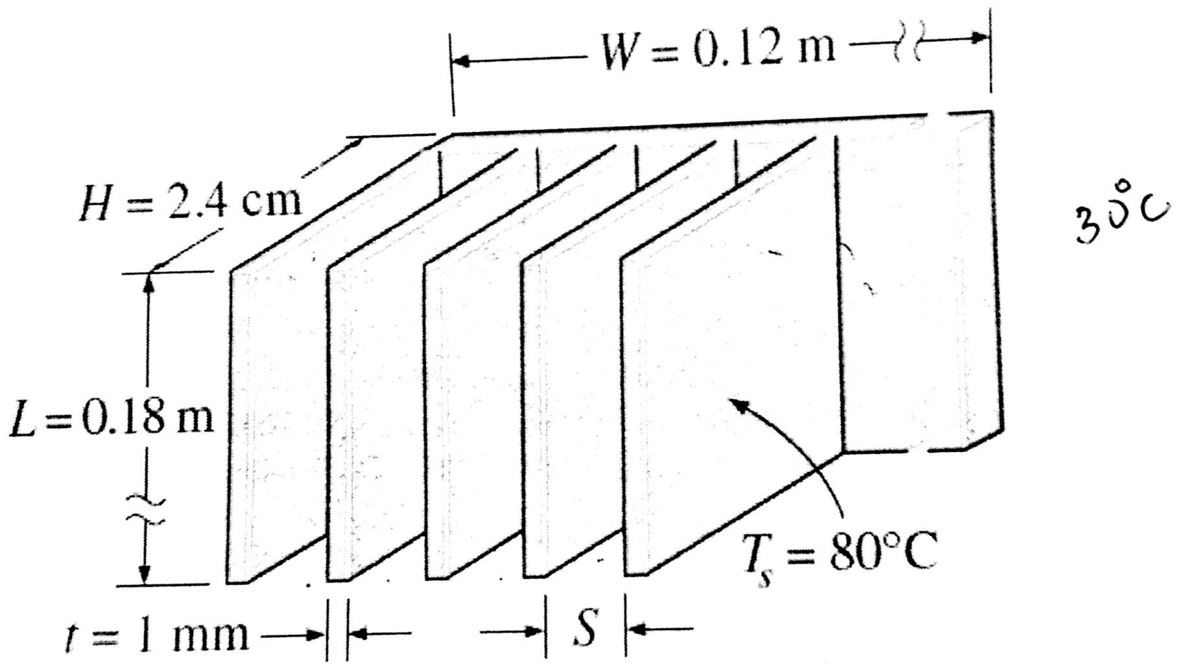
CLL251 Major Exam 07/05/2016 Duration: 2 hours

1. A 12 cm. wide and 18 cm. high vertical hot surface kept in a 30°C ambient environment is to be cooled using equally spaced fins of rectangular profile. The fins are 0.1 cm thick, 18 cm. long and 2.4 cm. wide.

   (i) Determine the optimum fin spacing to maximize the heat transfer if the temperature of fins is uniform at 80 °C. The optimum fin spacing for this case is given by $S_{opt} = 2.714\left(\frac{S^3L}{Ra_S}\right)^{0.25}$, where the subscript 'S' denotes that the calculation of Rayleigh number is done based on the spacing between the fins. The air properties at the film temperature are given as follows: k=0.02772 W/m-K; Pr=0.7215; $\nu=1.847\times10^{-5}$ m²/s

   (ii) If the fin spacing is exactly the same as the optimum spacing, do you think if the boundary layers of the two consecutive fins will merge? Discuss. (6+4)



2. A vertical wall in a room is at a temperature T_s which is uniformly maintained along the length of the wall. The ambient temperature is T_∞ which is less than the wall temperature, due to which heat transfer will take place by natural convection. It is given that the energy balance for this system is given by $u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2}$ and we need to solve this equation using similarity transforms. Assume that similarity variable and stream functions are given by $\eta = \frac{y}{x}Gr_x^{1/4}$ and $\psi = \nu F(\eta)Gr_x^{1/4}$, respectively, and the dimensionless temperature is given by $\theta = \frac{T-T_\infty}{T_s-T_\infty}$. Express the energy balance such that it becomes an ordinary differential equation with η as the independent variable. (Note that the expressions for η and ψ above are not the same as those used in the class) (10)

