BINDURA UNIVERSITY OF SCIENCE EDUCATION

FACULTY OF SCIENCE AND ENGINEERING

AEH 308

Department Of Engineering and Physics
Bachelor of Science (Honours) in Agricultural Engineering
Food Engineering

3 HOURS (100 MARKS)

APR 2025

INSTRUCTIONS

Answer any ***FOUR*** questions. Each question carries 25 marks.

Question 1

a. Calculate the component mass balance for mixing ingredients to make 18 kg of beef sausages having a fat content of 25%, using fresh beef meat and beef fat. Typically, beef meat contains 15% protein, 10% fat and 73% water and beef fat contains 82% fat, 10% water and 6% protein. **[6 marks]**

b. A 5 cm inside diameter pipe is being used to pump liquid food into a buffer tank of 2.5 m diameter and 3.5 m height. If the density of the liquid is 1250 kg/m^3 and viscosity is 1540×10^{-6} Pa s, calculate time to fill the tank under laminar conditions in the pipe. **[9 marks]**

c. Briefly describe five functional properties of ingredients used in meat processing. **[10 marks]**

Question 2

a. With the aid of practical examples, explain how the distillation process is used to achieve great purity. **[8 marks]**

b. Calculate the temperature of tomato juice (density = 995 kg/m^3) in a steam jacketed hemispherical kettle of 0.8 m radius after 4 min. of heating. It is given that the initial temperature of tomato juice is 18°C, surface temperature of the kettle is 70°C and the convective heat-transfer coefficient in the steam jacket is 6500 $W/(m^2\,°C)$. Assume a specific heat of tomato juice of 4.12 kJ/(kg°C). **[8 marks]**

c. Calculate the freezing time of a spherical food product being frozen in an air-blast freezer using Plank's equation. It is given that the initial product temperature is 15°C, cold air is (-)35°C, the product has a 12 cm diameter with density of 1050 kg/m^3 , the initial freezing temperature is (-)3°C, the thermal conductivity of the frozen product is 1.65 W/(m K), heat transfer coefficient is 82 $W/(m^2K)$ and the latent heat of fusion is 320 kJ/kg. **[9 marks]**

Question 3

a. With the aid of diagrams, describe the essential operational differences between co-current and counter-current modes of continuous extraction processes. **[12 marks]**

b. Bran flakes (MC_{wb} 80%) are being dried in a concurrent flow drier. The moisture content of the air entering the drier is 0.07 kg of water per 1 kg dry air. The moisture content of air leaving the drier is 0.20 kg water per 1 kg of dry air. The air flow rate in the drier is 130 kg dry air per hour.

If 65 kg of wet bran flakes enter the drier per hour at a steady state, calculate:

i. the mass flow rate of dried bran, [5 marks]

ii. the MC_{db} of dried bran exiting the drier. [8 marks]

Question 4

a. With the aid neat sketches, explain the principle of operation of the following types of solid particle size reduction equipment:

i. Hammer mill, [5 marks]

ii. Attrition mill. [5 marks]

b. A liquid food (specific heat = 6.5 kJ/[kg °C]) flows in the inner pipe of a double pipe heat exchanger. The liquid food enters the heat exchanger at 25°C and exits at 70°C. The flow rate of the liquid food is 1.2 kg/s. In the annular section, hot water at 98°C enters the heat exchanger and flows counter-currently at a flow rate of 1.8 kg/s. Assuming steady-state conditions, if the average specific heat of water is 4.18 kJ/(kg °C), calculate:

i. the exit temperature of water, [5 marks]

ii. log-mean temperature difference, [5 marks]

iii. the length of the heat exchanger when the average overall heat transfer coefficient is 1800 W/(m^2 °C) and the diameter of the inner pipe is 8 cm. [5 marks]

Question 5

a. An air-vapor mixture is at 20°C and 50% relative humidity. Using the psychrometric chart, determine:

i. the wet bulb temperature, [1 mark]

ii. humidity ratio, [1 mark]

iii. specific volume, [1 mark]

iv. enthalpy, and [1 mark]

v. dew-point temperature. [1 mark]

b. Calculate the rate of thermal energy required to heat 6.5 m^3/ s of outside air at 30°C dry bulb temperature and 80% relative humidity to a dry bulb temperature of 80°C. [8 marks]

c. In fruit juice processing, apple juice is preserved at room temperature by treatment with SO_2. It is desired to strip some of the SO_2 from the sulphured juice. The stripping of the juice will be carried out with a counter-current flow of air in a tray column. The air has a temperature of 20°C and contains water vapour at equilibrium with liquid juice at this temperature. The juice flow rate is $0.82 m^3 s^{-1}$. The SO_2 concentration in juice (mole fraction) is to be reduced from 10^{-4} to 10^{-7}. The initial and final concentrations of SO_2 in air are y_i=0 and y_o= 0.6×10^{-3} (mole fraction). If the partitioning coefficient is 5 (mole fraction c_e/c_r basis), calculate:

i. the air flow rate, [4 marks]

ii. separation factor (S) and [3 marks]

iii. the number of equilibrium stages. [5 marks]

