ME EN 5830/6830: Aerospace Propulsion
Problem Set #3: Combustion III and IV
Due date: 01/30/2025 by 11:59pm

Submission

Assignments can only be submitted on Gradescope, which can be accessed through Canvas. If you have any questions about submission, please email the class TA, John Gardner at u0763966@utah.edu. Submissions will be automatically locked at the due date given above.

Introduction

This problem set primarily covers the material from Lectures 5 and 6. The goal is for students to work with the different modes of combustion, turbulent flames, molecular structures, and pollutants relevant to aerospace applications. By the time this homework is completed, students should be able to:

- Draw the flame structure for premixed flames
- Perform preliminary design of injector ports for a combustor with laminar and turbulent flames
- Draw various molecules based on their names

Assignment

Problem #1: In this problem, you will consider the flame structure of a **premixed flame.**

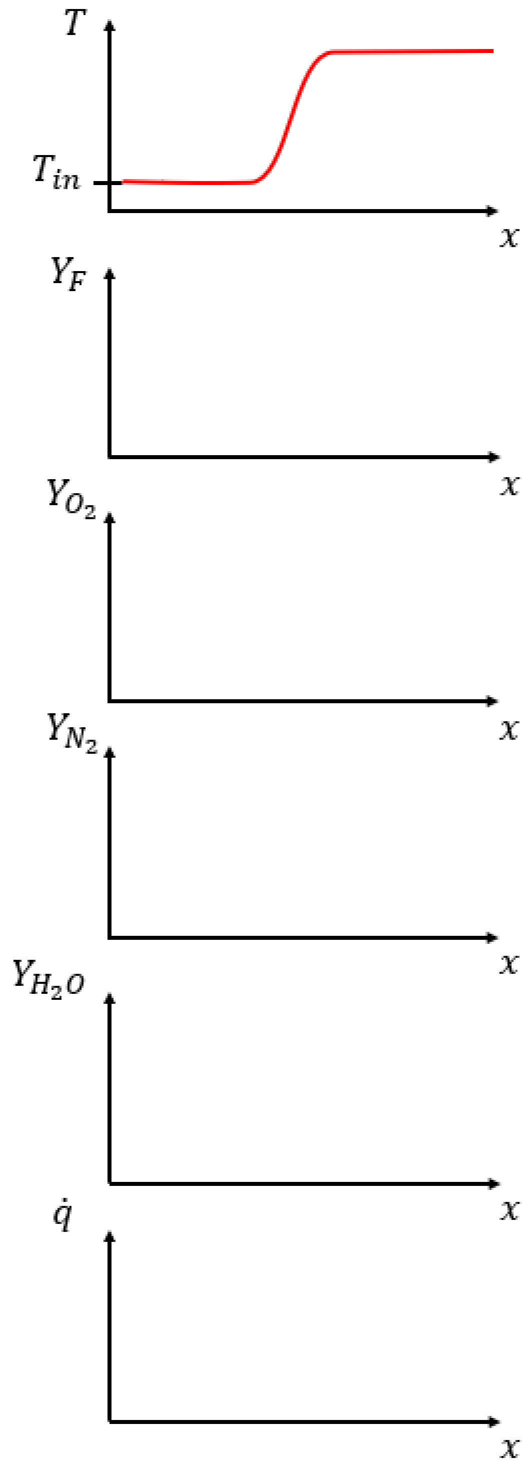
a) Consider a one-dimensional **premixed flame** burning fuel and oxidizer at $\phi = 1$. Draw and label the <u>**qualitative**</u> structure of the flame as a function of the spatial coordinate (x) in figures like those to the right. In these figures, the fuel+oxidizer inlet is on the left. The temperature profile is already drawn and labelled. You need to identify the mass fraction of the fuel (Y_F), the mass fraction of oxygen (Y_{O_2}), the mass fraction of nitrogen (Y_{N_2}), and the mass fraction of water (Y_{H_2O}). On each figure, it should be clear when the inlet and outlet quantities are zero, whether the outlet is less than the inlet quantity, and whether the outlet is more than the inlet quantity. Note that all your figures should line up with respect to the spatial coordinate.