3. In a shell and tube heat exchanger with one shell pass and one tube pass, water is being heated in the tubes using hot benzene in the shell side. The overall flow of the fluids is counter-current to each other. The dimensions of the exchanger are given below: Shell internal diameter = 88.9 cm; Total number of tubes = 828; Inner diameter of tubes = 1.8 cm; Outer diameter of tubes (D_o) = 1.9 cm; Tube length = 3 m; Tube pitch = 2.5 cm; Baffle spacing = 30.5 cm; Fraction of cross-sectional area occupied by baffle=80.45%. The total mass flow rate of benzene in the shell is 12.6 kg/s and that of water in the tubes is 3.8 kg/s. The inlet temperature of benzene in the shell side is 60 °C and that of water at the tube inlet is 30 °C.

(i) Case 1: Calculate the overall heat transfer coefficient based on the outer tube diameter assuming that the thermal conductivity of the tube material is very high. Also, calculate the outlet temperature of benzene.

(ii) Case 2: Modifications are made to case 1 such that one shell pass and two tube passes are used with the tube length per pass maintained at 3 m and number of tubes per pass reduced to 414. All other geometric parameters and flow conditions such as total flow rate remain the same as in case 1. Calculate the overall heat transfer coefficient and the outlet temperature of benzene. Assume that the heat transfer coefficient for the shell side is same as that for case 1.

(iii) Compare the heat transfer coefficient, outlet temperature of benzene and pressure drop in the tubes for the two cases and comment. (10+10+10)

The following additional information may be used for solving.

Heat transfer coefficient on the shell side (based on the outlet tube diameter) is given by the following equation: $\frac{h_o D_o}{k} = 0.2\left(\frac{D_o G_e}{\mu}\right)^{0.6} Pr^{0.33}\left(\frac{\mu}{\mu_w}\right)^{0.14}$, where $G_e = \sqrt{G_b G_c}$, $G_b = \frac{\dot{m}}{S_b}$, $G_c = \frac{\dot{m}}{S_c}$. S_b represents the area available for flow parallel to the tubes whereas S_c represents the area for transverse flow. The tube side coefficient can be calculated using the following relation:

$$Nu_d = 3.66 + \frac{0.0668\left(\frac{d}{L}\right) Re_d Pr}{1 + 0.04\left[\frac{d}{L} Re_d Pr\right]^{2/3}}$$

Physical properties of benzene:

Viscosity at wall temperature (μ_w)=3.8x10^{-4} kg/m-s.

The following are properties at the bulk temperature; μ=7x10^{-4} kg/m-s; C_p=1715 J/kg-K; k=0.159 W/m-K; Pr=7.55.

Physical properties of water can be assumed independent of temperature and are given as follows: μ=10^{-3} kg/m-s; ρ=1000 kg/m^3; Pr=5; C_p=4200 J/kg-K; k=0.6 W/m-K.

