The CO Concentrations Research Based on the Gaussian Plume Diffusion Model of the High-rise Building Fire Smoke

Jiang Wei[1a] Wei Yuan[1b] Hou Long-fei[2c]

[1]School of Information and Safety Engineering Zhongnan University of Economics and Law Wuhan, China

[2]College of Resources and Environmental Engineering Wuhan University of Science and Technology Wuhan, China

[a]Safety_doctor@163.com, [b]Weiyuanabcd.2008@163.com, [c]longfeihou@sina.com

Abstract

For the sake of measuring the safety distance of high-rise buildings fires in theory, based on Bei-pei building fire, using fire dynamic software-FDS to build the high-rise building fire epidermis model, combining with the Gaussian model which is widespread applied in environmental monitoring, do normal distribution hypothesis on the high temperature flue gas in fire, and exports hypothesis function. Then count the CO concentrations in a high plane x axis after the fire turns into the stable stage. By means of statics analysis software-SPSS, according to export function, do a fitting analysis to get the distribution function about the concentration of CO. From the correlation inspection, get the goodness of fit which was 0.996, this meets the normal distribution hypothesis. The experimental results provide the basis to research further flue gas diffusion mode function by using normal distribution hypothesis.

Keywords: CO concentrations; Fitting analysis; Gas diffusion; High-rise building fire

1. Introduction

With the rapid development of Chinese economic, more and more high-rise building and super high-rise buildings appear in the city. For some high-rise building fire can’t be timely to fight the blaze, it is due to the limited fire-fighting ability. Fire is often continued to burn for several hours to produce large amounts of toxic or harmful gases, on the one hand these gases spread to interior building poses a direct threat to the life safety of building residents, on the other hand these uncontrolled toxic and hazardous gases spread to the surrounding environment also poses a serious threat to the fire building closer residents [1]. In the process of CCTV Beipei building fire in February 2009, nearly one thousand people have been evacuated. Large numbers of people in the same residential neighborhood in 2010 “Shanghai ultra large fire”, while the Environmental Monitoring Station of the Jing’an district test on ambient air quality to determine that the condition of the adjacent buildings’ ambient air quality before starting to move back [2].

According to the “Code for Fire Protection Design of Tall Buildings”, the fire protection spacing between two high-rise buildings is 13m [3]. The fires are similar to “CCTV Beipei building fire” and “Shanghai 11.15 ultra large fire”, whose burning are concentrated in the surface of the building and special type fire. It allows the author to put forward the new thinking about the fire protection spacing between high-rise buildings. The present research of the high-rise building fire smoke diffusion mainly concentrates in the spread of fire smoke situation in the building. Hou Longfei adopts FDS fire simulation software to simulate the “CCTV Beipei fire building fire”, it mainly analyzes the fire spread and the distribution of CO concentrations of the fire building and the distribution of wind speed on the high temperature gas [4], while the study of smoke spread in the surface fire of high-rise building environment is few.

Smoke diffusion model research mainly concentrated in environmental monitoring and smoke diffusion and nuclear accident atmospheric diffusion. Gauss model is most widely used in the environmental monitoring at home and abroad [5], the random walk particle-puff model is often used in studying of the atmospheric diffusion of smokescreen and the nuclear accident in the military [6]. The smoke of the high-rise building fire and the smoke of factory chimneys are similar in smoke diffusion. The Gaussian elevated point source continuous diffusion model is currently the main choice of the chimney exhaust smoke diffusion model. Therefore, the author forecast that smoke diffusion model in the high-rise building is also consistent with the Gauss model. This paper mainly studies in the CO concentrations distribution. According to the CCTV Beipei building fire, the author established the surface fire FDS model, based on monitoring the high temperature smoke, using SPSS software to fit the CO concentrations with the Gaussian model to explore whether the same high plane smoke diffusion the normal distribution. Thus, it can provide a preliminary theoretical support for in depth discussion of the smoke diffusion under different wind environment model and provide a theoretical basis to determine the high-rise building safe distance.

