數值模擬低速空氣噴流衝擊一大直徑加熱圓板之混合對流新渦流結構研究

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中 文 摘 要

本篇論文利用三維暫態數值模擬方法探討低速空氣噴流衝擊一大直徑加熱圓板之混合對流所產生之新渦流結構及其特性；以商用套裝計算流體力學軟體 STAR-CD 對流體的統御方程式進行求解，論文先定義出不同於以往混合空氣噴流常見的圓環形渦流結構之新流場結構；數值結果指出針對未加熱的底板(雷利數為 0)發現有兩個穩定的圓環形渦流結構產生，分別為 primary 與 secondary inertia-driven rolls。當底板加熱，在較低的雷利數下，規則性圓環形 buoyancy-driven vortex flow 由圓形底板的邊緣開始產生；接著在適中的雷利數下，許多的 buoyancy roll 開始出現在底板與頂板間的區域，且開始嚴重的變形，可清楚發現 roll 的中斷與分裂。在某些高的雷諾數下，inertia-driven roll 會分裂變成數個短的 radial rolls。

Numerical Investigation of New Vortex Flow Patterns in a Low Speed Confined Air Jet Impinging onto a Large Heated Disk

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ABSTRACT

A transient three-dimensional numerical simulation is carried out in the present study to investigate the new vortex flow patterns resulting from an air jet impinging onto a large horizontal heated disk with an upper plate confinement. The commercial computational fluid dynamics software STAR-CD is employed to solve the governing equations of the flow. Attention is focused on the identification of new flow structures other than the circular vortex rolls which are frequently seen in a mixed convective impinging jet. The results from this simulation indicate that the predicted steady vortex flow pattern for the cases with the unheated target plate (Ra = 0) consists of two circular rolls. They are the primary and secondary inertia-driven rolls. When the target disk is heated, the buoyancy-driven vortex flow in the form of regular circular rolls appears near the edge of the disk at low Rayleigh number. At intermediate Rayleigh numbers many buoyancy rolls appear in the region of the space between the target plate and confinement. These rolls are highly deformed. The termination and splitting of the rolls are clearly seen. At a certain high jet Reynolds number the primary inertia-driven roll may split into a number of short radial rolls.

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NOMENCLATURE

D	Disk diameter
D_j	Jet diameter at the injection pipe exit (mm)
g	Gravitational acceleration (m/s^2)
Gr	Grashof number, $g\beta\Delta TH^3/\nu^2$
Gr/Re_j^2	Critical buoyancy-to-inertia ratio for the onset of buoyancy induced roll
H	Distance between the exit of injection pipe and heated plate (mm)
P	Nondimensional pressure
P_{amb}	Pressure of the ambient, 101325 Pa
P_m	Motion pressure
Pr	Prandtl number
p	Dimensional pressure (Pa)
Q_j	Jet flow rate (Standard Liter per Minute, slpm)
r_s	The center of the location of secondary inertia-driven roll (mm)
r, θ, z	Dimensional cylindrical coordinates
R, Θ, Z	Dimensionless cylindrical coordinates, $r/R_c, \theta, z/H$
Ra	Rayleigh number, $g\beta\Delta TH^3/\alpha\nu$
Ra_c	Critical Raleigh number for longitudinal rolls
R_c	Radius of processing chamber (mm)
Re	Reynolds number defined by Santen et al. [21] as $Re = v_r H/\nu$, where $v_r(r,z) = \frac{1}{r}\frac{3Q_j}{\pi H^3} z(H-z)$
Re_j	Jet Reynolds number, $\overline{V_j} D_j/\nu$

Re_H	Local Reynolds number in the wall-jet region, $\bar{u}H/\nu$
S_I	Size of primary inertia-driven roll (mm)
S_O	Size of buoyancy-driven roll (mm)
T	Temperature
T_C	Temperature of the confinement cold wall (℃)
T_{ini}	Temperature of the initial state (℃)
T_H	Temperature of the heated plate (℃)
t, τ	Dimensional (sec.) and dimensionless times
u, v, w	Dimensional velocity components in the radial, azimuthal, and axial directions
$\bar{u}$	Average velocity of the flow at wall-jet region (m/s), $(Re_j D_j \nu)/(8rH)$
U, V, W	Dimensionless velocity components in the radial, azimuthal, and axial directions
V_j	Uniform velocity of the air jet at the injection pipe inlet (m/s)

Greek symbols

α	Thermal diffusivity (cm^2/s)
β	Thermal expansion coefficient (1/K)
ΔT	Temperature difference between the heated disk and the injected air (℃)
ν	Kinematic viscosity (cm^2/s)
Φ	Non-dimensional temperature, $(T-T_j)/(T_f-T_j)$
η, ξ	Nondimensional coordinates in the radial and axial directions
Θ	Nondimensional temperature