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AERODYNAMIC STUDIES ON JETS ISSUING FROM SWIRLED DOUBLE-CONCENTRIC NOZZLES WITH DIVERGENT EXITS

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SUMMARY Swirled burners used for the combustion of pulverised coal are generally concentric, the central primary nozzle containing the coal and about 20% of the air for combustion, with the secondary flow being swirled. To accommodate the expansion of the secondary stream, the nozzle is generally divergent.

The swirl level is to establish an internal reverse flow zone on the axis. This flow, containing hot recirculated products of combustion, impacts the primary flow to heat and ignite the coal. The flow patterns established in the near field of such a flow is shown to depend on the swirl levels as well as the ratio of the momentum flux ratios of the two streams.

The aerodynamic characteristics of a typical black-coal burner have been studied experimentally in scaled, but cold, burner models. The effect of the swirl levels and the momentum flux ratios have been examined. The effect of a central oil gun has also been studied. Three flow types are identified, two previously found for oil and gas burners and one for a brown-coal burner.

1. INTRODUCTION

Swirling flow is used in fuel burners to control the flame shape, combustion stability and intensity. The swirling motion produces an internal reverse flow zone on the axis of the jet that contains hot recirculated combustion products. There is an exchange of mass and heat between the recirculated combustion gases and combustible mixture flowing in adjacent layers. This results in heating and ignition of the fuel.

Experimental studies (1,2), carried out at International Flame Research Foundation (IFRF) on oil burners showed the formation of swirl-induced central reverse-flow zone. Formation of this reverse-flow zone greatly enhanced flame stability. Later, the IFRF performed several studies on swirling natural gas flames (3). In these studies, two flow types were identified, referred to as type-1 and type-2, are illustrated in Figure 1. In type-1 flows, the primary jet penetrated completely the internal reverse-flow zone, leaving a relatively small annular region of reverse flow. These types of flows were observed at high primary-gas velocities and gave long flames. Type-2 flows were characterised by a large central reverse-flow zone which prevented the forward progress of the primary jet, and deflected it radially away from the axis. Type-2 flows were observed at relatively low primary gas velocities and gave short high-intensity flames. Dixon, Truelove and Wall (4), studied the aerodynamics of a typical brown-coal burner. They identified a different flow type, which could not be classified as either a type-1 or type-2 flow. In this type of flow, the primary jet penetrated partially into the reverse-flow zone and then deflected radially. The degree of penetration increased with increasing momentum flux ratio. This type of flow was referred to as type-3. Wall et al.(5) studied the flow pattern and mixing within the quarl of an air model of brown-coal burner. They also identified type-2 and type-3 flow.

There are considerable variations in the geometry of pulverised-coal burners. The burner geometry depends on the stoichiometric and transport requirements of the fuel being used. The various burner geometries are illustrated in Figure 2. In the present experimental investigations, the aerodynamic characteristics of a cold model of a typical black-coal burner have been studied. The jets under investigation are coaxial and strongly swirled, issuing from a divergent nozzle into stagnant-air surroundings. The experimental studies are aimed to provide a clear understanding of the isothermal swirling flows and the mechanism of flame stabilisation. The effect of a central oil gun on the black-coal burner flows has also been studied. The measurements are compared with the experimental results and theoretical predictions of Dixon et al.(4) for brown-coal and black-coal burners.

2. EXPERIMENTAL

2.1 Model Burner

A 1/9th scale air model of a black-coal burner was used to carry out the experiments. The model burner is illustrated in Figure 3. The burner geometry is defined in Figure 2(b). Swirl was induced by introducing air through a number of tangential slots located well upstream of the burner exit. Air was supplied to the axial and tangential air inlets of the primary and secondary swirl generators by two centrifugal fans. The degree of swirl was varied by varying the proportions of the air flow introduced tangentially and axially into the swirl generators.

