CHEMICAL ENGINEERING TRANSACTIONS

VOL. 46, 2015

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Peiyu Ren, Yancang Li, Huiping Song

**ISBN** 978-88-95608-37-2; **ISSN** 2283-9216

DOI: 10.3303/CET1546164

# Numerical Simulation and Experimental Research on Flow Field of Swirling Cold Air Diffuser

Dongyi Zhou*, Chuping Shi

Department of Mechanical and Energy Engineering, Shaoyang College, Shaoyang, 422000, China
zhoudongyi2005@163.com

Experimental and numerical research was carried out on swirling cold air diffuser. In experimental research, following the cold air distribution requirements, cold air distribution experiment table was constructed for testing specimen of swirling cold air diffuser. In numerical research, Fluent software was applied to analog calculate air distribution of air conditioning room flow field for this air diffuser. The obtained result was compared with the experimental result, both were in good agreement. It indicated that temperature field and velocity field is uniform in swirling cold air diffuser room, which supplied theoretical and experimental basis for actual application of this air diffuser.

## 1. Introduction

The supply air temperature can reach 4-6ºC in the ice of the cold air system and the small air easily result in the unevenness of indoor air temperature and caused uncomfortable feeling of cold air blowing (Gusel, L & Rudolf, R, 2015; Lee, W. S, et al, 2009). At the same time the low surface temperature of air device perhaps is to condense (Li, P. et al, 2009; Memon, R. A, Chirarattananon, S & Vangtook, P, 2008). Many researchers have carried out extensive research on the outlet for cold air distribution (Yu, H, et al, 2009 ;). J.S. Elleson offered a high-current and high-temperature air diffuser, and this kind of low-temperature air diffuser allows jet of cold air to mix with indoor air in a very short distances and is appropriate to hang in a higher place, but its diffuser is easy to condense dew. The surface of the diffuser need use special materials to process (Chuah, Y. K, 2004). In 1993, D. E. Knebel, and d. A. John offered a cold-air nozzle outlet, and proved with lots of experiments that in most of the load range the outlet can maintain good indoor air circulation, but the air resistance is larger (Z. Yanlin, et al 1997). Southwest Jiaotong University, Deyuan Cai with others developed a new kind of cold air diffusers-Windmill-fan inducible diffusers, that is exactly the windmill-fan-induced diffuser air supply, but the structure was a little complicate with vulnerable and moving parts (Windmill-fan unit) (Liu, J & Yu, B, 2010; Hong, B. Z, et al, 2004).

Among the available outlet products for cold air distribution currently, there are few products which have the advantages of simple construction, low cost, good induction ratio, low resistance, non-condensate, small noise, high performance cost ratio and meanwhile a uniform temperature filed can be provided when it is used (Zhili, B. Z, 2005). For that we develop a new-style swirling cold air diffuser after an in-depth study. In order to test the function of this swirling cold air diffuser, we applied computational fluid mechanics software Fluent to analog calculated the air distribution of air conditioning room flow field, then we did comparison between the achieved result and the experimental result (Zhou, D, et al, 2010).

## 2. Swirling cold air diffuser

Profile picture of swirling cold air diffuser see Figure 1, and construction see Figure 2. This diffuser is a circular vortex chamber structure with the primary air nozzle on tangents and the mixed diffuser on radial direction. In the center under vortex chamber, there is a secondary return air inlet (L. Zhongqi, 1980). Deflector is provided on the diffuser. Specimen is made of organic glass, nominal blowing rate is 100 m3/h.

Please cite this article as: Zhou D., Shi C.P., 2015, Numerical simulation and experimental research on flow field of swirling cold air diffuser, Chemical Engineering Transactions, 46, 979-984 DOI:10.3303/CET1546164

## 3. Numerical simulation of flow field

### 3.1 Physical model

Assumed flow rate of testing diffuser is 100 m3/h (means primary and secondary air flow rates are theoretical flow rate of 50 m3/h respectively), induction ratio is designed to 1, inner and outer diameters of annular mixed air outlet are 200 mm and 300 mm, secondary diffuser diameter is 200 mm. Experiment measures that temperature is 16.5ºC at mixed air outlet, and 22ºC at return air temperature. The size of air conditioning room (length*width*height) is 3200 mm*3000 mm*3200 mm, diffuser is installed at the room center and 2.8 m higher than ground. Diffuser bottom flushes with roof dale. South side in air conditioning room has a window with size of 2350*1750; other three sides are inner walls. Adjacent room has no air conditioning system. In the room, thermal load is simulated by electrical heating film which is laid on the ground and can generate heat of 19 W/m2 (Awni. Al., et al, 2015). The Layout of the testing room for diffuser is shown in Figure 3.