Question 6

a. Briefly explain three factors that affect the duration of completely frying foods. [6 marks]

b. Calculate the size of the motor required to avocado oil and sunflower oil in a ratio of 1 to 4 by a propeller agitator 25 cm in diameter operating at 1200 rpm in a cylindrical tank of 1 m diameter at 25°C. It is given that P_o is 0.7, the viscosity of avocado oil at 25°C is 0.09 Nsm^{-2}, the density of avocado oil 860 kg m^{-3}, the viscosity of sunflower oil 0.2 Nsm^{-2} and the density of rapeseed oil 920 kg m^{-3}. [9 marks]

c. An 8 kW oven has a hearth area of 4 m^2 and operates at 210°C. It is loaded with two batches of bread dough in baking tins; 150 loaves on the first batch and 120 loaves on the second batch. The surface of each loaf measures 12 cm x 20 cm. Assuming that the emissivity of dough is 0.85, that the dough bakes at 100°C, and that 90% of the heat is transmitted in the form of radiant energy, calculate the efficiency of energy use for each batch. [10 marks]

End of paper

FOOD ENGINEERING (AEH308)

MATHEMATICAL FORMULAE

GRINDING AND CUTTING

$dE/dL = KL^n$

Kick

$K = K_K f_c$

$dE/dL = K_K f_c L^{-1}$

$\mathbf{E = K_K f_c \log_e(L_1/L_2)}$ **[law]**

Rittinger

$K = K_R f_c$

$dE/dL = K_R f_c L^{-2}$

$\mathbf{E = K_R f_c (1/L_2 - 1/L_1)}$ **[law]**

Bond

$\mathbf{E = E_i (100/L_2)^{1/2}[1 - (1/q^{1/2})]}$ **[law]**

$q = L_1/L_2$

Modification of the grinding energy equations

Energy required E (kWh/kg) for reducing particle size from x_1 to x_2

Rittinger $E = K_R\left(\frac{1}{x_2} - \frac{1}{x_1}\right)$

Kick $E = K_k \ln\left(\frac{x_1}{x_2}\right)$

Bond $E = K_B\left[\left(\frac{1}{x_2}\right)^{1/2} - \left(\frac{1}{x_1}\right)^{1/2}\right]$

EXTRACTION / LEACHING / WASHING

$$\alpha = \frac{Ce}{Cr}$$

$\Phi vfCf + \Phi vsCs = \Phi veCe + \Phi vrCr$

$$\frac{\text{Amount extracted}}{\text{Amount in raffinate}} = \frac{\phi veCe}{\phi vrCr} = \alpha\frac{\phi ve}{\phi vr} = S$$

NB// for single stage

$$S = \frac{Vs}{Vr}$$

$$\text{Non extracted fraction} = 1 - f = \frac{Cr}{Cf} = \frac{1}{1+S}$$

Where f=extracted fraction

$$f = \frac{\text{amount extracted}}{\text{amount in feed}} = \frac{\phi veCe}{\phi vfCf}$$

Therefore for only 1 stage, $f = \frac{S}{S+1}$

For multistage:

$$N = \frac{\ln\left[\left(\frac{S-1}{1-f}\right)+1\right]}{\ln S} - 1$$

REFRIGERATION CHILLING AND FREEZING

Plank's equation

$$t_f = \left[\frac{(\rho\Delta H_L)}{(T_f - T_a)}\right]\left[\left(\frac{2\Pr}{h}\right) + \left(\frac{4Rr^2}{\lambda}\right)\right]$$

ΔH_L= the latent heat of crystallisation of ice (334kJ/kg)

Shape factors

	Shape		
	Sphere	Infinite Plate	Infinite Cylinder
Shape factor	P=1/6, R=1/24	P=1/16, R=1/24	P=1/16, R=1/24

Pham's equation

$$t_f = \frac{1}{E}\left[\left(\frac{\Delta H_1}{\Delta T_1}\right)+\left(\frac{\Delta H_2}{\Delta T_2}\right)\right]\left[\left(\frac{r}{h}\right)+\left(\frac{r^2}{2\lambda}\right)\right]$$

$\Delta T_1=0.5(T_i+T_{fm})-T_a$
$\Delta T_2=T_{fm}-T_a$
$\Delta H_1=\rho C_{pu}(T_i-T_{fin})$
$\Delta H_2=\rho\Delta H_L+\rho C_{pf}(T_{fm}-T_{fin})$
$T_{fm}=1.8+0.263T_{fin}+0.105T_a$

$$E=1+\left[\frac{\left(1+\left(\frac{2}{\beta_i}\right)\right)}{\left(\beta_1^2+\left(\frac{2\beta_1}{\beta_i}\right)\right)}+\left(\frac{\left(1+\left(\frac{2}{\beta_1}\right)\right)}{\beta_2^2+\left(\frac{2\beta_2}{\beta_i}\right)}\right)\right]$$

