\varepsilon = \frac{1 - \exp[-NTU(1 + C_r)]}{1 + C_r}$
Counterflow	$\varepsilon = \frac{1 - \exp[-NTU(1 - C_r)]}{1 - C_r \exp[-NTU(1 - C_r)]} \quad (C_r < 1)$
	$\varepsilon = \frac{NTU}{1 + NTU} \quad (C_r = 1)$
Shell and Tube	
One shell pass (2, 4, ... tube passes)	$\varepsilon_1 = 2 \left\{ 1 + C_r + (1 + C_r^2)^{1/2} \times \frac{1 + \exp[-NTU(1 + C_r^2)^{1/2}]}{1 - \exp[-NTU(1 + C_r^2)^{1/2}]} \right\}^{-1}$
n -Shell passes ($2n, 4n, \dots$ tube passes)	$\varepsilon = \left[\left(\frac{1 - \varepsilon_1 C_r}{1 - \varepsilon_1} \right)^n - 1 \right] \left[\left(\frac{1 - \varepsilon_1 C_r}{1 - \varepsilon_1} \right)^n - C_r \right]^{-1}$
Cross flow (single pass)	
Both fluids unmixed	$\varepsilon = 1 - \exp \left[\left(\frac{1}{C_r} \right) (NTU)^{0.22} \left\{ \exp[-C_r (NTU)^{0.78}] - 1 \right\} \right]$
$C_{\max}$ (mixed), $C_{\min}$ (unmixed)	$\varepsilon = \left(\frac{1}{C_r} \right) \left\{ 1 - \exp \left\{ -C_r [1 - \exp(-NTU)] \right\} \right\}$
$C_{\min}$ (mixed), $C_{\max}$ (unmixed)	$\varepsilon = 1 - \exp \left\{ -C_r^{-1} [1 - \exp[-C_r (NTU)]] \right\}$
All exchangers ($C_r = 0$)	$\varepsilon = 1 - \exp(-NTU)$