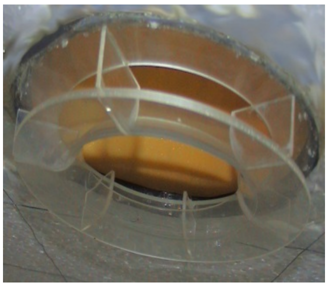


*Figure 1: Photo of the swirling cold air diffuser*

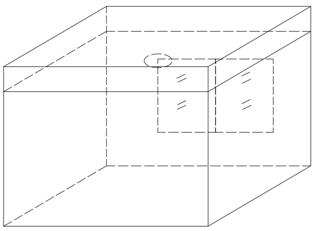
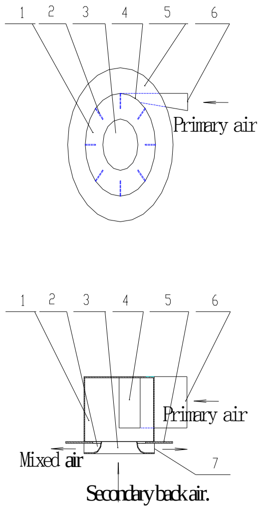


*Figure 3: Layout of the testing room for diffuser*




*1. Circular room 2.Deflector 3. Center back vent 4. Tangential nozzle 5.The above air Board 6.The below air Board 7. Radial inlet*

*Figure 2: Schematic diagram of the swirling cold air diffuser*

The cold source of experimental device applies the way of making cold by chiller and adding broken ice to maintain the temperature of storage tank is 1-3ºC, and to adjust spraying volume and cooler's supply of water to control the temperature of the supply air.

### 3.2 Mathematical simulation

$k-\varepsilon$ turbulence model, which is the most widely used, most tested and most mature numerical simulation technology, is applied. In order to simplify the problems, the following condition is assumed (Koskela. H, 2004; Y. Hong, et al, 2015; Xu. j., et al 2015):

(1) All east, west and north walls are all inner walls, assumed their temperatures are constant that is the same temperature with indoor design temperature 22ºC; south wall is a heating surface, assumed wall temperature is fixed and 3ºC higher than other walls.

(2) Indoor is stimulated thermal load by electrical heater which is laid on the ground, but ground is adiabatic.

(3) Internal air cannot be compressed.

(4) Air jets parameters of outlet are even, internal air properties are fixed value.

(5) Without considering effect of air leaking, door and windows are closed; tightness inside of air conditioning room is excellent (Yang, I. H, et al, 2004; T. Wenquan, 2001).

Turbulence model (ASHRAE, 2009):

$$\frac{\partial \rho \phi}{\partial t} + \nabla\left(\rho U \phi\right) = \nabla\left(\Gamma_{\varphi}\frac{\partial \phi}{\partial x_k}\right) + S\phi \tag{1}$$

Where:

$$\varphi = \left[1\ u_1\ u_2\ u_3\ k\ \varepsilon\right]$$

$$\Gamma_{\varphi} = \left[ 0 \ \mu_e \ \mu_e \ \mu_e \ \frac{\mu_e}{\delta_k} \ \frac{\mu_e}{\delta_\varepsilon} \right]$$

Formation item of turbulence kinetic energy:

$$G = \mu_1 \left( \frac{\partial u_i}{\partial u_j} + \frac{\partial u_j}{\partial u_i} \right) \frac{\partial u_i}{\partial u_j} \quad (i, j = 1,2,3) \tag{2}$$

$$\mu_1 = \frac{C_\mu \rho k^2}{\varepsilon} \tag{3}$$

Other parameters selections are shown in reference [6].

**3.3 Results and analysis**

Room gridding structure sees Figure 4. Temperature field distribution is indicated as Figure 5 to Figure 10. Figure 5 is the temperature distribution when height Z=2000 mm, Figure 6 is the temperature distribution when height Z=1800 mm, Figure 7 is the temperature distribution when height Z=1500 mm, Figure 8 is the temperature distribution on the section when X=1500 mm, Figure 9 is the temperature distribution on the section when X=160 mm. Figure 10 is the velocity distribution on the section when X=1500 mm, and Figure 11 is the velocity distribution on the section when X=1600 mm.

