Numerical Modelling and Physical Testing of Gas Flows in a Flash Smelting Burner

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ABSTRACT

A two dimensional, single phase, isothermal numerical model was developed using the fluid flow code CFX-4.1 (AEA Technology, 1995) to predict the gas velocity profile exiting a pilot plant flash smelting burner. The burner comprises a central concentrate feed pipe surrounded by two concentric annuli (Figure 1). Natural gas is injected axially through the inner annulus and oxygen is injected with a moderate swirl through the outer annulus.

Velocity profiles of the free jet exiting the burner were measured with a four hole pressure probe (cobra probe), under simulated operating conditions using air.

The model predictions, after some grid refinement to achieve grid independence, were compared with the velocities measured with a cobra probe. Very good agreement was achieved between the measured and predicted velocity profiles.

The single phase numerical model is the first step towards the validation of an overall flash smelting numerical model developed at CSIRO Minerals.

KEY WORDS: Numerical modelling, swirl, flash smelting, Cobra probe

1. INTRODUCTION

Since May 1995, CSIRO Minerals, has been conducting an externally sponsored research project, to develop a numerical model of flash smelting. The work has been conducted in several stages.

In the first stage of the project, a CFX model including some special codings, was developed to simulate the smelting of the concentrate. The gas was first combusted using a "mixed-is burnt" model and the results restarted for particle reactions in a separate zone.

In the second stage (Koh et al., 1996), the two combustion models were combined. The gas and particle reactions were solved simultaneously in one calculation. The combined model was applied to a low swirl burner in a pilot plant reaction shaft. Smelting performance and burner operation were evaluated with different concentrate injection positions and particle sizes.

In the third stage of the work reported here, a two dimensional single phase CFD model was developed to predict the velocity profiles below the actual pilot plant burner. The same velocity profiles were measured with a cobra probe at air flow rates equal to the gas flow rates expected during actual operation. The measured profiles were compared with those predicted by the CFD model.

2. EXPERIMENTAL METHOD

2.1 Burner Setup

Measurements were conducted on the actual full scale test burner. The dimensions of the burner are shown in Figure 1. The burner was positioned on a 650 mm ID open ended steel cylinder 1.2 m long, to simulate the top of the burner shaft. A number of 25 mm diameter access holes were drilled into the steel

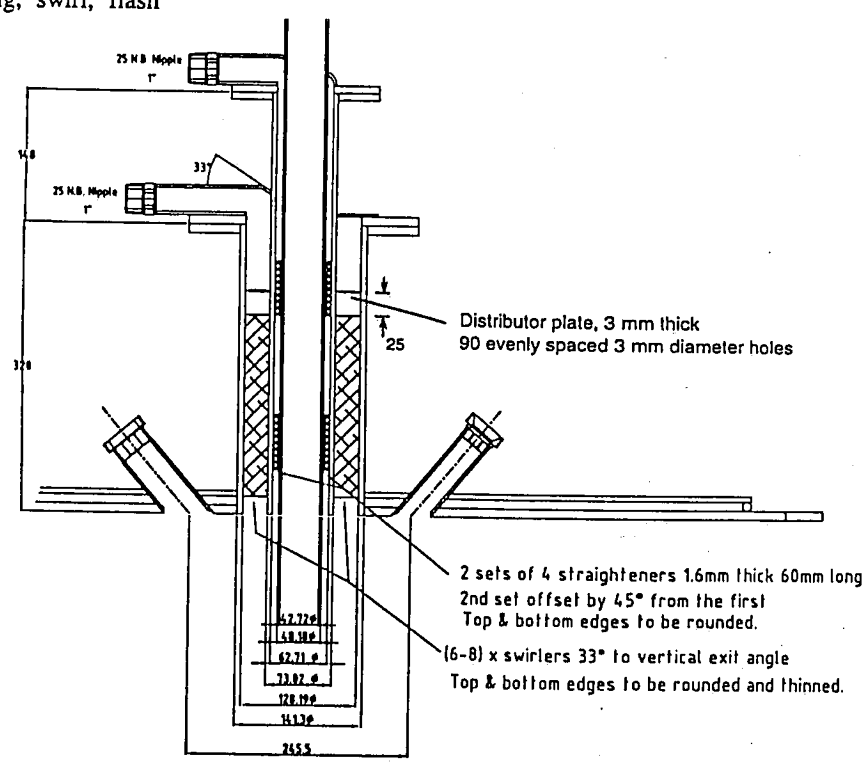

Figure 1. Burner showing the distributor plate which was installed after the first tests.

cylinder at heights where Cobra probe traverses were made.

