# An Experimental Study on the Dynamic Behavior of Premixed Propane/Air Flame Propagating under the Potential Field of Ultrasonic Standing Wave

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## Abstract
An investigation into the influence of ultrasonic standing wave on the dynamic behavior of premixed propane/air flame propagating in half-open horizontal duct has been made at various equivalence ratios to get a clue to the deterioration of flame stability as well as combustion reaction acceleration. These results can apply to several applications like ramjet, afterburner, gas turbine, and chemical rocket engine for active controlling of the instability which may occur in those systems. Visualization technique utilizing the Schlieren photography was employed for the observation of structural variation of the flame reaction zone. Evolutionary characteristics of the flame front were caught by the high-speed Schlieren image, through which local flame velocity of the moving front were analyzed in detail, too. The vertical locations of distortions and depth of dents of the front are strongly dependent upon the characteristics of standing wave. It is also revealed that the propagation velocity of flame front floored with the standing wave is greater than that without the excitation.

## 1. Introduction

Generally, combustion instability appears in combustion and propulsion system such as automobile engine, plant burner, gas turbine engines, and rocket engines, etc. The instability is strongly linked to the pressure oscillation which is accompanied by excessive thermal-structural loads. In other words, it is an interactive phenomenon between the flame and pressure wave. The interaction is a leading factor of the decrease in system efficiency and the damage to the system. Recently, however it has been reported that an adjustment of the pressure wave may expedite the combustion reaction and contribute to the active control of combustion instability. Similar studies dealing with the influences of electric field and magnetic field are being conducted, too.

We scrutinize the effects of the ultrasonic standing wave field on the propane/air premixed flame behavior in half open chamber, eternally aiming at an active control of combustion instability and enhancement of the combustion efficiency.

## 2. Experimental Setup

The experimental set-up is schematically shown in Fig. 1, which mainly consists of a half open duct, a high-speed camera, a Schlieren system and a DACS (Data Acquisition & Control System). The Schlieren system is composed of two spherical mirrors (2 m focal length), halogen light source, vertical knife edge, and high speed camera whose frame rate and exposure time are 25,000 fps and 2 μs, respectively. The test section around the transducer is focused for obtaining the interactive effect of ultrasonic standing wave with flame. The DACS monitors and controls all sequences in the experiments.

The combustion chamber is a horizontal rectangular duct which is made of PMMA with the dimension of 15 cm × 6 cm × 100 cm (width × height × length) as shown in Fig. 2. a PZT (lead zirconate titanate, $Pb(Zr,Ti)O_3$) ultrasonic transducer and reflector generating the ultrasonic standing wave field (40 kHz) are installed at the bottom and top at 30 cm away from left end of the chamber (x = 30 cm). The chamber was filled with a fuel and oxidizer fed into right end of the chamber through an isolating valve. The equivalence ratio is controlled by high precision mass flow controller. The spark igniter positions at the other end of the chamber. A discharge vent is located the top near the right end of the chamber.

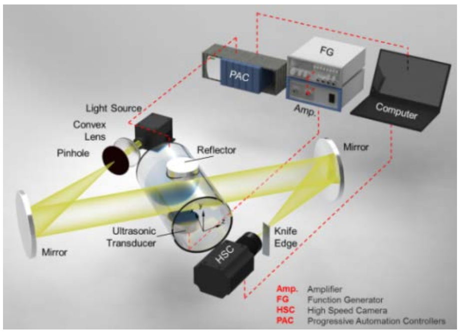



**Fig. 1 Schematic of experimental set-up**

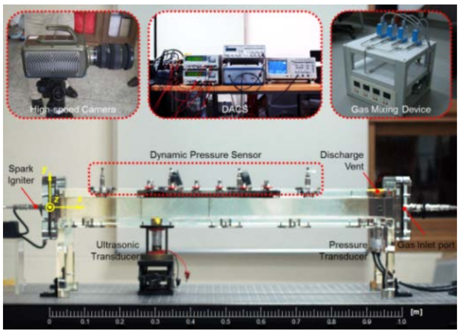
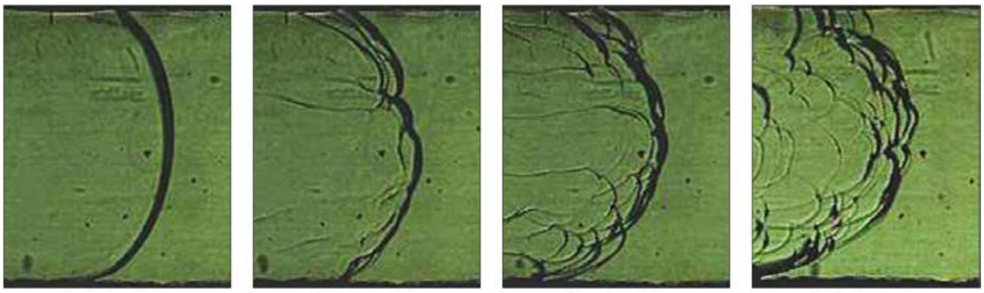



