Research paper

Blast extinguishment of a methane-air jet diffusion flame using a silver azide pellet

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Abstract

To elucidate the effect of an explosion location on the blast extinguishment, extinguishing experiments of a methane-air jet diffusion flame have been performed by using a 10 mg silver azide (AgN_3) pellet. We have recorded the extinguishing process with a high-speed camera and measured the extinguishing probability by varying the explosion location. From the results, the optimum explosion height for the blast extinguishment has been clarified.

Keywords: post-earthquake fire, blast extinguishment, diffusion flame, explosive

1. Introduction

After occurrence of a huge earthquake, simultaneous multiple fires break out in Japan, such as the Great East Japan Earthquake. At the same time, infrastructure such as water utilization for firefighting, roads and so on, gets severely damaged due to earthquake impacts. In the emergency, ordinary fire extinguishing methods cannot be used. In order to minimize the damage caused by the post-earthquake fires, a development of a new firefighting method is needed.

The authors consider that blast extinguishing method with an explosive[1)] is a candidate for the emergency firefighting method because it can quickly blow off a high intensity fire such as an oil well fire. However, there are a few studies on the blast extinguishment[1)–5)] and the blowoff characteristics and mechanisms have not been clarified in detail. From the extinguishing experiments of a counterflow diffusion flame with a laser-induced breakdown[2)] and of a diffusion flame formed over a polymethyl methacrylate plate with a laser ablation[3)], the authors revealed that the effective range of the blast extinguishment depended on the one-third power of the input energy to the explosion. In addition, from the extinguishing experiment with a 10 mg charge of silver azide (AgN_3), it was found that the vortex pair motion appeared in the combustion area due to interaction between a shock wave and diffusion flame structure[1)], that is, the Richtmyer-Meshkov instability[6)] which is caused by the misalignment of local pressure and density gradients. At the initial stage of the blast extinguishing process, a local extinction occurred due to the vortex flows which were caused by the Richtmyer-Meshkov instability[1),5)]. Then, detonation products produced from the explosive charge flowed to and affected the flame with the local extinction[1),5)]. Finally, the flame was blown off completely. Thus, the Richtmyer-Meshkov instability and the flow of detonation products are a key factor in the blast extinguishment.

In the present study, to elucidate the effect of the explosion location on the blast extinguishment, blowoff experiments of a methane-air jet diffusion flame by using a 10 mg AgN_3 pellet have been performed. The extinguishing processes have been recorded with a high-speed camera. The extinguishing probability has been measured changing the explosion location. Based on the results, we have discussed the optimal explosion location for the blast extinguishment.

2. Experimental apparatus and method

Figure 1 shows the experimental setup. A methane-air diffusion flame was formed with a round tube burner which was embedded in aluminum plate and had an inner diameter of 2.8 mm. The averaged flame height was about 88 mm at a fuel flow rate of 8.3 $cm^3\ s^{-1}$. A 10 mg AgN_3 pellet (Showa Metal Industrial Co., Ltd.), which released energy of about 18 J was used and ignited by a pulsed laser beam (energy: 30 mJ, wavelength: 532 nm and pule duration (full width at half maximum, FWHM): 6 ns). To arrange the AgN_3 pellet at the arbitrary position, it was attached to a fishing line with a glue as shown in Figure 1. The horizontal distance, R, and height, Z, of the explosion location were varied. The blowoff process was recorded with a high-speed camera (Nac, memrecam HX-7, 10000 fps). A blowoff probability, P, was calculated as a ratio of the number of the successful blast extinguishment to the number of total experiments of 10.

