Combustion 522 Review Questions

Combustion and flame characteristics

- What are the key characteristics of combustion?
- What makes a flame a flame?
- Sketch the reactant and product profiles for a premixed flame and a nonpremixed flame.
- What are the key characteristics of a premixed flame (e.g., color, shape, burning mechanism)?
- What are the key characteristics of a nonpremixed flame?
- Name three applications or examples of premixed flames; do the same for nonpremixed flames.
- Are premixed flames normally sooting? Why or why not? If they are, can they be made to not produce soot? If they are not, can they be made to produce soot?
- What are four key combustion pollutants?

Stoichiometry

- What is the molar composition of air that we prefer?
- What is the mean molecular weight of air?
- What is the molar ratio of N_2 to O_2? Of Air to O_2?
- What is the formula for the mean molecular weight in terms of species mole fractions?
- What is the formula for the mean molecular weight in terms of species mass fractions?
- What is the formula to convert between mole fractions and mass fractions?
- Define the equivalence ratio. Are the fuel and air amounts specified on a mass basis or a mole basis?
- Define the mixture fraction in terms of unburnt fuel and air.
- What are key properties and how and why are mixture fraction and equivalence ratio used?
- Write down the ideal gas law in terms of density.
- What is the criteria for there to be no change in moles from reactants to products?
- What are three reasons ethylene is Dr. Lignell's favorite fuel?

- Write the balanced reaction for a C_xH_y fuel reacting with air.
- Write the reaction of C_xH_y under rich conditions in terms of ϕ
- Write the reaction of C_xH_y under lean conditions in terms of fraction excess air E.
- For burning methane to products of complete combustion, compute the percent excess air needed for there to be 5% dry O_2 in the products.
- T/F: methane is a reasonable surrogate for natural gas.
- Compute the stoichiometric mixture fraction of methane-air combustion.
- On a mass basis, what is the approximate stoichiometric air-to-fuel ratio.

Mixture fraction

- Sketch qualitatively the mass fraction profiles for methane-air combustion as a function of mixture fraction.
- How do we compute a local mixture fraction based on species mass mass fractions in a reacting environment?
- Write a formula for computing an elemental mass fraction from species mass fractions.
- What is the criteria needed to get the same value of the mixture fraction based on different conserved scalars (like elements)?
- How can we use the mixture fraction to simplify the calculation of real flame profiles?
- What is the name of the most commonly used mixture fraction definition?

Flame temperatures

- T/F: there is no “one” temperature of a flame.
- What does the flame temperature depend on for a laminar premixed flame?
- What does the flame temperature depend on for a laminar nonpremixed flame?
- Write down the formula for the adiabatic flame temperature.
    - What is the defining relation in terms of energy?
    - What is the formula in terms of the temperature?
    - Is the equation linear or nonlinear?
    - If nonlinear, under what conditions is it linear?
- If you increase the reactant temperature by 100 K, does the product temperature increase by 100 K or more or less? Why?
- What is the approximate value of the adiabatic flame temperature for a stoichiometric methane-air flame?
- What is the approximate change in volume (at constant pressure) between reactants and products (that is, the volume ratio)?

- Using provided thermodynamic data, calculate the adiabatic flame temperature for a stoichiometric methane-air flame.
    - Think about how you would do this in cantera for products of complete combustion and for equilibrium products.
- What does LHV and HHV mean?
    - Which one is bigger?
    - What is the difference between then?
    - Which one is more “realistic” in real-world applications?
    - How are these related to the heat of reaction?
- Sketch qualitatively the temperature profile of a nonpremixed flame versus mixture fraction.
- Which flame is hotter: burning in air or burning in O_2?
- Which flame is hotter: burning under constant pressure or constant volume?
- Which flame is hotter: burning to products of complete combustion, or burning to equilibrium products?