2.2 Cobra Probe

The cobra probe is a 4 hole pressure probe capable of measuring gas speed, direction and total pressure at the probe head (Hooper and Musgrove, 1991). The probe head has a truncated triangular pyramid head with pressure tappings on the four flat faces with the side surfaces angled at 45 degrees (Figure 2). Flows can be resolved when the mean flow is directed within a cone of 45 degrees half angle from the tip. The probe tip is located on the rotational axis defined by the central stem. This the measuring position of the probe tip remains the same when the stem is rotated.

The pressure signal is transmitted through four 0.5 mm ID tubes and sampled by four differential pressure transducers located in the probe body. A Fourier transform is used to calculate the undistorted pressure signals as 'seen' by the probe head.

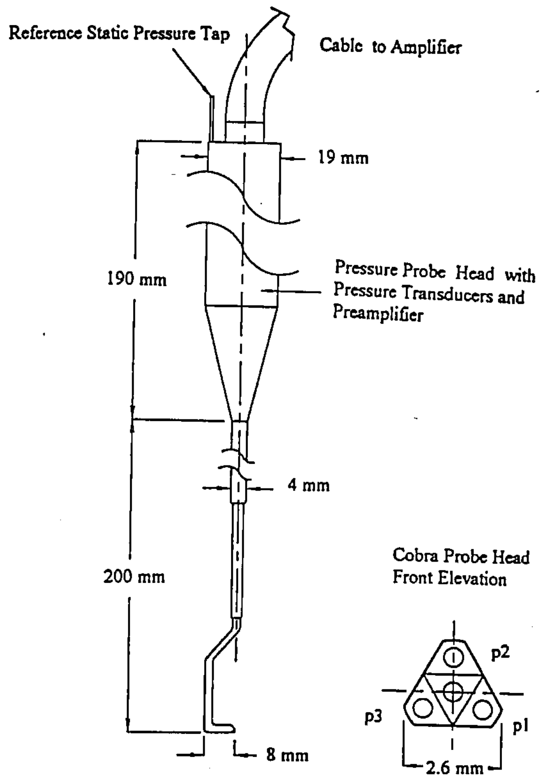

Figure 2. Cobra probe.

Pressures were sampled at 5 kHz for 1.6 sec at each point. The time averaged velocities are reported.

2.3 Cobra Probe Positioning System

The Cobra probe was mounted on a computer controlled automatic traverse system. Stepper motors were coupled to a drive mechanism to rotate the probe to through a full 360° and move it laterally across the shaft. The automatic traverse system was mounted on a drill press. The height of the traverse system was adjusted manually.

2.4 Flow Conditions

Air was supplied to the burner from a large Rootes blower. The air flows into the burner were measured by orifice plates in the three gas supply lines. Air flow rates were set at the expected actual gas flow rates. The estimated error in flow rates is ± 2%.

2.5 Velocity Profile Measurements

Velocities were measured at four horizontal planes 40, 77, 144 and 288 mm below the burner.

The flow was traversed in 3 or 5 mm increments, in three equally spaced planes, by rotating the burner relative to the probe. The probe was traversed across the jet through the centreline.

2.6 Flow Visualisation

A video camera was used to record the flow patterns formed when smoke was blown through the outer annulus. The smoke was generated by burning glycol in a theatrical smoke generator and injected into the air stream just upstream of the burner.

3. FLOW MEASUREMENTS

3.1 Original Burner

The velocity profiles of air exiting the burner as it was first received showed an unexpectedly high degree of asymmetry about the centreline axis in the swirl region at a radius greater than 40 mm. This asymmetry was confirmed in flow visualisation tests. The asymmetry of the swirl flow was caused by poor flow distribution upstream of the swirl vanes in the outer annulus. The flow maldistribution was eliminated by installing a distributor plate in the annulus above the swirl vanes in the burner.

3.2 Modified Burner

A high degree of flow symmetry was found below the modified burner. Axial and tangential velocities measured in the 3 planes are overlain in Figures 3 and 4, respectively. The maximum axial velocity (at the centreline) was between 22 and 24 m/s. In the swirl region the maximum axial and tangential velocity occurred at the same radial distance (r=60 mm). The maximum axial velocity in the swirl region was between 9 and 12 m/s while the maximum tangential velocity was between 10 and 15 m/s.

Two traverses were made at 77 mm and 147 mm below the burner and a single traverse was made 288 mm below the burner. No measurements were made farther from the burner because the differential pressures were small and the errors become very large.

