PHYS-310 Demographics, Heat Transfer, Heat Engines, Problem Set #2. Due Friday 4/12

1) Please go to: http://www.animatedengines.com/ and pick out at least 4 engines that interest you and watch the apps for each. Please identify how and where WE put work into the gas, and then add heat and then the gas does work FOR us that we get out. Also be aware of why the work we get out is more than the work we put in.

6 Different Engines A+

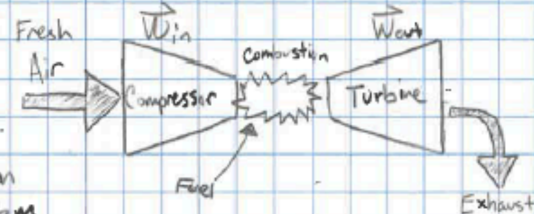
a) Reciprocating Engines

A two stroke engine has all its action in one cylinder where everything is completed in two strokes. On the down stroke, the fuel enters the top chamber from the left and fuel leaves out the right. The other stroke is the compression/explosion. A four-stroke engine has these events take place with more strokes and more gears and space used. Two-strokes are more compact and useful for things like lawn mowers, chain saws, etc.

b) Diesel VS Gas Engine

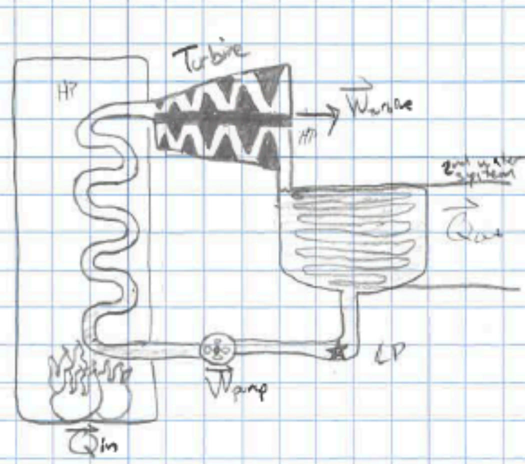
While both the two-stroke and four-stroke engine, both mainly gasoline engines, help combustion with a spark from a spark plug or the like, a diesel engine combusts purely from the rapid decrease in volume/spike in pressure. The intake/outtake valves open and close by rotating two things against them, pushing at different times.

c) Brayton Cycle (Gas Turbine)



The Brayton Cycle compresses air ($\vec{W}_{in}$) using multiple blades and then injects fuel (E_{chem}) that gets ignited in the compressed air region. This heat from the fuel raises the temperature of the compressed air, thus increasing the pressure of the air that is wanting to expand in volume. This leads to a surge out of the exhaust which helps propel the plane forward ⇒ thus get more air compressed and this process can continue.

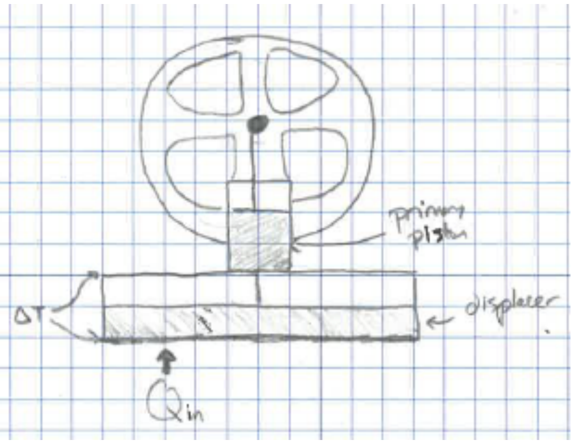
d) Rankine Cycle (Steam Turbine)



If starting from the ☆ position on the figure, the pump ($\vec{W}_{in}$) takes the water from the low pressure region, and while pumping through a hot chamber (Q_{in}) turns into steam (1000× more volume than liquid form). The work of the steam pushing the blades is W_{out} and the steam cools in a cooling chamber where it comes into contact with cool pipes from secondary water and condenses back into water itself.

e) Stirling Engines

The Stirling Engine works off of a temperature difference between the bottom plate and top plate. For instance, if the displacer is along the bottom plate and that plate gets hot, the air between the displacer and plate gets hot and expand. This pushes the displacer up which affects the primary piston



2) Go to Gapminder.org, and click on “Try our new tools” at the top of the webpage. Explore demographics of the world’s people. Pay particular attention to the country of your community of interest. How did the things you’re looking at develop over time? Take at least two screen shots to discuss with your colleagues.

