Research on the Pollution of Exhaust-Gas System from Cooking to Human Living Environment

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Abstract: This paper investigates and analyzes the pollution diffusion of exhaust-gas system from cooking in a closed kitchen with a range hood, the effects of the location of a kitchen-stove, the height of the range hood, and the gear of the range hood on the diffusion and on the human life. With the Data Fit method and experimental data, establish the distribution mathematical models of the exhaust-gas concentration and the exergy and the total exergy intensity. Make software with VC++ visual programming techniques to simulate the pollution distribution laws, and compare the simulation results to actual test results. The authors present the pollution distribution figures and tables of simulation results and experimental test results in CO_2 and CO concentration, exergy, and exergy intensity. The research shows that the exhaust-gas diffusion has laws and direction; and it is possible for us using VC++ to simulate the diffusion laws numerically at certain boundary and certain conditions for a kitchen burning liquefied gas. This research will be of an important meaning in the field of how to eliminate polluted gas from the kitchen.

Keywords: Kitchen; Exhaust-gas system; concentration distribution; exergy; exergy intensity

1 Introduction

The exhaust gas from cooking is one of main sources in indoor air pollution. It is harmful on people health. The study on diffusion of pollutants in the kitchen and developing the kitchen visual simulation software with friendly and simply operating interface has practical significance for improvement of people living standard. In this paper, we choose CO_2 as a representative of the exhaust gas whose mass number is heavier than air (or called heavy-gas), and CO is lighter than air (or light-gas), simulate the pollution distribution laws with VC++ visual programming techniques, and compare the simulation results to the practical test results.

2 The Actual Test of CO_2 and CO Concentration and Data Fit

2.1 Physical Model of the Experimental Kitchen Structure

The experimental kitchen structure and the studied plane are shown in **Figure 1**, the length of the kitchen is 4.3m, the width is 2.8 m, and the height is 2.8 m, the door and the window are closed. The initial temperature in the kitchen is 20℃, and the atmospheric pressure is 101325 Pa, the average flow rate at the outlet of cooking is about 0.8 m/s and the combustion temperature there is about 863 K.

2.2 Measurement Instrument and Methods

The instrument used to measure CO_2 and CO concentration is the multifunction TESTO 400. We set 16 measuring points in the XOY plane as shown in **Figure 1**.

For the installation height of the range hood, we refer to the following national standards: The National Standard GB/T 18884.4-2002; The National Standard GB 4706.28-1999.

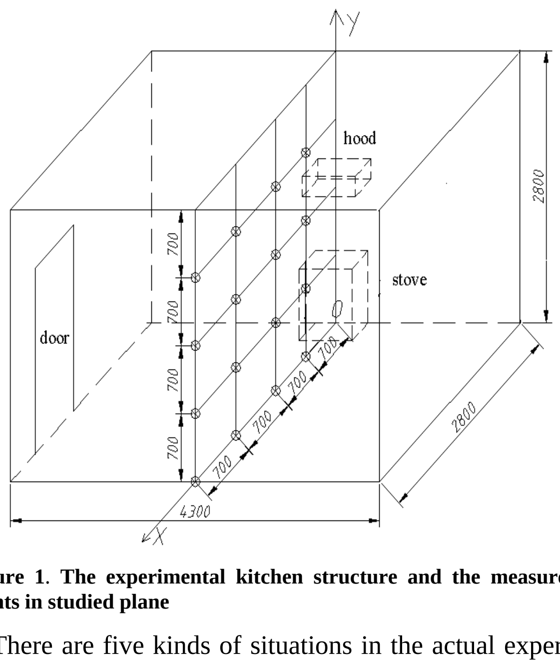

Figure 1. **The experimental kitchen structure and the measured points in studied plane**

There are five kinds of situations in the actual experiment according to the center distance between the range hood and the stove, which is 600 mm, 700 mm, 800 mm, 900 mm and 1100 mm, respectively; each situation also

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has two conditions, top and low gear with different turning-speed.

2.3 The Results of Concentration Actual Test and Exergy Calculation

In order to study the pollution diffusion laws clearly, we make concentration, exergy, and exergy intensity to be evaluation index separately. The data shown in **Table 1** and **Table 2** are from the 700 mm situation measurement. **Figure 2** presents the curves of exergy intensity under five experimental conditions.

