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Combustion of Pulverized Coal in Vortex Structures

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Abstract

This seventh quarterly report describes the activities and accomplishments of the research team at the University of Oklahoma, Norman, Oklahoma, related to the project entitled "Combustion of Pulverized Coal in Vortex Structures" during the period April 1, 1995 to June 30, 1995. The work performed in this quarter consisted of the following four tasks: (i) conducting experiments with particulate laden shear layers to measure mean velocity and turbulence intensity field (ii) preparing an abstract for the 1995 UCR contractor's meeting, and a paper for the Energy Conference to be held in Houston in 1996, (iii) participating and presenting a paper UCR meeting in Nashville, Tennessee, (iv) design and installation of devices to traverse the test section while keeping the optics undisturbed, and (v) and design and testing of a natural gas burner system to heat either of the streams to conduct pyrolysis and combustion experiments. In the next quarter, we plan to continue this work with heated shear layers in which particles undergo pyrolysis and combustion. Flow visualization and mean velocity field measurement instrumentation will continue as the major experimental techniques.

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I. INTRODUCTION

This seventh quarterly progress report covers the overall objectives, the specific objectives for the reporting period, the organizational details, the work that has been accomplished during the reporting period, the work planned for the next quarter, and an assessment of the anticipated problems.

II. OVERALL OBJECTIVES

The overall objectives of the project are: (i) to investigate the changes in the characteristics of large scale vortex structures in the shear layer caused by the introduction of inert solid particles in one of the feed streams; (ii) to understand the effects of pyrolyzing solids on the shear layer behavior; (iii) to study the effect of combustion of the pyrolysis products on the shear layer structure, heat release rate, and pollutant emission characteristics; and (iv) to study the effect of modifying the shear layer characteristics on the ensuing flame behavior.

III. SPECIFIC OBJECTIVES FOR THE REPORTING PERIOD

The specific objectives for the reporting period were: (i) to conduct experiments with particulate laden shear layers to measure mean velocity and turbulence intensity field and (ii) to design and testing of a natural gas burner system to heat either of the streams to conduct pyrolysis and combustion experiments, (iii) to conduct flow visualization of heated streams, (iv) to prepare an abstract for the 1995 UCR contractor's meeting, and a paper for the Energy Conference to be held in Houston in 1996, and (v) to participate and present a paper in UCR meeting in Nashville, Tennessee.

IV. ORGANIZATIONAL DETAILS

Mr. Nelson Butuk, a graduate student in the School of Aerospace and Mechanical Engineering, pursuing his Ph. D. degree program continued to work as a research assistant assisting the principal investigator, Professor S. R. Gollahalli. Another graduate student

Mr. Michael Babb helped Mr. Butuk. The mechanical engineering technician of the School, Mr. Bill Hill, and the machinist, Mr. Steve Dean helped the research team during the reporting period.

V. WORK ACCOMPLISHED DURING THE REPORTING PERIOD

VA Mean Velocity and Turbulence Intensity Measurements in Unheated Particulate -Laden Shear layers

The three-dimensional traverse that was designed and constructed in the previous quarter was employed to traverse the laser velocity meter along a vertical plane at several streamwise locations. The traverses in two directions x and y (streamwise and horizontal direction perpendicular to it) were manually controlled. The traverse in the vertical z direction was computer-driven. The soft ware-using Strawberry systems QUICKLOG program was adopted for traversing the optics, recording pressure and temperature readings in the test section, and Pitot-tube data on-line. A GATEWAY microcomputer was used for this purpose.

The LDV is based on a helium-neon laser and grating-controlled detector system. The system was operated in forward scatter-mode. The laser Doppler analyzer operated with a transmitter lens of focal length 500 mm, a receiver lens of focal length 500 mm, and a 10 mW helium-neon laser. The transmitting and receiving optics were mounted on two identical precision x-y traversing mechanisms located on opposite sides of the combustion chamber. These devices had a traverse resolution of 80 μm. The instrument was operated in the forward scatter mode with a beam separation of 23.8 mm and a beam intersection waist width of 176 μm. Both nozzle and air-flow streams were seeded with magnesium oxide particles whose average size was about 5 μm. A microcomputer-based data acquisition system with a 16-MHz clock was used to acquire and process the output data of the LDV. The mean velocity in the axial direction, U, and the root mean square value of the fluctuating component, u', were determined from the LDV measurements. During experiments with cold jets only nitrogen was used as the jet fluid and its flow rate was adjusted to yield the same exit Reynolds number as that of the fuel jet of the corresponding flame. In all runs 200-2000 validated samples with a sampling time less than 15 seconds were acquired. The preliminary experiments showed that above 200 samples per run the measured values of the mean and r.m.s. components of the velocity were not sensitive to the sampling rate. For temperature measurement, a type K thermocouple (0. 25 mm diameter) was used. Some experiments were repeated 3 to 5 times to establish repeatability. The estimated values of the uncertainties in the measurements with thermocouple and LDV, and are ±3% and ±10% respectively.

For measuring continuous phase velocity, magnesium oxide particles of mean diameter 2 μm were injected with a fluidized bed feeder into the top stream. When coal particles were injected they were fed into the top stream with the same feeder. Both MgO and Coal particles prepared following the procedure explained in the sixth quarterly progress report were treated heated in furnace at 75 °C for over four hours, again to minimize agglomeration. The fludization was achieved by supplying air from a compressor or bottled nitrogen through a rotameter. The flow rate of gas that carries the fluid into the stream was maintained less than 0.01% of the flow rate of the top stream. The fludizing gas was passed through a moisture absorber to avoid coagulation of particles in the feeder. An electric solenoid valve was installed in the gas line entering the feeder with on-off switches located in the control room and in the test cell. With these switches, particle flow into the stream could be established for the desired measurement period only. The dispersed phase velocities were measured using injected particles. A COMPAQ microcomputer and data processors were used for data acquisition and on-line/off-line data analysis. The data obtained include, streamwise component of mean velocity, r.m.s value of the fluctuating components of the streamwise velocity, and size-velocity correlations.

