

Abstract

Thermal plumes are buoyancy-driven flows from localised heating, featuring slender stems capped by mushroom-like vortices. Ubiquitous in natural and engineered systems, they act as coherent structures in convective heat transport. This thesis employs two-dimensional simulations to examine plume behaviour in open and confined domains across laminar to chaotic regimes.

The first part analyses laminar plumes from cylindrical line heat sources for Rayleigh flux numbers $Ra_f = 10^4$ – 10^8 , based on constant heater flux and Prandtl number $Pr = 7$, beginning with a single plume and extending to two plumes with varying separations. Empirical correlations are obtained for cap-tip velocity and heater temperature. Compared to point sources, line-source plumes are less sensitive to Ra_f . Merged plumes from widely spaced sources show enhanced stability due to suppressed vorticity and fluctuations, with increased side mass ejection boosting lateral heat transport at the expense of downstream transport.

The second part investigates the transition of these plumes to chaos under constant temperature heating. As the Rayleigh number (Ra) increases from 10^5 to 10^8 , a bifurcation sequence unfolds: steady flow, Hopf bifurcation at $Ra \approx 6.0 \times 10^6$, pitchfork bifurcation at $Ra \approx 6.7 \times 10^6$, quasiperiodicity at $Ra \approx 1.7 \times 10^7$, and chaos beyond $Ra \approx 5.0 \times 10^7$, delineated through spectral, Lyapunov, and modal analyses. Periodic regimes feature flapping without subharmonics, indicating geometry-driven deviations from flat-surface plumes. Heat transfer scales as $Ra^{1/4}$, while mass transfer follows regime-specific trends.

The final part analyses plume dynamics in a two-dimensional partitioned square cavity heated from below and cooled from above, for $Ra = 10^6$ to 10^9 . Partitions induce thermosiphon loops, promoting plume clustering and wall jets. The constriction gap \mathcal{S} , defined as the distance between the partition tip and the conducting wall, optimally enhances heat transfer within $0.2\delta_{RB} < \mathcal{S} < 0.4\delta_{RB}$, where δ_{RB} is the average thermal boundary layer thickness. Numerical simulations and analytical modelling validate the \mathcal{S}^3 scaling of the Nusselt number for

narrow gaps.

Altogether, this work advances the understanding of plume-driven convection, offering insights for efficient thermal management in natural and engineered systems.