

Experimental investigations of the deflagration pressure attenuation using a water gel barrier in a vented explosion chamber

Nam Il Kim* and Dal Jae Park**†

*Department of Safety Engineering, Graduate School of Energy and Environment, Seoul National University of Science and Technology, 138 Gongneung-gil, Nowon-gu, Seoul 01811, KOREA

**Department of Safety Engineering, Seoul National University of Science and Technology, 138 Gongneung-gil, Nowon-gu, Seoul 01811, KOREA
Phone : +82-2-970-6308

†Corresponding author : pdj70@seoultech.ac.kr

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Abstract

Experimental investigations were performed to examine deflagration pressure attenuation of a LPG-air mixture using a water gel barrier in an explosion chamber that is, 1400 mm in length, and has a square cross-section of $100 \times 100 \text{ mm}^2$. Two independent variables were explored: the concentration of gel and the thickness of the water gel barrier. The gel concentration ranged from 10 % to 40 % with intervals of 10 % by weight of gel, and the thicknesses ranged from 10 mm to 25 mm with intervals of 5 mm. Displacement of the gel barrier was measured using a high-speed video camera, and pressure development was measured using pressure transducers and a data acquisition system. It was found that the displacement curve of the barrier displayed a similar trend as that of the pressure. It was also found that as the concentration and thickness of the gel barrier increased, the reduction percentage of the peak pressure also increased. This indicates the possibility of using gelatin gel as a deflagration pressure-reducing material.

Keywords : explosion attenuation, water gel, gel displacement

1. Introduction

Gas explosions occurring within structures have been treated with special concern due to the potential for loss of life, destruction of property, etc. Presently, different explosion mitigation techniques^{1),2)}, such as explosion venting, explosion suppression, isolation, and protection barriers are available for minimizing the consequences due to such explosions. These techniques have their own advantages and disadvantages in terms of their applications²⁾. An alternative method is to find an effective and economical explosion-resistant agent that can be integrated into the explosion resistant design of a building.

Many experimental studies³⁾⁻⁸⁾ to attenuate blast waves using materials, such as water columns, gel, foam, and sand, have been performed⁴⁾. The main objectives of the studies were the attenuation of blast waves with explosives. The attenuation properties of blast waves due

to explosives using a water gel barrier have been well reported in previous studies³⁾⁻⁵⁾. However, little attention has been paid to examine the mitigation characteristics of a water gel for attenuating the deflagration explosion. The main objective of this study was to investigate the attenuation characteristics of the deflagration pressure occurring due to gas explosions by varying the thickness and concentration of a water gel barrier within a laboratory explosion chamber.

2. Experimental

Figure 1 shows the schematic diagram of the experimental set-up. The dimensions of the chamber were 1400 mm in length with a square cross-section $100 \times 100 \text{ mm}^2$. The rig was made of 10 mm thick transparent perspex to visualize the movement of the water gel barrier. The water gel barrier was placed in a

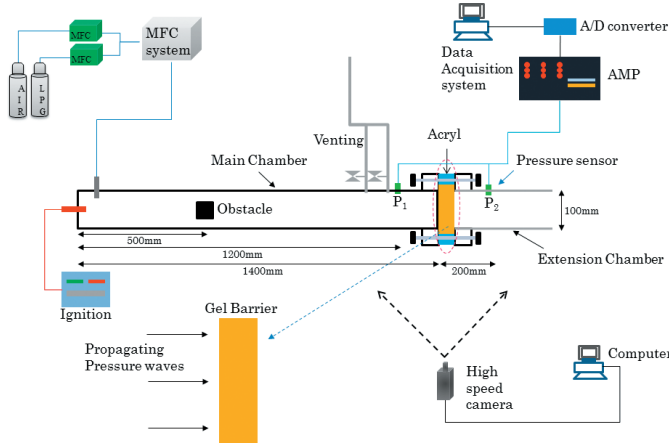


Figure 1 Schematic diagram of the experimental set-up.

