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# ISOTHERMAL TWO-PHASE FLOW DEVELOPMENT FROM A MODEL SLOT BURNER

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ABSTRACT

An isothermal two-phase flow study has been undertaken to characterise the near field flow development engendered by coal-fired slot burners installed in tangentially fired furnaces. The influence of the rotating flow in the furnace on the near field flow development from the burner is represented by imposing a cross flow at the burner outlet.

Flow field observations indicate that burner geometry and velocity ratio, fuel characteristics and cross flow speed and orientation can play a substantial role in the near field flow development for slot burners. In a number of representative conditions it was observed that the particle (fuel) stream did not fully mix with the secondary (oxygen) flow which is a potential cause of furnace fouling and combustion instability.

Numerical modelling of the thermo-fluid flow field in tangentially fired furnaces should be undertaken with caution.

## 1. INTRODUCTION:

Power station furnaces represent immense capital investments and therefore the incentive for improved design of these furnaces is large. Efficient combustion of the fuel and efficient subsequent conversion to electricity results in lower operating costs, reduced capital investment and capital servicing costs, lower emissions of greenhouse gases and conservation of non-renewable energy resources. The design of the furnace and its burners directly influences the level of greenhouse emissions, the stability of the combustion process, especially at low firing rates, and the degree of wall fouling and hence the furnace availability.

Many large coal fired furnaces are tangentially fired. In this process the momentum of the flow from the burners engenders a rotating flow in the furnace by being directed tangentially towards an imaginary centrally located circle. A burner consists of three vertically spaced slots with the central one providing fuel (plus fluidizing inert gases and/or fuel air) and the outer two providing preheated combustion air. Each burner assembly may consist of one or more such slot burners, vertically stacked, with the units wall or corner mounted.

The flow mixing processes in these furnaces are complex and not well understood, especially in the regions close to the burners. Since 1981 the Swinburne University of Technology (SUT) has collaborated closely with the State Electricity Commission of Victoria (SECV) in a number of research projects designed to improve understanding of these interaction processes. These projects include physical modelling of the near-field flow development from a slot burner operating in isolation (Perry & Pleasance, 1983), and the isothermal flow development in a representative model of a complete tangentially fired furnace (Mierisch et al, 1990). This work has been supported by the parallel development of a generalised three-dimensional thermo-fluid numerical model (INFERNO) of furnace flows accounting for aerodynamics, particle dynamics, heat transfer and combustion (Mackenzie et al, 1990).

The first of these projects considered the influence of burner geometry and velocity ratio on the near-field, single phase isothermal flow development downstream of a slot burner in isolation (Perry et al, 1986). Burner velocity ratio, $\lambda$, was defined as the ratio between the outer jet velocity (secondary) and inner jet (primary) velocity. The results showed that both geometry and velocity ratio played a significant role in the development of the flow field with, in some cases, the primary (fuel) jet diverging substantially away from the geometric axis of the burner and the secondary jet (figure 1). Such a characteristic raises the question as to where the solid fuel particle paths would lie under these circumstances.

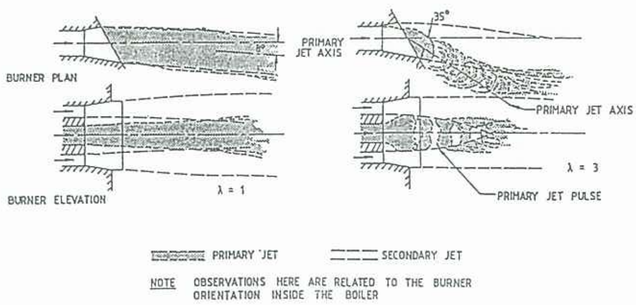


FIGURE 1. JET CHARACTERISTICS AND MIXING FIELDS - GEOMETRY 'D'

Also, as part of the development of the three-dimensional numerical model (INFERNO), a typical tangentially fired furnace was analysed with INFERNO using high grid resolution to explore the burner/furnace interaction processes (figure 2). It is clear that the rotating flow in the furnace may also significantly influence the near field flow development from the burner.

