

Mechanisms of Vapor Absorption into Hygroscopic Liquid Desiccant Droplets

王, 振英

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氏 名 : 王 振英 (ワン ジェンイン)

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Desiccant Droplets (吸湿性液滴への水蒸気吸収のメカニズム)

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論 文 内 容 の 要 旨

Liquid desiccant is one type of salt solution characterized by its hygroscopic properties, which has been widely applied in the fields of air conditioning, heat recovery, and desalination. This thesis focuses on the physical process of vapor absorption into hygroscopic liquid desiccant droplets. Especially, we reveal the droplet kinetics, the motion of contact line, the heat and mass transfer, as well as the evolution of interfacial parameters of absorptive droplets.

Experiments on hydrophobic and hydrophilic substrates aim to reveal the effect of surface wettability on the droplet behaviors and on the rate of vapor absorption. Results show that droplets grow in a quasi-constant-contact-angle mode on hydrophobic PTFE substrates, while apparent droplet spreading is observed on hydrophilic glass substrates. Moreover, the rate of vapor absorption is higher on hydrophilic substrates than that on hydrophobic ones owing to the apparently shorter characteristic length of solute diffusion within the droplets. Besides, the slowly-spreading phenomena of droplets on hydrophilic glass substrates are explained based on a force balance analysis at the triple contact line, by the evolution of liquid-gas surface tension, and by the development of a precursor film during vapor absorption.

The coupled heat and mass transfer process is then investigated combining optical imaging and infrared thermography. Results show that the droplet experiences the highest temperature right after contacting the substrate owing to the rapid vapor absorption during droplet deposition. The droplet then gradually cools down as a joint result of heat dissipation and decreasing rate of vapor absorption. The vapor pressure difference between the droplet interface and the ambient is further evaluated combining the evolution of interfacial temperature and solute concentration. The results explain the saturation increasing trend of droplet volume along with time for six representative experimental conditions. Besides, a summary is given to elucidate the similarities and differences between droplet evaporation and vapor absorption.

For better understanding the droplet dynamics during vapor absorption/desorption, a lubrication model is developed by direct numerical simulation (DNS), and solved with finite element method (FEM). The model allows for the free motion of contact line with the assumption of a precursor film in front of the droplet bulk. The simulation results reveal the distribution of mass flux across the droplet surface, and also demonstrate the evolutions of droplet profile, interfacial temperature, interfacial water concentration, and surface tension

along with time. We further relate the contact line motion with the decomposed interior flow, which explains the spreading phenomena of hygroscopic droplets on hydrophilic substrates along with vapor absorption and desorption.

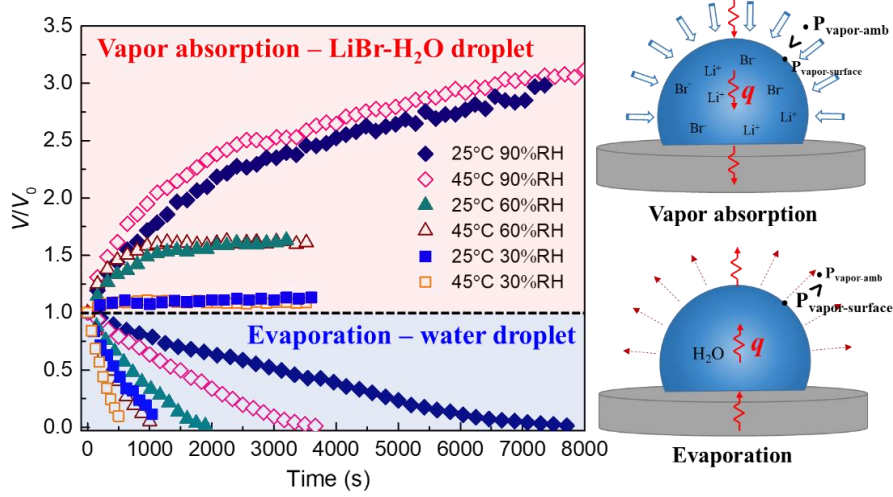


Figure 1 Evolution of non-dimensional droplet volume, V/V_0 , along with time, t (s), during vapor absorption and evaporation.

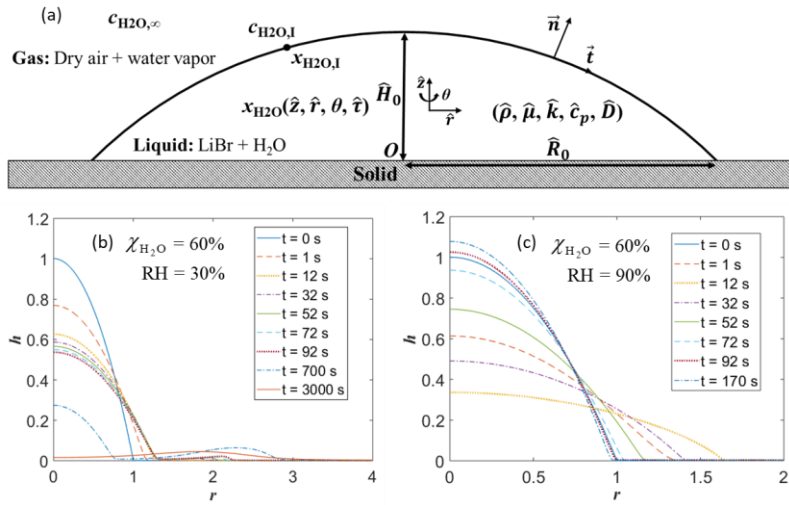


Figure 2 Model development and simulation results: (a) Physical model of a sessile LiBr-H₂O droplet in contact with humid air; (b) Evolution of droplet profile along with vapor desorption; (c) Evolution of droplet profile along with vapor absorption. (h refers to dimensionless droplet height,

$$h = \frac{\hat{h}}{\hat{H}_0}, r \text{ refers to dimensionless contact radius, } r = \frac{\hat{r}}{\hat{R}_0}.)$$