Recent Investigations of Liquid Cooled Small-Scale Heat Sinks for High Flux Heat Removal: A Critical Summary of Experimental Data and Modeling Approaches

Heat dissipation from electronic devices is increasingly encountered in the range from 100 to 1000 W/cm2 in devices ranging from processors to power modules to concentrated solar photovoltaics. In that range, cooling with air is increasingly difficult. Indirect liquid cooling, in which liquid is circulated through a small scale heat exchanger or “heat sink” attached to the heat source, is one of the most common emerging thermal management solutions. Over the past five years, the authors’ research group has experimentally and computationally investigated the behavior of a broad class of single and multi-layer single pass parallel flow heat sinks, with single phase and two-phase flow of water. The experimental devices were fabricated from Silicon Carbide using an innovative extrusion free form (EFF) fabrication technique and in copper using conventional machining techniques. In this talk, I will discuss the experimental techniques used and the data obtained in order to characterize their behavior. I will then offer a critical summary of conventional and emerging techniques that have been used for modeling the devices. The conventional techniques include uncoupled finite-resistance or finite volume approaches and coupled conjugate finite volume approaches. It will be shown that conjugate effects are important, but not overwhelmingly so. As such, the data from these studies was used to support the development of a general modified effectiveness-NTU approach that allows the evaluation of these types of heat sinks using well-accepted heat exchanger methodologies. The effectiveness-NTU approach allows the introduction of scaling principles that help to unify our understanding of apparently disparate geometrical heat sink designs, and in particular allow the comparison of deterministic machined designs and non-deterministic structures such as metallic foams. Finally, I will discuss a novel porous media modeling approach using both one- and two-equation formulations to describe the flow and heat transfer in these deterministic heat sinks. We find that one-equation formulations that adopt a local thermal equilibrium (LTE) assumption are generally inaccurate, but two-equation formulations are accurate and robust. By adopting a porous media modeling approach, the parametric order of the problem can be greatly reduced and therefore offers powerful scaling principles. We will show recent results in which the porous media framework has been used to investigate the effects of scale variation on the performance of this type of heat sink. We find that scale variation as suggested by constructal theory may have some merit in the optimal design of these devices.

Friday, September 25, 2009, 2:30 - 4:00 pm,
ICTAS, Room 310
Sponsored by ICTAS

Alfonso Ortega
James R. Birle Professor of Energy Technology
Laboratory for Advanced Thermal and Fluid Systems
Department of Mechanical Engineering
Villanova University

Alfonso Ortega is the James R. Birle Professor of Energy Technology at Villanova University and Associate Dean for Graduate Studies and Research for the College of Engineering. He received his B.S. in 1976 from The University of Texas-El Paso, and his M.S. and Ph.D from Stanford University in 1978 and 1986 respectively, all in Mechanical Engineering. He started his professional career at Sandia National Laboratories in Albuquerque, New Mexico, where he served as a member of the technical staff from 1978-81 and 1986-88, focusing on research in solar and geothermal energy topics. He was on the faculty of Aerospace and Mechanical engineering at The University of Arizona from 1988 to 2005 where he founded and directed the Experimental and Computational Heat Transfer Laboratory. From 2004 to 2006, Dr. Ortega was the Program Director for Thermal Transport and Thermal Processing in the Chemical and Transport Systems Division of The National Science Foundation in Arlington, Virginia, managing a $6.5 million program that awarded in excess of $12 million in grants in emerging areas of thermal science under his tenure. He joined the faculty of Mechanical Engineering at Villanova University in 2005 where he now holds the James R. Birle Endowed Chair in Energy Technology. Dr. Ortega is the Associate Dean for Graduate Studies and Research in the College of Engineering and is responsible for oversight of all graduate educational programs and research initiatives in the College. He is a teacher of the science and design of thermal systems as well as an internationally recognized authority in the cooling of electronic systems. He is the Director of the Laboratory for Advanced Thermal and Fluid Systems where he directs research in the heat transfer and fluid mechanics fundamentals of convective heat transfer in single and two phase flow, especially in problems that arise from the technology of electronics thermal management, gas turbine cooling, and alternative energy technologies. He has supervised nearly 40 M.S. and Ph.D. candidates to degree completion and is the author of over 300 journal and symposia papers. Dr. Ortega is a Fellow of the ASME and is currently Associate Editor of the ASME Journal of Heat Transfer.