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New Observations on Dropwise Condensation of Moist Air on a Horizontal Superhydrophobic Surface

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Extended Abstract

Superhydrophobic surfaces (SHS) (contact angle > 150° and contact angle hysteresis < 5°) have great importance in dropwise condensation, atmospheric water generation, self-cleaning, and anti-icing [1]. Coalescence-induced droplet jumping during condensation generates a continuous relay of jumped droplets [2], that crawl along the horizontally mounted condensing surface [3][4]. The dynamical stages of coalescence-driven jumping droplets include secondary jumps [5], trigger jumps [6], billiard-induced droplet jumping [7], and in-plane droplet jumping from the sidewalls of the structured surfaces [8]. At a higher degree of subcooling, the jumping droplet changes from a self-propelled mode to forced jumping [9]. Condensation studies of humid air have primarily been performed on nano-textured functionalized non-metallic surfaces. Also, precise control of the dimensions of hierarchical textures on metallic substrates is expensive and restricts scalability beyond the laboratory environment over a longer time duration [10]. Coalescence dynamics have been studied at the initial stages of droplet growth using environmental scanning electron microscopy (ESEM), restricting the vapor pressure to 700-1300 Pa [11].

The objective here is to study the condensation of humid air on a superhydrophobic metallic surface for a longer duration in an open environment. The commercially available copper substrate of size 20 mm × 20 mm × 2 mm is the condensing surface. The substrate is made superhydrophobic using Glaco mirror coat (colloidal solution of SiO_2 in iso-propyl solution). Two T-type thermocouples are embedded sideways in the substrate for measuring the condensing surface temperature. The copper substrate is thermally pasted on an aluminum cooling block. The inlet and exit temperatures of the coolant flowing in the block are measured using T-type thermocouples. The humidity and ambient temperature around the experimental apparatus is measured using TESTO 176H1 humidity sensor. The condensing surface temperature is maintained constant in time using a constant temperature bath at temperatures below the dewpoint. The moisture present in the immediate environment starts to condense as the temperature of the condensing surface falls below the dew point. A Leica M205A stereomicroscope having maximum and minimum resolutions of nearly 0.2 µm/pixel and 4 µm/pixel, respectively is used to record the plan-view of the condensation process. A high-speed camera with 2000 fps and pixel resolution of 1024 × 1024 over the substrate is used to record the side view of the condensation behavior.

Sessile droplets on a Glaco-coated superhydrophobic substrate of copper at a subcooling of 4.8 K form a dropwise condensation pattern in moist air. For an experimental duration of three hours, coalescence-triggered droplet jumping events are identified using a Photron SA3 high-speed camera and droplet distribution patterns are recorded under a Leica stereomicroscope. While previously studied mechanisms of droplet growth and coalescence are visible, the bouncing of droplets is visibly tracked. On returning to the surface, micron-sized drops settle over the larger ones on the millimetric size for an extended length of time. At later times, nucleation of droplets below a grown droplet around the three-phase contact line is also observed. The existing numerical model of droplet condensation does not account for these details. Hence, the observations of the present study have an impact on the modeling of the dropwise condensation process and the determination of condensate productivity.

References

[1] B. El Fil, G. Kini, S. Garimella, A review of dropwise condensation: Theory, modeling, experiments, and applications, Int. J. Heat Mass Transf. 160 (2020). https://doi.org/10.1016/j.ijheatmasstransfer.2020.120172.
[2] C. Lv, P. Hao, Z. Yao, Y. Song, X. Zhang, F. He, Condensation and jumping relay of droplets on lotus leaf, Appl. Phys. Lett. 103 (2013). https://doi.org/10.1063/1.4812976.

[3] Y. Cheng, B. Du, K. Wang, Y. Chen, Z. Lan, Z. Wang, X. Ma, Macrotextures-induced jumping relay of condensate droplets, Appl. Phys. Lett. 114 (2019). https://doi.org/10.1063/1.5082727.

[4] B. Mohammadian, R.K. Annavarapu, A. Raiyan, S.K. Nemani, S. Kim, M. Wang, H. Sojoudi, Delayed Frost Growth on Nanoporous Microstructured Surfaces Utilizing Jumping and Sweeping Condensates, Langmuir 36 (2020) 6635–6650. https://doi.org/10.1021/acs.langmuir.0c00413.

[5] S. Baba, K. Sawada, K. Tanaka, A. Okamoto, Dropwise Condensation on a Hierarchical Nanopillar Structured Surface, Langmuir 36 (2020) 10033–10042. https://doi.org/10.1021/acs.langmuir.0c00950.

[6] S. Wang, W. Zhang, X. Yu, C. Liang, Y. Zhang, Sprayable superhydrophobic nano-chains coating with continuous self-jumping of dew and melting frost, Sci. Rep. 7 (2017) 1–7. https://doi.org/10.1038/srep40300.

[7] J. Xie, J. Xu, Q. Liu, X. Li, Coupling Diffusion Welding Technique and Mesh Screen Creates Heterogeneous Metal Surface for Droplets Array, Adv. Mater. Interfaces 4 (2017) 1–12. https://doi.org/10.1002/admi.201700684.

[8] X. Qu, J.B. Boreyko, F. Liu, R.L. Agapov, N. V. Lavrik, S.T. Retterer, J.J. Feng, C.P. Collier, C.H. Chen, Self-propelled sweeping removal of dropwise condensate, Appl. Phys. Lett. 106 (2015). https://doi.org/10.1063/1. 4921923.

[9] Q. Peng, L. Jia, J. Guo, C. Dang, Y. Ding, L. Yin, Q. Yan, Forced jumping and coalescence-induced sweeping enhanced the dropwise condensation on hierarchically microgrooved superhydrophobic surface, Appl. Phys. Lett. 114 (2019). https://doi.org/10.1063/1.5090360.

[10] J. Ma, S. Sett, H. Cha, X. Yan, N. Miljkovic, Recent developments, challenges, and pathways to stable dropwise condensation: A perspective, Appl. Phys. Lett. 116 (2020). https://doi.org/10.1063/5.0011642.

[11] K. Rykaczewski, J.H.J. Scott, A.G. Fedorov, Electron beam heating effects during environmental scanning electron microscopy imaging of water condensation on superhydrophobic surfaces, Appl. Phys. Lett. 98 (2011). https://doi.org/10.1063/1.3560443.