# Numerical investigation of the influence of burner's bluff body on air-fuel mixing and reaction

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## ABSTRACT

**One way to improve air-fuel mixing in a gas diffusion flame is to produce targeted vortices and circulate the flow using a bluff body. In this study, the influences of radius, thickness and location of a disk-shaped bluff body on the performance of a methane gas diffusion flame are numerically studied. This investigation is carried out under both cold mixing and hot mixing (with combustion reaction) conditions. The present simulation is verified against experimental data. The results show the substantial influence of the mentioned parameters on the size and intensity of downstream vortices, and a direct dependence is observed between the sizes of inner and outer recirculation zones and air-fuel mixing. It is also observed that the flow pattern and level of air-fuel mixing are more dependent on the bluff body's radius than its thickness. Based on the hot mixing simulation results and regarding the dependence between the rates of chemical reaction and turbulence mixing, the higher rate of air-fuel mixing is associated with the decreased flame length. Among the cases investigated, the bluff body with the radius of 6mm, thickness of 5mm and axial location of 5mm away from the air channel exit results in the best air-fuel mixing.**

## KEYWORDS

**Gas diffusion flame, bluff body, air-fuel mixing, numerical simulation.**

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## 1. Introduction

Mounting a bluff body (BB) at the burner head is a simple passive method which can substantially enhance the reactants mixing and combustion quality through inducing some targeted vortices downstream.

Various research works, mainly experimental, have been conducted to figure out the influence of BB on the burner performance. As a brief summary, it was observed that: A planar BB led to larger vortices, as compared to cylindrical and wedge-shaped BBs [1]. Increasing the cone angle of a conic BB resulted in larger and more elliptical vortices [2]. A tulip-shaped BB produced a more stable flame, as compared to a planar BB [3]. A larger diameter of a disk-shaped BB resulted in a shorter flame [4]. Targeted downstream vortices could enhance the turbulence and air-fuel mixing [5]. The size of vortices was highly affected by BB obstruction ratio [6]. Mounting a BB 10mm after the air channel exit resulted in larger vortices and a more stable flame [7].

This study numerically investigates the influences of thickness, radius and location of a disk-shaped BB on air-fuel mixing and properties of resulting gas diffusion flame. Furthermore, the sensitivity of the results to the mentioned variables is analyzed. To the authors' knowledge, such quantitative study and sensitivity analysis have not been addressed in literature.

## 2. Methodology

A gas diffusion burner (shown in Fig.1), with the specifications reported in [7], is considered as the case study. Governing equations and simulation approach are briefly described in this section. Methane oxidation is assumed to be single-step. The mass, momentum, energy and species transport equations are shown in Eqs.(1)-(4), respectively [8]. In which, $\mu_t$, $Sc_t$ and $Pr_t$ are turbulent viscosity, Schmidt and Prandtl numbers. $Y$, $h$ and $S_{Reaction}$ represent species molar fraction, enthalpy, and reaction heat source, respectively. $R$ denotes the rate of creation of species and is obtained from Eddy Dissipation model [9]. The fluctuation term (last term) in Eq. (2) is modeled using *k-ω* (SST) turbulence model [10]. $S_{Radiation}$ is the radiation heat source which is calculated by Discrete Ordinates (DO) approach [11]. The governing equations are solved via finite volume scheme by using ANSYS Fluent software.

To verify the present simulation, it is compared with the experimental data of [7]. Figure 2 shows a good agreement between the current simulation and the experimental data.

$$\frac{\partial\left(\rho u_i\right)}{\partial x_i}=0 \qquad (1)$$

$$\frac{\partial\left(\rho u_i u_j\right)}{\partial x_j}=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}-\frac{2}{3}\delta_{ij}\frac{\partial u_k}{\partial x_k}\right)\right]+ \frac{\partial}{\partial x_j}\left(-\rho\overline{u_i' u_j'}\right) \qquad (2)$$

$$\frac{\partial}{\partial x_i}(\rho u_i h)=\frac{\partial}{\partial x_i}\left(\sum_k\left(K+\frac{c_p\mu_t}{Pr_t}\right)\frac{\partial T}{\partial x_i}\right)+\frac{\partial}{\partial x_i}\left(\sum_k h_k\left(\rho D_k+\frac{\mu_t}{Sc_t}\right)\frac{\partial Y_k}{\partial x_i}\right)+ S_{Reaction}+S_{Radiation} \qquad (3)$$

$$\frac{\partial}{\partial x_i}(\rho u_i Y_k)=\frac{\partial}{\partial x_i}\left(\left(\rho D_k+\frac{\mu_t}{Sc_t}\right)\frac{\partial Y_k}{\partial x_i}\right)+R_k \qquad (4)$$