3) Coal Power Production

Coal and natural gas are the two predominant forms of fossil fuels used for generating electricity in the world. Compared to the NGCC, coal is a worse polluter on two levels – criteria pollutants (like toxins), and in terms of CO_2 production.

a) What does NGCC stand for? *Natural Gas Combined Cycle*

Why does burning coal emit more toxins into the atmosphere and what are some of these toxins? *Coal has two problems: it’s a solid (so it can’t be used in a Brayton Cycle, eliminating it from combined cycle efficiency), and it’s a solid (locking in all the toxins making it hard to purify). These toxins include mercury and sulfur. Mercury is a big one. There is mercury in the ocean only because we burn coal to generate electricity. There is enough mercury in the ocean to make some fish at the top of the food chain (like tuna) toxic... especially for pregnant women. We've found that the toxicity of the Atlantic fish have decreased since we've stopped using so much coal in USA and Europe. Likely when China stops using so much coal, Pacific fish will also have less mercury. Additionally, sulfur results in SO_2 and SO_3, which result in very acid rain.*

b) For the same amount of electricity, coal emits more CO_2 than the most efficient Natural Gas electricity generation by what factor? *~ 3*

c) Why is it that Coal Electricity emits more CO_2 than natural gas electricity generation? Please give two reasons. *Coal has two problems: it’s a solid (so it can’t be used in a Brayton Cycle, eliminating it from combined cycle efficiency), and it inherently has greater carbon intensity. For instance, natural gas has many C-H bonds, producing lots of energy and water upon combustion. Coal has way more C-C bonds, emitting more CO_2 in combustion.*

d) What portion of the world’s coal does the US consume? China? What portion of the world’s NG does the US consume? China?

f. World Total ≈ 160 quadrillion BTU
US Total ≈ 20 quad BTU ~ 12.5 %
China Total ≈ 80 quad BTU ~ 50 %
$\Big\}$ coal

World Total ≈ 120 trillion ft^3
US Total ≈ 30 trillio ft^3 ~ 25 %
China ≈ 5 %
$\Big\}$ Natural gas

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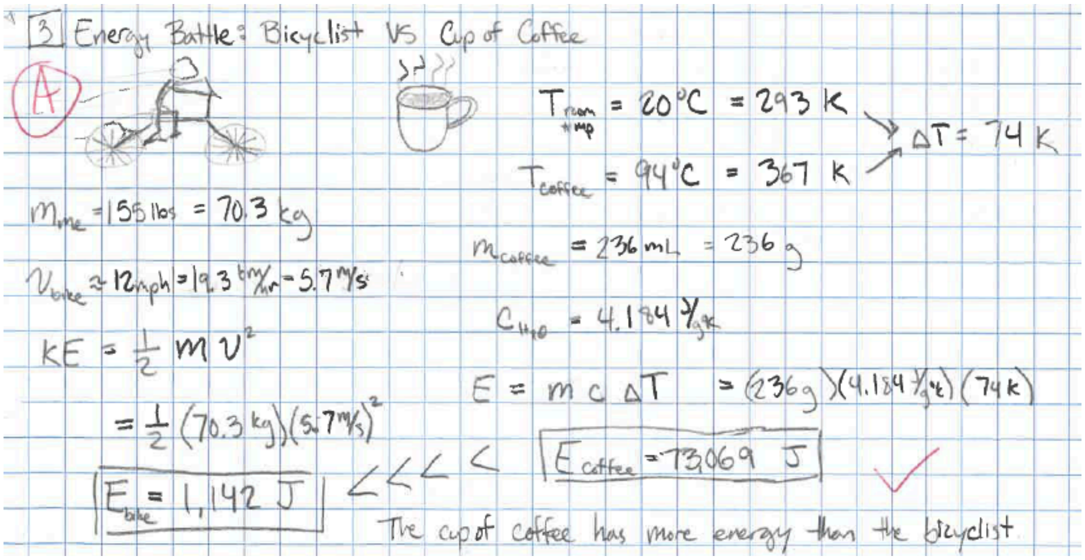
4) Guessing Energy: Please do this question in two parts:

a) What do you think requires more energy: you riding fast on your bicycle, or a hot cup of coffee? By what factor do you think they vary: That is E_{bike} ~ ___ E_{coffee}

b) Please do the calculations and see which has more energy.


