ADVANCED MEASUREMENTS IN INDUSTRIAL COMBUSTION SYSTEMS

David Honoré

CORIA – UMR 6614 CNRS
INSA de Rouen
Technopôle du Madrillet, 76801 Saint Etienne du Rouvray, France

1 Introduction

Large scale combustion systems are encountered in many industrial sectors such as material processes in melting glass furnaces, refineries, cement industry, metallurgy,…, as well as for hot water or steam production in boilers. Industrial combustion facilities consist mainly of a combustion chamber and one or more burners used for fuel (natural gas, fuel oil, biogas, …) and comburent air (or oxygen) injections, generating non initially premixed turbulent flames. The goal of the system is obviously to transfer the heat released by the flame to the load. For more than one century, developments of industrial combustion systems were focused on first the optimisation of this energy transfer and the thermal balance, and more recently on minimisation of flue gas emissions of pollutants (CO, SOx, NOx, VOC,…) as well as greenhouse effect gases (HC, CO_2).

For a long time, these developments have been based on a "try-and-cut" methodology thanks to experimental tests. The latter are performed in semi-industrial facilities, which can be defined as an experimental combustion chamber which first reproduces the main characteristics of real industrial systems, such as the large scale, the flame confinement, the presence of the load,…and second, enables independent control of operating conditions and inlets, outlets and in-flame measurements. Few experimental studies exist for the fine determination of flame characteristics in such semi-industrial facilities. And yet, it allows to point out the main physical phenomena leading flame behaviour in a configuration closest to the real application. Notably, it permits to study different scaling effects on the aero-thermo-chemical characteristics of the flame.

This lecture focuses on the interest of advanced measurements for the determination of flame characteristics at industrial scale. In the following, we present measurements techniques used at semi-industrial scale, and detail their specific adaptation needed for this purpose. Their benefits for the comprehension of industrial turbulent flames are shown through some examples. First measurements in semi-industrial facilities have been made thanks to intrusive probes allowing local measurements in the core of the flame. Temperature can be measured by suction thermometer or fine wire thermocouples, and mean concentrations of stable species by probe sampling. Later, Laser Doppler Velocimetry has been applied for the measurements of velocity. Recent developments of imaging diagnostics in research laboratories have enable their application in semi-industrial facilities. We present some illustrations of radical chemiluminescence imaging, Laser Induced Fluorescence and Particle Image Velocimetry, enabling the determination of flame structures and velocity fields of industrial turbulent flames.

2 Local measurements in semi-industrial facility

First experiments in turbulent flames of semi-industrial facilities have been made in late 60's thanks to intrusive probes allowing local measurements of main combustion parameters: temperature, concentrations and velocity. Complete characterisation of the flow in the combustion chamber requires repetition of local measurements at different positions. This is usually done by radial crossings of the probes at successive longitudinal locations in the combustion chamber, following a grid, of which dimensions have to be adapted to the expected gradients.

In practical, care has to be taken when immersing a probe in a flame. Indeed, intrusion of the probe can affect the local characteristics of the turbulent flow. For example, it could induce a wake effect as a Bluff-Body, and then provoke stabilisation of the flame at a position where the flame would not be present without the probe!

2.1 Temperature measurements in semi-industrial turbulent flames

Even if they are used in laboratory flames [1], thermometric techniques based on laser diagnostics (e.g. CARS, Raman or Rayleigh scattering) are still too complex to be implemented and used in a semi-industrial facility. On the other hand, thermocouple has been adapted to semi-industrial facility, as it is one of the easiest technique to measure temperature.

In reactive flow, DC voltage delivered by thermocouple is related to the temperature of the hot junction, not the "real" surrounding gas temperature. Measured temperature corresponds to the steady state of energy balance between the thermocouple and its surroundings by radiation, convection, conduction and catalytic effects [2, 3]. This means that the probe is at a lower temperature than the gas. Then determination of local flame temperature requires to take into account these corrections. This has been done in semi-industrial turbulent flames with two main configurations.

2.1.1 The suction pyrometer

The first configuration developed to minimize these sources of errors has been to set the thermocouple in a sheath to minimize the radiation loss. The whole setup is called suction pyrometer (Figure 1). Sampling gas is drawn in the radiation shield at high velocity (from 40 to 250 m/s) in order to consider convection as the main form of energy exchange from the flame to the thermocouple [3]. In practical, flow in the probe is ensured by a suction effect thanks to an ejector [4]. Outer form of the pyrometer depends on the characteristics of the flame, notably the eventual presence of dusts and soot to avoid blockage of the probe.