ME-446 Liquid-Gas Interfacial Heat and Mass Transfer

Homework 10

Presentation by Group 10 on Thursday 27th November

Problem 1: Thermal conduction in a droplet

Consider a hemispherical water droplet on a substrate with a contact line diameter d. The substrate temperature is uniform at T_s, and the droplet surface is exposed to convective heat transfer with h the heat transfer coefficient and T_a the ambient temperature. We aim to develop a numerical model to study heat conduction within the droplet.

A) Given the problem domain is 2-D axisymmetric, draw your simulation domain and specify the boundary conditions.

B) Write your own code to solve the heat conduction problem within the droplet. Assume that the thermal conductivity of water is $k = 0.6\ W/m.K$ and the droplet has a diameter of $d = 5mm$. Set the surface heat transfer coefficient at $h = 10'000\ W/(m^2.K)$, the ambient temperature at $T_a = 50\ °C$, and vary the substrate temperature T_s from $10\ °C$ to $40\ °C$. Plot the heat flow rate across the droplet, q_d, as a function of the temperature difference $\Delta T_{cond} = T_i - T_s$, where T_i is the average surface temperature. Additionally, on the same graph, plot Eq. 9.28 from Van Carey's book.

Note: We recommend following the workflow in Homework 4, Problem 2 on the sessile droplet evaporation. To evaluate the temperature at the interface (needed for the calculation of ΔT_{cond}), one can use the following technique:

```
% Find the nodes at the Edge 1
Ne1 = findNodes(mesh , region  , Edge ,1);
% Query the temperatures at the given nodes
Ti = result.Temperature(Ne1);
```

Problem 2: Laminar film condensation (Carey P9.15)

Laminar film condensation occurs on semi-infinite, vertical, isothermal surface as shown in Figure 1. The cold surface at temperature T_w is surrounded by saturated steam at atmospheric pressure. An infinite hot surface at temperature T_h is positioned parallel to the cold surface.

The liquid-vapor interface and the hot surface radiate like blackbodies so that the net radiative heat flux to the interface at any location is given by

$$q''_R = \sigma_{SB}(T_h^4 - T_{sat}^4)$$

where $\sigma_{SB} = 5.67 \times 10^{-8} W/(m^2.K^4)$.

A) Write down an appropriate set of governing equations and boundary conditions that could be solved to predict the film thickness variation and heat transfer coefficient along the x-direction for the condensation process on the cooled surface. Be sure to include all the necessary relations to close the system.

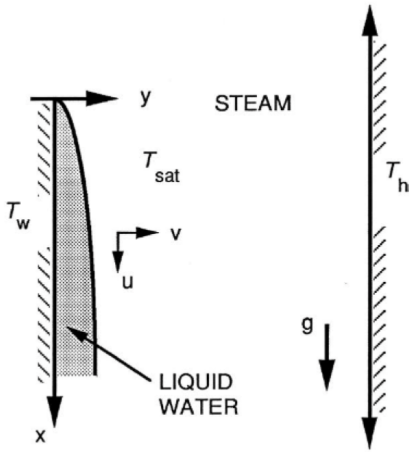

Figure 1: Laminar film condensation on semi-infinite, vertical, isothermal surface with a parallel infinite hot surface.

B) Assuming that the film remains laminar and that heat transfer across the liquid film is by conduction only, determine the asymptotic variation of the liquid film thickness far from the leading edge (large x) for $T_w = 50°C$ and $T_h = 400°C$.

Problem 3: Dropwise condensation correlation (Carey P9.1)

Rose et al. recommended Eq. 9.42 in the Carey book as the empirical correlation for steam dropwise condensation heat transfer coefficient below 1 atm pressure. Use this to predict the heat transfer coefficient for dropwise condensation of steam at a surface subcooling of $5°C$ for pressures ranging between atmospheric pressure and 9460 kPa. Plot the variation of the heat transfer coefficient over this range of pressures.

Quantitatively describe what fluid properties you expect to affect this predicted variation the most and how they vary with saturation pressure.