3 Energy Battle: Bicyclist vs Cup of Coffee

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$T_{\text{room temp}} = 20°C = 293\ K$

$T_{\text{coffee}} = 94°C = 367\ K$

$\Delta T = 74\ K$

$m_{me} = 155\ \text{lbs} = 70.3\ kg$

$m_{\text{coffee}} = 236\ mL = 236\ g$

$V_{\text{bike}} \approx 12\ mph = 19.3\ km/hr = 5.7\ m/s$

$C_{H_2O} = 4.184\ J/gK$

$KE = \frac{1}{2} m v^2$

$= \frac{1}{2}(70.3\ kg)(5.7\ m/s)^2$

$E = m c \Delta T = (236\ g)(4.184\ J/gK)(74\ K)$

$\boxed{E_{\text{bike}} = 1{,}142\ J} \ll\ll\ <\ \boxed{E_{\text{coffee}} = 73069\ J}$

The cup of coffee has more energy than the bicyclist

5) I make a house out of adobe, (mud, cob, earth whatever you like to call it). The walls are 3m high, 4m wide, and is 50 cm thick. Assume that the roof is really well insulated, so no heat escapes from it. It is 70 °F inside and 30 °F outside. *This provides an inside temperature of about 293 K and a temperature difference of about 22 C*

a) How much power do I need to dissipate in the room to keep the temperature constant?

b) I put a window in one wall. It is 2m wide and 1m high. It's single paned, perfectly transparent glass of thickness 2 mm. Estimate the house's heat loss with the window.

So, DH made this calculation extra challenging. Not only did he provide no units, but he sometimes refers to resistivity, such as 3 mm window glass having an R value of 0.005(Km^2/W), and sometimes to the inverse, the thermal transmittance, U=1/R, such as that for air is usually 6(W/m^2K). So, let's stay alert. We have three independent heat flows: convection/conductivity (in series) through the adobe walls, radiative cooling through the window, and convection/conductivity (in series) through the window pane. So, we need to set up something like the circuit diagram in page 391:

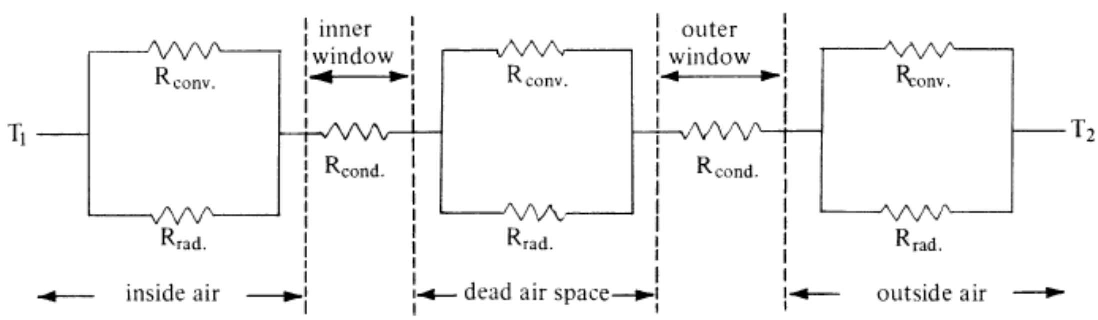


Figure 11.1. Double-glaze heat transfer circuit diagram.