To address these concerns the Electricity Supply Industries Research Board (ESIRB) approved a research programme with the following objectives:

> Characterise the flow field development in the near field of a generalised model of a slot burner considering plane and cavity burner geometries, typical burner velocity ratios and crossflow velocities, and single and two-phase (gas/solids) flows.

The agreed programme covers flow visualisation studies, numerical model comparison and detailed flow velocity measurements. This paper covers some of the work undertaken under the first two parts.

## 4. DISCUSSION:

The results presented have been limited to those for $\lambda$=3 as this level is representative of jet momentum ratios in tangentially fired furnaces.

For the configurations shown in figures 4 to 7 the primary jet, due to its lower momentum, is turned further away from the geometric axis of the burner by the crossflow than the secondary jets. For all configurations, bar Geometry 'D' in the AXF configuration, the particles (representing fuel) move outside the secondary jet boundary. Also in these cases the primary flow is unsteady and in the WXF configuration has a cyclic characteristic of attachment and separation from the furnace wall.

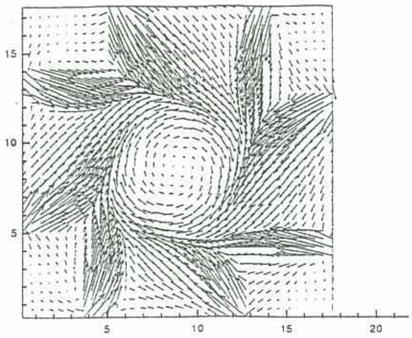


FIGURE 2. LOY YANG 'A' 500 MW ISOTHERMAL FURNACE MODEL X-Y PLANE AT THE LEVEL OF THE LOWEST SECONDARY BURNER

## 2. EXPERIMENTAL FACILITY & MODELLING PROGRAMME:

Based upon earlier work (Perry et al, 1986) the two burner geometries selected for the above programme were:

- geometry 'B': A three jet system where the burner face is located at the burner wall, the jet flow direction set at 60 deg. to the boiler wall, and the inclination plane normal to the stacking axis for the burner, and
- geometry 'D': As for geometry 'B' but having the burner duct terminating a short distance upstream of the furnace wall and with a sudden expansion into a cavity having diverging side and endwalls bounding the flow between this exit plane and the boiler wall. This geometry is representative of cavity burners used in recent boiler installations in the Latrobe Valley.

Burner velocity ratios considered were $\lambda$ = 1.0 & 3.0.

It was proposed to modify an existing facility located at the SECV which had been used to study isothermal two-phase flow development downstream of a swirl burner. To obtain an appreciation of the interaction processes between burner, cross flow and the containment box and to determine a suitable crossflow arrangement, a simplified hydraulic model of the proposed facility was built and flow studies undertaken (Yan & Perry, 1992). Based on these flow observations the airflow model configuration was specified as shown on figure 3 with the cross flow duct twice the height of the burner and the same width. The centre of the cross flow duct was located in the same vertical plane as the burner centre. Two burner orientations were considered, the first where the furnace wall component of the burner exit velocity was directed away from the cross flow source (WXF), matching the right hand burner on the south wall of the furnace flow crossection shown on figure 2, and the second where it is directed toward the source (AXF), which matches the left hand burner. Particle scaling laws were used to specify a representative range of particle size and loading(Yan & Perry, 1992). A suitable particle feeding system was selected.

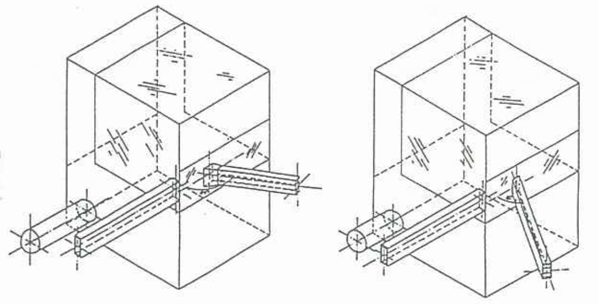

FIGURE 3. LOCATION OF BURNER AND FLOW EXHAUST

## 3. RESULTS:

A detailed presentation of the results is given in Yan & Perry (1992) with a selection of the more interesting results presented in figures 4 to 8 for geometries 'B' and 'D', $\lambda$=3, cross flow velocity equal to the primary jet velocity and burner configurations AXF & WXF. The results presented in figures 4 to 7 are for a second phase particle size of 0.100mm, density 137kg/m3 and mass loading ratio of 0.027. Figure 8 compares results for two other particle conditions.