2.4 Analysis of Experimental Results

2.4.1 Analysis of Concentration Diffusion

Table 1 and **Table 2** show that the CO_2 concentration in the XOY plane is the minimum at the point when y = 0 m, no matter the hood gear is at top or low condition; and the concentration is the maximum at the point when y = 2.1 m (the point is rightly over the top of the fire). The more closer the point next to the roof, the higher CO_2 concentration is, then the point concentration closed to the roof surface is the maximum. The concentration of CO is the minimum at the point when y = 0 m. The higher gear of the hood is effective than the lower, however, the effectiveness is not obvious in this experiment.

Table 1. The values of the 700mm situation at low gear

item / Y	Average CO_2 concentration (ppm)	Average CO_2 Exergy	Average CO concentration (ppm)	Average CO Exergy	Average Heat Exergy	Average Exergy intensity
0	290.43	0.0910	0.450	0.0369	5.170	1.429
0.7	296.50	0.0913	0.525	0.0374	6.881	1.439
1.4	302.50	0.0917	0.550	0.0375	8.587	1.443
2.1	342.00	0.0943	0.650	0.0381	10.287	1.473
Average	307.86	0.0921	0.543	0.0375	7.731	1.446

Table 2. The values of the 700mm situation at low gear

Item / Y	Average CO_2 concentration (ppm)	Average CO_2 Exergy	Average CO concentration (ppm)	Average CO Exergy	Average Heat Exergy	Average Exergy intensity
0	245.75	0.0876	0.250	0.0350	4.837	1.370
0.7	271.00	0.0894	0.250	0.0347	6.540	1.377
1.4	294.25	0.0911	0.375	0.0359	8.246	1.411
2.1	333.50	0.0938	0.375	0.0363	9.948	1.436
Average	286.13	0.0904	0.313	0.0355	7.393	1.399

2.4.2 Analysis of Exergy Diffusion

In thermodynamics, the exergy of a system is the maximum effective work changing from its state to the reference environment. If the system is without boundary, the lager exergy value is, the more serious pollution is. In this research, the exergy of exhaust-gas only include diffusion exergy and heat exergy, the temperature of the reference environment is 298.15 K and the atmospheric pressure is 1 atm.

Table 1 and **Table 2** also show that the more serious pollution is, the lager exergy value is. The analysis results of diffusion exergy accord with the results of concentration diffusion in the XOY plane. Under the same conditions, exhaust-gas diffusion has laws, direction. It transports to the direction of the maximum exergy difference. In order to ensure the safety of operator, try to reduce the value of exergy where near operator (or near bedroom).

2.4.3 Analysis of Variation of Exergy Intensity

The value of pollution index can be calculated by exergy intensity, and exergy intensity is the ratio of a system exergy to its standard exergy, it include concentration exergy intensity, heat exergy intensity, kinetic energy exergy intensity, potential energy exergy intensity and the other. But exergy intensity only include concentration exergy intensity and heat exergy intensity in this research. According to indoor air quality standard (GB/T 18883-2002), the allowed values of CO concentration is 10 mg/m^3 and CO_2 is 0.1% mg/m^3. The diffusion exergy intensity of pollutant is the ratio of diffusion exergy to its standard exergy; the heat exergy intensity is the ratio of heat exergy to the exergy of the temperature that human

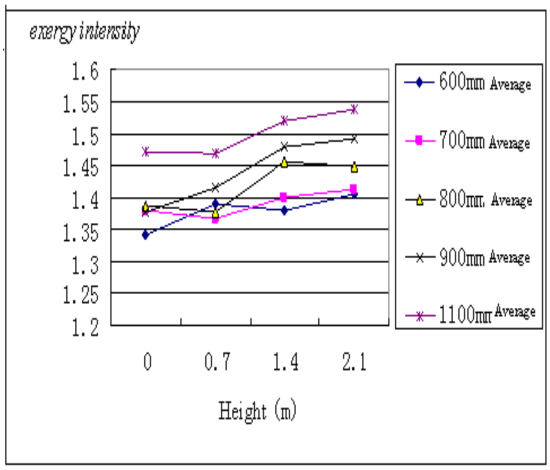

Figure 2. Exergy intensity in five conditions at top gear

body can withstand. Total exergy intensity is the sum of concentration exergy intensity and heat exergy intensity.

Table 1, **Table 2** and **Figure 2** show that if the hood is at 700mm situation, the kitchen is less pollution where the space is at the height above the ground 0.7-1.4 m; If the hood is at 600 mm situation, it is less pollution where the space is at the height above the ground 1.5 m; Considering the heath of women and children who spend more time at home, the 700 mm situation or installation height is the best choice.

