Exercise 9.1

Saturated steam at $0.1bar$ condenses on the outside of a vertical stack of 10 brass tubes having inner and outer diameters of 16.5 and 19 mm respectively. The surface temperature of the tubes is kept $7.3K$ lower than the saturation temperature of the vapor by flowing water with a mean temperature of $30°C$ inside the tubes. Calculate:

a) the average external convection coefficient due to condensation on the bank of tubes

b) Assuming that the convection coefficient for water flowing inside the tube is $5200W/m^2K$, calculate the overall heat transfer coefficient for a single tube.[**Brass properties**: thermal conductivity - $k_B = 110W/mK$].

c) Under the previous assumptions, calculate the steam condensation rate per unit length of one tube

d) In an effort to increase condensation rate, an engineer proposes to apply $t = 100\mu m$ thick Teflon coating to the exterior surface of the brass tube to promote drop-wise condensation. Using the following correlation for the average external convection coefficient due to dropwise condensation:

$$\overline{h}_{dc} = 51104 + 2044T_{sat}[°C]$$

which is valid for $22°C < T_{sat} < 100°C$, estimate the new condensation convection coefficient and the steam condensation rate per unit length of the tube after the application of the coating. Comment on the proposed scheme's effect on the condensation rate. [**Teflon properties** thermal conductivity - $k_T = 0.35W/mK$.]

Solutions:

a) $\overline{h}_D \approx 6800W/m^2K$

b) $U_{out} \approx 2627W/m^2K$

c) $\dot{m}' \approx 1.11x10^{-3}kg/sm$

d) $\dot{m}' \approx 7.56x10^{-4}kg/sm$

Exercise 9.2

Consider a container exposed to saturated vapor T_{sat}, having a cold bottom surface $T_s < T_{sat}$ and with insulated sidewalls (see figure). Assuming a linear temperature distribution for the liquid, perform a surface energy balance on the liquid/vapor interface to obtain the following expression for the growth rate of the liquid layer:

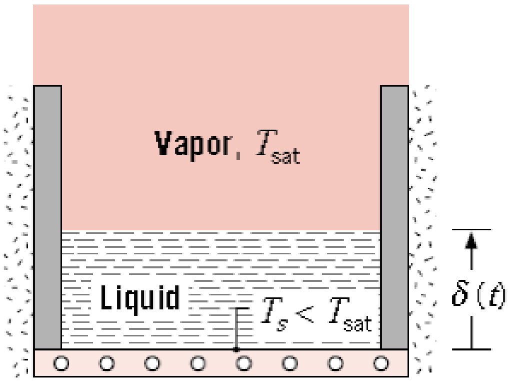
$$\delta(t) = \left[\frac{2k_l(T_{sat} - T_s)}{\rho_l h_{fg}} t\right]^{1/2}$$

Based on the above equation:

a) Calculate the thickness of the liquid layer ($\delta(1hr)$) and the total condensate mass (M) formed in $1h$ for a $200mm^2$ bottom surface maintained at $80°C$ and exposed to saturated steam at $1atm$.

b) Compare this result with the condensate formed by a *vertical* plate of the same dimensions for the same period of time. Can you explain why there is a difference between the two situations?

Hint: assume that the mass of condensate is uniformly distributed across the entire surface at all times and use this information to determine the change in the condensate layer thickness with time.



Solutions:

a) $\delta(1hr) = 6.69mm$, $M = 1.29 \cdot 10^{-3}kg$

b) $M_{vp} = 9.7 \cdot 10^{-2}kg$

Exercise 9.3

A number of thin plates are to be cooled by vertically suspending them in a water bath at a temperature of $20°C$. If the plates are initially at $54°C$ and are $0.15m$ long, what minimum spacing would prevent interference between their free convection boundary layers?

