ME – MTech(Res) Thesis Defense

Analysis of free convection heat transfer over smooth and rough surfaces

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ABSTRACT

Heat transfer in flows created by buoyancy, or natural convection, is a widely studied topic across various disciplines spanning the natural flows as well as those with engineering applications. The convective heat transfer rate on a surface is commonly represented by the Nusselt number (Nu), a ratio of convective to diffusive transport, expressed often as $Ra^n Pr^m$, where Ra is the Rayleigh number, the buoyancy forcing parameter, and Pr the Prandtl number. Motivated by the observation that $n \sim 1/3$ for turbulent convection, which implies the heat flux is independent of the length scale (L, characteristic length related to the geometry), an alternate and physically more meaningful non-dimensional heat transfer parameter, denoted by C_q, is proposed. C_q is derived using only the near wall variables, and does not contain L. For $n = 1/3$, C_q is constant. Even for laminar convection, where $n \sim 1/4$, $C_q \sim Ra^{-1/12}$, and is a weak function of Ra. We show that the heat transfer data for natural convection over several geometries the C_q values lie in a small range; the same data in terms of Nu varies over orders of magnitude. The different geometries include Rayleigh-Benard Convection (RBC), free convection over horizontal and vertical flat (plates, discs) and curved surfaces (cylinders, spheres).We also show that C_q is analogous to the non-dimensional representation of wall shear stress, skin friction coefficient C_f.We believe that just like C_f, C_q will be an equally useful non-dimensional measure of heat transfer in natural convection flows. In the second part of the thesis, reported experimental heat transfer data for RBC with rough walls is analysed in terms of C_q. The available data is for two surface roughness geometries: pyramidal and cuboidal. The available heat transfer data for rough RBC is plotted in terms of C_q, both based on the planform area (C_{q-p}) and the total surface area (C_{q-t}) against different non-dimensional parameters. These parameters, newly introduced in this study, include Rayleigh numbers based on the roughness length scales, roughness height (Ra_h), and roughness spacing (Ra_λ). The introduction of these parameters enables a more comprehensive analysis of heat transfer mechanisms in rough-walled RBC. Importantly, the analysis reveals that the variation in C_q across these parameters remains significantly smaller when compared to the variation observed in the Nusselt number Nu. Nu exhibits large variations across different conditions and geometries, which are difficult to interpret, while C_q demonstrates remarkable consistency, emphasizing its robustness as a universal and physically meaningful measure for characterizing heat transfer in natural convection. This reduced variation makes C_q particularly advantageous for identifying underlying trends and understanding the effects of surface roughness on the heat transfer. C_{q-p} directly gives the enhancement in heat transfer due to roughness, and C_{q-t} the heat transfer per unit surface area. There seems to be an upper bound on the value of C_{q-t} equal to about 0.2. Additionally, we examine the variation of the Deardorff velocity, which characterizes the strength of the outer circulation, representing the large-scale flow in RBC, and compare it with the experimentally determined characteristic velocity (V_{osc}) of large-scale circulation [Wei et al. (2014) and Xie et al. (2017)], obtained from large eddy turnover time measurements. The ratio of the Deardorff velocity to V_{osc} consistently falls within the range of 0.55 to 0.65, demonstrating that this scaling is applicable to both smooth and rough-walled RBC.

ABOUT THE SPEAKER

Omshree Mahapatra is a M.Tech (Res) student in the Department of Mechanical Engineering working with Prof. Gaurav Tomar and Prof. Jaywant Arakeri at Indian Institute of Science (IISc) Bengaluru. Her research interests include convective heat transfer and fluid mechanics.