

Numerical Simulation on Smoke Spread and Temperature Distribution in a Corn Starch Explosion

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Abstract. It is discovered from dust explosion accidents in recent years that deep causes of the accidents lies in insufficient cognition of dust explosion danger, and no understanding on danger and information of the dust explosion. In the study, Fire Dynamics Simulator (FDS) evaluation tool is used aiming at Taiwan Formosa Fun Coast explosion accidents. The calculator is used for rebuilding the explosion situation. The factors affecting casualties under explosion are studied. The injured personnel participating in the party are evaluated according to smoke diffusion and temperature distribution for numerical simulation results. Some problems noted in the fire disaster after actual explosion are proposed, rational site analysis is given, thereby reducing dust explosion risk grade.

1. Introduction

There are a lot of dust explosion accidents every year with the development of modern industry. There were nearly 300 dust explosion accidents in the United States since the 1980s to present, and more than 100 people died. Wherein, dust escaped from the production process equipment to the workshop work area and dust explosion occurred in the United States Royal Sugar Mill in 2008, and 13 people died [1]. It can be known that dust explosion accidents show an increasing trend year by year with industry development according to Chemical Safety and Hazard Investigation, CSB and USA data [2]. Fire disasters happened everywhere. Reasons thereof are investigated for preventing the risks. However, FDS software has quite widespread application scope, and it is generally used for discussing fire disasters in households, factories, buses, stores, mine, steel and concrete, etc. For example, a number of papers have been published on the heat release rate of mining vehicles [3]. [4] The highway tunnel is characterized by long depth, complex structure, small space, strong enclosure. Once fire disaster occurs, it is difficult to rule out smoke. Yao, etc. [5] adopted 1:10 tunnel model. An experience formula for solving critical wind speed under the condition that there is a ventilation shaft for wind flows on fire sources is finally obtained. The application scope of the formula is explained and described. Glassman, Aziz, et al. [6] studied the shear failure and bending failure of reinforced concrete box-girder under fire disasters, and carried out finite element model prediction. Full-size fire disaster simulation is quite expensive. Therefore, the calculator simulation has low cost, and the entire working time is shortened. There are quite a lot of activities on the playground, party participants are gathered, and flow rate is especially high. Once a fire disaster breaks out, evacuation is difficult. If there are more causes of fire disasters, combustible goods are excessive, fire disaster load is large, and firefighting is difficult. If personnel can not be evacuated safely, accurately and rapidly, good medical



information is provided, and casualties must be caused, thereby leading to great loss. In the paper, Taiwan Formosa Fun Coast explosion accidents are numerically simulated. Influence on harm degree and evacuation condition of personnel participating in parties is proposed according to the results of simulation. More rational viewpoints of reducing death and injury are proposed.

2. Numerical theory and model

2.1. FDS theoretical basis

FDS+Evac software refers to fire dynamics software. FDS is adopted in the paper. FDS is free and open-source software tools provided by the National Institute of Standards and Technology (NIST) of the United States Department of Commerce. Fire Dynamics Simulator (FDS) is a large-eddy simulation (LES) code for low-speed flows, with an emphasis on smoke and heat transport from fires [7-9]. The control equation is shown as follows, including Conservation of Mass, Conservation of Momentum, Conservation of Energy and Equation of State for a Perfect Gas(Eq. 1~Eq. 4).

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{u} = \dot{m}_b''' \quad (1)$$

$$\frac{\partial}{\partial t}(\rho \mathbf{u}) + \nabla \cdot \rho \mathbf{u} \mathbf{u} + \nabla p = \rho \mathbf{g} + \mathbf{f}_b + \nabla \cdot \tau_{ij} \quad (2)$$

$$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot \rho h \mathbf{u} = \frac{Dp}{Dt} + \dot{q}''' - \dot{q}_b''' - \nabla \cdot \dot{q}'' + \varepsilon \quad (3)$$