TABLE 5: PROPERTIES OF SATURATED WATER

Temp., t (°C)	Pressure, P (kPa)	Specific Volume v _g (m ³ /kg)	Heat of Vapor- ization, h _{fg} (kJ/kg)	Specific Heat c _{pg} (kJ/kg·K)	Viscosity, μ (N·m ⁻²)	Thermal Conductivity k (W/m·K)	Prandtl Number, Pr	Surface Tension, σ (N/m)	Expansion Coeff., β (K ⁻¹)	Temp., t (°C)			
273.15	0.00611	1.000 2063	2502	4.217	1.854	0.02	569	18.2	17.99	0.015	73.5	-6.03	273.15
273	0.00907	1.000 1817	2497	4.231	1.855	0.02	569	18.4	17.92	0.017	73.4	-3.74	73
275	0.0131	1.000 1304	2485	4.198	1.858	0.02	569	18.5	17.85	0.025	73.4	-6.04	280
280	0.02090	1.000 994	2473	4.189	1.861	0.02	569	18.9	17.80	0.033	73.3	-14.1	285
285	0.03187	1.001 697	2461	4.184	1.864	0.02	569	19.3	17.56	0.041	73.7	-17.0	290
290	0.04617	1.001 697	2449	4.181	1.868	0.02	569	19.5	16.82	0.049	72.7	-22.5	295
300	0.07513	1.003 5194	2438	4.179	1.872	0.02	569	20.1	16.20	0.057	71.7	-26.1	300
310	0.10412	1.005 2974	2426	4.178	1.877	0.02	569	20.4	15.20	0.065	70.9	-30.6	305
310	0.06221	1.007 2293	2414	4.178	1.882	0.02	569	20.7	14.42	0.073	70.0	-36.9	315
315	0.08132	1.009 1782	2402	4.179	1.888	0.01	564	20.7	13.88	0.083	69.2	-40.4	315
320	0.1033	1.011 1358	2390	4.180	1.895	0.01	569	21.0	13.77	0.094	68.3	-43.7	320
325	0.1351	1.016 1106	2378	4.182	1.903	0.01	569	21.3	13.42	0.101	67.5	-47.2	325
330	0.1719	1.016 882	2366	4.184	1.911	0.01	569	21.7	13.15	0.098	66.6	-50.0	330
335	0.2167	1.018 709	2354	4.186	1.920	0.01	569	22.2	12.88	0.096	65.8	-53.5	335
340	0.2713	1.021 574	2342	4.188	1.930	0.01	569	22.7	12.66	0.095	64.9	-56.0	340
345	0.3372	1.024 4683	2329	4.191	1.941	0.01	569	23.5	12.45	0.093	64.1	-59.4	345
350	0.4163	1.027 3466	2317	4.195	1.954	0.01	569	24.0	12.29	0.092	63.2	-62.2	350
355	0.5100	1.030 2180	2304	4.199	1.968	0.01	569	24.3	12.14	0.091	62.3	-65.3	355
360	0.6299	1.034 2645	2291	4.203	1.983	0.01	569	24.7	11.99	0.090	61.4	-67.9	360
365	0.7514	1.038 2212	2278	4.209	1.999	0.01	569	25.1	11.81	0.089	60.5	-70.1	365
370	0.9060	1.041 1861	2265	4.214	2.017	0.01	569	25.5	11.65	0.088	59.5	-72.7	370
373.15	1.0133	1.045 1679	2252	4.217	2.029	0.01	569	25.8	11.50	0.088	58.6	-75.1	373.15
375	1.0815	1.049 1574	2239	4.220	2.036	0.01	569	26.0	11.36	0.087	57.8	-76.1	375
380	1.2869	1.053 1357	2225	4.226	2.057	0.01	569	26.4	11.14	0.086	56.6	-78.8	380
385	1.5333	1.057 1162	2212	4.232	2.080	0.01	569	26.8	10.93	0.084	55.6	-81.4	385
390	1.794	1.058 0980	2212	4.239	2.104	0.01	569	27.2	10.74	0.083	54.6	-84.1	390
400	2.465	1.067 0731	2185	4.256	2.158	0.01	569	28.0	10.48	0.081	52.5	-89.6	400
410	3.526	1.077 0553	2173	4.278	2.221	0.01	569	28.8	10.24	0.079	50.3	-93.2	410
420	4.970	1.088 0423	2162	4.302	2.291	0.01	569	29.6	10.01	0.077	47.9	-97.0	420
430	5.699	1.099 0331	2091	4.331	2.369	0.01	569	30.4	1.09	0.075	45.2	-101.0	430
440	7.333	1.110 0261	2059	4.356	2.46	0.01	569	31.2	1.04	0.074	42.3	-105.0	440
450	9.213	1.123 0208	2024	4.40	2.56	0.01	569	32.0	1.01	0.073	39.6	-109.0	450
460	11.719	1.137 0167	1989	4.44	2.68	0.01	569	32.8	0.95	0.072	36.9	-113.0	460
470	14.55	1.152 0136	1951	4.48	2.79	0.01	569	33.6	0.89	0.071	34.2	-117.0	470
480	17.90	1.167 0111	1912	4.53	2.94	0.01	569	34.4	0.83	0.070	31.5	-121.0	480
490	21.83	1.184 00922	1870	4.59	3.10	0.01	569	35.2	0.77	0.069	28.8	-125.0	490
500	26.40	1.201 00766	1825	4.66	3.27	0.01	569	36.0	0.71	0.068	26.1	-129.0	500
510	31.66	1.222 00651	1779	4.74	3.47	0.01	569	36.8	0.65	0.067	23.4	-133.0	510
520	37.70	1.244 00455	1730	4.84	3.70	0.01	569	37.6	0.59	0.066	20.7	-137.0	520
530	44.58	1.268 00445	1679	4.95	3.96	0.01	569	38.4	0.53	0.065	18.0	-141.0	530
540	52.38	1.294 00715	1627	5.08	4.27	0.01	569	39.2	0.46	0.064	15.3	-145.0	540
550	61.19	1.323 01017	1564	5.24	4.64	0.01	569	40.0	0.39	0.063	12.6	-149.0	550
560	71.08	1.355 01369	1499	5.43	5.09	0.01	569	40.8	0.32	0.062	10.0	-153.0	560
570	82.16	1.392 00228	1429	5.68	5.67	0.01	569	41.6	0.25	0.061	7.3	-157.0	570
580	94.51	1.433 01913	1353	6.00	6.40	0.01	569	42.4	0.18	0.060	4.6	-161.0	580
590	108.3	1.487 01613	1274	6.41	7.35	0.01	569	43.2	0.11	0.059	2.0	-165.0	590
600	123.5	1.541 01517	1175	7.00	8.5	0.01	569	44.0	0.07	0.058	0.5	-169.0	600
610	139.2	1.611 01115	1068	7.85	11.1	0.01	569	44.8	0.04	0.057	0.1	-173.0	610
620	156.1	1.705 00964	941	9.35	15.4	0.01	569	45.6	0.02	0.056	0.0	-177.0	620
625	169.1	1.778 00885	858	10.6	18.3	0.01	569	46.4	0.01	0.055	0.0	-181.0	625
630	179.7	1.848 00705	781	12.4	22.1	0.01	569	47.2	0.0	0.054	0.0	-185.0	630
635	190.9	1.935 00606	683	16.4	27.6	0.01	569	48.0	0.0	0.053	0.0	-189.0	635
640	202.7	2.037 00507	560	25	42	0.01	569	48.8	0.0	0.052	0.0	-193.0	640
645	215.2	2.151 00405	361	90	—	0.01	569	49.6	0.0	0.051	0.0	-197.0	645
647.3	221.2	2.170 0032	0	—	45	0.01	569	50.4	0.0	0.050	0.0	-201.0	647.3

