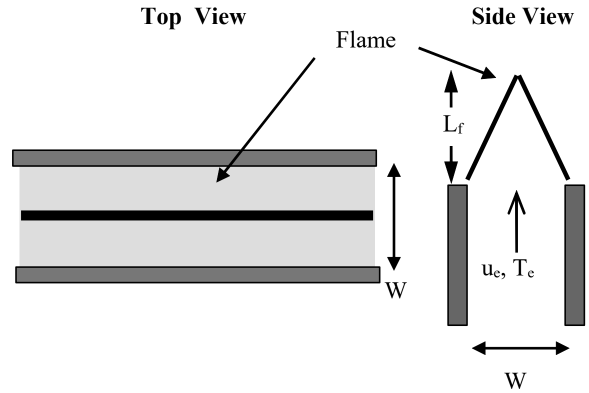
AE/ME6766/Seitzman
Spring 2021
Due Wed., March 31

Homework #2: Deflagrations/Laminar Premixed Flames

- Homework solutions should be neat and logically presented, see format requirements http://seitzman.gatech.edu/classes/ae6766/homeworkformat.html.

1. **Combustor Length** (based on former midterm problem)

A premixed, stoichiometric, atmospheric pressure ethane/air laminar flame is stabilized on top of a two-dimensional slot burner as shown. The width of the burner (distance between the walls of the slot) is W. The flame length (or flame height at the middle of the burner) is L_f, and the burner exit velocity and temperature are u_e and T_e.



Consider a situation where W=2 cm and u_e=2 m/s. You might also find the following information for ethane useful.

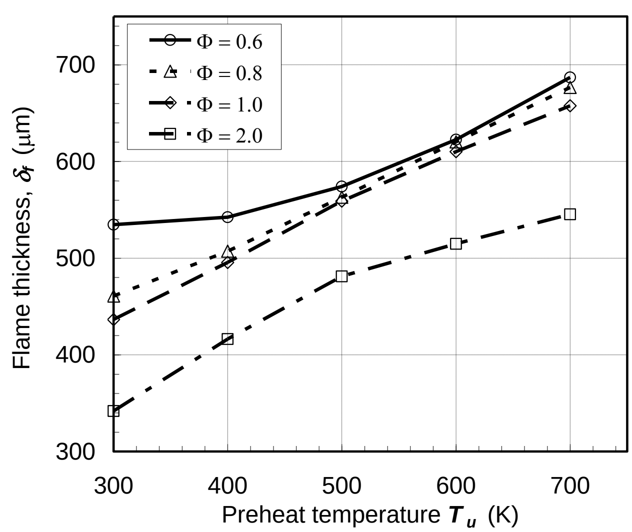
T_{ad} (ϕ=1, p=1atm, T_u=operating T_e)	2260 K
S_L (ϕ=1, p=1atm, T_u=operating T_e)	48 cm/s
δ_f (ϕ=1, p=1atm, T_u=operating T_e)	0.9 mm
Global Reaction Rate for $\dot{m}'''_{fuel}$ (kgm^{-3}s^{-1})	$-4 \times 10^6 \rho_{fuel}^{0.1} \rho_{O2}^{1.65} e^{-15,098K/T}$

a) Provide an estimate of L_f for these conditions.

b) What would L_f be if we operated the system at a pressure to 5 atm but *used the same reactant mass flow rate through the burner as in the original case*. You may assume the exit temperature remains unchanged and the flame remains anchored at the burner exit.

