Journal of Visualization, Vol. 8, No. 4 (2005)293-294

**Short Paper**

# Simultaneous Flow Visualization and PIV Measurement of Turbulent Buoyant Plume

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Received 1 June 2005 and revised 19 July 2005

## Introduction

Turbulent buoyant plume is a fundamental flow configuration in thermal and fluid engineering. So far, the statistical properties of the turbulent plume have been studied by Murota et al. (1989), Shabbir and Geroge (1994), Funatani et al. (2004) and others. However, the mechanism of heat transfer in the plume has not been fully understood in literature, which is mainly due to the lack of experimental technique for visualizing the three-dimensional structure of complex flow phenomena (Fujisawa and Adrian, 1999).

The purpose of this paper is to introduce an experimental technique to the turbulent buoyant plume for visualizing the three-dimensional flow structure.

## Experimental Setup

A schematic illustration of experimental apparatus for a turbulent buoyant plume is shown in Fig. 1. The experimental test section is filled with cold water (30 deg), in which hot water (60 deg) is issued through a circular nozzle from the bottom of the test section to generate a turbulent buoyant plume in stagnant surroundings. The diameter of the nozzle is $d$ = 20 mm and the bulk velocity $V_0$ at the nozzle exit is $V_0$ = 10 mm/s, so that the source Reynolds number Re = 420 and the source Froude number $F_{ro}$ = 0.2. The experimental details have been described by Funatani et al. (2004).

The simultaneous flow visualization and PIV measurement of planar velocity fields was carried out at vertical and horizontal planes of the plume, synchronously. The flow visualization was conducted by laser-induced fluorescence technique using the Rhodamine B solution and an Ar continuous laser sheet (488 nm, 0.8 W) in the vertical plane and a Nd:YAG pulse laser sheet (532 nm, 50 mJ) in horizontal plane. Note that nylon tracer particles of 20 μm in diameter are added to the test fluid for visualizing the velocity field by PIV. The observations are made by two color CCD camera (768 x 494 pixels with 8 bit for each RGB), which are placed normal to each light-sheet plane and are operated synchronously. It should be mentioned that the tracer particles appear in the blue or green image and the orange color of Rhodamine B appears in the red image. Therefore, the particle image and Rhodamine B image can be separated by color image analysis. The time interval of the Nd:YAG lasers was set to 25 ms using the pulse generator control, while that of the vertical plane was fixed to the frame rate of the camera (= 1/60s). The PIV analysis was conducted by using a cross-correlation analysis with sub-pixel interpolation.

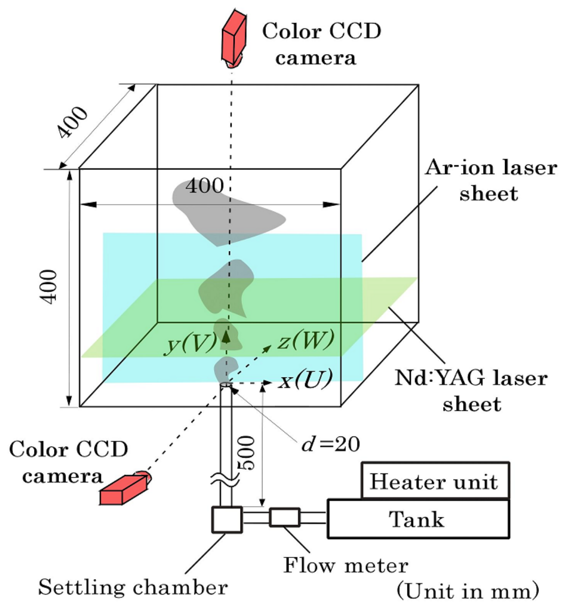


Fig. 1. Experimental setup.

