Fuel 128 (2014) 396–403

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Effect of propagation behaviour of expanding spherical flames on the blast wave generated during unconfined gas explosions

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HIGHLIGHTS

- The flame behaviour and the blast wave of combustible gas/air mixtures were investigated by using a soap bubble method.
- Flame is accelerated by the onset of the flame front instabilities.
- The overpressure increases by both the increase in the absolute value of the burning velocity and the acceleration.

ARTICLE INFO

Article history:
Received 30 July 2013
Received in revised form 21 February 2014
Accepted 25 February 2014
Available online 21 March 2014

Keywords:
Gas explosion
Flame acceleration
Blast wave
Flame instability
Soap bubble method

ABSTRACT

In the present study, the flame propagation behaviour and a blast wave of homogeneous premixed combustible gas/air mixtures in unconfined areas were experimentally investigated. The tests of hydrogen/air, methane/air, propane/air and hydrogen/methane/air mixtures conducted using a soap bubble method at room temperature and atmospheric pressure. The results demonstrate that the flame for an $Le < 1$ mixture was wrinkled by diffusional-thermal instability, accelerating the flame speed and consequently increasing the overpressure with time. The flame for rich mixtures was intensively wrinkled and accelerated in the later stage by the non-uniformity of the concentration distribution, which was induced by the bursting of a soap bubble. This result indicates that rich mixtures have the potential for severe explosion because this phenomenon can generate flame acceleration. The results from the experiments with hydrogen addition in methane/air mixtures indicate the flames were intensively wrinkled and accelerated with the hydrogen addition, and consequently, the overpressure also increased. The results demonstrate that the overpressure increases with the absolute value of the burning velocity, as well as the acceleration of the burning velocity, due to diffusional-thermal instability and heterogeneous concentration areas for rich mixtures.

1. Introduction

All facilities using combustible gases are subject to accidental gas explosions, and the industrial processing and storage of combustible gases often creates explosion hazards that require precision risk management. To perform effective gas explosion risk management, consequence analysis of the possible damage induced by an accidental gas explosion must be conducted. In particular, the damage caused by blast wave generation during gas explosions is extremely serious because the strong blast wave can destroy the constructions. To evaluate the consequence of the blast wave damage, the intensity of the blast wave in partially unconfined regions has been studied [1–9].

A theoretical study performed by Strehlow et al. [7] investigated the blast wave generated by a spherical flame using a constant velocity and acceleration of the flame propagation velocity. They proposed that the dimensionless overpressure $\bar{p}$ can be expressed using the following equation.

$$\bar{p} = \frac{p - p_0}{p_0} = \frac{2\gamma M_p^3}{1 - M_p^2}\left[\frac{a_0 t}{d} - 1\right] \quad (1)$$

where p is the overpressure, p_0 is the ambient pressure, γ is the dimensionless heat capacity ratio, a_0 is the sound velocity in the surrounding air, t is time, d is the distance from the ignition point and ε is the volumetric expansion ratio. Additionally, $M_p = M_f(1-1/\varepsilon)^{1/3}$ and $M_f = (R_f/a_0 t)$ are the Mach number of the surface of

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http://dx.doi.org/10.1016/j.fuel.2014.02.062
0016-2361/

