Effects of Air Curtains on Momentum, Heat and Mass Transfer in an Open Vertical Refrigerated Display Cabinet- Numerical Simulation

Student ：Yu-Shin Huang　　　　　Advisor ： Tsing-Fa Lin

Department of Mechanical Engineering

National Chiao Tung University

ABSTRACT

A steady two-dimensional numerical simulation is conducted to investigate the momentum, heat and mass transfer in a vertical open cavity resulting from a laminar cold air curtain flowing over the open surface of the cavity, simulating that in a vertical refrigerated display cabinet. The commercial computational fluid dynamics software PHOENICS is adopted to solve the problem. Particular attention is focused on how the parameters associated with the air curtain affect the characteristics of the flow in the cabinet. Computations are performed for the air curtain Reynolds number vanying from 100.5 to 717.8 and the injection slot width ranging from 0.016 to 0.024 m for the air discharge-to-return grille separation distance fixed at 0.2 m and for the cabinet depth of 0.1 m. The temperature difference between the air discharge and ambient is 20 ℃, corresponding to T_j = 5 ℃ and T_{amb} = 25 ℃. The relative humidities at the air discharge and ambient are respectively fixed at 90% and 60%. Effects of various parameters on the flow, thermal and solutal characteristics in the cabinet are examined in detail. Furthermore, we proceed to investigate the possibility of retarding the air curtain bending by inclining the jet at the air discharge grille toward the ambient. Moreover, how the installation of a secondary air curtain affects the flow in the display cabinet is examined. For the limiting case in the absence of the thermal and solutal buoyancy forces, the results indicate that a single large recirculating

vortex is induced by the inertia force of the air curtain for all Re_b. However, when the Richardson numbers (buoyancy to inertia ratio) increases to certain level, the air curtain bends toward the cavity and the intrusion of the warm and humid air from the ambient into the cavity becomes relatively prominent. At the same Gr_t, when the Re_b is lowered to some degree, the air curtain bending is so large and two counter-rotating flow recirculations are induced in the cabinet. However, at the same Re_b, milder air curtain bending and warm air intrusion are noted at reducing the injection width. Besides, inclining the jet toward the ambient can significantly delay the air curtain bending and the distortions in the isotherms and iso-concentration lines. The results from installing a secondary air curtain indicate that at this low V_{2j} the effects of the jet width and location on the flow are rather slight. But at higher V_{2j}, installing the jet some distance away from the cabinet causes a significant bending of the original air curtain. However, installing a high speed secondary air curtain near the cabinet can substantially reduce the bending of the original air curtain and hence improves the cabinet performance.

CONTENTS

LIST OF FIGURES

LIST OF TABLE

NOMENCLATURE

A	Ratio of the discharge to return grille distance to the discharge width $A = H / b_j$
b_j	Jet width at the air curtain discharge (m)
c_p	Specific heat at constant pressure, $J/(kg \cdot K)$
D	Solutal diffusivity, m^2/s
g	Gravitational acceleration (m/s^2)
Gr	Grashof number, $Gr_t = g\beta_t \Delta T H^3 / \nu^2$, $Gr_m = g\beta_m \Delta w_1 H^3 / \nu^2$
GR/Re_b^2	Ratio of thermal buoyancy-to-inertia force, Richardson number
H	Distance between the discharge grilles to return grilles (m)
k	Thermal conductivity
Le	Lewis number, $Le = \nu / \alpha$
N	Buoyancy ratio, $\beta_m (w_{1a} - w_j) / \beta_t (T_{amb} - T_j)$
P	Non-dimensional pressure
p_{amb}	Pressure of the ambient, 101325 Pa
p_m	Motion pressure
Pr	Prandtl number, $Pr = \nu / \alpha$, $Pr_t = \mu_t C_p / k_t$
p	Dimensional pressure (Pa)
x,y	Dimensional Cartesian coordinates
Y^+	Non-dimensional distance from wall in wall coordinates
X,Y	Dimensionless Cartesian coordinates, $x/H, y/H$
Ra	Rayleigh numbers, $Ra_t = g\beta \Delta T H^3 / \alpha\nu$, $Ra_m = g\beta \Delta w_1 H^3 / \alpha\nu$
Re	Reynolds numbers, $Re_b = \bar{V}_j b_j / \nu$, $Re_H = \bar{V}_j H / \nu$

Sc	Schmidt numbers, $Sc = \nu / D$, $Sc_t = \mu_t / \rho D$
T	Temperature
T_C	Temperature of the inner cold plate (℃)
T_j	Temperature of air at the discharge grille (℃)
T_{amb}	Temperature of the ambient surrounding (℃)
t, τ	Dimensional (sec.) and dimensionless times
u, v	Dimensional velocity components
U, V	Dimensionless velocity components
w_1	Mass fraction of moisture
w_{1a}	Mass fraction of moisture of the ambient
w_{1j}	Mass fraction of moisture of the air discharge

Greek symbols

α	Thermal diffusivity of the mixture (cm^2/s)
γ	Jet inclined angle (degree)
ΔT	Temperature difference between the ambient and the air discharge (℃)
Θ	Nondimensional temperature, $\left(\bar{T} - T_C\right) / \left(T_{amb} - T_C\right)$
β_t	Thermal expansion coefficient, ($1/T_0$)
β_m	Concentration expansion coefficient, (M_a/M_v-1)
ν	Kinematic viscosity of the mixture (m^2/s)
ρ	Mass density of the mixture
ε	Turbulence dissipation rate, $N/(sm^2)$
ϕ	Relative humidity
λ_ρ	Ratio of density, ρ / ρ_0

λ_μ	Ratio of dynamic viscosity, μ / μ_0
λ_{cp}	Ratio of specific heat at constant pressure, C_p / C_{p0}
λ_k	Ratio of thermal conductivity, k / k_0
λ_D	Ratio of mass diffusivity, D / D_0

Subscripts

0	At reference condition
a	of air
amb	at ambient condition
j	At air curtain discharge
v	of water vapor
b	Parameters based on air discharge width
H	Parameters based on distance between air discharge to return grilles
i	Inner curtain of double curtain design
o	Outer curtain of double curtain design