Knock Problem

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In spark-ignition engines, knock occurs when the unburned fuel-air mixture ahead of the flame reacts homogenously, i.e., it auto-ignites. The rate of pressure rise is the key parameter in determining knock intensity and propensity for mechanical damage to the piston-crank assembly.

Pressure vs. time traces for normal and knocking combustion in a spark-ignition engine are shown here:

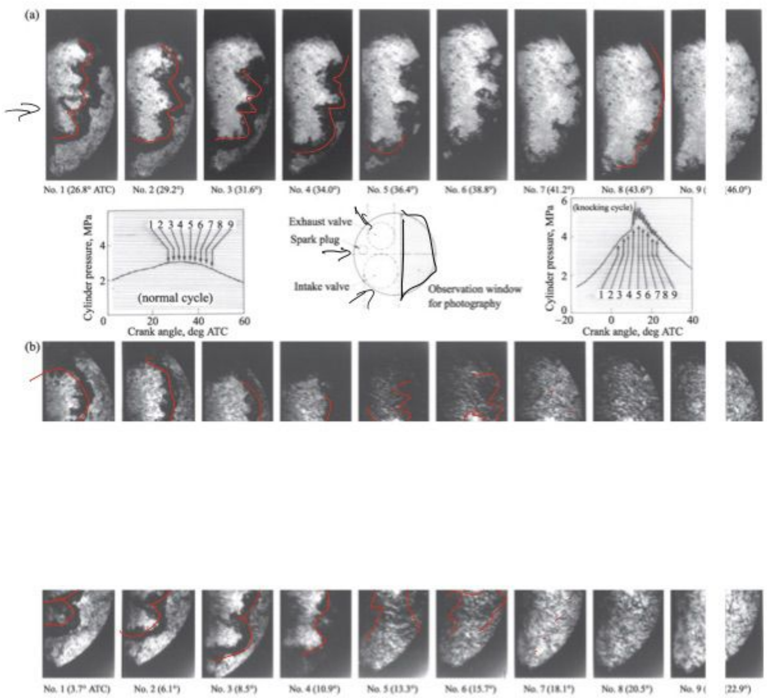

Figure 6.3 Schlieren photographs from high-speed movies of (a) normal combustion and (b) knocking combustion. Pressure–time traces corresponding to the photographs are also shown.
| SOURCE: From Refs. [2] and [17]. Reprinted by permission of McGraw-Hill, Inc.

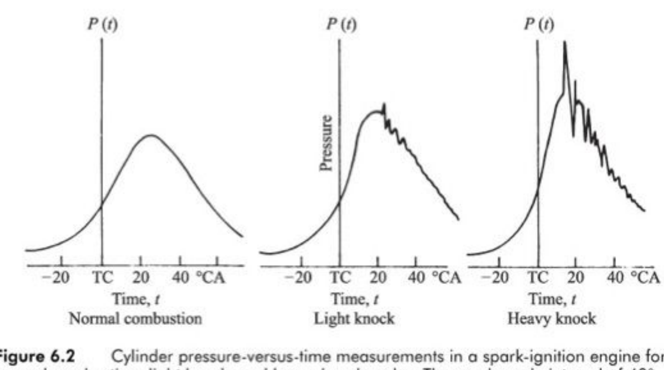

Figure 6.2 Cylinder pressure-versus-time measurements in a spark-ignition engine for normal combustion, light knock, and heavy knock cycles. The crank angle interval of 40° corresponds to 1.67 ms.
| SOURCE: Adapted from Refs. [1] and [17] by permission of McGraw-Hill, Inc.

This photo of a badly damaged piston indicates the effects of long-term engine knock.

Question 1: Which reactor model is most appropriate to simulate the knock event of a SI engine and why?

Question 2: What is the temperature, fuel concentration, and product concentration histories as a function of time. What is dP/dt as a function of time?