For simultaneous measurement of particle and continuous phase velocity, MgO and pulverized coal were mixed and placed in the particle feeder. Histograms of velocity versus size show binary distribution. From the velocity-particle size correlation data the velocity associated with particle size could be isolated and thus particle and continuous phase velocities were obtained.

Tables 1 and 2 show the details of coal particles used and ranges of variables covered for particle-laden shear layer experiments. Figure 1 and 2 show the profiles of mean velocity at various distances from the splitter plate. Figure 3 shows the shear layer growth rate represented in terms of vorticity thickness variation with distance from the virtual origin with particles. Figure 4 compares the shear layer spread parameter correlation plotted in the manner indicated by Brown and Roshko (1974). Figure 5 shows the effects of particles on the turbulence (rms value of fluctuation in streamwise velocity) profiles and Figure 6 compares the effects of particle size on the on turbulence.

VB Design and Testing of Natural Gas Burner System to Heat the Streams.

The pyrolysis temperature of the coal employed in this study is 570 K (Prasad, 1987). Hence, to study the effects of pyrolyzing particles on the shear layer characteristics, the stream into which the particles are injected has to be heated above that temperature. Since, the temperature drops in the shear layer due to mixing with the other stream, to ensure the temperature remains above the coal pyrolysis temperature the particle stream was to be heated to about 1000 K. Also, to achieve ignition and sustain combustion of coal particles in the shear layer, the shear layer has to be maintained above the ignition temperature of coal which in the present case is about 673-1073 K (Bartok and Sarofim, 1991). To allow for the radiation cooling and convective heat transfer to the test section walls, we decided to maintain a over ventilated diffusion flame of natural gas in the test section. For accomplishing both these goals, we designed a burner system fueled with compressed natural gas. This burner was designed such that it could be mounted at different distances upstream of the splitter plate and could be easily exchanged from the top stream to the bottom stream.

Figure 7 shows a sketch of the burner. It consisted of several 6 mm diameter stainless steel tubes attached to a 25 mm diameter manifold which was connected to the CNG cylinder through a pressure regulator and a rotameter. On each tube, holes of 1 mm diameter have been drilled to allow the natural gas flow in the air stream direction. This burner tube bank can be mounted in either top or bottom flow, downstream of the contraction section in the shear layer tunnel, thus allowing heating and combustion in either of the flow streams. With regulation of the location of the burner relative to the splitter plate, the location of ignition of particles injected can be changed. Also, by suitably regulating the natural gas flow, the temperature in the test section can be adjusted to the desired value. The temperature profile in the section at the end of the splitter plate show that the temperature is uniform within ± 2% except near the walls of the test section due to the thermal boundary layer.

VC Development of Iso-Kinetic Sampling System

The concentration of particulates (coal or MgO) were determined by drawing samples of the particle-laden flow with a large probe (internal diameter 5 mm), filtering the sample of a known volume of flow, and weighing the filtered particles. In turbulent flows, if the velocity of flow entering the probe is not the same as the free stream mean velocity, because of the deflection of the streamlines, sampling bias will be introduced. Hence, iso-kinetic sampling where the two velocities were kept equal was employed in this project. Figure 8 shows the experimental facility constructed for this purpose. The apparatus consists of a stainless sample probe, a detachable filter holder in the line, a calibrated rotameter, and a vacuum pump. The procedure consisted of adjusting the flow rate through the filter to make the velocity at the entrance to the probe equal to the free stream mean velocity in the gas flow with the filter and timing the flow for a known volume of gas passing through the filter. The filter paper was conditioned and weighed before and after the particle collection. By noting the flow rate, time of collection, and the particulate mass collected, the dust loading (mass concentration) in the gas was determined.

VI. WORK PLANNED FOR THE NEXT QUARTER

In the next quarter, we plan to pursue the following: (i) conduct the mean velocity field probing in nonisothermal shear layers with burning and pyrolyzing particles, (ii) continue our effort to improve schlieren visualization system to resolve vortical structures, (iii) obtain the rms values of fluctuating velocity and its distribution at several locations of the shear layer with combusting-particle laden flows, and (iv) condcut exhaust gas analysis.

VII. ENCOUNTERED and ANTICIPATED PROBLEMS

In this quarter we experienced several problems in the operation were encountered in the design and fabrication of the burner system to yield the desired temperature levels in the test section. Now the burner system is working well and the initial tests are encouraging. Further, the installation of safety system to cut off the fuel flow to the test section under emergency situations introduced some delays. Because of these cumulative factors and vacations and resignations of personnel in the machine shop on which we have no control, we expect some more delay in completing the project. Hence, we will be requesting a " 90-day no cost extension" of the project.

VIII. CONCLUDING REMARKS

During the seventh quarter we have achieved substantial progress in the project. The accomplishments include (i) completion of all LDV measurements in both cold and heated homogeneous flows, (ii) preparing a paper on heated shear layers for the 1996 Energy conference in Houston, Texas, (iii) presenting our project in the DOE contractors' meeting in Nashville, Tennessee, (iv) designing and constructing the burner system to conduct experiments with combusting particles, (v) designing and constructing the iso-kinetic sampling system to determine concentration of particles, and (v) installing an automated traverse to move the test section while conducting LDV experiments.

Because the problems encountered in developing the burner system, additional time required to install the safety features, and the work-slow down due to personnel resignations and vacations in the machine shop beyond our control, we expect some delay in completing the project. Hence, we are requesting a 90-day extension of the project until December 31, 1995.