The shape $\beta_1=A/(\pi r^2)$
$B_2=3V/(4\pi\beta_1 r^3)$
$B_i=(hr)/\lambda$, Biot number

SEDIMENTATION

$$u=\frac{\left[d_{st}^2(\rho_s-\rho)g\right]}{18\mu}$$

FILTRATION

$$\frac{\delta V}{\delta t}=\frac{(A\Delta P)}{R}$$

$$R=\mu r(L_c+L)$$

$$L_c=\frac{wV}{A}$$

$$R=\mu r[w\left(\frac{V}{A}\right)+L]$$

$$\frac{\delta V}{\delta t}=\frac{A\Delta P}{\mu r[w\left(\frac{V}{A}\right)+L]}$$

$$\Delta P=\frac{V}{At}\times\mu r\left[w\left(\frac{V}{A}\right)+L\right]$$

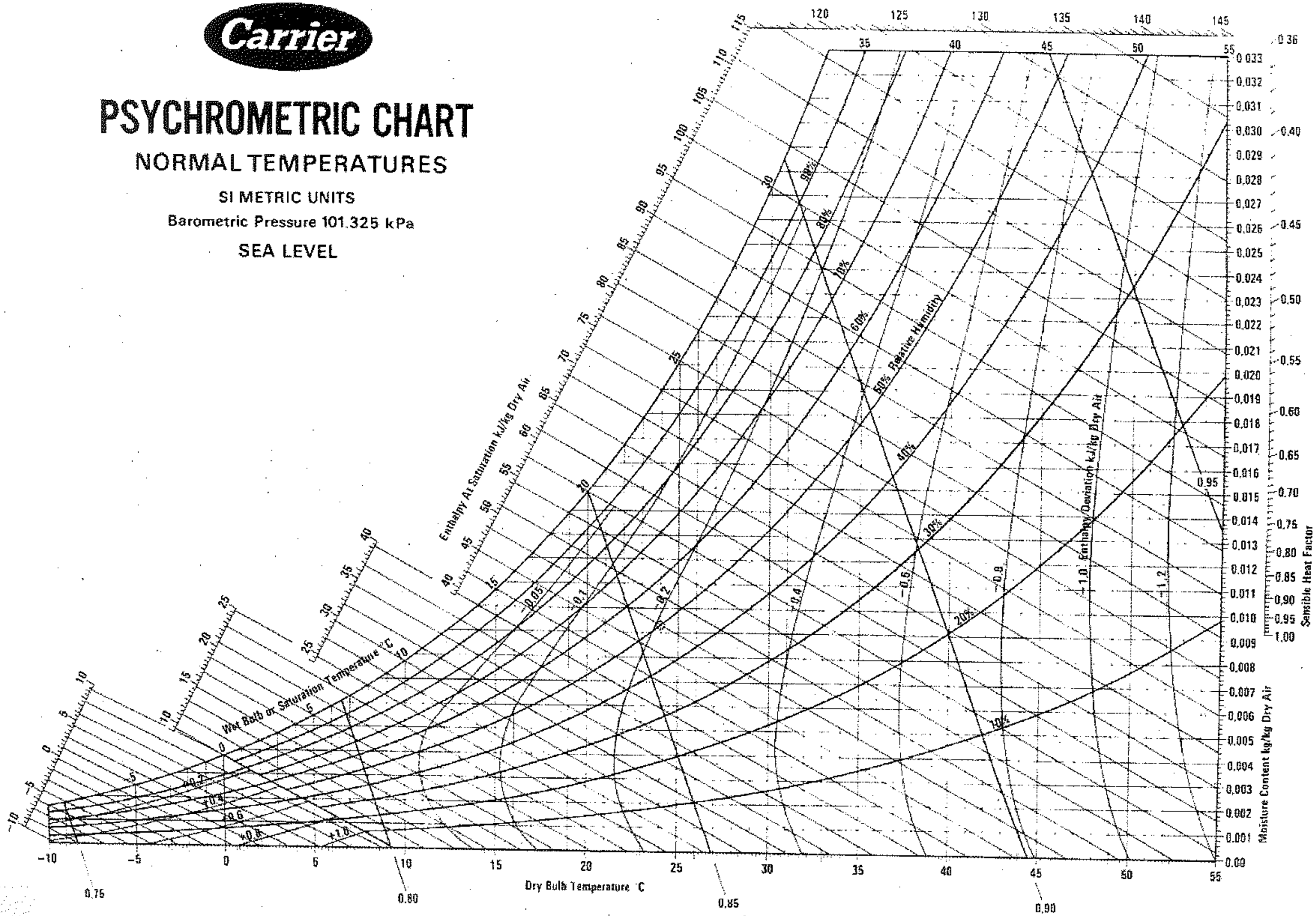
PSYCHROMETRIC CHART

NORMAL TEMPERATURES

SI METRIC UNITS

Barometric Pressure 101.325 kPa

SEA LEVEL



Below 0°C Properties and Enthalpy Deviation Lines Are For Ice