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Research Article

Evaluation of Aerosol Fire Extinguishing Agent Using a Simple Diffusion Model

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Aerosol fire extinguishing agents have been recognized as an effective replacement of Halon. The uniform diffusion time and the effective concentration of the aerosol fire extinguishing agent are important parameters for putting out a fire. In this work, the effective concentration is derived based on the diffusion equation, and its variation with changing diffusion coefficient and diffusion time is analyzed. The uniform diffusion time could then be conveniently estimated using this equation. Based on experimental data, the concentration kinetics of the aerosol is drawn and the relation between the diffusion coefficient and the uniform diffusion time is analyzed. It was found that the uniform diffusion time is not dependent on the shape of the closed room but dependent on the total room volume and the position of its diffusion source. This model is demonstrated as a facile tool for the convenient evaluation and reasonable application of the aerosol fire extinguishing agent by predicting the uniform diffusion times of extinguishing aerosol in closed rooms.

1. Introduction

Halon has been banned by most countries worldwide because of its adverse effect on the ozone layer. This has brought the development of alternative fire-fighting materials into attention, among which the aerosol fire extinguisher has gained popularity due to its advantages such as high efficiency, low cost, and easy maintenance [1, 2]. The pyrotechnic fire extinguishing aerosol consists of 0.001–1 μm microparticle agglomerates generated from pyrotechnic agent burning [3, 4]. The microparticles have very large surface area, which increases the efficiency of flame quenching. Besides, the microparticles in violent turbulent motion can rapidly fill up available space in a "total flooding" manner, which enables special protection against particular risks [5]. The aerosol fire extinguishing agents have been widely used in various settings such as aircraft, ship, land combat vehicle, computer lab, and control room.

The turbulent diffusion of extinguishing aerosol is complicated because the diffusion process is a continuous flux during which slow physical and chemical changes take place, and the distribution of temperature and humidity is not uniform [6]. The uniform diffusion time is the time span from the initial release of the aerosol until the space is completely filled by the extinguishing aerosol, and the effective concentration is the critical concentration of the extinguishing aerosol that can put out a fire. Therefore, the uniform diffusion time and the effective concentration of the extinguishing aerosol are important parameters to ensure timely fire extinguishing. The diffusion course is influenced by not only the intrinsic aerosol properties but also environmental factors such as temperature, humidity, and air current. The diffusion involves mass transfer among multiple gaseous, liquid, and solid components with complicated chemical equilibrium, which makes it difficult to precisely calculate when a fire will die out, especially in a room of complicated structure. Therefore, the aim of this work is to establish a technical guideline for the evaluation and application of aerosol fire extinguishing agent. Based on performance tests, the diffusion model of the extinguishing aerosol is first built to explore the uniform diffusion time of the fire extinguishing aerosol and study the time of fire. Note that this paper relies on a statistic analysis and circumvent complicated issues such as the fluid mechanics and the reaction dynamics between flame and extinguishing agent. Instead, the objective is to find a simple method to estimate the time of fire to die out, which can then suggest the optimal allocation of the fire extinguishing aerosol, that is, the best structure, overall arrangement, and manner.

2. Diffusion Model of Extinguishing Aerosol

After the release of the aerosol, the extinguishing aerosol rapidly (within 0.3 s) generates an approximately spherical cloud of radius r_0 before its spontaneous diffusion, and then for a considerably long period the diffusion coefficient attenuates only very slowly. There are many models for aerosol diffusion [6, 7]. In this paper, the movement law of the extinguishing aerosol cloud can be described by the second order partial differential equation as

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2}\right), \tag{2.1}$$

where (x, y, z) is an arbitrary point in the infinite space at time t, $C(x, y, z, t)$ is the concentration of the extinguishing aerosol at the point (x, y, z), and D is the diffusion coefficient. Idealization of $C(x, y, z, t)$, $R^2 = x^2 + y^2 + z^2$ as equivalent to a spherical surface then gives [8, 9]

$$C(R, t) = \frac{Q}{(4\pi D t)^{3/2}} e^{-R^2/4Dt} \Longrightarrow R^2 = 4Dt \ \ln \frac{Q}{C \cdot (4\pi D)^{3/2} t^{3/2}}, \tag{2.2}$$

where Q is the amount of released extinguishing aerosol.

According to (2.2), a series of curves of aerosol concentration, time and aerosol cloud radius can be plotted. The aerosol concentration is normally distributed with regard to radius and rapidly diminishes as time elapses.