IX REFERENCES

Bartok, W. and Sarofim, A. F., 1991, "Fossil Fuel Combustion, A Source Book," John Wiley and Sons, Inc., New York, NY, USA.

Brown, G. L. and Roshko, A., 1974, "Density Effects and Large Scale Structures in Turbulent Mixing Layers," J. Fluid Mechanics, Vol. 26, pp. 225-236.

TABLE 1

Particles

Continuous Phase	MgO (2±1 μm)		
Coal:	Bituminous, Illinois No. 3		
Size	38±5 ; 68±5 μm		
Composition	Moisture	5.36 %	
	Volatile matter	39.20 %	
	Fixed Carbon	52.48 %	
	Ash	8.36 %	
	Carbon	73.82 %	
	Hydrogen	4.94 %	
	Nitrogen	1.68 %	
	Oxygen	8.75 %	
	Total sulfur	2.27%	
Calorific Value		31.24 Mj/kg	
Particle Density			
	Coal	1.4 kg/m^3	
	MgO	3.5 kg/m^3	
Particle loading	(top stream)	0.01	kg/kg
Number density		10^9 / m^3	

TABLE 2

RANGES OF EXPERIMENTAL SETTINGS

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I. Homogeneous Shear Layer Experiments

IA Cold-flow experiments

	Stream 1 (top)		Stream 2 (bottom)	
Set No.	Velocity (m/s)	Temperature (K)	Velocity (m/s)	Temperature (K)
1	12.8	298	4.6	300
2	15.3	297	4.8	299
3	20.4	297	4.9	300
4	21.2	297	14.2	298
5	19.6	299	6.3	301
6	18.0	299	14.5	300
7	18.0	300	15.4	300

IB Experiments with one stream (top) heated

8	12.3	385	4.6	307
9	14.7	377	5.1	303
10	20.3	360	5.0	305
11	25.3	360	8.9	314
12	24.0	360	17.3	294
13	24.0	364	18.9	299

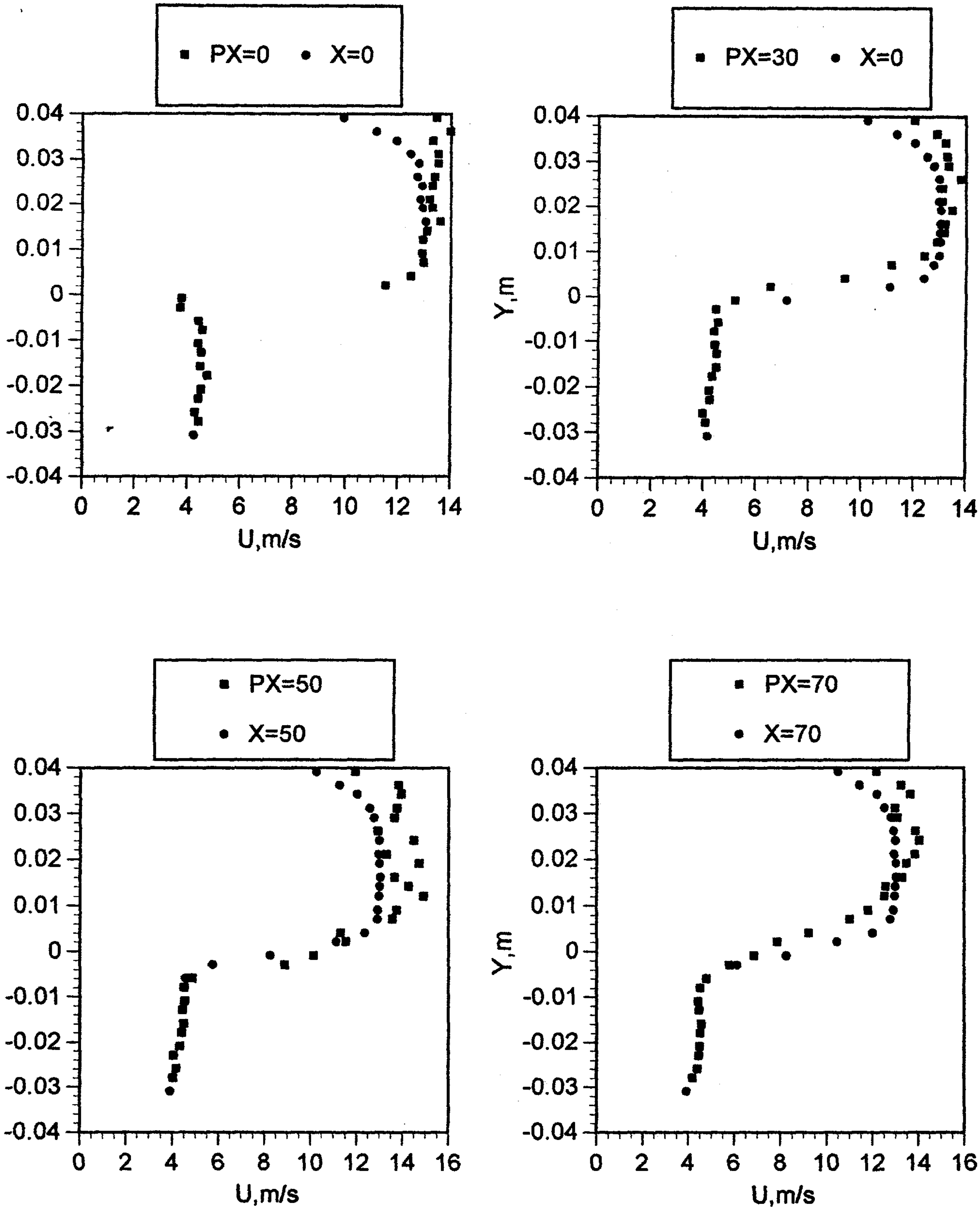
II Particle-Laden Shear Layer Experiments

