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BRIEF COMMUNICATION

TWO-PHASE FLOW MEASUREMENTS IN CONFINED COAXIAL JETS

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INTRODUCTION

The physical model implemented in Albagli & Levy (1990) predicted the mixing characteristics of particle-laden, confined, coaxial, turbulent jets with coupled mass transport, dynamic and thermal nonequilibrium effects in a simulated ram combustor. The equations governing the flow of both gas and particle phases were assessed according to a Eulerian approach. The first of the two ram combustor simulations described in the previous work, representing low-speed, cold-flow of confined two-phase jets, is the counterpart of the present study.

Conducting an experimental investigation on the flowfield in a ram combustor is extremely difficult, because of the hostile environment of high-temperature, high-pressure, nontransparent two-phase flow. Basic studies for understanding the governing mechanisms of specific phenomena are therefore confined to simplified experimental models. According to this methodology, the present work focuses on the mixing process in particle-laden, ducted, concentric, turbulent jets.

The velocity measurements involve complicated techniques to satisfy the needs of the experimental study, comprising information on the local instantaneous velocity histograms of the phases. The measurement technique selected for this purpose is laser-Doppler velocimetry (LDV) which allows tracing of the velocities of particles scattered in the host fluid. In the case of two-phase flow, two types of particles are simultaneously present: the fine (tracking) particles, which follow the flow and reveal the instantaneous velocity of the continuous phase; and the larger ones representing the discrete phase and having their own trajectories. One of the great advantages of the LDV technique is that it supplies, with certain modifications, simultaneous information on the velocity and the size of an individual particle. The information on the size of the particle is obtained from the shape of the signal recorded by one or more photodetectors, and is affected by the properties of the particle and by the specific technique used (Levy & Timnat 1986/87).

Aluminum oxide particles were used to simulate both phases; 5 μm particles for the host fluid and 20 μm particles for the discrete phase. These arbitrary-shaped particles of various refractive indices are best measured by the pedestal amplitude technique which is based on the relation between the size of the particle and the pedestal amplitude of its signal. The accuracy of the size measured by this technique is relatively low, with an error of about 30%. However, it can be increased to some extent if measurements are limited to areas where the intensity of the laser light in the control volume is almost uniform. Since only two groups of particles simultaneously exist in the flow, with corresponding signal amplitudes of different orders of magnitude, by imposing a variable threshold level on the photodetector output one can distinguish between the scattered light originating from large discrete particles and that from the fine tracking particles (Levy & Lockwood 1981).

EXPERIMENTAL INVESTIGATION

The major objective of the experimental program was to obtain a general insight on the mixing phenomena in the initial region of confined, concentric, chemically inert two-phase jets by measurement of concentration and velocity distributions of the two phases.

The experimental test section is schematically shown in figure 1 and the experimental conditions are summarized in the following. They were selected to match those of the numerical simulation described in Albagli & Levy (1989), to facilitate validation of the predicted values:

External dia	0.103 m
Internal dia	0.014 m
Particle mean dia	20 μm
External air velocity	22.5 m/s
Internal air velocity	42.5 m/s
Internal particle velocity	41.4 m/s
Internal CO_2 mass fraction	0.10

Measurement of CO_2 mass fraction distribution

CO_2 was used as a tracer gas during the concentration measurements in order to determine the mixing characteristics of the two coflowing concentric streams. The concentration measurements were performed at four axial locations using thin wall probes of 1 mm i.d. A suction pump equipped with a rotameter was used to ensure on-line isokinetic sampling of the gas in coordination with the local velocity measured by a Pitot-static tube. The analysis of the gas samples was done by means of a Philips PV-4000 series chromatograph.

Measurement of axial velocity profiles

The LDV system used during the experiments included a 15 mW He–Ne laser (Spectra Physics model 120S) directed to an LDV modular optics unit (DISA 55X). The signals were processed by an LDV counter unit (TSI model 1096) connected to a 12-bit A/D converter interfaced with a PDP 11/84 minicomputer. The comparator accuracy of the LDV counter unit, which determines the maximum allowable error in the frequency measurements, was usually set to 2%. The validated data rate of the counter was of the order of 1000 particles/s. The analog output was sampled at a frequency of 100 Hz, revealing a [validated data rate]/[sampling rate] ratio of the order of 10, in order to reduce velocity bias error. A population of 5000 samples was collected at each point. To allow for continuous seeding of the flow during LDV measurements, a particle seeder utilizing the fluidized bed principle was incorporated. A mixture of 5 and 20 μm mean diameter aluminum oxide particles, available from Buehler Ltd (Evanston, Ill.) was used for seeding. The smaller particles were assumed to follow the gaseous phase while the larger ones simulated the discrete particle phase.

