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著者(和文)	ShanJIANG
Author(English)	Shan Jiang
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論文題目：“Numerical study on next-generation hydrogen-oxygen multi-cluster burners”
（次世代酸素水素マルチクラスターバーナに関する数値的研究）

This thesis entitled “Numerical study on next-generation hydrogen-oxygen multi-cluster burners” is composed of five chapters as follows:

In Chapter 1 “Introduction”, the current environmental and social context of the carbon neutrality (CN) goal has been introduced, leading to the significance of decarbonization of combustion devices, such as gas turbine combustors for power generation. This chapter points out that the development of new burners fueled by hydrogen is urgent to achieve CN. The purpose of this thesis is clarified, namely, that due to the combustion characteristics of hydrogen, it is necessary to develop a multi-cluster type hydrogen burner, which is formed by an assembly of small nozzle units. This thesis focuses on gas turbine burners for power generation, industrial furnace burners, and direct heating boiler burners, aiming to clarify the characteristics of the multi-cluster type hydrogen-fueled combustion. Additionally, this thesis aims to establish a numerical prediction method for the multi-cluster type burner.

In Chapter 2 “Characteristics of steam diluted O2-H2 combustion under gas turbine conditions”, investigation has been conducted on a semi-closed oxygen-hydrogen combustion gas turbine currently under development. This chapter includes predictions of burner outlet characteristics using Perfectly Stirred Reactor (PSR) analysis, clarification of combustion characteristics of burner nozzle unit through Direct Numerical Simulation (DNS), and the development of a simplified numerical prediction method for multi-cluster burners using Large Eddy Simulation (LES). In the semi-closed gas turbine system, since the gases are directly introduced into the turbine, controlling the temperature and chemical composition is crucial. The PSR analysis reveals that to achieve sufficiently low residual levels of oxygen and hydrogen, and to maintain the temperature below 2000K, a steam dilution rate of over 80% is required. For the nozzle unit planned for use in this gas turbine system, the design features an oxidizer jet, a hydrogen jet, and an oxidizer jet arranged in a straight line in sequence. By introducing an inclination angle to the oxidizer jets, an impingement region of the oxidizer jets is formed in the downstream area, where the hydrogen jet is introduced to create a non-premixed flame. The oxidizer used here is oxygen diluted with steam. DNS was conducted on this nozzle unit under gas turbine conditions, and the results revealed that the nozzle unit itself stabilizes the flame by forming a recirculation zone. The flame has two premixed branches as the edge flame base and basically has a triple flame structure. Additionally, the heat flux on the nozzle surface and the amount of hydrogen remaining in the upstream region depend on the inclination angle of the oxidizer jets.

In Chapter 3 “Characteristics of H2-O2 Combustion under Industrial Furnace Burner Conditions”, a 200 kW hydrogen-oxygen multi-cluster burner for industrial furnaces is investigated. Burner outlet characteristics are predicted using PSR, combustion characteristics corresponding to the individual nozzle unit are elucidated through DNS, and global characteristics of the multi-cluster burner are clarified using LES. Given that the heating of metals and other materials is crucial in industrial furnaces, the need to generate high-temperature combustion gases is emphasized. The PSR analysis reveals that using pure oxygen as the oxidizer can achieve temperatures exceeding 3000K at the burner outlet. Additionally, DNS simulations were conducted on single nozzle unit of the same design as those in the previous chapter, demonstrating that even under industrial furnace conditions, where the momentum difference between the oxidizer and hydrogen jets is significantly different from that in gas turbine conditions, the unit burner can still achieve stable combustion. Furthermore, it was found that by increasing the inclination angle of the oxidizer jets, stable combustion can be maintained while extending the reach of the high-temperature region.

In Chapter 4 "Characteristics of H2-O2 Combustion under Boiler Conditions", a 60 kW direct heating boiler is investigated. The study includes predictions of burner outlet characteristics using PSR analysis and clarification of the combustion characteristics of individual unit burners through DNS. In direct heating boilers, the composition and temperature of the combustion gases are crucial because the steam generated from oxygen-hydrogen combustion is directly utilized. A new PSR model was developed to predict the control of gas composition and temperature by injecting water downstream of the burner. The study reveals that by appropriately controlling the amount of water injected, the residual hydrogen concentration can be reduced to below 2%. Additionally, DNS results indicate that, compared to gas turbine and industrial furnace conditions, the turbulence intensity generated in the impingement region of jets under boiler conditions is weaker, and the turbulent mixing of oxidizer and hydrogen is not as pronounced. However, nozzle unit is still able to form a sufficiently stable flame.

In Chapter 5 "Conclusions", main conclusions of each chapter are summarized. This thesis provides an insight into the flame and flow characteristics of a novel multi-cluster type burner for hydrogen-oxygen combustion, specifically investigates three industrial applications of this configuration, revealing its flexibility and broad applicability, and offering an understanding of the burner's thermochemical characteristics, flame and flow structure, and flame stabilization.