IIA Cold Flow Experiments- (continuous phase seeding with 2 μm MgO)

Set No.	Velocity (m/s)	Temperature (K)	Velocity (m/s)	Temperature (K)	Particle size (μm)
14	12.5	299	5.0	302	38
15	12.5	297	5.0	299	68
16	17.6	296	5.0	298	38
17	17.6	299	5.0	301	68
18	12.5	298	5.0	300	0
19	17.6	298	5.0	300	0

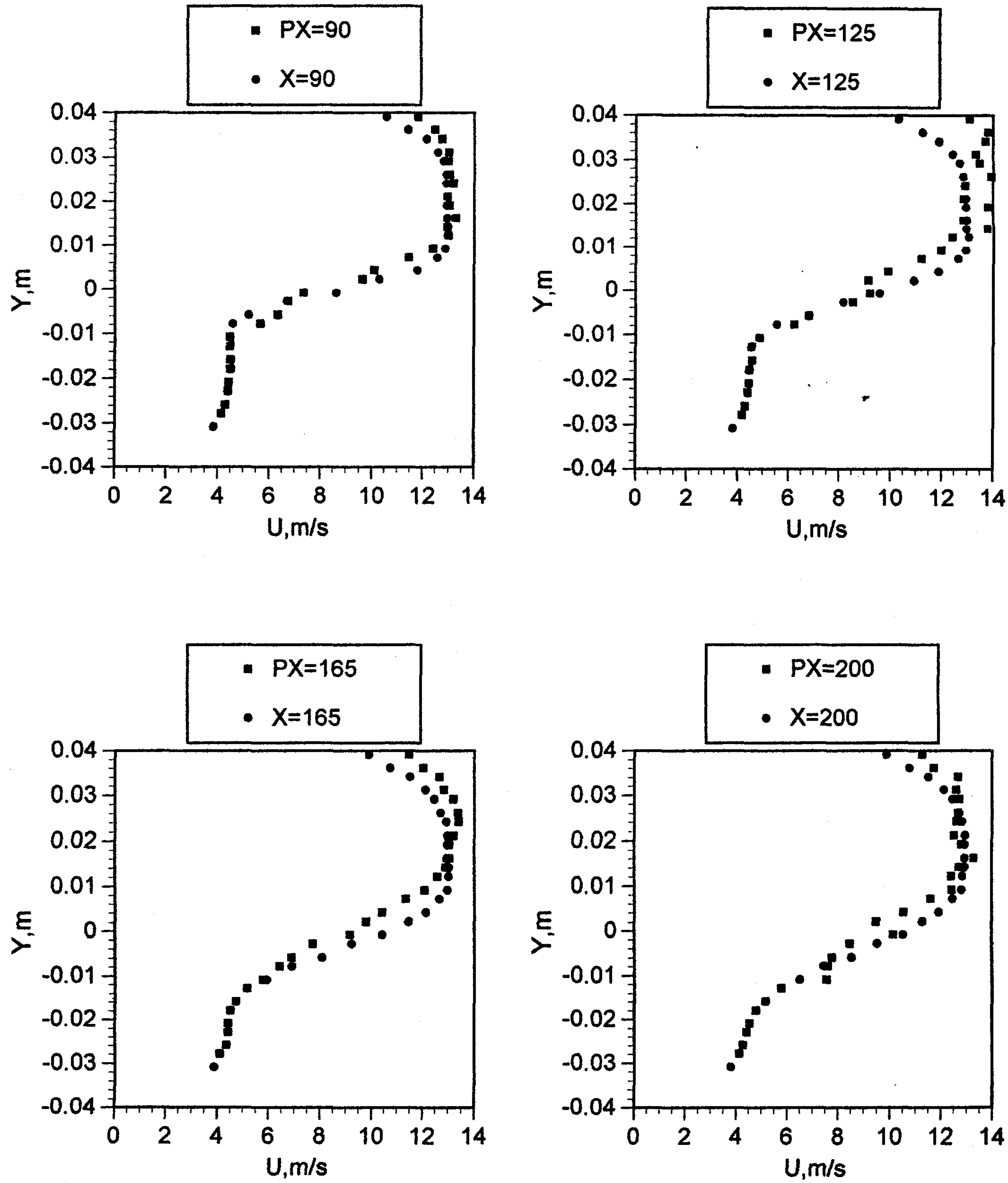
III Turbulence Data Comparison at x=200 mm (continuous phase seeding with 2 μm MgO)

20	12.5	297	5.0	298	(Heated)
21	12.5	298	5.0	300	38 μm
23	12.5	298	5.0	300	68 μm
24	12.5	385	5.0	306	(Heated)



