Effects of Channel Width on the Shock and Ignition of High-Pressure Hydrogen Release into Air

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INTRODUCTION

Hydrogen is an important feedstock for various chemical processes as well as an emerging clean fuel without global warming potential. However, hydrogen is very difficult to liquefy and normally stored in gaseous state at elevated pressure. Although hydrogen is not pyrophoric in ambient air, there have been numerous incidents reporting spontaneous ignition of hydrogen release following catastrophic failure of storage vessels or pipelines. The mechanisms and conditions of the ignition are not yet clear in the literature but are generally agreed to be caused by the shock wave compression from the high pressure release which heats up the hydrogen/air mixture in the contact surface.

Most early experimental work focused on the flow structure of high-pressure hydrogen release at the exit of discharge tube, e.g. Mogi et al. (2009). Recently, Kim et al. (2013) studied the shock and flow structure inside the flow channel with the aids of double glass window. The visualization channel has a square cross-section of 10×10 mm and a total tube length of 300 mm. Two high-speed cameras with shadowgraph and direct image recording were taken. Detailed structure of shock wave, mixing spot, ignition, and flame propagation were revealed.

Although the work of Kim et al. (2013) is valuable for better understanding of the ignition mechanism, there remains lack of systematic studies on the conditions of ignition. There also lacks of information on how the shock compression theory can be extended to splits in actual incidents. As most splits or cracks in vessels are longitudinal with large aspect ratio, it is of interest to study the effects of channel width on conditions of ignition. In particular, it would be interested to study the release from a thin channel which resembles the most accidental release from a crack of a vessel wall. With a diminishing channel width, the boundary layer will strongly perturb the flow and shock wave, which in turn will affect the shock compression, mixing and ignition of hydrogen and air mixture.

In this work, visualization channels similar to that of Kim et al. (2013) with different widths were used to study the shock wave and ignition from pressure release of hydrogen into air. The minimum pressure required for ignition was determined for each channel. Shock wave speed was also measured. The result found that with diminishing channel width, the minimum release pressure required for ignition is also decreased which suggests that most accidental release from a thin crack will favors spontaneous ignition. This result is in consistent with the common observation that most accidental release from a crack of a vessel wall did result in ignition.

RESULTS AND DISCUSSION

A rectangular visualization channel was used to study the shock, ignition and flame propagation following the release. The channel was bounded by two pressure-resistant glasses. Three different visualization channels were used. The channel cross-sections are 15.6×32 mm, 10×6 mm, 10×4 mm, and 10×3 mm, respectively. The lengths for the three channels are the same of 140 mm.

Figure 1 summarizes the overall results of measured shock wave speed as a function of release pressure and channel width. Data with solid symbol indicates test with ignition. Figure 2 shows the comparison of minimum pressure with ignition and maximum pressure without ignition as a function of channel width. For the channel with width of 3 mm, the minimum pressure for ignition is found to be around 3.4 MPa.

Comparison of the shock shadowgraphs between different channel widths and release pressures provided significant insights on the effects of channel width. It is likely that the channel width contributes to the ignition in two folds. With smaller channel, the critical volume of mixed material required for undergoing flame spreading is also reduced as indicated by a weaker mixing front in a larger channel for the same release pressure. On the other hand, the boundary layer in a narrower channel will also contributes the better mixing for the same release pressure as the shock speed were reduced slightly with reduced channel width. Thus, in most accidental release with a thin crack spontaneous ignition is favored. This is in consistent with the common observation that most accidental release from a crack of a vessel wall did result in ignition. The present study also indicates that ignition is unlikely with a storage pressure less than 1.99 MPa.

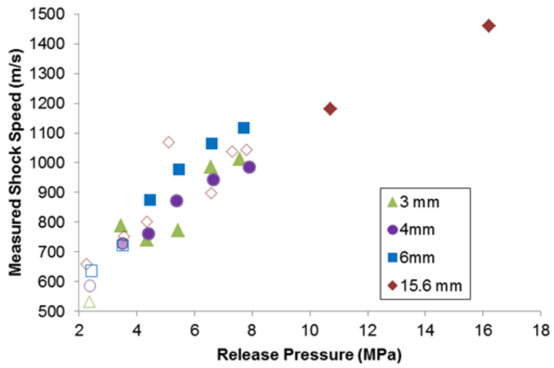

Fig. 1. Summary of measured shock wave speed as a function of release pressure and channel width.

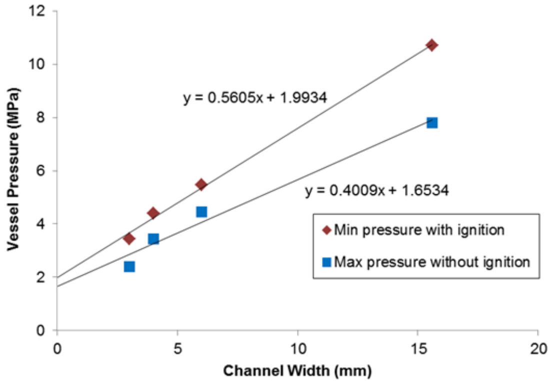

Fig. 2. Comparison of minimum pressure with ignition and maximum pressure without ignition as a function of channel width.

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