The concentration profile of 5000 g extinguishing aerosol released in an infinite space is shown in Figure 1. As clearly shown in Figure 1, at 1 m from the diffusion source, the aerosol

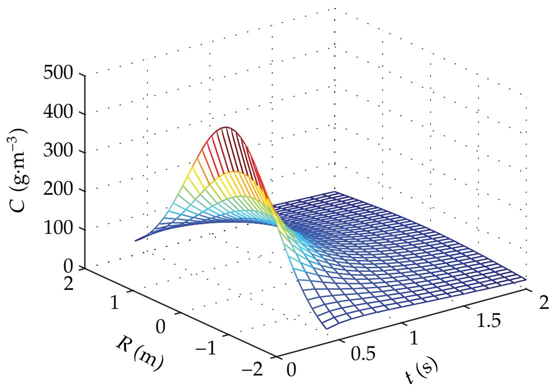

Figure 1: Distribution of extinguishing aerosol concentration at different positions and diffusion times.

concentration fell notably from 238 g·m^{-3} at 0.4 s to 35 g·m^{-3} at 2.0 s. In contrast, at 2 m from the diffusion source, the aerosol concentration initially increased to about 50 g·m^{-3} but then started to decline.

3. Practical Application of the Extinguishing Aerosol Model

3.1. Measurement of Diffusion Coefficient

Equation (2.2) can be transformed into

$$\frac{Q}{C \cdot (4\pi D)^{3/2} t^{3/2}} = e^{R^2/4Dt}. \tag{3.1}$$

Let two fire sources be placed at different positions along the diffusion direction, and two groups of data are then measured. However, the diffusion coefficient does not remain constant during the turbulence diffusion of aerosol; rather, it is influenced by temperature, humidity, and air current and weakens gradually as time elapses. To reduce error in the evaluation, the best solution is to take the average of the diffusion coefficient.

According to (3.1)

$$\frac{Q}{C_1 \cdot (4\pi D)^{3/2} {t_1}^{3/2}} = e^{R_1^2/4Dt_1}, \tag{3.2}$$

$$\frac{Q}{C_2 \cdot (4\pi D)^{3/2} {t_2}^{3/2}} = e^{R_2^2/4Dt_2}, \tag{3.3}$$

where R_1 and R_2 are distances to the diffusion source and t_1 and t_2 are the time when the two same fire sources die out, so $C_1 = C_2$.

Figure 2: The expansion and formation of aerosol cloud.

Divide (3.3) by (3.2), then

$$D = \left(\frac{R_1^2}{t_1} - \frac{R_2^2}{t_2} \right) \left(4 \ln \frac{t_2^{3/2}}{t_1^{3/2}} \right)^{-1}. \tag{3.4}$$

The diffusion coefficient D can thus be calculated from the measured values of R_1, R_2, t_1, t_2.

Due to the turbulence diffusion of the aerosol fire extinguishing agent, there are large errors in measuring R_1 and R_2. To avoid this problem, (3.4) can be transformed into

$$D = \frac{1}{\pi} \left(\frac{\pi R_1^2}{t_1} - \frac{\pi R_2^2}{t_2} \right) \left(4 \ln \frac{t_2^{3/2}}{t_1^{3/2}} \right)^{-1} \Longrightarrow \left(\frac{S_1}{t_1} - \frac{S_2}{t_2} \right) \left(4\pi \ln \frac{t_2^{3/2}}{t_1^{3/2}} \right)^{-1}, \tag{3.5}$$

where S_1 is the area of the circle with radius R_1, and S_2 is the area of the circle with radius R_2. Because the change in total area always has a well-defined pattern regardless of whether the aerosol cloud has an ideal spherical shape, the measurement errors of R_1 and R_2 are thus not introduced into the equation. The area can be determined by standardized image processing methods, such as edge detection. Figure 2 illustrates the formation of aerosol cloud.

The parameters S_1, S_2, S_3, S_4, S_5, S_6 and t_1, t_2, t_3, t_4, t_5, t_6 can be determined from the individual figures in Figure 2, thus allowing to calculate a series of diffusion coefficient as well as the average diffusion coefficient, shown in Table 1 by (3.5).

The magnesium powder and strontium nitrate-based pyrotechnic aerosol fire extinguishing agents have diffusion coefficient in the range of $0.1 \sim 1.0\,\mathrm{m^2{\cdot}s^{-1}}$, and the value of diffusion coefficient depends on the type of formulation. To facilitate calculation, $D = 1.0\,\mathrm{m^2{\cdot}s^{-1}}$ is assumed in the subsequent sections.