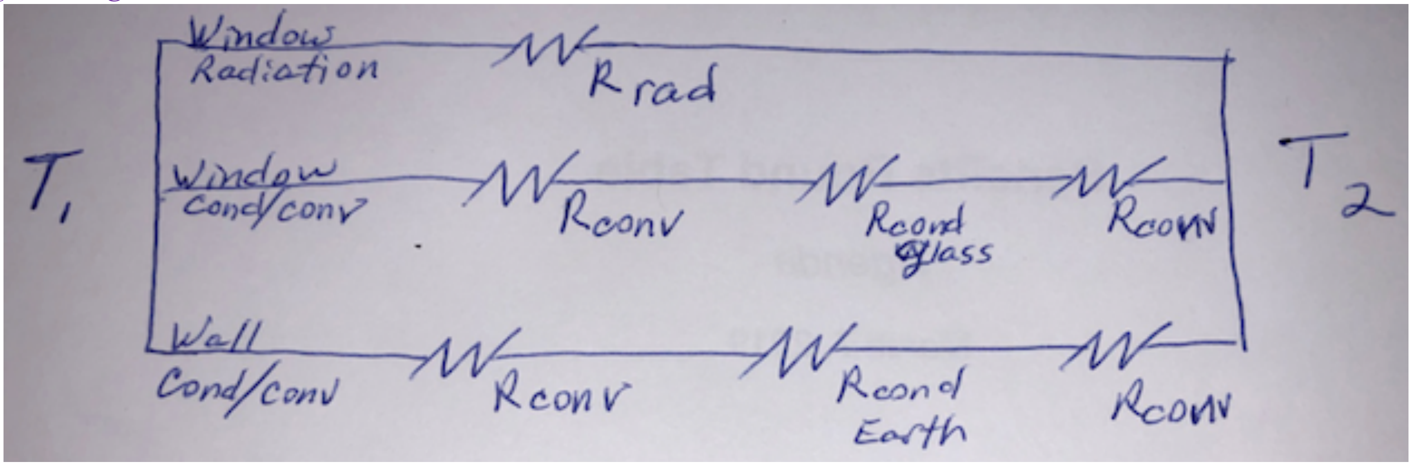
Our diagram will have three parallel circuits with a few changes:

a) *We said that our window pane is 100% transparent, so the radiative cooking will go directly from the house to the outside world without being in series with conduction across the glass. We will need to make some kind of estimate about the emissivities of the inside and outside of the room. I looked up and saw that brick has an emissivity of ~ 0.8, so I'll use that.*

b) *Conduction/convection series through the adobe walls will be limited by conduction through the ½ m earth wall, because it is thick and not very conductive, but we will check this to be sure.*

c) *Conduction/convection series through he window will be limited by the convection because the thin window provides very little resistance to thermal flow, but we will check this.*

So, our diagram will look something like the following:



In series we add resistances. In parallel, we add transmittance. We set out to find the resistance of each of these three heat transfer mechanisms:

We start with radiative cooling. We can find the exact value, or make the linearization with temperature I showed in class:

$$P_{rad} = \epsilon A \sigma (T_i^4 - T_o^4)$$

$$= \epsilon A \sigma [(T_o + \Delta T)^4 - T_o^4)$$

$$\approx \epsilon A \sigma [\cancel{T_o^4} + 4T_o^3 \Delta T + ..\text{H.O.T.} - \cancel{T_o^4})$$

$$\approx \epsilon A \sigma (4T_o^3)\Delta T = \underbrace{\epsilon \sigma (4T_o^3)}_{U_{rad}} A \Delta T$$

Using the emissivity for brick and the average temperature of 283 K, I get $U_{rad} \sim 4.1\ W/m^2K$

For the single pane glass, it seems that Table 11.2 provides the full $U_{cond/conv}$=6.1 W/m^2K, so we don't have to calculate anything, but we can verify that the glass thickness plays little role in the insulative properties by looking at table 11.1. The R value of 3 mm glass is 0.005, meaning that the R value of 2 mm would be 2/3 that. Thus the U factor is huge!... as if it wasn't even there. Thus, the insulative properties of the window lie in the convective heat transfer between the air and glass surface. This may not be the case with earth. The thermal conductivity of earth is about 1 W/mK, and because we know that $P=Ak(dT/dL) = (k/dL)AdT$, we can make a U value for the half meter walls: $U_{cond} = (k/dL) \sim 2W/m^2K$, which is way less than the convective heat transfer from the thin windows, so the conductivity measurement will dominate. Adding them correctly like conductance in series, we get about <u>1.5 W/m^2K</u>. Alas, we cannot just add these three conductances because there are different areas for the window (2 m^2) and the earthen wall ($48m^2$ - $2m^2$). In any case, we get a total conductance of the window to be:

$U_{Win} = U_{rad} + U_{cond/conv} = (4.1+6.1) W/m^2K = 10.2\ W/m^2K$. The window loses about 7 times the heat as the wall per surface area. Multiplying by the surface area and the temperature difference, yields the approximate power loss to the cold outside:
Through the windows: $P \sim 450\ W$
Through walls: $P \sim 1450\ W$
Total Power Loss $\sim 1900\ W$