The experiments were carried out with a secondary-flow mean exit velocity ($\overline{U}_s$) of approximately 12.5 m/s, secondary swirl number (S_s) of 1.06, primary-flow mean exit velocities ($\overline{U}p$) upto 28.0 m/s and primary swirl number (Sp) upto 1.6.

The swirl number is defined as,

$$S = \frac{G_\phi}{G_x \cdot R} \qquad (2.1)$$

$$\text{where } G_\phi = 2\pi \int_0^r \rho U W r^2 \, dr \qquad (2.2)$$

$$\text{and } G_x = 2\pi \int_0^r (\rho U^2 + P) \, r \, dr \qquad (2.3)$$

For double-concentric jets, R is the outer radius of the annular stream.

2.2 Probe

A two-hole pilot tube with opposed sensing holes was used to determine the boundary of the reverse-flow zone (U=0 contour). The probe was introducted into the quarl region through a narrow slot in the quarl wall. The slot was covered with thin adhesive tape to prevent inleakage of air. During measurements, the sensing holes were aligned parallel to the burner axis. In this position, the sensing holes were sensitive to the axial component of velocity. The change in flow direction was indicated by a change in sign of the pressure differential as the probe was traversed radially.

3. RESULTS AND DISCUSSION

3.1 Boundaries of Reverse-Flow Zone

The effect of primary jet velocities on the boundary of the reverse-flow zone has been studied at a secondary swirl number of 1.06 and no primary swirl. The maps of the reverse-flow zone are shown in Figure 4(a) and are labelled in terms of the momentum flux ratio, which is defined as:

$$F = \frac{\rho_p \, \overline{U}_p^{\,2}}{\rho_s \, \overline{U}_s^{\,2}} \qquad (3.1)$$

The momentum flux ratio has been used previously (6) as a parameter for recirculation in brown-coal burners. A comparison with Figure 4(b) for brown-coal burner (4) reveals that the present flow can be classified as type-3. Upto momentum flux ratio 3.6, the primary jet penetrates partially the reverse-flow zone and then deflects radially. The degree of penetration increases with increasing momentum flux ratio. At a momentum flux ratio 4.82, complete penetration of the reverse-flow zone by primary jet occurs giving a relatively small annular region of reverse flow. The flow can be classified as type-1. The results of the experiment conducted on natural gas swirling burner at IFRF (3) indicate that at momentum flux ratio 5.29, the flow becomes type-1, which agrees reasonably well with present findings. Dixon, Truelove and Wall (4) reported that at the highest momentum flux ratio examined (1.19) for brown-coal burner, the flow was strongly asymmetric and the primary jet was deflected to one side of the reverse-flow zone. Due to the relatively large primary nozzle diameter, it was difficult to maintain a stable and symmetric flow at high momentum flux ratio.

Figure 5 shows, the effect of primary swirl number on the boundary of the reverse-flow zone at a secondary swirl number of 1.06 and momentum flux ratio of 0.41. When there is no primary swirl, the flow can be classified as type-3. At a high primary swirl number (1.6), the primary jet is deflected radially, close to the nozzle exit and type-2 flow is produced.

3.2 Effect of Central Oil Gun

The central oil gun is represented by adding a dummy tube on the axis of the primary nozzle. Its effect on the black-coal burner flows has been studied at a blockage ratio of 0.5. Figure 6(a) shows, the large reverse-flow zone created by the swirling flow at secondary swirl number of 1.06 and no primary swirl. The reverse-flow zone produced by the small oil gun is merged with the large swirl-induced reverse flow and a single large reverse-flow zone attached to the central oil gun is formed. This flow can be classified as an attached type-2 flow. The momentum flux ratio upto 4.78 has been examined but there is no evidence of penetration of primary stream into the reverse-flow zone.

A comparison with the calculated streamlines pattern by Dixon, Truelove and Wall (4) shown in Figure 6(b) with primary swirl (Sp = 0.7) reveals that the present flow pattern is qualitatively similar to that shown in Figure 6(b). It was reported (4) that the predicted flowpatterns with primary swirl and without primary swirl were very similar.