Table 1: Calculation of diffusion coefficient.

Time/s	4	5	6	7	8	9
Area /m^2	94	99	109	116	120	120
D/$m^2\,s^{-1}$		0.880	0.476	0.550	0.625	0.751

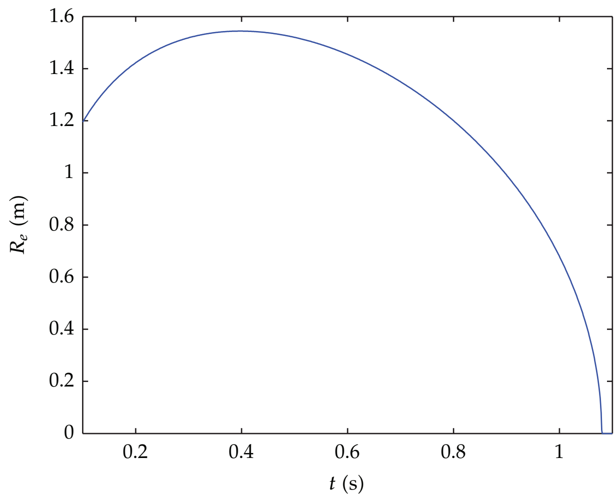

Figure 3: The variation curve of R_e with diffusion time based on (2.2).

The calculated results are in good agreement with the measured ones [8, 9]. Note that the fast formation of the extinguishing aerosol causes vigorous turbulent motion of the aerosol cloud, which results in the much greater diffusion coefficient compared with the typical molecular diffusion of gases ($D \approx 1.0 \times 10^{-5}\,m^2{\cdot}s^{-1}$).

3.2. *Effective Concentration of the Extinguishing Aerosol*

The effective concentration of the extinguishing aerosol that can put out a fire is C_e. Assuming the effective concentration $C_e = 100\,g{\cdot}m^{-3}$ and having 5000 g extinguishing aerosol released in an infinite space, only an area of less than 1.5 m in radius can reach the effective concentration based on (2.2).

R_e is defined as the spherical radius where $C = C_e$. By (2.2), the radius R_e of the spherical surface will change during diffusion. The curve describing the kinetic variation of radius is drawn in Figure 3. It can be seen that the radius R_e grows from 0.1 s to 0.4 s to reach a maximum of 1.5 m but then decreases to zero from 0.4 s to 1.09 s.

Essential differences exist in the extinguishing behavior between the area inside R_e and the area outside R_e. The aerosol concentration in the area inside R_e is always higher than the effective concentration, as shown in Figure 4, and the maximum radius R_e is less than 1.5 m. In this zone, the extinguishing aerosol can directly swallow the flame (Figure 4).

In contrast, the aerosol concentration in the area outside R_e cannot reach the effective concentration from diffusion alone but gradually grows to the effective concentration in the closed room. The flame in this area becomes increasingly thin and faint and finally dies out,