Assumptions:

- Initial conditions correspond to the compression of a fuel-air mixture from 300 K and 1 atm to top-dead-center for a compression ratio of 10:1.
- The initial volume before compression is 3.68×10^{-4} m^3 which corresponds to an engine with both a bore and a stroke of 7.5 mm.
- Ethane (C_2H_6) is the fuel.
- One step global kinetics:
  $d[F]/dt = -6.19 \times 10^9 \exp(-15098/T)[F]^{0.1}[Ox]^{1.65}$ in kmol/m³-s
- Fuel, air, and products have equal Molecular Weights
  $MW_F = MW_{Ox} = MW_{Pr} = 29$
- Fuel, air, and products have equal heat capacities
  $c_{p,F} = c_{p,Ox} = c_{p,Pr} = 1200$ J/kg-K
- Enthalpy of formation of air and products is 0, $h_{f,F} = 4 \times 10^7$ J/kg
- Assume stoichiometric A/F ratio is 16 and restrict combustion to stoichiometric or lean combustion

$$\frac{d[x_i]}{dt} = \dot{\omega}_i MW_i$$

$$\frac{d[F]}{} = -6.19 \times 10^9 \exp\left(\frac{-15098}{T}\right)[F]^{0.1}[O_2]^{1.65}$$

$$\frac{d}{dt} = \cdot 6.11 \times 10 \exp(\quad T \quad)$$

$$(A/F)_s = \frac{MW_{ox}[Ox]\cancel{V}}{MW_F[F]\cancel{V}} \rightarrow [Ox] = (A/F)[F]$$

$$\frac{d[Ox]}{dt} = 16\frac{d[F]}{dt}$$

$$\frac{d[Ox]}{dt} = 16\frac{d[F]}{dt}$$

$$\rightarrow Air + F = [Pr]V\,MW_{pr} = P_r$$

$$F = [F]V\,MW_F$$

$$\frac{(A+F)}{F} = \frac{[Pr]\cancel{V}\cancel{MW_{pr}}}{[F]\cancel{V}\cancel{MW_F}} \rightarrow [Pr] = [F]\left(\frac{A}{F}+1\right)$$

$$\frac{d[Pr]}{dt} = -\frac{d[F]}{dt}(16+1)$$

$$\frac{d[F]}{dt}, \quad \frac{d[Ox]}{dt}, \quad \frac{d[Pr]}{dt}$$

Const v:

$$\frac{dT}{dt} = \frac{\cancel{(\dot{Q}/V)} + R_u T\cancel{\sum_i \dot{\omega}_i} - \sum_i(\bar{h}_i\dot{\omega}_i)}{\sum_i\left([X_i](\bar{c}_{p_i} - R_u)\right)}$$

$$\sum_i \frac{d[X_i]}{dt} = {}^{(1)}\frac{d[F]}{dt} + \frac{d[Ox]}{dt} + \frac{d[Pr]}{dt}$$

$$16\frac{d[F]}{dt} - 17\frac{d[F]}{dt}$$

$$\sum_i \bar{h}_i\dot{\omega}_i$$

$$\underline{h_{f,T} = T_{sys}} \qquad \bar{h}_i = h_{f,T_{ref}} + c_p(T - T_{ref})$$

$$\sum_i \bar{h}_i\dot{\omega}_i = \underline{\bar{h}_F\dot{\omega}_F} + \cancel{\bar{h}_{ox}\dot{\omega}_{ox}} + \cancel{\bar{h}_{pr}\dot{\omega}_{pr}}$$

$$= \bar{h}_F\frac{d[F]}{dt}$$

$$-\sum_i\left([X_i](\bar{c}_{p_i} - R_u)\right) = (\bar{c}_p - R_u)\sum_i [X_i] = (\bar{c}_p - R_u)\sum_i \frac{x_i P}{R_u T}$$

$$= (\bar{c}_p - R_u)\frac{P}{R_u T}$$

$$\frac{dT}{dt} = \frac{-\frac{d[F]}{dt}\frac{1}{MW_F}\bar{h}_{f,F}}{(\bar{c}_p - R_u)\, P/RT}$$

$$P = \left[\frac{N}{V}\right] R_u T = R_u T \left([F] + [Ox] + [Pr]\right)$$

$$\frac{P}{T} = \underbrace{R_u \left([F] + [Ox] + [Pr]\right)}_{\text{Const.}} = \frac{P_0}{T_0}$$

$$P = \frac{P_0}{T_0} T \rightarrow \frac{dP}{dt} = \frac{P_0}{T_0}\frac{dT}{dt}$$

get T_0, P_0

BDC $\rightarrow$ 300 K

1 atm

V_{BDC}

$$T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{\gamma - 1} \qquad \gamma = c_p / c_v$$

$$T_0 = 300 \left(\frac{10}{1}\right)^{1.4-1} = 753\ \text{K}$$

$$P_2 = P_1 \left(\frac{V_1}{V_2}\right)^{\gamma - 1}$$

$$P_0 = P_{BDC} \left(\frac{10}{1}\right)^{\gamma - 1} = 25.12\ \text{atm}$$