4. CONCLUSIONS

A cold model tests have shown that a stable, symmetric reverse-flow zone can be produced for a range of flow conditions. Without primary swirl, the primary jet penetrates the reverse-flow zone partially and type-3 flow is produced. With the increase in momentum flux ratio, the degree of penetration increases and at a high momentum flux ratio, complete penetration occurs, resulting in type-1 flow. A minimum level of primary swirl is required for a fixed momentum flux ratio to produce a stable type-2 flow. A central oil gun placed on the burner axis producing a large reverse-flow zone which is essentially an attached type-2 flow. A considerable change in flowpattern takes place due to the presence of the central oil gun. Without primary swirl a transition from a type-3 flow to an attached type-2 flow occurs.

5. NOMENCLATURE

D = diameter at throat of divergent quarl
F = momentum flux ratio
G_x = axial momentum flux
G_ϕ = angular momentum flux
L = quarl length
p = time-mean static pressure
r = radial co-ordinate
R = nozzle radius
S = swirl number
U = time-mean axial velocity
W = time-mean tangential velocity
ρ = density

Subscripts

p = primary
s = secondary

6. REFERENCES

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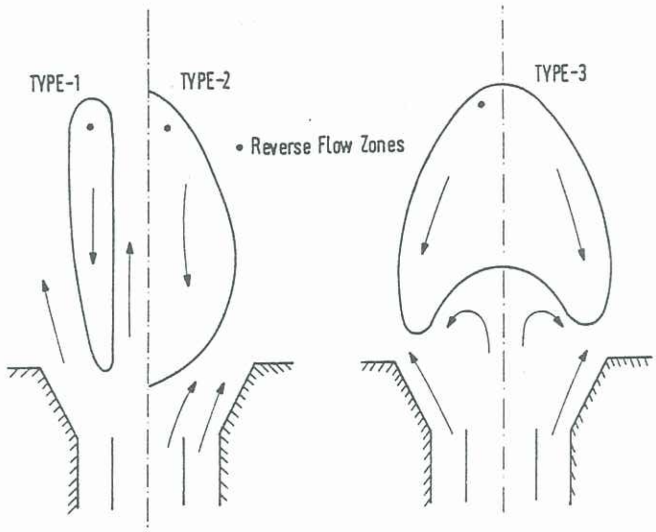