Equilibrium

- Starting with some amount of A and B, find (symbolically) the equilibrium composition for a reaction $aA + bB \leftrightharpoons cC$.
    - Use the equilibrium constant method.
    - Write the equation for the equilibrium constant in terms of the Gibbs free energy of reaction.
    - Write down the equilibrium constant in terms of the appropriate measure of species amounts.
    - How would we extend the problem if we had two reactions?
- T/F: The equilibrium constant depends on pressure.
- T/F: The equilibrium composition can depend on pressure.
- Under what conditions will the equilibrium composition of an ideal gas reaction not depend on pressure?
- Write down the equation for the water-gas-shift reaction.
- T/F: most of the heat of combustion comes from the heat of reaction of a hydrocarbon comes from reaction of the intermediate CO to CO_2.
- Outline the approach for solving equilibrium for complex systems?
    - which function are we minimizing?
    - what are the contraints on the equilibrium?
        - how many constraints are there?

        - what is the name of the approach used to minimize the function and satisfy the constraints?
    - what is assumed “constant” in this approach?
        - Does that mean we can only equilibrate systems for which those quantities are constant?
    - How many equations and unknowns are we solving for?
        - What do those unknowns correspond to?

Engines and fuels

- Draw the PV diagram for the Otto cycle.
- Draw the PV diagram for the Diesel cycle.
- Label the PV diagrams with work steps and heat steps, and any other Key assumptions during the steps.
- For the same compression ratio, which cycle has the higher efficiency, Otto or Diesel?
    - Explain why this is in terms of the shapes of the PV diagrams.
- What is the difference between the ideal cycles with air as the working fluid versus combustion gases as the working fluid (in terms of heat and mass transfer)?
- How is the work of the Otto cycle computed?
    - What is it conceptually in terms of the shape of the PV diagram?
    - How would you actually compute it?
- What type of flame (premixed or nonpremixed) do the Otto and Diesel cycles use?
- Which fuel has the higher ignition temperature: Diesel or Gasoline?
- Which fuel is “cheaper” in terms of requiring less refining from crude oil?
- Which fuel has the smaller molecular weight, Gasoline or Diesel?
- Define the octane number.
- How would living in Provo versus Southern California affect the minimum required Octane rating of gasoline? Why?

Mass transfer

- What is the formula for the version of Fick’s law that is most accurate for combustion?
    - $J_i = -cD\nabla x_i$
    - $j_i = -\rho D\nabla y_i$
- How can you convert J_i to j_i above?
    - and then how can you convert it to be in terms of y_i instead of x_i?
- T/F: for multicomponent mixtures, species can diffuse “up” their concentration gradient?

- What is a key property of combustion in air that allows more accurate use of Fick's law over a full multicomponent treatment?
- What is a constraint on the species diffusion flux j_i.
- Write the species diffusion flux in terms of the species diffusion velocity v_i^D.
- What is the relationship between the species velocity v_i, the mean velocity v, and the species diffusion velocity v_i^D?
- What is the formula for the mass average velocity v in terms of the species velocities v_i?
- What are the definitions of the Lewis, Schmidt, and Prandtl numbers?
- What are the units of diffusivity D, kinematic viscosity ν, and thermal diffusivity α?

Kinetics

- For reaction $aA + bB \rightarrow cC$, write the rate of change of concentration $[A]$ in terms of the rate constant.
- What is the form of the rate constant used in combustion systems?
- If you were given a kinetic expression for rates of change of species concentrations for a reaction, how could you tell if the reaction were a global reaction or an elementary reaction?
- How would you convert the rate of progress variable q to the species rate ω?
- Write down the Zeldovich mechansim.
    - Write the expression for the Quasi Steady State concentration of $[N]$.
    - How does using a QSSA help us?
- Write the expression for a reverse rate constant in terms of a forward rate constant and the equilibrium constant.

Kinetic mechanisms

- What are the three key types of combustion reactions?
    - Give an example of each
    - At a given temperature, which are generally the slowest?
- What is the difference between a chain reaction and a chain branching reaction?
- If you had to write a two-step chemical mechanism for methane combustion, what would be your two "fuels"?
- What species is important for increasing the speed of CO oxidation?
- T/F mechanisms with 1000 species or more are not uncommon?

NOx Chemistry

- What are the two mechanisms we considered for NOx formation?
- What are the three key properties that influence thermal NO formation?
- What are two general categories for reducing NO in combustion systems?
- What do SCR and SNCR stand for?
- What are three methods for reducing NOx by combustion controls?
- What is a typical equlibrium value of NOx near stoichiometric?
- What is a typical value or range for emitted NOx?
- Why are emitted NOx concentration levels given for a specific O_2 level in the exhaust?