ENSC 388

Assignment #9 (Local Heat Transfer Coefficient)

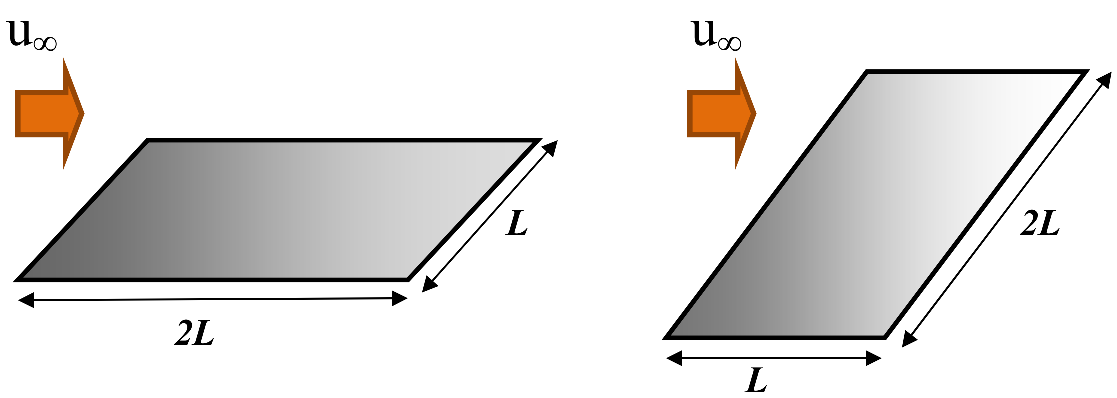
Assignment date: Wed Nov. 25, 2009

Due date: Wed Dec. 2, 2009

Problem 1

Explain under what conditions the total rate of heat transfer from an isothermal flat plate of dimensions *L* by *2L* would be the same, independent of whether parallel flow over the plate is directed along the side of length *L* or *2L*. With a critical Reynolds number of 5×10^5, for what values of Re_L would the total heat transfer be independent of orientation?

We assume that the plate temperatures and flow conditions are equivalent.

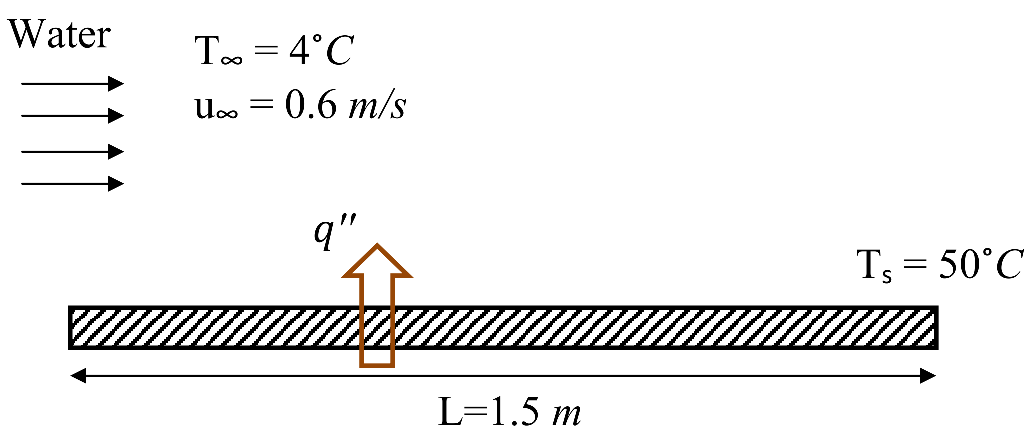


Problem 2

The surface of a 1.5 m long flat plate is maintained at 50°C and water at a temperature of 4°C and a velocity of 0.6 m/s flows over the surface. Determine:

a) The heat transfer rate per unit width of the plate in W/m.

b) If a wire were placed near the leading edge of the plate (to induce turbulence), what would be the heat transfer rate?



Problem 1:

Known:

- Flow regime
- Size and oriantation of plates
- Isothermal plates

Find:

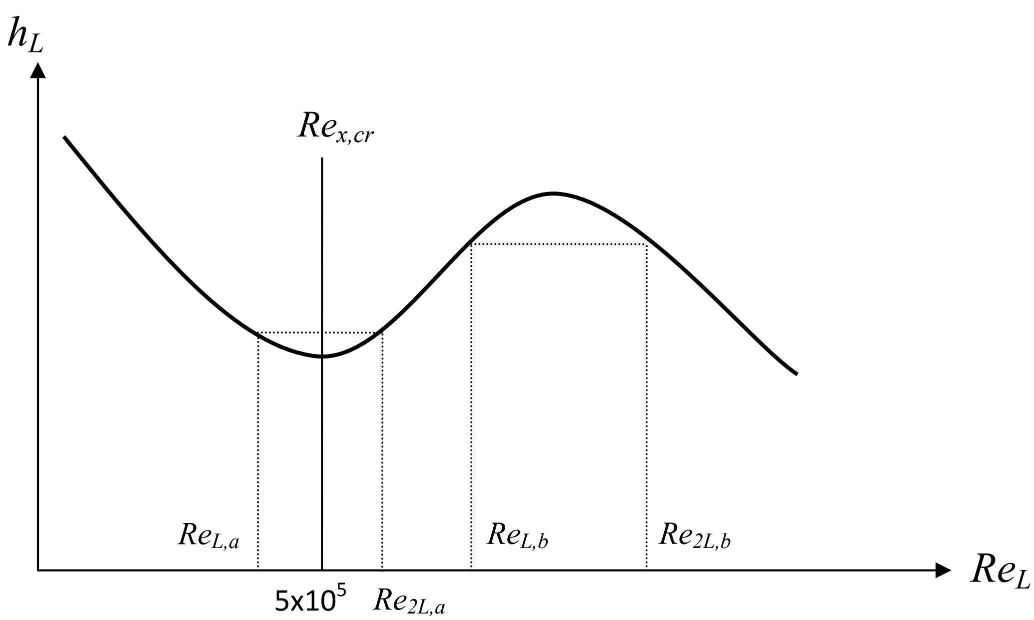
- Re_L number for which the total heat transfer is independent of orientation.