By selecting a cross flow velocity equal to the primary jet velocity, the curvature of the burner near flow field was observed to closely match that shown in the furnace numerical model studies (figure 2).

Three particle sizes have been used in the two phase flow experimental programme as follows:

- hollow glass spheres, 100 $\mu$m dia.and 137 kg/m$^3$ density
- solid glass spheres, 100 $\mu$m dia.and 1450 kg/m$^3$ density
- aluminium oxide particles, 50 $\mu$m dia. and 580 kg/m$^3$ density

For the size of particles considered, the spacing of the particles for the flow in the model, compared to the prototype, has been substantially reduced and this has contributed to difficulties in adequately feeding the particles into the primary flow. To stabilise the particle feed and to make this spacing more representative, the mass loadings have been reduced from typical furnace levels of order 0.38 to values ranging from 0.027 to 0.2, depending upon the particles used.

Figure 3 shows the relative positions of the burner, cross flow and exhaust ducts on the flow containment box. The experimental facility layout, flow measurement technique, burner and ducting dimensions, particle scaling and feeding methods, and flow velocities are detailed in Yan & Perry (1992).

The methods used for visualising and recording the flow field are detailed in Yan & Perry (1992). Briefly, the fluid flow component of the two phase flow field has been observed by seeding the flow with 'smoke' droplets. The size of these droplets are of order 10E-6 m and for this size it is expected that the particles will faithfully follow the air flow field. The flow plane of interest is illuminated by a suitably positioned light sheet in the flow field. Contrast is optimised by enclosing the flow containment box with a black cloth curtain to shut out external light through the viewing windows. Similar techniques are used to illuminate the second phase (solid particles) of the burner flow. Unfortunately it is not possible to simultaneously view both phase flow fields using this technique as it is not possible to differentiate between the smoke and the second phase particles. Due to the relatively low mass loading of the second phase in the model experiments it is not expected that the momentum exchange between the two phases in these cases will have a significant influence on the flow field development.

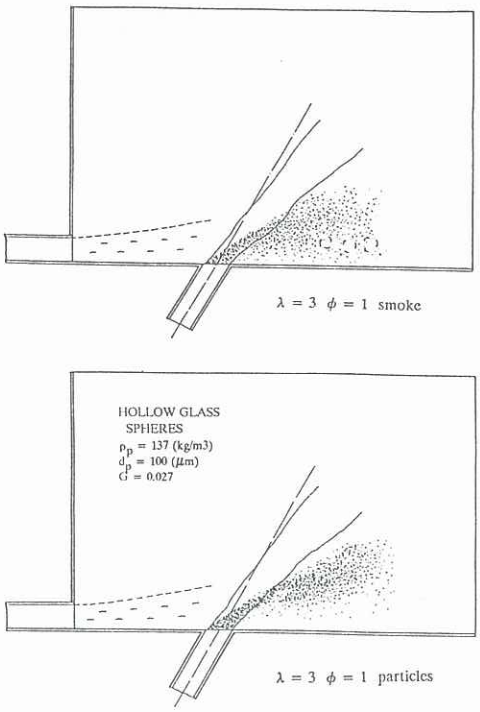


FIGURE 4. FLOW DEVELOPMENT OF BURNER 'B' CONFIGURATION 'WXF'

