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An exploration of thermal characteristics of a permeable inclined moving inverted exponential fully wet magnetized stretching/shrinking fin

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Abstract

The effective cooling technology aims at removing the excess heat from the thermal components, equipment, and systems by ensuring their reliable operation and proper functioning. The fins play a vital role in such phenomena among various passive and active cooling options. In the present work, the thermal performance of a magnetized, fully wet, moving, porous, convective-radiative longitudinal inverted exponential oblique fin subjected to a shrinking/stretching mechanism is investigated numerically. The problem is modeled as a second-order non-linear ordinary differential equation, which is transformed into a non-dimensional equation, and using bvp4c of MATLAB, a numerical solution is obtained. The impacts of geometric and flow factors such as Hartmann number, wet porous parameter, Peclet number, stretching/shrinking parameter, etc., on the thermal characteristics and fin's base heat transfer rate are analyzed, and the results are presented graphically. It is also inferred that the Peclet number, wet porous parameter, thermal conductivity parameter, and convective sink temperature accelerate heat transfer, whereas the Hartmann number and radiation number decelerates heat transfer. Further, shrinking intensifies the cooling than stagnant and stretching mechanisms. The current examinations set a platform for the engineers to design an efficient fin in heat transfer devices functioning under the influence of an active magnetic field set with a mechanism like a conveyor belt.

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1. Introduction

Fins, also known as extended surfaces, are widely used to enhance heat transfer in various thermal systems. A fin is a structural projection from a surface that increases the effective surface area available for heat dissipation. The primary purpose of a fin is to improve heat transfer by facilitating greater contact with the surrounding fluid, whether air, water, or another medium. The effectiveness of fin depends on three key factors *i) Temperature Difference*: The rate of heat transfer is directly proportional to the temperature difference between the surface and the surrounding fluid. A higher temperature gradient results in more efficient heat dissipation. *ii) Surface Area*: Increasing the surface area enables the fins to achieve greater interaction with the surrounding fluid, thereby improving heat transfer. *iii) Heat Transfer Coefficient*: This parameter repre-

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sents the ability of the fluid to carry away heat from the surface. Materials with high thermal conductivity and fluids with strong convective properties contribute to better performance.

Fins are commonly employed in applications like heat exchangers, radiators, electronic cooling systems, and engine components to ensure efficient thermal management. Their design and material selection are critical to optimizing the performance based on specific operational requirements. Researchers have extensively studied fin design to optimize thermal performance by considering critical factors such as *geometry,* i.e., different shapes, such as straight, pin, annular, and triangular fins, and *materials,* i.e., high thermal conductivity materials like aluminum, copper, and advanced composites are commonly chosen to improve heat dissipation. Material properties such as weight, cost, and durability are also factored into the selection process, especially for applications in aerospace, automotive, and electronics; finally, *operating conditions*, i.e., parameters like fluid flow rate, temperature gradient, and environmental factors. Fin efficiency, temperature, and heat transfer rate could be impacted by mechanisms like stretching, shrinking, and magnetizing. Shrinking and magnetizing enhance the fin's efficiency, while stretching depletes the efficiency.

Owing to this, fins are used to regulate the heat in a wide range of applications. Electronic devices, including computers and electrical devices such as substation transformers and power plants, primarily use fins. It is also utilized in IC engine cooling systems, like radiators in automobiles. The idea of finned surfaces, fin performance, and designs taking heat transfer functions into consideration was presented by Kraus *et al.* [1]. Çengel and Ghajar [2] outlined the fundamentals of heat transport in his book. The concepts of convection, heat exchange, radiation, electronic equipment cooling, mass transport, etc. were explained by Çengel and Ghajar [2]. Descriptions about the feeling of grasping real-world issues and the underlying physical processes were also highlighted by Çengel and Ghajar [2]. The penetrable fin gives up the traditional solid with an increase in the surface area-to-volume ratio, according to Kiwan's [3] modeling of the natural convective porous fin problem via Darcy's formulation. Gireesha and Sowmya [4] have investigated the thermal performance of an inclined porous fin having a longitudinal profile in the presence of convection and radiation effects. A comparison of the solution obtained by a semi-analytical method, namely, the Adomian decomposition method, with a strong numerical method, namely, the Runge-Kutta-Fehlberg method, has been presented. They have concluded that the thermo-geometric parameter and radiative parameter augment the rate of heat transfer from the fin surface.

