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# PIV measurement of the flow field in rectangular tunnel

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**Abstract** : The development of fluid mechanics is briefly reviewed and the importance of fluid flows to heat and mass transfer in nature as well as to science and engineering is outlined. This paper presents the experimental results of air flow in the rectangular tunnel which has four different exhaust outlets, each distance of which from the inlet is 0, 30, 60 and 90mm respectively. This experiment is conducted by using the olive oil as the tracer particles and the kinematic viscosity of the air flow is $1.51\times10^{-5}$ $m^2/s$. The flow is tested at the flow rate of 1.3 $m^3/h$ and the velocity of 0.3 m/s. PIV technology can be used to make a good description of the smoke flow characteristics in the tunnel.

**Key words** : PIV, Average velocity vector, Streamlines, Vorticity, Flow manager

## 1. Introduction

The study of flow field in the rectangular tunnel has been investigated by numerous researchers during the past century or more. The earliest quantitative velocity measurements in fluid flows were obtained using Pitot-static tubes[1]. The subsequent introduction of hot-wire anemometers in the 1920s was a significant advance, especially in terms of probe miniaturization, frequency response, and the ability to measure multiple velocity components. But this technique requires the insertion of a physical probe which can intrude into the flow itself. The invention of the laser in the 1960s led to the development of the laser-Doppler anemometer which uses a laser probe to enable non-intrusive velocity measurements. At that time, most flow field data available were obtained by using laser doppler velocimetry(LDV). Liou et al[2]. observed mean velocities, turbulence intensities and Reynolds stresses by LDV in a rectangular tunnel(1:2) at a Reynolds number of 33,000. Halim (1988)[3] also carried out the LDA measurements both in staggered and in-line geometries and found higher transverse mean velocities in the staggered array but the turbulence levels in both geometries were similar. Meyer (1994) also employed LDA to measure two

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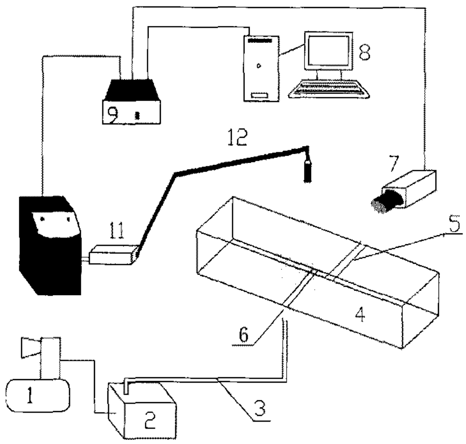
dimensional mean velocities and Reynolds stresses in two successive rows in the middle of tube bundle. The measurements were compared with predictions using both a standard k-e model and the second moment closure proposed by Launder et al. (1975). Hirota et al.[4] performed the secondary flow patterns caused by perpendicularly arranged square ribs in a square duct. However, most available data were limited to perpendicular ribs in square ducts or high aspect ratio rectangular ducts at high Reynolds numbers. In addition, because LDV usually makes measurements at a single point, it has the limitation that it can not capture the simultaneous spatial structure of a flow field.

In this study, particle image velocimetry (PIV) is used to observe the characteristics of the flow structure in a rectangular tunnel. PIV is a whole-flow-field technique providing instantaneous velocity vector measurements in a cross-section of a flow. It is a non-intrusive optical method and is possible to obtain instantaneous velocity maps in a flow plane of interest. By post-processing, the mean velocity maps and instantaneous or average vorticity maps can be obtained[5]-[6]. Over the past decades, PIV has matured from its developmental stage to a reliable whole field flow measurement technique and now finds usages in a continuously broadening range of applications. This of course made a number of special implementations of the PIV technique necessary to suit the needs of many different fields such as biological research or turbo machinery, for instance. An especially important field of PIV applications is that of industrial aerodynamic research. PIV systems for the investigation of air flows in wind tunnels must be capable of recording low speed flows[7] (e.g. flow velocities of less than 1 m/s in turbulent boundary layers) as well as high speed flows with flow velocities exceeding 500 m/s (e.g. supersonic flows with shocks). Flow fields above solid, moving or deforming models are also frequently associated with flow reversals. The application of the PIV technique in large, industrial wind tunnels poses a number of special problems: large observation areas, large observation distances between camera and light sheet, time constraints in the setup of the PIV system and high operational costs of the wind tunnel[8].

This paper presents the experimental results of air flow such as velocity field, streamline field and vorticity in the rectangular tunnel which has the different locations of the exhaust outlets. The main objective of this paper is to implement PIV measurement technique to study air flow and to investigate the flow in a rectangular tunnel model by using PIV.

