KIGAS Vol. 15, No. 3, June, 2011
(Journal of the Korean Institute of Gas)

정전기 방전에너지에 따른 가솔린-공기 혼합물의 화염전파

†박달재 · 김남일*
서울과학기술대학교 안전공학과, *서울과학기술대학교 산업대학원 안전공학과

(2010년 12월 13일 접수, 2011년 3월 24일 수정, 2011년 4월 12일 채택)

Flame Propagations of Gasoline-Air Mixtures by Electrostatic Discharge Energies

†Dal-Jae Park · *Nam Il Kim
Dept. of Safety Engineering, Seoul National University of Science and Technology, Seoul 139-743, Korea
**Dept. of Safety Engineering, Graduate School of Industry, Seoul National University of Science and Technology, Seoul 139-743, Korea*

(Received December 13, 2010; Revised March 24, 2011; Accepted April 12, 2011)

요 약

실린더형 챔버내에서 정전기 방전에너지 변화에 따른 가솔린-공기 혼합물의 화염전파에 관한 영향을 조사하기 위해 실험적 연구를 수행하였다. 3개의 서로 다른 정전기 방전 에너지(1 mJ, 50 mJ 및 98 mJ)를 실험변수로 사용하였으며, 점화원 전극 주변의 미연소가스 유동장을 가시화하기 위해 고속 PIV 시스템을 적용하였다. 정전기 방전 에너지가 증가할 때, 점화원 핵은 찌그러면서 초기화염에 영향을 미치는 것으로 나타났다. 초기화염 동안에 화염속도는 점화에너지가 높을수록 증가하는 것으로 나타났으나, 초기화염 이후에 시간이 증가할수록 화염속도는 점화에너지에 관계없이 거의 유사하였으며, 이는 문헌[5]에서 보여진 전산유체 모델링 결과의 경향과 거의 유사하였다. 또한, 점화에너지가 증가할 때 전파하는 화염 전면의 미연소가스 속도장은 증가하는 것으로 나타났다.

Abstract - Experimental studies were carried out to investigate the effects on flame propagation of gasoline-air mixtures by different electrostatic discharge energies in a cylindrical chamber. Three different ignition energies were used: 1 mJ, 50 mJ and 98 mJ. In this work, a high-speed particle image velocimetry technique was applied to visualize the flow-field around ignition electrodes. It was found that as the ignition energy increased, the ignition kernel was different. The different ignition kernel caused different flame initiation. During the flame initiation, the higher ignition energy was applied, the higher flame speed was observed. However, with increasing time, the flame speeds were independent of the ignition energies used. Theses observed flame behaviors were similar to computational simulations shown in the literature. It was also found that as the ignition energies increased, the velocities of unburnt mixtures ahead of propagating flame fronts increased.

Key words : ignition energy, flame propagation, gasoline

---

†교신저자:pdj70@snut.ac.kr

I. Introduction

It is well known that the severity levels of gas explosions have been become depending on a number of variables: fuel reactivity, concentration, obstacle density, ignition sources, and etc. Ignition sources of these variables have a great effect on determining the consequences of a gas explosion. Common sources of ignition tend to be point wise such as a spark, however, planar and surface sources of ignition may occur such as incentive sparking and hot surfaces, respectively. Experiments of Hjertager et al.[1], and Phylaktou and Andrews[2] showed that a planar mode of ignition rather than a point ignition source caused higher overpressures and flame speeds in methane-air mixture. Experiments performed by Moen et al.[3] and McKay et al.[4] showed that jet flame ignition of a cloud caused very strong overpressures and produced transition to detonation in acetylene. The ignition information available in their experiments has been only limited to ignition types.

The effects of ignition energy intensities on gas explosions have been done by Bradley et al.[5] and Zhen and Leuckel[6]. The energies in the computational studies of Bradley et al.[5] were varied between 4.09 mJ and 10.40 mJ, and their results showed that the flame speed in methane-air mixtures was independent of ignition energy. Zhen and Leuckel[6] have used strong pyrotechnic igniters with different energies from 1 J to 10 kJ in the measurements, and mentioned that the pressure peak was sensitive to the ignition energies.