Solution $d = 12.6mm$

Exercise 9.4 [DIFFICULT] FOR REVISION

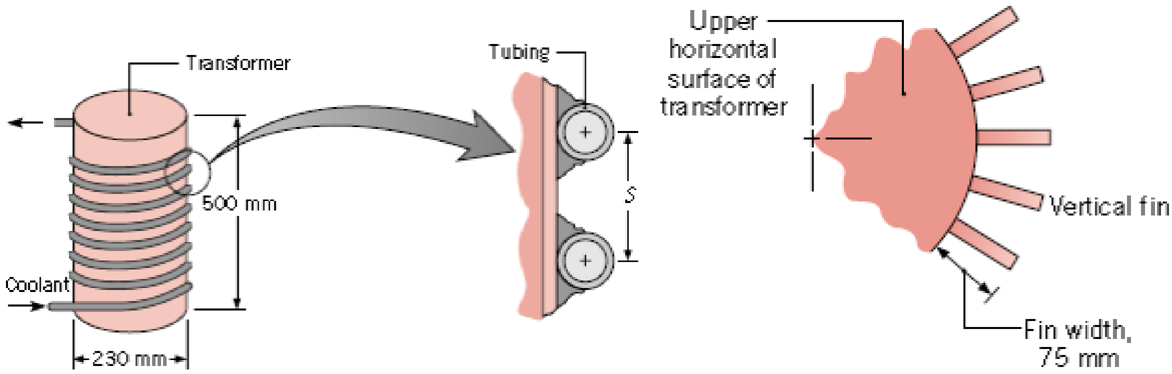
An electrical power transformer of diameter $230mm$ and height $500mm$ dissipates $1000W$. It is desired to maintain its surface temperature at $47°C$ and different solutions are considered:

a) Ethylene glycol at $24°C$ is supplied through a thin walled tubing of $20mm$ diameter welded to the lateral surface of the transformer (see figure below). All the heat dissipated by the transformer is assumed to be transferred to the ethylene glycol. Assuming the maximum allowable temperature rise of the coolant to be $6°C$, determine the required coolant flow rate, the total length of the tubing and the coil pitch S between turns of the tubing.

b) On the other hand, cooling of the transformer by free convection and radiation is explored. Assuming that the surface has an emissivity $\epsilon = 0.8$, determine how much power could be removed by free convection and radiation from the lateral and upper horizontal surfaces when the ambient temperature and the surroundings are at $27°C$.*Hint*: solve the free convection on each face choosing the appropriate correlations as if it were an infinite plate.

c) Finally, to improve free convection, vertical fins, $5mm$ thick, $75mm$ wide and $500mm$ long are welded to the lateral surface. Assuming that the fins have the same temperature of the transformer along their entire length (ideal fins), what is the heat removal rate by free convection if 30 such fins are attached?

d) Describe in words what you should do to solve the problem if the fins were not ideal and you wanted to use forced convection for the cooling. What advantages could you have?



Solutions

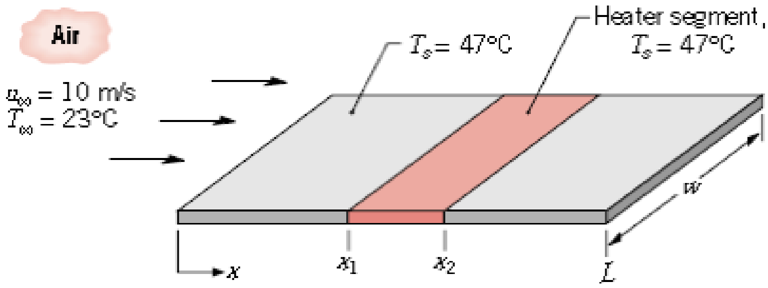
a) $\dot{m} = 6.9 \cdot 10^{-2} kg/s$, $L = 17.25m$, $S = 22.7mm$

b) $Q = 72.7W$

c) $Q = 483W$

Exercise 9.5 FOR REVISION

A highly polished aluminum plate of length $0.5m$ and width $0.2m$ is subjected to an air stream at a temperature of $23°C$ and a velocity of $10m/s$. Because of upstream conditions, the flow is turbulent over the entire length of the plate. A series of segmented, independently controlled heaters is attached to the lower side of the plate to maintain approximately isothermal conditions over the entire plate. The electrical heater covering the section between the positions $x_1 = 0.2m$ and $x_2 = 0.3m$ is shown in the schematic. Assuming that the bottom surface is thermally isolated and considering that the emissivity of highly polished aluminum is 0.03:



a) Estimate the electrical power that must be supplied to the designated heater segment to maintain the surface temperature at $T_s = 47°C$.

   Note: assume that the convection coefficient over the heater is the average value between the convection coefficient at x_1 and x_2.

b) If the blower that maintains the air stream velocity over the plate malfunctions, but the power to the heaters remains constant, estimate the surface temperature of the designated segment. Assume that the ambient air is extensive, quiescent and at $23°C$.