Further, research interest in the study of the thermal conductivity of constantly moving surfaces, such as casting, hot rolling, extrusion, glass sheet or wire drawing, and powder metallurgy processes for rod and sheet fabrication, has also risen. In each of these processes, heat exchange between the fixed or moving component and its surroundings is typically present. Because of the adaptable and broad range of uses, the continuous moving fin has been the subject of substantial research. Consequently, a large number of studies on the thermal analysis of moving fins have been presented in earlier research. Torabi *et al.* [5], Singh *et al.* [6], and Sobamowo *et al.* [7] studies explained the thermal properties of the moving fin. Recently, Sobamowo *et al.* [8] investigated the impact of the Peclet number on the thermal efficiency of the internally heated movable fin. Parvinder and Surjan [9] presented the detailed study of a convective and radiative movable fin having a heat transfer coefficient that is dependent on temperature, internal heat generation, and thermal conductivity. A semi-analytical analysis of heat transfer in a radiative moving fin that is accompanied by tri-hybrid nanofluid is reviewed by Pavithra *et al.* [10]. Therefore, scanning through the major published works as presented in literature, the discussion on the thermal responses of moving fins, which is affected by the Peclet number, seems significant.

In many engineering applications, excessive heat generation in thermal devices is inevitable. The performance and functionality of such components may be adversely affected by this extreme heat. Therefore, the employment of suitable cooling technology is necessary for the dependable operation of such components. Fins or extended surfaces are essential for accelerating the rate of heat transmission, despite the fact that many cooling methods have been used for a long time to eliminate heat. An exhaustive attempt has been made by Torabi and Aziz [11] to compile the developments in the field of extended surface technology. Torabi and Aziz [11] have scrutinized a T-shaped fin by making an allowance for non-uniformity of convective, conductive, and radiative heat transfer coefficients; hence, they reported that the fin efficiency is strongly guided by the dependence of these parameters on temperature distribution. Many researchers have always looked for novel ways to enhance their efficiency and model them to be more adaptable to meet the demands of the sectors because of their extensive use in industry.

The rate of fin heat transfer is accelerated by the radiative environment, according to research by Gorla and Bakier [12], who calculated the amount of heat loss of the porous fin due to convection and radiation. In addition to internal heat generation, the effectiveness of a totally damp porous convective-radiative movable radial fin along with shape-dependent hybrid nanofluid was investigated numerically by Keerthi *et al.* [13]. Later, Pavan Kumar *et al.* [14] examined the transient heat transfer properties of a convective–radiative longitudinal porous fin completely wetted in hybrid nanofluid.

A significant amount of study has been done on the impact of the intrinsic nonlinearities in the created thermal models (caused by their thermal characteristics) on the pliable components' thermal efficiency. In addition to this, employing the magnetic field to the stretching/shrinking fin enhances the heat transmission rate. Using the least squares approach, Hoshyar *et al.* [15] investigated a fin system with porosity in the presence of an active magnetic field. The results showed that improving the heat dissipation process was facilitated by an increase in the magnetic field. Oguntala *et al.* [16] analyzed the fin problem subject to the magnetic environment using an iterative technique and numerically confirmed the conclusions they obtained. The study found that the fin's thermal characteristics were positively impacted by the magnetic field.

Kundu *et al.* [17] examined the distinctive arrangement of two principal surfaces situated at the fin structure's terminals and looked into the time-variant behavior in a damp fin formation. This arrangement demonstrated how wet fin structures could improve heat transmission. In order to reveal the combined effect of heat retentiveness and magnetism, Das and Kundu [18] looked into the heat distributed on a permeable radiating fin. Investigating the radiating porous fin's surface temperature response to the magnetic field and heat retentiveness was the main goal of the study. The thermal performance of a porous fin having a radiating design surrounded by the active magnetic field was investigated numerically by Gireesha *et al.* [19]. They discovered that the heat transfer rate from the radiating porous fin's surface was amplified by the Hartmann number, which is a representation of the magnetic effect. Considering the linear and nonlinear temperature-dependent thermal conductivities, Sowmya *et al.* [20] investigated the convection, internal heat generation, and radiant heat transference of an unfixed rod. Girish *et al.* [21] have performed a comparative study of the thermal variations in a dovetail and exponential fin, considering fully wet conditions, ternary nanofluid, and internal heat generation in the form of both linear and nonlinear functions under the influence of a magnetic field using the differential transformation method (DTM). The findings indicate that ternary nanoliquid exhibits a higher thermal response compared to nano- and hybrid nanoliquid. Abdulrahman *et al.* [22] have studied the steady-state thermal distribution and heat transfer within a longitudinal porous fin of exponential profile wetted with hybrid nanoliquid subject to conduction, radiation, and convection. It is inferred that the surface wet condition by hybrid nonliquid and porous nature of the exponential fin will have a significant effect on the temperature distribution.

