Due Monday 3/23/15, 4:30 pm in the drop box in OHE 430N (Xerox room). If you're off campus, you can fax it to 213-740-8071. DEN students should submit through the usual channels. Late homework marked down 10 points (out of 100 possible) per day late.

Part 1: paper review

Read any one of the research papers (not review papers, not textbooks) listed below (along with the reason I think they're important papers). Most of these papers are available in the “papers” folder in the lecture note folders on the course website. Also look on the course home page, towards the bottom of the page under “Getting copies of articles cited in the lecture notes” for information about getting the papers through the USC library online journals system. If you have another paper relevant to the subjects of lectures 1 – 3 that you’d really like to read instead of one of my references because it relates to your research or work, I’ll consider it, but you’ll have to get my approval in advance. Notice that most of these papers are somewhat older, but this is mostly intentional since these papers have “stood the test of time” at least in my opinion. Papers written by me are off limits, because you need to be free to criticize the paper, which you might not feel comfortable doing to my papers (at least, if you know what’s good for you…)


S. E. Vargo, E. P. Muntz, G. R. Shiflett, W. C. Tang, “Knudsen compressor as a micro- and macroscale vacuum pump without moving parts or fluids,” Journal of Vacuum Science and
Technology A, Vol. 17, p. 2308 (1999). (Description of the Knudsen compressor experiments and modeling.)


Prepare a critical review of the article, not to exceed 2 pages, structured as follows. PLEASE IDENTIFY EACH SECTION WITH A HEADING.

1) Why the author(s) conducted the work – what did they intend to do that was new at the time?
2) Summary of the methods used
3) Summary of the most important results
4) Summary of the conclusions
5) Your opinion of the merits of the work
6) Your opinion of the shortcomings of the work
7) ONE sentence summary of the most important message the authors were trying to convey.

In discussing the importance of the paper that you’re reviewing, you may find it useful to look at how many times it has been cited and what others have done with the information. To do this:

1. Go to http://www.usc.edu/libraries/
2. Above the search box, click on “Databases” then enter “Web of Science” in the search box
3. Type in some information about the paper in the search fields - author(s), journal, key words in the title, etc.
4. When you find the paper, click on the number next to “Times cited”

That will show you what articles have cited this paper and how recently the paper has been considered important by others. I’m particularly interested in having you review “classic” papers, i.e. ones that are older but continue to be cited often - which is an indication that it represented a breakthrough in the field at the time it was published.

Suggestions:

• Put the paper in its proper historical context. That is, don’t say, “in the past few years some researchers have proposed that the earth is round…” Say, “at the time this paper was written, most scientists believed that the earth was flat but Prof. Columbus proposed the
revolutionary idea that the earth was spherical in shape and set out to prove this by reaching India (which was known to be east of Spain) by sailing west across the Atlantic Ocean.

- Don’t repeat text that is in the paper, and don’t copy/paste from Wikipedia. Summarize in your own words – it shows me that you really do understand the paper.
- Don’t use buzz words from the paper without defining them. If you don’t understand them and don’t feel inclined to learn what they are (which is ok, I don’t expect you to understand every detail of the paper) then leave the buzz words out! In other words: “everything you say can and will be used against you…” (Sounds harsh, but that’s the way real science is – anything you write in a paper is subject to evaluation and potentially to criticism).
- Points 1 and 7 are the most important. This really shows what you learned from the paper. It also helps you to generate your own ideas for research.
- If you state specific numbers (e.g., “The authors found that the engine used 6.3886 grams of fuel per minute to produce 1567.83 watts of power and 9.47982 grams of fuel per minute to produce 22.4857 watts of power”) then you need to indicate why you mentioned these numbers, and are they good numbers or bad numbers? What did they prove or disprove? (In general, for any technical paper, if you state a fact you have to put it in context, i.e. why did you consider that fact important enough to state it?)

Part 2. The usual type of homework questions

1. You have just been hired as an Assistant Professor at UC Berkeley to replace Prof. Fernandez-Pello, who retired and moved to Bora Bora. You are trying to initiate a new project on the development of a 4-stroke single-cylinder piston engine running on propane fuel that provides 10 Watts of electrical power. You can’t utilize Prof. Pello’s group’s prior knowledge because his hard disk crashed and he never backed it up. His former graduate students and postdocs have all taken jobs in Syria and cannot be reached due to poor phone and internet service. Since you have taken AME 514 and are familiar with microscale combustion and power generation, your job is to figure out how to scale down an existing IC engine. (There’s a lot of parts to this problem but breaking it up this way makes it easier to keep you on the intended path.)

   a) Estimate the fuel flow (in kg/s) required assuming 5% conversion efficiency of fuel to electricity.
   b) Estimate the air+fuel flow (in both kg/s and m³/s) assuming stoichiometric propane-air
   c) If the propane-air mixture is compressed by a 10:1 volume ratio, what is the post-compression (but pre-combustion) pressure, temperature and thermal diffusivity? (Use GASEQ or a similar program).
   d) Estimate $S_L$ for this condition. Use the $S_L$ correlations for propane at elevated T and P by Metghalchi and Keck (Combustion and Flame, Vol. 38, p. 143, 1980) which I have uploaded to the Lecture 6 papers folder.
   e) Estimate the quenching distance $= 40\alpha/S_L$ for this mixture.
   f) Assume that the clearance height (distance from the top of the piston to the cylinder head) should be twice this distance to avoid quenching. The stroke (distance traveled by the piston) must be 9 times this distance to obtain a 10:1 volume compression ratio. What is the stroke?
   g) Assuming bore (cylinder diameter) = stroke, what is the volume of the cylinder?
h) At what revolution rate must the engine rotate in order to obtain the required volume flow? (For a 4-stroke engine, the engine must complete two revolutions for each gulp of fuel-air mixture.)

