On the characterization of dispersed particle laden turbulent buoyant plume

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Abstract

The vertical release of a lighter buoyant fluid, commonly referred as a plume, into a dense linearly stratified environment is a usual occurrence in atmosphere and ocean. These releases may have heterogeneity in them in form of particles having varied sizes, shapes, and concentrations. Normally, the particle sizes may range from few microns to millimeters, and the concentrations could range from $\phi_v=0.1\text{-}10\%$. Classical models suggest that maximum height of a buoyant plume can be related to the entrainment coefficient, $\alpha$, initial buoyancy flux, $B_0$, and the buoyancy frequency, $N$. However, these models work only for a single-phase plume where the effect of particles is not considered. We experimentally studied the effect of low concentration of particles ($\phi_v < 1\%$) on the plume dynamics. As a first case, spherical particles having dia, $d_p=100\mu\text{m}$ and density, $\rho_p = 2500 \text{ kg/m}^3$ was used.

The results interestingly show that presence of dilute particle concentration changes the plume structure and affects its dynamics. We theoretical determined the critical particle concentration at which the collapse of the plume occurs in the stratified medium and these results were compared with our laboratory experiments. We also observed that dynamics of particle fall-out and re-entrainment of particles from the umbrella (or neutral buoyant layer) cloud leads to the formation of a parabolic cloud below the plume spreading height ($Z_s$) as shown in Fig. 1 & 2. The evolution of the parabolic cloud for three different volume fractions ($0.35\%, 0.5\%$, $0.7\%$) from the experiments were compared with our theoretical model. The theoretical model satisfactorily explained the horizontal extent of the parabolic cloud for different particle volume fractions. The effect of particle concentration on the cone angle of the plume was also investigated. It was
found that the jet cone angle of the particle laden plume was higher than the single-phase plume. Further investigations are in progress to better understand the dynamics of particle-laden plumes.

Fig:1 Parabolic cloud obtained in the experiments.

Fig 2: Measurement of parabolic cloud depth, $L_p$ with radial distance at 80s for three different volume fraction

Keywords: Buoyant plume, Buoyancy frequency, Parabolic cloud, Spreading height.