Hence, a meticulous review of the literature reveals that no earlier studies have addressed the issue of analyzing the thermal performance of shrinking/stretching magnetized porous fully wet moving convective and radiative transposed exponential fins by modeling the thermal conductivity as an exponential function of temperature, where the fin is connected to the prime prime surface obliquely. Fin generally operates in relatively high temperatures, so the assumption of thermal conductivity as a temperature-dependent linear function is inadequate to predict the heat transfer through fin effectively. The novelty of the present work is to model thermal conductivity as a temperature-dependent exponential function and is the motivation for the current work.

2. Mathematical formulation

Consider a convective-radiative longitudinal inverted exponential, moving, fully wet, porous fin, where thermal conductivity varies exponentially with temperature, subject to an external constraint of applied magnetic field as conveyed in Figure 1. Let L, W and t_b respectively be the length, width and base thickness of the fin which is attached obliquely with an angle of inclination τ to the horizontal axis with the temperature of the base being T_b. Heat is released from the fin to the surrounding by radiation and convection, where the surrounding temperature is T_a and the solid permeable fin model is completely moisten

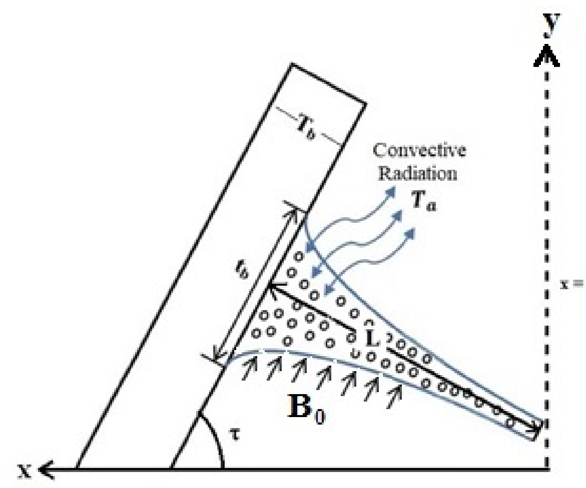

Figure 1. Physical configuration of inclined inverted exponential porous magnetized fin.

by the fluid. Convective heat transfer h is a power law function of fin temperature T, whereas the thermal conductivity k is an exponential function of fin temperature T. Let U be the constant speed at which the fin progress along the x-axis, i.e., either the fin's base surface is movable along the x-axis with a constant speed U when the surrounding fluid remain fixed or vice versa. The interaction between the fluid and fin surface is strongly influences by the fin structure. Hence, velocity U remains fixed but its distribution is proportional to fin structure [23–25]. A constant magnetic field of strength B_0 is applied along the y-direction. Furthermore, unidirectional temperature distribution along the fin (x-axis), Darcy model, adiabatic fin tip and steady state condition are the assumptions made while developing the model.

The equation for energy balance per unit fin width is [26–28]:

$$\begin{aligned}&\frac{d}{dx}\left(t(x)\,k(T)\,\frac{dT}{dx}\right)+\rho C_p U t(x)\,(1+S^* x)\,\frac{dT}{dx}\\&-\frac{2\rho C_p g K\beta(T_a-T)^2\sin\tau}{\nu_f}+2\varepsilon\sigma\left(T_a^4-T^4\right)+2h(T)\\&\times(1-\phi)(T_a-T)-2h_D(1-\phi)\,i_{fg}\,(\omega-\omega_a)\\&+\frac{J_c\times J_c}{\sigma^* a}(T_a-T)=0,\end{aligned} \tag{1}$$

