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Research paper

# Effect of external surface emissivity on flame-splitting limit in a micro cavity-combustor

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## HIGHLIGHTS

- Effect of emissivity on flame-splitting limit of micro cavity-combustors was studied.
- Flame-splitting limit increases as the external surface emissivity is reduced.
- Heat-loss ratio drops sharply with the decrease of external surface emissivity.
- The recirculated heat amount rises with the decrease of external surface emissivity.
- The fuel consumption rate at the flame tip is faster for smaller surface emissivity.

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## ABSTRACT

Heat transfer processes are of significance for combustion in microscale channel. In the present paper, three different values (i.e., $\varepsilon = 0.1$, 0.5 and 0.92) are selected to numerically investigate the effect of external surface emissivity on the flame-splitting limit (the critical velocity when the combustion efficiency drops to 80%) using Fluent 6.3. The results demonstrate that the flame-splitting limit has a negatively monotonic variation trend with the external surface emissivity. This feature is interpreted from viewpoints of heat-loss from the exterior wall and heat recirculation through the upstream wall. The analyses show that the heat-loss ratio decreases with the reduction of external surface emissivity, which gives rise to a more intense reaction in the cavity and a higher wall temperature level. Therefore, more heat is recirculated to upstream wall and a better preheating of the fresh mixture can be achieved. Consequently, the chain reactions of $H_2$/air mixture start earlier and the reaction rates are much faster for a smaller surface emissivity. The combined actions of heat loss and heat recirculation lead to a faster consumption of the hydrogen fuel at the flame tip, and a larger flame-splitting limit can be obtained for a smaller surface emissivity.



## 1. Introduction

With the rapid development of MEMS (Micro-Electro-Mechanical Systems) technology, microscale combustors for micro-power generation and micro-propulsion systems are receiving increasing attention. Compared with conventional electrochemical batteries, which have disadvantages including a short life span, long recharging period and low energy density, micro-power-generation devices utilizing combustion energy are considered to be promising alternatives due to the higher energy density [1–3]. Therefore, the fuel conversion efficiency of in micro combustors is of great significance for the whole system.

Because of the increased heat-loss ratio and radical quenching effect resulting from a large surface-area-to-volume ratio, it is hard to maintain a stable flame in micro combustors [3,4]. Many unstable micro flames have been reported hitherto [5–14]. For instance, Maruta et al. [5] observed a flame with repetitive extinction and ignition (FREI) in their experiment of a 2-mm-diameter tube. Richecoeur and Kyritsis [6] identified the similar phenomenon in a 4-mm-diameter curved duct. This combustion mode was later numerically re-produced by other researchers [7,8]. After that, flame splitting phenomenon during the FREI processes

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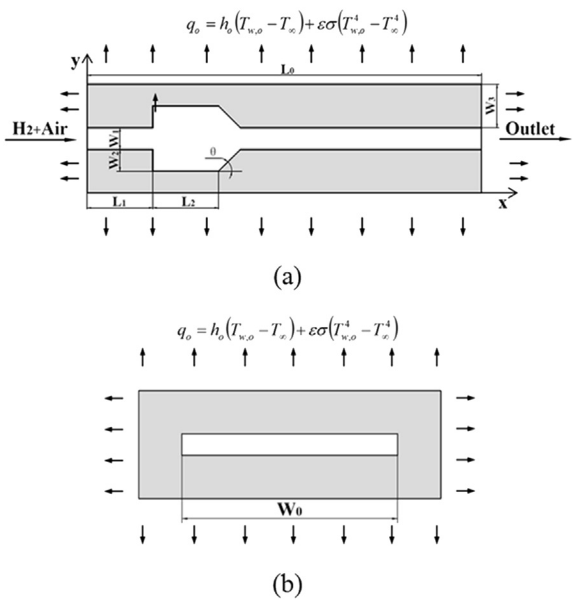


**Fig. 1.** Schematic diagram and coordinates of the micro-channel with cavities: (a) longitudinal cross section, (b) combustor exit.

was numerically predicted [9] and experimentally confirmed [10]. Moreover, Kumar et al. [11,12] and Fan et al. [13,14] observed some special flame patterns, such as the rotating spiral flame, in a heated radial micro-channel.

Those adversities impose rigid challenges to researchers in developing micro combustors of high efficiency. Various strategies have been put forward to improve flame stability in micro combustors. Heat-recirculating type micro-combustors, which can utilize the heat released and reduce heat loss, are frequently employed. For instance, "Swiss-roll" structure [15,16] and porous media [17] were applied to micro combustors to sustain stable flames. Porous wall was also used to stabilize the flame in a miniature cylindrical combustor [18].

