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A study on the characteristics of the deflagration of hydrogen-air mixture under the effect of a mesh aluminum alloy

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HIGHLIGHTS

- Existing MAA product is unable to effectively suppress the deflagration of hydrogen.
- Intensity of hydrogen deflagration under MAA is far more than that of no MAA.
- MAA has a promoting/suppressing dual effect on hydrogen deflagration.
- Promoting effect of MAA was a dominating figure in hydrogen deflagration.
- Targeted MAA products should be developed based on reaction characters of hydrogen.

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ABSTRACT

Mesh aluminum alloys (MAAs) have been widely used in military and civilian applications to suppress the explosion of flammable gases (fluids) inside containers. However, MAAs have not been tested in or applied to the hydrogen suppression-explosions. Hence, a typical MAA product, i.e., one that has been in wide use, is selected as the experimental material in the present study. The characteristics of the deflagration of hydrogen-air mixture inside an MAA-filled tube are investigated, and the effects of the filling density of the MAA and the concentration of hydrogen in air on the deflagration are examined. The suppressing effect of the MAA on the deflagration of hydrogen-air mixture is compared with its effect on the deflagration of a typical hydrocarbon fuel in air. The results show that not only is the existing MAA product unable to effectively suppress the deflagration of hydrogen-air mixture, but it also increases the maximum explosion pressure, which is opposite to the satisfactory suppressing effect of the MAA product on the deflagration of hydrocarbon fuels such as methane. The results of this study provide a scientific basis for the effective prevention of explosion accidents with hydrogen and for the development of explosion-suppression products.

1. Introduction

Hydrogen is a dangerous material, characterized by a high chemical reactivity, broad explosion limits, low minimum ignition energy and a high explosion risk [1]. Nonetheless, hydrogen is a high-quality energy source with great potential. In recent years, hydrogen energy has been widely used in many fields, such as the nuclear power generation industry and the chemical industry. However, hydrogen explosions in sealed containers or limited spaces have also frequently occurred with the extensive application of hydrogen energy. The hydrogen explosion accidents that can potentially occur during the production, utilization, storage and transportation of hydrogen have attracted attention from researchers worldwide.

In recent years, there have been several studies on hydrogen explosion accidents, which primarily focus on the mechanisms of the explosion accidents. Some of these studies focus on the basic parameters of the combustion and explosion of hydrogen-air mixture, such as the laminar burning velocity [2] and the explosion limit [3,4]. Other studies have been conducted to investigate aspects such as the characteristics of the explosion behavior of hydrogen-air mixture in certain settings [5–8], the factors that affect the explosion process, including the pattern in which the explosion process is affected [9–11] and the evaluation of the consequences of the explosion [12,13]. There have also been studies that focused on the characteristics of the detonation of hydrogen [14] and the mechanism of the transition from deflagration to detonation [15–16]. Because of the characteristic chemical reactivity

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of hydrogen and the existence of hydrogen in various types of gas mixtures, studies have been conducted to understand the effect of hydrogen on intensifying the explosion processes of premixed gases that contain hydrogen [17–19].

The studies related to the techniques of preventing and controlling hydrogen explosion accidents primarily address explosion venting, explosion isolation, inerting and the research and development of explosion suppressors and explosion-suppression materials. It has been proven that certain metal meshes have a suppressing effect on the explosion of flammable and explosive liquids (gases) inside containers [20]. These materials are fabricated using the following method. An extremely thin metal foil is cut and pieced together. It is then pulled and extended to form a structure that contains meshes. It is subsequently folded or coiled to form a three-dimensional material block. Because of the pulling and extending of the thin metal foil, the splicing bar between two adjacent meshes is twisted, resulting in a detachment of the meshes from the original plane, which in turn results in an increase in the effective thickness of the foil. The three-dimensional material block is then placed inside storage and transportation containers of flammable and explosive liquids (gases) according to specifications to prevent the occurrence of explosions inside the containers. Aluminum alloy is currently the raw material of choice for the mesh explosion-suppression metallic materials, i.e., mesh aluminum alloys (MAAs). The transition elements in an MAA, such as manganese and titanium, can improve the corrosion resistance and the strength of the MAA. As early as 1982, the United States (US) published the military specifications for mesh explosion-suppression materials fabricated from aluminum and used for suppressing explosions in the fuel tanks in airplanes (the United States Air Force (USAF), 1982) [21]. Currently, similar explosion-suppression products have been patented in the United Kingdom, France, the US and Germany. This type of explosion-suppression product, manufactured by companies in Canada, the US and Austria, has been extensively used in the military industry (primarily in the oil tanks of fighter aircrafts, tanks and armored vehicles). China began research on explosion-suppression technologies later than other countries, but these explosion-suppression technologies have been rapidly popularized and applied. In 2005, China published a civil standard for explosion-suppression MAAs used in civilian oil (gas) stations, light fuel and liquefied petroleum gas tank cars and skid-mounted refueling (regassing) devices for vehicles [22,23], and MAAs have been popularized and used in civilian applications since the publication of this civil standard. Because MAAs are primarily used in the military field and have not been made compulsory in civilian applications, there are relatively few openly published technical articles that are directly related to MAAs. Birk (2008) gave a relatively comprehensive commentary on the production backgrounds of similar MAA products, including their advantages in suppressing explosions inside containers, and also suggested directions for further exploration of MAA products, one of which was to consider the special applications of MAA products for special fuels or special containers [20]. Researchers from China have also explored the explosion-suppression performance of MMA products [24,25]. Some researchers have also studied the quenching characteristics of flames generated by the explosion of gases in narrow spaces [26], which provides a specific reference value for further exploration of the explosion-suppression mechanisms of MAA products and improving the performance of MAA products.

