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## Note

# Some characteristics of flames stabilised in swirling streams

G. V. S. N. RAO AND V. SRIRAMULU
*Department of Mechanical Engineering, Indian Institute of Technology, Madras (India)*
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Combustion in swirling streams finds extensive application in gas turbine combustors and burners[1]. But the data available on the characteristics of such systems from the point of view of establishing the mechanism of combustion are not adequate and, in fact, only recently a fairly comprehensive model for swirl combustion has been reported[2], the validity of which however has not yet been fully tested. The rapidity with which the swirl imparted upstream of a jet decays along the burner, the complex interaction between aerodynamics and combustion and variation of turbulence parameters are some of the significant factors which render a thorough analysis of the problem extremely difficult. There have been some attempts[3,4] to apply the "boundary layer" type analysis to swirling jets but these are naturally confined to weak swirls, that is, to situations where there is no recirculation in the core of the jet. Experimental results reported[5–9] reveal some of the peculiarities of swirl combustion. A perusual of the literature shows that the behaviour of cold swirling jet does not in any way legislate the behaviour of the jet when a flame ensues. This is substantiated by the fact that the turbulence parameters are quite different for the two cases considered in the theoretical analysis[10]. In good agreement with this observation is the experimental evidence which points to the fact that rotation imparted to a burning jet can considerably influence turbulence intensity[7].

The raison d'être of the present investigation is to determine experimentally the characteristics of flames when subjected to a rotating environment. These are analysed both quantitatively and qualitatively.

## EXPERIMENTAL

The schematic arrangement of the test rig is shown in Fig. 1. Through the central tube of 12.5 mm inner diameter a mixture of exactly determined composition is conducted. Concentric with the tube is the swirl generator which has four slots cut at 45° to the radial direction. This imparts tangential motion to the entering secondary stream. The flame is stabilized at the burner exit in rotating surroundings. LPG (67% iso-butane, 26% n-butane, 7% propane) is used as fuel.

A conventional twin-mirror arrangement was used to obtain shadowgraphs of the flames. The light source used was capable of giving high intensity flashes and the duration of each flash was very short (18 nsec). The advantage of such a light source is that it provides an instantaneous picture of the phenomena occurring in the region of interest and hence serves as a tool in putting the vital information that is qualitatively sought in proper perspective.

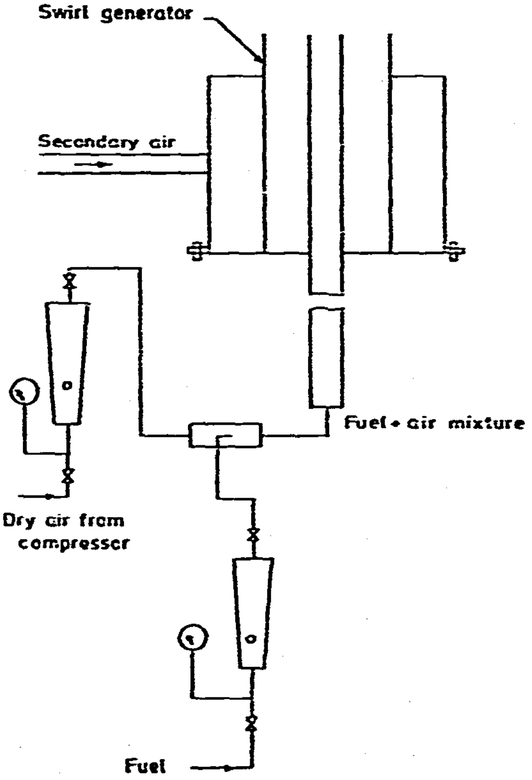

Fig. 1. Schematic arrangement of the swirl burner.

## RESULTS AND DISCUSSION

Two sets of experiments were conducted which facilitated separating the effects of aerodynamics of the jets from those of secondary diffusion. The latter significantly affects the performance of open flames[11] and when surrounded by an inert medium such as nitrogen exhibits a remarkable change in the stability data[12]. Hence, it was conjectured that when a coaxial nitrogen stream could have such a substantial influence on the performance of an ordinary burner, a swirling nitrogen stream could have an equally spectacular influence on its performance. Therefore, in the first run only air was used as a swirling medium whereas in the second case nitrogen was used. In each instance the blow-off velocity was accurately determined making sure in the process that the data were reproducible. Figure 2 shows the blow-off data when using swirling air, plotted against the equivalence ratio ($\emptyset$), the fuel fraction stoichiometry. It is obvious from the graph that as the swirling flow-rate ($\dot{V}_{ua}$) increases, the blow-off

