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Propagation of blast waves from a bursting vessel with internal hydrogen-air deflagration

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ABSTRACT

Most studies on blast waves generated by gas explosions have focused on gas explosions occurring in open spaces. However, accidental gas explosions often occur in confined spaces and the blast wave generates from a bursting vessel as a result of an increase in pressure caused by the gas explosion. In this study, blast waves from bursting plastic vessels in which gas explosions occurred are investigated. The flammable mixtures used in the experiments were hydrogen-air mixtures at several equivalence ratios and a stoichiometric methane-air mixture. The overpressures of the blast waves were generated by venting high-pressure gas in the enclosure and volumetric expansion with a combustion reaction. The measured intensities of the blast waves were greater than the calculated values resulting from high-pressure bursting without a combustion reaction. The intensities of the blast waves resulting from the explosions of hydrogen-air mixtures were much greater than those of the methane-air mixture.

Introduction

A blast wave is a significant element in the cause of serial damage over a wide area in the event of an accidental gas explosion. In order to decrease the damage caused by an accidental explosion and take appropriate measures, it is necessary to understand how blast waves are generated by gas explosions. To this end, many studies, both experimental and theoretical, have been conducted on blast waves generated by gas explosions. In almost all these studies, gas explosions occurring in open spaces were examined. In the experimental studies, the flammable mixtures were confined in balloons, soap bubbles, and thin-film plastic tents—all of which easily burst after ignition [e.g., 1–5]. Therefore, the phenomena were almost the same as gas explosions occurring in open spaces. From these studies, it was understood that the intensity of blast waves from open-space gas explosions depends on the flame propagation behavior [6].

On the other hand, gas explosions in confined spaces generate a sudden rise in internal pressure and cause extensive damage such as the destruction of the structure, the generation of blast waves, and the scattering of fragments. Therefore, many investigations about the behaviors of confined gas explosions have been also reported [e.g., 7–9]. The maximum explosion pressure and the rate of pressure rise are used for evaluating the consequence of the gas explosions [10].

In real-life accidents, flammable mixtures are generated in enclosures, such as buildings or tanks, meaning that, in practice, accidental gas explosions occur in confined spaces. When a gas explosion occurs in a confined space, the pressure in the confined space increases and the vessel bursts, then a blast wave is generated. The phenomena of confined-space

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gas explosions are thus are different from those of open-space gas explosions.

To estimate the intensity of a blast wave from a bursting vessel, the blast model developed by Baker is available [11]. Baker studied the blast wave from a spherical vessel bursting as a result of excessive high pressure in the vessel. The blast model was experimentally examined by Esparza and Baker [12]. If the vessel bursts as a result of excessive high pressure, the high-pressure gases in the vessel suddenly expand and a shock wave is generated. Gas explosions are induced by the combustion reaction of flammable gas mixtures. However, Baker's model does not consider combustion reaction. If a vessel bursts after the combustion reaction in the vessel has finished, the model is appropriate. On the other hand, if a vessel bursts while the combustion reaction is still taking place, the blast model is not applicable. There are few studies that have examined in detail blast waves emanating from bursting vessels in which gas explosions occurred.

We have studied the intensity of a blast wave generated by a bursting vessel [13], and vessels of various strengths were used to understand the influences of vessel strength on the blast wave. It was found that the peak overpressure and impulse depended on the strength of the vessels, and that they were larger than those from bursting vessels without a combustion reaction.

In this study, in order to investigate blast waves emanating from bursting vessels in which gas explosions occur, gas explosion experiments were performed in vessels of various strengths. In particular, in order to investigate the influence of the material of the flammable gases on the blast wave, hydrogen-air mixtures and methane-air mixtures were used, and the equivalence ratios of the hydrogen-air mixtures were varied.

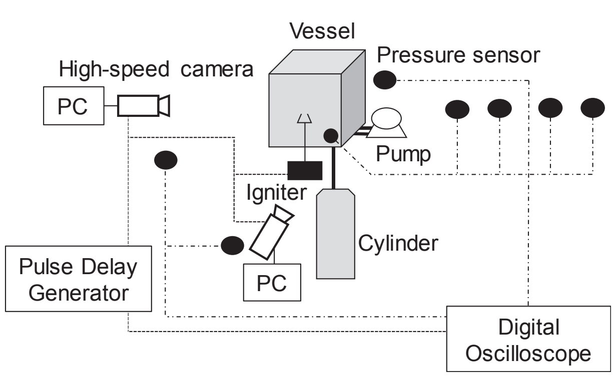

Fig. 1 – Experimental setup.

Experimental setup

Fig. 1 shows a schematic diagram of the experimental setup. The vessel was a cube measuring 0.5 m on each side, and the volume of the vessel was 0.125 m^3. The cube had a stainless steel frame and six walls. The bottom of the vessel was a stainless steel plate located 0.75 m above the ground, and the other five walls were polyvinyl chloride (PVC) plates fixed to the stainless steel frame. The thickness of PVC plates was varied to change the pressure in the vessel when the vessel burst. In the experiments, one or five walls of the vessel burst as a result of the increase in pressure caused by the gas explosion which occurred in the vessel. In the case where five walls burst, the thicknesses of the five walls were the same. In the case where just one wall burst, only one of the walls was thin and the other walls were thick. The thicknesses of the PVC plates used in this study were 0.5, 1, 2, 3, 4, 5, and 6 mm. In addition, thin polyethylene sheets were used as walls to obtain data on open-space gas explosions.

Hydrogen-air mixtures with equivalence ratios of 0.5, 1.0, 1.8, and 2.5, and a stoichiometric methane-air mixture were used in this study when one wall burst. Only the stoichiometric hydrogen-air mixture was used when five walls of the vessel burst. The physical properties of the flammable mixtures used in the experiments are summarized in Table 1. Flammable gases were supplied to the bottom of the vessel from a cylinder, and the mixture in the vessel was circulated by a pump to produce a uniform flammable mixture at a pressure equivalent to the atmospheric pressure. The mixture in the vessel was sampled during circulation to measure the concentration of flammable gas using a gas concentration measuring instrument (Riken Keiki, FI-21). Pressure sensors (PCB Piezotronics, 106B52) were located at positions 5, 10, 20, and 50 m from the center of the vessel in the four cardinal directions to measure the pressures of the blast waves. Each pressure sensor was located 1 m above the ground. In addition, a pressure sensor (KYOWA, PGM-1KG, PHL-A-1MP-B, or PHL-A10MP-B) was installed on the bottom of the vessel to measure the pressure within the vessel. The pressure histories were recorded by a digital oscilloscope (YOKOGAWA, DL850). The explosions were captured by a high-speed digital color video camera (PHOTRON, FASTCAM SA2) and a high-speed digital monochrome video camera (Vision Research, Phantom IR300) with a long-pass filter (ASAHI SPECTRA, LI0990, $\lambda > 990$ nm). The use of a long-pass filter enables the IR emission from the propagating flame to be observed. To initiate an explosion, a pulse delay generator (Berkeley Nucleonics, BNC505-2c) was used to send a

Table 1 – Physical properties of flammable mixtures.

Flammable gas	Equivalence ratio	Specific heat ratio of burned mixture[a]	Flame temperature in confined space/K[a]	Final gauge pressure in confined space/kPa[a]
Hydrogen	0.5	1.2525	1986.98	514
Hydrogen	1.0	1.1682	2747.3	708
Hydrogen	1.8	1.2214	2551.35	663
Hydrogen	2.5	1.1741	2309.16	602
Methane	1.0	1.170	2586.13	789

[a] Calculated by NASA-CEA program [14].

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