Hydrogen is similar to the majority of hydrocarbon fuels with respect to its explosion hazards and the evolution process of these kinds of gas explosion accidents. The MAA-related standards published by various countries do not separately consider hydrogen as a special material. In addition, there is no explosion-suppression materials specifically designed for hydrogen. For example, the types of flammable gases are not specified, and no individual specification is given for hydrogen in the Chinese standards (AQ3001-2005 and AQ3002-2005) [22,23] or in the US military standard (MIL-B-87162A) [27], indicating that these standards are suitable by default for any type of flammable gas, hydrogen, hydrocarbon fuels, etc. However, there is a significant difference in the physical and chemical properties between hydrogen and typical hydrocarbon fuels (e.g., methane and propane). Because of the extremely active reaction chemical reactivity of hydrogen, it is unknown whether MAAs are suitable for hydrogen, whether there is a difference between the applicability of MAAs for hydrogen and the applicability of MAAs for hydrocarbon fuel gases, and how large the difference is if one exists. Hence, in this study, the deflagration characteristics of hydrogen-air mixture under the effect of a typical MAA are investigated using a test tube, the patterns of the effects of the filling density of the MAA and the concentration of the fuel on the deflagration characteristics are examined, and a comparative analysis of the deflagration characteristics of hydrogen-air mixture and the mixture of a typical hydrocarbon fuel (methane) and air is conducted with the goals of providing a reference for the prevention of hydrogen explosion accidents and a basis for the optimization of the performance of MAA products.

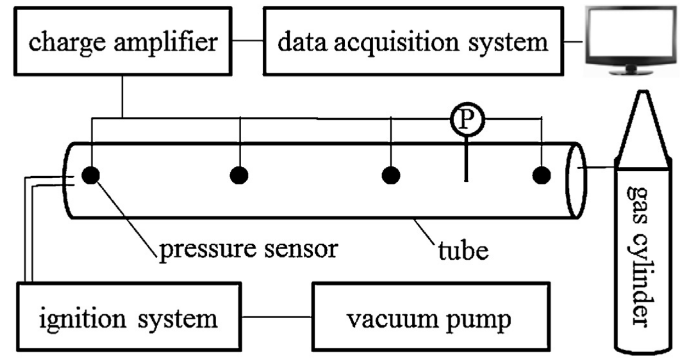

Fig. 1. Diagram of test system.

2. Experiments

2.1. Test system

The test system consists of a test tube, an ignition system, a signal amplifier, a data acquisition system, a vacuum pump, pressure sensors and other auxiliary devices. Fig. 1 shows a block diagram of the system. The test tube, which is fabricated through cutting and welding 45# seamless steel tubes, is composed of a main body and such auxiliary components as connecting flanges, sealing discs, washers and sensor-hole plugs. This study did not consider the influence of thermal effect of the wall surface on explosion suppression ability of MAA. It has two reasons. Firstly, it is well known that the explosion pressure is the measure index for explosion suppression ability of MAA in many national standards, such as MIL-B-87162A in USA and AQ 3001-2005 in China. We think that the thermal effect of wall surface has weak influence on the distribution of the explosion pressure. Practically, we have studied the influence of the thermal effect on the gas explosion process in a long narrow confined space, and obtained the same conclusions [27]. This study indicate that the thermal effect of wall surface takes great influence on the temperature field of the gas explosion in a long narrow space, but almost takes no influence on the explosion pressure field.. Secondly, related standards required the tightness, geometric scale, test method, etc. of the test tube, but the heat transfer of the walls of test tubes is not also required mandatorily. The tube in this study meets the test requirements of related standards.