Thermodynamics Scratch Sheet

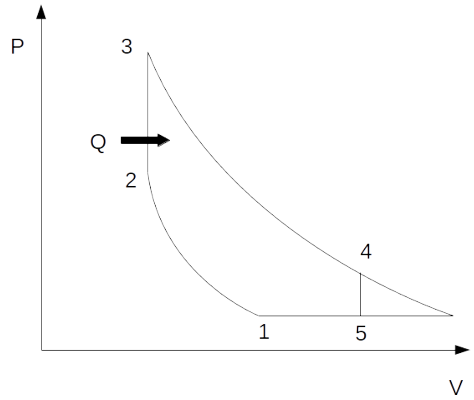

Figure 1: PV Diagram of Modern Atkinson Cycle

The engine has 6 cylinders and 3000 c.c. total swept volume. The fuel used will be standard octane gasoline. Intake is taken from the ambient atmosphere. A modern atkinson cycle is chosen in-lieu of the traditional Otto cycle for it's increased ideal efficiency and better mixing properties.
These parameters completely define our thermal cycle. Since the proportion of gasoline is small, and gasoline composed of nonpolar substances, an air standard model is used. The air is not assumed cold - the cold assumption results in far too significant of errors. NASA empirical air curves are used instead.

Initial Constraints

Our compression ratio is taken to be 10, a high compression ratio that prevents knocking.
a standard air to fuel mixture ratio of 14.7 is chosen.

$$C_R = \frac{V_1}{V_2} \tag{1}$$

$$M_R = \frac{m_A}{m_G} = 14.7 \tag{2}$$

The volumes are constrained by the total c.c. of the engine. Likewise, it is noted process 3-4 is isochoric.

$$\frac{3000 \text{ c.c.}}{6} = V_4 - V_2 \tag{3}$$

Finally, point 1 and point 2 are at ambient pressure p_{amb}, temperature T_{amb}, and density ρ_{amb}. Also calculations will use a reference STP density ρ_o and T_o.

Likewise the gas constant for air is used.

$$R_A = 287.1 \tag{4}$$
$$p_{amb} = 101325 \text{ Pa} \tag{5}$$
$$T_{amb} = 288.7 \text{ K} \tag{6}$$
$$\rho_{amb} = 1.225 \text{ kg m}^{-3} \tag{7}$$
$$T_o = 273.15 \text{ K} \tag{8}$$
$$\rho_0 = 1.2754 \text{ kg m}^{-3} \tag{9}$$

The lower value of the heat of combustion from the U.S. EIA.

$$H_G = 46.7 \text{ MJ kg}^{-1} \tag{10}$$

State 1

This is the start of the compression stroke right after the intake stroke. The air is at ambient conditions, noted in the previous section. Additionally the specific volume is calculated and the internal energy taken from an air table.

$$u_1 = 205.98 \text{ kJ kg}^{-1} \tag{11}$$
$$v_1 = 0.8163 \text{ m}^3 \text{ kg}^{-1} \tag{12}$$

State 2

The process from state 1 to state 2 is an isentropic process.

$$C_R = \frac{v_1}{v_2} \tag{13}$$
$$v_2 = \frac{v_1}{C_R} \tag{14}$$
$$v_2 = 0.08163 \text{ m}^3 \text{ kg}^{-1} \tag{15}$$
$$\rho_2 = 12.25 \text{ kg m}^{-3} \tag{16}$$

From the air tables:

$$T_2 = 705 \text{ K} \tag{17}$$
$$u_2 = 516.4 \text{ kJ kg}^{-1} \tag{18}$$

0.1 State 3

The process from state 2 to state 3 is an isochoric process with an input Q. The specific heat is given by the mass ratio.

$$m_t = m_G + m_A = m_G + M_R m_G \tag{19}$$
$$Q = m_G H_G \tag{20}$$
$$q = \frac{Q}{m_t} = \frac{H_G}{1 + M_R} \tag{21}$$
$$q = 2.975 \text{ MJ kg}^{-1} \tag{22}$$

W = 0, so our final internal energy is given by adding the heat and initial internal energy.

$$u_3 = q + u_2 \tag{23}$$
$$u_3 = 3490.9 \text{ kJ kg}^{-1} \tag{24}$$

At this point, the extremely high pressures and temperatures cause significant deviation from the Ideal Gas Model. Empirical curve fits are used here to better estimate the pressures. However, the internal energy and density of this state are known, since the process is isochoric.

$$\rho_4 = 12.25 \text{ kg m}^{-3} \tag{25}$$
$$\log \frac{\rho_3}{\rho_o} = 0.98249 \tag{26}$$
$$\log \frac{u_3}{RT_o} = 1.6486 \tag{27}$$
$$\gamma = 1.2881 \tag{28}$$
$$p_3 = 12.318 \text{ MPa} \tag{29}$$
$$\frac{s_3}{R_A} = 29.196 \tag{30}$$

0.2 State 4

This is the expansion stroke - modeled as an isentropic process. The pressure it expands to is chosen so enough power is produced.

$$\frac{s_4}{R_A} = 29.196 \tag{31}$$
$$p_4 = 1.75p_o = 177.32 \text{ kPa} \tag{32}$$

The empirical curves are used to get the density. After the density is found, ideal gas relations are used to find the temperature and internal energy.

$$\rho_4 = 0.4285 \text{ kg m}^{-3} \tag{33}$$
$$v_4 = 2.334 \text{ m}^3 \text{ kg}^{-1} \tag{34}$$
$$T_4 = 1441.5 \text{ K} \tag{35}$$
$$u_4 = 1151 \text{ kJ kg}^{-1} \tag{36}$$

0.3 Total Cycle Analysis

The isentropic processes have no heat transfer - $W = \Delta U$.
The isochoric processes have no work.
The isobaric process has a simple work relation - $W = P\Delta V$.
Our specific work is given below:

$$w_{cyc} = (u_3 - u_4) - (u_2 - u_1) - p_{amb}(v_4 - v_1) \tag{37}$$
$$w_{cyc} = 1875.8 \text{ kJ kg}^{-1} \tag{38}$$

The total mass can now be found:

$$\frac{3000 \text{ c.c.}}{6} = m_t(v_4 - v_2) \tag{39}$$
$$m_t = 222.2E - 6 \text{ kg} \tag{40}$$

Finally, one total cycle is completed per piston for every 2 rotations. The power is given by the mass, specific work, and rotational frequency. The power is evaluated at 8000 R.P.M.

$$P = 6 m_t w_{cyc} \frac{f}{2} \tag{41}$$

$$P = 166.7 \text{ kJ s}^{-1} \tag{42}$$

$$P = 223.4 \text{ hp} \tag{43}$$

$$\eta = \frac{w_{cyc}}{q} \tag{44}$$

$$\eta = 63.05\% \tag{45}$$