Table 1 Thickness and concentration of water gel barriers used in the tests.

| Symbol | Thickness [mm] | Concentration [%] |
|--------|----------------|-------------------|
| 10T10C | 10 | 10 |
| 10T20C | | 20 |
| 10T30C | | 30 |
| 10T40C | | 40 |
| 15T10C | 15 | 10 |
| 15T20C | | 20 |
| 15T30C | | 30 |
| 15T40C | | 40 |
| 20T10C | 20 | 10 |
| 20T20C | | 20 |
| 20T30C | | 30 |
| 20T40C | | 40 |
| 25T10C | 25 | 10 |
| 25T20C | | 20 |
| 25T30C | | 30 |
| 25T40C | | 40 |

holding frame between the open end of the chamber and an extension of the chamber. The left end plate of the chamber remained closed, and a square obstacle with a cross-section area of $30 \times 30 \text{ mm}^2$ was mounted inside the chamber and centered 500mm downstream from the closed end. The LPG (88 % C_3H_8 , 10 % C_3H_6 and 2 % C_4H_{10} by vol.) concentration in air was approximately 4.0 %. The LPG was premixed with air using mass flow controllers before entering the chamber.

As indicated in Table 1, two independent variables were used in the experiments: the concentration of gel and thickness of the water gel barrier. The concentration of gel ranged from 10 % to 40 % with intervals of 10 % by weight of gel, and the thicknesses ranged from 10mm to 25mm with intervals of 5mm. The gel was made from commercial gelatin (protein 85–90%, humidity 8–13%, ash 0.5–2%), mixed with water. The gel barrier was set 1400 mm away from the closed end plate of the chamber.

The pressure developments were measured using two pressure transducers (KISTLER 701A), a channel charge amplifier (KISTLER 5019 B), and a data acquisition

computer. One transducer was placed in front of a gel barrier and was referred to as P_1 . The other was mounted behind the barrier, and this was referred to as P_2 . The distance from the closed end of the plate in the chamber was 1200mm and 1600mm for the P_1 and P_2 transducers respectively. The images of a gel barrier movement during the explosions were photographed with a high-speed video camera (Phantom v210). The elastic modulus of each gel was measured using a Texture Analyser (TA-XT2). The strain of the gel was kept at a certain value while increasing the stress. The stress was then recorded when the applied force reached that certain strain.

Each test was repeated at least five times in order to ensure reproducibility. The results were averaged and the average results are presented. The reproducibility between all tests was found to be reasonable; the error was $\pm 5\%$ at peak pressure.

3. Results and discussion

Figure 2 shows measured flame propagation images, which display flame speed and pressure development versus time for the case with no gel. The pressure results in the figure were obtained by P_1 . The flame speed was obtained by measuring the position of the tip of the propagating flame front from the ignition point.

In the early stages of flame propagation, the flame follows the path of an expanding hemisphere, similar to a flame propagating from its ignition point. The propagating flame fronts reached the nearest face of the obstacle at approximately 41 ms after ignition. After impinging on the obstacle, the flame front emerged from the gap between the obstacle and the chamber side walls.

As the time went on, the flame began to roll up in the wake of the obstacle. The propagating flame fronts reconnect in the wake of the obstacle at approximately 45 ms. After the flame reconnected, the propagating flame front approached the chamber exit at approximately 50 ms, with a terminal flame speed of approximately 27 ms^{-1} . The peak pressure was approximately 27 kPa, and this occurred when the main flame was exiting the chamber.

Figure 3 shows examples of pressure vs. time of P_1 and

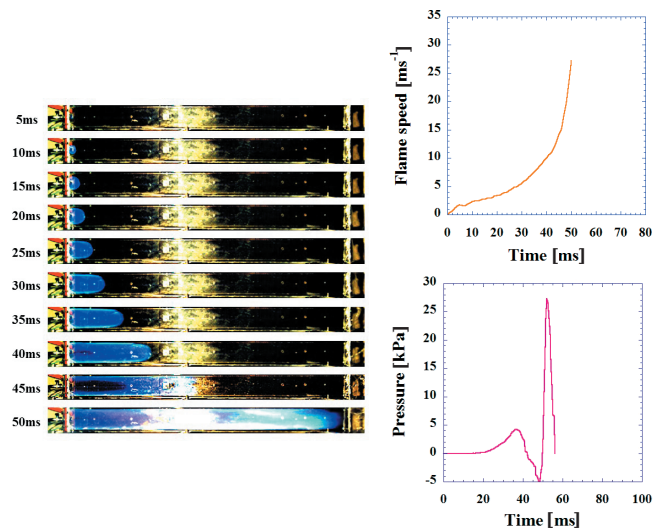


Figure 2 Flame propagation images, flame speed and pressure development with no gel barrier.

