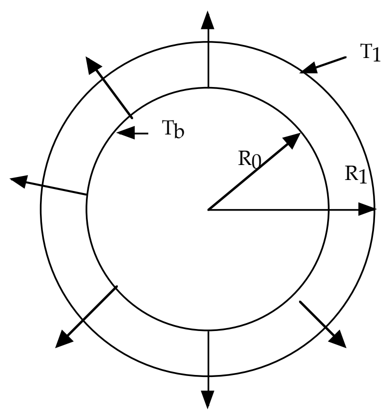
CBE 30356 Transport II
Problem Set 7
Due via Gradescope, 11:55 PM 3/23/23

1). A classic problem in convective heat transfer is transpirational cooling. The idea is that if you are trying to keep a tank of liquefied gas cold by insulating it, you can reduce the losses by forcing the boiling gas out through the insulation rather than just letting it escape. Suppose we have a spherical tank of radius R_0 surrounded by a spherical shell of porous insulation of outer radius R_1. The insulation has conductivity k, and the heat capacity per unit mass of the boiling gas flowing outwards through the insulation is C_p. If the latent heat of evaporation of the boiling liquid gas is L (units would be energy/mass), the inner temperature is the boiling point T_b and the temperature outside the insulating layer is T_1, solve for the rate of evaporation with transpiration and without (e.g., if we just let the gases escape). Note that the heat flux into the tank is what causes the liquefied gas to boil and come out (through the insulation or not)! It's actually easier to set up the temperature equation by doing a shell balance approach over a spherical surface, where you have an energy flux in via conduction through the insulation and a convective flux due to the gas (in thermal equilibrium with the local insulation temperature). These spherical shell balances are described in BS&L.



2). Heat exchangers. A process produces water at a rate of 2 liters/s at a temperature of 85°C. It is necessary to cool this down to 30°C for reuse, so it's heat exchanger time! You have a source of cooling water at 25°C with no restrictions on flow rates.

a. What is the minimum cooling water flow rate (in an ideal world) necessary to achieve the desired level of cooling? Assume counter-current heat exchange.

b. If all you have is a co-current heat exchanger, what would be the minimum possible flow rate?

c. OK, now we size our heat exchanger! Suppose we have a counter-current heat exchanger consisting of an interior pipe 5cm ID, a wall thickness of 0.32cm steel (e.g., 1/8", use k = 36 W/m°K), and an inner diameter of the outer pipe of 10cm (annular gap would be 2.18cm). Using this, determine how long the heat exchanger would have to be to achieve the desired heat transfer if the flow rate of the cooling water is 50% greater than the minimum calculated in part a.

3). In lecture we used scaling to determine the heat transfer from a vertical plane due to natural convection. In this problem we do the inverse: Suppose a plane of height H has a constant heat flux through the surface (say, we have some dissipation or reaction occurring that is releasing heat at a uniform rate per area). By scaling the equations in the same manner as was done in the notes (but now with a different boundary condition so things will change!) determine the characteristic temperature of the plane as a function of height to within some unknown O(1) dimensionless constant.

4). A house (mine) is maintained at 68°F while the temperature outside is a chilly 24°F (average temperature in January). In this problem we shall solve for the heat loss for a variety of glazing options. Parameters are as follows: total window area = $40m^2$ (it's a house built in the mid-70's – that's the 1870's – and has a lot of windows!) interior film heat transfer coefficient = 5 W/m^2°K (it's also a bit drafty…), exterior film heat transfer coefficient = 20 W/m^2°K, gap heat transfer coefficient for double or triple glazing (for each gap) = 2 W/m^2°K, transmitivity for solar radiation = 1, emissivity of normal glass for thermal radiation = 1, reflectivity of low emissivity glass for thermal radiation = 0.75. For each of the following options calculate the energy loss and, assuming 15¢/kWhr, the dollar value of the lost energy per month. You may find it helpful to construct a circuit diagram for each.

a. single glazing (you don't use this in Indiana).

b. double glazing.

c. triple glazing (this would not fit in our existing frames).

d. double glazing with a reflective coating on the inside of the outer pane of glass. Why is this the best place to place a single coat of Fe_2O_3? (This is what we did…)