where

$$t(x)=t_b e^{\nu\left(1-\frac{x}{L}\right)}, \tag{2}$$

is the fin thickness which depends on shape parameter ν. In this paper $\nu = 1.0$ is assumed, which corresponds to an inverted exponential fin [26].
The fully wet fin assumption is put as,

$$\omega-\omega_a=b_2\,(T-T_a). \tag{3}$$

The heat conductivity and also convective heat transfer of fin are presumed to be temperature dependent, and are given by Aziz and Torabi [29]:

$$k(T) = k_{eff} e^{\alpha(T-T_a)}, \tag{4}$$

$$h(T) = h_a \left(\frac{T-T_a}{T_b-T_a} \right)^p = h_D C_p L e^{\frac{3}{2}}, \tag{5}$$

subject to the boundary constraints

$$\frac{dT}{dx} = 0 \text{ at } x = 0, \tag{6}$$

$$T = T_b \text{ at } x = L, \tag{7}$$

substituting Eqs.(2) to (5) in Eq.(1), to obtain

$$\begin{aligned} &\frac{d}{dx}\left(k_{eff} e^{\alpha(T-T_a)} t_b e^{\nu(1-\frac{x}{L})} \frac{dT}{dx} \right) + \rho C_p U t_b e^{\nu(1-\frac{x}{L})} \\ &\times (1+S^* x) \frac{dT}{dx} - \frac{2\rho C_p g K \beta (T-T_a)^2 \sin\tau}{\nu_f} \\ &- 2\varepsilon\sigma \left(T^4 - T_a^4 \right) - 2 h_D C_p L e^{\frac{3}{2}} (1-\phi) \frac{(T-T_a)^{p+1}}{(T_b-T_a)^p} \\ &- 2 h_D (1-\phi) i_{fg} (\omega - \omega_a) - \frac{\sigma^* B_0^2 U^2}{A} (T-T_a) = 0. \end{aligned} \tag{8}$$

The dimensionless scales to write Eq. (8) in non-dimensional form are

$$\begin{aligned} &\theta = \frac{T}{T_b}, \ \theta_a = \frac{T_a}{T_b}, \ X = \frac{x}{L}, \ A = \alpha T_b, \\ &N_r = \frac{4\sigma\varepsilon T_b^3 L^2}{k_{eff} t_b}, \ N_C = \frac{\rho g \kappa \beta C_p T_b L^2}{\nu_f k_{eff} t_b}, \\ &m_0 = \frac{2 h_D L^2 (1-\phi)}{k_{eff} t_b}, \ m_1 = \frac{2 h_D i_{fg} b_2 L^2 (1-\phi)}{k_{eff} t_b C_p L_e^{\frac{3}{2}}}, \\ &P_e = \frac{\rho C_p U L}{k_{eff}}, \ S = s^* L, \ H = \frac{\sigma^* B_0^2 U^2}{k_f A}. \end{aligned} \tag{9}$$

Eqs. (6) to (8) on using Eq. (9) yield

$$\begin{aligned} &e^{A(\theta-\theta_a)} e^{\nu(1-X)} \frac{d^2\theta}{dX^2} + e^{\nu(1-X)} \left[P_e (1+SX) - \nu e^{A(\theta-\theta_a)} \right] \\ &\times \frac{d\theta}{dX} + A e^{A(\theta-\theta_a)} e^{\nu(1-X)} \left(\frac{d\theta}{dX} \right)^2 - 2N_c (\theta-\theta_a)^2 \sin\tau \\ &- m_2 \frac{(\theta-\theta_a)^{p+1}}{(1-\theta_a)^p} - (2N_r + H)(\theta-\theta_a) = 0, \end{aligned} \tag{10}$$

$$\frac{d\theta}{dX} = 0 \text{ at } X = 0, \tag{11}$$

$$\theta = 1 \text{ at } X = 1, \tag{12}$$

where Eq. (10) is a non-linear, second order, ordinary differential equation which is a dimensionless form of Eq. (8), Eqs. (11) and (12) represents dimensionless boundary condition, A refers to thermal conductivity parameter, θ_a refers to ambient temperature, N_r refers to radiation parameter, N_C refers to convective parameter, P_e indicates Peclet number related with the fin movement, m_2 indicates the wet parameter, H denotes Hartmann number and S denotes the shrinking/stretching parameter.