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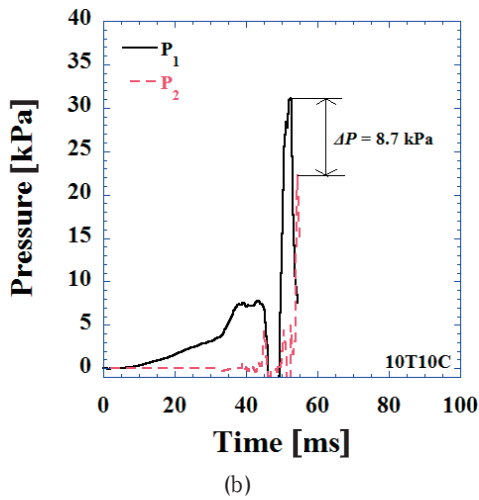
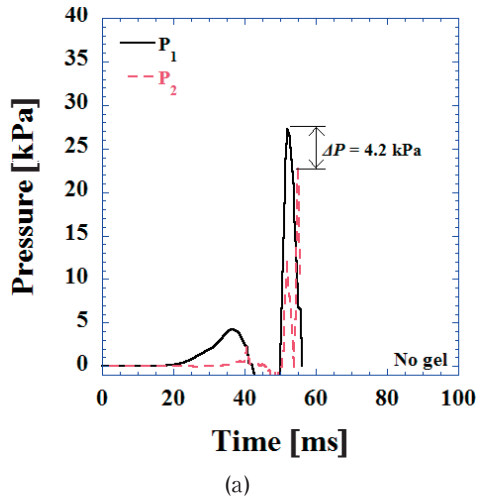


Figure 3 Pressure time-histories of P_1 and P_2 for two cases: (a) no gel and (b) gel barrier (10T10C).

P_2 for cases with and without a water gel barrier (10T10C). Here, P_1 is measured in the front of a gel barrier, and P_2 is measured behind the gel barrier. The pressure trends of P_2 were similar to those of P_1 . Although, the magnitude of P_2 decreased a bit. The peak pressure differences measured at P_1 and P_2 were approximately 4.2 kPa with no gel and 8.7 kPa with 10T10C. When using the gel barrier, the maximum pressure was reduced by approximately 28%, and it was reduced by approximately 15% with no gel.

Figure 4 shows snapshots from the high-speed images at various times during the movement of the gel barrier using 15T20C. The time shown represents the elapsed time after ignition. The displacement of the gel barrier was obtained by measuring the position of the leading edge of an expanding gel towards the extension chamber. Here, pressure data were obtained from the P_2 transducer. As shown in the figure, two distinct pressure peaks occurred. The first peak was related to the flame impinging on the obstacle, and the second was related to the rupture of the gel barrier. Until approximately 20 ms, there were almost no changes in either the gel displacement or the pressure development. After that time, the gel displacement begins to increase slowly with increasing pressure. The first peak pressure, approximately 9.5 kPa, occurred at 43 ms, which corresponds to a displacement of approximately 70 mm.