3. Results and discussion

3.1 Blowoff process of blast extinguishment

Figure 2 shows typical blowoff processes observed in

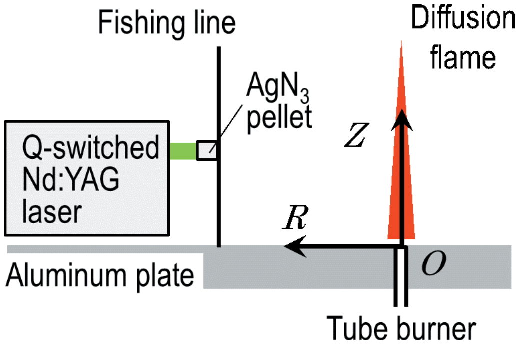
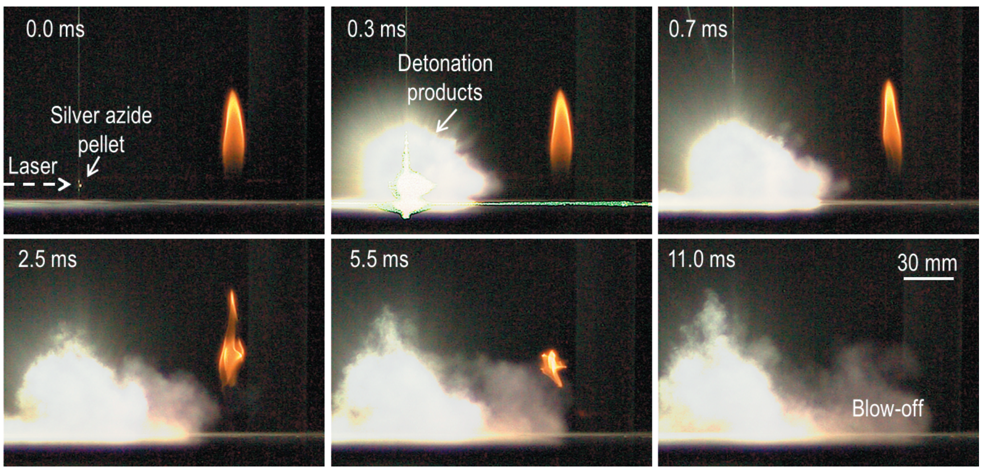


Figure 1 Experimental setup.

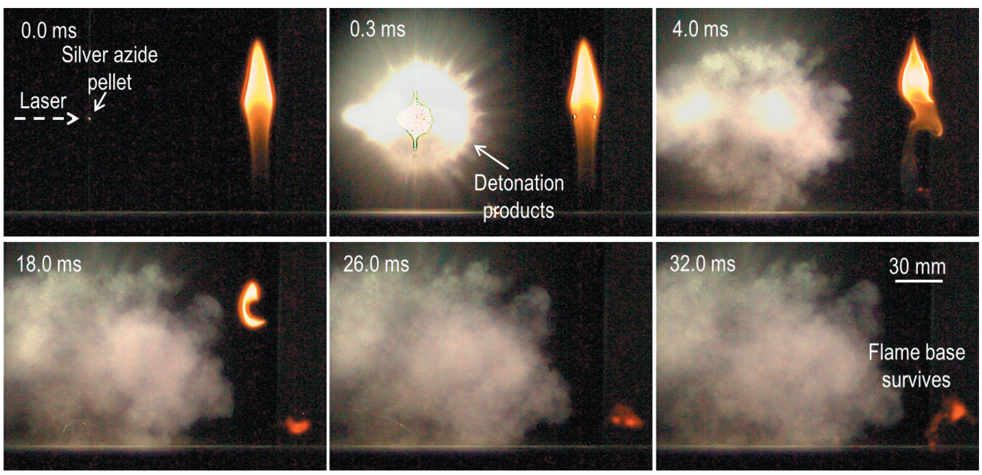
the blast extinguishment. The elapsed time from the ignition is shown in each image.

Figure 2(a) shows the successful extinguishment. The explosion location was set at R=90 mm and Z=10 mm. At 0.3 ms, the silver azide pellet explodes and releases the detonation products which is observed as a white fog in the image. Then at 0.7 ms, the flame shape begins to deform due to the Richtmyer-Meshkov instability, that is the interaction of a shock wave with the flame structure. At 2.5 ms, it is observed that the flame base region which is the most important flame portion to stabilize a diffusion flame[7),8)] is locally extinguished due to the high-speed flow induced by the shock-flame interaction. When a diffusion flame is highly stretched by a steep velocity gradient in the flow, the heat production from the combustion reaction cannot balance the heat conduction out of the reaction zone. As a result, a local extinction is generated[9)]. Moreover, the detonation products travel along the aluminum plate and reaches the burner position at 5.5 ms. The rest of the flame is blown off by the flow of the detonation products. Finally, the blast extinguishment is achieved.

