A MODEL FOR THE PENETRATION RATE OF A BOUSSINESQ STARTING FORCED PLUME

ADRIAN WING-KEUNG LAW[1], JIAO JIAN AI[2] and S.C.M. YU[2]

[1]School of Civil and Environmental Engineering,
Nanyang Technological University, Singapore 639798
[2]School of Mechanical and Aerospace Engineering,
Nanyang Technological University, Singapore 639798
(e-mail : CWKLAW@ntu.edu.sg)

Abstract

The characteristics of Boussinesq starting forced plumes were investigated in this study. Two distinct periods in the transient plume penetration were identified, namely the Period of Flow Development (PFD) and Period of Developed Flow (PDF). PFD refers to the time period whereby the penetration rate is governed by the complex vortex dynamics initiated by the exit conditions that can include vortex coalescence, vortex leapfrogging, pinching off of the head vortex from the trailing stem and the eventual reconnection. The pinch-off and reconnection leads to an overshoot of the plume front which is a common observation reported in previous studies. The penetration rate in PDF is more predictable and depends on the continuous feeding of buoyancy and momentum into the head vortex by the trailing buoyant-jet stem. Similarity solutions are developed for PDF to describe the temporal variation of the penetration rate, by incorporating the behavior of an isolated buoyant vortex ring and recent laboratory results on the trailing buoyant jet. In particular, the variations of velocity ratios between the head vortex and trailing buoyant jet are analytically computed. To verify the similarity solutions, experiments were conducted on vertical starting forced plumes using planar laser induced fluorescence (PLIF).

REFERENCES

Ai, J.J., Yu, S.C.M., Law, A.W.K. and Chua L.P. (2005a). "Vortex dynamics in starting square water jets." *Phys. Fluids*, 17, 014106, 1-12.

Ai, J.J., Law, A.W.K. and Yu, S.C.M. (2005b). "On Boussinesq and non-Boussinesq starting forced plumes." *Submitted, under review.*

Delichatsios, M.A. (1979). "Time similarity analysis of unsteady buoyant plumes in neutral surroundings." *J. Fluid Mech.*, 93, part2, 241-250.

Gharib, M., Rambod, E., and Shariff, K. (1998). "A universal time scale for vortex ring formation." *J. Fluid Mech.,* 360, 121-140.

Lamb, H., (1932). *Hydrodynamics*. Cambridge University Press.

Middleton, J.H. (1975). "The asymptotic behaviour of a starting plume." *J. Fluid Mech.,* 72 part 4, 753-751.

Morton, B.R. (1959). "Forced plumes." *J. Fluid Mech.*, 5, 151-163.

Morton, B. R., Taylor G. I. and Turner, J. S. (1956). "Turbulent gravitational convection from maintained and instantaneous sources." *Proc. Roy. Soc.*, Series A, 234, 1-23,

Turner, J.S. (1962). "The 'starting plume' in neutral surroundings." *J. Fluid Mech.* 13, 356-368 2.

Wang, H.W. and Law, A.W. K. (2002). "Second-order integral model for a round turbulent buoyant jet." *J. Fluid Mech.,* 459, 397-428.