The fin heat transfer rate is another metric used to evaluate the fin's thermal performance. It measures the quantity of heat that enters the fin through the base. The application of Fourier's law at the base gives [26]:

$$q = k(T) A_b \frac{dT(L)}{dx}. \tag{13}$$

The non-dimension heat transfer rate of the fin is written as

$$Q = \frac{Lq}{k_{eff} A_b T_b} = e^{A(1-\theta_a)} \frac{d\theta(1)}{dX}. \tag{14}$$

3. Method of solution

Raikar *et al.* [30] have highlighted the significance of a numerical model based on the finite difference scheme to estimate the concentration of pollutants in the atmosphere. The governing partial differential equations were solved using the finite difference technique. Hence, a finite difference technique based boundary value problem (BVP) solver, bvp4c of MATLAB, is implemented to resolve the second order non-linear ordinary differential equation (ODE) Eq. (10) with the corresponding boundary condition Eqs. (11) and (12). The boundary value problem is transformed into a system of first order ODEs along with the boundary condition. The solver bvp4c discretizes the given interval into a mesh of points and employs a collocation method with piecewise polynomial interpolation to obtain the solution at each of the mesh points using fourth order Runge-Kutta (RK) method. Algorithm bvp4c combines a collocation method for BVP with an adaptive RK method; hence, high accuracy in the solution is achieved. The accuracy obtained here is 10^{-6} with adaptive step size. Eqs. (10), (11) and (12) are solved by taking

$$\frac{d\theta}{dX} = f_1,$$

$$\frac{df_1}{dX} = \frac{-1}{T_1} \times$$

$$\left[T_2 f_1 + T_3 (f_1)^2 + T_4 (\theta-\theta_a)^2 + T_5 (\theta-\theta_a) - m_2 \frac{(\theta-\theta_a)^{p+1}}{(\theta-\theta_a)^p} \right],$$

$$\theta(1) = 1,$$

$$f_1(0) = 0,$$

where

$$T_1 = e^{A(\theta-\theta_a)} e^{\nu(1-X)},$$

$$T_2 = e^{\nu(1-X)} \left[Pe(1+SX) - \nu e^{A(\theta-\theta_a)} \right],$$

$$T_3 = A T_1,$$

$$T_4 = -2 N_C \sin\tau,$$

$$\text{and } T_5 = -(2N_r + H).$$

4. Validation of the results

In the absence of the applied magnetic field, angle of inclination, i.e., $B_0 = 0$, $\tau = 0$, and when the coefficient of thermal expansion is very small i.e., $\alpha \ll 1$ the governing Eq. (8) coincides with the Eq. (2) of Gireesha *et al*. [26] in the absence of internal heat generation i.e., $q* = 0$. Also, the results obtained in the absence of applied magnetic field, angle of inclination and negligible value of coefficient of thermal expansion coincides exactly with the results presented by Gireesha *et al*. [26].

5. Results and discussion

The influence of key factors on the thermal distribution and rate of heat transfer at the base of the permeable, magnetized shrinking ($S = -1$), stagnant ($S = 0$), and stretching ($S = 1$) fins with transposed exponential profile by varying each parameter while keeping others constant are depicted in Figures 2 to 19. The representative set of values are $\nu = 1.0$, $m_2 = 1.0$, $P_e = 0.25$, $N_r = 1.0$, $p = 2.0$, $\theta_a = 0.4$, $\tau = \frac{\pi}{4}$, $N_C = 1.0$, $H = 1.0$, $A = 0.5$ [26].

The exposure time and surface interaction, enhances the overall heat transfer rate. This behavior makes stretching fins more effective in applications requiring high thermal efficiency under dynamic conditions. The energy distribution for various values of thermal conductivity parameter A on inverted exponential fin subject to shrinking, stagnant and stretching processes is illustrated graphically in Figure 3. It is observed that when A increases from 0 to 2 temperature of the fin surface rises in all the three cases. An increase in fin temperature leads to improved energy distribution because the mean value of fin's material thermal conductivity rises as Aincreases. Further, stretching process augments thermal distribution, whereas shrinking processes diminishes it. The influence ofθ_a, the convective sink temperature on the thermal distribution along the fin which is subjected to shrinking, stagnant and stretching processes is represented in Figure 4. Evidently, as θ_a increases the temperature also increases monotonically in all the three cases. This is due to the fact that, as the heat sink increases, heat transfer from the fin to the surrounding fluid decreases. It is worth to note that a shrinking fin with lower value of θ_a is favorable in cooling the prime surface. The importance of the exponential index p on the thermal characteristics of the shrinking, stagnant and stretching fins of the exponential profile is displayed in Figure 5.