The flow continued to maintain symmetry with increasing distance from the burner. Outside the inner annulus the flow became highly turbulent and many pressure samples were discarded because they fell outside the 45° acceptance cone of the probe.

4. NUMERICAL MODELLING

A two-dimensional isothermal numerical model of the burner shown in Fig. 1 was developed. The grid in this model was refined so that the flows from the different gas streams could be resolved and compared with cobra probe measurements. Axis-symmetry was assumed in a 120 by 56 rectangular grid using cylindrical coordinates. The use of the standard k-ε turbulence model was consistent with the modelling work carried out in the previous stages (Koh et al., 1996)

Plots shown in Figures 3 to 12 show the measured and predicted axial or tangential velocity profiles across the shaft below the burner. There was generally very good agreement between the measured and predicted velocity profiles, particularly closer to the burner exit. This is highlighted in Figure 5 and Figure 7 where the average velocities of the three traverses are compared to the model. Because of the mesh size chosen, the model is able to accurately predict the rapid changes in axial velocity of the gas exiting the different annuli.

Agreement between the model and measurements diminished at lower horizontal planes and farther from the centreline. This is also the region where there was more uncertainty in the accuracy of the measurements as the increasing scatter in the data shows. Predicted axial velocity profiles tend to overestimate the velocity in the central flow region and underestimate the velocity in the swirl region. No definite trend was observed in the tangential velocity profiles.

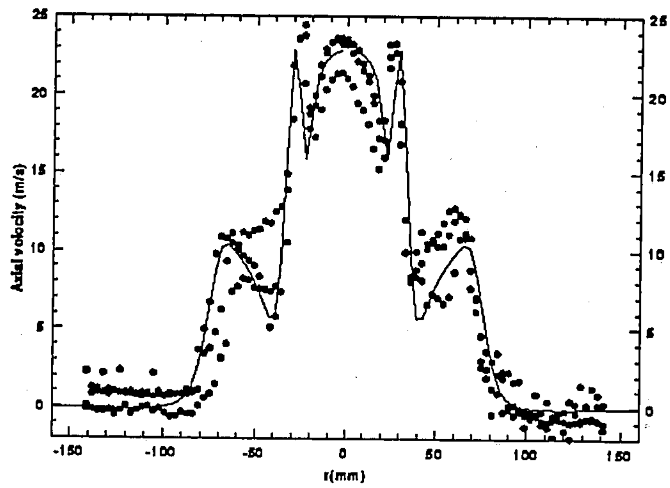

Figure 3. Comparison of measured (3 separate traverses shown as dots) and predicted (solid line) axial velocity 40 mm below burner exit.

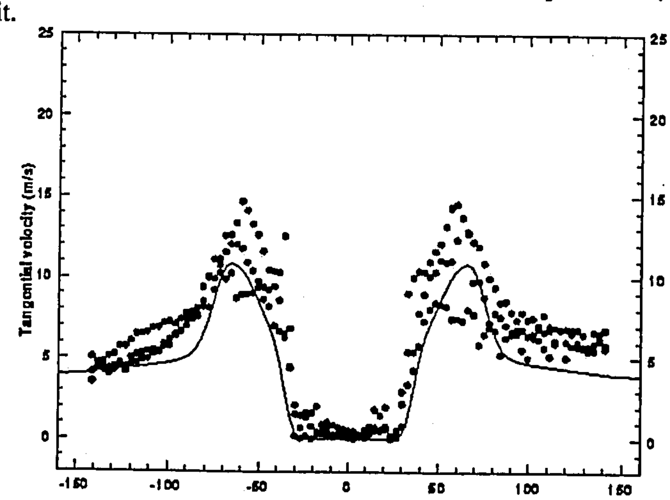

Figure 4. Comparison of measured (3 separate traverses shown as dots) and predicted (solid line) tangential velocity 40 mm below burner exit.

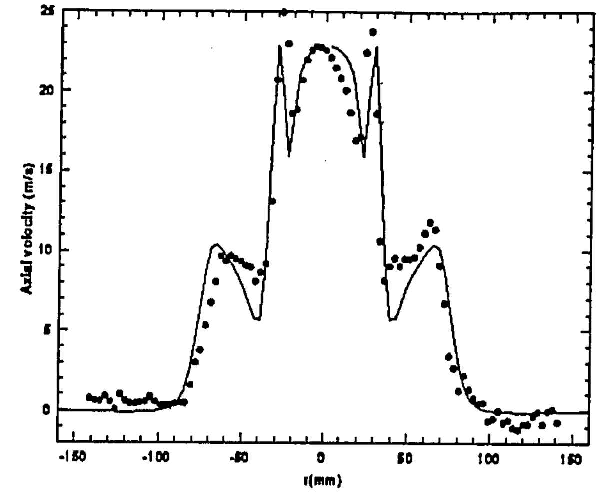

Figure 5. Comparison of the averaged Cobra measurements over the 3 traverses (dots) and predicted axial velocity at 40 mm below burner exit.