b) For the same conditions as above, draw the qualitative structure of the heat release rate ($\dot{q}$) within this flame on the bottom-most axis on the right. *Hint: Remember that heat is released as reactants are converted to products. Thus, heat release is promoted when there are high concentrations of* ***both*** *reactants still available. In addition, recall that chemical reactions occur faster at higher temperatures. Thus, heat release is also promoted at higher temperatures. However, you need to consider these factors simultaneously.*

c) Repeat parts a) and b) for the same flame, however, with an equivalence ratio of $\phi = 0.5$ using a new set of figures.

d) Qualitatively, how does your outlet temperature compare between the flame at $\phi = 1$ and the flame at $\phi = 0.5$? Why?

e) Qualitatively, how does the maximum magnitude of your heat release rate compare between the flame at $\phi = 1$ and the flame at $\phi = 0.5$? Why?



Problem #2: Consider a hypothetical jet engine combustor. At cruise conditions, **nonpremixed** fuel and air flow through this combustor at a total mass flow rate of $\dot{m} = 50$ kg/s. This flow rate is required to reach the necessary thrust and cannot change. Additionally, in order to fit within the rest of the engine and minimize weight, the combustor is $L = 0.5$ m long and cannot be made longer. Make the (bold) assumption that the laminar/turbulent flame length equations we derived in class are exact, rather than scalings. That is, assume that for a laminar flame, the flame length is given as:

$$h_l = (2R)^2 U/\nu$$

Where R is the radius of the jet outlet, U is the bulk velocity of the flow, and ν is the kinematic viscosity (otherwise known as the momentum diffusivity). In addition, for a turbulent flame, assume the flame length is given as:

$$h_t = 2R$$

a) Assume flow enters the combustor through a circular injector and is perfectly laminar. For the flow rate given above, how long would the flame be? You may estimate the properties of the gas entering the combustor as $\nu = 1 \cdot 10^{-4}\mathrm{m}^2/\mathrm{s}$ and $\rho = 5\ \mathrm{kg/m}^3$. *Hint: The given values are sufficient to solve this problem. If there's a variable that you think you need a value for but it isn't given, you will likely need to cancel those terms out with another equation.*

b) The flame length above should be absurdly long, and importantly, much longer than our combustor. We can try to shorten our flame by using many smaller circular injectors instead of a single hole. Again, assuming circular injectors, perfectly laminar flow, and the gas properties from part a), how many injectors would be required to limit the flame length to the combustor length?

c) You likely computed an absurd number of holes in part b) that cannot reasonably fit into our combustor. Let's finally decide that laminar flow might not be for us, and instead focus on turbulent flows. Assume now that we have multiple circular injectors, turbulent flow, the gas properties from part a), and our flame length is equal to the combustor length. In addition, assume that we need to limit the velocity of the flow so that it can balance with the turbulent flame speed. For this problem, assume we limit our maximum inlet velocity to $U = 30\ \mathrm{m/s}$.

   1. What is the radius of each injector? (*Note: These are a bit large but can be scaled down to something more reasonable. Scaling down would increase the number of injectors you compute in the next part, but as you'll see, that's still a much more reasonable number of injectors than what we computed in the laminar case.)*

   2. How many of these injectors are required? (Round to the nearest whole injector)

Problem #3: In this problem, you will practice drawing molecules.

a) Draw the molecular structure of 2,3-dimethyloctane. *Hint: this molecule has two (di) methyl groups attached to n-octane at carbon positions 2 and 3.*

b) Draw the molecular structure of 3-methyl-1-pentene. *Hint: this molecular has a methyl group attached to a 1-pentene molecule at carbon position 3.*

c) Draw the molecular structure of ethyl methyl ether. *Hint: start from the oxygen atom and attach one of each hydrocarbon group on either side*