Moreover, catalytic combustion is an effective measure to attenuate the radical-quenching effect of the wall surfaces. Maruta et al. [19] investigated catalytic combustion of $CH_4/O_2$ mixture in a tube coated with platinum catalyst. Suzuki et al. [20] explored microscale catalytic combustion of butane in a micro catalytic combustor with tailored porous alumina. Chen et al. [21] designed segmented catalyst with inert intervals to improve the effect of catalytic combustion. Li et al. [22] numerically studied effects of catalyst segmentation with wall cavities on the combustion characteristics of $CH_4/O_2$ mixture. Their results confirm that catalytic reaction plays a positive role in micro combustion.

Flame can also be anchored in micro combustors by forming a recirculation zone or low velocity zone. Khandelwal and Kumar [23] investigated premixed $CH_4/O_2$ flames in a diverging microchannel. Yang et al. [24] and Pan et al. [25] compared flame stability in micro-combustors with and without a backward facing step. Khandelwal et al. [26] investigated the flame stabilization ability in a micro-combustor with two backward steps. Their work shows that stable flame can exist in this kind of structure. Wan et al. [27] developed a micro bluff-body combustor which can greatly extend the flame blow-off limit. Later, Fan et al. [28–30] systematically investigated the effects of dimension, shape and material of the bluff body on the flame stabilization performance of this combustor.

Very recently, Wan et al. [31–33] developed micro- and meso-scale cavity-combustors to anchor the flame. Their experimental investigation of $CH_4$/air mixture shows that stable symmetric flame even cannot occur in the straight channel with a gap distance of 4 mm, and only inclined and pulsating flames were observed in the case without wall cavity [31]. In comparison, when the cavity is present in the wall, stable symmetric flames can be effectively anchored and a blow-off limit which is several times of the corresponding burning velocity can be achieved. These indicate that the cavity has a strong ability to extend the operational range of inlet velocity. However, for lean $H_2$/air mixture, "flame-tip opening phenomenon", which is frequently observed in stretched premixed flame with a sub-unity Lewis number, was numerically confirmed by Wan et al. [32]. The flame-tip opening leads to large amount of fuel leakage and sharp drop in the combustion efficiency. For a convenience of comparison, they defined a "flame-splitting limit" as the critical velocity when the combustion efficiency descends to around 80% [32]. In addition, Wan et al. [33] numerically examined the impact of channel gap distance, which demonstrated a non-monotonic variation of the flame-splitting limit. It is well known that heat loss from external walls, which depends strongly on surface emissivity, can significantly affect the combustion characteristics in micro-channels. Therefore, the major objective of the present paper is to numerically investigate the effect of external surface emissivity on the flame-splitting limit of lean $H_2$/air mixtures in a micro cavity-combustor. The results are analyzed in terms of interplays between heat transfer processes and chemical reactions.

## 2. Numerical methods

### 2.1. Geometric model

Fig. 1 shows the schematic of the micro cavity-combustor. The length ($L_0$), width ($W_0$) and gap distance ($W_1$) of the combustor are

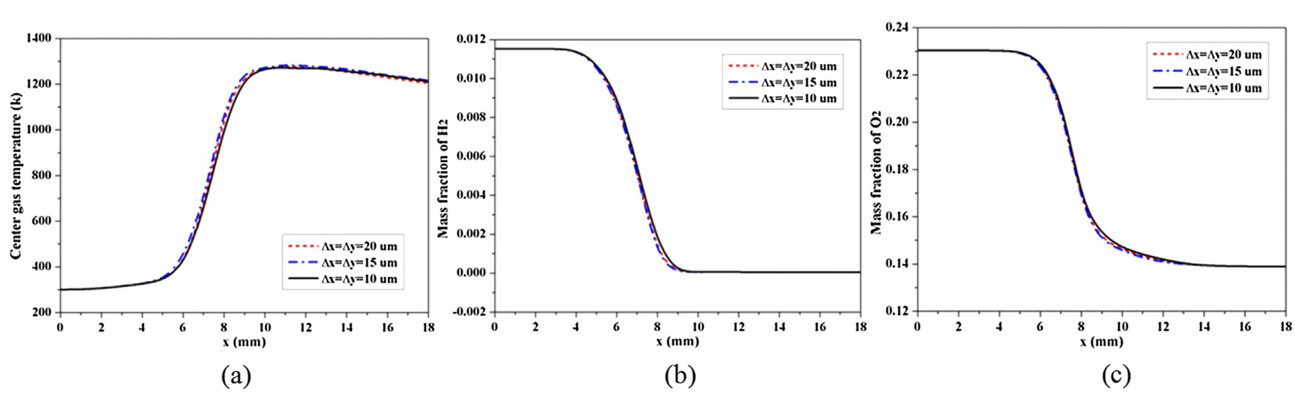


**Fig. 2.** Gas temperature profiles and mass fraction profiles of H2 and along the centerline of the quartz combustor for different grid resolutions under $\phi = 0.4$ and Vin = 8 m/s.