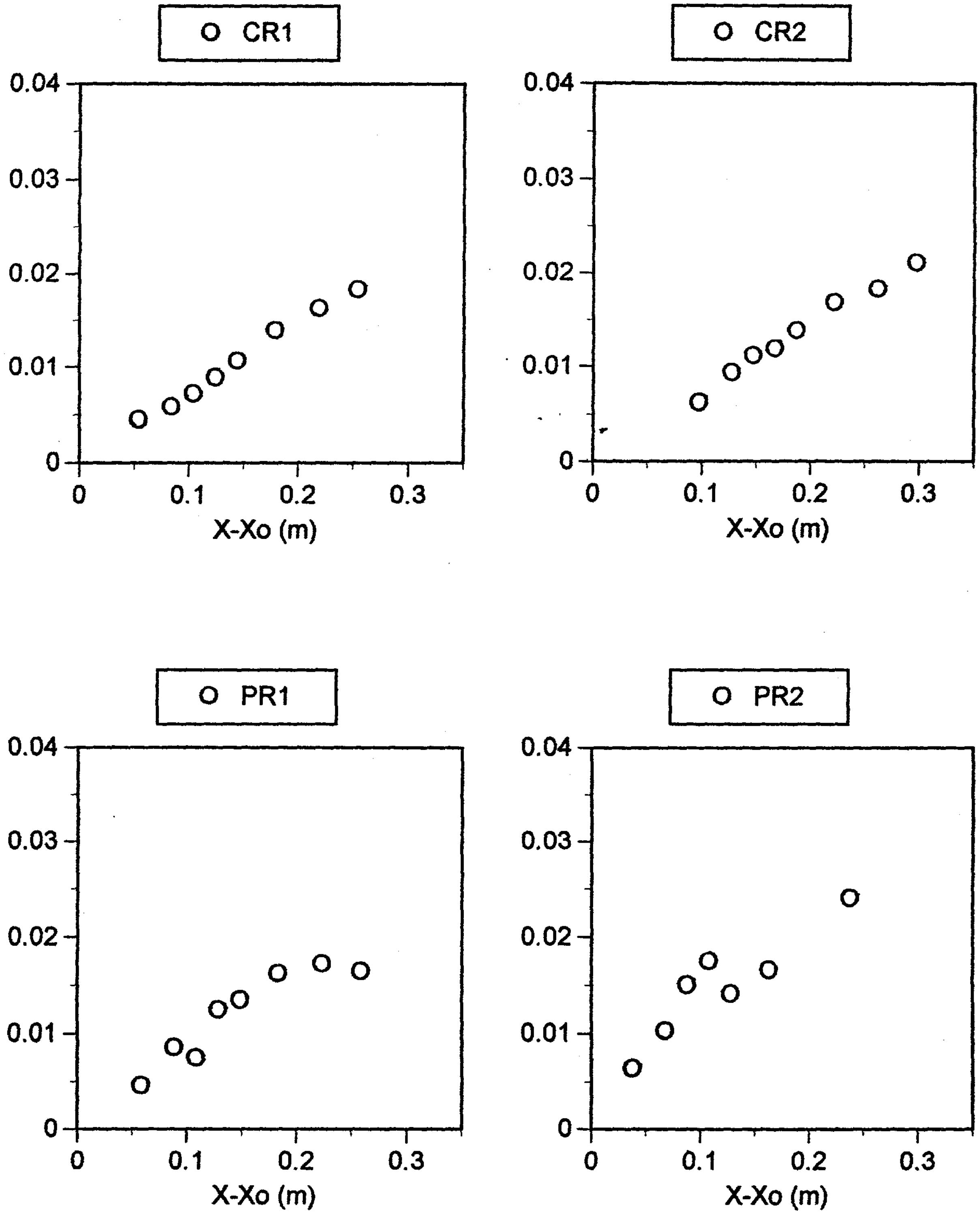
Comparison of shear layer velocity profiles for homogeneous and particle laden flow. X refers to homogeneous at velocity ratio R1=0.42. PX refers to particle laden flow at the same velocity ratio. Particle size is 38 microns.

Fig. 1



Comparison of shear layer velocity profiles for homogeneous and particle laden flow. X refers to homogeneous at velocity ratio R1=0.42. PX refers to particle laden flow at the same velocity ratio. Particle size is 38 microns.

Fig. 2



Growth rate, delta (m) vs X (m) for homogeneous and particle laden shear layers. The velocity ratios were R1=0.42 and R2=0.29. The particle size was 38 microns. C refers to homogeneous and P to particle laden flows.

