

Fuel Air Cycles

- 1-2 Reversible adiabatic compression of a mixture of air, fuel vapor, and residual gas without change in chemical composition.
- 2-3 Complete combustion. (Constant volume, constant pressure or limited pressure). Adiabatic. Result is burned gas in chemical equilibrium.
- 3-4 Reversible adiabatic expansion of the burned gases which remain in chemical equilibrium. (In my models I take the gas at 4 to have a fixed chemical composition.)
- 4-5-6 Ideal adiabatic exhaust blowdown and displacement process with the burned gas in fixed composition.
- 6-7-1 Ideal intake process with adiabatic mixing between residual gas and incoming charge, both of which have fixed composition.

Thermodynamic Relations

1. Compression Stroke. Start with T_1 (may have to guess, it depends on residual fraction x_r) and P_1 ($=P_i$).

$$v_2 = \frac{v_1}{r_c} \quad s_2 = s_1$$

This will get T_2 . P_2 is found with the ideal gas law.
specific work done on system. $w_{12} = u_2 - u_1$.

We have already demonstrated an EES file which models the compression stroke. We need:

- mole fractions of all components: fuel, O_2 , N_2 , CO_2 , H_2O , CO , H_2 , etc.
- residual component depends on whether we have rich or lean mixture -- see Table 4.4
- Molecular weight of unburned mixture.

- Use standard formulas for combining the specific properties of the components to get the corresponding specific property of the charge.

2. Combustion.

For constant volume: $v_3 = v_2$. Also since adiabatic we must have

$$u_3 = u_2 = u_{s2} + \Delta u_{f,u}^{\circ}$$

in other words the sum of the sensible internal energy plus the internal energy of formation of fuel and other species.

For constant pressure: $p_3 = p_2$. Also, since it's adiabatic we must have

$$h_3 = h_2 = h_{s2} + \Delta h_{f,u}^{\circ}$$

in other words the sum of the sensible enthalpy plus the enthalpies of formation of fuel and other species.

For limited pressure: (Dual Cycle)

Please note that $P_3 = P_{3a} = P_{3b}$ is usually given. Also

$$v_{3a} = v_2$$

Again, adiabatic.

$$u_{3a} = u_2 = u_{s2} + \Delta u_{f,u}^{\circ}$$

$$h_{3b} = h_{3a} = u_{3a} + p_3 v_2 = u_{s2} + \Delta u_{f,u}^0 + p_3 v_2$$

We have to calculate these specific properties based on the state of the burned gas just at combustion. To do this we can call a chemical equilibrium program and the JANAF tables in EES.

We must use the ideal gas law relationship between pressure, temperature and specific volume.

3. Expansion Stroke

$$v_4 = v_1 \quad s_4 = s_{3b}$$

For the constant volume Otto cycle, $w_{34} = u_3 - u_4$ is the specific work done during the expansion

For the constant pressure cycle the specific expansion work is

$$w_{34} = u_3 - u_4 + p_2 (v_3 - v_2)$$

For the limited pressure cycle the expansion work is

$$w_{34} = u_{3b} - u_4 + p_3 (v_{3b} - v_{3a})$$

4. 4-5 Isentropic Blowdown. Here most of the gas exits. (AT BC)
That remaining in the cylinder will execute an isentropic expansion.

$$s_4 = s_5 \quad \text{where } P_5 = P_e$$

This is followed by a displacement of the gas with constant properties as the piston moves up to TC.

The residual fraction is $x_r = \frac{(v_4 / v_5)}{r_c}$

In all cases the gross work / cycle is

$$W_c = W_{34} - W_{12}$$

The fuel conversion efficiency is

$$\eta_f = \frac{W_c}{\frac{m_f}{m} Q_{LHV}}$$

where

$$\frac{m_f}{m} = \frac{(1 - x_r)}{1 + AF}$$

Imep may be calculated as

$$imep = \frac{W_c}{V_1}$$

Next, we turn our attention to software implementations:

1. Day26 EES file. You may download it. You will have to do some work to get it running successfully - it's sensitive to initial guesses. But we'll take a quick tour.
2. CSU applets.

Things that we can learn from this approach.

- Indicated efficiency increases with increasing compression ratio. It is basically independent of starting temp and pressure.
- Indicated efficiency goes up as ϕ decreases. (Lean Combustion)
- Imep is maximized slightly rich of stoichiometric
- All temperatures and pressures are maximized slightly rich of stoichiometric