## Results and Discussion

Figures 2(a) and (b) indicate a typical result of simultaneous flow visualization and PIV measurement of the buoyant plume, showing the visualization picture of the plume and the velocity field, respectively. Each consists of the result on the vertical plane through the plume axis and that on the horizontal plane at height 3d (= 60 mm) from the nozzle exit. The flow visualization picture in vertical plane indicates that the plume develops vertically entraining the surrounding fluid into the plume and forms staggered vortices on both sides of the plume. The plume undergoes compression and expansion phases, where the width of the plume becomes narrower and wider, respectively. These flow features are well reproduced in the velocity field measured by PIV, that is, the higher velocity is observed in the compression phase and lower velocity is found in the expansion phase. On the other hand, the synchronous observation of horizontal flow visualization shows non-circular shape of the plume in radial direction, representing an asymmetric growth of the plume structure. Note that the flow in the horizontal plane is found to be in compression phase. According to the horizontal velocity field, a higher radial velocity is found in the colored region in the visualization picture. Therefore, the feature of the horizontal velocity field is similar to that of the flow visualization picture, too. These results indicate that the experimental technique for simultaneously visualizing the flow and velocity field in multiple planar-sections provides a useful tool for understanding the structure of the turbulent buoyant plume.

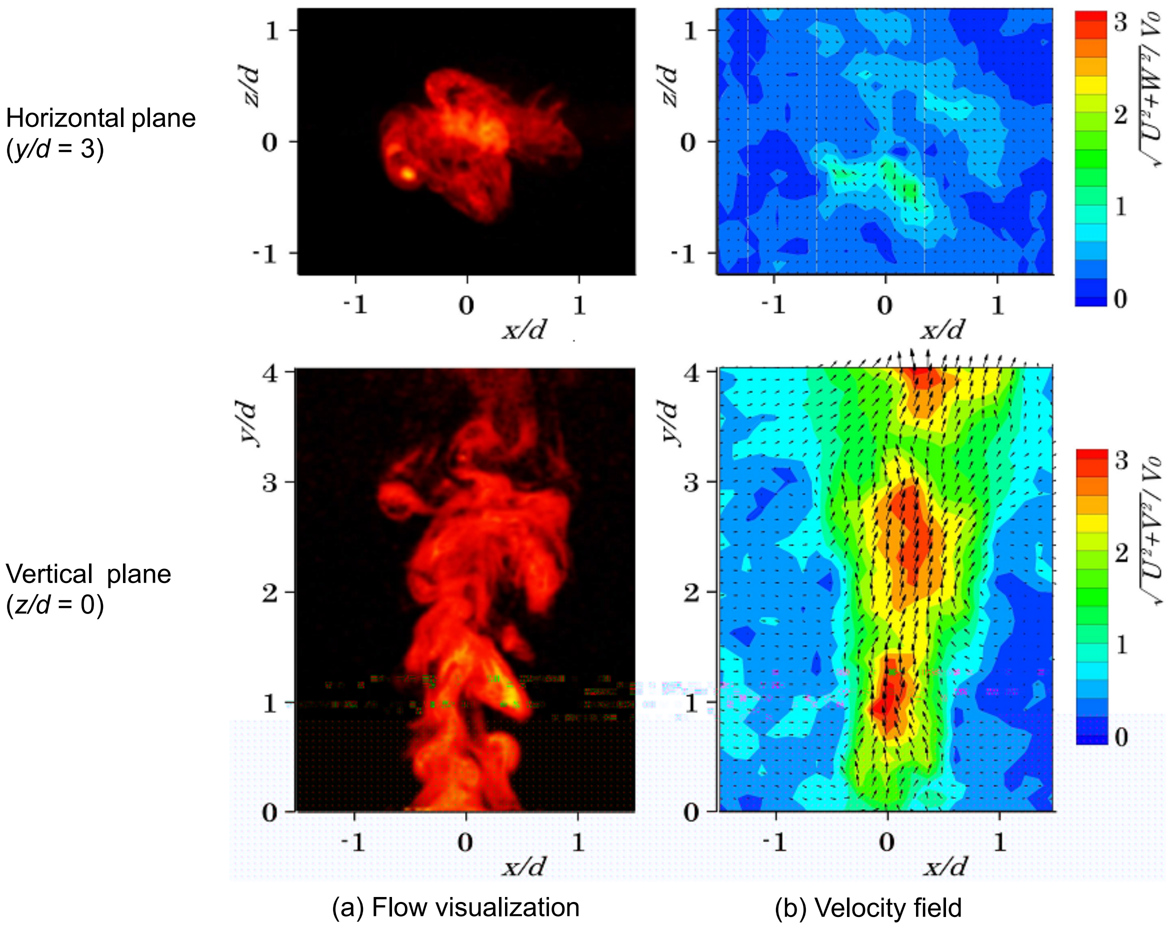


Fig. 2. Flow visualization and instantaneous velocity field of buoyant plume.

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