**Fig. 2 Experimental apparatus**

## 3. Results and discussion



(a) $\Phi = 1.0$, w/o Standing Wave | (b) $\Phi = 1.0$, w/ Standing Wave | (c) $\Phi = 1.2$, w/ Standing Wave | (d) $\Phi = 1.5$, w/ Standing Wave

**Fig. 3 Schlieren images of the flame front**

A frontal configuration of the propane/air flame with typical smoothness is shown in Fig. 3(a). The leading front is distorted when the flame is excited by an ultrasonic standing wave as shown in Fig. 3(b)-(d). As the flame comes under the influence of standing wave, horizontal planes at pressure anti-nodes in reaction zone tend to spread into the adjacent nodes of the standing wave, resultantly giving rise to a vertical stretching of reaction layer followed by acoustic radiation force. This is why the distortion of flame front occurs and horizontal pattern of stripes is shown in burnt zone as in Fig. 3(b)-(d).

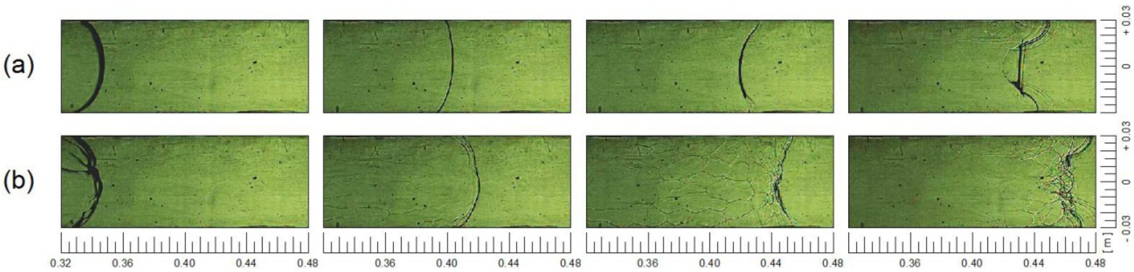



**Fig. 4 Sequential images of propagating flame wave at $\Phi$ = 1.0 (time interval: 8 ms) (a) without standing wave, (b) with standing**

Figure 4 shows the sequential images of the propagating flame with or without the ultrasonic standing wave at equivalence ratio $\Phi$ = 1.0. For the case of ultrasonic excitation as in Fig. 4(b), horizontal chopping over the burnt zone encompassing the flame front is induced by the influence of standing wave, differently from the Fig. 4(a), the case without excitation. As the flame propagates, the standing-wave effect on the laminar flame front becomes more prominent.

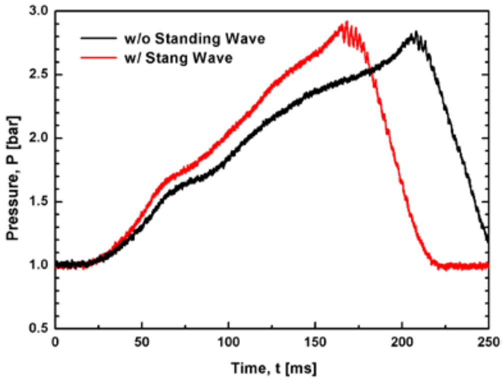



**Fig. 5 Pressure variation at $\Phi$ = 1.0**

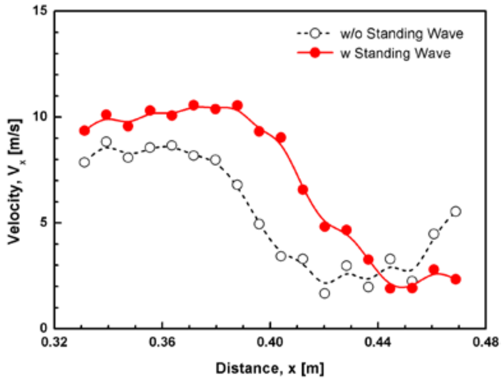



**Fig. 6 Flame velocity variation at $\Phi$ = 1.0**

A distinctive impetus of ultrasonic standing wave to the combustion reaction is shown in Figs. 5 and 6. The rate of pressure rise in the case of excitation is larger than that without standing wave. Fig. 6, which depicts the flame velocity variation at $\Phi$ = 1.0, also reveals that the velocity floored with the standing wave is greater than the case without the excitation throughout the propagation. These are because the effects of ultrasonic standing wave such as the increment of flame surface area, the supplements of additional activation energy, and the vigorous mixing of reactants are considered for the reaction enhancement. In Fig. 6, the flame velocity steadily decreases after about x = 0.38 m, from which the flame shape starts to change from the curved to the tulip flame. Frontal surface area of the flame initially decreases with the onset of flame shape modification, but it finally increases drastically with the appearance of cellular structure which may be affected by the standing wave or the other effect such as Lewis number.

## 3. Conclusion

Effects of the ultrasonic standing wave field on the propane/air premixed flame behavior in closed chamber have been investigated by the high speed Schlieren imaging. The observations are summarized as follows:

(1) The horizontal chopping in the flame front and product phase was found by the ultrasonic standing wave.
(2) The premixed flame velocity with the standing wave increases at the same equivalence ratio, compared to that without standing wave.