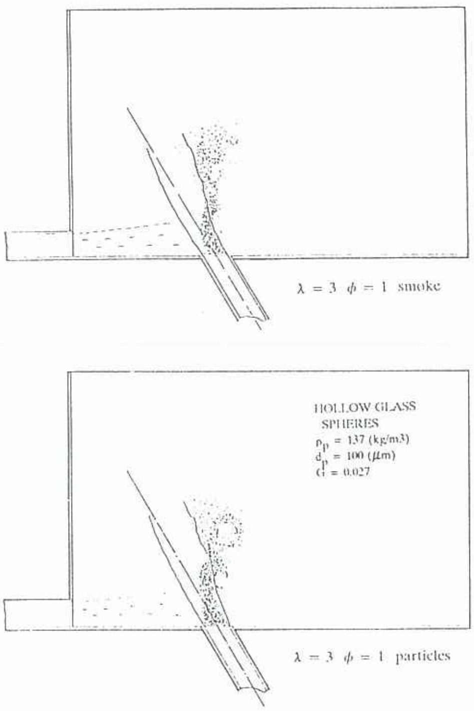


FIGURE 5. FLOW DEVELOPMENT OF BURNER 'B' CONFIGURATION 'AXF'

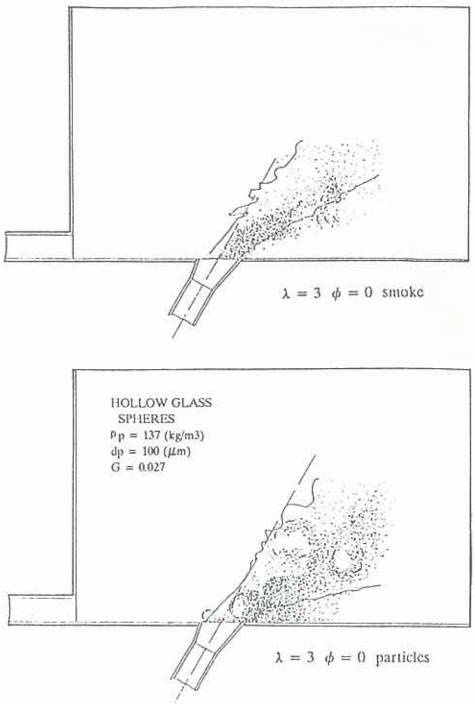


FIGURE 6. FLOW DEVELOPMENT OF BURNER 'D' CONFIGURATION 'WXF'

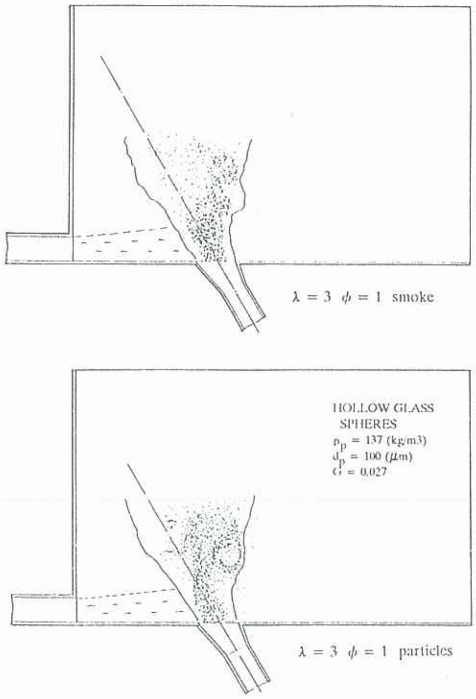


FIGURE 7. FLOW DEVELOPMENT OF BURNER 'D' CONFIGURATION 'AXF'

Burner flow fields of this nature in a furnace may engender combustion in low oxygen levels near the furnace wall which could contribute to wall fouling, combustion instability and carbon carry over.

For different particle properties, such as size and density, for a fixed burner configuration and flow velocity ratio, the particle flow field can be substantially different to that discussed above (see figure 8). For example the heavier particles resist turning in the cross flow field and more closely follow the geometric axis of the burner.

