Multiple V-flame burner: investigation on flame interaction

Aldo Coghe*, Giulio Solero*, Gianni Brunello+
*Dipartimento di Energetica - Politecnico di Milano, Italy
+CNR – Tempe, Milano, Italy

Introduction

Lean premixed combustion is today one of the more promising techniques aiming to reduce environmental impact of combustion processes [1].

In the field of small burners (that is, domestic heating applications) the use of lean premixed methane-air V-flames (inverted Bunsen cone flames) seems highly advantageous, with respect to traditional ones, in order to reduce thermal NOx emissions. Behaviour of a single V-flame generated by means of a stabilization rod downstream the efflux of the combustible mixture has been already investigated in literature, under the point of view of stability limits [2] and fluid dynamic features [3]. It has been reported that flame morphology strictly depends upon operating conditions of the burner (excess air, efflux velocity of the mixture) and can range from conventional Bunsen one (for rich or stoichiometric mixtures) to V morphology (for lean flames) till blow-off limit.

This paper deals with the experimental characterization of multiple adjacent V-flames in a burner prototype, with the possibility of feeding a controlled air stream (separated from the air in the combustible mixture) parallel to the main mixture flow, in inter-flame position. Secondary air feeding (present also in conventional burners with Bunsen flames) seems to produce deep effects upon the combustion process, for instance enlarging the operating field of the burner. In fact, it promotes the transition from an undesired unstable regime to a fully stable one with V-flames, maintaining constant flow rate and composition of the combustible mixture, but lowering flame temperature and reducing pollutants emissions (especially Thermal NOx, for local mixture dilution). Therefore, influence of the secondary air stream upon the combustion process has been investigated by temperature and fluid dynamic measurements, by means of thermocouples and LDA (laser Doppler Anemometry) respectively.

Experimental set-up

A schematic view of the investigated burner is shown in Fig. 1 (more details about the mixture feeding system have already been reported in [3]). As it can be seen, the burner head is constituted by a perforated plate (n° holes=2980, φ_hole=0.8 mm) and V-flame morphology is obtained by means of four stabilization rods, generating four adjacent V-flames downstream the rods. As previously outlined, a controlled air stream can be fed in inter-flame position, outflowing from the same burner plate, through channels separated from the combustible mixtures. A combustion chamber equipped with quartz windows for optical access and a chimney cowl for exhaust gases complete the experimental apparatus.

The velocity measurements have been performed by a dual-beam, two-components LDA system operated in back-scatter with a 5 Watt Argon-ion laser (Spectra Physics, mod. 2020). Sensitivity to the flow direction was provided by a 40 MHz light frequency shifting through a Bragg cell. Measurement volume dimensions were around 0.1 mm diameter by 1.0 mm length. Oil droplets of nominal 1 µm size were used as tracers, by adding the particles to the secondary air stream, parallel to mixture flow. The light scattered by the particles was focused onto preamplified photomultipliers and the Doppler signals were monitored by a 58N10 PDA Dantec processor interfaced with a PC through a DMA module. The oil droplets present an evaporation temperature of about 400 °C, thus ensuring “conditional” velocity measurements in the pre-flame region and identifying the position of the flame front.

Thermal features of the combustion process were investigated by means of a Pt6%Rh vs Pt30%Rh thermocouple (junction diameter 250 µm).
Fig. 1: schematic view of the burner and the perforated plate, with indication of axes used to report the experimental results (secondary air is fed through independent channels positioned under the plate, between the stabilization rods).

**Experimental results**

**Operating conditions diagram**

As previously outlined, the operating field of the burner (that is, the existence field of stable V-flame), has been characterised at first, as a function of combustible mixture efflux velocity, excess air and secondary air flow rate, expressed as a percentage of air flow rate fed in the combustible mixture (10% and 20% of secondary air flow rate have been examined). Fig. 2 shows the obtained diagram, with indication of the lines at constant output thermal power of the burner (up to 4 kW).

