What is ignition?

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Author(s):	Maximilian Lackner and Franz Winter
Source(s):	See CF
Sub-editor:	Neil Fricker
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1. Introduction

Ignition is the process of starting **radical** reactions until a self-sustaining flame has developed. One can distinguish between auto ignition, **induced ignition** and photo-ignition, the latter being caused by photolytic generation of radicals. For qualitative description, two models have been developed: Homogeneous ignition (Semenov) and inhomogeneous ignition (Frank-Kamenetskii). Laser induced ignition is discussed in CF268, while characteristics of laser ignition are presented in CF269.

1.1 Auto ignition

The question within which ranges of temperature, pressure and composition a mixture can ignite is of utmost importance e.g. for safety reasons. At certain values of temperature and pressure a mixture will ignite spontaneously and at other conditions only a slow reaction is observed (depicted in so-called explosion diagrams, see Figure 1).

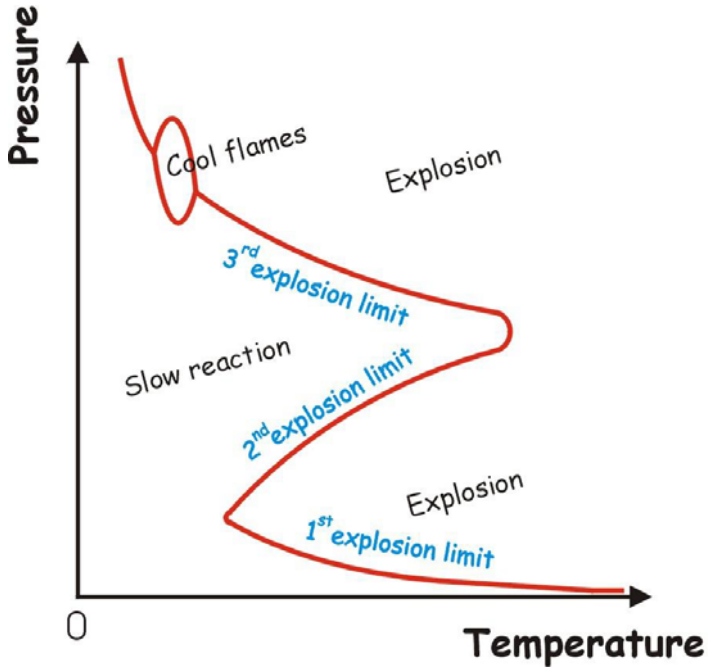

Figure 1: Schematic explosion diagram (modified from [1]).

When an ignitable hydrocarbon/air mixture is supplied with sufficient energy, it still will not ignite until an induction time (ignition delay time) has passed. This ignition delay time can be as long as several hours or as short as microseconds and is characteristic for radical-chain explosions. During this time span, the radical population (see below) increases exponentially. These chemical reactions (radical formation) do consume fuel but the temperature remains nearly constant. As soon as the radical pool has grown enough to consume a significant fraction of the fuel, ignition occurs and the temperature starts to rise. In contrast, in a purely thermal ignition process there is no induction time, and the temperature increases immediately.

Combustion processes involve radical chain reactions. Chain initiation steps start the reaction. In chain propagation reactions, the number of radicals does not change. It is the chain branching reactions that lead to an exponential increase in the radical pool. Chain termination can occur in a homogeneous or inhomogeneous manner.

Table 1 lists examples of these types of chain reactions.

H_2	+	O_2	= 2 $OH^{\cdot}$			(a)	chain initiation
$OH^{\cdot}$	+	H_2	= H_2O	+	$H^{\cdot}$	(b)	chain propagation
$H^{\cdot}$	+	O_2	= $OH^{\cdot}$	+	$O^{\cdot}$	(c)	chain branching
$O^{\cdot}$	+	H_2	= $OH^{\cdot}$	+	$H^{\cdot}$	(d)	chain branching
$\frac{1}{2}$ ($H^{\cdot}$ + $H^{\cdot}$)			= $\frac{1}{2}$ H_2			(e)	chain termination (heterogeneous)
$H^{\cdot}$ + O_2 + M			= HO_2	+	M	(f)	chain termination (homogeneous)

Table 1: Important reactions in the H_2/O_2 system.

1.2 Induced ignition

A process where a mixture, which would not ignite by itself, is ignited locally by an ignition source (i.e. electric spark plug, pulsed laser, microwave ignition source) [2] is called induced ignition. In induced ignition, energy is deposited, leading to a temperature rise in a small volume of the mixture, where auto ignition takes place or the energy is used for the generation of radicals. In both cases a subsequent flame propagation occurs and sets the mixture on fire.

1.3 Alternative ignition systems

In technical appliances like **automatic burners** and **internal combustion engines**, the electric **spark plug** has been in use for more than a century.

For the ignition of especially fuel lean mixtures, alternatives to conventional electric spark ignition systems have been devised: high-energy spark plugs, **plasma** jet ignitors, rail plug ignitors, torch jet igniters, pulsed-jet igniters, **exhaust gas recirculation (EGR)** ignition systems, laser-induced spark ignition and flame jet igniters. More information on laser-induced ignition (laser ignition) is available in a linked combustion File CF268.

Glossary

Automatic burner – A burner that can operate without manual intervention including start up and shut down processes.

exhaust gas recirculation (EGR) - Process of redirecting a portion of the burnt gas (exhaust gas) back into the flame with the effect of reduced emissions and fuel consumption.

Ignition - The process of starting radical reactions until a self-sustaining flame has developed.

induced ignition - A process where a mixture, which would not ignite by itself, is ignited locally by an ignition source

internal combustion engine - Is used to convert the chemical energy contained in a fuel into mechanical or electrical energy. In contrast to external combustion engines like steam engines, internal combustion engines burn the fuel inside the engine.

Plasma - A plasma is electrically neutral, ionized matter at high temperatures, e.g. in an electric discharge (spark plug). A plasma is characterized by free ions and electrons. It is sometimes regarded as the fourth state of matter.

Radical - Unstable excited molecules, intermediate in combustion chain reactions, before stable products are obtained

spark plug - Ignition device commonly found in internal combustion engines. A spark plug is essentially formed by two insulated electrodes with a gap between them. For ignition, a high voltage (typically 10-25 kV) is applied to the device so that a spark is produced between the electrodes.

Keywords

Ignition, laser, infrared, plasma, radical, breakdown, ignite, light, spark plug, EGR

Related Combustion Files

268 – What is laser induced ignition?

269 – What are the characteristics of laser ignition?

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Sources

[1] Warnatz, J.; Mass, U.; Dibble, R. W.; Combustion, Springer, Third edition (1996).

[2] Lewis B.; Von Elbe G.; Combustion, Flames and Explosions of Gases, Academic Press Inc., Third edition (1987).

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