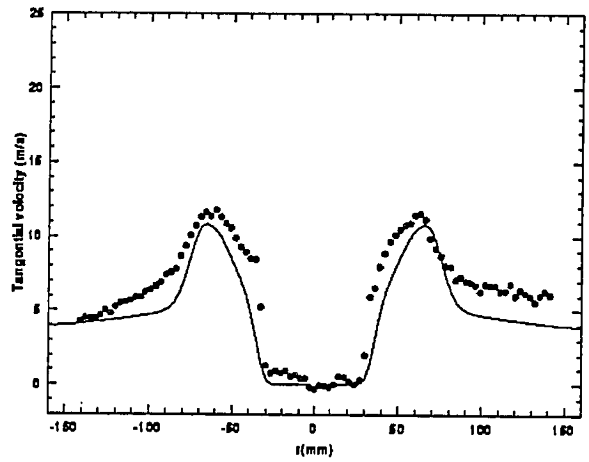

Figure 7. Comparison of the averaged Cobra measurements over the 3 traverses (dots) and predicted (solid line) tangential velocity at 40 mm below burner exit.

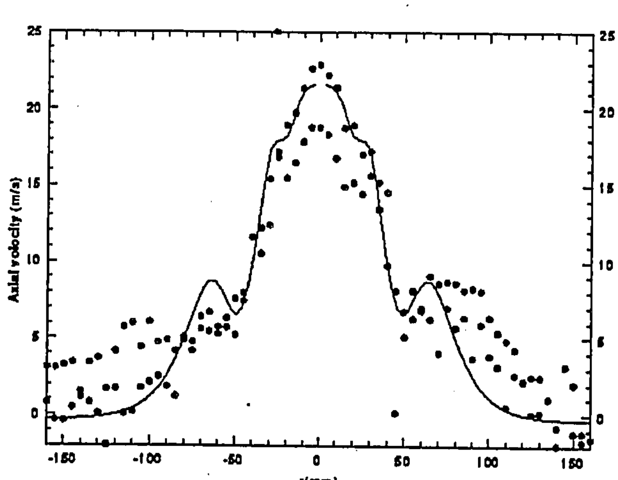

Figure 8. Comparison of measured (2 separate traverses shown as dots) and predicted (solid line) axial velocity at 77 mm below burner exit.

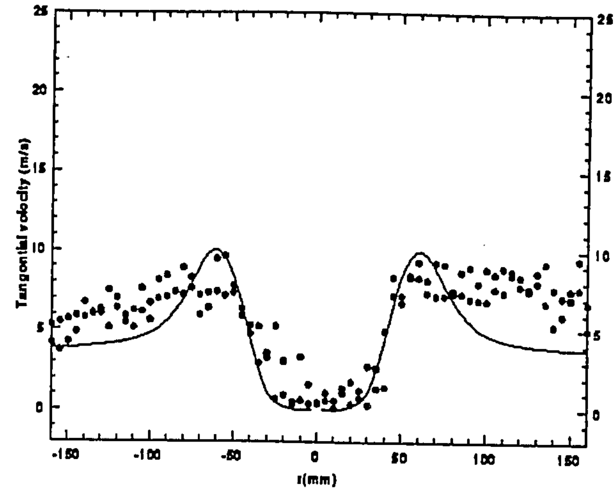

Figure 9. Comparison of measured (2 separate traverses shown as dots) and predicted (solid line) tangential velocity at 77 mm below burner exit.