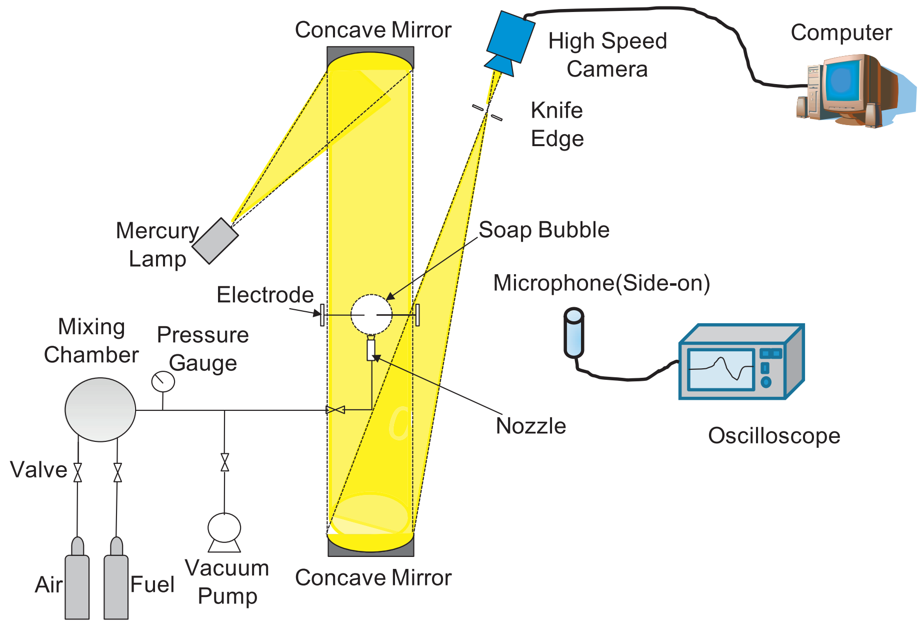

Fig. 1. General arrangement of apparatus.

the expanding sphere and the apparent flame Mach number with respect to the ambient velocity of sound, respectively. This equation indicates that the dimensionless overpressure decreases rapidly with inverse distance and is proportional to time. Otsuka et al. [8] compared the experimental value from hydrogen/air explosions with the results of a scaling model for deflagration based on Eq. (1). The theoretical predictions of overpressure were higher than the experimental values because the model was derived without flame extinction.

Hasegawa and Sato [9] conducted an experimental and a theoretical study of the blast wave generated by unconfined vapour cloud explosions in deflagration. They determined the relationship between the expansion process of the flames and the blast wave generation using both experimental and numerical results. These

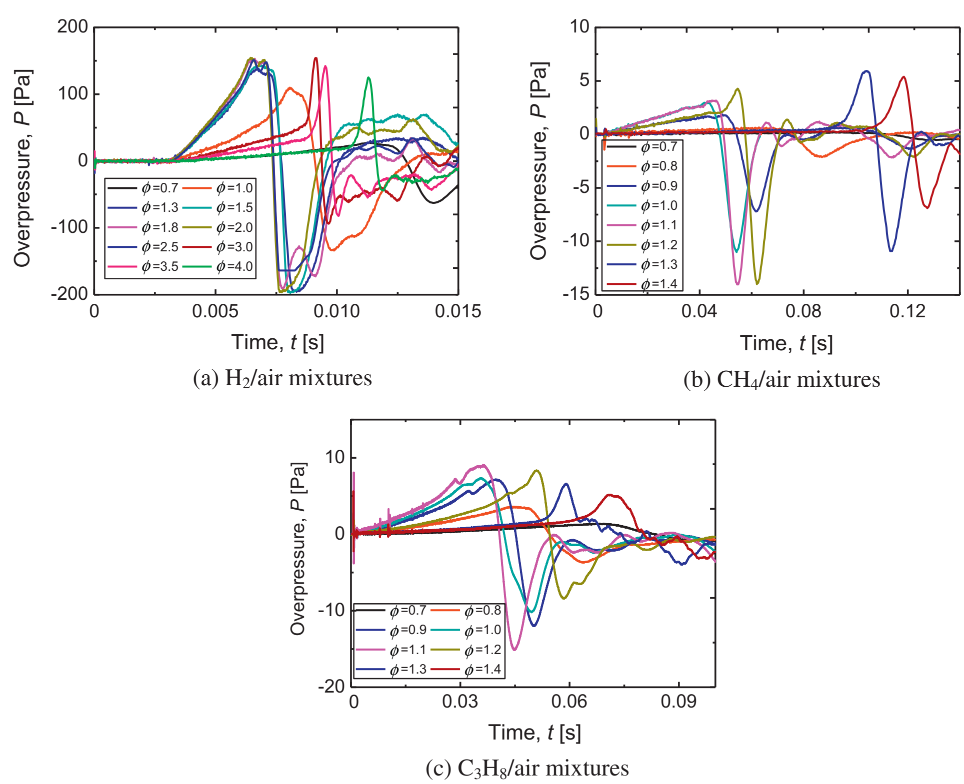

Fig. 2. The time histories of overpressure of H2/air, CH4/air, and C3H8/air mixtures at various equivalence ratios. (a) H_2/air mixtures. (b) CH_4/air mixtures. (c) C_3H_8/air mixtures.