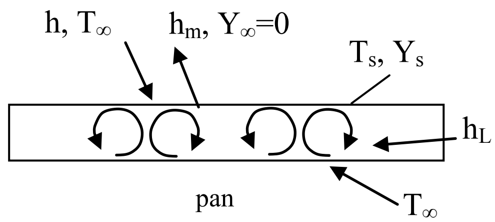
Fire Science
Exam 2 Compilation

1) A small spill of ethanol (C_2H_5OH) has created a pool of 10 mm thick in a pan.

The free stream temperature is 350 K and ethanol boils at 351 K. Assume that there is no ethanol in the atmosphere. The latent heat of vaporization of the ethanol is 0.84 kJ/g. Assume that the specific heat capacity is 1 J/(gK). State all assumptions as you answer the following questions.



a) When a heat transfer coefficient of 4 W/m^2K exists above the pan and h_L=0 W/m^2K, the surface temperature (Ts) is 286 K. Show by a quick calculation that this is the correct surface temperature. (15 pts)

b) What are the surface vapor pressure and mass fraction of ethanol at the condition given in part (a)? (10 pts)

c) What is the ethanol evaporation rate (mass flux in $kg/(m^2s)$) for the scenario specified in part (a)? (5 pts)

d) What is the total heat flux to the surface for the scenario specified in part (a) (W/m^2)? (5 pts)

e) When a heat transfer coefficient of 4 W/m^2K exists above the pan and h_L=100 W/m^2K, the surface temperature (Ts) is 332 K. Show by a quick calculation that this is the correct surface temperature. (15 pts)

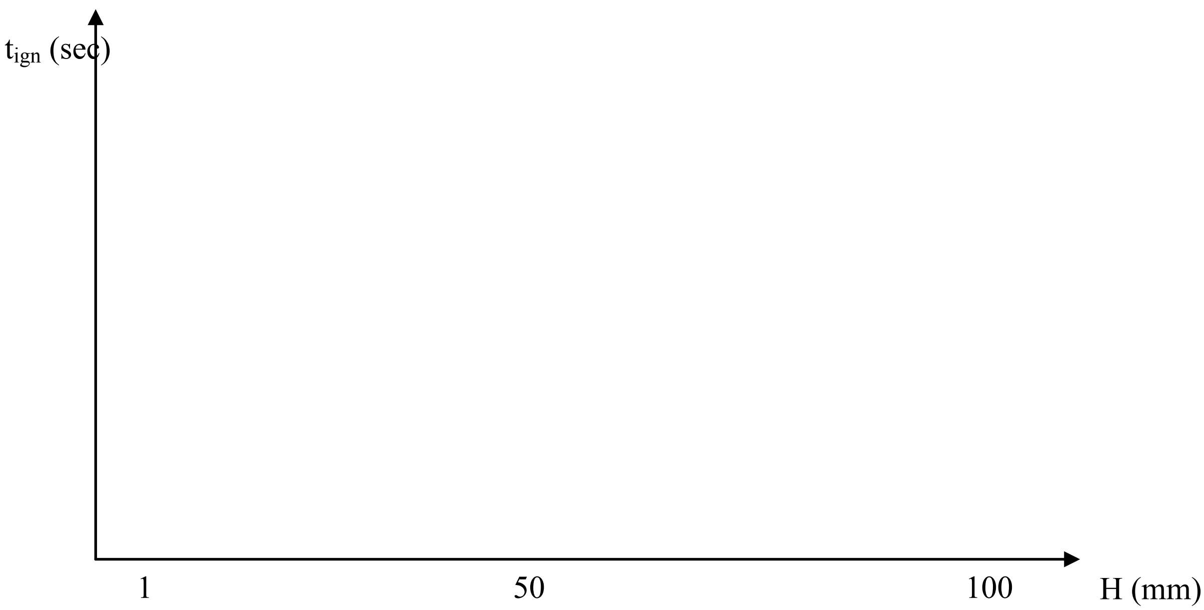
f) What is the total heat flux to the surface for part (e)? (5 pts)

g) For part (e), what is the fraction of heat transferred to the surface from the free-stream? (5 pts)