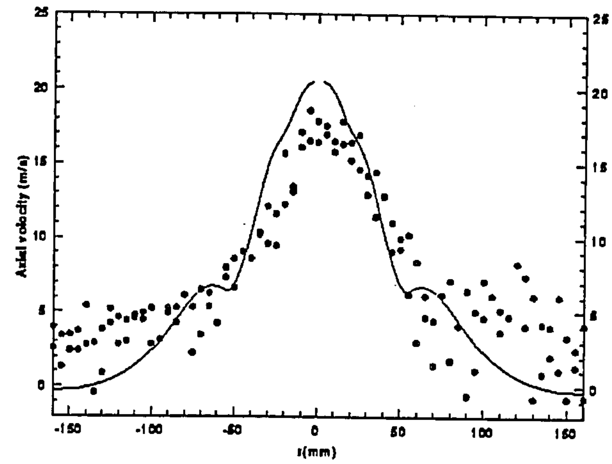

Figure 6. Comparison of measured (2 separate traverses shown as dots) and predicted (solid line) axial velocity at 147 mm below burner exit.

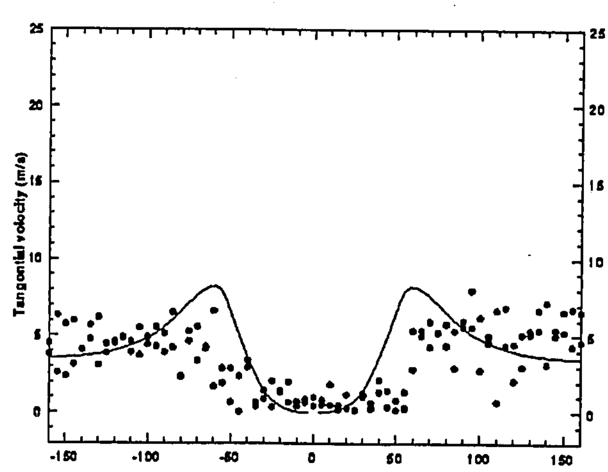

Figure 10. Comparison of measured (2 separate traverses shown as dots) and predicted (solid line) tangential velocity at 147 mm below burner exit.

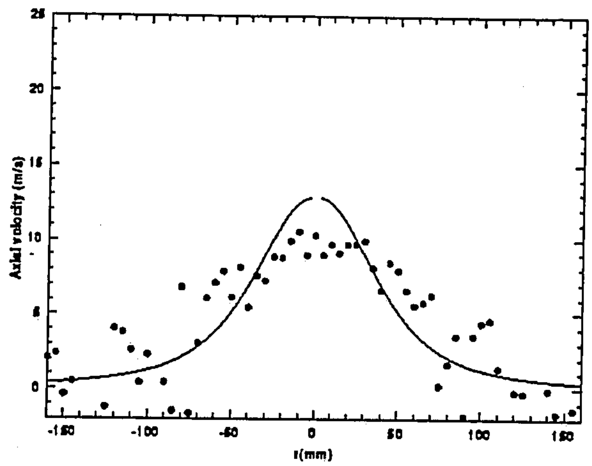

Figure 11. Comparison of measured (single traverse shown as dots) and predicted (solid line) axial velocity 288 mm below burner exit.

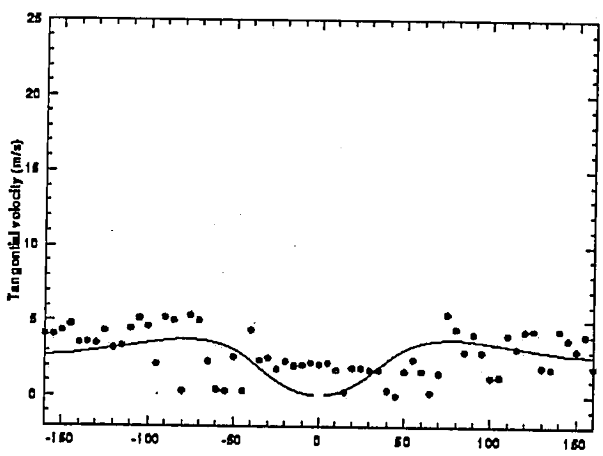

Figure 12. Comparison of measured (single traverse shown as dots) and predicted (solid line) tangential velocity 288 mm below burner exit.

5. CONCLUSIONS

Physical testing and CFD are complementary tools for successfully developing processes involving fluid flows.

This work highlights the importance of performing measurements on the actual equipment to ensure the boundary conditions used in the CFD are valid.

The cobra probe was a very useful tool for measuring velocity profiles below the burner. It is robust, straight forward to use, relatively inexpensive, and requires little extra equipment to operate. Furthermore, it is portable and can be used in situ. The probe is intrusive, however, the geometry and dimensions of the probe mean its effect on the measured flow can be minimal.

In the modified flash smelting burner, which had symmetrical flow, there was very good agreement between the measured flow and the two-dimensional numerical model of the flow exiting the burner.

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