Figure 1. Flow patterns for pulverised-coal burner

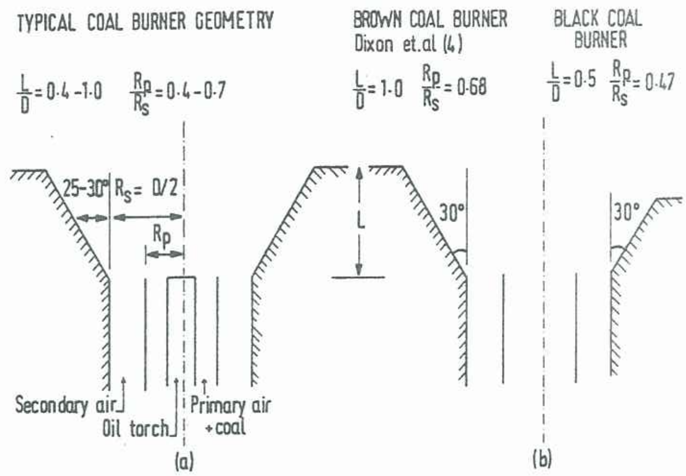

Figure 2. Geometries for pulverised-coal burner

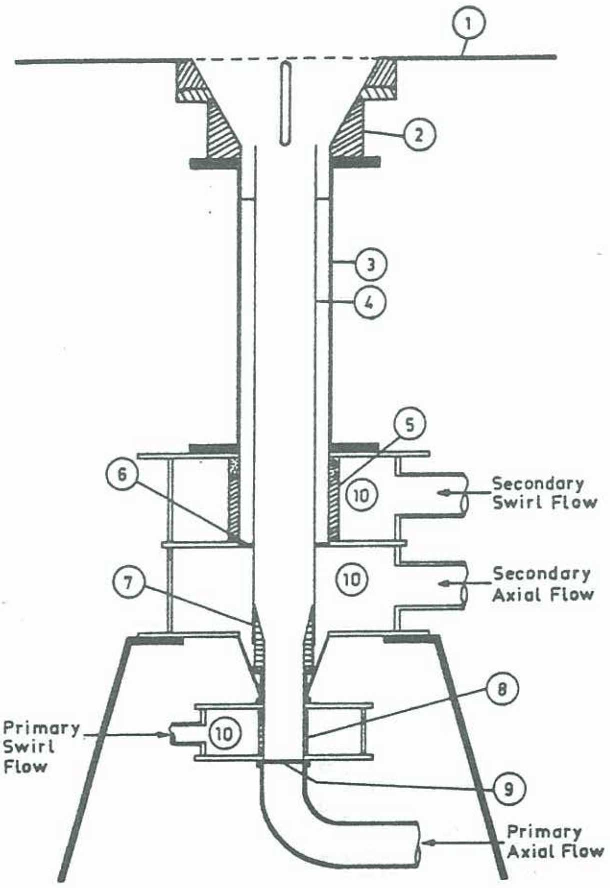

Figure 3 Arrangement of the Isothermal Experimental Swirl Burner.

1. Burner Exit Wall
2. Segmented Divergent Quarl
3. Flow Straightener Section
4. Removable Primary Nozzle
5. Secondary Tangential Swirl Generator
6. Secondary Axial Distributor Plate
7. Primary Nozzle Adaptor
8. Primary Tangential Swirl Generator
9. Primary Axial Distributor Plate
10. Annular Supply Chamber

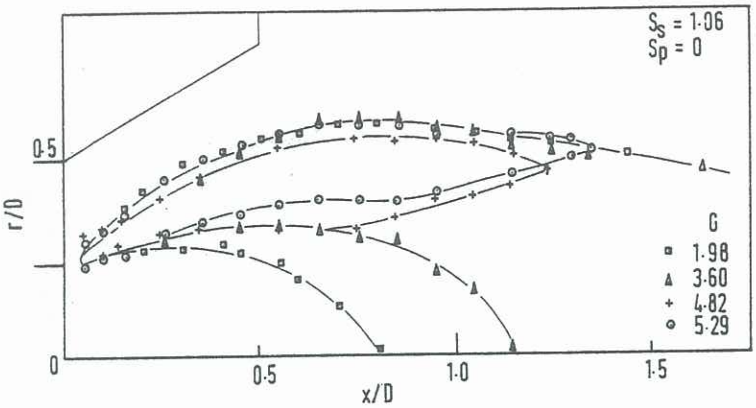

Figure 4(a) Effect of momentum flux ratio on the reverse-flow boundary

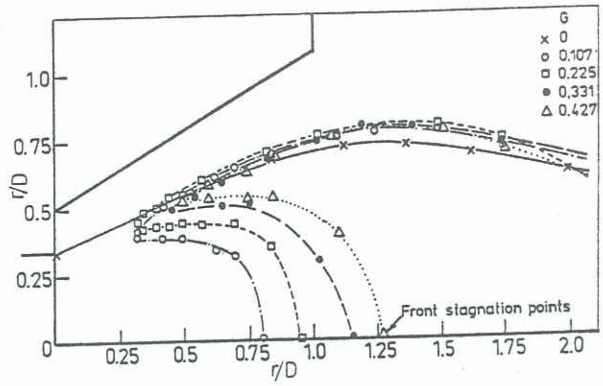

Figure 4(b) Variation of the reverse-flow boundary with momentum flux ratio
From Dixon et al (4)