The problem of crosstalk between the phases, where the signal amplitude of a large particle passing through the edge of the probe volume might be of the same order as that of a small particle crossing the center of the probe volume, was insignificant in this study, due to the large difference between signals originating from the two phases. The reduction of the acceptable signal zone in the control volume to $\sim 60\ \mu$m dia, by means of the pinhole in the photodetector, decreased the intensity differences within the effective control volume.

RESULTS AND DISCUSSION

The results of the experimental investigation are presented in figures 2 and 3. These comprise tracer gas concentration (mass fraction) and two-phase velocity measurement results. The predicted values of the corresponding variables described in Albagli & Levy (1990) are superimposed on these figures for convenience.

The measured CO_2 mass fraction distributions comply well with the predicted values, as seen in figure 2. Centerline ($r = 0$) CO_2 concentration decay is predicted better than that within the mixing layer ($r = 7$ mm), possibly because of the relatively simple mathematical model used to describe the turbulent diffusion of the gaseous species.

The evolution of the measured axial mean and fluctuating gas velocity profiles at distances of 25, 125 and 325 mm from the inlet plane are shown in figure 3(a). Smoothed profiles based on the measurements at the inlet plane were fed as the inlet conditions in the computer simulation (Albagli & Levy 1990). The predicted and measured values exhibit a rather sound agreement, though minor

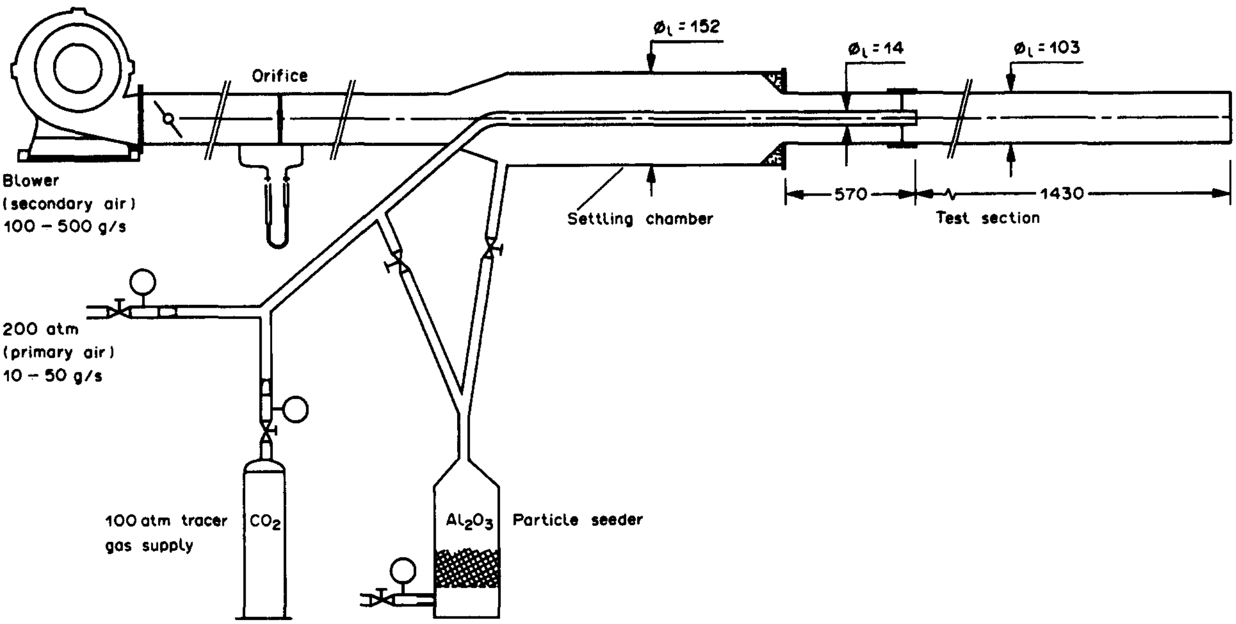

Figure 1. Schematic diagram of the experimental setup.

differences in the mixing region (at $z = 125$ mm plane) and on the centerline (at $z = 325$ mm plane) are observed. This is possibly due to the fact that the adopted conventional boundary conditions for the turbulence equations on the symmetry axis do not satisfactorily describe the behavior of the flow. On the other hand, the limited accuracy ($\sim 5\%$) of the LDV system in processing low signal-to-noise ratio signals originating from very small tracking particles might also contribute to the aforementioned discrepancies. The fluctuating velocity profiles also exhibit good agreement with predicted values. Although differences are larger than those of the mean velocity component, the general pattern is in nice agreement with predicted profiles.

