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Numerical simulation of premixed methane–air deflagration in large L/D closed pipes

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ABSTRACT

A three-dimensional numerical model in which the heat loss through pipe walls was included was developed to simulate gaseous deflagration in pipes of large length to diameter ratio (L/D). The simulated pressure time histories are in good agreement with published data, and the error between experimental and computed maximum pressure is less than 15.3%. The attention is focused on the flame propagation and flow field during deflagrations, as well as the effects of ignition point (at the center or at one end of the pipe) and L/D ($L/D = 6 - 10.35$) of the pipe on them. The numerical results show that a tulip flame is formed during flame propagation, which is related to the reverse flow and vortices motion. The maximum fame speed is 30% higher with the ignition point at the end than that at the center, and it increases linearly with increasing L/D. The deflagration pressure decreases when the distance that flame travels increases due to the effect of the heat loss through pipe walls.

1. Introduction

Considerable losses of life and property have been caused by gaseous deflagrations, especially those in enclosures of large length to diameter ratio ($L/D > 3$ [1]), such as tunnels, reaction vessels and pipes connecting them. Phylaktou et al. [1,2] studied premixed methane–air deflagrations experimentally in pipes of large L/D ($L/D = 6.2 - 21.6$). They divided the pressure time history into four stages. In the initial stage, the pressure did not change much. In the second stage, the pressure rose fast, but it lasted a short time. Next, the rate of pressure rise slowed down. In the final stage, the pressure rose with vibrations. They also found that the high rate of pressure rise in the second stage was related to the fast mean flame speed, which was a feature of deflagrations in such pipes. Kirkby et al. [3] gave the experimental results of deflagrations in a pipe of $L/D = 20$ with the ignition point at one end, which showed the mean flame speed was higher than that in a sphere with the ignition point at the center. Deflagration in long pipes, the flame accelerated and the flame surface area increased exponentially in the early stage, which were analyzed [4] based on mechanism proposed by Clanet et al. [5]. Dunn–Rankin et al. [6] analyzed high speed schlieren images of propagating flame in long closed pipes, their results showed the tulip flame began after the rapid decrease of flame area due to the flame quenching at walls. Deflagrations for certain conditions were investigated using premixed combustion model by many researchers. Bielert et al. [7] developed a one-dimensional model in which a flame tracking method was used to simulate premixed combustion processes in long closed pipes($L/D = 12.3$ or 18.4). They suggested that the effect of the heat transfer to walls should be included in simulation due to the long duration of the combustion process of methane–air mixtures. Makarov et al. [8] simulated the stoichiometric hydrogen–air deflagration in a 2.3 m-diameter spherical vessel using large eddy simulation (LES) for turbulence and premixed combustion model for chemical reaction. In their results, the cellular structure of flame front, which was detected in experiments, was obtained, and they suggested using LES in laminar, transitional, and turbulent combustion modeling. Sarli et al. [9] calculated deflagrations in a small-scale vented explosion chamber which was 150 mm × 150 mm × 500 mm, and the deflagration pressure was related to combustion rate and venting rate. However, deflagrations in pipes of large L/D were seldom investigated numerically.

This paper aims at studying deflagrations using numerical simulation method in relatively long pipes which were filled with premixed methane–air. The model was based on the premixed combustion method to calculate chemical reaction and LES to model turbulence, and the heat conduction of pipe walls was included to consider the heat loss. With the model validated, we investigate the deflagration in large L/D pipes and the effects of L/D, methane concentration and ignition position on maximum deflagration pressure and flame propagation.

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