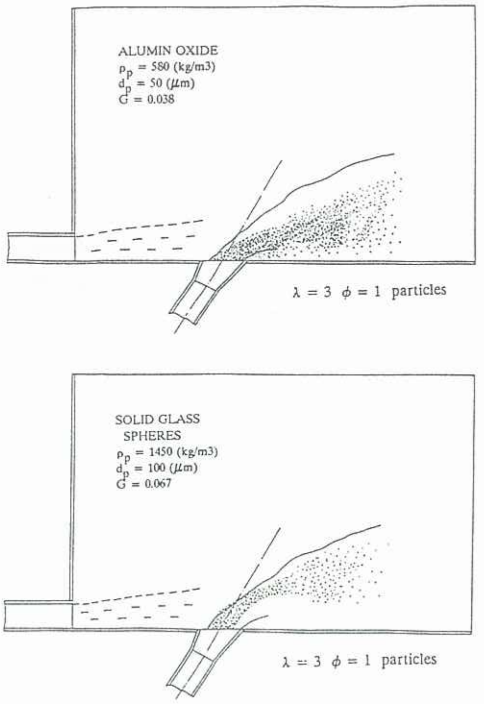


FIGURE 8. INFLUENCE OF PARTICLE LOADING TO FLOW DEVELOPMENT

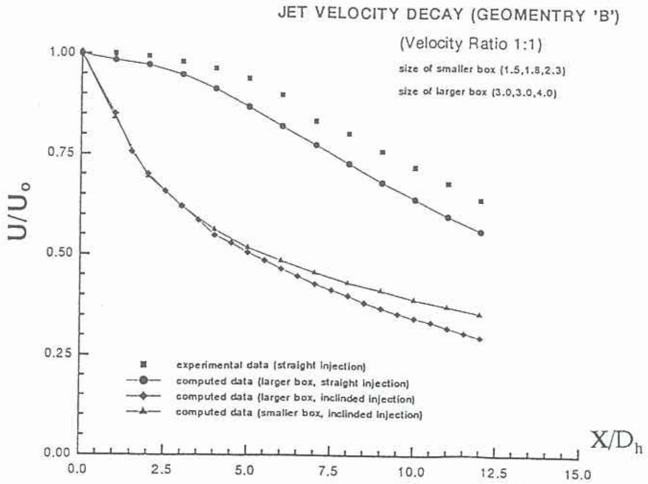


FIGURE 9. JET VELOCITY DECAY ( GEOMETRY 'B')

## 5. NUMERICAL MODEL COMPARISON:

Figure 9 shows a comparison between experimental results and predictions using a three-dimensional thermo-fluid numerical model. The model (INFERNO) is described in Mackenzie et al, 1990, and is a finite difference, staggered rectangular grid code using the hybrid differencing scheme.

The physical results were reported in Perry et al, 1986, and covered measurement of the decay of primary jet centerline velocity for a slot burner with distance along the geometric axis of the jet for discharge normal to and 60 deg to the wall. The results were similar for both conditions.

The numerical solution considered two boundary conditions for the discharge volume; the first as equivalent to the flow containment box dimensions and then for twice that volume. The level of correlation between the physical and numerical results for discharge normal to the wall is relatively encouraging but for discharge at 60deg the comparison is very poor. In the first case the flow is directed along the grid axis whereas in the second case the jet develops at an angle to the grid. In the latter case the numerical result reflects the influence of numerical diffusion. Further work is in hand to explore the influence of alternative differencing schemes and grid arrangements to eliminate this problem.

## 6. CONCLUSIONS:

Observations of the flow field indicate that burner geometry, velocity ratio and the relative speed of the cross flow can significantly influence the near field fluid flow development of a slot burner. Further, with particles in the primary jet flow representing pulverised coal, there are cases where for certain realistic burner geometries and operating conditions, the particle flow field development is beyond the boundary of the secondary (oxygen bearing) flow field. Such a behaviour may contribute to combustion instability and/or furnace fouling.

Numerical solutions of the flow field in tangentially fired furnaces need to be very thoroughly explored before being applied, particularly in the burner near field.

## 7. ACKNOWLEDGEMENTS:

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