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Experimental investigation on effects of central air jet on the bluff-body stabilized premixed methane-air flame

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Abstract

Flame stabilized by a bluff-body is a common scene in many engineering applications due to the enhanced mixing characteristics, improved flame stability, and ease of combustion control. We recently designed a burner which has a conical bluff body with a central air injector. In the current work, effects of the central air jet on the heat load of the bluff body, the flame structures and the flame blowoff limits were investigated. It was found that the central air jet can significantly reduce the heat load to the bluff body. It is a considerable solution to the problem caused by the high heat load in practical applications. The flame structures and blowout limits were altered with the addition of central air jet as well. Different blowout behaviors caused by the air jet were observed and reported. The bluff-body could be cooled down by the center air injection but then it seems not to stabilize the flame any more.

Keywords: Blow off; bluff-body; flame structures; premixed combustion.

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1. Introduction

Flame stabilization in premixed fuel–air streams has long been a subject of significant technological interest for a variety of applications, such as in gas turbine combustors, afterburners, heat recovery steam generators, and industrial furnaces [1]. Bluff-body flame holder is a commonly employed practical methodology to stabilize the flame due to the enhanced mixing characteristics as well as the ease of combustion control. The recirculation of hot gas behind a bluff-body can help to reignite gas mixtures, and thus stabilize the flame [2].

Bluff-body stabilized premixed flame has been investigated in a number of seminal works by Zukoski [3],[4], Longwell [5],[6], Wright [7] and Pan [8]. The main focus of the bluff-body stabilized premixed flame was the blowoff mechanism or lean flame stabilization limits of the flame holder. Lefebvre et al. [9] summarized the effects of inlet air temperature, pressure, velocity, turbulence and bluff-body geometry on the lean blowoff performance of bluff-body flame holders supplied with homogeneous mixtures of gaseous propane and air. Moreover, Shanbhogue et al. [10] reviewed the dynamics of two-dimensional bluff-body stabilized flames and described the phenomenon of the blowoff process in the bluff-body. Chaudhuri et al. [11] claimed that the bluff-body stabilized flames had the features of a centrally piloted flame, with much of the outer flow remaining unburnt at low equivalence ratios. Chaudhuri et al. [12] also investigated the blowoff dynamic of bluff body stabilized turbulent premixed flame and illustrated the hypothesis for flame blowoff mechanism. A change of flame shape between conical and columnar shapes was also observed with the changing of equivalence ratio of the premixed fuel-air mixture. The unstable flame behavior (local extinction and re-ignition) near blowoff was recorded and presented as well. Fan et al. [13] claimed that the heat loss to the confinement wall have a negligible effect on the flame blowoff limits in the bluff-body stabilized micro-combustor. Additionally, Fan et al. [14] also concluded that solid materials of the bluff-body with relatively low thermal conductivity and emissivity were beneficial to obtain a large blowoff limit.

Usually the bluff-body used to stabilize the premixed flame is a simple solid cone or solid plate with different geometries. Whereas thebluff-body with a central jet is commonly employed to stabilize a diffusion flame. Roquemore et al. [15] tested the behavior of reacting and non-reacting flows in an axisymmetric bluff-body burner. Illustration of the time-averaged flow field of a bluff-body with a central jet from [15] is shown in Fig.1. The flow field downstream of the bluff-body was determined by the ratio of the annular and central jet velocities. Caetano et al. [16] presented three different flame types in the bluff-body flame holder in their experimental work and concluded that combustion presented a weak influence on the averaged velocity field. Based on the change of the central jet to annular air velocity ratio and the corresponding flow structures, Esquiva-Dano et al. [17] summarized six different regimes of non-premixed bluff-body stabilized flames. Tang et al. [18] investigated the effects of the Reynolds number of both central fuel and annular air jet on the flame structures and its dynamics. They concluded that the central fuel jet Reynolds number mostly determines the flame extinction phenomenon while the annular air Reynolds number influences the flame structures more.

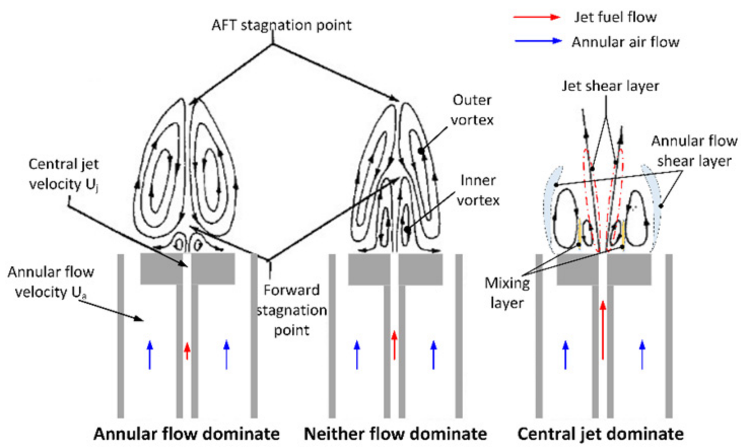

Fig.1. Illustration of the time-averaged flow field of a bluff-body with a central jet (reproduced from [15])