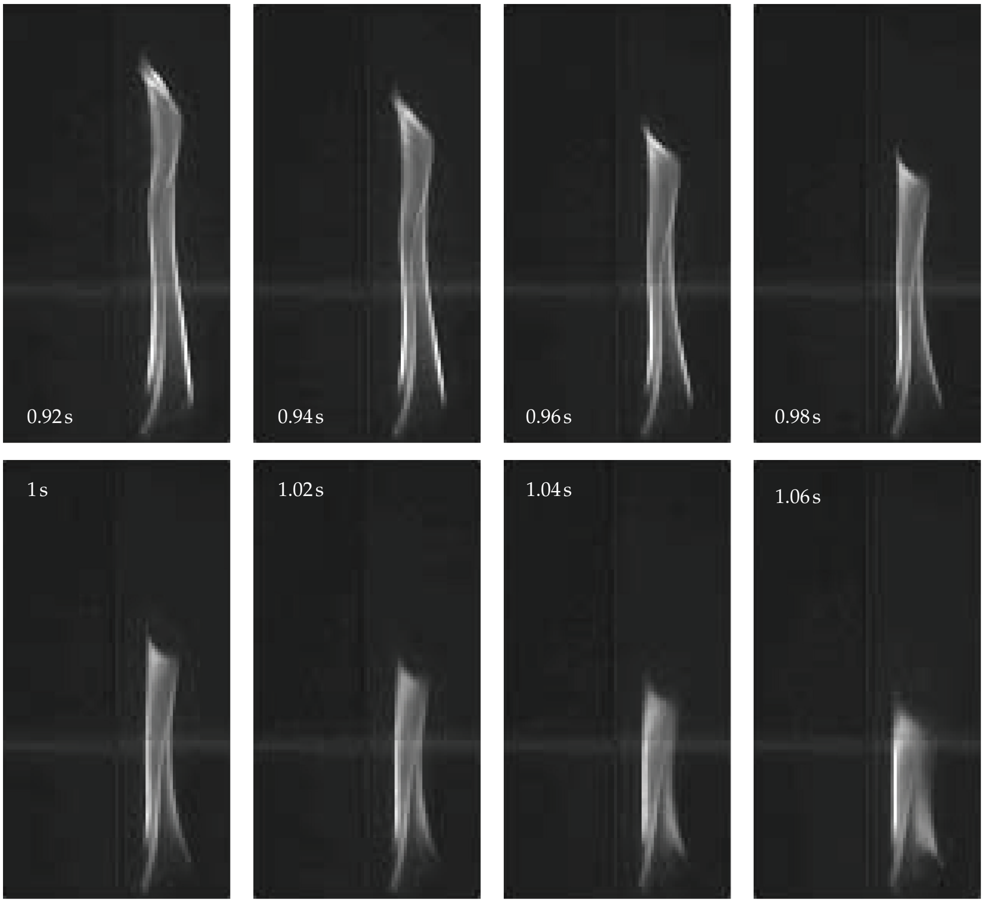

Figure 4: Photographs of flame quenching inside the immediate effective concentration zone. Because of the effects of high concentration, the flame is suppressed directly. The photographs are from high speed camera, the time interval is known, and the height of flame can be determined, so the local diffusion coefficient can be calculated based on Figure 4.

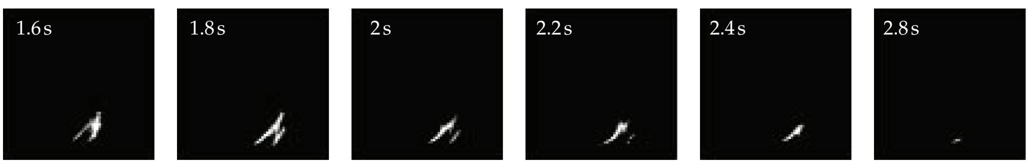

Figure 5: Photographs of flame quenching within the buffer area. It is different from the immediate effective concentration zone in Figure 4 as the flame cannot be suppressed directly, and the flame is smothered by the gradual increase of the aerosol concentration in the buffer area.

as shown in Figure 5. The uniform diffusion time is the time span between the release of the aerosol of the extinguishing agent and the final flame quenching.

3.3. The Buffer Zone and Its Interface of Extinguishing Aerosol Diffusing in a Closed Room

A relatively closed room with $50\,\mathrm{m}^3$ spherical space has a radius of about 2.3 m. Because the effective concentration of extinguishing aerosol $C_e = 100\,\mathrm{g{\cdot}m^{-3}}$, the space will require 5000 g extinguishing aerosol. Figure 1 is based on (2.2), and the application of (2.2) in a relatively closed room is now further explored.

Aerosol diffusion in a closed room is subject to the wall effect. Because the aerosol particles can hit and bounce from the wall, the aerosol concentration near the wall can rapidly increase. Figure 1 and (2.2) give the concentration gradients of the aerosol diffusion. Note that the aerosol concentrations near the wall cannot exceed the lowest concentration gradient from the diffusion source in the closed room. As a result, a buffer area forms near the wall, and the aerosol concentration increases uniformly in this area. As the aerosol diffuses, the buffer area will gradually widen and eventually reach the center of the diffusion source, as shown in Figure 6. At this point, the room becomes uniformly filled with the extinguishing aerosol.

Equation (2.2) shows how the aerosol concentration varies from the diffusion source to the surrounding. The mechanism of the diffusion process is the mass transfer from high concentration area to low concentration area. Therefore, based on Figure 6, in which R_t is the radius of interface between the buffer area and concentration gradients, a range that is less than R_t in radius satisfies (2.2). During the diffusion, R_t becomes increasingly smaller and eventually reaches zero. Meanwhile, the buffer area expands gradually until a uniform aerosol concentration is reached throughout the room, at which time this uniform concentration is higher than or equal to the effective concentration.

