Volume-Adjusted Thermal Analysis Of Convective-Radiative Pin Fins In Motion Using Wavelets

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ABSTRACT

We consider heat transfer with convection and radiation effect on continuously moving fully wet pin fins of different profiles, namely cylindrical, concave parabolic, conical, and convex parabolic pin fins. All these fins with varying degrees of concavity and convexity are modeled so that they are attached to a primary surface from which heat is transferred and consume the same area of the primary surface. The base heat transfer rates for all the fins and their thermal profiles and fin efficiencies are found. The volume-adjusted base heat transfer rate is also calculated. Heat transfer at the sharp tip is negligible, so we resort to the adiabatic tip condition, which poses a challenge for the highly nonlinear governing equation to be solved numerically. Wavelets help us handle the nonlinear equation effectively, and we utilize the continuous Taylor wavelet in due process. Further validation of the result obtained is carried out with the help of the discrete Haar wavelets and the finite difference scheme. The impact of the critical dimensionless parameters on the thermal profile of the fin, the base heat transfer rate, the volume-adjusted base heat transfer rate, fin efficiency, and the fin tip temperature are analyzed graphically. The quantitative influence of the variation in the parameters on the thermal profile, heat transfer rate, and fin efficiency are discussed in detail. Peclet number improves the thermal profile and fin efficiency but also deteriorates the base heat transfer rate for all fin profiles. The volume-adjusted base heat transfer rate drop with an increase in the Peclet number is more significant in convex profiled fins than in concave profiled fins.

1. INTRODUCTION

Heat transfer coefficient, surface area, and temperature difference between the surface and surrounding fluid all affect how quickly heat is transferred from a surface through convection and radiation processes. The other two being fixed, the surface area can be increased artificially to maximize the heat transfer, resulting in extended surfaces or fin structures. These extended surfaces enrich the heat transfer from the primary surface into the ambient fluid. Fins are employed in various day-to-day applications ranging from automobiles, heat exchangers in the industry, refrigerators, electric and electronic components, etc., to achieve a faster exchange of heat and thus enhance the performance of the systems. Owing to its larger practical applications, the extended surface technology continues to attract researchers to meet evolving needs.

2. PHYSICAL DESCRIPTION OF THE MODEL

Pin fins of length L, depicted in Figure 1, are considered. They are mounted on a primary surface at a temperature T_b and are fully wetted with a fluid at a temperature T_a. Either the fins are considered to be in a uniform motion with a velocity U along the horizontal axis, or the ambient fluid flows with the said uniform velocity along the stationary fins. The heat entering the fins at the base is lost to the ambiance by radiation and convection, and the heat transfer within the fin is one-dimensional. The extended surfaces and the ambient fluid are now in thermal equilibrium. $b = 0$ gives the cylindrical profile; the concave parabolic profiles are obtained for $0 < b < 1$; with $b = 1$ depicting a conical profile; convex parabolic profiles are a consequence of $b > 1$.

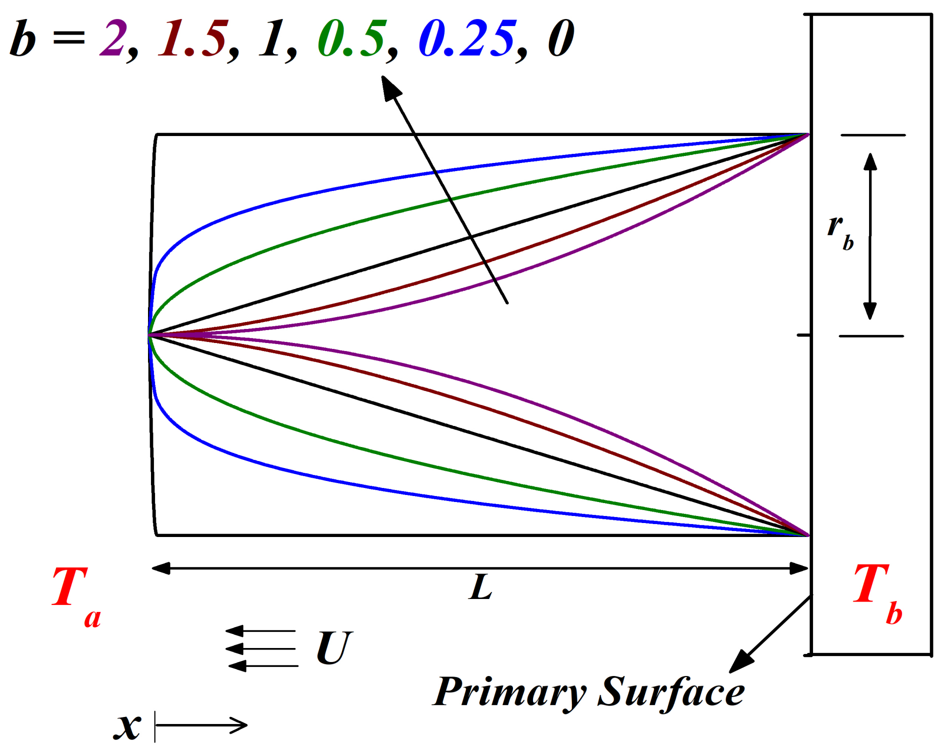

Figure 1 Longitudinal fin of trapezoidal profile

3. SOLUTION METHODOLOGY

The primary energy balance equation describing the physical model is nondimensionalized, and the resultant ordinary differential equation, which is a nonlinear boundary value problem, is solved numerically by the Taylor wavelet collocation method(TWCM) and further validated by the Haar wavelet collocation method(HWCM) and the finite difference method(FDM). The unknown function's highest-order derivative in the differential equation is expressed as a linear combination of the wavelets. Upon integration, the unknown function and its derivatives are obtained in terms of the wavelets and their integrals. These, when substituted in the given differential equation, result in a system of algebraic equations, which is then solved for the coefficients with which the solution of the highly nonlinear differential equation is obtained. Wavelets effectively handle the adiabatic condition imposed at the sharp tip in our model, where most numerical methods fail. The thermal profile is verified for a limiting case by comparing it with the HWCM result in the literature. The integrals involving the unknown functions in computing the fin efficiency are evaluated using the Simpson's $1/3^{rd}$ −rule.

4. IMPORTANT FINDINGS

The thermal profile, the base heat transfer rate, the volume-adjusted base heat transfer rate, and the fin efficiency are all obtained using the TWCM and are extensively compared with that obtained by the HWCM and the FDM. They are in excellent agreement. The thermal profile and the fin tip temperature drop with an increase in the curvature parameter from cylindrical $(b = 0)$ to concave parabolic$(0 < b < 1)$ to conical$(b = 1)$ to convex parabolic$(b > 1)$. The base heat transfer rate(Q) drops during this transition, but the volume-adjusted base heat transfer rate(Q_V) increases significantly.

With an increase in the velocity(Pe) of relative motion between these fins and the ambient fluid, the thermal profile is enhanced, but both Q and Q_V decreases. The drop in Q is larger in concave profiled fins in comparison with that of convex profiled but is the other way for Q_V. The ambient temperature and the coefficient of convective heat transfer are found to have a similar effect on the thermal profiles and the base heat transfer rates.

The convection, radiation, and wet parameters negatively affect the thermal profile and shoot the base heat transfer rate. Though Q increases nearly at the same rate for all the profiled fins we consider, Q_V increases at a faster rate for convex profiled ones than the concave profiled ones with the increase in these parameters.

The fin efficiency increases with the increase in the relative velocity and the coefficient of convective heat transfer, and it drops significantly when either the convection parameter, the radiation parameter, or the wet parameter is increased.