The thermal distribution of the fin enhances as $p$value increases from -0.25 to 3.0, these values respectively denote the cases of laminar boiling film or condensation, laminar and turbulant natural convection, nucliate boiling and radiative heat transfer. Here, the ascending values of p indicate that heat transfer coefficient is more sensitive to the fin temperature. This heightened sensitivity adversely affects heat loss through convection, leading to reduced thermal dissipation. As a result, the fin retains more heat, causing an increase in its surface temperature and diminishing its effectiveness in managing heat transfer. Furthermore, the energy profile in the case of stretching fin is higher than that of shrinking energy profile, hence implying that stretching is unfavorable to enhance the cooling. The parameters P_e, A, θ_a and p exhibit an identical behavior on the thermal efficiency of a transposed exponential fin encountered to shrinking, stagnant and stretching process. It is possible to achieve the desired cooling at the minimum values of these parameters; further, to intensify the cooling shrinking mechanism is preferred. Controlling these parameters would result in reducing the temperature of the fin from 78% to 40%. The implications of the wet parameter m_2 on a permeable fully wet transposed exponential fin governed by the shrinking, stagnant, and stretching process are featured in Figure 6. Note that, maximizing values of m_2 minimizes the fin surface temperature which enhances the cooling process of fin. The parameter m_2 accounts for both the wetness of the fin and the convective fin surface. The wetness around the fin amplifies the heat absorption by the ambient fluid promotes to the convective heat loss. Moreover, the shrinking process is noted to be in assistance with cooling of fin rather than in the stretching process. Figure 7 presents the influence of the Hartman number H on the inverted exponen-

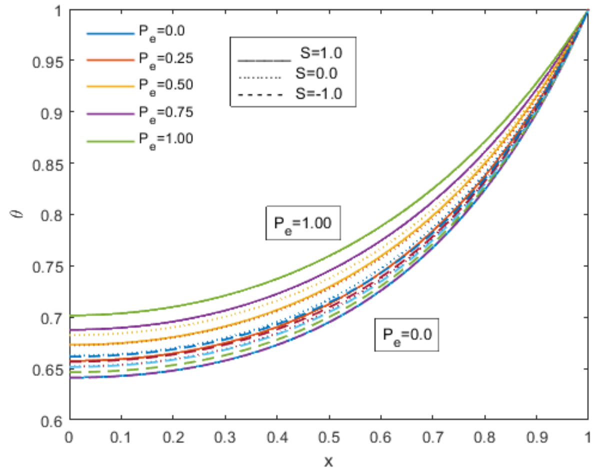

Figure 2. Thermal profiles θ versus x for varying P_e.

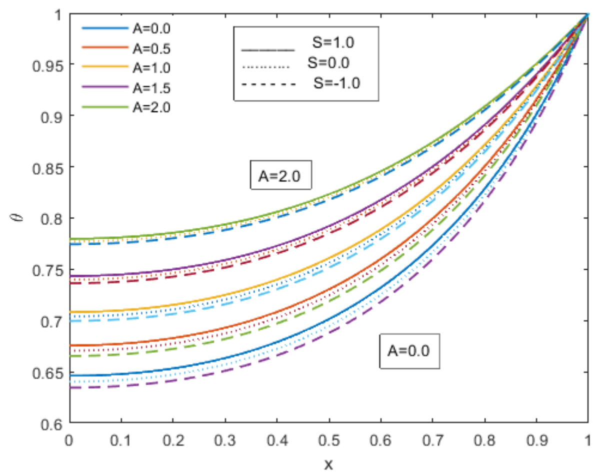

Figure 3. Thermal profiles θ versus x for varying A.

