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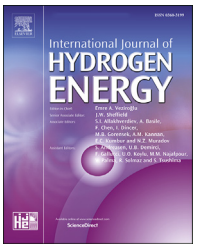

Shape effect of cavity flameholder on mixing zone of hydrogen jet at supersonic flow

Rasoul Moradi [a], *A. Mahyari* [b], *M. Barzegar Gerdroodbary* [c,*], *A. Abdollahi* [d], *Younes Amini* [e]

[a] *Department of Chemical Engineering, School of Engineering & Applied Science, Khazar University, Baku, Azerbaijan*

[b] *Department of Chemical and Petroleum Engineering, Sharif University of Technology, Tehran, Iran*

[c] *Department of Mechanical Engineering, Babol Noshirvani University of Technology, Babol, Iran*

[d] *Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran*

[e] *Department of Chemical Engineering, Isfahan University of Technology, Isfahan, Iran*

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ABSTRACT

Cavity flameholder is known as an efficient technique for providing the ignition zone. In this research, computational fluid dynamic is applied to study the influence of the various shapes of cavity as flameholder on the mixing efficiency inside the scramjet. To evaluate different shapes of cavity flame holder, the Reynolds-averaged Navier–Stokes equations with (SST) turbulence model are solved to reveal the effect of significant parameters. The influence of trapezoidal, circle and rectangular cavity on fuel distribution is expansively analyzed. Moreover, the influence of various Mach numbers (M = 1.2, 2 and 3) on mixing rate and flow feature inside the cavity is examined. The comprehensive parametric studies are also done. Our findings show that the trapezoidal cavity is more efficient than other shapes in the preservation of the ignition zone within the cavity. In addition, the increase of free stream Mach number intensifies the main circulations within cavity and this induces a stable ignition zone within cavity.

Introduction

Scramjets are known as the most efficient engine for the increasing of the flight speed. This engine is simple and low cost and does not need high amount of fuel tank which is the main challenge for the long flight. Development of the combustion efficiency inside the cavity is a crucial for increasing the performance of scramjets (supersonic combustion ramjet) [1,2]. Since weight of this engine is low and the working mechanism is simple, this type of engine is more recommended. Hence, researchers have tried to increase the efficiency of this engine. Among numerous subjects for refining the scramjets, efficient mixing of fuel to air is crucial for future development of these engines [3]. Since the velocity of free stream inside the main chamber is high and more than sonic, the process of ignition is supersonic main stream occurs very fast, and this augments the importance of mixing in these engines [4–6].

In order to enhance the mixing rate inside the combustion chamber, scholars and engineers have investigated different methods [7–12]. Various techniques and geometries of scramjets are proposed [13–16] and investigated to enhance the efficiency [17,18]. It is important to note that the most

* *Corresponding author.*
E-mail address: mbarzegarg@yahoo.com (M. Barzegar Gerdroodbary).

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favorable approaches for the development of these engines are geometrical modifications of the domain and applications of different techniques such as multi jets injectors, micro air jets and shock generators. In addition, combinations of these methods are also considered to enhance the mixing efficiency of the fuel within cavity. Since this topic is very significant, several review papers have focused on many features of fuel injection within supersonic free stream [19]. In our previous works [20–26], computational techniques are applied for investigations of different possible mechanisms of fuel and air injections. Among different geometries, cavity-based flameholder concept seems a good mechanism for supersonic combustors [27].

The shape effect of the cavity in different applications within the scramjets are studied by various scholars. Kummitha et al. [28] applied CFD method for analyzing of fluid flow behavior inside the scramjet combustor with different cavity-based flame holders in presence of shock generator. In their study, shock interactions and their effects on the flow pattern inside the model are extensively explained. Investigated effects of passive methods for optimizing the performance of scramjet combustor. He also presented numerical analysis of hydrogen fuel scramjet combustor with different turbulence models. Huang et al. [29–31] examined the result of geometric constraints on the significant parameters of the cavity flameholder such as drag and temperature based on the variance analysis technique.