3 Simulation Results and Analysis

We establish the mathematical models of the exhaust-gas concentration at the 700 mm situation with Data Fit tool, and simulate it with VC++. There are some processing results of experimental data which is measured at low gear.

3.1 Mathematical Model and Simulation Results with Concentration Index

The mathematical model of CO_2 concentration from Data Fit is:

$$C(x,y) = 289.63e^{(0.01x^2+0.13(y-1.03)^2)} \text{ (ppm)}. \quad (1)$$

And the mathematical model of CO concentration from Data Fit is:

$$C(x,y) = 0.462e^{(0.0176x^2+0.0724y^2)} \text{ (ppm)}. \quad (2)$$

The simulation results are shown in **Figure 4**.

Comparing the simulation results to the actual test results, the relative error of concentration of whether CO_2 or CO is less than 10%. The simulation results meet the error requirement, so the mathematical models are correct.

3.2 Mathematical Model and Simulation Results with Diffusion Exergy Index

The mathematical model of CO_2 diffusion exergy is:

$$E(x,y) = 0.0921e^{(0.0021x^2+0.0031y^2)} \quad (KJ/mol) \quad (3)$$

And the mathematical model of CO diffusion exergy is:

$$E(x,y) = 0.037e^{(0.0011x^2+0.0061y^2)} \quad (KJ/mol). \quad (4)$$

Comparing the simulation results to the actual test results, the relative error of diffusion exergy of whether CO_2 or CO is less than 5%. The simulation results meet the error requirement, so the mathematical models are correct.

3.3 Mathematical Model and Simulation Results with Exergy Intensity Index

The mathematical model of total exergy intensity from Data Fit is:

$$D(x,y) = 1.472e^{(-0.0024x^2-0.0002y^2)} \quad (5)$$

The simulation results are shown in figure 7. Comparing the simulation results to the actual test results, the relative error of exergy diffusion is less than 3%. The simulation results meet the error requirement, so the mathematical model is correct.

4 Conclusions

1) We can clearly point out that the location where the pollution is the most serious whether we use the exergy evaluation index or the concentration. Under the same conditions, the exhaust-gas diffusion has laws and direction, and It transports to the direction of the maximum exergy difference. So this research will be of an important meaning in how to control or reduce kitchen pollution for cooking people or indoor air pollution for inhabitants.

2)The pollution situation which generated by the interaction of pollutants can be intuitively observed when the exergy intensity is evaluation index. And we can easily determine the transport tendency of the pollutant with the change of the exergy intensity.

3) It is possible for us using VC++ to simulate the diffusion laws numerically at certain boundary and certain conditions for a kitchen burning liquefied gas with total exergy intensity of the exhaust-gas system. According to

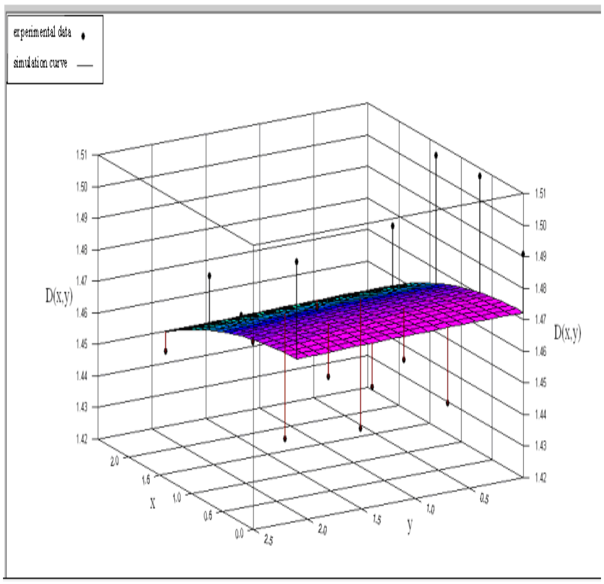

Figure 3. The simulation results of total exergy intensity

the evaluation results, we can predict the location of a stove, the installation height of a hood, and the location of ventilation, and then can reduce the concentration of the exhaust gas and avoid indoor air pollution. With software simulation results, it is easy to determine the installation location of range hood. The software will be of an important meaning in the field of how to eliminate polluted gas from the kitchen and improve people's living standards.

4) For children and women health, the best installation height of range hood is 700mm above the platform of stove from the three evaluation indexes study. The higher gear of the hood is effective than the lower, however, the exhaust volume is not enough on the top gear in this experiment.

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