Fig. 3

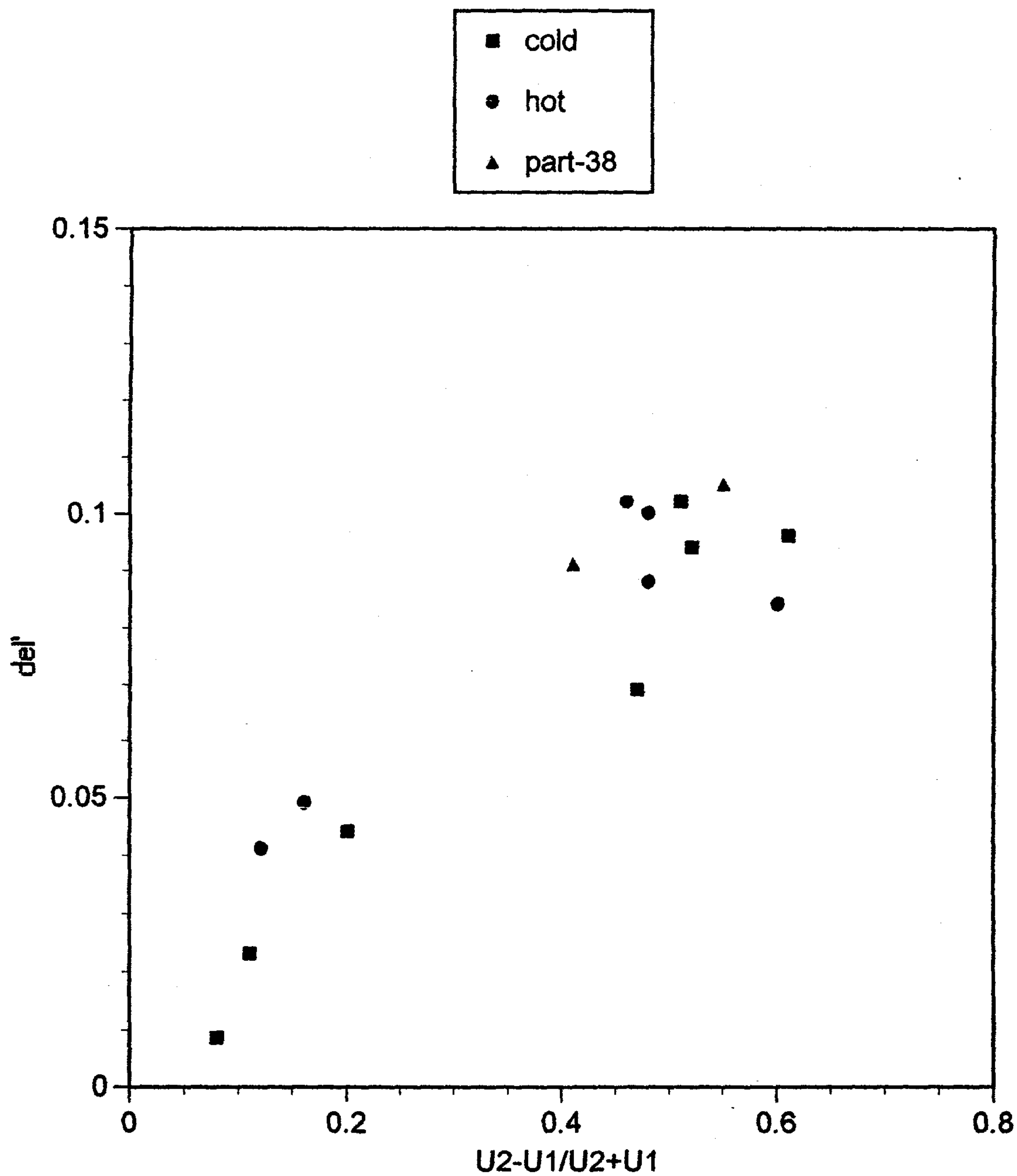
