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Guest Editorial

Frontiers, Fundamentals, and Future Directions of Transport: From Theory to Applications - A Special Issue Honoring Dr. P. S. Ayyaswamy

Dr. P. S. Ayyaswamy

Dr. P. S. Ayyaswamy, or "Ayya" to his friends and colleagues, came to Columbia University to pursue his graduate studies after receiving a Bachelor's degree from the University of Mysore in 1962. He worked with Professor Harold G. Elrod, Jr., on his Master's thesis on Supercritical Heat Exchangers. After receiving his Master's degree from Columbia, Dr. Ayyaswamy moved to UCLA to pursue his Ph.D. He worked with Professor Ivan Catton on pioneering work in natural convection in rectangular enclosures tilted at arbitrary angles with respect to the gravity vector which is now considered classical in the field. His elegant scaling of Nusselt number for a vertical configuration to various tilted geometries is now commonly employed in industrial practice [1]. After receiving his Ph.D. in 1971, he continued to work at UCLA as a postdoctoral scholar for three years, first with Professor Friedrich H. Busse at the Geophysics and Planetary Physics Institute (Turbulent Flows) and then with Professors David Okrent (Nuclear Reactor Safety) and Donald K. Edwards (Capillary Flows). In 1974, Dr. Ayyaswamy joined the faculty of the University of Pennsylvania where he was appointed as the Asa Whitney Professor of Dynamical Engineering in 1996. In his 44 year career at Penn, he made seminal contributions in as diverse fields as plasma arc heat transfer to biotechnology to nanoscale transport to phase change processes.

Pennsylvania-based Kulicke & Soffa Industries approached Dr. Ayyaswamy to improve their wire-bonding process for making integrated circuit chips. To connect the circuitry in the chip to terminals that connect with an external device is by a process in which a low energy plasma discharge is used to heat and melt the end of a very fine wire forming a ball. This ball is pressed down on a bond pad of a chip with some heat and ultrasonic power to form a "ball or wire bond." Dr. Ayyaswamy, with his long-term collaborator and colleague, late Professor Ira Cohen, launched a comprehensive numerical modeling and experimental effort to improve all the aspects of the wire bonding process. They made fundamental contributions to plasma heat transfer identifying role of electrode polarity [2,3] and numerical methods for three-phase moving interface problems [4] and dramatically changed the wire bonding process.

Dr. Ayyaswamy is world renowned for his work on moving fluid particles that experience a thermodynamic phase change at the interface. His monograph on the subject of drops and bubbles [5] is now a standard in the field. He identified a new singularity that accounts for both the inertial and the viscous forces together with phase change at the interface and displays Stokeslet-like characteristics at infinity [6]. Also, he examined a range of Reynolds numbers that cover diverse applications as in process industries, nuclear reactor containment spray systems, the atmospheric sciences and climate physics, the aerosol sciences, and droplet studies under microgravity conditions [7,8].

He developed long term, intellectually enriching collaborations with his colleagues (Dr. Ravi Radhakrishnan in SEAS and Dr. David Eckmann in Penn Medicine) that have resulted in major advances at the interface of engineering and medicine and secured large-scale research funding from government agencies (NIH, NSF, NASA, and ONR). Dr. Ayyaswamy developed a new numerical technique by significantly modifying front tracking method and used it to investigate the effect of a soluble surfactant on a gas embolism bubble in a blood vessel [9]. The study revealed a new mechanism of shear stress induced endothelial cell injury associated with gas embolism [10] and produced major advances toward surfactant-based intervention for gas embolism treatment. Earlier, he developed and described scaling laws for the local temperature fluctuations near isolated and counter current thermally significant blood vessels during hyperthermia providing important input to the use of thermal techniques in the treatment of cancer with local hyperthermia [11]. He received two patents for his discoveries of new bioactive degradable hollow spherical microcarriers that support 3D bone cell culture that generate differentiated bone-like tissue structures in cell culture within cylindrical rotating wall bio reactors [12,13].

His recent noteworthy contributions are in targeted drug delivery using functionalized nanocarriers (NCs) coated with specific targeting ligands in therapeutic and diagnostic applications. A wide range of length and time scales are required for describing the physics of hydrodynamic and microscopic molecular interactions mediating NC motion in blood flow and endothelial cell binding in targeted drug delivery. Dr. Ayyaswamy and his collaborators developed new computational techniques for investigating this problem by bridging the relevant multiple scales to create a major impact in the areas of in silico systems pharmacology. They were able to make significant advances in understanding the complex interactions of molecular dynamics, mesoscale binding interactions, and hydrodynamics governing deformable NC transport in a non-Newtonian fluid medium and cellular adhesion [14]. Dr. Ayyaswamy demonstrated why this level of analysis is essential for establishing multiscale computation as a means of optimizing endothelial-targeted, NC-based drug delivery, by directing pharmacological experiments in vitro and in vivo, and by serving as an indispensable platform for NC design and optimization for clinical applications [15].

Dr. Ayyaswamy's research contributions are recognized by numerous awards including distinction of Fellow (1990) by ASME, Aerospace Professional of the Year by AIAA (1997), the Heat Transfer Memorial Award (2001), Worcester Reed Warner Medal (2007) for "outstanding contributions to the permanent literature of engineering," and the 75th Anniversary Medal of the

ASME Heat Transfer Division (2013). In 2014, AIChE and ASME jointly conferred upon him the highest award in the field of heat transfer, the Max Jakob Memorial Award, which "recognizes an eminent scholarly achievement and distinguished leadership in the field of heat transfer." His alma mater honored him with the UCLA Engineering Alumni Professional Achievement Award in 2017. He was elected as ASME Honorary Member in 2018.

Dr. Ayyawamy is known as an excellent teacher and an outstanding mentor to his graduate and undergraduate students. He received the Reid Warren Award (1978) and the Lindback Award (1979) for Distinguished Teaching from Penn and Outstanding Faculty Advisor Award from ASME (1979). He not only mentored his doctoral students in their professional career but also many young Ph.D. students in heat transfer who joined academia. He has extensive involvement in ASME through HTD K-3 and K-17 committees, two terms as associate editor (1997–2000, 2001–2004) and currently the Chief Technical Editor of the ASME Journal of Heat Transfer (2016–2021). He has been an invited member of the National Research Council of the National Academies Committee for NASA Strategic Roadmap and NAE Benchmarking to determine the best of the best researchers in Mechanical Engineering. He was elected to the Governing Board of American Society for Gravitational and Space Research in 2014. He has also served as an Expert Consultant to NASDA and United Nations Expert and as a Consultant for Engineering and Technology, UNIDO, Vienna, Austria.

A symposium honoring Dr. P. S. Ayyaswamy was held at the University of Pennsylvania in May 2018. Many luminaries in the fields of heat transfer, fluid dynamics, bio heat/mass transfer, and biotechnology contributed papers in this issue from their presentations at the symposium. The papers in this special issue cover a vast range of topics from interfacial transport to boiling to mass transfer in biological systems. These papers are a tribute to Professor Ayyaswamy's lasting contributions to diverse fields in fluid dynamics, heat and mass transfer and serve to celebrate and recognize his long lasting impact on extending frontiers of thermal-fluids science.

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