The mean and fluctuating particle velocity profiles at the same measurement stations are shown in figure 3(b). The predicted and measured particle mean velocity values are in very good agreement, indicating the adequacy of the physical model and the measurement technique employed. No comparison is made between the fluctuating particle velocity values as this component was not modeled in the numerical simulations.

CONCLUSIONS

An experimental investigation on ducted mixing of coaxial two-phase jets has been described. The measured tracer gas concentration and two-phase velocity profiles are in close agreement with the previously reported predictions of a numerical simulation. The differences between the

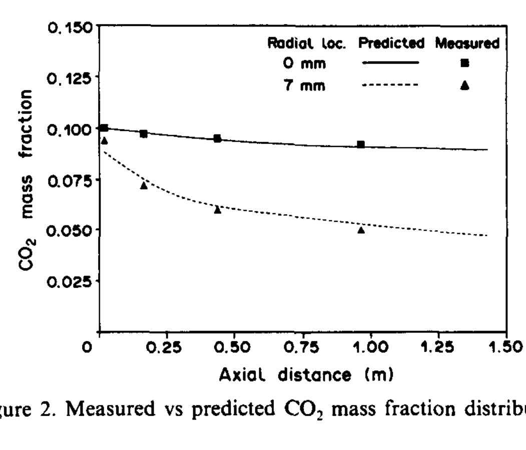

Figure 2. Measured vs predicted CO_2 mass fraction distributions.

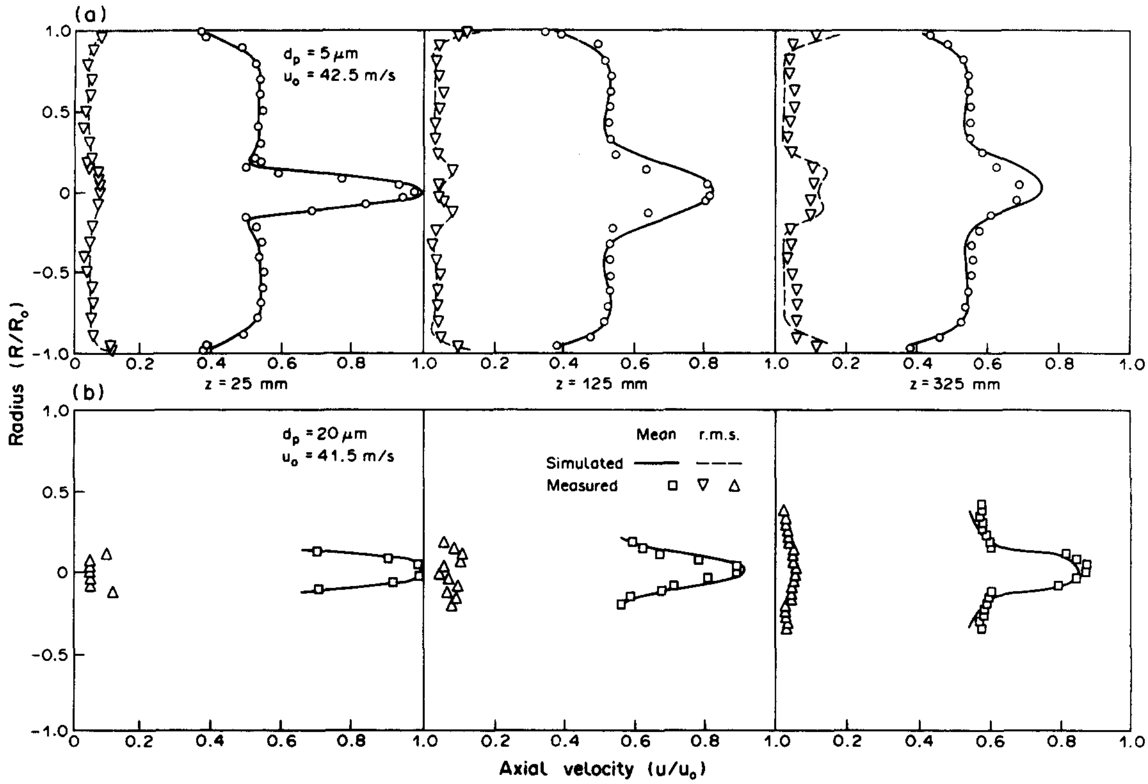

Figure 3. Measured vs predicted (a) gas and (b) particle phase velocity profiles downstream of the concentric jets.

measured and predicted velocity values are relatively low when all potential error sources are considered. This indicates that the measurement techniques used, including the two-phase LDV system, are appropriate for such studies.

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