The basic study of the relation between the safe areas and fan position by using the Particle Image Velocimetry

Liu Hong*
School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

*Corresponding author e-mail: sjtuhongliu@sjtu.edu.cn

Abstract. Nowadays, the safety of large areas has become the focus of attention. The gas leak will easily cause the terrible losses of lives and property if the appropriate measures are not taken immediately. Therefore, once the similar situation happens, the toxic gas must be dealt with timely to adjust the safe areas of the large space and ensure the necessary security of people. On the basis of the background, this paper introduces a method to study the relationship between the safe areas and the fan position by using the PIV (Particle Image Velocimetry).

1. Introduction
It is known that public areas such as conference rooms, subway stations and building groups are densely populated. Once the gas leak or attack occurs, due to the complexity of the flow field and the difficulty of timely evacuation of personnel, it may cause huge losses to lives and property. Therefore, the study of the gas diffusion and space fluid mechanics has become an important research topic. In recent years, many scholars have done lots of theoretical and experimental studies on gas diffusion and made a great progress in this field. Dr. Deng studied the characteristics of indoor air convection and conducted experiments and simulations to prove some basic flow and heat or mass transfer laws in the air environment [1]. Shen et al. conducted a CFD numerical simulation study on the leakage of harmful toxic gases. The motion characteristics of gas clouds and the spatial-temporal distribution of gas concentrations were calculated more accurately, which provided the key information for the preparation of emergency plans and the control of accident scenes [2]. Ding et al. analyzed the diffusion of the flammable and explosive gas using numerical simulation in the wind tunnel [3]. Zhang et al. analyzed the gas diffusion CFD modeling sensitivity [4]. Teodosiu et al. investigated the ventilation efficiency with two ventilation strategies in a subway system, showing that both ventilation alternatives can lead to the secure evacuation of passengers without suffering from the $CO$ and $CO_2$ due to fire [5]. In this paper, I studied the relationship between the distribution of the safety zones and the fan position by using the PIV (Particle Image Velocimetry) and provided a method to analyze the gas diffusion.

2. Concepts of the basic equations
To study the problem of the gas diffusion, we must understand the basic governing equations of fluid mechanics. The law of the fluid motion follows the three basic laws of physics: conservation of mass, conservation of momentum and conservation of energy. The basic equations of fluid dynamics are mathematical descriptions of the three laws.
2.1. Mass Conservation Equation

\[
\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} = 0
\]  

Among them, \( t \) presents time, \( u, v, w \) are the components of the velocity vector in the axis direction. It can be rewritten into a vector form as:

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho V) = 0
\]  

In the above equation, \( V \) is the speed.

2.2. Momentum Conservation Equation

This law is defined as: the rate of change of the response between the momentum and time is equal to the sum of the various forces acting on the microelement body. According to this law, the momentum conservation equation can be derived in three directions.

\[
\frac{\partial (\rho u)}{\partial t} + \nabla \cdot (\rho uV) = -\frac{\partial P}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x
\]

\[
\frac{\partial (\rho v)}{\partial t} + \nabla \cdot (\rho vV) = -\frac{\partial P}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f_y
\]

\[
\frac{\partial (\rho w)}{\partial t} + \nabla \cdot (\rho wV) = -\frac{\partial P}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z
\]

These equations are also called the Navier-Stokes equation.

2.3. Energy Conservation Equation

The law of energy conservation is a basic law that must be satisfied in a system where heat exchange occurs when fluid flows.

\[
\rho \frac{D e}{D t} = \rho Q + \frac{\partial}{\partial x} \left( k \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( k \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left( k \frac{\partial T}{\partial z} \right) - \frac{\partial P}{\partial x} \frac{\partial u}{\partial x} + \frac{\partial P}{\partial y} \frac{\partial u}{\partial y} + \frac{\partial P}{\partial z} \frac{\partial u}{\partial z} + \tau_{xx} \frac{\partial u}{\partial x} + \tau_{yx} \frac{\partial u}{\partial y} + \tau_{zx} \frac{\partial u}{\partial z} + \tau_{xy} \frac{\partial v}{\partial x} + \tau_{yy} \frac{\partial v}{\partial y} + \tau_{zy} \frac{\partial v}{\partial z} + \tau_{xz} \frac{\partial w}{\partial x} + \tau_{yz} \frac{\partial w}{\partial y} + \tau_{zz} \frac{\partial w}{\partial z}
\]  

These basic equations can easily help us understand the fluid laws.

