Abstract

Many natural and technological processes involve spray or cluster of droplets which are subjected to chaotic external environment. Study of the behavior of a single droplet is therefore crucial to understand the dynamics of the entire system.

This thesis describes different types of instabilities induced in acoustically levitated droplets. Acoustic levitation is an excellent method to study droplet dynamics without any surface contamination. Distinct thermal acoustics–induced deformation regimes (ligaments and bubbles) and breakup dynamics are identified in externally heated bicomponent (benzene-dodecane) droplets with a wide variation in volatility of the two components (benzene is significantly more volatile than dodecane). Different modes of instabilities leading to the final atomization and the physical mechanism are explained using governing laws and scaling analyses which are corroborated with the experimental data.

Thermally induced atomization modes are also investigated in contact free nanoparticle laden fuel droplets (alumina in dodecane). Dominance of different break-up modes has been quantified based on the external heat flux, dynamic variation of surface tension, acoustic pressure, and droplet size. The modes of atomization are analyzed and the time scales are estimated using energy balance to determine the criterion suitable for parent droplet rupture. All the different modes of breakup have been well identified in a regime map determined in terms of Weber number and the heat utilization rate (which is defined as the energy utilized for transient heating, vaporization, and boiling).

Evaporation of solvent and agglomeration of particles leads to porous shell formation in acoustically levitated nanosilica droplets (droplets of aqueous silica suspension). Deformation of the surface leading to the buckling phenomena and subsequent development of different final structures are identified under natural drying and laser heating conditions. Effect of addition of surfactants (sodium dodecyl sulphate) and salts (aniline hydrochloride) upon the process of buckling and alteration of the morphological features are explained based on the mechanical properties of the shell formed at the droplet surface and the external heating rates.

Finally, thermally induced instabilities at both the molecular level and macroscopic explosions in MWCNT particle laden contact-less polymer blend droplets are investigated. Rapid phase separation in PS/PVME polymer blends using unique contact free droplet based architecture is performed. De-mixing of homogeneous blends due to inter component dynamic asymmetry is aggravated by the externally supplied heat. Separation of polymer blends is usually investigated in the bulk which is a tedious process and requires several hours for completion. Alternatively, separation in droplet configuration reduces the process timescale by about 3–5 orders due to a constrained micron-sized domain [fast processing and high throughput] while maintaining similar separation morphologies as in the bulk. The effect of heating rates on the phase separation length and timescales are identified. Furthermore, the separation length scale can be precisely controlled across one order by simply tuning the heating rate. The methodology can be scaled up for applications ranging from surface patterning to pharmaceutics. Effects of multi-walled carbon nano tubes (MWCNTs) on the dynamics of phase separation in PS/PVME blend are also investigated. Addition of MWCNTs in the polymer blend delays the separation phenomenon as it interacts with the polymers and alters the stability criteria. The stability of the solution is analyzed using free energy model based on the contribution of the added nano particles and the external heat flux. Furthermore, addition of nano particles also introduces a different mode of instability at higher external heating rates. Heat accumulation due to particles causes boiling of the solvent (toluene) trapped inside the droplet which leads to subsequent explosion of the entire droplet, in addition to the phase separation phenomena (at the microscopic level). Volumetric expansion due to bubble growth leads to the formation of a unique hollow structure which is distinctly different from the globular mass obtained at lower heating rates in droplets or in bulk processing (thin film) techniques.

The different types of instabilities studied in this thesis are observed in many industrial and natural processes. The experimental results corroborated with semi-theoretical explanation provides new physical insights to these processes. Acoustic levitation models real application, such as in combustion system, wherein droplets are subjected to severe environmental conditions (heat, flow and acoustics, among others). Studying the behaviour at a single droplet level can act as a base study towards the understanding of practical cases which involves complicated multi-droplets interaction with the environment. The results of complex thermo-physical interactions at droplet interface are presented in non-dimensional regime plots in this thesis. These plots can act as reference for further investigation into practical complex phenomena.