Though cavity flameholder has been applied as a well-organized model for providing fuel in a combustor of the scramjet [32–34], limited works studied the effects of flow feature and shape of cavity on its performance. In fact, analyzing and finding of the main parameters which is significant on the hydrogen mass distribution inside the cavity could present the valuable data and improve the knowledge of the design of the future scramjets. In addition, the effect of the free stream velocity on the shock effect on the fuel distribution inside the cavity was not investigated. Previous works have always investigated the formation of the shock structure on the main flow patterns as the key point for the analyzing of the fuel distributions in supersonic combustion chamber. Indeed, the formation and structure of the fuel jet with the free stream reveal the main effective terms in the mixing efficiency of the various methods.

Our work has tried to comprehensively focused on these deficiencies and explain the main advantages of each cavity shapes on the performance of the scramjets. As shown in Fig. 1, three different geometries of cavity such as circle, rectangular and trapezoidal are investigated. Meanwhile, the criteria of the ignition zone are displayed to clearly demonstrate the effect of each parameter on this zone. Furthermore, streamline patterns are compared for different models to show the influence of the streamline on the various conditions. It should be noted that circulations are the main results of the cavity in the supersonic flow patterns. Hence, the formation and effective term of this phenomena is crucial for the recognition of the main parameters. It is clear that the injection of the fuel with sonic condition highly disturbs the main circulation within the cavity. As it will be further explained in the next sections, the injection of the hydrogen divides the main circulation inside the cavity and the role of the cavity

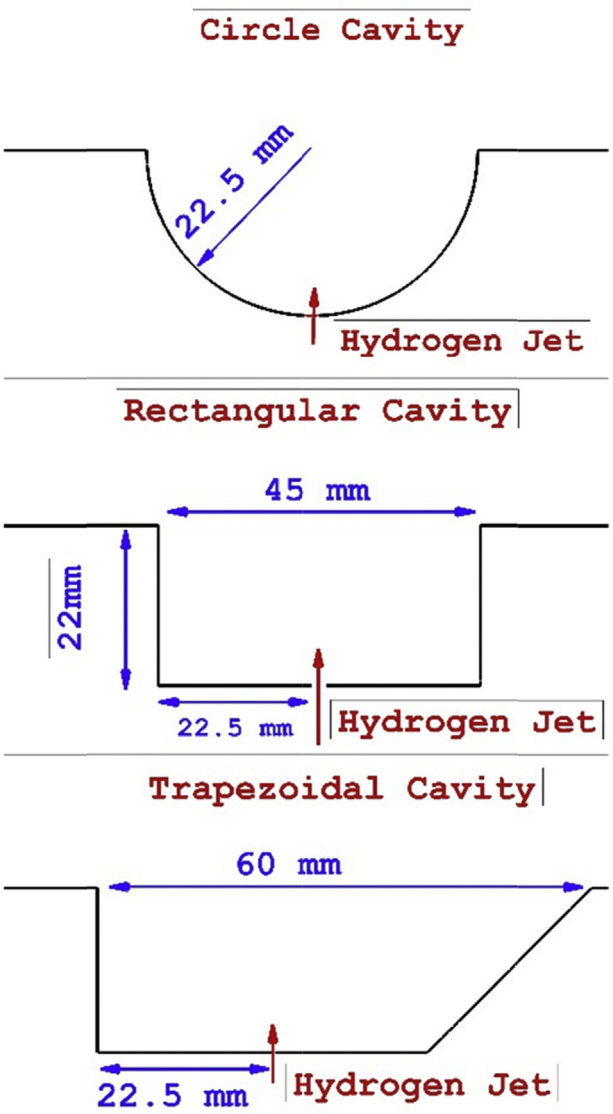

Fig. 1 – Plan of three shapes of cavity (circle, rectangular and trapezoidal).

shape is significant for the formation of the circulations inside the cavity. This study also analyzes the flow pattern in the downstream of the cavity. Hence, the obtained results could be valuable for the next generation of the scramjets.

In order to analyze the shape effects of cavity, circle, rectangular and trapezoidal cavities are examined to analyze the role of the flow inside the cavity on feature and mixing performance of scramjet. Furthermore, the result of free stream Mach number on the mixing rate of hydrogen jet is comprehensively investigated.

Numerical approach

In this work, geometry of the DLR experimental work [35,36] is used as the main size for further investigations. Since the 2D model is applied, the size of the domain in x and y direction is 300 and 50 mm, respectively. Fig. 2 shows the applied grid for

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