Abstract
Deformable heat exchangers could provide a multitude of previously untapped advantages ranging from adaptable performance via macroscale, dynamic shape change (akin to dilation/constriction seen in blood vessels) to enhanced heat transfer at thermal interfaces through microscale, surface deformations. So far, making deformable, ‘soft heat exchangers’ (SHXs) has been limited by the low thermal conductivity of materials with suitable mechanical properties. The recent introduction of liquid-metal embedded elastomers by Bartlett et al1 has addressed this need. Specifically, by remaining soft and stretchable despite the addition of filler, these thermally conductive composites provide an ideal material for the new class of “soft thermal systems”, which is introduced in this work. Understanding such thermal systems will be a key element in enabling technology that require high levels of stretchability, such as thermoregulatory garments, soft electronics, wearable electronics, and high-powered robotics. Shape change inherent to SHX operation has the potential to violate many conventional assumptions used in HX design and thus requires the development of new theoretical approaches to predict performance. To create a basis for understanding these devices, this work highlights two sequential studies. First, the effects of transitioning to a surface deformable, SHX under steady state static conditions in the setting of a liquid cooling device for thermoregulation, electronics and robotics applications was explored. In this study, a thermomechanical model was built and validated to predict the thermal performance and a system wide analysis to optimize such devices was carried out. Second, from a more fundamental perspective, the effects of SHXs undergoing transient shape deformation during operation was explored. A phase shift phenomenon in cooling performance dependent on stretch rate, stretch extent and thermal diffusivity was discovered and explained. With the use of a time scale analysis, the extent of quasi-static assumption viability in modeling such systems was quantified and multiple shape modulation regime limits were defined. Finally, nuance considerations and future work of using liquid metal-silicone composites in SHXs were discussed.