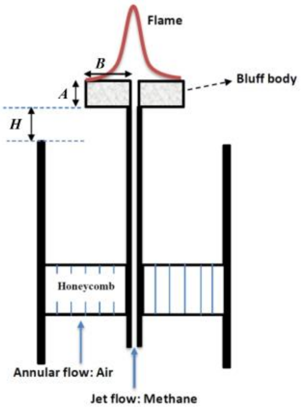

**Fig.1. Schematic view of the burner**

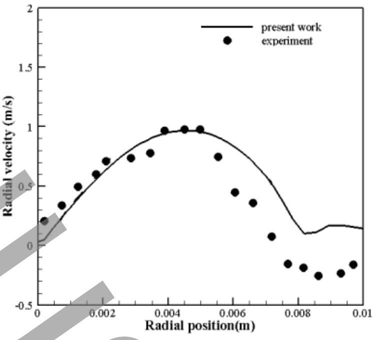

**Fig.2. Verification study: radial velocity on the line perpendicular to the axis and 2mm away from BB (fuel and air inlet velocities are 10m/s and 5.84m/s, respectively)**

## 3. Results and Discussion

The burner has been numerically simulated for the different set values of BB thickness, BB radius, and the gap between BB and air inlet (designated with "A", "B", and "H" in Fig.1, respectively). Contours of methane molar fraction (for air velocity of 3.75 m/s, fuel velocity of 10m/s, and BB thickness and radius of 5mm) are shown in Fig.3. The steeper the drop of methane along the burner centerline (or axis), the greater the diffusion of surrounding air into the fuel. Therefore, the rate of fuel drop along the axis can be considered as a mixing quality indicator. The influences of BB thickness and radius are illustrated in terms of methane molar fraction in Figs. 4 and 5, respectively. These figures indicate that the air-fuel mixing is more affected by BB thickness than BB radius. Figure 5 also shows that the air-fuel mixing improves as BB radius increases. To analyze this observation, the streamlines are illustrated for the smallest and largest BB radii in Figs. 6 and 7, respectively. These figures indicate that a larger radius resulted in larger inner and outer recirculation zones, thereby enhancing the air-fuel mixing. Similar analyses were carried out for the effect of BB location on the burner performance, and it was observed that from among the different locations, a gap of 5mm between the BB and the air inlet led to the best air-fuel mixing (or steepest drop in methane along the axis). The results are not repeated to be graphically shown for the sake of conciseness.

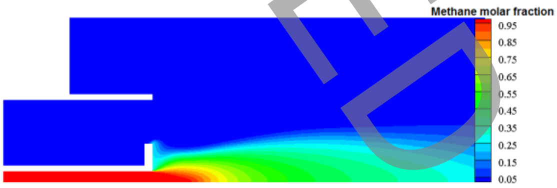

**Fig.3. Contours of methane molar fraction**

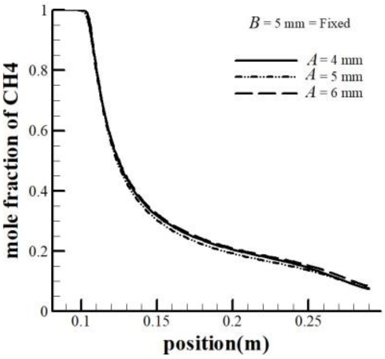

**Fig.4. Effect of BB thickness on methane drop along axis**

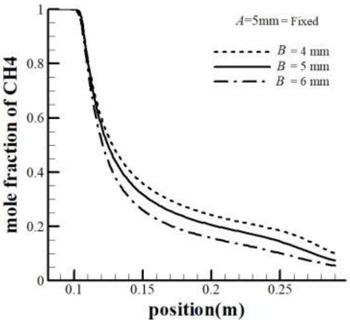

**Fig.5. Effect of BB radius on methane drop along axis**

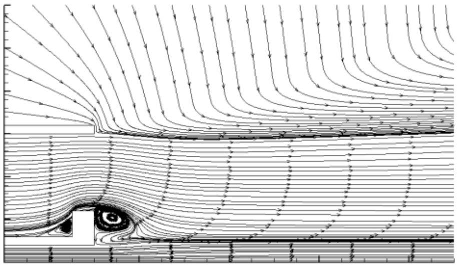

**Fig. 6. Streamlines for BB radius of 4 mm**

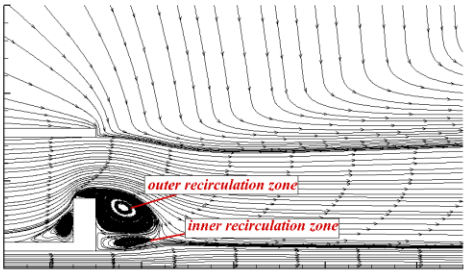

**Fig. 7. Streamlines for BB radius of 6 mm**

## 4. . Conclusions

In this study, the influences of bluff body location and size on the performance of a gas diffusion burner were numerically investigated. The rate of methane drop (or oxygen rise) along the burner axis was considered as a measure of air-fuel mixing quality. The results indicated that the mentioned parameters had substantial effects on burner performance; furthermore, it was observed that the bluff body radius had a greater effect on the downstream vortices and air-fuel mixing, as compared to the bluff body thickness. Among the cases studied, a bluff body with a thickness of 5mm, radius of 6mm and a distance of 5mm from the air inlet resulted in the best air-fuel mixing.

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