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Lift-off characteristics of non-premixed jet flames in laminar/turbulent transition

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ABSTRACT

The stabilization mechanism of a laminar lifted flame has been explained theoretically. However, variation of the stabilization mechanism of the lifted flame in the transitional regime between laminar and turbulent flames has not been clarified. In this study, lift-off heights were estimated in relation to variation of the fuel tube diameter, fuel jet velocity, and proportions of methane and propane. With increase of the fuel jet velocity, stable lifted flames could be obtained under various conditions and the soot emission reduced. The stabilization mechanisms were explained based on the concepts of laminar and turbulent mixing cores. These were classified into five regimes: laminar similarity, laminar near-core, external mixing, transitional, and fully turbulent. Improved relationships between the flow rate and the lift-off height were proposed in two regimes (external mixing regime and the fully turbulent one). In addition, the blowout mechanism was explained using the turbulent intensity. Finally, an overall stabilization diagram showing the various stabilization mechanisms of the lifted flames was presented.

1. Introduction

Non-premixed flames have been used in many practical combustion systems, and a single fuel tube and the surrounding air is the simplest configuration. With increase of the fuel flow rate, a flame can be detached from the fuel tube exit. After that, a lifted flame can form if the stabilization condition is satisfied or can be blown out in other cases. Such lifted flames have been widely adopted in various combustion systems for various purposes (i.e., to avoid the thermal damage of the fuel tube, to shorten the flame length, or to reduce the emission of particulate matter: PM). Thus, the characteristics of lifted flames have been of great interest. In particular, PM emissions are drawing more interest concerned with human health and environmental issues, so clean combustion technology to achieve less PM emission has become important [1,2]. Turbulent lifted flames have been employed as the simplest practical method by which to reduce PM because they could help the oxidation of soot particles due to enhanced partial premixing at the flame base.

Nevertheless, our knowledge of the stabilization mechanism of a lifted flame is not enough, as explained below. Many studies have been conducted to investigate flame stabilization mechanisms for laminar and turbulent lifted flames. The stabilization mechanism of a laminar lifted flame was first explained schematically by Chung and Lee [3], and related studies were summarized in a few review papers [4,5]. Additionally, some recent studies have been conducted regarding to the other factors related to the laminar lifted flame such as pressure or gravity [6–9]. A detailed theoretical explanation was provided very recently [10], and it was shown that the lift-off height could be explained based on variation of the effective Schmidt number, which is closer to that of fuel when the lift-off height is small and varies closer to that of air when the lift-off height is large. The minimum lift-off height was achieved when the effective Schmidt number was unity, and all lifted stable flames above the minimum lift-off heights had an effective Schmidt number larger than unity.

However, this approach based on the effective Schmidt number is only applicable when the flame base of the laminar lifted flame is formed above the developing core. The laminar lifted flames having notable lift-off heights and satisfying the similarity solutions could be formed when the fuel-tube diameter was sufficiently small (order of 0.1 mm). Therefore, most of the previous studies on laminar lifted flames were explained based on the similarity solutions, and they used fuel jet diameter smaller than 1 mm. For instance, the maximum fuel tube diameter was 0.247 mm in Ref. [3] and 0.311 mm in Ref. [10]. Such studies could not explain a suitable mechanism for laminar lifted flames using ordinary fuel jet diameters larger than 1 mm. Furthermore, the mechanism or characteristics of lifted flames have not been clar-

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