CH EN 3453 – Heat Transfer

Introduction to Natural Convection

Chapter 9

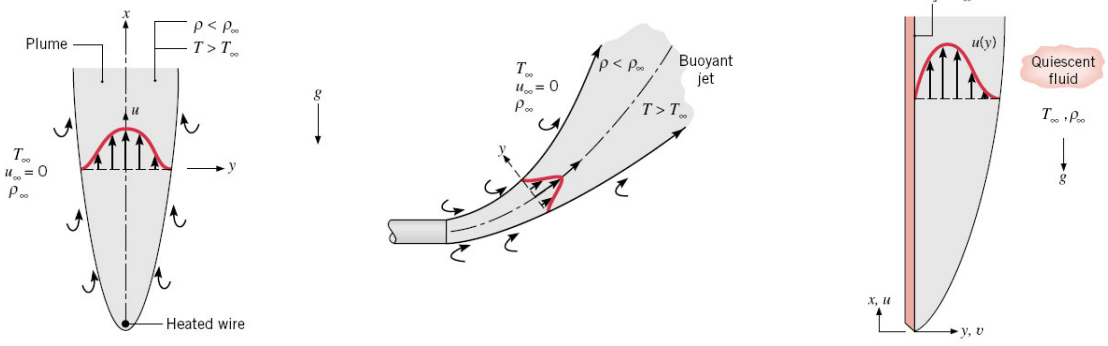
Reminders…

- Homework #9 due Friday
- Project Theory section due Friday this week
- Project Results & Discussion section due Friday next week
- Midterm #2 Wednesday next week
  - Covers chapters 6,7,8,9,11
  - Review in class Monday

Natural (Free) Convection

- Heat transfer due to fluid motion induced by buoyancy forces
- Buoyancy forces typically caused by temperature differences
- However, temperature differences do not always cause buoyancy

Types of Free Convection



Plume Buoyant Jet Boundary Layer

Stable vs. Unstable Gradients

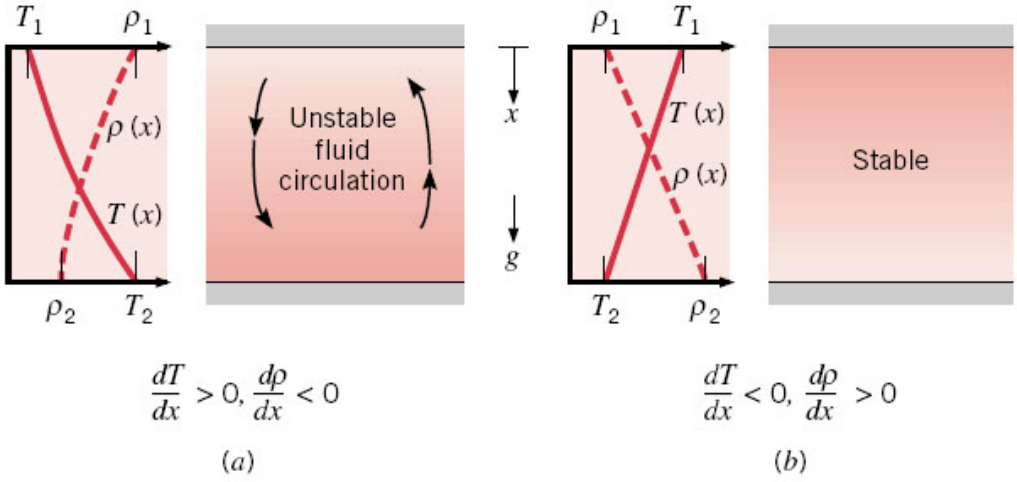
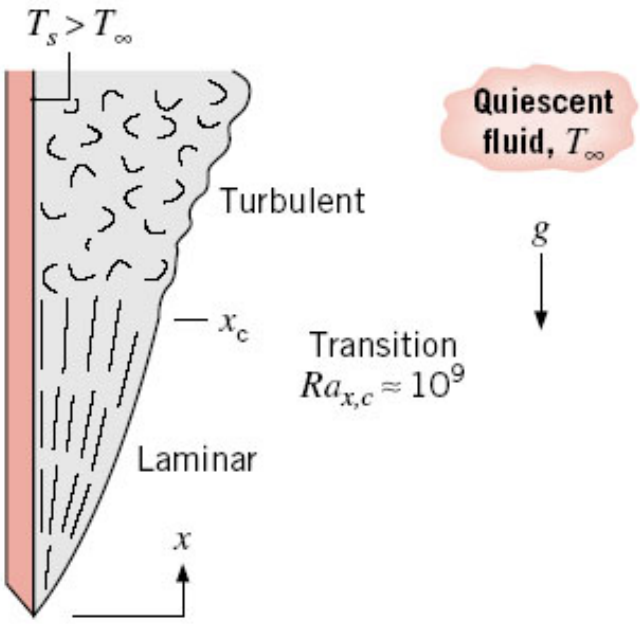


FIGURE 9.1 Conditions in a fluid between large horizontal plates at different temperatures. (*a*) Unstable temperature gradient. (*b*) Stable temperature gradient.