2. Introduction of the FDS fire model

The simulation experiment focuses on analysis of the temperature and distribution of gas after the fire spread into the stable stage. The establishment of FDS surface fire model based on the CCTV Beipei building fire, described in *Reflection on Curtain Wall of New CCTV Building Fire* by Long Wen zhi[7].In the burned surface of model, bubble mainly used instead of insulation materials, insulation materials and decorative materials which are burning in the actual. Approximate burned surface as a bubble bar of 2.5m horizontal distance, and 2m vertical distance (Fig. 2), the bubble bar is 1m width, and 0.5 m thickness. The main support structure of the model is concrete, the dimensions of building are L × W × H = 50m × 43m × 100m, and the simulation time is 800s. Probe point sets in the surrounding environment of the model, the horizontal distance of exploration point is 1m and the vertical distance of exploration point is 2 m. The fire source height is 27 meters, and the power is 3MW.

Subject to the limitations of the computer's performance, in order to ensure the accuracy of the calculation, in the experiment, the entire simulation space is divided into three regions (Fig. 1). Higher calculation accuracy is needed the fire surface close to and the region furnished with probe. The grid size is 1m × 1m × 1m. Other regions of the calculation accuracy can be slightly smaller and grid size is 1m × 1m × 4m. The actual grids parameters see in TABLE I.
The experimental model is as follows:

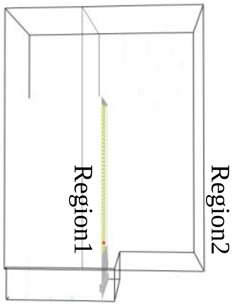

Fig.1: The side view of the FDS model

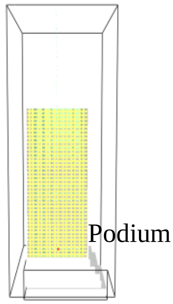

Fig.2: The main view of FDS model

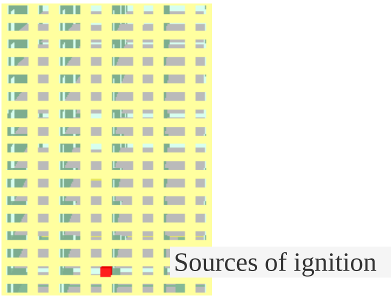

Fig.3: The enlargement of the ignition surface foam

Tab1. Parameters of the regional grid

Regional number	Axis	Min	Max	Grid size(m)	Number of grids
1	X	0	35	1	35
	Y	-4	50	1	54
	Z	16	144	4	32
2	X	35	90	1	55
	Y	-4	50	1	54
	Z	16	144	1	128
3	X	0	50	1	50
	Y	0	50	1	50
	Z	0	16	4	4

3. Introduction of the Gaussian plume model

3.1 Coordinate System

The Gaussian plume model, based on analysis of large experimental data, using statistical theory of turbulence gets diffusion model under the assumption of normal distribution [8].The coordinate system of Gaussian model is shown in Fig. 4, Origin is the projection of the point of discharge on the ground, positive direction of x-axis being wind direction, the y-axis is located in the horizontal plane, perpendicular to the x-axis, Forward in the left side of the x-axis, z-axis perpendicular to the plane of xoy, the positive direction upward. In this coordinate system, the diffusion centerline of flue gas coincides with the x-axis in the plane of xoy.

3.2 Gaussian Model Assumptions [9-10] and the Difference with Fire Smoke Dispersion Model

Basis of Gaussian model fundamental assumption refer to related literature:

1. The distribution of the concentration of pollutants in y, and z-axis being normal distribution;
2. Pollutant source strength is continuous and uniform;
3. In the diffusion process, wind speed of all the space is uniform and stable, do not change with the time and place;
4. In the diffusion process the mass of pollutants unchanged;
5. In the diffusion process, pollutants do not occur deposition, decomposition, and not a chemical reaction.