Although there are some investigations[1-6] reported on the influence of ignition energies and ignition mode, their ignition sources were electric spark not electrostatic discharge(ESD) and, their measurements have been mainly focused on methane, acetylene, LPG not gasoline. One of the most overlooked and preventable ignition sources is electrostatic discharge. Electrostatic discharges are a major ignition hazard in industries. Most studies of electrostatic discharge on gas or dust explosions have been mainly focused on explosion ignitability.

However, little attention has been given to studies on flame initiation and propagation in gasoline-air clouds by different electrostatic discharge energies. The present study focuses on the nature of the initial flame propagation and the flow-field of unburnt gasoline-air clouds during the explosions by electrostatic discharge energies.

II. Experimental

Fig. 1 shows a schematic diagram of the experimental setup. The explosion chamber is cylindrical one having 200 mm in height and 108 mm in diameter and has a transparent window of 50 mm in diameter for visualizing flame propagation within the chamber. The ignition electrode is needle-like(copper rod, diameter 2mm, electrode gap is about 4mm). The ignition source is provided by an electricity system(KIT101) after charging the capacitor within the system. The electrostatic discharge energy is supplied through the electrode after the explosion chamber is filled with the flammable gas. The capacitance is changed from 5pF to 1000pF. The electrostatic ignition energy is calculated as $E=1/2CV^2$ where E is energy in joules, C is capacitance in farads and V is potential in volts. Three different energies were used: 1 mJ, 50 mJ and 98 mJ. The ignition energies were higher than the minimum ignition energy of gasoline (MIE=0.4 mJ). Each test was repeated at least five times in order to ensure reproducibility.

The flame images were photographed with a digital high speed video camera (KODAK Motion corder Analyzer, SR-ULTRA-C) operating at 500 frames/s, providing a temporal resolution of 2 ms. For the

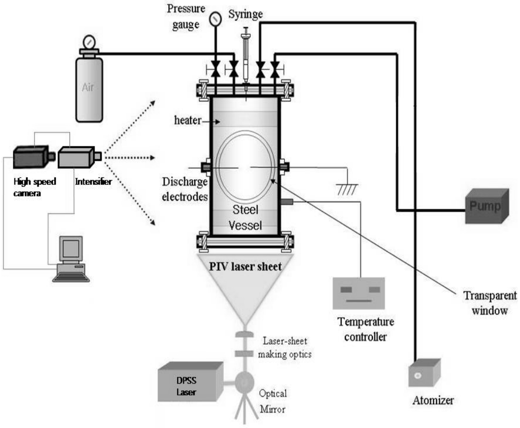


Fig. 1. Schematic diagram of the experimental set-up.

high-speed PIV measurements of the flow-field around the ignition electrode at subsequent times during flame initiation, a DPSS laser (BLITZ) with a power of 8W and a high-speed camera (HotShot 512 SC) with a full resolution of 1280 by 1024 pixels was employed.

Intensifier (UVi 1850-10) was used for intensifying intensity of laser. 1um-diameter olive oil particles were seeded before the ignition. During the measurements, images of 512 by 512 pixels were recorded at the rate of 2000 frames/s, providing a temporal resolution of 500 us. The field of view was 25.6 × 25.6 mm^2. For the vector processing, a cross-correlation algorithm based on two-dimensional FFT was applied and the interrogation windows with 32 × 32 pixels overlapped as much as 75 %. Also, window shifting and recursive correlation methods were adopted to enhance the signal-to-noise ratio.

