Chapter 5

Concluding Remarks and Recommendations for Future Work

5.1 Concluding remarks

Combined experimental flow visualization, transient and steady temperature measurement have been conducted in the present study to explore the onset, steady and time dependent vortex flow characteristics associated with a low speed air jet impinging onto a horizontal circular heated disk confined in a vertical cylindrical chamber. Effects of the jet flow rate, temperature difference between the heated disk and cold air jet, and geometry of the chamber including diameter of the injection pipe and jet-to-disk separation distance on the vortex flow structures were inspected in detail. The formation of the inertia-driven vortex flow in the chamber during the transient stage is also examined. The major results obtained can be briefly summarized in the following:

(1). The typical steady vortex flow in the processing chamber consists of the inertia-driven and buoyancy-driven circular rolls.

(2). The critical jet Reynolds numbers for the onset of the primary, secondary and tertiary inertia-driven rolls increase noticeably when H is reduced from 20.0 to 10.0 mm. But the corresponding critical jet Reynolds numbers for the primary and tertiary inertia-driven rolls do not change for a reduction of H from 30.0 to 20.0 mm.

(3). The secondary inertia-driven roll appears in the chamber with the jet issued from the small injection pipe as Re_j approximately exceeds 180 at H=20.0 mm and 240 at H=10.0 mm. For the large injection pipe the secondary inertia-driven roll is induced for Re_j above 220 at H=20.0 mm, for Re_j above 306 at H=15.0 mm and for Re_j above 427 at H=10.0 mm.

(4). A tertiary inertia-driven circular vortex roll is first identified in the confined impinging air jet as the jet Reynolds number is sufficiently high. The tertiary roll is relatively small compared with the primary inertia-driven roll and becomes smaller at increasing Ra. Beyond the critical Re_j for onset of the tertiary roll the high jet inertia causes the vortex flow to become time dependent at $H \leqq 20.0$ mm.

(5). A reduction in H results in a significant decrease in the Rayleigh number since $Ra \propto H^3$ and can substantially reduce the size and strength of the buoyancy-driven roll. The present data of the critical condition for the onset of the buoyancy-driven roll can be approximately expressed as the local buoyancy-to-inertia ratio at the edge of the disk $Gr/Re_{we}^2 \approx 33.0$ at $H \leqq 20.0$ mm.

(6). At increasing jet Reynolds number the primary and the secondary inertia-driven rolls grow in size and strength with the accompanying decay of the buoyancy-driven roll. For H=20.0 mm, the radial extent of the buoyancy-driven roll is much larger than that for the largest jet-to-disk separation distance with H=30.0 mm because the buoyancy-driven roll can merge with the secondary inertia-driven roll as Re_j and Ra exceed certain level. At H=30.0 mm the primary inertia-driven and the buoyancy-driven rolls both become so large and they contact with each other. Thus no space is left for the secondary inertia-driven to appear.

(7). The inertia-driven rolls become smaller with decreasing jet-to-disk separation distance at Ra=0. Moreover, the inertia-driven rolls are insignificantly affected by ΔT at the shorter jet-to-disk separation distance with H=10.0 mm.

(8). At the same ΔT and Q_j the small injection pipe results in a larger and stronger primary inertia-driven roll and a secondary inertia-driven roll is prone to appear. However, the size of the buoyancy-driven roll is almost unaffected by the injection pipe diameter at $H \leqq 15.0$ mm.

(9). The existence of a peak in the radial temperature distribution is noted to result from the presence of the counter-rotating primary inertia-driven and buoyancy-driven rolls in the chamber, and hence the nonmonotonic radial air temperature distribution prevails in the flow.

(10). Empirical equations are proposed to correlate the size and position of the steady vortex rolls and the oscillation frequency of the time periodic vortex flow.

(11). At a high buoyancy-to-inertia ratio the vortex flow becomes time dependent and two new vortex rolls are induced due to an additional thermal plume rising from the heated disk and the splitting of the primary inertia-driven roll. In the region occupied by the two new rolls, the vortex flow oscillates significantly with time. Besides, the oscillation frequency and amplitude of the time periodic vortex flow respectively increases and decreases noticeably with the jet Reynolds number.

(12). A flow regime map is given to delineate the temporal state of the vortex flow for H=20.0 mm.

(13). During the flow formation for the limiting case of an unheated disk the primary inertia-driven roll appears immediately after the jet is injected into the chamber and it grows at a quicker speed for a high Re_j and reaches steady state in a shorter period of time. For the large injection pipe the rolls are induced in the slightly upper region of the chamber during the entire transient.

5.2 Recommendations for future work

During the course of this investigation it is realized that the jet Reynolds number, Rayleigh number, injection pipe diameter and jet-to-disk separation distance can exhibit significant influences on the vortex flow structure. The present study only covers limited ranges of these parameters. More works need to be done. A summary of the possible future work is given in the following.

(1). Vortex flow formation for the jet impinging onto the heated disk needs to be investigated. In particular, how the buoyancy-driven roll evolves during the transient stage has to be examined.

(2). The unstable vortex flow resulting from the jet inertia at high jet Reynolds number is also of interest. How the unsteady inertia-driven roll is stabilized by the increase in the Rayleigh number for H$\leqq$30.0 mm should be examined in detail. Besides, the possible existence of the quaternary flow needs to be explored.

(3). Does the rotation of the disk produce stabilizing effects on the vortex flow? How does the disk rotation affect the detailed characteristics of the vortex flow structure? These problems need to be addressed.