Gas Cycle Analysis-1

- Finite Heat Release Model: model the engine power cycle in which the heat addition process is characterized as a function of the crank angle
- Define heat release function as $Q(\theta)=Q_{in}x_b(\theta)$, where Q_{in} the total heat addition during one power cycle, and x_b is the cumulative heat release fraction.
- Use Weibe function as a popular model, such that

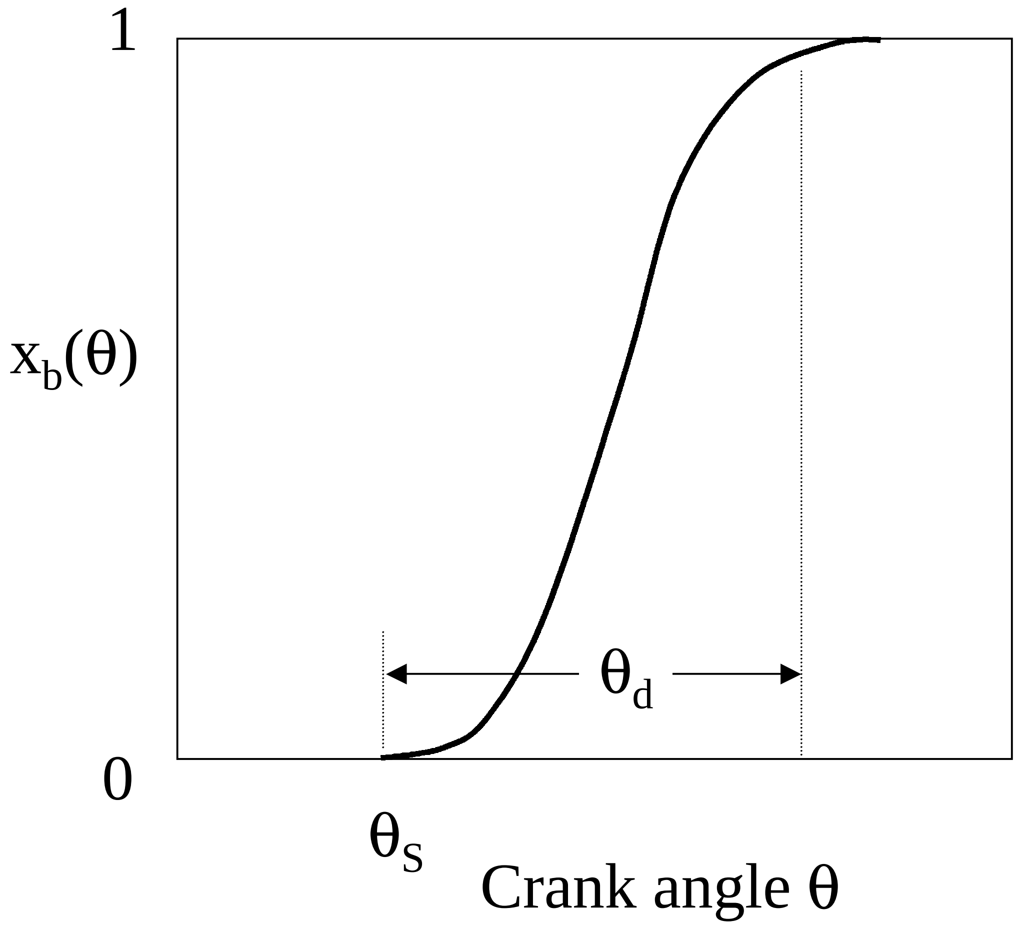
$$x_b(\theta) = 1 - \exp\left[-a\left(\frac{\theta - \theta_S}{\theta_d}\right)^n\right],$$

where θ=crank angle, θ_S is the start of heat release,

θ_d is duration of heat release,

n is Weibe form factor, and a is the Weibe efficiency factor.