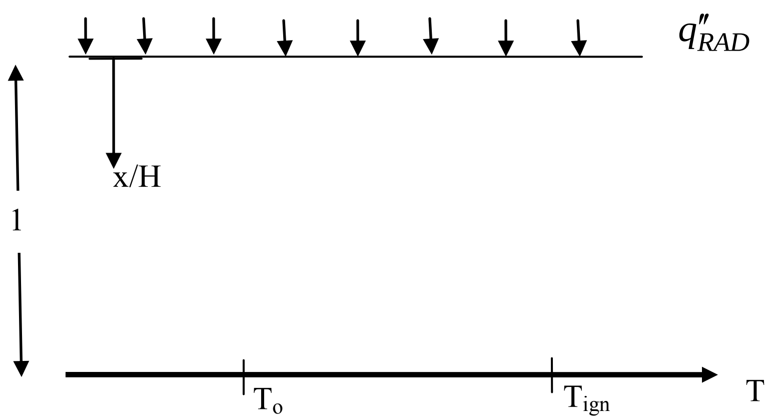
2) A sample of plastic (PMMA) is subjected to a radiative heat flux of 15 kW/m^2. The radiative absorptivity is assumed to be unity (1). A pilot flame is near the sample. Assume that the piloted ignition temperature is 310 C and that the sample was initially at 25 C. Assume that the heat transfer coefficient from the sample is 20 W/m^2K.

$k=0.26$ W/(mK), $\rho=1200$ kg/m^3, $c_p=2.1$ J/(gK), $T_{ig}=380$ C, $T_\infty=25$ C, $h=20$ W/m^2K

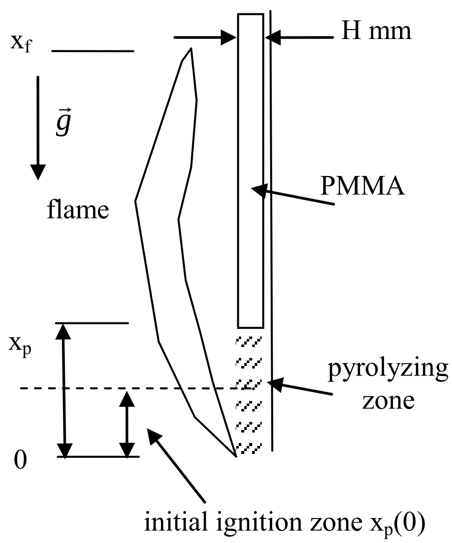
a) Qualitatively sketch the variation of ignition time with thickness for samples between 1 mm and 10 cm thickness. Note any interesting features of the variation on the sketch. (15 pts)



c) A 1 mm thick PMMA sample and a 10 cm PMMA sample are shown below. The spatial coordinate is normalized by the thickness so that on the graph x/H=1 is the bottom of the 1 mm sample and also the bottom of the 10 cm sample. For the radiatively heated sample, sketch an approximate spatial temperature profile at t=0, t=tign, and at two intermediate times for both samples on the graph below. Use a dashed line for the 1 mm sample and a solid line for the 10 cm sample. (10 pts)



c) Several thickness PMMA samples in a vertical orientation are ignited and a flame spread process results. The thinnest sample is 1 mm thick, while the thickest is 10 cm thick. After some critical time of burning, the pyrolysis length (x_p) for each thickness sample is recorded. Sketch your best estimate of what the pyrolysis length variation with length is at some time t_{cr} after which flame spreading as started. <u>Detailed calculations are not required.</u> (15 pts)