The distribution of extinguishing aerosol can be calculated at any time and any point by the following, which is derived from (2.2)

$$Q_\tau = \int_0^{R_\tau} 4\pi R^2 \cdot C(R,\tau)\,dR = \int_0^{R_\tau} 4\pi R^2 \cdot \frac{Q}{(4\pi D\tau)^{3/2}} e^{-R^2/4D\tau}\,dR, \tag{3.6}$$

where R_τ is the radius of a named point at time τ, and Q_τ is the total quantity of aerosol within a radius R_τ. Therefore, the kinetic variation of aerosol quantity can be calculated and the variation of R_t can be analyzed.

Thus (3.7) can be derived based on (2.2) and (3.6) and Figure 3 to describe the variation of the R_t interface, which is the interface where forward diffusion concentration equals to the counter flow concentration:

$$\frac{Q}{(4\pi Dt)^{3/2}} e^{-R_t^2/4Dt} = \frac{Q - \int_0^{R_t} 4\pi R^2 \cdot \left(Q/(4\pi Dt)^{3/2}\right) e^{-R^2/4Dt}\,dR}{(4/3)\pi R_c^3 - (4/3)\pi R_t^3}. \tag{3.7}$$

Simplifying (3.7), the following is derived

$$\left(\frac{4}{3}\pi R_c^3 - \frac{4}{3}\pi R_t^3\right) \frac{1}{(4\pi Dt)^{3/2}} e^{-R_t^2/4Dt} + \int_0^{R_t} 4\pi R^2 \cdot \frac{1}{(4\pi Dt)^{3/2}} e^{-R^2/4Dt}\,dR = 1, \tag{3.8}$$

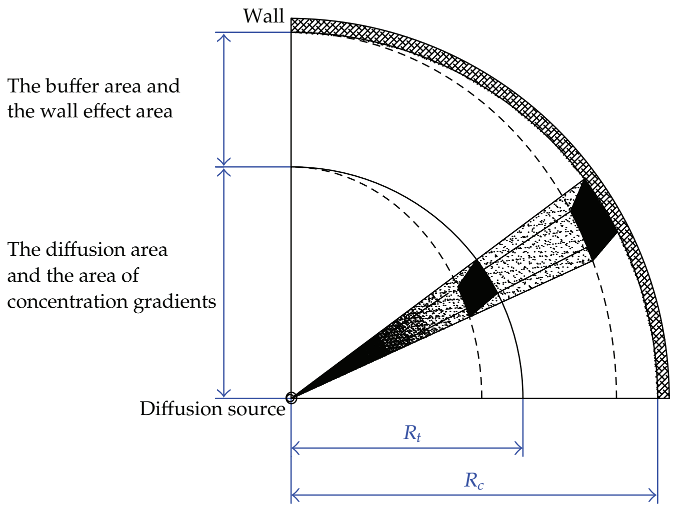

Figure 6: Schematic of extinguishing aerosol diffusion in a spherical closed room. R_t is the radius of the interface between the buffer area and the concentration gradients, and R_c is the radius to the wall of the closed room.

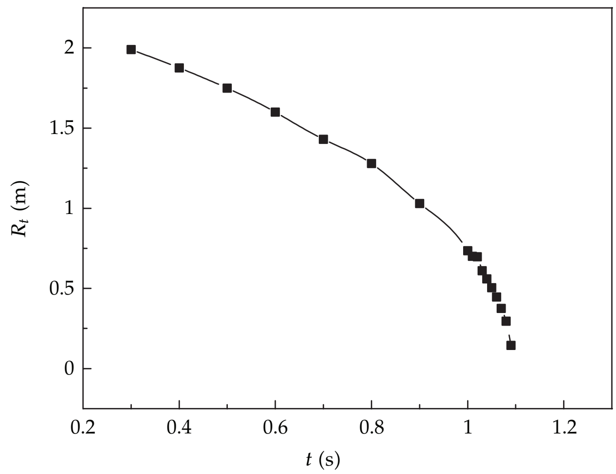

Figure 7: The variation curve of the interface between the diffusion area and the buffer area.

where R_c is the radius of the spherical room shown in Figure 6. Equation (3.8) is the relationship function between the interface R_t and time. Figure 7 can be drawn from Figure 6 and (2.2) and (3.7).