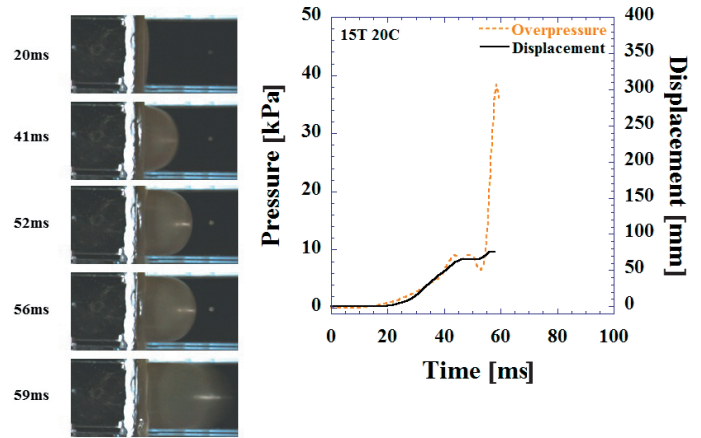


Figure 4 Left) Measured gel displacement images. Right) Pressure and gel displacement versus time for case of 15T20C.

After the first peak pressure, the pressure slowly decelerated between 48 and 52 ms. After the pressure deceleration, the pressure was found to be significantly higher. The second peak pressure was approximately 39 kPa, and this occurred at $t = 56$ ms, which corresponds to a displacement of approximately 77 mm. Due to the failure of the barrier, the deflection was high, and the barrier did not return to the starting point although the pressure had subsided. The trend in gel displacement was very similar to the pressure curve until the rupture of the gel barrier. The time taken to reach the maximum deflection of the gel barrier was very close to the arrival time of the peak pressure.

Figure 5 shows the effects of increasing gel concentrations on the displacement of the gel barrier as a function of time, with a barrier thickness of 15 mm. The gel displacement was similar for each case until approximately 40 ms. A faster increase in gel displacement was found at lower gel concentrations. Despite some fluctuations, the general trends of gel displacement were similar for the 10, 20, and 30% by weight gel. However, the presence of 40% by weight gel began to show a difference of the displacement compared to other concentrations at approximately 45–70 ms. As the gel concentration increased, the failure time of the gel barrier was delayed.

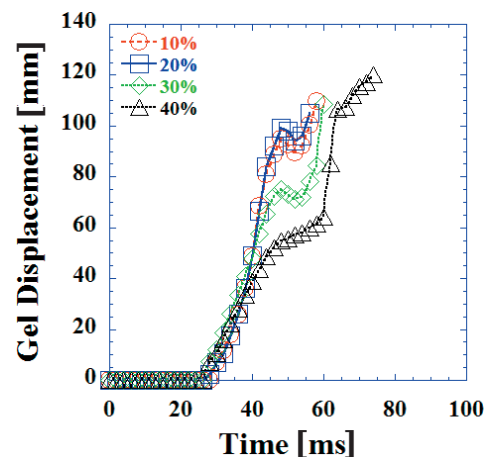


Figure 5 Displacement variations versus time for four different gel concentrations at a 15 mm thick gel barrier.

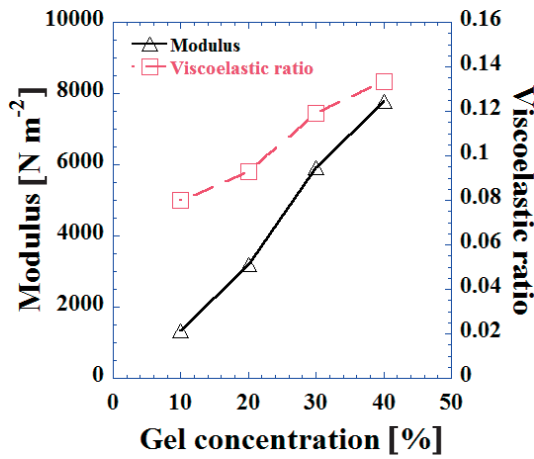


Figure 6 Modulus and viscoelastic ratio for four different gel concentrations.

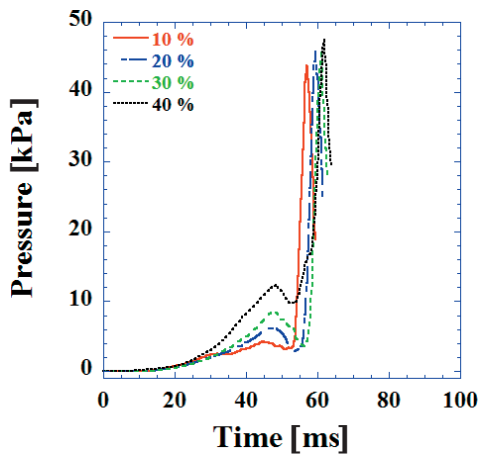


Figure 7 Pressure-time curves for different gel concentrations with a 25 mm thick gel barrier.