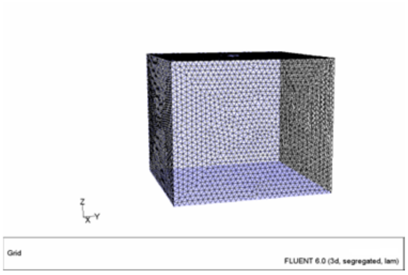



*Figure 4: Room gridding structure*

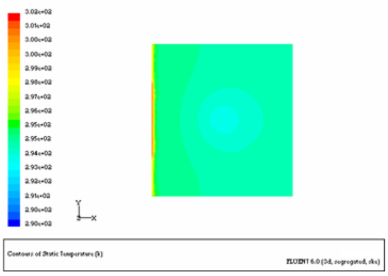


*Figure 5: The temperature distribution on the section when height Z=2000 mm*

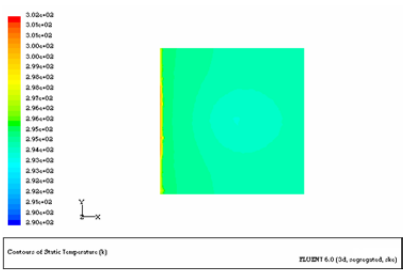


*Figure 6: The temperature distribution on the section when height Z=1800 mm*

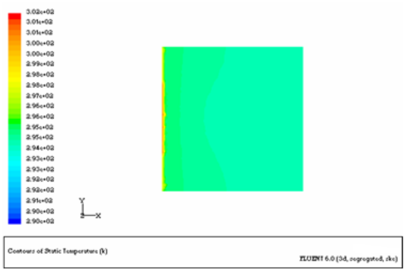


*Figure 7: The temperature distribution on the section when height Z=1500 mm*

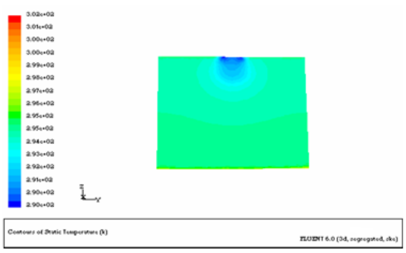


*Figure 8: The temperature distribution on the section when height X=1600 mm*

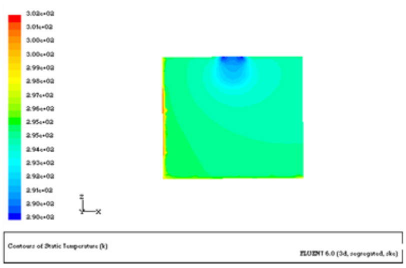


*Figure 9: The temperature distribution on the section when height Y=1500 mm*

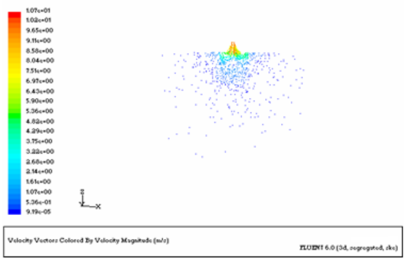


Figure 10: Velocity distribution on the section when X=1600 mm

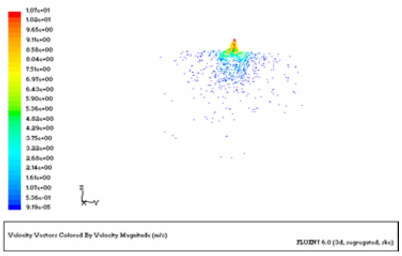


Figure 11: Velocity distribution on the section when X=1500 mm

## 4. Experimental research on flow field

### 4.1 Experimental procedure

Air supply system consists of cold air diffuser, cold air blast pipe, air fan, air regulating and stabilizing device, cold water spray chamber, surface heat exchanger, ice storage tank and ice maker. Air supply temperature is 8°C, relative humidity is 95%. Primary air is formed after supply air passing through blast pipe and overheating, its temperature is 9°C, and relative humidity is 92% [5].

Generally, the height that is lower than 2 m above ground is the major work area for staff. Therefore, 2 m height is as a limitation, six different heights with 0.3 m distance are adopted along room vertical direction, means Z=0.5 m, Z=0.8 m, Z=1.1 m, Z=1.4 m, Z=1.7 m, Z=2.0 m. In horizontal direction, diffuser is considered as a center point, 10 sets of positions with 0.2m distance are adapted from center to both sides, and totally 60 measuring points. Each measuring point has the copper-constantan thermoelectric couple probe and hot-wire anemometer to measure temperature and air velocity. See Figure 12.

