Ignition

1 Overview

Ignition in the context of combustion refers to the process that initiates the reaction between fuel and oxidizer, thus starting the combustion. Ignition provides the energy needed to overcome the activation energy barrier for the combustion reaction to proceed.

2 Spark Ignition

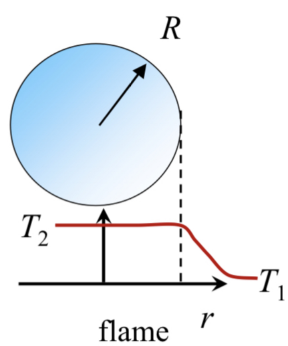

Figure 1: Spark Ignition

Assume that spark produces a spherical volume (**ignition kernel**) in the premixed gas. Here, T_1 is the initial temperature, T_2 is the temperature after spark. The spherical region will only continue to self-propagate if **energy release** $>$ **losses**. Therefore:

$$\dot{q}'''_{chem} V > \dot{q}''_{cond} A_{surf} \tag{1}$$

$$\dot{q}'''_{chem} \frac{4\pi R^3}{3} > \dot{q}''_{cond} 4\pi R^2 \tag{2}$$

We define the **critical radius** as:

$$R_{crit} = \frac{3\dot{q}''_{cond}}{\dot{q}'''_{chem}} \tag{3}$$

Similar with quench distance calculation:

$$\dot{q}'''_{chem} = \dot{m}'''_f \Delta h_R = \frac{S_L^2}{2\alpha}(T_2 - T_1)\rho_1 c_p \tag{4}$$

$$\dot{q}''_{cond} \approx k\frac{T_2 - T_1}{R_{crit}} \tag{5}$$

Therefore:

$$R_{crit} \approx \sqrt{6}\delta_f \tag{6}$$

Now, we can calculate the **minimum ignition energy:**

$$\begin{aligned} E_{min} &= \rho V c_p(T_2 - T_1) \\ &= \frac{4}{3}\pi R_{crit}^3 \rho_2 c_p (T_2 - T_1) \\ &= \frac{4}{3}\pi(\frac{\sqrt{6}\alpha}{S_L})^3(\frac{p}{RT_2})c_p(T_2 - T_1) \\ &\approx 61.6p\frac{c_p}{R}\delta_f^3\frac{T_2 - T_1}{T_2} \end{aligned} \tag{7}$$

For STP Methane-Air:

$$\frac{c_p}{R} \approx 2.5 - 5, \frac{T_2 - T_1}{T_2} \approx 0.5 - 1 \tag{8}$$

$$\begin{aligned} E_{min} &\approx 180p\delta_f^3 \\ &= 180(10^5 Pa)(10^{-3}m)^3 \\ &= 18mJ \end{aligned} \tag{9}$$

For the pressure dependence:

$$R_{crit} \propto \delta_f \propto p^{-n/2} \tag{10}$$

$$E_{min} \propto p\delta_f^3 \propto p^{(2-3n)/2} \tag{11}$$

For hydrocarbons, $n = 1 - 2$:

$$E_{min} \propto \frac{1}{p^{1/2}} - \frac{1}{p^2} \tag{12}$$

Therefore, the minimum ignition energy drops at high pressure.

3 Auto Ignition

Autoignition (or thermal ignition), refers to the spontaneous ignition of a fuel-air mixture without the need for an external ignition source like a spark or a pilot flame. This occurs when the mixture reaches a certain temperature, known as the autoignition temperature.

Here are some important points. Assume we put hydrogen and oxygen inside a container, at first at relatively low temperature. **At this time, there are still reaction going, even though this is ignorable.** There are also creations of radicals, but the production is so low, much lower than the termination, so the burning could not start.

When we heat the container, the temperature will pass a certain magic value (this will be dependent on the geometry, environment and all sorts of things), then at this temperature, after a very long time, it will be ignited (enough radicals).

If we keep heating the container, then it will reach a temperature so that the mixture will start to burn in a very short time. This temperature is finally what we called **autoignition temperature**. This is not an exact value, but a ambiguous terminology.

Common autoignition temperature:

1. H2/O2: 833K
2. H2/Air: 845K
3. CH4/Air: 810K
4. C2H2/Air: 578K