## 2 Experiment

The experiment equipments are made up of four basic components: (1) An optically transparent test-section containing the flow seeded with tracer particles; (2) A light source (laser) to illuminate the region of interest (plane or volume); (3) Recording hardware consisting of either a CCD camera, or film, or holographic plates; (4) A computer with suitable software to process the recorded images and extract the velocity information from the tracer particle positions. The experiment equipments are shown in Fig. 1.




1. Compressor
2. Atomizer
3. Inlet tube
4. Tunnel model
5. Outlet
6. Inlet
7. CCD Camera
8. Host computer & Software
9. System Hub
10. Operating device of Nd-YAG Laser
11. Nd-Yag Laser
12. Mirror arm

**Fig. 1 A schematic of experimental equipments.**

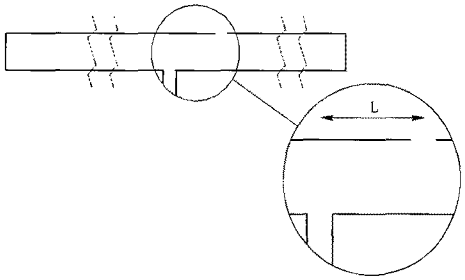



**Fig. 2 The test section of the experiment. (L=0, 30, 60 and 90mm)**

The transparent acrylic rectangular tunnel of the test section is presented in Fig. 2. The length, height and width of the tunnel model is 800 mm, 80 mm, and 80 mm respectively. As shown in Fig. 2, the inlet is positioned in the middle of the tunnel bottom, while the outlets are located at four different positions at the top of the tunnel. The distance between the inlet and each outlet is specified as L (L=0, 30, 60, and 90 mm). The width and length of the inlet, as same as each outlet, is 30 mm and 80 mm respectively. The olive oil flow made by an air compressor enters the rectangular tunnel through the plastic-pipe and then exits through the upper outlets. In order to get the appropriate flow speed, a plastic-trunk is used for lower speeds and a small axial flow fan is installed to provide uniform flow speed. Each image is captured by the CCD camera which is positioned at right angle to the light-sheet in the Dantec PIV 2000 system. And the each image corresponds to two pictures: the picture A taken at time T and the picture B taken at time T+Dt (Dt depends on the time between pulses). Then the pictures are input into the PIV processor software FlowManager.

In this software, for reasons of experimental reproducibility, the raw vector map is archived and a new validated vector map is output. Further analysis can produce streamlines, vorticity and so on.

## 3. Results and discussion

In this experiment, the experimental flow is an atomizing smoke at the same speed and the same thickness, using the jet fan to control and change the speed of the smoke flow in the tunnel. The olive oil has been used as the tracer particles and the kinematic viscosity of the air flow is $1.51\times10^{-5}\ m^2/s$.

### 3.1 The average velocity vector graph

The smoke flow characteristics have been tested at the flow rate of $1.3 m^3/h$ and the velocity of 0.3 m/s. In Figures 3 to 6, mean velocity vector fields are analyzed at the same Reynolds numbers, Re=1600. In order to show the flow velocity fields at the inlet and outlet, the cross-sectional image of 145 mm x 80 mm area has been examined by using PIV.