Room thermal load includes heat output of person, equipment and lights, and heat transmitted from outside to inside. In experiment, due to outside temperature was low (19ºC), we applied 1.5kw electrical heater (power self-regulating) to simulate thermal load to keep room heat gain. When indoor temperature is constant, room can be considered to achieve dynamic thermal equilibrium. Meanwhile, temperature and air velocity can be measured respectively.

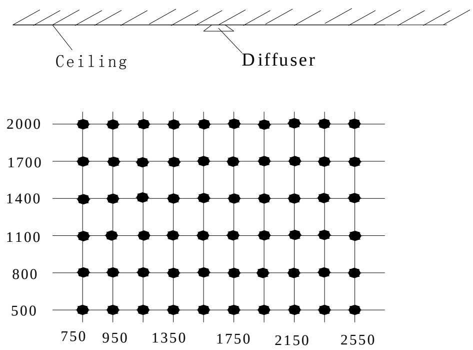



Figure 12: The layout of the measuring points of temperature field and speed field

### 4.2 Measurements

Experimental data in each point are shown in the Figure 13 and Figure 14.

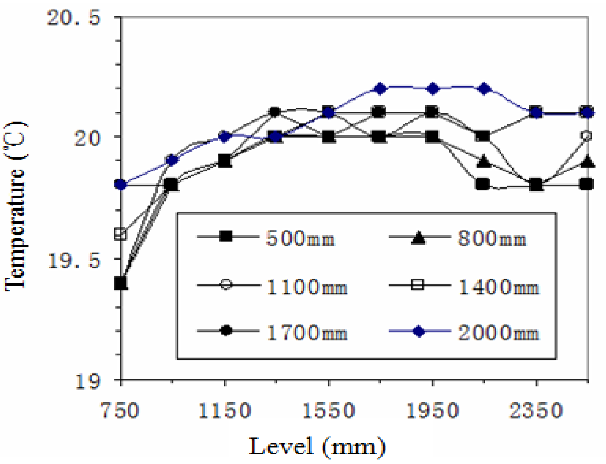



*Figure 13: Temperature of measurement points in the different distance from floor in Figure 12*

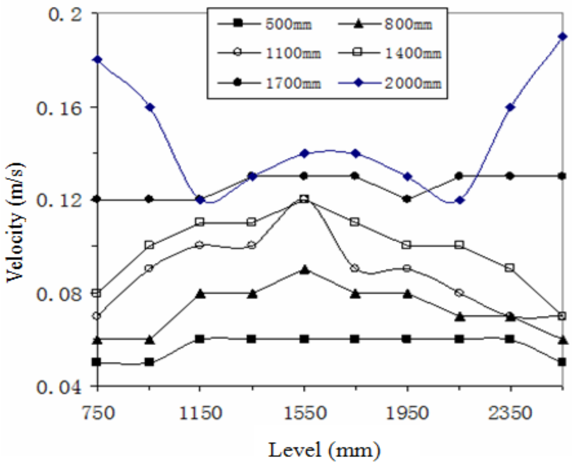



*Figure 14: Temperature of measurement points in the different distance from floor in Figure 12*

### 4.3 Comparison between analog results and experimental results

According to analog results, we can achieve:
(1) Temperature range: 19.2ºC-20.4ºC, maximum temperature difference on measuring point in horizontal direction is 1.2ºC, and in vertical direction is 0.5ºC, average temperature t=19.91ºC.
(2) Air velocity range: 0.04 m/s-0.20 m/s, below 2 m in people work area, average air velocity v=0.95m/s
According to experimental results, we can find out:
(1) Temperature range: 19.4ºC-20.2ºC, maximum temperature difference on measuring point in horizontal direction is 0.7ºC, and in vertical direction is 0.4ºC, average temperature t=19.95ºC.
(2) Air velocity range: 0.05 m/s-0.19 m/s, below 2 m in people work area, average air velocity v=0.99 m/s
As shown above, we can see analog results and experimental results are in good agreement.

## 5. Conclusions

(1) By means of numerical simulating and experimental measuring, temperature field and velocity field are uniform in the room of swirling cold air diffuser.
(2) Swirling cold air diffuser can evenly mix primary and secondary air in diffuser, but uniformity of air supply in circumferential direction shall be improved.
(3) Research work in this paper has many shortages, for example, due to condition limitation in experiment, we cannot obtain enough effective information; more accurate and effective methods have not applied in calculation, and etc., which shall be improved in the further research.

### Acknowledgments

This project was supported by Hunan education department Foundation under Project 14K087, China, and by the science and technology office of Hunan Foundation under Project 2014ZK3094, China.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