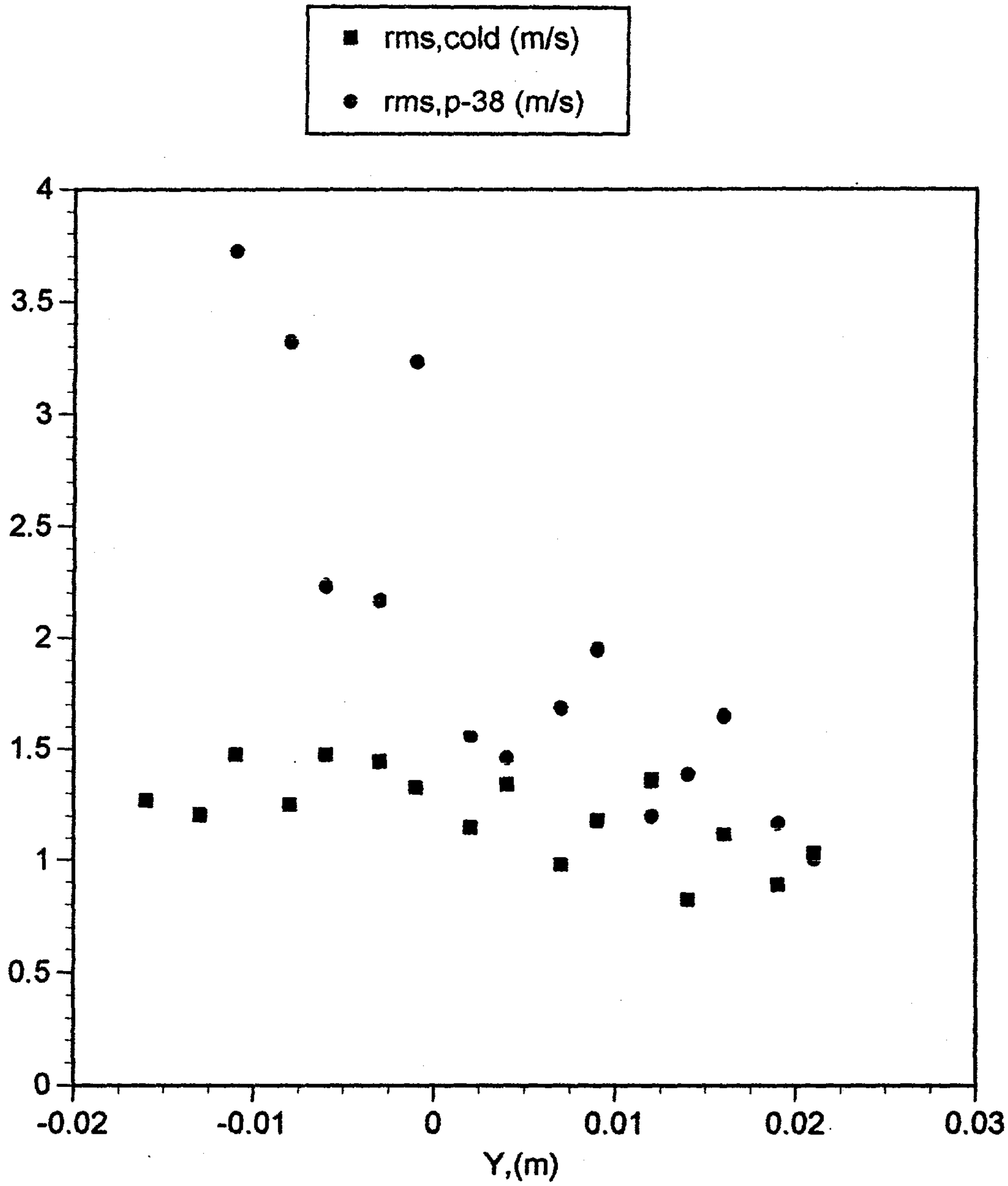
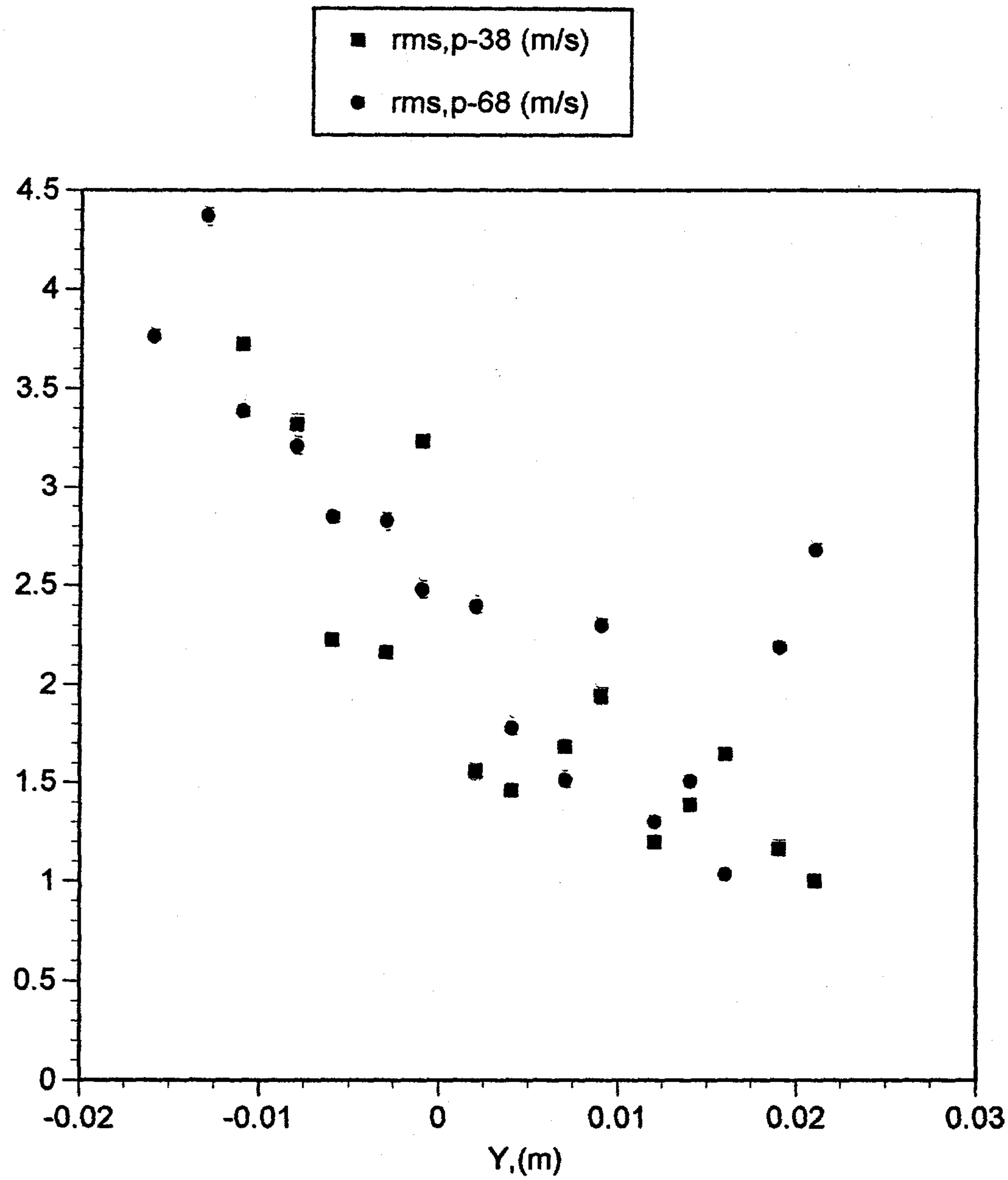