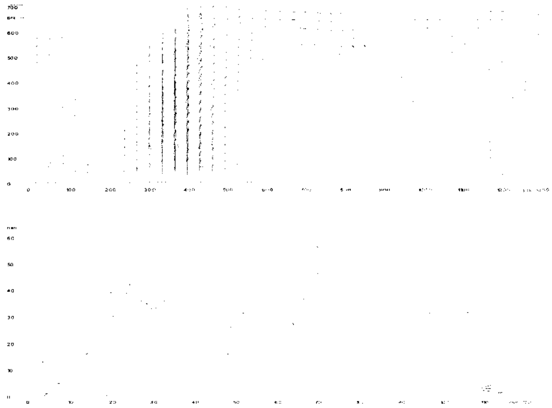


**Fig. 3 The average velocity vectors and streamlines (Re=1600, L=0 mm)**

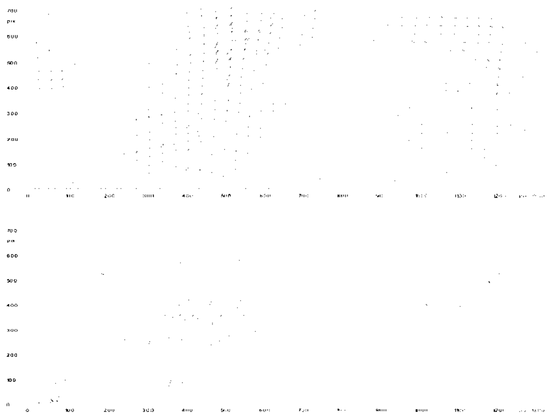


**Fig. 4 The average velocity vectors and streamlines (Re=1600, L=30 mm)**

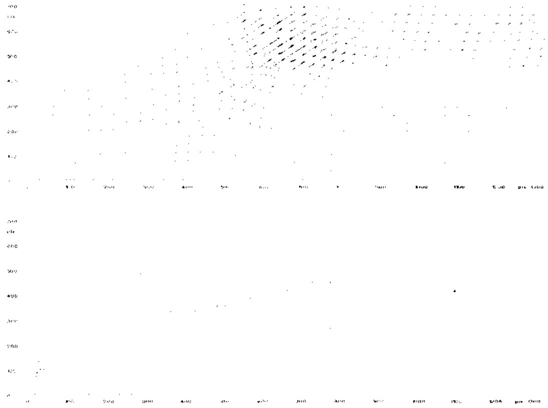


**Fig. 5 The average velocity vectors and streamlines (Re=1600, L=60 mm)**

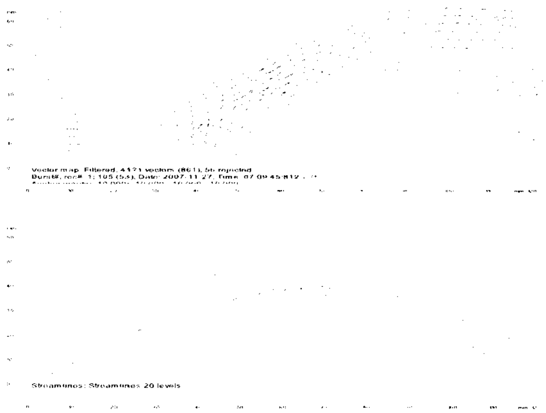


**Fig. 6 The average velocity vectors and streamlines (Re=1600, L=90 mm)**

Figures 3 to 6 demonstrate the image of distribution of average velocity produced by PIV test analysis. Fig. 3 reveals the average velocity vector graph as well as the streamlines at the cross section (145 mm x 80 mm area) of the tunnel. The Reynolds number is 1600. When the exhaust outlet is at the top of the inlet position, smoke flows windward in the upwind direction near the inlet point, and the circumfluence is more active. Getting away from the inlet point region, the diffusion and emission of smoke have not been significantly improved. Therefore, without considering the temperature, the exhaust device installed on the top of the inlet point is not conducive to people who stay in the leeward direction to escape. Moreover, because of the smoke flowing to the windward direction, it is adverse to prevent the spread of fire as well as to put out the fire by fire fighters. Nevertheless, the exhaust situation near the outlet has not been improved significantly.

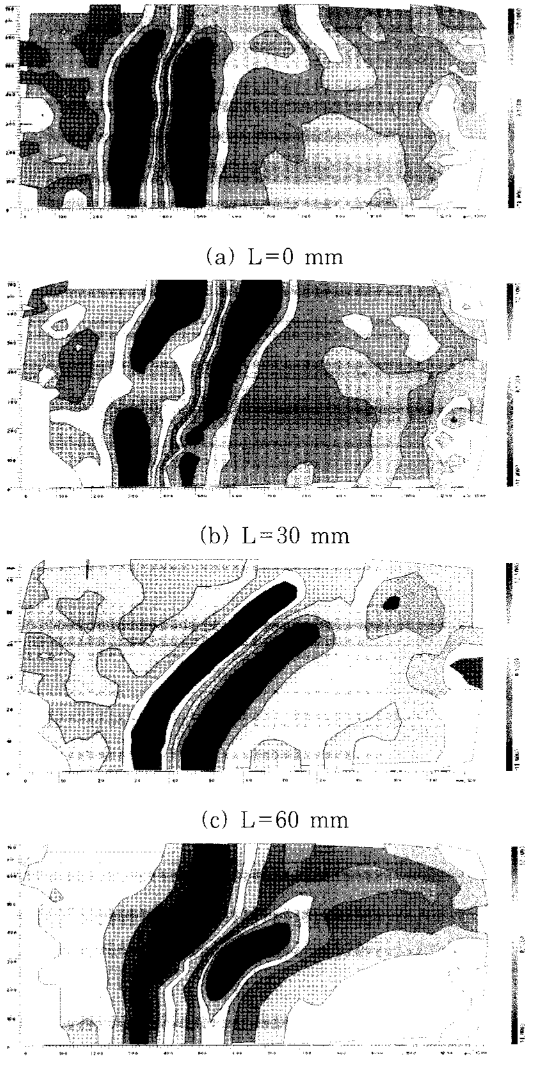
In Fig. 4, the exhaust outlet is located at the right upper 30 mm away from the inlet position. The smoke in the region of the inlet point gets improved especially by circumfluence which is found at the tunnel bottom from the region of inlet point to the exhaust outlet. The increase of longitudinal velocity of the smoke makes the smoke spread to leeward direction. It brings a lot of convenience for firemen to put out the fire, but smoke emission has not been improved near the exhaust outlet. If the exhaust device is installed in this position, there will not be much difference in longitudinal smoke velocity from the top of tunnel to the bottom and also is not conducive to the emission of smoke.