According to Figure 7, at 2 m from the diffusion source and $\tau = 0.3$ s, the concentration of counter flow reaches a balance with the concentration of forward diffusion because of the wall effect. The same balance is observed at 1.8 m from the diffusion source and $\tau = 0.4$ s. According to the total aerosol quantity and the room size, the average concentration is $100\,\text{g}\cdot\text{m}^{-3}$, and the extinguishing aerosol will reach uniform diffusion when the concentration

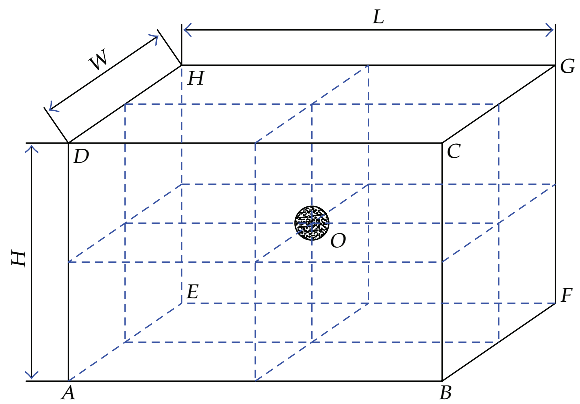

Figure 8: Schematic of diffusion in the rectangular room.

of counter flow reaches the average concentration. When $R_t = 0$, the aerosol reaches uniform diffusion in the spherical room, and (3.8) becomes

$$t = \frac{1}{(36\pi)^{1/3}} \frac{R_c^2}{D} = \frac{\sqrt[3]{V^2}}{4\pi D}. \tag{3.9}$$

Taking $R_c = 2.3\,\mathrm{m}$ and $D = 1\,\mathrm{m}^2 \cdot \mathrm{s}^{-1}$, the uniform diffusion time is $t = 1.09\,\mathrm{s}$, which is consistent with the end point in Figures 3 and 7.

3.4. Comparison of Diffusion Time in Different Room

Note that the above calculations consider a spherical room. If the room is rectangular with edges and corners, the wall effect would become very complicated. Nevertheless, for the rectangular room, obviously the extinguishing aerosol diffuses to vertically opposite corners (angles) regardless of the position of the diffusion source. As the mass transfer from the diffusion source proceeds, the concentration of extinguishing aerosol of the farthest corners continues to increase and the interface of the concentration balance will return to the diffusion source.

For example, assume a closed rectangular room with the dimensions of $L \times W \times H$ and with the source of extinguishing aerosol placed at the center. To simplify, the room is separated into eight symmetric parts as shown in Figure 8 and only one octant needs to be considered and analyzed. Based on Figure 8, no matter how the diffusion proceeds, it has an added wall effect from the diffusion source O to point A. In fact, the process is very similar to the diffusion from the top angle of a tapered container to the top angle of another tapered container, both sitting on the bottom of each other. Assuming walls are rigid with smooth surfaces, two identical tapered containers are used to simplify the calculation process (Figure 9).

According to (3.8) and Figure 8, the height of the tapered container equals $OA/2$ and the volume of the tapered container is one-sixteenth of the room. Using this setting, the total volume of the two tapered containers is equal to one-eighth of the rectangular space. Besides, assuming the diffusion source is at the center of the rectangular space, the diffusion modes

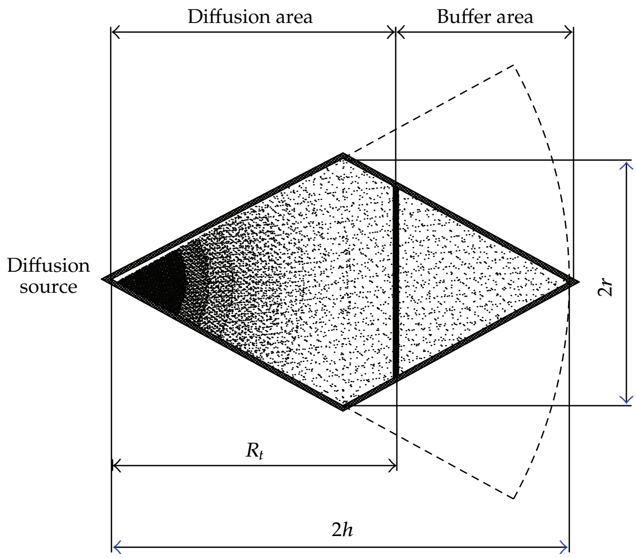

Figure 9: Schematic of diffusion in two tapered containers.