Figure 10-13 | Effectiveness for counterflow exchanger performance

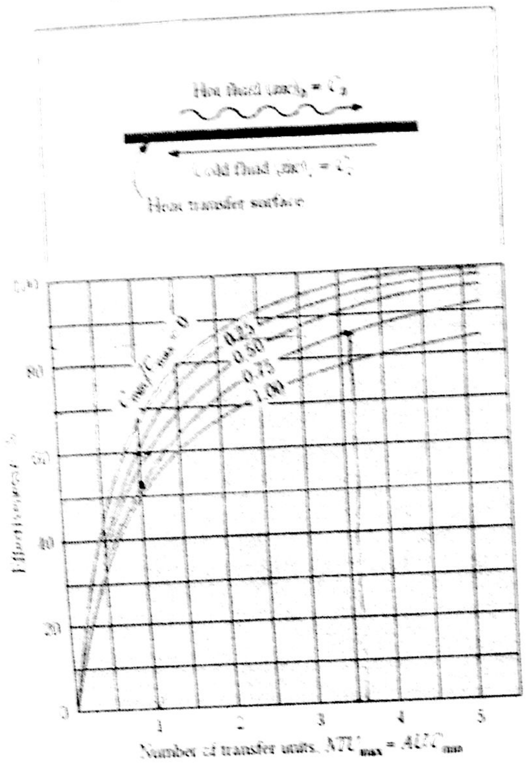
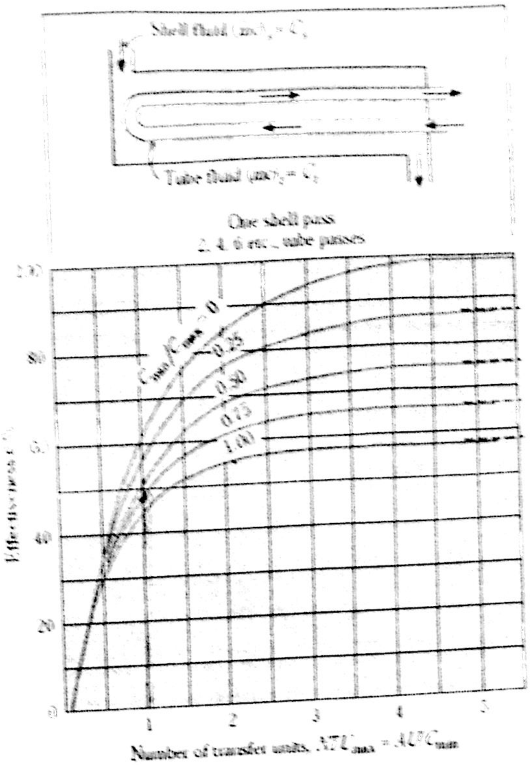
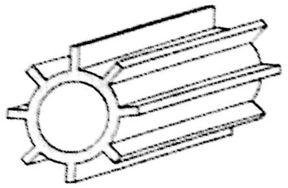


Figure 10-16 | Effectiveness for 1-2 parallel counterflow exchanger performance



(10)

4. A finned tube is constructed as shown in the figure below.



The construction material is aluminum whose thermal conductivity is 204 W/m °C. The base temperature of the fins may be assumed to be 100°C and they are subjected to a convection environment at 30 °C and h=15 W/m^2-°C. The longitudinal length of the fins is 15 cm and the peripheral length is 2 cm. The fin thickness is 2 mm. Calculate the total heat dissipated by the finned tube. Consider that the heat loss takes place only by the fins. Corrected fin length for equivalent fin with insulated tip given as: $L_c = L + t/2$.

You can take help of the following table:

TABLE 3.4 Temperature distribution and heat loss for fins of uniform cross section

Case	Tip Condition ($x = L$)	Temperature Distribution θ/θ_b		Fin Heat Transfer Rate q_f	
A	Convection heat transfer: $h\theta(L) = -k\,d\theta/dx\vert_{x=L}$	$\dfrac{\cosh m(L-x) + (h/mk)\sinh m(L-x)}{\cosh mL + (h/mk)\sinh mL}$	(3.70)	$M\dfrac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}$	(3.72)
B	Adiabatic $d\theta/dx\vert_{x=L} = 0$	$\dfrac{\cosh m(L-x)}{\cosh mL}$	(3.75)	$M \tanh mL$	(3.76)
C	Prescribed temperature: $\theta(L) = \theta_L$	$\dfrac{(\theta_L/\theta_b)\sinh mx + \sinh m(L-x)}{\sinh mL}$	(3.77)	$M\dfrac{(\cosh mL - \theta_L/\theta_b)}{\sinh mL}$	(3.78)
D	Infinite fin ($L \to \infty$): $\theta(L) = 0$	e^{-mx}	(3.79)	M	(3.80)

$\theta \equiv T - T_\infty$ $\qquad m^2 \equiv hP/kA_c$

$\theta_b = \theta(0) = T_b - T_\infty$ $\qquad M \equiv \sqrt{hPkA_c}\,\theta_b$

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