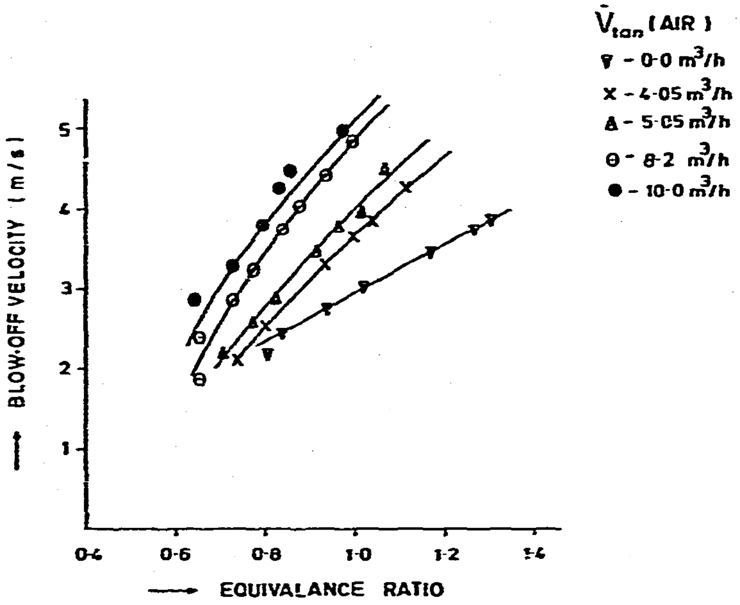

Fig. 2. Blow-off data with air.

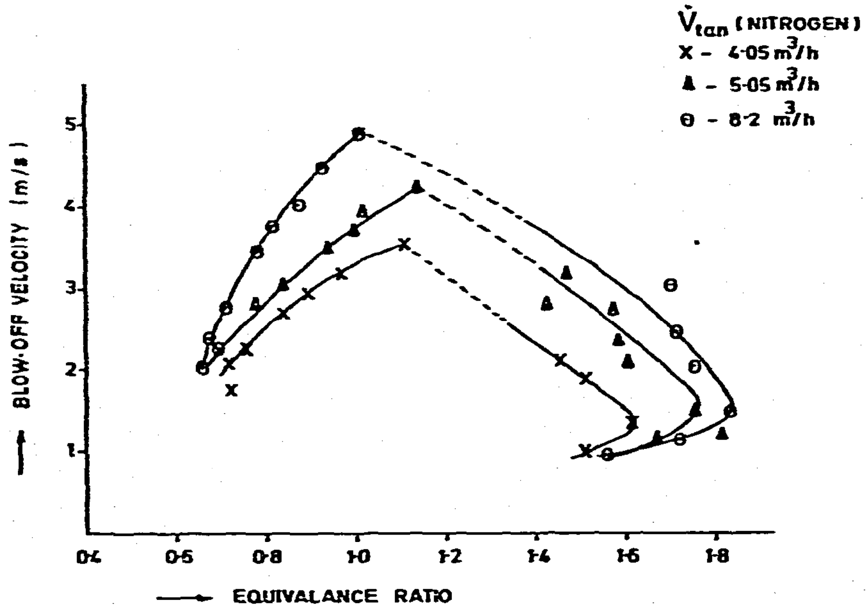

Fig. 3. Blow-off data with nitrogen.