$$p = \frac{\rho RT}{\bar{W}} \quad (4)$$

Herein, ρ : density (kg/m^3); \mathbf{f}_b : external force vector (N/m^3); \mathbf{g} : gravity vector (m/s^2); h : sensible enthalpy (kJ); p : pressure (pa); R : universal gas constant (J/K mol); T : temperature ($^{\circ}\text{C}$); \mathbf{u} : velocity vector $\mathbf{u}(u, v, w)$ (m/s); \dot{m}_b''' : mass production rate per unit volume (kg/s m^3); \dot{q}''' : heat release rate per unit volume (kg/s m^3); \dot{q}_b''' : energy transferred (kg/s m^3); \dot{q}'' : heat flux vector (J/s m^2); ε : dissipation rate (kg/s m^3); τ_{ij} : viscous stress tensor (N/m^2); \bar{W} : molecular weight of the gas mixture (g/mol).

2.2. Event description

On 27 June 2015, flammable starch-based powder exploded at the Formosa Fun Coast, a recreational water park in Bali, New Taipei, Taiwan, injuring 508 people, with 199 in critical condition [10], as show in Fig. 1. As of 29 November 2015, fifteen fatalities were attributed to the explosion. The dust explosion, which occurred on a music stage during a "Color Play Asia" party. The powder was identified, by some sources, as colored corn starch. It is preliminarily estimated that 600 people can be accommodated. The height difference from 'temporary dance floor' and the ground is 2 meters. Since people gathered together in the large low-lying land, the wall becomes escape barrier during accidents.



Figure 1. Explosion site

2.3. Model establishment

The water park is located at the seaside section. The party is held in the swimming pool without water. The main activity site size is 40m long X 20m wide X 2m dep, and its area is 800m². The swimming pool has other three directions except the stage performance zone on the north, namely the south side, the west side and the north side respectively.

Explosion belongs to quick burn. It is different from fire disaster in momentary release of huge energy, shorter combustion time and large heat release rate as a result. Fire source heat release rate is about 80MW. The t-squared parabolic growth equation (Eq. 5) is given by

$$\dot{Q} = \alpha t^2 \quad (5)$$

Where \dot{Q} the HRR (kW) is, α is the fire growth coefficient (kW/s²), and t is time (s). Fire growth model is t^2 fire model. α of 800 kW/s² or so is obtained after evaluation according to the situation then due to fast explosion and huge energy as shown in Fig. 2. The actual activity area of the amusement park [10] is shown in Fig. 3. Seven fire sources are planned according to explosion sequence. The coordinates of the site dimensions are shown as red part in Fig.4. The calculation amount is considered, the calculation grid dimension is set as 0.25m×0.25m×0.2m due to larger calculation space. The fire disaster simulation time is set as 50S after evaluation according to site condition.

Cause of fire in Formosa Fun Coast dust exploration: after the accident cause is identified and experimented by fire-fighting police, it is determined that the accident is caused by too high temperature of stage lighting beam lamp. The lamp temperature is up to 1250 °C on the activity stage during the accident. Dust can combust at 369 °C. The working personnel responsible for spraying carbon dioxide gas fell carelessly, thereby a large number of color powder are gathered towards the computer lamp on the right of the stage. The power is fired in the lamp, thereby leading to explosion.