![Operating conditions diagram](image)

As it can be seen, the operating range of the burner is limited at the right by the blow-off line (which remains practically constant varying the secondary air flow rate) and at the left by the line representing the transition from the V-flames stabilized downstream the rods to a “carpet” flame anchored to the burner plate, upstream the rods. This second configuration, that strictly depends on the secondary air flow rate (line with triangles for 20% and line with squares for 10%) is highly undesired owing to intense thermal stresses of the burner head and higher pollutants emissions. The point in the diagram indicated as “analysed” represents the condition selected for fluid dynamic measurements, maintaining...
constant the feeding conditions of the combustible mixture (excess air and efflux velocity) and varying secondary air flow rate. In fact, it can be seen that a slight variation of secondary air flow rate induces a radical change from an oscillating unstable flame (for 10% of secondary air flow rate) to a stable V-flame (for 20% of secondary air flow rate). The 10% secondary air flow rate corresponds to a momentum ratio at the efflux between the two parallel streams equal to 0.09 (20% corresponds to a momentum ratio equal to 0.19). Fig. 3 represents a picture of the two central adjacent flames acquired by a digital camera with exposure time set to 1/8 s in correspondence of the operating condition “analysed” with 10% of secondary air flow rate; Fig. 4 is referred to the same condition, but with 20% of secondary air flow rate.

In Fig. 3 the apparent thickening of the flame front due to initial instability and transition from V-flame shape to “carpet” one is clearly visible, while in Fig. 4 a sharp and distinct front is noticeable.

Thermal characterization

Fig. 5 shows the variation of temperature (already corrected for radiative errors) in the correspondence of two fixed points (Y=0, X=0, that is exactly in the centre of the burner plate; Y=0, X=4 mm, that is closer to the flame front), at a height from the efflux Z=16 mm, that is 6 mm downstream the stabilization rods, as a function of secondary air flow rate (as usual, expressed as a percentage of air flow rate in the combustible mixture). Feeding conditions of the combustible mixture have been maintained constant, with excess air equal to 1.44. The “cooling” effect at progressive increase of secondary air flow rate is clearly visible, especially at X=0, where it is presumable that secondary air flows more “segregated” from the parallel mixture flow. At the contrary, at X=4 mm, the effect of secondary air is less pronounced owing to interaction with primary mixture and subsequent partial mixing.

Fig. 5: temperature variation as a function of secondary air flow rate.
Flow field structure

Axial (that is, Z-directed) and transverse (that is, X-directed) velocity components have been measured in a X-Z plane positioned at Y=-23 mm, between the two central adjacent flames, because this position seems to be the more critical with respect to flame attachment to the burner head and generation of “carpet” flame morphology. Results are summarised in Figs. 6-7, representing the 2-D velocity fields.

Fig. 6: velocity field with 10% secondary air flow rate (line: mean position of the flame front).

Fig. 7: velocity field with 20% secondary air flow rate.

In the case reported in Fig. 6, the flame front is not clearly distinguishable for Z>22 mm, putting into evidence the onset of possible flame instability phenomena. In fact, higher turbulence levels and bimodal velocity distributions were measured by LDA. Frequency analysis of the LDA data in selected regions of the flow field showed a predominant frequency of 30 Hz, probably associated with periodic oscillations of the flame front, due to local lack of dynamic equilibrium between flow velocity and turbulent flame velocity. Conditional measurements in this case were possible in a wide region of the flow field (even with a progressive reduced data rate), giving evidence to the absence of high temperature gradients. At the contrary, in the 20% of secondary air case, the existence of a distinct and sharp flame front is clearly identifiable where evaporation of droplets occurs due to intense temperature gradient through the front. Moreover, in the 20% case, secondary air flow appears more “segregated” and less interacting with the parallel combustible mixture: isothermal velocity measurements performed in the same operating conditions (not reported here) confirmed this result. It seems thus possible to assume that the influence of the secondary air (contributing to progressive mixture dilution and increase of total excess air) is governed by the momentum ratio at the efflux of the two parallel streams.

Acknowledgements

The authors would like to thank Mr. E. Canal and Mr. F. Argeri for the helpful support.

References