of the two cases are similar, as the diffusion proceeds from the apex of one tapered container to that of the other. The aerosol diffusion in the two tapered containers is then calculated, as shown in Figure 9. Because the room size is $L \times W \times H$,

$$h = \frac{\sqrt{L^2 + W^2 + H^2}}{4}, \qquad r^2 = \frac{3 \times L \cdot W \cdot H}{4\pi\sqrt{L^2 + W^2 + H^2}}, \tag{3.10}$$

where h is the height of the tapered container, and r is the radius of the bottom. Let l denote the side length of the tapered container, so $l = \sqrt{r^2 + h^2}$. When $2h > R > l$, the concentration balance can be expressed as

$$\frac{Q}{(4\pi Dt)^{3/2}} e^{-R^2/4Dt} = \frac{Q - \int_0^R 4\pi R^2 \cdot \left(Q/(4\pi Dt)^{3/2}\right) e^{-R^2/4Dt} dR}{8 \times \left[(1/3)\pi(((2h - R + x)/h)r)^2 (2h - R + x) - (\pi x/6)\left(3(((2h - R + x)/h)r)^2 + x^2\right)\right]}, \tag{3.11}$$

where x is a chord height changing with R following

$$R^2 = \left(\frac{2h - R + x}{h} r\right)^2 + (R - x)^2 \Longrightarrow \left(\frac{2h - R + x}{h} r\right)^2 - 2Rx + x^2 = 0. \tag{3.12}$$

In contrast, when $R < l$, the concentration balance gives

$$\frac{Q}{(4\pi Dt)^{3/2}}e^{-R^2/4Dt} = \frac{Q - \int_0^R 4\pi R^2 \cdot \left(Q/(4\pi Dt)^{3/2}\right)e^{-R^2/4Dt}dR}{8\times\left\{(2/3)\pi r^2 h - \frac{\pi x}{6}\left[\left(3(R-x)^2 r^2/h\right) + (R-x)^2\right] - (\pi/3)\left((R-x)^3/h^2\right)r^2\right\}}, \tag{3.13}$$

where x is a chord height changing with R following

$$(R-x)^2 + \left(\frac{R-x}{h}r\right)^2 = R^2 \Longrightarrow x = R - \frac{Rh}{\sqrt{r^2+h^2}}. \tag{3.14}$$

Because when $R < l$ a value may be assumed, namely, $R = 0$, so $x = 0$, and then (3.13) becomes

$$t^3 = \frac{4r^4h^2}{9\pi D^3}. \tag{3.15}$$

In practice, assuming the volume of the room is still $50\,\text{m}^3$ and the dimensions are $L = 3\,\text{m}$, $W = 4\,\text{m}$, and $H = 4.167\,\text{m}$, then $h = 1.63\,\text{m}$ and $r = 1.164\,\text{m}$ and it can be calculated that $t = 1.09\,\text{s}$.

This result is not coincidental. In fact, regardless of the container shape, the Fick diffusion theory states that the diffusion proceeds to the farthest position. For either the spherical room or the two tapered containers, ignoring the intermediate processes of complicated calculation, the final results are always the same with (3.9), and the end points of Figures 3 and 7. Again notice the above rectangular room in Figure 8 with dimensions of $L \times W \times H$. Because the result relates only to the final equation based on the models of the spherical and the two tapered containers, the equation only needs to consider the final stage near the diffusion source. Diffusing from point O to point A is exactly equivalent to diffusing through one-eighth of the rectangular room. So

$$\frac{Q}{(4\pi Dt)^{3/2}}e^{-R^2/4Dt} = \frac{Q - \int_0^R 4\pi R^2 \cdot \left(Q/(4\pi Dt)^{3/2}\right)e^{-R^2/4Dt}dR}{8\times(V/8 - (1/8)\times(4/3)\pi R^3)},$$
$$\left(V - \frac{4}{3}\pi R^3\right)\frac{1}{(4\pi Dt)^{3/2}}e^{-R^2/4Dt} + \int_0^R 4\pi R^2 \cdot \frac{1}{(4\pi Dt)^{3/2}}e^{-R^2/4Dt}dR = 1. \tag{3.16}$$

When $R = 0$,

$$V = (4\pi Dt)^{3/2} \Longrightarrow t = \frac{\sqrt[3]{V^2}}{4\pi D}. \tag{3.17}$$

The result is identical with (3.9). Despite the different room shapes, when $R = 0$, the uniform diffusion time is the same. The results of the above models are analyzed again.

