FLOW AND MIXING CHARACTERISTICS OF FREE AND CONFINED MULTI-JET

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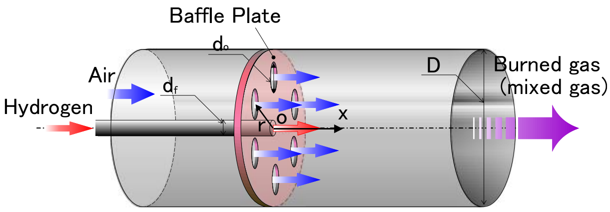
Fluid mixing is one of the most essential phenomena in fluid mechanics and is applied in numerous industrial applications concerning combustions, chemical reactions, thermal controls, etc. More demands are inevitably rising for developing a mixing technique which can produce sufficient and effective mixing in a more compact size. For example, a high performance micro-combustor is one of the key technologies for developing the micro gas turbine (MGT) well-known as the core part of the distributed power supply system [1, 2]. For this combustor, a good mixing between fuel and oxidizer is required since a failure in having a pertinent mixing will incur both deterioration of the system efficiency and increase of the emissions of unburned fuel, soot, CO, and NO_x from the MGT.

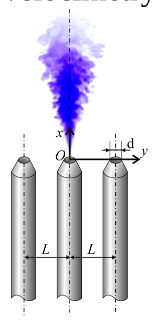
The problem of significant deterioration of the fluid mixing performance is strongly related to the decrease of flow Reynolds number accompanied by the reduction of the system size. Therefore, it is essential to develop an effective mixing method under such low Reynolds number conditions. For such a purpose, the authors have proposed a baffle-plate-type-multi-jet mixer [2, 3]. In this combustor, as shown in Fig. 1(a), a baffle plate, to which several nozzle holes are drilled, is introduced where the fuel and air are supplied from the baffle plate through the nozzles. The air nozzles are circularly arranged to surround the center-located fuel jet. The mixing performance has been markedly improved in this system mainly due to the increase of the local Reynolds number and interaction between the jets, and generation of flow recirculation in the downstream area of the plate.

Three-dimensional numerical simulation solving the flow and concentration fields was conducted in the present paper for this compact confined multi-jet mixer to evaluate the mixing performance. The effects of the nozzle location and size, Reynolds number and various upstream conditions on the flow and mixing characteristics are discussed. In addition to this, the effects of the swirl motion applied by tilting the surrounding jet holes in the circumferential direction, and of the buoyancy are also evaluated.

Furthermore, to have a better understanding of the interaction effects and mixing mechanism of such multiple jets, the flow characteristics of multi-jet under unconfined (free) conditions, as shown in Fig. 1(b), are also evaluated experimentally [4]. The velocity distributions using hot-wire anemometry and laser Doppler velocimetry (LDV),



(a) Baffle-plate type confined multi-jet



(b) Multi-free-jet

Figure 1. Schematic view of mult-jet.

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and flow visualization were carried out to discuss the effects of the jet flow rate, external acoustic excitation, cyclic pulsation of the jet flow rate on the flow and mixing characteristics.

In below are introduced the major results of these multi-jet under confined and free conditions. Detail discussion will be made in the presentation.

In the confined multi-jet case, the changes of the nozzle-size and location produced a large effect on the flow pattern and resulting mixing performance. A better mixing was obtained under the conditions of larger distance or larger momentum difference between the surrounding jets (air jets) and center jet (fuel jet). This was due to the fact that by increasing these values, the pressure decreased at the downstream of the center jet, and flow circulations were formed in the area located between the air and center jets. Enhancement of the mixing between the fuel and air was obtained in this circulation zone. The results predicted for various upstream conditions also indicated that the baffle plate could damp out undesirable disturbances included in the upstream flow.

By inclining the surrounding jet holes in the circumferential direction, a strong swirl motion was obtained in the chamber. However, adding the swirl motion, which is a typical technique applied to large-scale combustors to improve the combustion performance, incurred a deterioration of the mixing performance due to the interruption of the radial flow near the baffle plate and increase of pressure near the chamber walls.

Buoyancy effect was small for the baffle plate case without swirl motion when its operating direction was inline with the central axis. However, when a certain angle existed between the gravity and central axes, an undesirable asymmetric flow and concentration patterns appeared that may cause a hot spot and thermal fatigue at the chamber sidewall. Furthermore, buoyancy effect increased when swirl was applied.

On the other hand, in the unconfined free-multi-jet case, it was shown that the interaction between each jet produced an early transition to turbulent flow compared with a single jet case and, hence, enhanced the mixing performance. When an acoustic wave having an identical frequency to the resonance value of the jet was applied, an earlier transition of the jet from laminar to turbulent flow took place compared with that in the case without sound, and an effective mixing performance was obtained. Moreover, a bifurcation phenomenon of the center jet was observed, i.e., the center jet was split into two and then each split jet was entrained to the side jets at the downstream.

In the pulsating-jet case, in which the flow rate was periodically changed, a better mixing was found in the vicinity of the nozzle exit in the pulsating-jet case evaluated from the results of comparing the time-mean velocity pattern of a single jet with and without pulsating motion. On the contrary, further downstream at the location of $x/d \leq 30$, an inverse phenomenon appeared; namely, the case without pulsation showed a better mixing. This was believed to be related to the instantaneous characteristics of the pulsating jet. Since the Reynolds number of the tested jet was in the range of 1,500 and was close to the transition Reynolds number, the jet varied between a laminar jet and a fully developed turbulent jet in one cycle. When the time-mean value was considered, the latter jet showed a larger influence in the region close to the jet and vice versa.

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