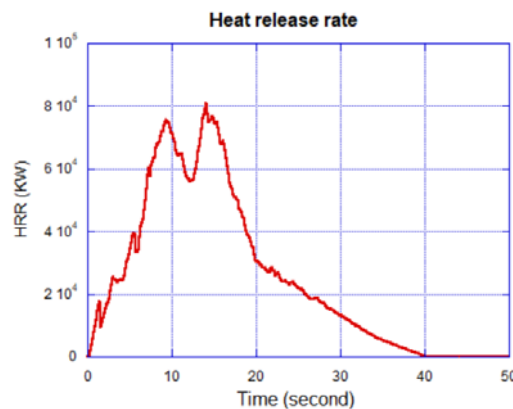


Figure 2. Heat release rate curve plan in the scenario



Figure 3. Activity site diagram

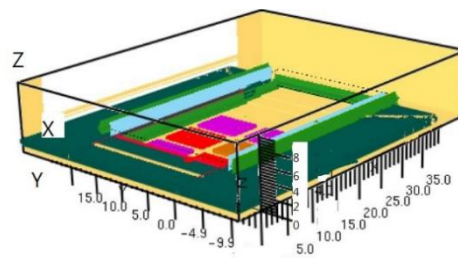


Figure 4. Design figure of simulation scene

3. Results and Discussion

3.1. Smoke Spread during fire disaster development

The simulation is simulated through setting the site in the scope of activity square. The smoke flow condition under different fire disaster conditions is shown in Fig. 5. The figure shows that the smoke spreading time is short, but it has powerful lethality in the crowded square with time in the same environment. It is obvious that smoke can not be controlled in the wide field. The smoke flow forward development is delayed after the peak of exploration is reached for 15s. The smoke flow drifts with wind moving direction under the condition of wind speed environment as shown in Fig. 6. Therefore, wind direction of smoke is considered during personnel escaping. They should escape and evacuate at the windward direction. Harm of smoke or flue gas can be avoided. Low gesture is adopted for moving forwards due to smoke spreading. The smoke flow development is not limited. Smoke spreads with wind, thereby polluting the environment. It is a necessary problem that must be faced in fire disasters. The experimental results are in line with previous research conclusions. Although there are some differences between explosion and fire disaster, the same aspect can be discovered for efficient utilization, thereby fully explaining the feasibility of FDS simulation.

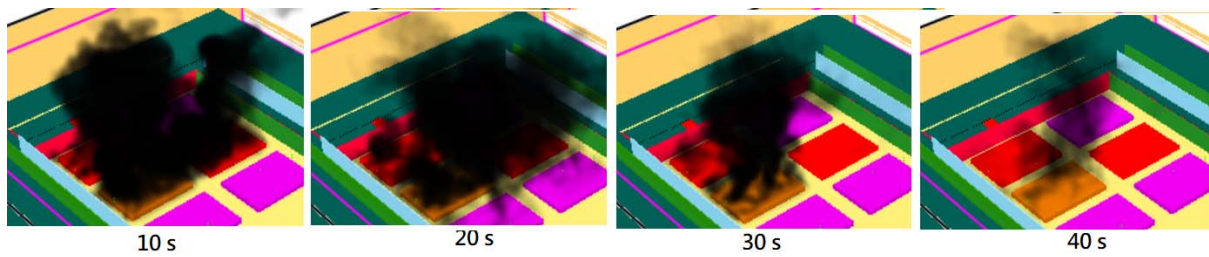


Figure 5. Smoke spread condition.



Figure 6. Smoke flowing condition under different wind speeds At 10s

3.2. Temperature distribution during fire disaster development

The temperature profiles are shot in 6m, 12m and 15m positions from the X axis as shown in Fig.7. In the fire place, many temperature profiles are set for observing the site situation. The figure shows that explosion occurs in the fire site at 10s under different time points, activity participants in the front area near the stage are harmed greatly. The highest temperature is about 450 °C. The fire is continuous at 20 seconds. Therefore, the skin is harmed by high temperature continuously, which is more severe than the grade IV burn. If the depth scope reaches full-thickness skin, subcutaneous tissue, muscle and bone. The fire situation is declined, and the influence is reduced at 30 seconds. The fire is subsided at 40 seconds. It is observed that the temperature is higher, and the temperature is lower in the place far away from the explosion, such as edge of activity field. The temperature is about 30 °C under stable environment at coordinate (10, 9, 1). However, there is fluctuation with wind speed change, but the fluctuation extent is small. It is within normal acceptable scope of human body temperature. The temperature change is prominently declined, which is lower than the fire disaster area as a whole. The declining extent is significant. The temperature is more and more balanced finally with development of fire.

The temperature profile of Z axis at 1m is shown in Fig. 8. It is observed that the fire is quite violent at 10s, the fire spreads to other areas at 20s, and therefore more people are injured. Burn area is

represented by the proportion of burn area in body surface area, and extremely severe burn is formed when the proportion is $> 25\%$ for adults. Though the fire disaster time is short, the fire temperature is enough to burn the clothes. Therefore, very severe burns are caused. The area of burn is very large. Many people die from burns due to delayed rescue work though perfect medical care is available subsequently.

