Flow regime of evaporating saline droplet with suspended nanoparticles

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Evaporation of multicomponent droplets has gained much attention nowadays because of their complex flow fields and various deposition patterns. Here we observe strong vortex flows in evaporating sodium chloride (NaCl) saline droplets with suspended alumina oxide (Al_2O_3) nanoparticles. The vortex flows taking place in the saline droplets with nanoparticles is enhanced with the proceeding of evaporation, which is distinctly different from the previously reported case of drying binary mixture droplets with the vortex decaying with time [1,2]. Moreover, such a flow regime occurs neither in the pure water droplet with suspended Al_2O_3 nanoparticles nor in the NaCl salt droplet with fluorescent microspheres. So the vortex flow is speculated to be resulting from the synergic effects of both nanoparticles and the NaCl salt. The objective of our study is to explore the evolution of the vortex flow and its dependence on the salt concentration.

The experiments were carried out in an open condition with the temperature at 22±1℃ and the relative humidity at 55±5%. The experiment setup is shown in Figure 1. Evaporation of the saline nanofluid droplet with 5% NaCl and 0.4 wt. % Al_2O_3 before crystallization from a top view are shown in Figure 2. The evolution of the flow can be roughly divided into two regimes. In Regime I, a Marangoni recirculation loop forms at the center of the droplet as shown in Figure 3. Figure 4 shows the diagram of the vortex flow in the evaporating droplet with 5% NaCl and 0.8 wt. % Al_2O_3 at the early stage of Regime II and the trajectories of particles tracked from the evaporating droplet with 5% NaCl and 0.01 wt. % Al_2O_3. In this regime, the recirculation loop loses its symmetry with its center migrating towards the droplet edge. The recirculation loop then breaks into several small vortex flows at the ultimate stage of evaporation.

The maximum velocity in Regime II of the evaporating droplet with 5% NaCl and 0.01 wt. % Al_2O_3 is obtained based on the particle trajectories with the order of magnitude at 1 mm/s. While the maximum velocity acquired from the analysis of Particle Imaging Velocimetry in the droplet containing 5% NaCl and 0.01 wt. % fluorescent microspheres is at the order of magnitude of 1 μm/s, indicating that the strong vortex do not occur in the saline droplet without nanoparticles. Study on the effect of different salt concentration reveals that with the decrease in the salt concentration, the acceleration of the recirculation loop in Regime I slows down while the droplet tends to generate more small vortex flows at the late evaporation stage before crystallization.

In summary, this study provides an insight into the flow structure in the evaporating saline nanofluid droplet and attempts to explore the effect of salt concentration in driving the flow.

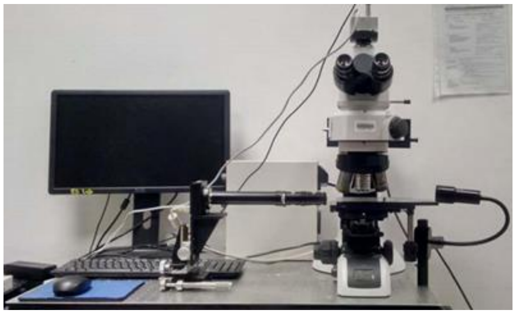

Fig. 1 Experiment setup.

REFERENCES:

[1] Zhong X, Duan F. Flow regime and deposition pattern of evaporating binary mixture droplet suspended with particles[J]. The European Physical Journal E, **2016**, 39(2): 1-6.

[2] Christy J R E, Hamamoto Y, Sefiane K. Flow transition within an evaporating binary mixture sessile drop[J]. Physical review letters, **2011**, 106(20): 205701.

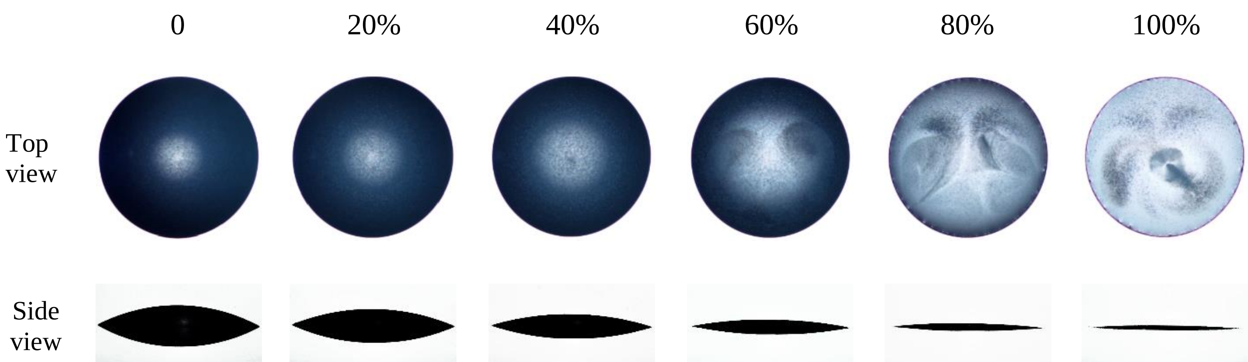

Fig. 2 Drying sequences from the top view and side view of 5% NaCl 0.4 wt.% Al_2O_3 saline nanofluid droplet before crystallization.

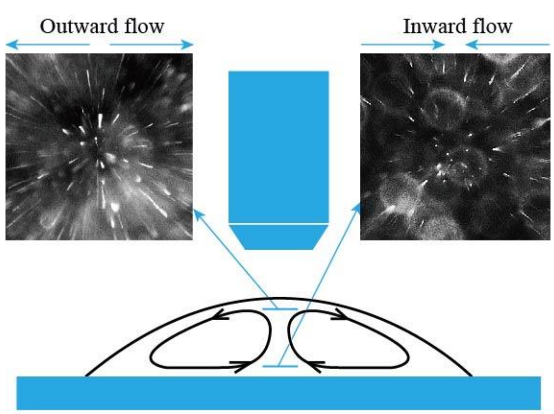

Fig. 3 Regime I: Top and bottom radial flow of the 5% NaCl 0.01 wt. % Al_2O_3 droplet.

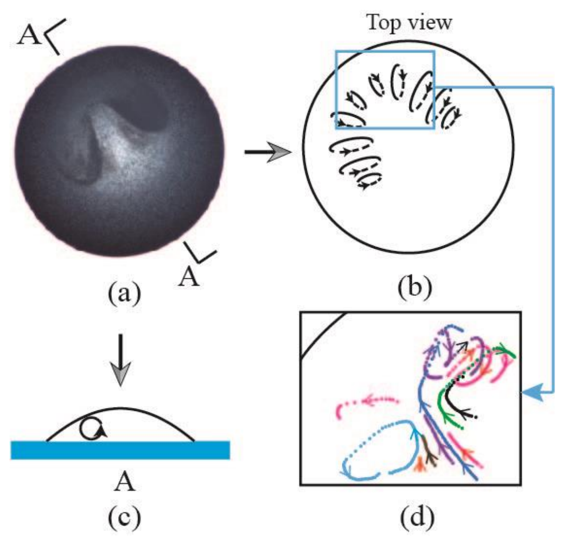

Fig. 4 Regime II: (a) Top view of the evaporating 5% NaCl 0.8 wt. % Al_2O_3 droplet; (b) Sketch map of the vortex flow in Regime II; (c) Cross section sketch map of the vortex flow; (d) Observed trajectories tracked from evaporating droplet of 5% NaCl 0.01 wt. % Al_2O_3 droplet.