3. Experimental equipment and environment

After understanding the background of the basic research and some theoretical equations, this chapter will introduce the PIV technology. Figure 1 shows the structure diagram of the PIV system, which consists of a doubled pulse laser source, a CCD camera and the experimental cavity. The laser irradiates the tracer particles in the cavity flow field and the CCD camera which is perpendicular to the light source simultaneously captures the images of the particles in the flow field layer at the two laser moments. According to the principle of the cross-correlation, the speed distribution of each particle in the flow field can be obtained:
\[ u = \lim_{t_2 \to t_1} \frac{x_2 - x_1}{t_2 - t_1}, \quad v = \lim_{t_2 \to t_1} \frac{y_2 - y_1}{t_2 - t_1} \] (5)

In the above two equations, \( t_1, t_2 \) respectively represent the two pulsed laser emission moments, \((x_1, y_1), (x_2, y_2)\) respectively represents coordinate position of a particle in the flow field at two moments, \((u, v)\) is the speed of the particle.

Figure 1. The structure and principle of the PIV

The figure below is the specific experimental environment. To ensure the quality of the experiment, I choose the wind tunnel as the experimental air environment.

Figure 2. Experimental Environment

4. Results
This experiment mainly studies the distribution of the flow field in the space at different position of the fan to judge the relationship between the safe areas and the position of the fan. Once the fan opens, the space gas will diffuse under the condition of air extraction. And then the gas distribution in the space will change. Here we judge the safe areas by the direction of the particle velocity vector in the 2D-PIV
We can conclude the gas molecules will diffuse in the direction of the arrows in the images. We define those directions where no diffusion is performed as safe areas. Therefore, we can find the proper safe areas from the images to judge that which parts in the air environment are safe. To study the problems of the fluid, we should know the flow of the gas in the space will always follow the equation of motion of the space flow field.

![Figure 3. The results of the PIV test one](image1)

![Figures 4. The results of the PIV test two](image2)

It can be seen from the above pictures, the directions of the velocity vectors are close to 0 degree, 45 degree and 90 degree in the Figure 3 and the directions of the velocity vectors are close to -45 degree, 45 degree and 90 degree. It is proved that the directions of the speed vectors are adjusted when the fan position changes during the experiments. Because of the air flow, the directions of the gas diffusion also change. We can learn from this experiment that once the gas leak occurs, adjusting the position of the exhaust system will effectively change the direction of gas movement and create the safe areas to ensure the safety.

5. Conclusion
The diffusion of gas in the space follows the laws of the three governing equations and specific practical problems need to be analyzed specifically. The study of the flow field can conducted through the numerical simulation and experiments. In this paper, I find that the direction of the gas flow under different conditions of the fan is related with the safe areas in the space by using the Particle Image Velocimetry and further provide an idea to for the evacuation of the poisonous gas.

References
[1] Deng Qihong, Modeling and Characteristics of Indoor Air Convection, Hunan University, 2003.
[2] Shen Yantao, Yu Jianguo, Numerical simulation of gas release with CFD model (1), Journal of Chemical Industry and Engineering (China), Vol.58 No.3. 2007.
[3] Wang Shulan, Meng Zhipeng, Ding Xinwei, Numerical simulation of homo-turbulent field of
explosive gas dispersion, Journal of safety and Environment, 2003, 3 (3): 25 - 28.

[4] Zhang Bo, Chen Guoming, Sensitivity Analysis on Computational Fluid Dynamics Modeling of Gas Dispersion, Articles, 2011, 29 (13).

[5] C. I. Teodosiu, V. Ilie, R. G. Dumitru, and R. S. Teodosiu, Assessment of ventilation efficiency for emergency situations in subway systems by cfd modeling, Building Simulation, vol. 9, no. 3. 2016, 319 – 334.