Assumptions:

- Steady state
- Costant properties

Analysis:

The total heat transfer rate would be the same ($q_L = q_{2L}$), if the convection coefficients were equal, $h_L = h_{2L}$. Conditions for which such an equality is possible may be inferred from a sketch of h_L versus Re_L .



For laminar flow $Re_L < Re_{x,cr}$, it follows that the $h_L \propto L^{-1/2}$. Similiarly, for mixed laminar and turbulent flow

$$h_L = C_1 L^{-1/5} - C_2 L^{-1} \; for \; Re_L > Re_{x,cr}$$

and h_L will vary with Re_L as shown above. Therefore, two possibilities are suggested:

Case a): Laminar flow exists on the shorter plate, while mixed flow conditions exist on the longer plate.

Case b): Mixed boundary layer conditions exist on both plates. In both cases, it is required that

$$h_L = h_{2L} \; and \; Re_{2L} = 2Re_L$$

Case a): From expression for h_L in laminar and mixed flow

$$0.664\frac{k}{L}Re_L^{1/2}Pr^{1/3} = \frac{k}{2L}\left(0.037Re_{2L}^{4/5} - 871\right)Pr^{1/3}$$

$$0.664Re_L^{1/2} = 0.032Re_L^{4/5} - 435$$

Since $Re_L < 5\times10^5$ and $Re_{2L} = 2Re_L > 5\times10^5$, the required value of Re_L may be narrowed to the range $2.5 \times 10^5 < Re_L < 5 \times 10^5$.

From a trial and error solution, it follows that $Re_L \approx 3.2 \times 10^5$

Case b): For mixed flow on both plates

$$\frac{k}{L}\left(0.037Re_L^{4/5} - 871\right)Pr^{1/3} = \frac{k}{2L}\left(0.037Re_{2L}^{4/5} - 871\right)Pr^{1/3}$$

$$0.037Re_L^{4/5} - 871 = 0.032Re_L^{4/5} - 435$$

$$Re_L \approx 1.5 \times 10^6$$

Note that it is impossible to satisfy the requirement that $h_L = h_{2L}$ if $Re_L < 2.5\times10^5$ (laminar flow for both plates). Also the results are independent of the nature of the fluid.

Problem 2:

Known:

- Surface length
- Size and oriantation of plates
- Flow condition

Find:

- The heat transfer rate per unit width of the plate.
- heat transfer rate if a wire were placed near the leading edge of the plate

Assumptions:

- Steady state
- Costant properties

Analysis:

The film temperature is

$$T_f = \frac{T_s + T_\infty}{2} = 27\ [°C]$$

Using Table A-7, the propoerties of water canbe found as

$$\rho = 997 \left[\frac{m^3}{kg}\right]$$

$$\upsilon = 0.86 \times 10^{-6} \left[\frac{m^2}{s}\right]$$

$$k = 0.608 \left[\frac{W}{mK}\right]$$

$$Pr = 5.88$$

a) First we must calculate the Reynolds number

$$Re_L = \frac{u_\infty L}{\nu} = 1.046 \times 10^6$$

Therefore, the flow is mixed and the appropriate correlation is:

$$\overline{Nu_L} = \left(0.037 Re_L^{4/5} - 871\right) Pr^{1/3}$$

$$\overline{Nu_L} = 2797.6$$

$$\bar{h} = \frac{\overline{Nu_L} k}{L} = 1133.9 \left[\frac{W}{m^2 K}\right]$$

Thus, the heat transfer rate is

$$q'' = h(T_s - T_\infty) = 52.163\ [kW]$$

b) if the flow were tripped at the leading edge, the flow would be turbulent over the entire length of the plate, in that case, we must use the correlation for turbulent regime:

$$\overline{Nu_L} = 0.037 Re_L^{4/5} Pr^{1/3}$$

$$\overline{Nu_L} = 4368.0$$

$$\bar{h} = \frac{\overline{Nu_L} k}{L} = 1770.5 \left[\frac{W}{m^2 K}\right]$$

Therfore,

$$q'' = h(T_s - T_\infty) = 81.443\ [kW]$$