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Tuned wettability of sol-gel coatings for humid air and saturated vapor condensation

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Saturated vapor and humid air condensation dynamics have a major influence on the efficiency of several industrial applications, ranging from heat exchangers to desalination plants to water harvesting devices. The condensation dynamics can be tuned by controlling how the vapor condenses on the surface, avoiding the formation of a liquid insulating film (filmwise condensation, FWC). The condensation of vapor in a dropwise (DWC) mode can promote an increase in the heat transfer coefficients (HTC) of an order of magnitude respect to FWC. The formation of water droplets instead of liquid films is mainly governed by two parameters, the surface wettability and morphology. The deposition of thin hydrophobic coatings on the hydrophilic metallic surfaces used in industries allows to increase and tune the heat exchange efficiencies.
For these purposes, several hybrid silica sol-gel coatings were deposited on aluminum substrates and their efficiency were studied in custom-made heat exchange apparatus. The sol-gel method is a low-cost and versatile process based on the hydrolysis and condensation of liquid precursors, which react in the solvent environment and gradually lead to the formation of a gel. The films were deposited by dip coating technique on the aluminum substrates and heat treated in an oven furnace at different temperatures, to eliminate the solvent and favor the formation of solid resistant coatings. The surface wettability of the silica coatings was tuned by introducing different organic groups in the silica network, which led to the formation of hybrid organic-inorganic coatings. The presence of organic groups led to the decrease of the surface wettability and favored the formation of water droplets during the vapor condensation. The influence of different types of organic groups (Si-O-R, in which R=Methyl-, Phenyl-, Octyl-) on the thermal efficiency was studied, and the optimization of the films was performed in terms of precursors ratio, baking temperatures, thermal transport barrier and resistance in harsh environment. The film thicknesses were tuned from 200 to 400 nm, to balance the coatings durability in harsh environment and the thermal barrier effect. It was observed that during the saturated vapor condensation tests the HTC of the coatings improved up to 100 kW $m^{-2}K^{-1}$ in heat flux ranges of 100-500 kW m^{-2}. The films were subjected to durability tests at 400 kW m^{-2} and the optimized films were able to maintain DWC for more than 100 h with minimal changes in the condensation mode. Finally, the hysteresis of the water contact angle was found to be a key parameter on promoting the DWC respect to a pure aluminum surface. [1]

[1] *R. Parin et al. Applied Thermal Engineering, 179 (2020) 115718*
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