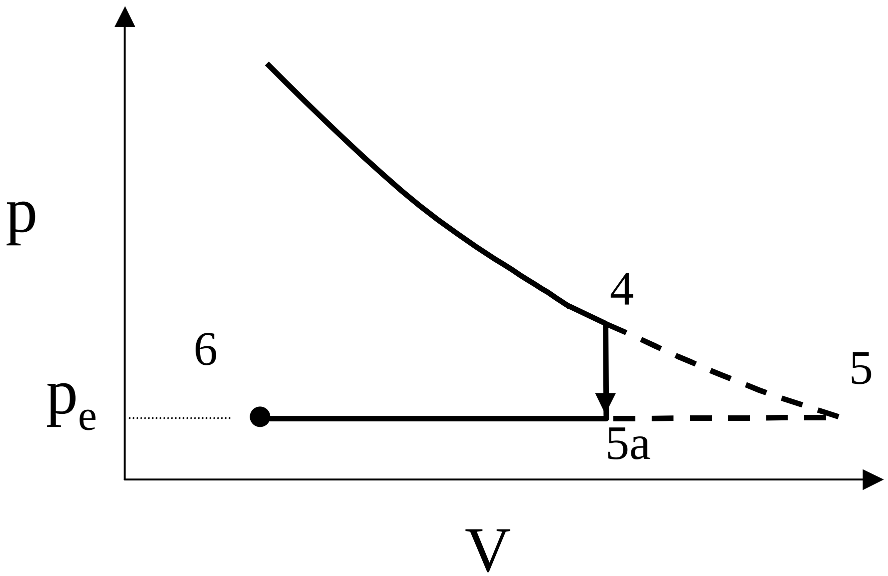
Finite Heat Release



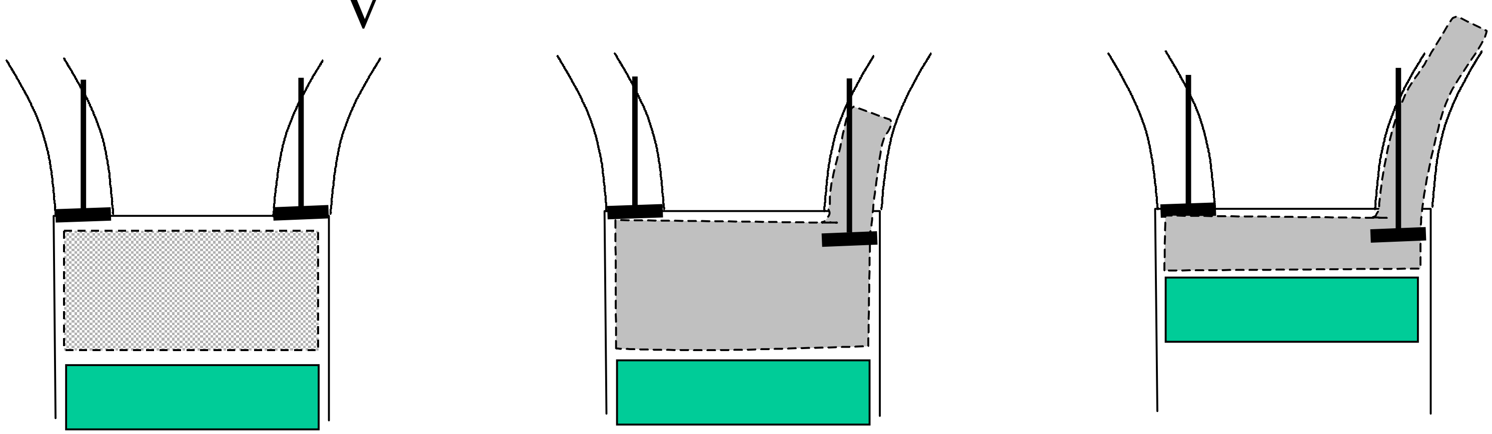
- Start of heat release: $\theta=\theta_S$, $x_b(\theta_S)=0$
- The end of combustion is defined as $x_b=0.993$ (rather arbitrary), corresponding to the value a=5
- n=3 is found to be reasonable choice also.

$$x_b(\theta) = 1 - \exp\left[-a\left(\frac{\theta-\theta_S}{\theta_d}\right)^n\right]$$

Intake and Exhaust Strokes



- Involves two steps: gas blowdown (pressure drops quickly from 4 to 5a) and gas displacement (process can be modeled as 4 to 5 to 6)



State 4

State 5a for pressure change inside cylinder; simulated the blowdown step as 4-5-5a as one tracks the moving control volume

State 6
From 5 to 6 the gas displacement phase

Exhaust Stroke

- The control mass during the blowdown phase is assumed to expand isentropically from 4 to 5 (consider the moving control volume)

$$T_5 = T_4 \left(\frac{P_5}{P_4} \right)^{\frac{\gamma - 1}{\gamma}}, \quad P_5 = P_e$$

- As the piston starts to move upward, it pushes the residual gases out. The process is represented by 5-5a-6. The energy balance from this process (assume adiabatic):

$\Delta U = \Delta W$, or $U_6 - U_5 = W_{5\text{-}6} = P_e(V_6 - V_5)$, $U_6 + P_e V_6 = U_5 + P_e V_5$ or $H_6 = H_5$

Consider $H = mc_P T$ and we have $T_e = T_6 = T_5$

Conclusion: temperature (and enthalpy) remains the same as residual gases flowing out of the exhaust valve during exhaust stroke. Work input by the cylinder is offset by the loss of internal energy due to expansion.

Residual gas fraction

• Define as the ratio of the residual mass in the cylinder at the end of the exhaust stroke to the total mass of the fuel-air mixture:

$$f = \frac{m_6}{m_1} = \frac{m_6}{m_4} = \frac{V_6 \rho_6}{V_4 \rho_4} = \frac{1}{r}\frac{\rho_6}{\rho_4} = \frac{1}{r}\frac{T_4}{T_e}\frac{p_e}{p_4} = \frac{1}{r}\left(\frac{p_e}{p_4}\right)^{\frac{1}{\gamma}}$$

• Typical residual gas fraction in spark-ignition engines range from 20% at light load to 7% at full load. It is smaller for Diesel engines because of the higher compression ratio (r). In some engines, a fraction of the engine exhaust is directed back to the intake to control No_x emission (diluting the fuel-air mixture hence lowering the combustion temperature). This process is called Exhaust Gas Recirculation (EGR) technique.