Effect of Aluminum Silicate Wool on the Flame Speed and Explosion Overpressure in a Pipeline

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Abstract: Problems of decreasing the flame speed resulting from pre-mixed gas explosions and attenuating explosion overpressures are discussed. A cylindrical test pipeline with an 89 × 4.5 mm cross section is used to study flame propagation characteristics of an acetylene–air mixture both in the empty pipeline and in the presence of aluminum silicate wool attached to the internal wall of the pipeline. Experimental results show that aluminum silicate wool, which is a kind of a fibroid porous material with a high specific surface area, decreases the increment of the outlet flame speed and attenuates drastically the explosion overpressure if the length of the porous insert exceeds the critical length.

Keywords: aluminum silicate wool, flame speed, explosion overpressure, explosion suppression.

INTRODUCTION

Flame and overpressure caused by gas explosions pose a huge threat to humans and environment. Hence, the measures how to reliably and efficiently decrease flame speeds and attenuate explosion overpressures have been the focus of numerous investigations owing to wide industrial applications [1–6]. The most common examples are the commercial flame arrestors employing wire gauzes and sintered metals to quench the flame. Polymer foams [5] and foam ceramics [7, 8] have also been studied recently. Porous materials used to suppress flame propagation have attracted the attention of scientists and engineers. It is believed that the suppression effect of porous materials can be ascribed to voids (pores) in the material. The wide range of sizes and highly developed specific interfacial areas of the pores lead to efficient heat transfer [9] and nonequilibrium reactions [10].

Products made of aluminum have been used for explosion suppression for a few decades [11]. A typical kind of a porous material and a compound of aluminum is aluminum silicate wool usually used as an insulation material. At the same time, it is also a novel material that can be used for explosion suppression because of its porosity and large specific area. However, there are no suppression data available for aluminum silicate wool in the literature. The suppression effect on flame speeds and explosion overpressures is experimentally studied in this work.
EXPERIMENTAL

Experimental Apparatus

The explosion suppression experiments were performed in a facility shown in Fig. 1, which includes a pipeline, gas mixing system, gas distribution system, ignition system, measurement system, and data acquisition system.

The pipeline consists of seven pipes connected by flanges. Each of the pipes has a length of 0.3 m with an $89 \times 4.5$ mm cross section. The pipeline is fixed on a support located 1 m above the ground. The total length of the pipeline is 2.1 m.

An acetylene–air mixture in a stoichiometric concentration was prepared by the partial pressure method in an evacuated mixing tank. The gaseous mixture was fed into the evacuated pipeline and ignited by a spark plug. To obtain a well-proportioned mixture, multi-point injection was adopted. In this experiment, four injection points were chosen. The positions of these points from the ignition source were at 0.15, 0.75, 1.35, and 1.95 m.

Instrumentation

The pressure sensor is an MD-HF piezoelectric sensor with a maximum range of 2 MPa and a sampling frequency of 200 kHz. Its outer signal voltage is 0–5 V. The flame sensor consists of a photoconductive diode in a detector. The detector is a hollow steel tube with a $7 \times 1.5$ mm cross section, designed to protect the diode and to reduce the spot size of the flame light passing through the diode. Figure 2 illustrates the arrangement of sensors in each pipe.

Prior to conducting the experiments, a lighted candle was moved first horizontally, and then vertically away from the tip of the sensor to verify the feasibility of the flame sensors. Figure 3 shows the changes of voltage $\Delta U$ versus the candle displacements. It can be found that, when the horizontal displacement $\Delta x$ increases from 0 to 5 mm, the voltage decreases from $\approx 2$ V nearly to zero rapidly, indicating that the flame sensor can only detect the flame whose light exactly passes through the diode. The voltage decreases more gently with the increase in the vertical displacement. However, the vertical displacement of 15 mm adopted in these experiments is appropriate for the photoconductive diode to detect the light signal.

The pressure at the point $O$ (see Fig. 2) was measured by the pressure sensor. The flame speed at the point $O$ approximately equals the average speed on the segment $AB$, which is calculated according to the distance and duration of the flame. In these experiments, a distance of 50 mm was chosen to improve the accuracy.

The ignition system is a spark plug with 48 J energy released each time, controlled by a computer and an explosion control box. A data acquisition card with 48 single channels is used to record all the pressure and flame signals and to control the ignition system.

Porous Aluminum Silicate Wool

Aluminum silicate wool is made of aluminum oxide (mass fraction 51%), silicon dioxide (46%), and other impurities. The sales company declared that it has the following physical properties: bulk density $\rho = 240$ kg/m$^3$, specific heat $c_p = 0.255$ J/(kg·K), thermal conductivity coefficient $\lambda = 0.106$ W/(m·K), porosity $\varepsilon = 0.8$, specific surface area $A = 10$ m$^2$/g, average pore size $d = 20$ $\mu$m, and fiber diameter $d_0 = 2–4$ $\mu$m.

Figure 4 demonstrates aluminum silicate wool with 10 mm thickness used in experiments. To fix the material on the internal wall of the pipeline, a ferrous wire was coiled into a cylinder as a framework. Aluminum silicate wool was wrapped along the framework and tied.