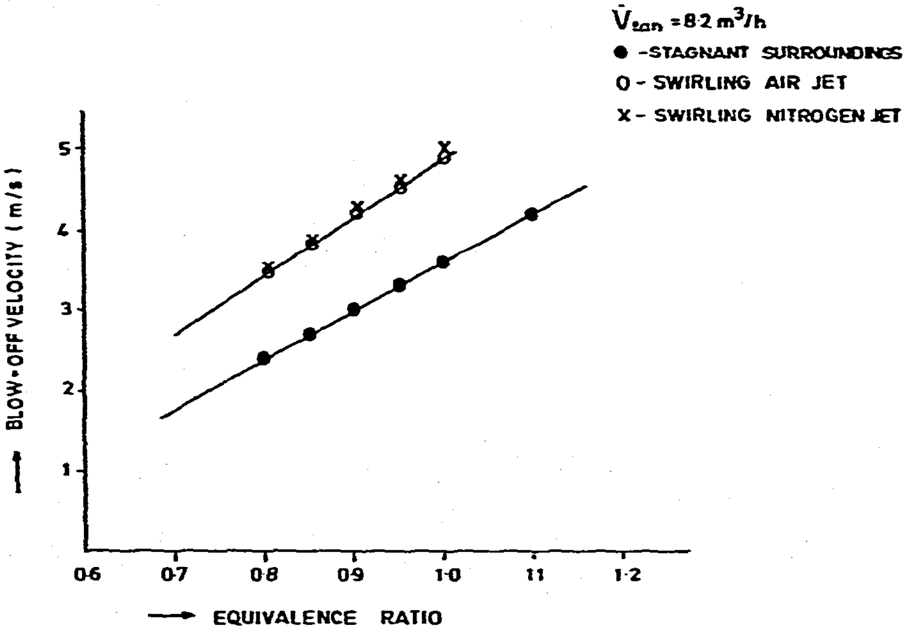

Fig. 4. Comparison of blow-off data.

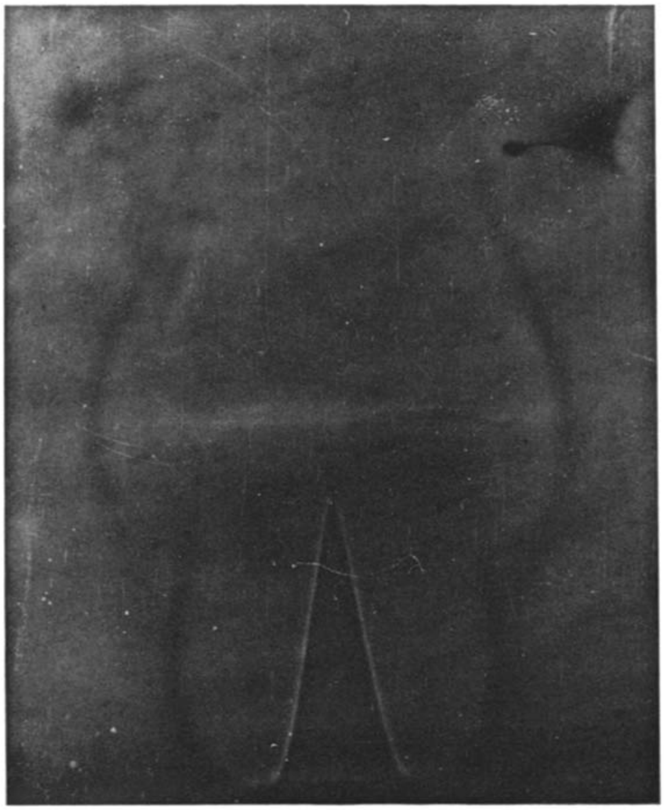

Fig. 5. Burner flame without secondary stream.