The result of the spherical room is (3.9)

$$t = \frac{1}{(36\pi)^{1/3}} \frac{R_c^2}{D} \Longrightarrow t^3 = \frac{1}{36\pi} \frac{R_c^6}{D^3} \Longrightarrow t^3 = \frac{1}{64\pi^2} \frac{\left((4/3)\pi R_c^3\right)^2}{D^3} \Longrightarrow t^3 = \frac{1}{64\pi^2} \frac{V^2}{D^3} \Longrightarrow t = \frac{\sqrt[3]{V^2}}{4\pi D}. \tag{3.18}$$

The result of the two tapered containers room is (3.9)

$$t^3 = \frac{4r^4h^2}{9\pi D^3} = \frac{\left((2/3)\pi r^2 h\right)^2}{(\pi D)^3}. \tag{3.19}$$

Because the room size $V = L \times W \times H$, and then $(1/3)\pi r^2 h = V/16$, so

$$t^3 = \frac{4(V/16)^2}{(\pi D)^3} \Longrightarrow t = \frac{\sqrt[3]{4V^2/16^2}}{\pi D} \Longrightarrow t = \frac{\sqrt[3]{V^2/64}}{\pi D} = \frac{\sqrt[3]{V^2}}{4\pi D}. \tag{3.20}$$

Therefore the obtained diffusion time in the rectangular room is the same in (3.17), and all results are the same as in (3.9).

In all the three models above, the diffusion source is placed at the center of the closed room. If the diffusion source is at the corner of the closed room, the result will be different. For example, if the diffusion source is placed at the corner, such as at point A in Figure 8, letting the aerosol diffuse through one octant, this will be equivalent to having eight times the initial aerosol mass when the diffusion source is at the room center. The final equation then becomes

$$\frac{8Q}{(4\pi Dt)^{3/2}} e^{-R^2/4Dt} = \frac{Q - \int_0^R 4\pi R^2 \cdot \left(8Q/(4\pi Dt)^{3/2}\right) e^{-R^2/4Dt} dR}{V - (1/8) \times (4/3)\pi R^3} \tag{3.21}$$

and can be simplified as

$$\left(V - \frac{1}{6}\pi R^3\right) \frac{8}{(4\pi Dt)^{3/2}} e^{-R^2/4Dt} + \int_0^R 4\pi R^2 \cdot \frac{8}{(4\pi Dt)^{3/2}} e^{-R^2/4Dt} dR = 1. \tag{3.22}$$

When $R = 0$,

$$t = \frac{\sqrt[3]{V^2}}{\pi D}. \tag{3.23}$$

Compared with (3.9), the diffusion time is four times than when the diffusion source is at room center. Clearly, if the diffusion source is placed at the middle of the line AB in Figure 7, the result becomes

$$t = \frac{\sqrt[3]{V^2}}{\sqrt[3]{4}\pi D}. \tag{3.24}$$

If the diffusion source is placed at the center of the *ABCD* plane in Figure 8, the result becomes

$$t = \frac{\sqrt[3]{V^2}}{\sqrt[3]{16}\pi D}. \tag{3.25}$$

The above results indicate that the differences in uniform diffusion time are due to the position of the diffusion source, and the shape of the closed room does not affect the results directly.

4. Conclusion

It is very difficult to estimate the time from the release of the aerosol to extinguishment due to the turbulent diffusion of aerosol fire extinguishing agent, the complicated room structure, and the environmental conditions. A simple method is developed to determine the uniform diffusion time of pyrotechnic aerosol fire extinguishing agent. First, the diffusion coefficient is experimentally determined, then a series of models are established using the Fick diffusion theory, and finally the uniform diffusion time is analyzed in detail for different shapes of closed room and different diffusion source positions. The conclusion is shown that

(i) This method can be used to easily estimate the extinguishing time.

(ii) It is found that the uniform diffusion time depends on the total room volume, the diffusion coefficient, and the diffusion source position, but not on the shape of the room.

(iii) The equations derived from the above models have illustrated the potential of the proposed method in predicting the diffusion time of extinguishing aerosols.

(iv) Because the diffusion time involves the effective concentration, the diffusion coefficient, and the diffusion source position, this method can be applied to determine the optimal allocation and quantity of aerosol fire extinguishing agent and evaluate the effect of fire extinguishment.

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