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Safety distance for preventing hot particle ignition of building insulation materials

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Abstract Trajectories of flying hot particles were predicted in this work, and the temperatures during the movement were also calculated. Once the particle temperature decreased to the critical temperature for a hot particle to ignite building insulation materials, which was predicted by hot-spot ignition theory, the distance particle traveled was determined as the minimum safety distance for preventing the ignition of building insulation materials by hot particles. The results showed that for sphere aluminum particles with the same initial velocities and diameters, the horizontal and vertical distances traveled by particles with higher initial temperatures were higher. Smaller particles traveled farther when other conditions were the same. The critical temperature for an aluminum particle to ignite rigid polyurethane foam increased rapidly with the decrease of particle diameter. The horizontal and vertical safety distances were closely related to the initial temperature, diameter and initial velocity of particles. These results could help update the safety provision of firework display.

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Keywords safety distance, hot metallic particle, critical ignition temperature, particle trajectory

Chinese has a tradition to enjoy watching aerial firework display in important festivals. However, firework display has caused some disastrous building fires in recent years. The infamous one is China Center Television (CCTV) fire in 2009, which caused a great economic loss and one firefighter's death.[1] The investigation reported that some hot metallic particles produced by firework display contacted and ignited the organic building insulation materials, and subsequently induced a violent burning. Reviewing of these fires reveals that safety provision of firework display can not meet the rapid development of buildings in China. On one hand, the newly constructed high-rise buildings make the distance between firework explosion point and the building too short to be safe. Therefore, the aerial firework display place should be farther away from the high-rise buildings. On the other hand, the envelope of many buildings is covered by building insulation layer for energy saving in China. Due to the low cost and superior adiabatic performance, the organic building insulation materials, such as rigid polyurethane foam and expanded polystyrene foam, are wildly used. However, these organic building insulation materials are flammable and prone to be ignited and burn violently. In order to make firework display safer, the mechanism of hot

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metallic particle movement and the ignition of building insulation materials should be understood.

Fireworks are a class of explosive pyrotechnic devices and the colors in fireworks are usually generated by pyrotechnic stars (usually just called stars) which produce intense light when ignited. The brightest stars are fueled by aluminum. Aluminum is used to produce silver and white flames and sparks and is a common component of fireworks. In this work, the hot metallic particles produced by fireworks are represented by aluminum particles. However, the analysis in this work is also valid for other metallic particles.

When the hot metallic particles are released from the explosion point of pyrotechnic stars, the particles obtain their initial velocity and temperature. When they fall, the trajectory and temperature history can be calculated. There are some articles about the ignition of wildland fuels by hot particles ejected from clashing/short-circuit overhead transmission lines.[2–5] In these studies, the metal particles were created by clashing or short-circuit of lines with given temperature and height and then the particle temperature at landing was predicted. If the temperature at landing exceeds the assumed ignition temperature of wildland fuels, ignition and fire will happen. Whether ignition occurs is only judged by the relative magnitude of the particle temperature at landing and ignition temperature of fuels. However, the ignition process depends on the interactive heat transfer of particle and fuel, and the constant ignition temperature assumption may not be valid. For the condensed materials contacted with hot particles with different diameters, the ignition process occurs at different temperature.[6–10]

This work addresses the safety distance for preventing hot particle ignition of building insulation materials. The trajectories of flying hot particles with different initial sizes, temperature, and velocities are predicted and the temperatures during the movement are calculated too. Once the particle temperature decreases to the critical temperature for a hot particle to ignite building insulation materials, which is predicted by the hot-spot ignition theory, the travelled distance is considered as the minimum safety distance.

When a hot metallic particle is ejected from a firework explosion point, it gets its initial velocity and temperature. Then the particle moves horizontally when it falls and the movement can be described by Newton's second law. The initial velocity is assumed to be U_0 in the X-direction (horizontally) and $V_0 = 0$ in the Y-direction. Under this assumption, the horizontal distance that particle travels is the longest for the same initial velocity and hence the corresponding safety distance will be more reasonable for all cases. For simplicity, the particle is assumed to be spherical with diameter d and density ρ_{P}, and is not burning (the initial temperature is below the ignition temperature of aluminum 2 327.15 K).[3] The particle mass $m = \rho_{\mathrm{P}}\pi d^3/6$ is constant during flying.[5] The ambient wind is not considered.

The motion equation in the X-direction is

$$m\,\mathrm{d}U_{\mathrm{P}}/\mathrm{d}t = -A_{\mathrm{P}}C_{\mathrm{D}}\rho U_{\mathrm{P}}^2/2, \tag{1}$$

then we have

$$\mathrm{d}U_{\mathrm{P}}/\mathrm{d}t = -3C_{\mathrm{D}}(\rho/\rho_{\mathrm{P}})U_{\mathrm{P}}^2(4d)^{-1}. \tag{2}$$