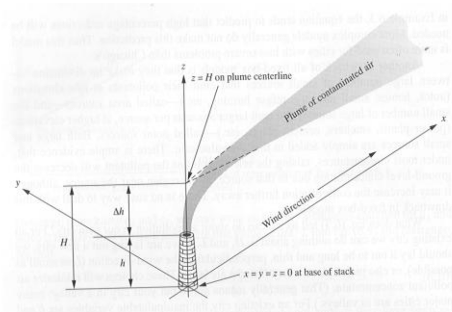

Fig.4: Coordinate system of Gaussian model

3.3 The Model Formula

The model focuses on discussing concentration distribution of flue gas in the x axis, and during fire process, the flue gas is still in the uplift of state, the model wind speed is 0 m / s, so the flue gas does not occur offset in the x direction, ideally. However, in the high-rise building fires, the distance of the flame center location from the fire surface varies with the height variation, and the process of change is also affected by the wind speed. This paper simulates fire wind speed is 0m / s, explore the distribution of fire smoke in the same high plane, therefore not to fit the research the flame offset law. In the research, take the diffusion information of flue gas in the H = 141m height of plane, in the fire, into fitting analysis, so the height z is constant. Study selects flue gas information at y = 0 to analyze, real variable is x, which is the distance of observation point from fire surface.

Distribution function can be exported from the normal distribution assumption:

$$X(x,y,z) = A(z)e^{-ax^2}e^{-by^2} \quad (1)$$

4. Experimental result annlysis

4.1. Flame Central Position

In the simulation experiments, the fire reaches stable stage in 400s, selecting the time of 700s to 800s as the temperature of the objects. The vertical height of the spacing of the measurement points is 2m, the horizontal spacing of the measurement points is 1m, recording a point temperature every 0.8s, each point data was recorded in 126.Selecting the highest temperature measurement points in each height plane, using smooth curve to connect the measuring points, then it can be derived the flame temperature of the central position from roof to 143m (Fig. 5). Fig. 6 is a side view of the combustion flame in the 800s. Through Fig. 5 and Fig. 6, it can be seen that the flame still offset the extension cord of the fire surface when the wind speed is 0m/s in high-rise building fire.

This shows that according to this model, the smoke of the rising phase in the x, y axis is a normal distribution, initially proved that the form of the normal distribution assumption the distribution function 1 is correct.

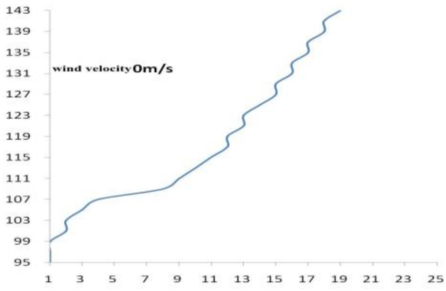

Fig.5: The curve of the flame central position

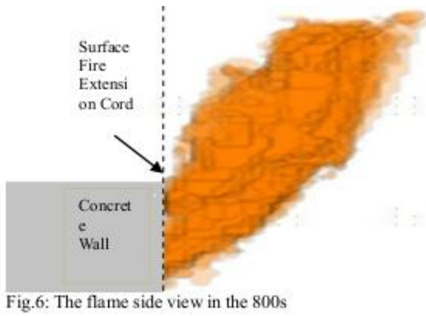

Fig.6: The flame side view in the 800s

4.2. The CO Concentrations Curve Fitting Analysis

According the statistics for the average CO concentrations of 141m X axis on the CO concentrations measuring points in the time of 700s-800s, it gains the axial CO concentrations distribution curve and uses the statistical analysis software to fit analysis of the CO concentrations distribution curve. Here is the goodness of fit and residual diagram (Fig. 7), in which residual curve represents the residual curve and actual curve represents the actual curve of the original data and fitted curve is based on the equation fitting. The residual curve shows the CO concentrations residuals change interval from -0.5 to 0.5.

Fitting curve estimation equation:

1. Including the parameters, C_{CO}=C (1) ×EXP (-0.5×(D-C (2)) ^2/C (3) ^2)

2. Not including the parameters, C_{CO}=7.865×EXP (-0.5×(D-17.856)^2/2.882^2)

$$C_{co} = 7.865e^{-\frac{(D-\mu)^2}{2\sigma^2}}$$,μ =17.856 , σ=2.882,C_{co} indicates the concentration of CO, the unit g/m^3 ; D indicates the distance from the fire, the unit m. Equation meaning: When the wind speed is in 0m/s, it is a function of CO concentration and the distance of the surface fire. The following is the test results. According to the result of TABLE II, the probability P-value of the three coefficients is 0.00 and is less than 0.05, the coefficients through the test of significance. R^2 is 0.996, goodness of the fit is better than the fit of the smoke concentration and it indicates that the equation can have a good explanation of the relationship between the variables.

