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ORGINAL ARTICLE

Convective-radiative fin with temperature dependent thermal conductivity, heat transfer coefficient and wavelength dependent surface emissivity

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Abstract In this paper, we have studied heat transfer process in a continuously moving fin whose thermal conductivity, heat transfer coefficient varies with temperature and surface emissivity varies with temperature and wavelength. Heat transfer coefficient is assumed to be a power law type form where exponent represent different types of convection, nucleate boiling, condensation, radiation etc. The thermal conductivity is assumed to be a linear and quadratic function of temperature. Exact solution obtained in case of temperature independent thermal conductivity and in absence of radiation conduction parameter is compared with those obtained by present method and is same up to ten decimal places. The whole analysis is presented in dimensionless form and the effect of variability of several parameters namely convection-conduction, radiation-conduction, thermal conductivity, emissivity, convection sink temperature, radiation sink temperature and exponent on the temperature distribution in fin and surface heat loss are studied and discussed in detail.

1. Introduction

In mechanical process heat is generated in machines. The significant question arises here is that how to release this heat in environment. Fins or extended surfaces are used to release heat in environment. In many industrial applications such as hot rolling, optical fiber and casting, exchange of heat with the

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Nomenclature

A_c	cross section area of fin (unit: m^2)
C_p	specific heat of the material (unit: $J/(kg \cdot K)$)
C_0	speed of light (unit: m/s)
h	convection heat transfer coefficient (unit: $W/(m^2 \cdot K)$)
h_b	convection heat transfer coefficient at the base (unit: $W/(m^2 \cdot K)$)
h_p	plank constant (unit: $J \cdot s$)
$k(T)$	temperature-dependent thermal conductivity (unit: $W/(m \cdot K)$)
k_a	thermal conductivity at the convection sink temperature T_a (unit: $W/(m \cdot K)$)
L	fin length (unit: m)
P	fin perimeter (unit: m)
q	surface heat loss by combined convection and radiation (unit: W)
T	local fin temperature (unit: K)
T_a	convection sink temperature (unit: K)
T_b	fin base temperature (unit: K)
T_s	sink temperature for radiation (unit: K)
U	speed of moving fin (unit: m/s)
x	axial distance measured from the base of fin (unit: m)

Dimensionless parameters

A	thermal conductivity parameter
B	surface emissivity parameter, when surface emissivity depend on temperature
exp	exponential function
Nc	convection-conduction parameter
Nr	radiation-conduction parameter
Pe	Peclet number
Q	surface heat loss, dimensionless
Q_a	advection component of heat loss
Q_c	base heat conduction
X	axial distance measured from the base of fin

Greek symbols

β	measure of surface emissivity variation with temperature (unit: K^{-1})
ε	fin surface emissivity dimensionless
ε_s	surface emissivity at the radiation sink temperature T_s
λ	wavelength (unit: m)
θ	dimensionless temperature
θ_a	dimensionless convection sink temperature
θ_s	dimensionless radiation sink temperature
ρ	density of material (unit: kg/m^3)
σ	Stefan-Boltzmann constant (unit: $W/(m^3 \cdot K^4)$)

ambient while it is in continuous motion. The book written by A.D. Kraus et al. [1] provides knowledge about different type extended surfaces and used power law type heat transfer coefficient in chapter 18. Heaslet and Lomax [2] first analyzed radiating fins with variable thermal conductivity and variable emissivity on the fin faces. They considered longitudinal fins of rectangular profile. Stockman and Kramer [3] studied one dimensional heat flow in fin and tube configuration, and considered the variation of thermal conductivity and emissivity as linear functions of temperature. Campo and Wolko [4] studied rectangular fin with power law type variations in thermal conductivity and emissivity with temperature as $k = k_0 T^n$, $\varepsilon = \varepsilon_0 T^m$. They considered fin with constant base temperature and insulated tip.

Jaluria and Singh [5] modeled such a problem and solved it numerically. They studied the effect of Biot number and Peclet number on temperature distribution in the material and the surface heat loss. Karwe and Jaluriya [6] used Crank-Nicolson finite difference method to compute the temperature fields in the fluid and in the moving material. Choudhury and Jaluria [7] found a double series solution for the two dimensional, transient temperature distributions in a moving rod or a plate moving with a constant speed and losing heat by convection to the ambient fluid through a constant heat transfer coefficient. Aziz and Lopez [8] studied the heat transfer process in a continuously moving sheet or rod of variable thermal conductivity that releases heat by simultaneous convection and radiation. They solved this problem using Runge-Kutta-Fehlberg method and effect of several parameters was studied in detail.

Aziz and Khani [9] studied convection-radiation of a continuously moving fin of variable thermal conductivity. They solved this problem using homotopy analysis method and analysed the effect of several parameters. Torabi et al. [10] studied heat transfer in a moving fin with variable thermal conductivity, which releases heat by simultaneous convection and radiation to its surroundings. Differential Transform Method was used in solution and the effects of several parameters were also studied. Aziz and Torabi [11] studied convective-radiative fin with thermal conductivity and surface emissivity as a linear function of temperature, and also studied heat transfer coefficient as power law type form of temperature. The Runge-Kutta-Fehlberg method of fourth and fifth order was used in solution [11]. Shukla [12] studied the temperature distribution in a sublimation-cooled coated cylinder in convective and radiative environments. Torabi and Yaghoobi [13], studied heat transfer in straight fin with a step thickness and thermal conductivity considered as temperature dependent. Differential transform method (DTM) and variational iteration method (VIM) have been used in the solution. They conclude that DTM results are more accurate in comparison to VIM and HPM.