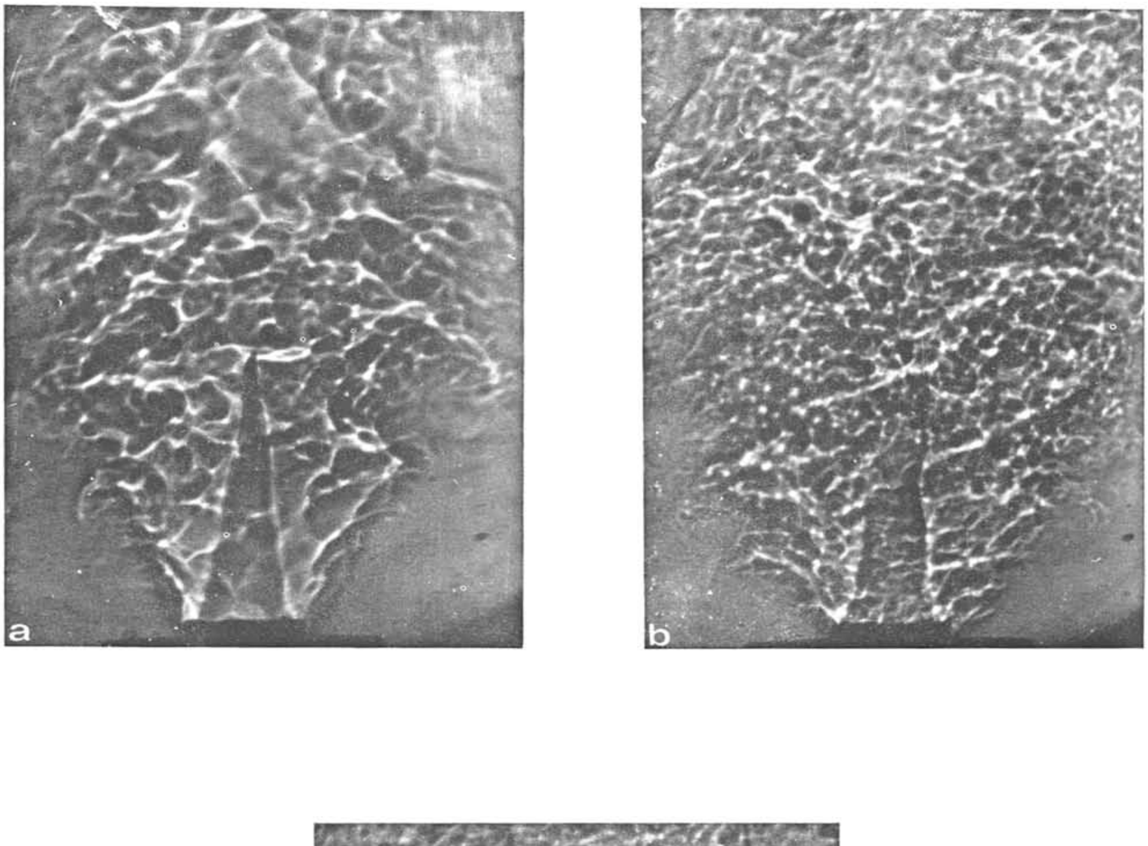

Fig. 6. Burner flame with secondary stream.

velocity also increases. Figure 3 shows the corresponding data obtained while employing nitrogen. When compared with an open flame in free atmosphere, in the presence of nitrogen the blow-off velocity decreases beyond $\varnothing = 1.0$ in much the same way as for a bluff-body. This is attributed to the suppression of the diffusion of the oxygen from the surrounding atmosphere to the zone of reaction[12]; the diffusion of oxygen plays a vital role in the reaction of rich mixtures and consequently enhances the blow-off velocity.

When the surrounding nitrogen stream is imparted a tangential motion the blow-off velocity increases and the similarity with the case when air is used is obvious. Figure 4 shows a comprehensive plot of blow-off velocity with $\varnothing$ for a tangential flow-rate of 8.2 $m^3 h^{-1}$. It is seen that both air and nitrogen are equally effective in improving the stability of the burner flame on the lean side; on the rich side, because of the fundamental difference in the nature of the process involved, the characteristics are different.

Figure 5 shows the shadowgraph of burner flame in stagnant surroundings. Figure 6 shows the short-exposure shadowgraphs of the flame with the tangential air flow-rates of 5.8, 14.8 and 21.0 $m^3 h^{-1}$, respectively. The sequence shows that when the swirling flow is introduced, the process of mixing between the flame products and the surroundings is accentuated as is shown by the greater dispersion of the dark and bright lines which characterise the shadow effect. As the tangential flow-rate increases the mixing is so violent that it penetrates into the zone of reaction which incidentally, appears broken and the tip of the flame completely disappears (Fig. 6c). The improved stability of the flames can be attributed to the thorough intermixing which alters the process of the combustion particularly in the zone of the reaction. The kinetic energy of the reactants is naturally increased by the swirling streams, whether the stream is nitrogen or air, and an additional supply of energy should more than compensate the loss of heat to the burner wall. This aspect of the problem is currently receiving attention.

## CONCLUSIONS

The effect of having a swirling stream surrounding an open flame is to increase the blow-off velocity and it increases with increased flow-rate of the secondary swirling stream.

If the swirling stream happens to be nitrogen the blow-off velocity decreases with increasing richness of the mixture. Surprisingly, even in this situation, increase of the tangential velocity seems to increase the blow-off velocity at a particular equivalence ratio suggesting thereby that the increased kinetic energy of the secondary stream has a profound influence on the mechanism of stabilization which manifests itself as a source compensating the loss of energy. Shadowgraphs obtained using a short duration light source (18 nsec) reveal the peculiarities of the mixing pattern with increased swirling rates.

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