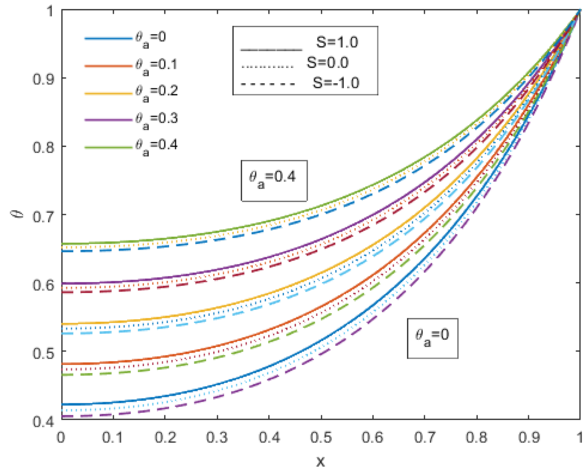

Figure 4. Thermal profiles θ versus x for varying θ_a.

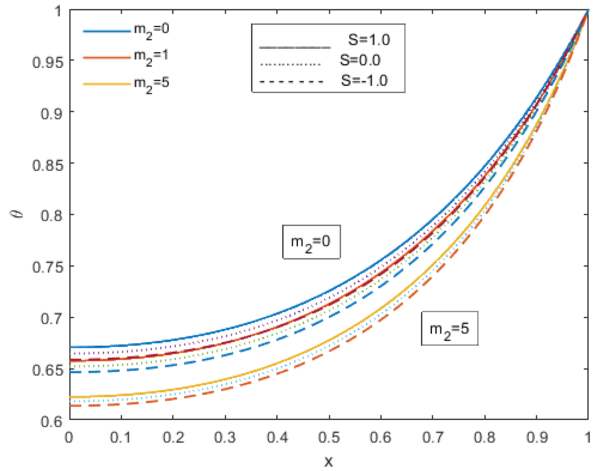

Figure 6. Thermal profiles θ versus x for varying m_2.

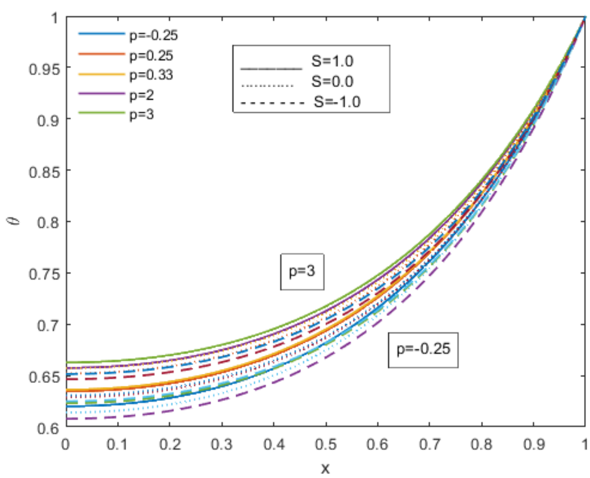

Figure 5. Thermal profiles θ versus x for varying p.

tial longitudinal fin subject to stretching, stagnant and shrinking processes. The findings demonstrate that with an increase in the Hartman number, the temperature along the fin declines, implying enhanced heat transfer rate. This phenomenon occurs due to the enhancement of the magnetic parameter, leading to a corresponding increase in the strength of the magnetism, hence, leads to suppressed convection effect. The effect is prominent in shrinking fin, moderate in stagnant fin and minimum in stretching fin, since, the shrinking process added to the movement would augment the magnetic field strength. The variation of the thermal field of the shrinking, stagnant, and stretching fins of a transposed exponential profile accompanied by the radiation parameter N_r is illustrated in Figure 8. It is observed that, an increase in N_r, the fin tip temperature decreases monotonically. This is due to the fact that a higher radiation coefficient results in a more pronounced radiation effect, which causes the fin's surface to emit more heat. Consequently, the fin's surface temperature declines, resulting in cooling of fin. Further, more heat is lost by the shrinking fin than the stagnant fin, which further bears more heat loss compared to the stretching fin. The influence of the angle of inclination, τ on the thermal performance of a transposed exponential fin is depicted in Figure 9 for the shrinking, stagnant, and stretching cases. It is observed that the increase in the angle of inclination leads to decrease in fin temperature. This is due to driving force for convection with amplification is along the angle of inclination. Hence, shrinking fin supports the cooling efficiency of the fin. Physically N_C measures how efficiently energy is transferred from the fin to the surrounding medium. Figure 10 describes the impact of convective parameter N_C on the thermal distribution along the transposed exponential fin subject to shrinking, stagnant, and stretching mechanisms. It is observed that, as the N_C values are augmented, temperature decreases exponentially along the fin. Augmenting N_C means convection dominates over the conduction, thus removes more heat via convection from the base by keeping the fin cool. Also, shrinking process is favorable to keep the fin cool.