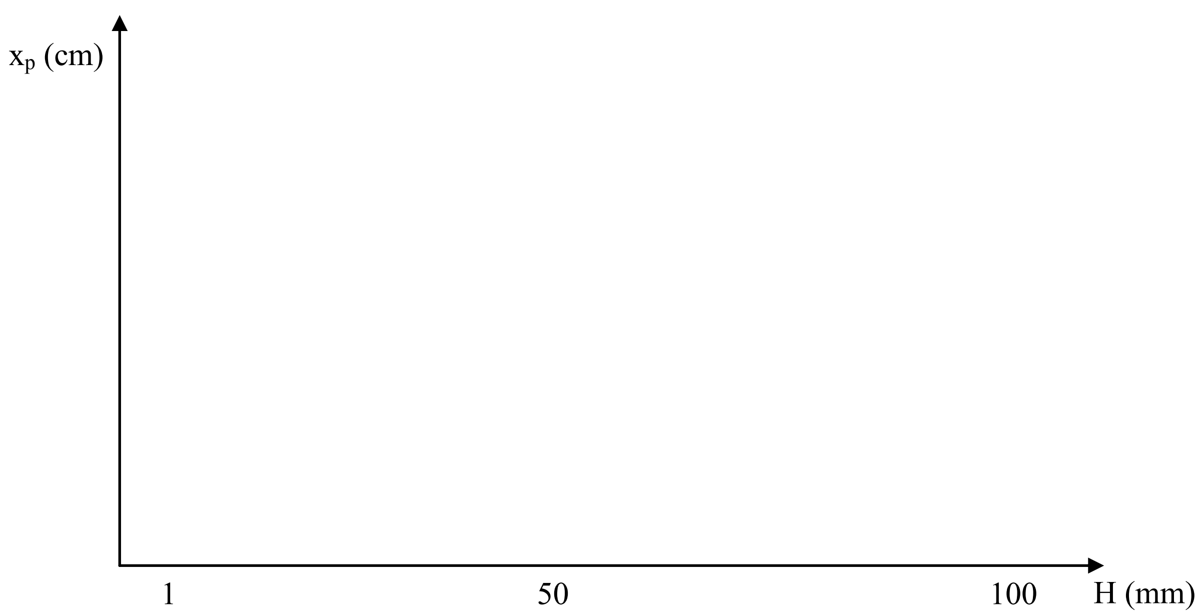
<u>Representative Values</u>

k=0.26 W/(mK), ρ=1200 kg/m^3, c_p=2.1 J/(gK),

T_{ig}=380 C,
T_∞=25 C,

Δh_c=20 kJ/g,
flame heat flux~25 kW/m^2,
$x_f = 0.01\dot{Q}'$,
h_{fg}=1.6 kJ/g (assume a heat of vaporization)

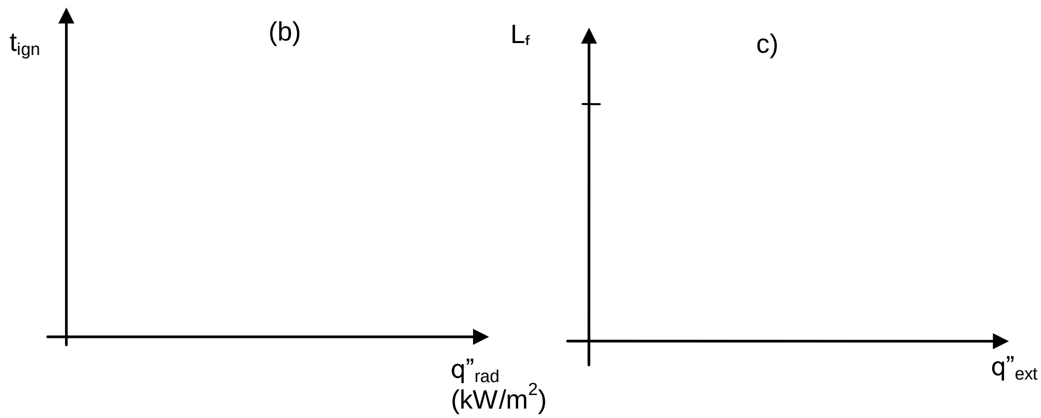
$x_p(0)$= 2cm
t_{cr}= 1 second as an example



