ME 410 Day 16

Topics

- Begin Review for Test - Practice Questions
- Calculations with Unburned Mixture

Calculations with Unburned Mixture (or Air for CI)

We are going to need to model the compression stroke. This means that the first law of thermodynamics is brought to bear on a system consisting of either air or mixture which is being compressed isentropically.

Isentropic = adiabatic + reversible.

Tools for the calculation

- Ideal Gas Law
- Polytropic process equation. (Here we need to assume a value of γ.)
- Thermodynamic property tables.
- Thermodynamic charts. See text p. 112-115.

EES makes this all much simpler and so we will use it.

Assumptions Made

1. Isentropic compression
2. Fuel is in vapor phase.
3. Mixture composition frozen.
4. Each species is an ideal gas.
5. Burned gas fraction is zero.

Entropy Accounting

$$s - s_0 = \int_{T_0}^{T} c_v \frac{dT}{T} + R \ln\left(\frac{v}{v_0}\right)$$

$$s - s_0 = \Psi(T) + R \ln\left(\frac{v}{v_0}\right)$$

$$s - s_0 = \int_{T_0}^{T} c_p \frac{dT}{T} - R \ln\left(\frac{p}{p_0}\right)$$

$$s - s_0 = \Phi(T) - R \ln\left(\frac{p}{p_0}\right)$$

Therefore, for unburned mixtures, compressed isentropically,

$$s_2 - s_1 = \Psi(T_2) - \Psi(T_1) + n_u R \ln\left(\frac{v_2}{v_1}\right) = 0$$

$$s_2 - s_1 = \Phi(T_2) - \Phi(T_1) - n_u R \ln\left(\frac{p_2}{p_1}\right) = 0$$

So

$$\Phi(T_2) - \Phi(T_1) = n_u R \ln\left(\frac{p_2}{p_1}\right)$$

$$\Psi(T_2) - \Psi(T_1) = -n_u R \ln\left(\frac{v_2}{v_1}\right)$$

The functions Φ and Ψ depend on the fuel and the fuel air equivalence ratio. They are plotted vs. temperature in the text. See Figure 4-4.

The sensible internal energy and sensible enthalpy are also useful. The word "sensible" refers to a change which involves temperature, but not chemical energy.

See Figure 4.4. This is useful when we are trying to get a handle on the compression stroke, which involves the unburned mixture.

Example Problem

(We will do this with both the charts and with EES. Sometimes I learn better if I use charts, actually.)

A SI engine has compression ratio of 9.5. We model the compression stroke as isentropic. Assume the ϕ = 1.0 mixture starts at 400 K (kind of hot!) and atmospheric pressure. Find the pressure, temperature and volume per kg air at the end of the stroke. You may assume that $n_u\tilde{R}$ = 0.292 kJ/(kg (air) K).

Use both EES and the charts.

Solution to the example:

The specific volume at 1 using the ideal gas law.

$$v_1 = \frac{n_u \tilde{R} T_1}{P_1} = \frac{(0.292\ \mathrm{kJ}/(\mathrm{kg\,air\,K}))(400\mathrm{K})}{101.3\mathrm{kPa}} = 1.153\,\frac{\mathrm{m}^3}{\mathrm{kg}}$$

Next focus on entropy.

$$\Psi(T_2) - \Psi(T_1) = -n_u R \ln\left(\frac{v_2}{v_1}\right)$$

$$\Psi(T_2) - 270 = -292 \ln\left(\frac{1}{9.5}\right)$$

$$\Psi(T_2) = 927.4$$

Now go to the chart and find that T_2 = 800 K (or thereabouts!?)