III. Results and discussion

Fig. 2 shows flame propagation images around the ignition electrode by three different ignition energies. The time shown in the Fig. 2 was set to 0 ms just after the electrostatic discharge and subsequent images were acquired with 4 ms intervals. As shown in the Fig. 2, the spark discharge at t = 0 ms produced an filament-shaped kernel between the gap. As the energy increased from 1 mJ to 98 mJ, the ignition kernel was more wrinkled. The kernel can give rise to different flame initiation near the electrodes. After the spark discharge, the flame slowly develops spherically in a manner of laminar flame from the ignition point.

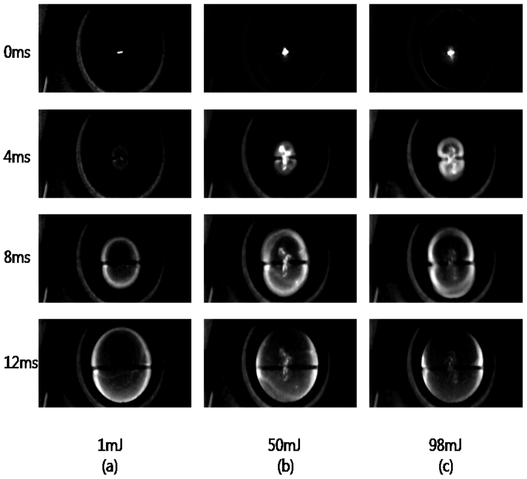
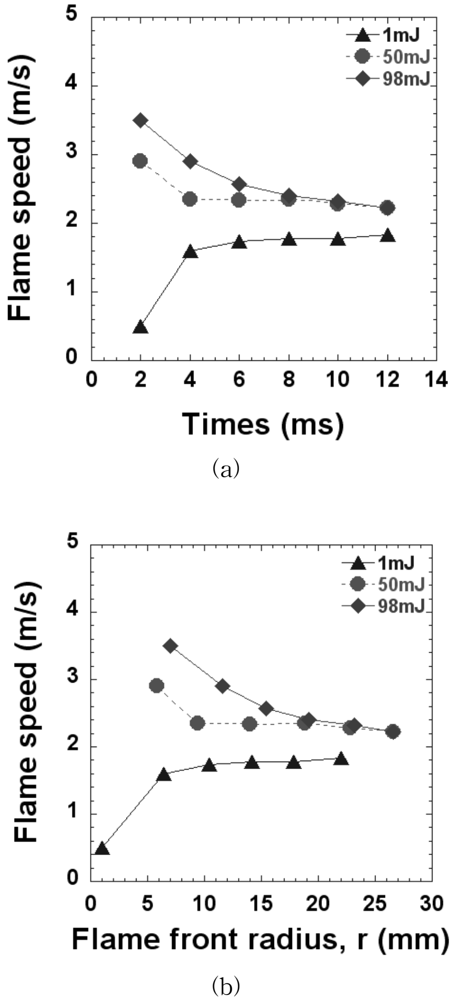


Fig. 2. Flame propagations by three ignition energies.

Fig. 3 shows the flame speeds as a function of time and distance for the three energies. Here, the flame speed was determined



(a)

(b)

Fig. 3. Flame speed as a function of time and distance for energies: (a) Flame speed versus time and (b) Flame speed versus flame front radius.

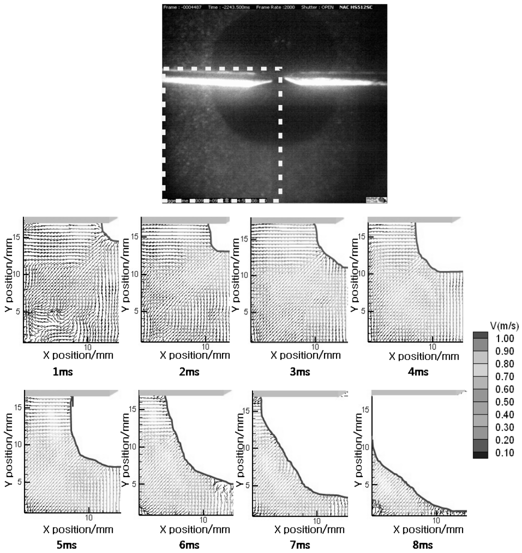


Fig. 4. Flow-field velocities as a function of time at 1 mJ.