3) This question relates to the ignition properties of a thick material. Nominal values c=1 kJ/(kgK), k=2 W/(mK), ρ = 1000 kg/m^3, T_{ign}=350 C, T_∞=20 C, h=15 W/(m^{2}K)

a) For a thick material, what are the mathematical expressions for the ignition time for both short time and long time approximations? (15 pts)

b) Sketch the ignition time t_{ign} for a thick material as a function of the incident heat flux for a less conductive and more conductive material. Label the curves. (15 pts)



c) The flame spread velocity can be written as a heating length divided by an ignition time (V_p=L_{heat}/t_{ign}). Typically the heating length is the difference between the flame length and the pyrolysis length. Assume that in addition to the flame heat flux q''_f there is an external heat flux incident on the surface q''_{ext}. Sketch how the flame length varies with an external heat flux for three values of the heat of gasification. Assume that $L_f = 0.01\dot{Q}''L_p$ where L_f is the flame length, L_p is the pyrolysis length, and $\dot{Q}''$ is the heat release rate per unit area. (20 pts)

4) A very well sealed V=10 m^3 volume compartment contains an open pan of ethanol (C_2H_5OH). There was only air in the compartment prior to the open fuel pan being placed in it. The pan initially contained 4 liter (4000 cm^3) of ethanol. A fan sits in the compartment. The average temperature over the period of time that the fuel evaporated was 25 C. The density of liquid ethanol is 790 kg/m^3. For questions (a) and (b) assume that the initial pressure is 1 atmosphere.

<u>For questions a-c assume that the fan is turned off</u>

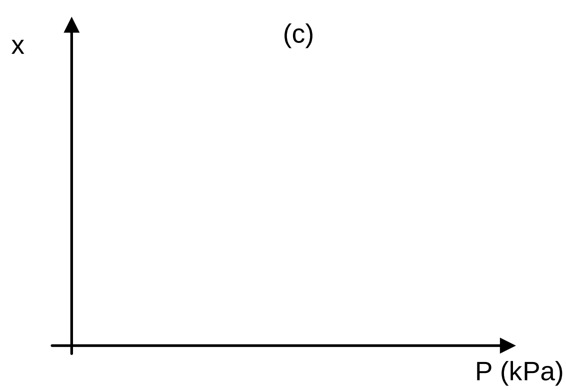
a) What is the equilibrium (after a long time) partial pressure of the ethanol vapor in the shed? (15 pts)

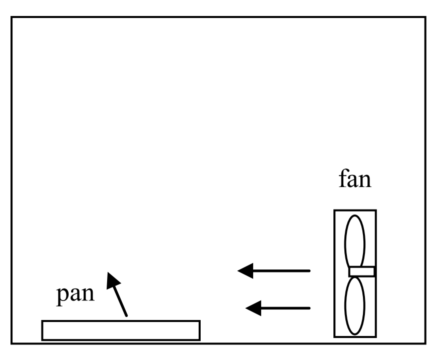
b) How much ethanol, either in volume or mass, remains in a liquid pool in the pan? (10 pts)

c) Sketch the equilibrium mole fraction of ethanol as a function of initial compartment pressure. Assume that the compartment temperature is held constant at 25 C for all compartment pressure cases. Show x_L on the graph. Assume that x_L has no pressure dependence. (15 pts)

<u>After an even longer time the fan turns on. The heat transfer coefficient between the gas mixture and the ethanol is 60 W/(m^{2}K)</u>

d) Calculate the partial pressure of vapor ethanol at the pool surface immediately after the fan has been activated. (10 pts)