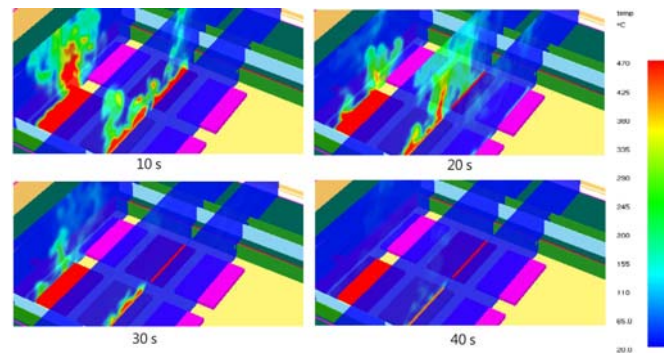


Figure 7. Temperature distribution diagram of X axis at 6m, 12m, and 15m positions

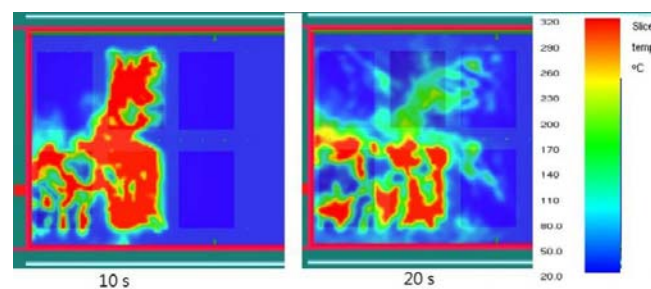


Figure 8. Temperature profile of Z axis at Z=1m

Tourists casualties are caused by temperature. Z axis is fixed at 1m at 8m through X axis. Y axis concurrent is taken for respectively setting Thermocouple device at a total of five points of Y=-8m, -4m, 0m, 4m and 8m, thereby obtaining the temperature curve diagram in the simulation process. The temperature distribution condition is analyzed, and the results are shown in Fig. 9. The temperature is up to 470°C at 12S in the position of Y = 4m. The corn starch is explored at the position. Meanwhile, activity participants are burnt. The corn starch on the floor is connected for exploration.

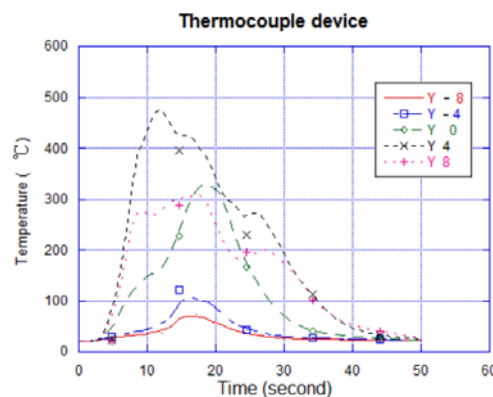


Figure 9. Temperature curve diagram of setting five points of X axis at 8m

4. Conclusion

The application of dust technology is becoming more and more extensive with the development of science and technology. In daily life, we get some opinions from numerical simulation during dust explosion preventive measures are adopted.

(1) We should recognize the hazards of dust explosion, strengthen safety education and safety management. Preventive measures are adopted in management to reduce the frequency of the risk or minimize the severity of its consequences

(2) Because the dust explosion process is very short, there is high degree of danger for people, therefore application of corn starch for show effect should be prohibited in entertainment activities. The accidents can be avoided, and danger can be reduced.

(3) If the outdoor activity suffers from a fire disaster, wind direction should be considered during escaping, and people should escape to the windward side as the benchmark.

(4) In the accidents, burns are caused by extremely high temperature, thereby causing death in succession. Therefore, proper sunscreen lotion should be smeared before activity to protect skin. Protective clothing even can be provided for protecting skin, thereby avoiding attack of fire.

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