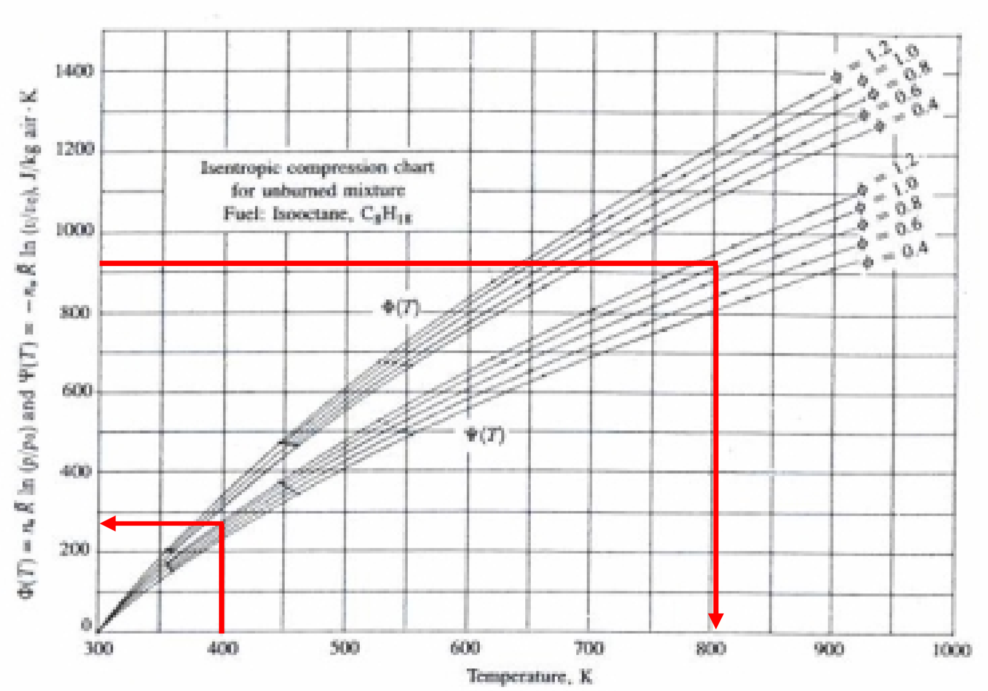

FIGURE 4-4
Isentropic compression functions, Φ and Ψ, as function of temperature for unburned isooctane-air mixtures. Units: J/kg air · K.

The specific volume is

$$v_2 = \frac{v_1}{r_c} = \frac{1.153\ kg/m^3}{9.5} = 0.1214\ kg/m^3$$

And the ideal gas law says that

$$P_2 = \left(\frac{T_2}{T_1}\right)\left(\frac{v_1}{v_2}\right)P_1 = \left(\frac{800}{400}\right)(9.5)(101.3\ kPa) = 1925\ kPa$$

Suppose that we also wanted to find the amount of work needed to compress the mixture. We could use the first law of thermodynamics, assuming of course that the process is adiabatic and reversible.

$$w_{12} = \Delta u = u_2 - u_1$$

Since there is no change in chemical composition, this change can be evaluated as a change in sensible internal energy, using the chart in the text. (FIGURE 4-3)

$u_1 = 80$ kJ/kg air

$u_2 = 470$ kJ/kg air

$w_{12} = 390$ kJ / kg air

For an equivalence ratio of 1.0 there is 1.0661 kg mixture per kg air.

Therefore we would find that the work done was about 365 kJ/kg of mixture.

Here's a copy of the FIGURE 4-3

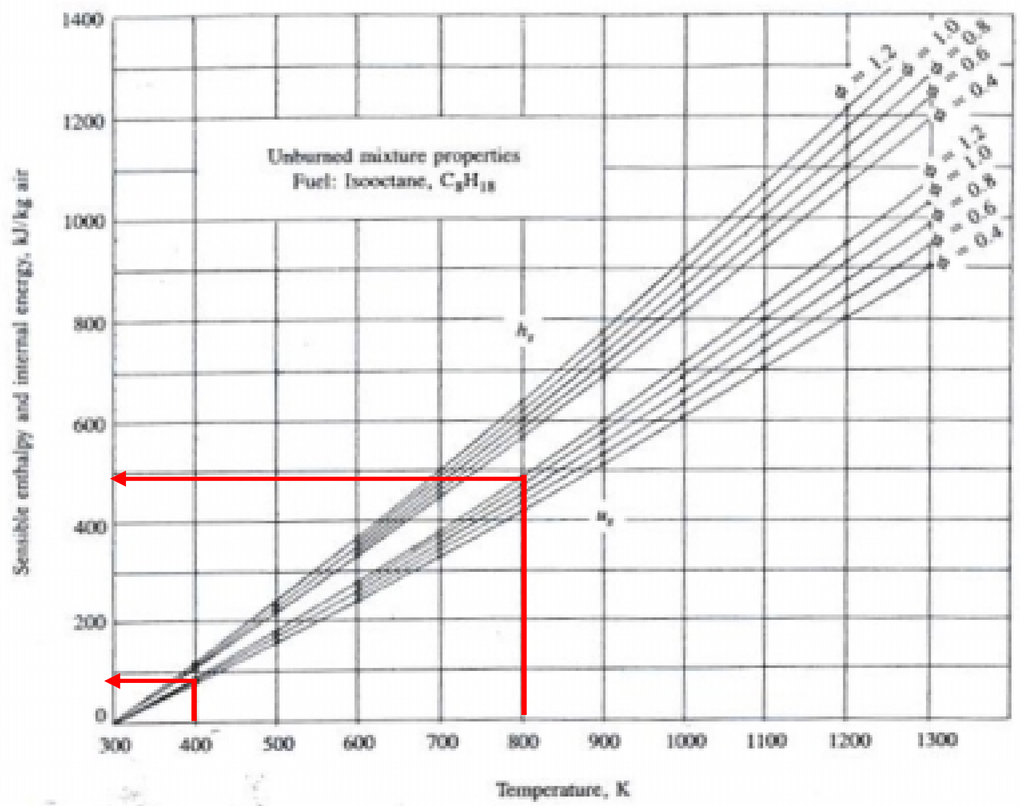

FIGURE 4-3.
Sensible enthalpy and internal energy of unburned isooctane-air mixtures as function of temperature. Units: kJ/kg air in mixture.

Next, let's see what can be done with EES. The EES solution to this problem is posted on the website.