Simulation of a typical fire process in a gas station

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Abstract: Fire simulation software PyroSim was used to simulate the occurrence and development process of a gas station kiosk fire, the change rules of key parameters such as temperature, CO, smoke spread and visibility in the fire process were briefly discussed. From the simulation process and results, when there is an open fire in the refueling booth, the smoke is mainly distributed below the refueling booth and will not enter the interior of the supporting office area. The visibility within 1m near the supporting office area is not significantly affected; the highest temperature near the burning surface and the lower wall of the roof of the refueling booth can reach more than 1000°C, and the temperature of the refueling unit and the column nearest to the burning surface can reach 400°C; the highest concentration of carbon monoxide within 1m of the supporting office area is 18ppm, which is not high enough to cause harm to human body.

1. Introduction

In recent years, with the development of fire safety technology, the safety management level of gas stations has been continuously improved. However, as gas stations are places involving dangerous goods, with dense personnel exchanges and large vehicle flow, fire accidents still occur from time to time. As can be seen from numerous fire accidents in gas stations, once a fire accident occurs, it will not only destroy the normal production and operation of gas stations, but also cause heavy property losses and heavy casualties [1-2]. Therefore, the study of gas station fire accident process, for understanding the gas station fire process law, emergency rescue, reduce or avoid casualties and property losses has important meaning.

In this paper, aiming at the typical fire process of gas station kiosk, the study method of numerical calculation and the application of PyroSim dynamic simulation software were adopted to discuss the change rules of key fire parameters in the process of fire occurrence and development. On the one hand, the research methods and conclusions can provide a reference for in-depth study of fire laws and emergency response plans of gas stations; on the other hand, they can provide some reference for performance-based design of fire safety of gas stations.

2. Model construction and parameter setting

2.1. Physical model

Establish the physical model as shown in Fig.1. The overall size of the gas station is 26m long, 26m wide and 7m high. The refueling pavilion is 17m long, 14m wide and 7m high, and contains four main
refueling islands, each of which has a refueling gun. The supporting office area is 15m long, 4m wide and 3m high, with two doors and three windows. There are three rooms in total. The leftmost room is the power distribution room, equipped with cables, distribution boxes and other facilities; the middle room is the appliance storage room, which is used to place auxiliary oil and fireproof equipment and other materials; the rightmost room is the duty room, which is used for the staff on duty and other staff to rest. There are wooden tables, sofas and metal cabinets for storing documents.

Fig. 1. Three-dimensional model and plan of gas station

2.2. Fire scene and parameter setting
Through extensive investigation, it is found that open fire and electrical factors are the main causes of fire in gas station rooms\(^{(3)}\). This paper focuses on the simulation of the fire process of open fire. The ignition point is the refueling booth. The fire conditions are as follows:

Fire scenario: Open fire caused by oil leakage due to improper operation in the process of oil unloading or oil receiving. The fire area is located in the refueling booth area.

Parameter Settings: The obstacles are an important geometric representation of the program. In order to draw the geometric model of the gas station, the corresponding three-dimensional coordinate system should be established according to the actual situation of the gas station at first, and the corresponding coordinates of each point of the gas station in the coordinate system should be determined according to the position relationship between each component of the gas station. The coordinate diagram of the gas station is shown in Fig. 2. Specific parameters are as follows:
Column: According to the coordinate system, there is a rectangular column with a side length of 1m and a height of 5.8m in (9,7), (18,7), (9,13) and (18,13) respectively, which is located at 1m outside the safety island 4m×0.6m×0.2m:

Refueling machine: Each refueling island has a single gun refueling machine with the size of 0.4m×1.0m×2.0m, which is located at 1m inside the column of the refueling island. It also takes the center of the refueling booth as the symmetric center to show central symmetry.

Ceiling: The top of the gas station has a size of 17.0m×14.0m×1.0m concrete canopy.

Fire location: Given a lot of gas station oil tank located in the heart of the refueling pavilion directly, so the central oil may leak zones for refueling station near the central area, oil spill on the ground will become a burning area, therefore in the middle of the refueling station bottom area near chose a 4 m * 4 m area as a flame of fire burning zone.

In order to simulate the fire development process, a total of four temperature detectors are set. Measuring point 1 and 3 are located 1 meter away from the door, measuring point 2 is located 20cm away from the auxiliary oil drum in the equipment room, and measuring point 4 is located 1 meter away from the window of the duty room. All the measuring points are located at a height of 1.8m. Three visibility, smoke layer height and other parameters measurement points were set, which were coincident with temperature detection points 1, 3 and 4. Temperature, visibility and CO concentration slices were arranged at x=19.2m, y=19.2m and z=1.8m, respectively, as shown in figure 3.

2.3. Setting of computing grid
In numerical simulation, the accuracy of mesh has an important effect on the accuracy of calculation
results. FDS provides a calculation method to determine the corresponding mesh size, and the calculation formula is as follows [4]:

\[ D^* = \left( \frac{Q}{\rho_c C_p T_o \sqrt{g}} \right)^{\frac{3}{2}} \]  

(1)

In the expression, \( Q \) Fire heat release rate, The unit is kW; \( D^* \) Fire characteristic diameter; \( \rho \) Environmental density; \( T_o \) Ambient temperature; \( C_p \) Specific heat at constant pressure; \( g \) stands for acceleration due to gravity.

Equation (1) shows that according to the environment of the gas station, the ambient temperature is set as 20℃, and various physical parameters of the air at this temperature are referred to. According to the relevant literature, the heat release rate of gasoline per unit area is 2500kW. Therefore, under the working conditions in this paper, the total heat release rate of the ignition surface is 40MW, and the total heat release rate of the ignition surface is 367.5KW.

