Micro-total analysis systems (μTAS) have attracted wide attention and are identified as a promising solution for sample transport, filtration, chemical reactions, separation and detection. Despite their popularity, the selection of an appropriate mechanism for droplet transport and coalescence has always been a challenge.

This dissertation investigates the motion of a levitated droplet experimentally and analytically against the Marangoni flow in an immiscible outer fluid at higher speeds than is possible currently. Based on our earlier experiments, when a droplet is released from a height of 1.5 to 4 times its diameter from the liquid surface, it can overcome the impact and stay levitated at the liquid-air interface due to the existence of an air gap between the droplet and the liquid film. In order to explain this behavior of droplet traveling against the counter-current motion, we propose a simple approach: first, the Marangoni convection inside the thin film is considered without the droplet floating on the surface. By using a level-set method and solving the Navier-Stokes equation, the free surface velocity and deformation are calculated. Then, these quantities are used to solve for droplet velocity and drag coefficient simultaneously using a force balance. In order to compare the simulation results, experiments with levitated water droplets on an immiscible carrier liquid, FC43, were conducted for various temperature gradients, and droplet velocities were measured at different locations using high-speed imaging. The experimental results are in good agreement with the developed theoretical model. For a Reynolds number range of 2-32, it is shown that the drag coefficients are up to 66% higher than those for the fully immersed sphere at the same Reynolds numbers. A correlation is proposed to calculate the drag coefficient of levitated droplets for various temperature drops across the channel.

In addition, for the first time, it is shown that it is possible to realize the natural coalescence of droplets through Marangoni effect without any external stimulation, and deliver the coalesced droplet to a certain destination through the use of surface tension gradients. The effects of shape and size on collision outcome are studied. Regions of coalescence and stretching separation of colliding droplets are delineated based on Weber number and impact number. The existence of the transition line between coalescence and stretching separation in this passive mode of transport is similar to what was observed in the literature for forced coalescence at significantly higher Weber numbers. It is also found that a thermocapillary environment improves the mixing process. In order to illustrate and quantify the mixing phenomenon, the droplets dispensed were made of potassium hydroxide and phenolphthalein which is used as a pH indicator. The experiments show the possibility to reach mixing rates as high as 74% within 120 ms. This study offers new insight to thermal coalescence and demonstrates how natural coalescence could be used to transport, mix and collect biochemical assays in an efficient manner. The results can be employed to enhance performance of self-cleaning surfaces, thermal diodes and micro-total analysis systems.