*Values from Reference [1].

1 bar = 10⁵ N/m².

Critical temperature.

FIGURE 3: PSYCHROMETRIC CHART FOR AIR-WATER SYSTEM

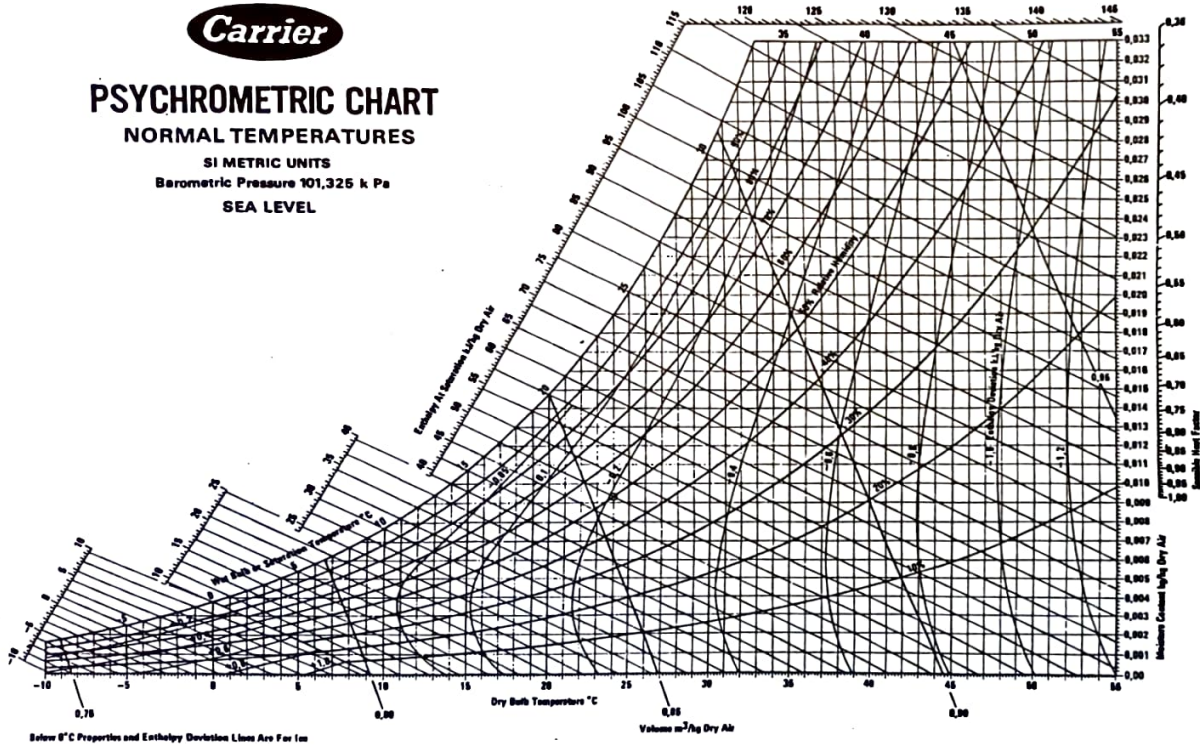


Figure 4: Air Enthalpy versus Water Temperature Diagram