Development of Boundary Layer



Similarity Solution for Vertical Plate

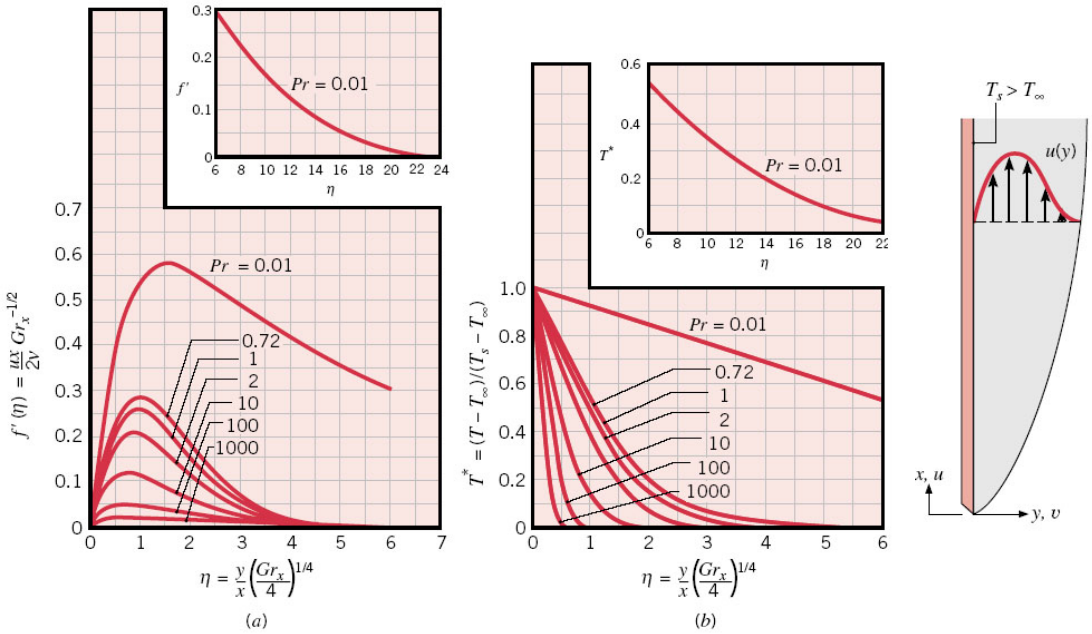


FIGURE 9.4 Laminar, free convection boundary layer conditions on an isothermal, vertical surface. (*a*) Velocity profiles. (*b*) Temperature profiles [3].

Empirical Correlations

- Similar to approach used previously for forced convection
  - Correlation for Nusselt number *Nu*
  - Instead of Re, we use Ra
  - Careful which expression to use
- Fluid properties determined at film temp.

$$T_{film} = \left(T_s + T_\infty\right)/2$$

- Solve for *h* through Nusselt number

$$\overline{Nu}_L = \frac{\bar{h}L}{k} \qquad \overline{Nu}_D = \frac{\bar{h}D}{k}$$

Flow over Vertical Plate

- Rayleigh Number:

$$Ra_L = Gr_L \Pr = \frac{g\beta(T_s - T_\infty)L^3}{\nu\alpha} \qquad (9.25)$$

- Laminar Flow ($Ra_L < 10^9$):

$$\overline{Nu}_L = 0.68 + \frac{0.670\ Ra_L^{1/4}}{\left[1 + (0.492/\Pr)^{9/16}\right]^{4/9}} \qquad (9.27)$$

- All Conditions:

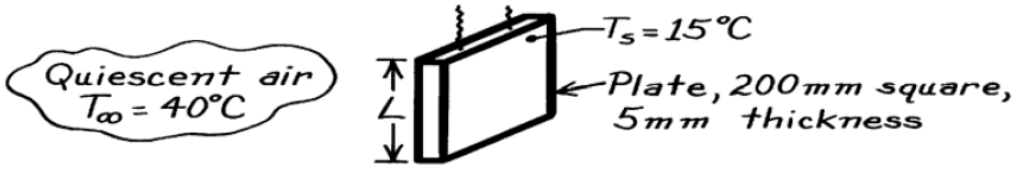
$$\overline{Nu}_L = \left\{0.825 + \frac{0.387\ Ra_L^{1/6}}{\left[1 + (0.492/\Pr)^{9/16}\right]^{8/27}}\right\}^2 \qquad (9.26)$$

Example: Problem 9.8

A square aluminum plate 5 mm thick and 200 mm on a side is heated while vertically suspended in quiescent air at 40°C. Determine the average heat transfer coefficient for the plate when its temperature is 15°C.

(a) using results from the similarity solution to the boundary layer equations

(b) using results from an empirical correlation



PROPERTIES: *Table A-4*, Air ($T_f = (T_s + T_\infty)/2 = (40 + 15)°C/2 = 300K$, 1 atm): $\nu = 15.89 \times 10^{-6}$ m^2/s, $k = 0.0263$ W/m·K, $\alpha = 22.5 \times 10^{-6}$ m^2/s, $Pr = 0.707$.