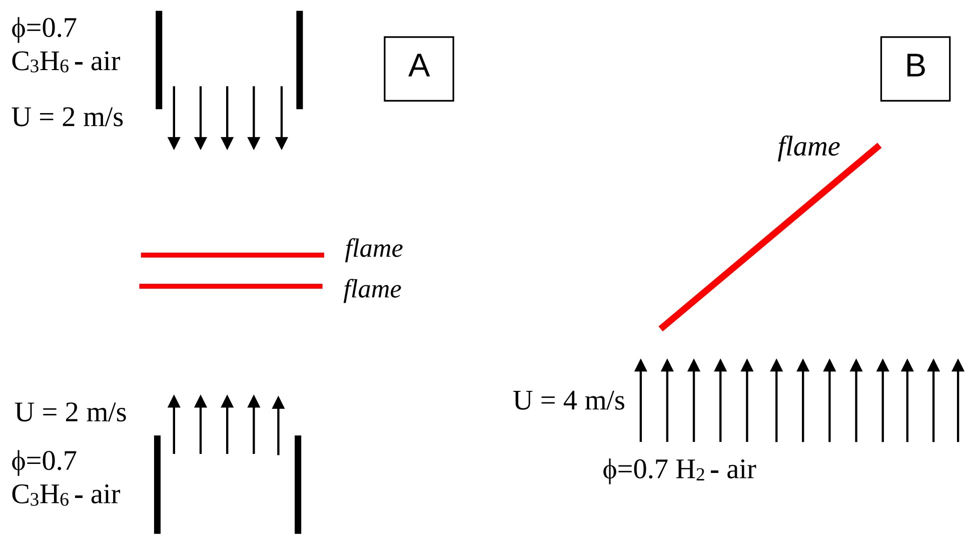
2. **Flame Thickness Scaling**

The graph shows the 1-d, laminar flame thickness (δ_f) for a fuel-air mixture as a function of the temperature of the unburned reactants (preheat temperature T_u). The fuel is composed of 50% H_2 and 50% CO by mole, and results are for p=1 atm at four equivalence ratios (Φ). The thickness values are based on the temperature rise divided by the maximum temperature gradient in the flame ($\delta_f = \Delta T / \nabla T_{max}$). Provide a convincing explanation of why the trends shown in the figure occur for this fuel-air system: a) impact of Φ changes on δ_f, b) impact of T_u changes on δ_f.



3. **Flame Stretch** (former midterm problem)

Two burner configurations are shown in the figure. Configuration A employs two, opposed, round jets - which can produce the twin flames shown in the figure; only the portion of the flames that might exist near the central axis are shown in the figure. Configuration B is created by a rectangular slot burner; only a portion of the flame that could exist on one side of the slot is shown. In the regions shown, both flames are planar. For each configuration, explain whether you would expect a drop in the flame speed below S_L^o in the flame regions shown due to stretch effects.



4. **Flammability Limits** (former midterm problem)

The following table gives measured flammability limits (at 1 bar, 300 K) for four fuel/oxidizer combinations, in terms of mole fraction of fuel in the reactants.

	Fuel Mole Fraction			
Fuel	Oxidizer=**Air**		Oxidizer=**O_2**	
	Lean Limit	Rich Limit	Lean Limit	Rich Limit
H_2	4%	75%	4%	94%
CH_4	5%	15%	5%	61%

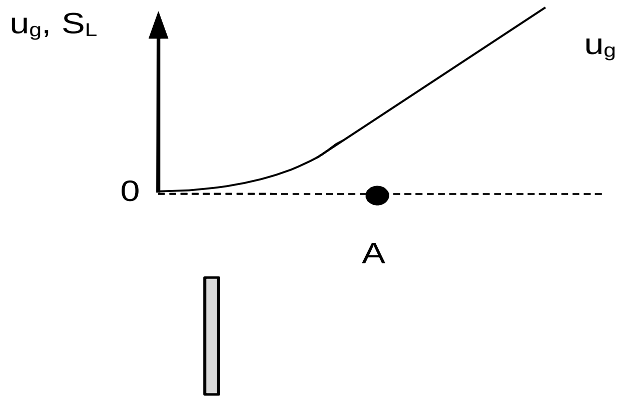
a) For each of the fuels, the lean flammability limits (in terms of fuel mole fraction) are independent of the oxidizer type. Explain.

b) Explain the change in rich limits when the oxidizer is switched from air to oxygen.

c) In terms of equivalence ratio (rather than fuel mole fraction), which oxidizer (O_2 or air) has a "leaner" lean flammability limit? Note, you do not need to calculate the actual equivalence ratios; a short explanation is also acceptable.

5. **Bunsen Burner - Lifted Flame Stabilization**

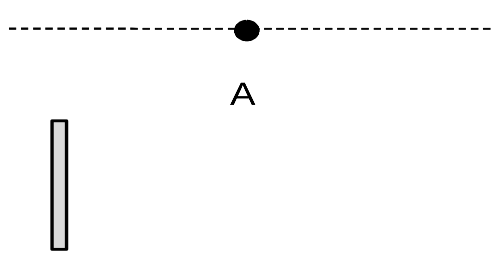
Consider a uniform gas mixture with a non-uniform flow velocity exiting a tube that produces a lifted flame (i.e., the flame begins at some distance above the burner). Shown below is a **magnified view** of the region near the edge of the burner. The gas velocity profile (at the height above the tube exit as indicated by the horizontal dashed line) is shown as u_g.



a) On a reasonable copy of this figure, draw a profile of the local flame speed (S_L) at the same height) that would correspond to a stationary flame which would pass through the point A, *but not exist at any lower position* (i.e., no closer to the exit plane of the burner).

b) Assume that the sketch you have just drawn is the flame speed for a stoichiometric fuel/air mixture exiting the tube into a surrounding gas consisting of nitrogen (denoted here as <u>Case 1</u>). Now keeping the gas exit velocity the same as above, consider two new cases: <u>Case 2)</u> a fuel rich mixture (near but within the flammability limit) exiting into nitrogen and <u>Case 3)</u> the same fuel rich mixture exiting into air. On the same diagram above, now draw S_L profiles (corresponding to the same height above the tube as the u_g shown) for these two cases. **Make sure to label each of your flame speed profiles.**

c) On a copy of the figure below, draw the flame front location for each of the above cases (**again be sure to identify each of the three cases**).



d) For which case will blowoff occur first as we increase the velocity of the gases exiting the burner tube.