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Effects of ignition disturbance on flame propagation of methane and propane in a narrow-gap-disk-burner

Hye Jin Jang, Sang Min Lee, Nam Il Kim*

Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong, Daejeon 34141, Republic of Korea

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ABSTRACT

Unsteady flame propagation within a narrow channel, namely a Hele-Shaw burner, exhibits complicated phenomena. Recently, a new narrow-gap-disk-burner (NGDB) was developed, of which the disk-gap could be varied continuously and precisely. Although various complicated flame structures have been observed successfully, their dependency on the initial ignition has not been clarified. In this study, the volume of the ignition part was varied to introduce disturbance at the ignition stage, and the propagation characteristics of premixed methane and propane flames were investigated. Conclusively, quenching distance was not significantly affected by the ignition volume, especially in propane-rich conditions. In contrast, the flame structure and propagation velocity were sensitive to the ignition volume if it was larger than a critical volume, and when the disk-gap was approximately 1.5 times the quenching distance. A strong initial disturbance could generate complicated cellular structures coupled not only with shear stress but also with heat transfer. These cellular structures could increase the flame propagation velocity when the Lewis number was sufficiently smaller than unity. In contrast, the flame shape became smoother when the disk-gap was sufficiently larger than the quenching distance. Thus, the flame propagation velocity was comparable to the laminar burning velocity when it was less affected by the initial disturbance.

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1. Introduction

Complicated premixed flame propagation within a confined combustion space was first visualized by Ellis [1]. After that, a number of studies were conducted using various burner configurations such as tubes or channels. Some related phenomena have also been investigated under different names: the 'finger flame' having a long flame skirt near the wall and the 'tulip flame' having a cusped flame shape along the center axis [2–8]. It was known that the combustion instability within a narrow channel is affected by factors such as pressure, flow, and heat transfer. Related phenomena were explained based on quasi-two-dimensional assumptions in the direction of the large-scale waves [9]. However, actual flame shapes in experiments could not accurately be predicted mainly because they were deformed in multiple dimensions by a variety of physical factors.

Recently, premixed flame propagation in a narrow parallel channel, namely a Hele-Shaw burner, was studied as a method to visualize the development of cellular flame structures [10–15]. It has been reported that the flame shapes in the Hele-Shaw burners are affected by various influences such as Darrieus–Landau, diffusive-thermal, Rayleigh–Taylor, and Saffman–Taylor instabilities. In addition, these flame behaviors were numerically simulated using various parameters [16–21]. However, the results have been ambiguous in some aspects. For instance, it was obvious that the cellular flame structure was practically affected by the gas viscosity and heat transfer within a narrow channel. Nevertheless, some numerical simulations obtained severe cellular flame structures even without considering viscosity or heat loss [5] just by accounting for asymmetric volume expansion in the combustion space. This means that volume expansion is a major parameter, but it does not mean that such phenomena are independent of other parameters or mechanisms. Therefore, a new experimental method to distinguish the volume expansion effects from the other parameters has been necessary.

The relationships at various length-scales concerned with the laminar flame theories are briefly described in Fig. 1. It is thought that the combustion phenomena and flame structure can be triggered by various mechanisms when the configurational length-scales of combustion spaces are varied. For instance, an arbitrary length scale 'a' between 1 mm and 1 cm at around standard state will disturb diffusion layers, the quenching (or thermal loss), and momentum layers simultaneously. On the contrary, a larger length scale 'b' will not disturb any other scales except for the cellular scale that is initiated by multi-dimensional flame instability

* Corresponding author.
E-mail address: nikim@kaist.ac.kr (N.I. Kim).

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