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Project Title: Understanding the Influence of Contact Angle Hysteresis on Pressure Drop and Heat Transfer Coefficient in Single Phase Flow

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In this project we are investigating the influence of contact angle hysteresis on the slip length, and consequently its influence on the pressure drop and the heat transfer coefficient in single phase flows (e.g., laminar vs. turbulent and polar vs. non-polar liquids) within a tube. Contact angle hysteresis (i.e., difference between the advancing contact angle and receding contact angle) of a liquid droplet on a solid surface is a measure of the surface slipperiness to that liquid.

In year 1 of this project, by systematically tuning various processing conditions (e.g., molecular architecture of the silanes, solvent type, type of catalyzer, molarity of the silane, volume of the catalyzer and the solvent, silanization time, and hydroxylation time) in our acid-catalyzed silanization technique, we varied the contact angle hysteresis of water from 15° to 70° on our modified copper plates. Since measuring slip length with a parallel plate rheometer was not sensitive enough, we have continued to use contact angle hysteresis as a measure of the slipperiness.

In year 2, through significant optimization of coating conditions, we have dip-coated the inner walls of thin and long copper tubes (inner diameter ~5 mm, outer diameter ~5.5 mm, length ~25 cm) to render them slippery (contact angle hysteresis ~15° for water). The coating consisted of a blend of a commercial adhesive (binder) and fluorodecyl POSS (highly fluorinated nanoparticles). In comparison, the inner walls of uncoated copper tubes were non-slippery (contact angle hysteresis ~75° for water). Our intention is to compare the pressure drop and heat transfer coefficient of the coated (low contact angle hysteresis) and uncoated (high contact angle hysteresis) to understand the influence of contact angle hysteresis. Due to the continued difficulties with reproducible measurements of pressure drop and heat transfer coefficient in our group, we are now seeking guidance and collaborating with Dr. Miljkovic at University of Illinois – we are in the process of developing a new rig with a Coriolis flow meter, a highly sensitive Rosemount pressure transducer, and an appropriate pump to conduct the experiments.

The progress in year 2 has been slower than expected because the experiments are a new direction in my research group. And because of this, we requested a no cost extension, which was approved in May 2019. Meanwhile, I (and my research group) moved from Colorado State University to North Carolina State University in July 2019. We are in the process of getting the grant transferred and setting up the new lab so that we can complete the work.

The following journal publications resulted from this grant:

1. W. Wang, H. Vahabi, S. Movafaghi, A. K. Kota, "Superomniphobic Surfaces with Improved Mechanical Durability: Synergy of Hierarchical Texture and Mechanical Interlocking," Advanced Materials Interfaces, 1900538, p. 1, 2019.
2. S. Movafaghi, M. D. Cackovic, W. Wang, H. Vahabi, A. Pendurthi, C. S. Henry, A. K. Kota, "Superomniphobic Papers for On-Paper pH Sensors," Advanced Materials Interfaces, 6, 1900232, p. 1, 2019.

Overall, supported by funding from ACS PRF, we expanded the research in our group to include a new direction – design and characterization of novel surfaces for enhanced heat transfer performance. The students are finding the interdisciplinary nature of the research – including materials science (fabrication and characterization of surfaces) and heat transfer (development of apparatus and measurement of heat transfer metrics) – very exciting. This is allowing crosstalk between the two fields and we hope that it will bridge the knowledge gaps. Further, as a result of this work, our group got more visibility among the nation's experts on heat transfer. This led to a new unfunded collaboration with Prof. Miljkovic at the University of Illinois. The collaboration is already bearing fruit in other areas unrelated to this grant. For example, the collaboration resulted in a joint publication in a prestigious journal (X. Yan, L. Zhang, S. Sett, L. Feng, Z. Huang, H. Vahabi, A. K. Kota, F. Chen, N. Miljkovic, "Droplet jumping: Effects of droplet size, surface structure, pinning, and liquid properties," ACS Nano, 13, p. 1309, 2019) and we anticipate submitting a joint NSF proposal soon.