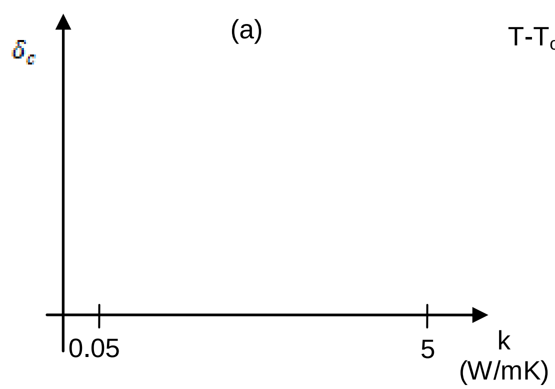


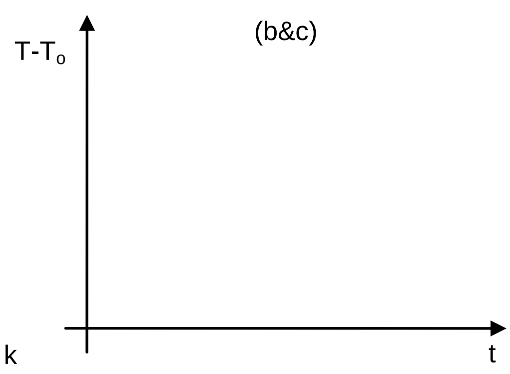
5) Answer the following questions about a material that is known to spontaneously ignite.

a) Large changes can be made in the effective thermal conductivity of the sample by addition of a filler material that does change the kinetic parameters. Assuming that the material is initially a very poor conductor, sketch on the graph below the change in the critical Damkohler number as the conductivity is increased. Assume that h=5 W/(m^2K) and a characteristic length L=10 cm. (5 pts)

b) Assume a sample of the material in a moderate conductivity case is initially at temperature T_o and is placed in an oven at T_h (with $T_h > T_o$). Sketch the variation of the surface temperature and centerline temperature as a function of time. Assume that for this case the Damkohler number is below the critical value. Label T_h on the graph. (10 pts)

c) For the same thermal conductivity case as you sketched in part (b), sketch the variation of the centerline temperature with time for an oven temperature that exceeds the critical Damkohler number. Label T_{h2} on the graph. (5 pts)





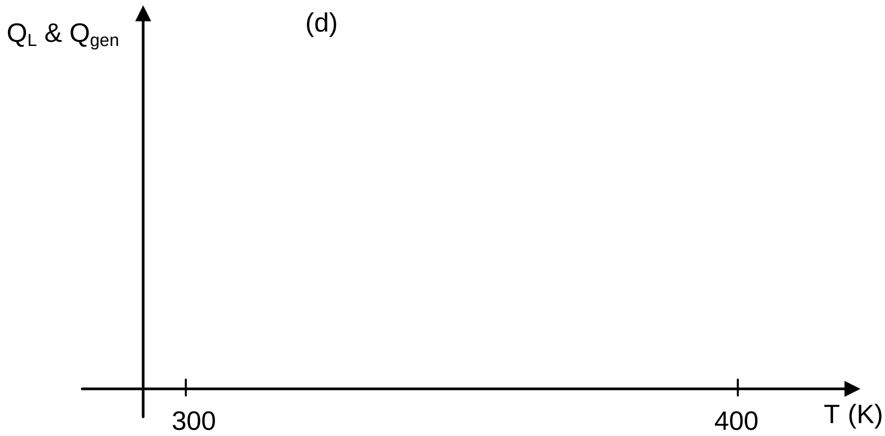
d) Consider a cube of material that can be modeled using a Semenov type ignition model but with non-Arrhenius kinetics. The material obeys the following ODE:

$$\rho c V \frac{dT}{dt} = -hS(T - T_\infty) + VA\Delta h \frac{(T-T_o)^2}{T_o^2}$$

$\rho = 300\ kg/m^3$, c=1 J/gK, V=1 m^3, h=10 W/(m^2K), S= 6 m^2, $A\Delta h = 30\ kW/m^3$, T_o=273 K

Sketch the heat generation versus material temperature and the heat loss versus material temperature for three values of T_∞ (300 K, 310 K, 320 K). (15 pts)

e) For the conditions provided in (d) what would happen to this material if placed in ovens at temperatures 295 C, 305 C, 315 C? Answer in words. (10 pts)


Q_L & Q_{gen}
(d)
300
400
T (K)