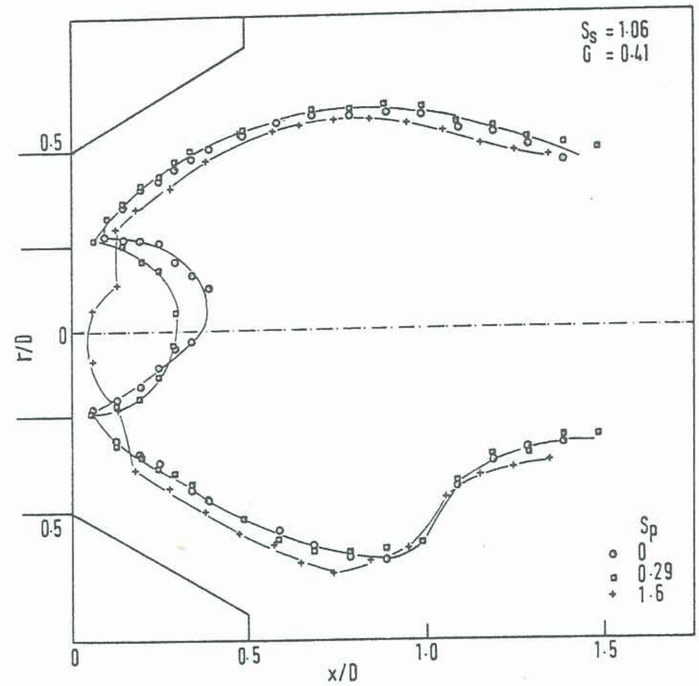

Figure 5. Effect of primary swirl on the reverse-flow boundary

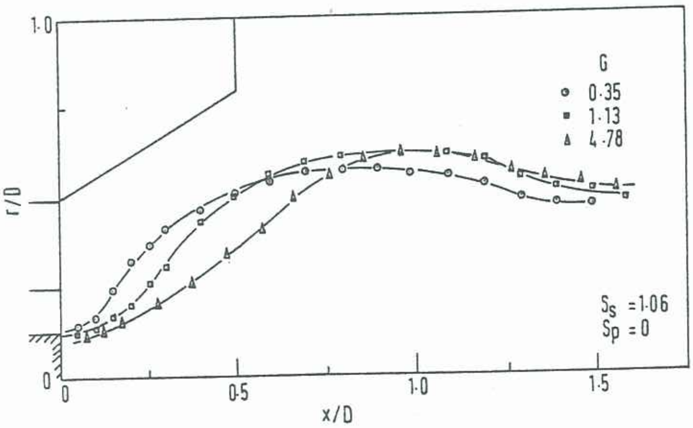

Figure 6(a) Effect of central oil gun on the reverse-flow boundary

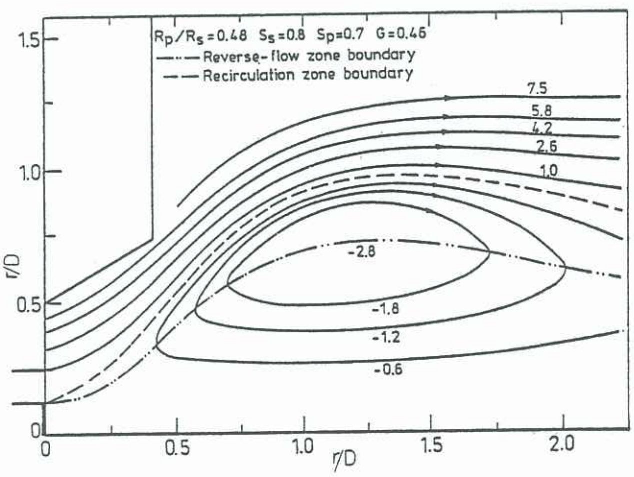

Figure 6(b) Predicted flow streamlines of black-coal burner with an oil gun
From Dixon et al (4)