i) Should you design the flow inside the cylinder to be laminar or turbulent? Do you have a choice? (What is the Reynolds number?)

j) By using the scaling analysis discussed in Lecture 4, estimate the importance of heat losses for this size of engine with this rotation speed and $S_1$.

k) By using the scaling analysis discussed in Lecture 4, estimate the importance of friction losses.

l) Estimate the importance of wall heat conduction (i.e. the ratio of gas-phase convection to wall conduction). Will the gas temperature increase significantly during compression?

m) Should this design using catalytic combustion instead of conventional (gas-phase) combustion? Why or why not? Use the Kaisare et al. model (Lecture 4) to estimate the heat release rate attainable from catalytic combustion; the spreadsheet used to generate the plots is at http://ronney.usc.edu/AME514S15/Lecture4/VlachosPropaneCatCombModel.xls.

n) If you found that the design was unfeasible due to friction or heat losses or heat transfer during compression, even after employing catalytic combustion, what is the minimum size of cylinder needed to avoid these problems?

(You’ll probably want to use a spreadsheet or Matlab program to keep track of your calculations; hang on to it because we’ll re-visit the problem after learning about turbulent combustion to see if combustion is fast enough under these conditions.)

2. After several years of work at Berkeley, you give up and decide to try some alternate power generation devices.

a) Estimate the area of a single chamber solid oxide fuel cell (use Hibino’s data under the most favorable condition) needed to produce 10 watts of electrical power. If you used this device in a “pizza” configuration (one disk exposed on both sides to ambient) and the heat loss coefficient to ambient were 10 W/m²K, how much thermal power would be lost to ambient?

b) Estimate the area of Bi$_2$Te$_3$ thermoelectrics that would be required to produce 10 Watts of electrical power assuming a hot-side temperature of 500K and cold-side temperature of 300K. The thermal conductivity of Bi$_2$Te$_3$ is about 2 W/mK and $ZT_a \approx 1$. Assume that you have massive fins attached to both the hot and cold side of the thermoelectrics that give you an effective heat transfer coefficient of 100 W/m²K. Use the $\Delta x$ for the thermoelectrics that maximizes the power (as explained in lecture 6, slides 10 - 12).

3. Using the formulas in the Lecture 6 notes, estimate the size (i.e. membrane area) and thermal power required for an aerogel-based thermal transpiration pump that will produce 0.1 N of thrust. Assume 300K inlet, 600K outlet, and a 1 mm thick membrane (meaning $L = 1 \text{ mm} / 10 = 100 \mu\text{m}$, and use the most efficient operating condition, i.e. $\Delta P/\Delta P_{\text{flow}} = 0.5$). The Knudsen number is 5. The thrust in this case is equal to the mass flow ($\dot{m} = \rho M c A$, where $\rho$ is the ambient air density, $M$ the Mach number you calculated, $c$ the sound speed, and $A$ the area you’re trying to find) multiplied by the exit velocity after expansion through a nozzle back to ambient pressure (in this case Bernoulli’s equation will do, $u = (2\Delta P/\rho)^{1/2}$). (I’ve neglected a lot of temperature-averaging of properties and other things in these formulas, but that adds a lot of
4. Using the equations in Lecture 4, show that the formula for the adiabatic, fast-reaction temperature $T_{\text{reactor}}$ of a heat-recirculating reactor (no heat loss so $h_2 = 0$, no wall conduction so $\tau = 0$, $Da = \infty$) so the temperature rise in the reactor $= T_e(L) - T_i(L)$ is just the adiabatic temperature rise $Y_{\text{fuel}}Q_R/C_p$ as given in class

$$T_{\text{reactor}} = T_{\text{adiabatic, no recirc}} + \frac{h_1LY_{\text{fuel}}Q_R}{2\dot{m}C_p^2}$$

Note that $T_{\text{adiabatic, no recirc}}$ is just the usual adiabatic flame temperature $= T_\infty + Y_{\text{fuel}}Q_R/C_p$.

5. (From a previous years’ final exam). Consider a “Swiss roll” heat recirculating combustor whose equivalence ratio at the extinction limits (minimum equivalence ratio required to support combustion) as a function of the mass flow $M$ or Reynolds number $Re$ is as shown in the attached figures. As discussed in class, at low mass flow $M$ or Reynolds number $Re$, there is a limit due to heat losses and at high $M$ or $Re$ there is a limit caused by insufficient residence time (the “blow-off” limit). Draw on the attached figure how this “baseline” curve would be affected if each change to the design were made. Explain each answer below in a few sentences. Turn in the following page with your homework.

a) The wall thermal conductivity increased
b) The wall is roughened, increasing the turbulence in the gas
c) The whole device is insulated, reducing heat losses to ambient
d) The device is taken to Planet Y, where the ambient pressure is twice that of earth but all other properties of air and fuels are the same on earth as on Planet Y
e) A fuel with a higher heating value than the baseline fuel but the same stoichiometric fuel-to-air mass and mole ratios is used
f) An effective catalyst is placed in the center of the Swiss roll
Problem #5

(a) The wall thermal conductivity is increased

(b) The wall is roughened, increasing turbulence in the gas

(c) The device is insulated, reducing heat losses

(d) The device is taken to Planet Y, where the ambient pressure is twice that of earth

(e) A fuel with higher heating value is used

(f) An effective catalyst is placed in the center of the device