Fig. 4



Turbulent, rms (u') values in m/s vs Y (m). The lines are fitted 4th polynomials.



Turbulent, rms (u') values in m/s vs Y (m).

Fig. 6

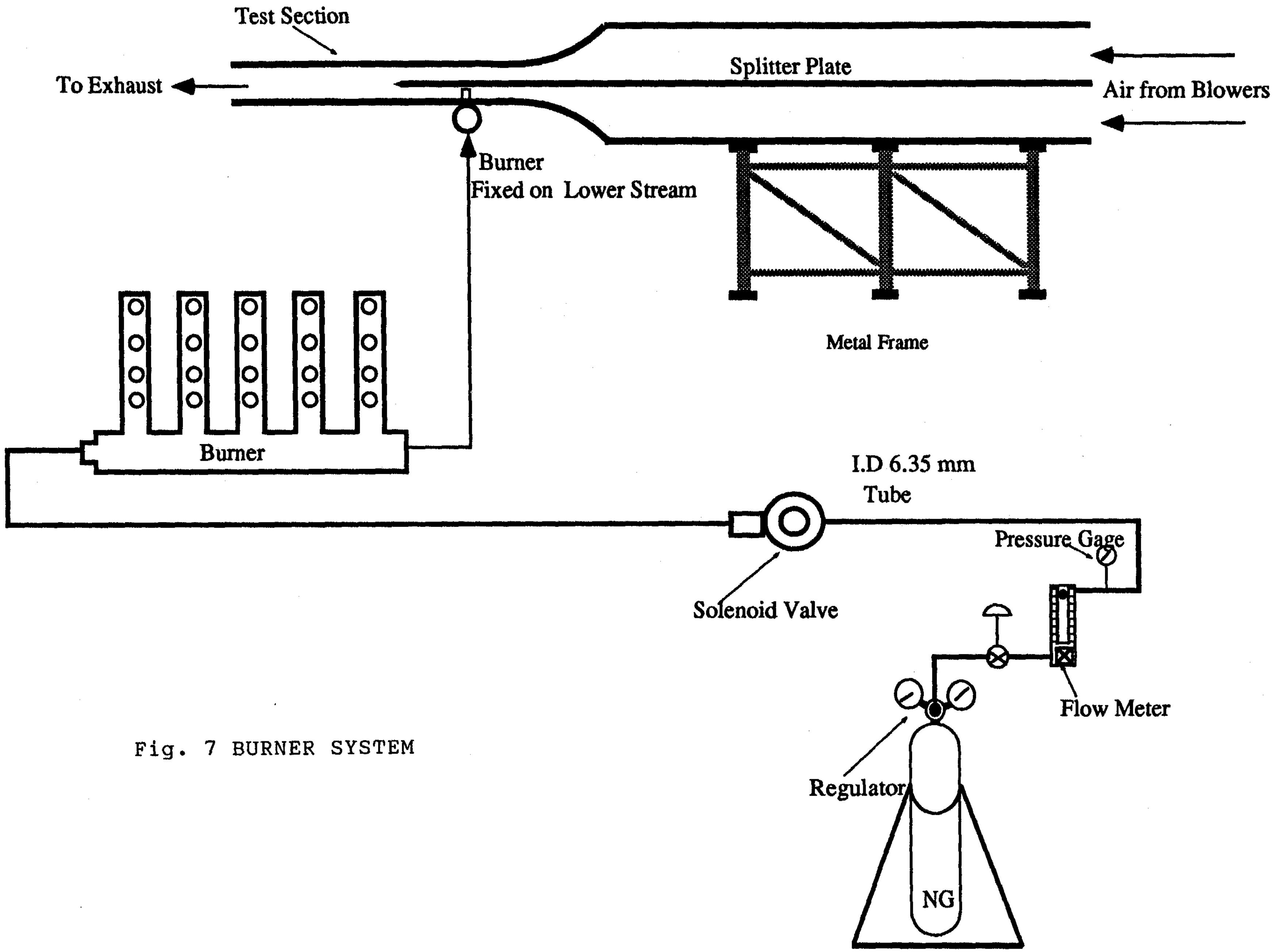


Fig. 7 BURNER SYSTEM

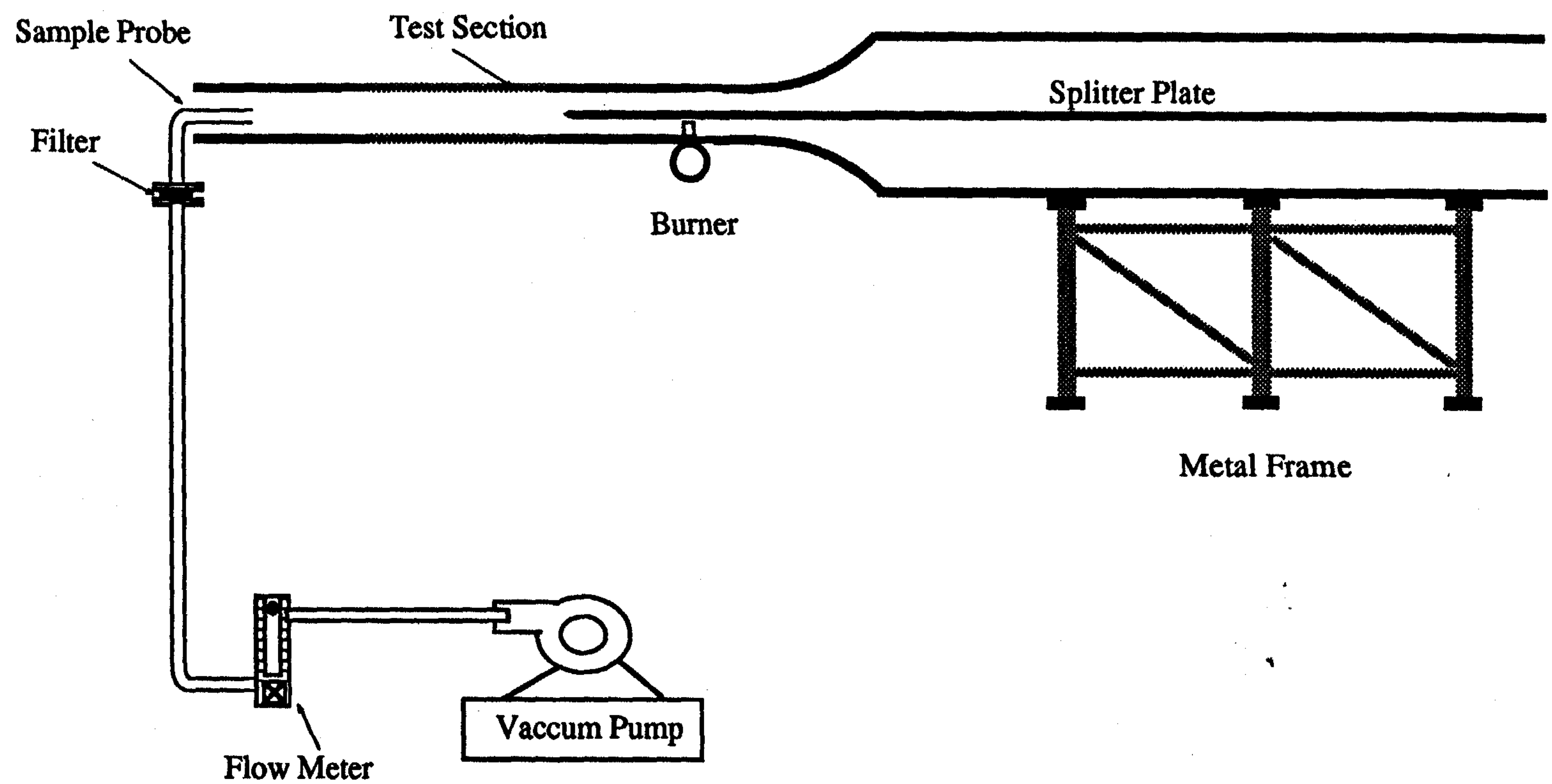


Fig. 8 ISO-KINETIC SAMPLING SYSTEM