This phenomenon seems to be due to viscoelastic properties of gelatin. Figure 6 shows the measured modulus and viscoelastic ratio at different gel concentrations. As the gel concentration increased, the modulus and viscoelastic ratio were increased linearly. Gelatin tends to behave elastically at lower concentrations and its viscosity increases as its concentration increases. Therefore, more viscous gelatin is likely to cause higher reduction in the pressure.

Figure 7 shows pressure-time curves for different gel concentrations with a 25 mm thick gel barrier. As the gel concentration increased, the pressure increased while the time taken to arrive at peak pressure was delayed. Figure 8 shows the effects of gel concentration on reduction percentage of the peak pressure for different gel barrier thicknesses. The reductions percentage of the peak pressures obtained from both P_1 and P_2 was calculated by $R(\%) = (PeakP_1 - PeakP_2) / PeakP_1 \times 100$ where $PeakP_1$ is the peak pressure measured from the P_1 transducer, and $PeakP_2$ is the peak pressure measured from the P_2 transducer. As the thickness increased at a constant concentration, the reduction percentage in the peak pressure also increased. Similar to the thickness of the gel barrier, the increase of gel concentrations also increased the reduction percentage of the maximum pressure. The maximum reduction occurred with a 25 mm gel barrier

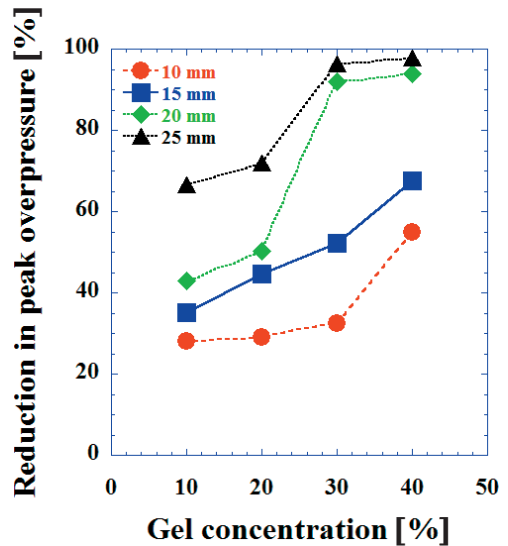


Figure 8 Reduction percentage of peak overpressure obtained from varying thickness and concentration of gel barrier.

and a gel concentration of 40 %. In this case, the reduction was approximately 94 %. The minimum occurred with a 10 mm gel barrier and a gel concentration of 10 %. Here, the reduction was 28 %

4. Conclusions

Experimental studies have been carried out to investigate deflagration pressure attenuation of a LPG-air mixture by varying the thickness and concentration of a water gel barrier. Four different gel concentrations and barrier thicknesses were used. The main results obtained from the present work are summarized as follows :

When compared with no gel, the water gel barrier decreased the explosion pressure. The decrease in the pressure was found to be sensitive to the gel concentration and barrier thickness. It can be said that the existence of a water gel barrier has an effect on explosion mitigation.

During flame propagation, the gel barrier was found to be elongated. In the early stages of flame propagation, gel displacement increased faster with lower gel concentrations. The maximum displacement found was the highest gel concentration used in the tests. This is because the barriers with a lower gel concentration failed more quickly than the barriers with a higher gel concentration. The trends in the displacement curves were similar for the lower concentrations of 10, 20 and 30 % by weight of gel. However, at 40 % by weight of gel, there was a slight difference in the displacement curve. The difference seems to be due to viscoelastic properties of gelatin.

As the concentration and thickness of gel barrier increased, the pressure decreased. This implies that a higher gel concentration and thicker barrier causes a higher reduction in the peak pressure. This suggests that a water gel may be used as an effective pressure agent for mitigating deflagration pressure due to gas explosions.

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