The simulation experiment shows that the CO concentrations distribution in the condition of no wind also fits with the normal distribution model, and even the fitting is higher than the smoke concentration curve fitting.

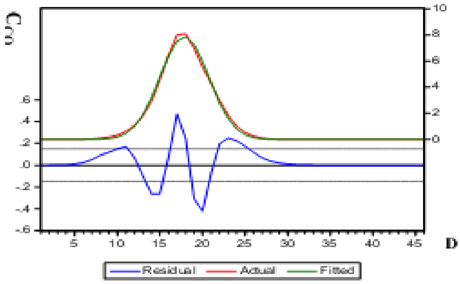

Fig.7: CO concentrations distribution fitting curve

Tab 2. Co concentrations fit test results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	7.864511	0.08253	95.29309	0
C(2)	17.85598	0.03492	511.3327	0
C(3)	2.881865	0.03492	-82.52654	0
R-squared	0.99591	Mean dependent var		1.26052
A-rsquared	0.99572	S.D. dependent var		2.3278
S.E of regression	0.152296	Akaike info criterion		-0.863
Sum squared resid	0.997345	Schwarz criterion		-0.7437
Log likelihood	22.84873	Hannan-Quinn criter.		-0.8183
Durbin-ws stat	0.918219			

5. Conclusion

This article uses fire dynamics software (FDS) which developed by United States Bureau of standards (NIST) to make numerical simulation and analysis of high-rise buildings in the windless environment. It also makes reference to the Gaussian gas diffusion elevated point-source model in the environmental monitoring so as to export the distribution function before doing normal distribution hypothesis on the CO concentration in fire. By analyzing flame central position curve, the accuracy of the distribution function is preliminarily-confirmed. Then apply statistical analysis software SPSS to analyze the CO concentration in fire at 141m on the X axis, according to the distribution function fitting the distribution curve and examine that function, the result shows that the CO concentration is in line with the normal distribution hypothesis, the relation is significant with the goodness of fit are respectively 0.996. But we should get further study to flame central position curve, it is beneficial to further amendments to the distribution function, and it also have significant meaning to further study on gas distribution of high-rise building fire.

6. References

[1] Hou Long-fei, Li Ming, Cui Wu-yuan, Liu Yu-chen. Numerical Simulation and Analysis of On-building High-rise Building Fires [J]. Procedia Engineering, 2011, 11:127-134.

[2] Zhang Xiao-hong. Air monitoring and analysis of teachers' apartment in Jiaozhou Road [J].Northern Environment, 2011, 23(1):149,154.

[3] People's Republic of China Ministry of public security GB 50045—95.Code for fire protection design of tall buildings(2005)[S].China plans Publishing House,2005

[4] Hou Longfei, Li Ming, Cui Wuyuan, Mo Heng. Wind effect on gas distribution of high-rise building fire in the environment [J].Journal of Safety Science and Technology, 2011, 7(8):53-59.

[5] Cai Xuhui, Chen Jiayi, Kang Ling. Nuclear accident under the conditions of atmospheric diffusion model and its application [J].Radiation Protection, 2003, 23(5):293-299.

[6] Huang Mingquan, Gao Junlin, Xiao Kaitao, Song Weiwei, Wang Xian. Numerical simulation of smoke diffusion [J].Initiating explosive device, 2006, (6):19-21.

[7] Long Wenzhi. The reflection of wall to the CCTV new site building [J].China construction metal structure, 2009, (3):16-26.

[8] Chen Yanping, Yuan Linjiang. High wind speed prediction of continuous point source ground concentration determined [J].Journal of environmental engineering, 2009, 3(4):765-768.

[9] Wang Ju,Fang Chunsheng, Dong Deming. Discussion on distance calculation of maximum ground concentrates on mode in the guidelines [J].Chongqing environmental science, 2003, 25(1):49-5l.

[10]Zhu Shiyun, Lin Chunmian. Environment impact assessment [M].Beijing, Chemical industry press, 2007:53-54.