Figure 2(b) shows the failed case. The explosion location was set at R=90 mm and Z=50 mm. At 4.0 ms, even though the flame is deformed by the local flow generated by the Richtmyer-Meshkov instability, the base flame is not



(a)Extinguished case ((R, Z) =(90 mm, 10 mm))



(b)Failed case ((R, Z) =(90 mm, 50 mm))

Figure 2 Sequaential images of blowoff process in blast extinguishment.

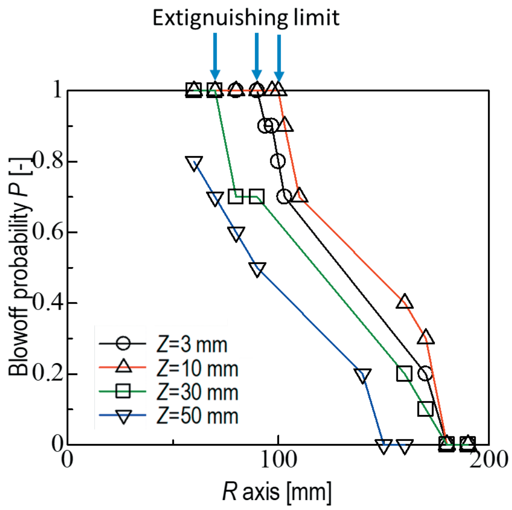


Figure 3 Blowoff probability.

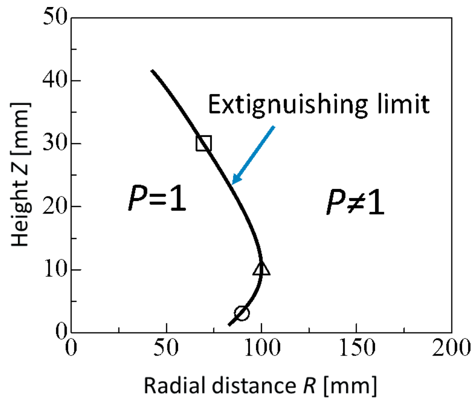


Figure 4 Extinguishing limit.

extinguished. Moreover, the detonation products do not arrive at the flame base region. As a result, the flame survives, and the blast extinguishment is not achieved. In Figure 2(b), the slant distance from the explosion location to the flame base increases in comparison with Figure 2(a). Therefore, the intensity of the blast wave which determines the local flow velocity induced by the Richtmyer-Meshkov instability becomes weaker and also the flow velocity of the detonation products decreases at the flame base region. As a result, the blast extinguishment shown in Figure 2(b) is not successful.

3.2 Distribution of blowoff probability

Figure 3 shows the probability profiles of the blast extinguishment. The horizontal axis shows R, that is, the radial distance from the burner center to the explosion location. The height of the explosion location, Z is varied as an experimental variable.

From Figure 3, it is seen that when the explosion location is close to the jet diffusion flame, all probability show unity except for Z=50 mm. Moreover, as the radial distance between the explosion location to the flame base increases, they decrease monotonically and eventually become zero. As a result, the maximum radial distance to indicate P=1 is defined as an extinguishing limit, within which the diffusion flame is always blown off by the explosion. Furthermore, by comparing the extinguishing limits at each explosion height, we can evaluate the extinguishing effectiveness of the blast extinguishment.

Figure 4 shows the extinguishing limits. The vertical and horizontal axes are the height and radial distance of the explosion location. As a result, it is found that the extinguishing limit shows the largest value at Z=10 mm. Therefore, it can be said that the explosion height of 10 mm is the optimal position to extinguish the jet diffusion flame with the blast wave in this study.

In addition, when Z is greater than 10 mm, the extinguishing limit decreases as the explosion height becomes larger because the slant distance from the explosion location to the flame base increases. On the other hand, when Z is less than 10 mm, the value of the extinguishing limit also decreases as the explosion height becomes smaller. The trend that the extinguishing limit decreases as the explosion location is close to the aluminum plate might be caused by variation of the interaction phenomena between the explosion and the ground, such as shock wave reflection phenomena.

4. Concluding remarks

In this study, in order to reveal the effect of the explosion location on the blast extinguishment, blowoff experiments of a methane-air jet diffusion flame have been performed by using a 10 mg AgN_3 pellet. From the experimental results, it is found that there is the optimal height of the explosion to extinguish the diffusion flame effectively by using the blast wave and the flow of the detonation products.

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