In Fig. 5, the exhaust outlet is located at the right upper 60 mm away from the inlet position. Near the exhaust outlet, the smoke flow velocity is high at the top of the tunnel and low at the bottom. The diffusion and emission of smoke have been significantly improved. Because of the impact of the tunnel wall, the vortex is produced from smoke in the windward region of inlet. At the same time, from the region of inlet to exhaust outlet, the circumfluence is found at the tunnel bottom.

In Fig. 6, the exhaust outlet is at the right upper 90 mm away from the inlet position. The vortex also exists from smoke in the windward region of inlet. The smoke longitudinal flow velocity near the inlet is low and the circumfluence is also found here. However, the smoke flow velocity in the leeward direction of exhaust outlet is low and the smoke which is distributed in the leeward direction of the exhaust outlet would not be improved.

### 3.2 Mean vorticity field

Fig. 7 reveals the average value of vorticity with each exhaust device in four different positions respectively when the Reynolds number is 1600. The average value of vorticity of smoke with the exhaust devices at different positions is found to be the largest at the intake point and except the intake area the vorticity is the lowest. When the exhaust device is installed at the 60 mm away from the inlet position, the average value of vorticity of smoke is larger in the upside around the outlet areas of the tunnel and the whole average value of vorticity in the tunnel is lower compared with other three outlet positions. It is conducive to people who stay in the leeward direction to escape and the effect of smoke emission is more evident. However, further study on the average value of vorticity of smoke flowing in the tunnel should be carried out in accordance with the changing of the structure of the tunnel as well as the specific influencing factor of flow.



(a) L=0 mm

(b) L=30 mm

(c) L=60 mm

(d) L=90 mm

**Fig. 7 Mean vorticity field at four different outlet positions**

## 4. Conclusion

From the experiments to investigate the influence of the mean velocity profile on the smoke dispersion characteristics, following conclusions can be made.

(1) PIV technology can be used to make a good description of the smoke flow characteristics in the tunnel.

(2) If the distance between the inlet position and the outlet position is too close, the flow circumfluence is more active around the upwind direction near the inlet, whereas when the exhaust outlet is installed far away from the inlet, the vortex will become strong and it is not conducive to the emission of smoke.

(3) In this experiment, it is best recommended that when the distance between the inlet position and the outlet position is 60mm without considering the influence of temperature, the diffusion and emission of smoke have been significantly improved.

## References

[1] Ajay K. Prasad (2000) Particle image velocimetry. Department of Mechanical Engineering, University of Delaware, Newark, DE, 103-116.

[2] T.M. Liou, Y.Y. Wu, Y. Chang, (1993) LDV measurements of periodic fully developed main and secondary flows in a channel with rib-disturbed walls, ASME J. Fluids Eng. 115(1) 109-114.

[3] Halim, (1988) Detailed velocity measurement of flow through staggered and in-line tube banks in cross-flow using laser Doppler anemometry. Ph.D. thesis, University of Manchester. 23-56.

[4] M. Hirota, H. Fujita, H. Yokosawa, (1994) Experimental study on convective heat transfer for turbulent flow in a square duct with a ribbed rough wall (characteristics of mean temperature field), ASME J. Heat Transfer 116 (2) 332-340.

[5] M. Raffel, C. Willert, J. Kompenhans, (1998) Particle Image Velocimetry, A Practical Guide, Springer, 88-123.
[6] Dantec Dynamics, (2000) FlowManger software and introduction to PIV: 2D PIV Installation and User's Guide, 33-118.
[7] R. J. Adrian, (2005) Twenty years of particle image velocimetry, Experiments in Fluids 39: 159 - 169.
[8] Grant I. (1997): Particle image velocimetry, A review, Proceedings Institute of Mechanical Engineers, 211, 55-76.

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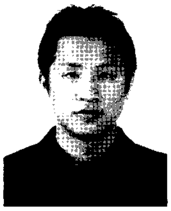

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