Homework #3: Non-Premixed Laminar Flames

• Homework solutions should be neat and logically presented, see format requirements <u>https://seitzman.gatech.edu/classes/ae6766/homeworkformat.html</u>.

1. Jet Diffusion Flame- Width (based on a former final exam problem)

Using the expressions developed in class for an axisymmetric, laminar jet diffusion flame, assuming isodensity, unity Schmidt number, constant diffusivities, and a flame sheet, find expressions for the maximum diameter of the flame and the fraction of the flame length at which the maximum diameter occurs. Based on these assumptions, how would the maximum diameter of a diffusion flame change if we doubled the flow velocity and decreased the pressure by a factor of two, without changing the burner size.

2. Jet Diffusion Flame - Length

Consider a fuel composed of 50.% ethane and 50.% CO by mole exiting into a quiescent environment, composed of 80.% N₂ and 20.% O₂, from a circular crosssection tube of 5.0 mm radius with a uniform exit velocity of 1.5 m/s. Using the expressions developed in class for an axisymmetric, laminar jet diffusion flame, assuming isodensity, unity Schmidt number, unity Lewis number, constant diffusivities, and a flame sheet, estimate the flame length. For this problem, use a thermal diffusivity of 170 mm^2/s . In addition, determine the change in flame length if the fuel exiting the tube was diluted by N₂, with the diluted fuel composed of 50% N₂ by mole. Specifically, find the ratio of flame lengths for the diluted fuel to the pure fuel, assuming no change in the burner, exit velocity, or diffusivity.

3. Flame Profiles using Equilibrium State Relations

As indicated in the class lecture, the assumption of fast chemistry without also assuming a single-step (irreversible) reaction will produce a nonpremixed flame with a finite thickness. Moreover, for very fast chemistry, adiabatic conditions, and no differential diffusion, chemical equilibrium can provide the state relations that govern the composition and temperature of the constituents as a function of mixture fraction.

Consider an atmospheric-pressure, ethane-air diffusion flame, where the fuel exits a 5.0 mm radius round tube at a velocity of 1.5 m/s, into an environment consisting of air (79%N₂ and 21%O₂). Both the fuel and the air have a temperature of 300.K. Using the approximate solution for the mixture fraction distribution in the flame (i.e., isodensity, unity Schmidt number, unity Lewis number, and constant diffusivities - use 170 mm^2/s), plot the <u>mixture fraction</u>, temperature and <u>species mass fractions</u> as a function of radial position in our flame at a height of 0.15 m above the tube exit.

At a minimum, include $Y_{C_2H_6}$, Y_{O_2} , Y_{N_2} , Y_{H_2O} , Y_{CO_2} , Y_{H_2} , Y_{CO} , Y_{OH} , Y_{CH_4} and Y_{CH_2O} in your graph(s). Please make sure your graphs have sufficient resolution to provide a clear and complete description of how these properties vary with radial position.

(Hint: you can use the results from a chemical equilibrium solver to find Y_i and T versus mixture fraction. It may help to remember that a given mixture fraction corresponds to a given ratio of O/C/H nuclei in the mixture and a given mixture enthalpy. Also, you will be working with very lean and very rich mixtures, so choose an extensive set of species to include in your equilibrium products.)

On the same plot(s) containing the mass fraction results, show the corresponding results for the flame sheet approximation, i.e., in which case the composition can only include the reactants and the "ideal" product species (i.e., those used to determine the stoichiometric relations).

4. Droplet Evaporation and Burning

A monodisperse, dilute fuel spray composed of n-decane ($C_{10}H_{22}$) with an initial temperature 25 °C is suddenly injected into quiescent air at 1 atm and 700 °C. (Monodisperse means all the droplets have the same initial diameter; dilute means the amount of fuel is much less than the amount of air.)

- a) Determine the evaporation rate constant *K*, for n-decane under these conditions. You may assume the wet bulb temperature can be reasonably approximated by the boiling point value ($T_{wb} \sim T_{bp}$), BUT if you do this, note you should calculate your answer based on the thermal Spalding transfer number (B_h in the notes).
- b) Neglecting any transient effects, calculate the mass evaporation rate (on a per droplet basis) for a spray consisting of 60 μ m droplets as a function of time and **plot** the result.
- c) Now compare the <u>normalized</u> **total** amount of fuel mass evaporated $(m_{evap,total}/m_{inject})$ up to a given time (i.e., the mass evaporated integrated from time zero to the given time) as a function of time for two sprays: 1) the original spray and 2) a second spray composed of 100 time more droplets but having the *same total mass* of injected liquid (m_{inject}) . Plot the normalized results for the both sprays (note: your results are for the spray, not for a single droplet) on the same graph.
- d) What impact, if any, would lowering the ambient pressure to 0.1 atm have on the mass evaporation rate?