by considering the tip of the flame front propagating towards the vertical directions from the ignition point. As shown in the Fig. 3(a), the flame speeds were found to be slightly increasing with times for 1 mJ. However, the flame speeds slowly decreased with times for 50 mJ and 98 mJ. The different trends of flame speed shown in both the 50 mJ and the 98 mJ compared to those of the 1 mJ may be linked to the wrinkling of initial ignition kernel. This result was found to be similar compared to that published in the literature[5]. As shown in the Fig. 3(b), for the energies greater than 1 mJ, the flame speed decreased as a function of flame front radius, then was constant. The propagation speed becomes independent of ignition energy for radius greater than 20 mm.

Fig. 4 shows flow-field velocities around the electrodes as a function of time at 1mJ. Here, the flame boundary is obtained by an image processing technique applied to the green line of the raw image. The velocity of the unburnt mixture increased as time goes on after the ignition. However, after t = 4 ms, the velocity of the unburnt mixture was almost constant.

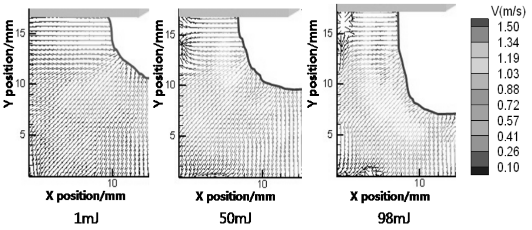


Fig. 5. Flow-field velocities around the electrodes for different energies at t = 3 ms.

Fig. 5 shows flow-field velocities around the electrodes at t = 3 ms after the ignition for three different energies. As the energy increased, the flame propagation was more developed and the velocities of the unburnt mixture were found to become faster.

Ⅳ. Conclusions

Experimental studies were performed to examine the effects on flame initiation of gasoline-air mixtures by three different electrostatic discharge energies in a laboratory-scale cylindrical chamber. Three different ignition energies such as 1 mJ, 50 mJ and 98 mJ were used. The main findings obtained from the present work can be summarized as follows;

When the ignition energy increased, the ignition kernel was different. The different ignition kernel resulted in the different flame initiation. The higher ignition energy was applied, the higher flame speed occurred during the flame initiation. However, with increasing time, the flame speeds were less sensitive to the ignition energies used. This result were almost similar to that of computational simulations reported in the literature. It was also found that as the ignition energies increased, the flow-field velocities of unburnt mixtures ahead of propagating flame fronts increased.

Acknowledgements

This research is supported by Electric Power Industry Basis Fund of the Ministry of Knowledge Economy.

References

[1] Hjertager, B.H., Fuhre, K. and Bjorkhaug, M.,

"Concentration effects on flame acceleration by obstacles in large-scale methane-air and propane-air vented explosions", Combustion Science and Technology, 62, 239-256, (1988)

[2] Phylaktou, H., Andrews, G.E., "Gas explosions in long closed vessels" Combustion Science and Technology, 77, 27-39, (1991)

[3] Moen, I.O., Bjerketvedt, D., Jenssen, A. and Thibault, P.A., "Transition to detonation in a large fuel-air cloud", Combustion and Flame, 61, 285-291, (1985)

[4] McKay, D.J., Murray, S.B., Moen, I.O and Thibault, P.A., "Flame-jet ignition of large fuel-air clouds", Twenty-Second on Combustion, Pittsburgh, 1339-1353, (1989)

[5] Bradley, D., Gaskell, P.H. and Gu, X.J., "Burning velocities, Markstein lengths, and flame quenching for spherical methane-air flames: A computational study", Combustion and Flame, 104, 176-198, (1996)

[6] Zhen, G., Leuckel, W., "Effects of ignitors and turbulence on dust explosions", Journal of Loss Prevention in the Process Industries, 10, 317-324, (1997)