According to the calculation results of the formula and combined with the calculation speed, the grid size calculated is set as 0.4m×0.4m×0.4m, and the total number of grids is about 76,050.

3. Results and discussions

3.1 Temperature distribution

Fig. 4 shows the simulation results of Z =1.8m and Y =19.2m temperature slices in the event of an open fire. As can be seen from the image, after the fire, the heat generated by the burning oil makes the area of high temperature on the plane expand rapidly in all directions. 2.8 seconds after the fire, the high temperature area on z=1.8m reached its maximum, at which time the maximum temperature of the pyrotechnic center had reached 1000℃. At the 60th second, the highest temperature area on the section of y=19.2m began to move to the lower wall area of the roof of the oiler booth, and the highest temperature area has been located in this area since then. In the whole simulation process, the shape and area of the high temperature area are constantly changing, but because there is no combustible near the fire source, the fire does not expand significantly, the fire center is always located at the fire source, and the high temperature area does not spread out of the refueling booth to the supporting office area.
3.2. Carbon monoxide concentration

The combustion process in the fire will produce a lot of substances, such as solid particles of flue gas, a variety of toxic and harmful gases and liquids. Toxic and harmful gases and some asphyxiating gases are the main factors that affect the evacuation of people in fire. Carbon monoxide is the main toxic gas common in fires. The density of carbon monoxide is similar to that of air, and it is easy to mix evenly with air. Toxicity occurs when excessive carbon monoxide is inhaled by human body. The harm caused by different concentrations of carbon monoxide to human body is shown in Table 1.

Table 1 Influence of different concentrations of CO on human body[^5^]

| CO concentration (ppm) | Duration of exposure | Human Adverse Reactions |
|------------------------|----------------------|-------------------------|
| 16                     | 8 hours              | The toxic effect is negligible |
| 30                     | 8 hours              | There was no obvious physiological reaction |
| 50                     | 2 hours              | No apparent consequences |
| 100                    | 2 hours              | Some people will have headaches and nausea |
| 300                    | 1 hour               | Headache, dizziness |
| 1000                   | 2-3 minutes          | Unconsciousness, vomiting |
| 10000                  | 2-10 minutes         | Cause of death |
| 20000                  | 1-2 minutes          | death |

Fig. 5 shows the simulation results of carbon monoxide concentration slices with \( Z = 1.8 \text{m} \) and \( Y = 19.2 \text{m} \) when an open fire occurred. Can be seen from the picture, when a fire, fire place produces severe oxidation reaction, rapid fire center oxygen consumption lead to fire center the carbon monoxide concentration of more than 20000 PPM, in 60 seconds after the fire broke out, the areas under the ceiling side become the most violent oxidation reaction, the carbon monoxide concentration reached more than 15000 PPM here, then on the \( y = 19.2 \text{ m} \) section, there has been below the ceiling and burning surface above two high concentration area. Outside the core, the production of carbon monoxide is inhibited because the oil molecules are in sufficient contact with oxygen to produce the complete oxide carbon dioxide. At the measuring point 1, the concentration of carbon monoxide
reached its peak at about 16ppm at about 30 seconds, at which time the harmful effect of carbon monoxide on human body was almost negligible.

3.3. Speed of smoke extend

Fig. 6 shows the smoke distribution at four time points in the process of an open fire. It can be seen from the simulation results that when an open fire occurs, a large amount of smoke and heat are generated and spread to the surrounding areas. 3 seconds after the fire, smoke has nearly spread to the roof of the refueling booth, began to diffuse around the burning plane. 4.5 seconds after the fire, the smoke has nearly spread out of the ceiling area of the gas station, at this time, the smoke has begun to spread to the supporting office area. 300 seconds after the fire, the smoke spread further, and some of the smoke reached the area near the door of the supporting office area. At the 600th second, the fire
continues to develop, but the smoke diffusion in the simulated area is not different from that at the 300th second. Thus it can be seen that the smoke is mainly distributed in the lower part of the refueling booth and the surrounding area when a fire occurs, and will not spread to the supporting office area in large numbers.

3.4. Visibility distribution

Fig. 7 shows the simulation results of visibility slice with $Z = 1.8m$ and $Y = 19.2m$ when an open fire occurs. As can be seen from the image, when a fire occurs, a large amount of soot is generated in the burning area, resulting in a significant decrease in visibility nearby. Visibility in the area above 3m height of the gas station is almost zero. In addition, some of the smoke diffused into the area in front of the appliance storage room, causing a small change in visibility in the area. Because the smoke has not been diffused into the office area, the visibility inside the office area has not changed significantly on this plane.
4. Conclusions
Aiming at the typical fire process of gas station, this paper used PyroSim fire dynamic simulation software to conduct numerical analysis on the occurrence and development process of gas station kiosk fire, quantitatively evaluate the fire risk, and briefly discuss the change rules of key parameters such as temperature, CO, smoke spread and visibility in the fire process. From the simulation process and results:

1. When there is an open fire, the smoke in the gas station is mainly distributed below the refueling booth, and a small amount of smoke will spread to the nearby supporting office area. Smoke will not enter the supporting office area. The visibility within 1m of the supporting office area was not significantly affected.

2. The highest temperature in the combustion zone can reach more than 1000℃. The area where the temperature exceeds 1000℃ is mainly located near the burning surface and the lower wall of the roof of the refueling booth. The temperature of the refueling unit and the column nearest to the burning surface reaches 400℃.

3. Due to the sufficient oxygen in the location where the fire occurred, the concentration of carbon monoxide within 1m of the supporting office area is up to 18ppm, which is not high enough to cause harm to human body.

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