ERCOFTAC course on "Flame stabilization for industrial burners"
26-27 September 2011

Course Contents

The course consists of 10 lectures leading from general principles and historical perspective, via modern developments in experimental diagnostics and theoretical modeling to advanced applications.

Lecture 1 (Roekaerts): General principles of burner design

The first lecture introduces fundamental concepts and terminology necessary to tackle the field. In this way also participants that are relatively new in the field of combustion will be able to follow the course. Examples of topics discussed are: premixed versus non-premixed combustion, equivalence ratio, mixture fraction, progress variable, ignition, extinction, blow-off, length and time scales of laminar and turbulent flows and flames. Reynolds, Damkohler and Karlovitz number, low Mach number approximation. The lectures also introduce some basic burner configurations and reasons to prefer one above the other depending on the application, the required throughput, and emission requirements. The meaning and use of scaling rules is explained.

Lectures 2 and 3 (Dreizler): Experimental techniques I and II

Experimental methodologies enabling an improved understanding of practical combustion including industrial burners will be explained. The intended content is:
1) Introduction to the importance of experimental combustion research: Knowledge is first built up in studies on generic configurations and then exploited in studies of systems of increasing complexity up to near-practical devices. The requirements for optical diagnostics will be explained. The importance of precise characterization of inflow and boundary conditions will be demonstrated and results for benchmark configurations will be presented.
2) Laser diagnostic methods:
- *flow field diagnostics (velocity)*
- *scalar field diagnostics (composition and temperature)*
- *combined multi-parameter diagnostics*

3) Application examples (lecture 3)

Lecture 4 (Mastorakos): Scaling rules for different burner designs *I*

The lecture will start with a review of historically important concepts and results on afterburner stabilization by recirculation zones (e.g. Longwell, Spalding, Marble & Zukoski theories). These theories will be looked at in detail and it will be shown that they are all essentially based on a Damkohler number criterion. A selection of various examples (bluff-body, swirl etc) from the more modern literature will be explained, showing qualitatively, how stabilization is achieved, what "lift-off" means, typical flame shapes etc. This will be illustrated with some very recent experimental results.

Lecture 5 (Roekaerts): Scaling rules for different burner designs II

Insight in NOx formation mechanisms have led to improvements in 'flame design' coupled to burner design and furnace design. To avoid thermal NOx formation high temperatures have to be avoided. Traditionally, in furnace applications this has been achieved by application of air staging. In modern combustion technologies this has been refined to combustion in diluted conditions, known as 'flameless combustion', MILD combustion or High Temperature

Air Combustion. In this lecture the basic principles and design rules for burners and furnaces exploiting this new technology will be explained. In particular this concerns the characteristics of ignition of a fuel burning in air diluted with combustion products. The links with developments in IC engine combustion (HCCI) will be explained.

Lecture 6 (Mastorakos):

Relation between flow-chemistry interaction and extinction and ignition

In this lecture first the fundamentals of extinction of a laminar flame will be discussed in detail. The difference between quenching/extinction and "lack of stabilization" will be explained. Next extinction of turbulent flames will be considered and we finish with comments on what should a turbulent combustion model have to include in order to capture blow-off, providing a link with lectures 7-10.

A short overview of special stabilization mechanisms such as plasma-assisted, using discharges, will also be included.

Lecture 7 (Vervisch): Turbulent combustion modeling

The challenges and basis of turbulent combustion modeling will be discussed. The impact of turbulent fluctuations on burning rate, mass fluxes and interlinks with flame stabilization in burners will be addressed. Then, the fundamentals of modeling tools will be listed along with their relation with flame dynamics observed in burners.

Lecture 8 (Vervisch): Simulating turbulent flames and burners

Turbulent combustion modeling found in most combustion CFD codes will be presented and an attempt will be made to classify them according to their prediction capabilities for flame stabilization in the context of burners. A link will be made with lecture 6, to highlight modeling techniques potentially having ingredients for capturing ignition, extinction and blow-off. Emerging techniques will also be discussed.

Lectures 9 and 10 (Gicquel): Modern developments: LES on real configurations

The last two lectures concern model simulations of a series of 'real' applications, with a focus on capability of Large Eddy Simulation to study instabilities. To understand the origin and nature of the many potential large scale instabilities that can occur in flame-flow interaction it is necessary to first introduce notions from acoustics: role of entropy, presence of waves, importance of boundary conditions. Then stability criteria can be identified. It will be explained that LES is an effective tool to study unsteady large scale interaction of flames with the flow. Also other types of modeling needed for the design of real industrial aeronautical burners will be explained.