The parameters m_2, H, N_r and N_C reveal an identical behavior on the thermal performance of a transposed exponential fin subject to shrinking, stagnant and stretching process. It is possible to achieve the desired cooling at the maximum values of these parameters; further, to intensify the cooling shrinking mechanism is preferred. Controlling these parameters would result in reducing the temperature of the fin from 68% to 42%.

Yet another parameter of importance is the energy transfer rate $Q$from the fin base. It is the measure of amount of energy extracted from the fin base or from the prime surface into the surrounding media through the fin. Higher value of Q indicates the efficient heat removal from the prime surface. It is worth to note that the energy transfer rate rises with the increase in the accessible surface area; hence an inverted exponential fin profile is preferred.

Figure 11 reveals the importance of S and H on the energy transfer rate Q of an inverted exponential fin. Increasing$H$, increases the fin energy transfer rate, considerably. This impact reverses when the stretching or shrinking parameter S slips to-

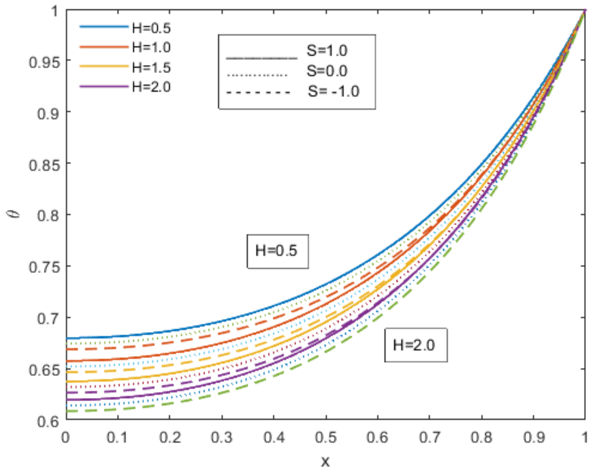

Figure 7. Thermal profiles θ versus x for varying H.

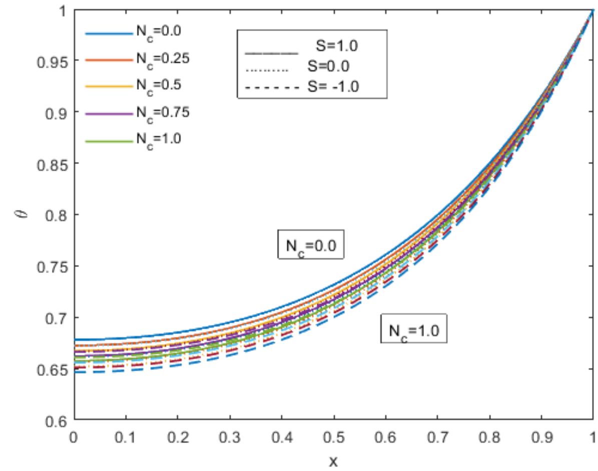

Figure 10. Thermal profiles θ versus x for varying N_C.

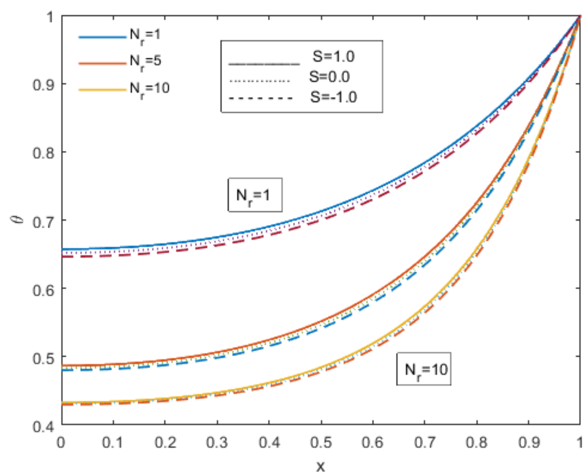

Figure 8. Thermal profiles θ versus x for varying N_r.

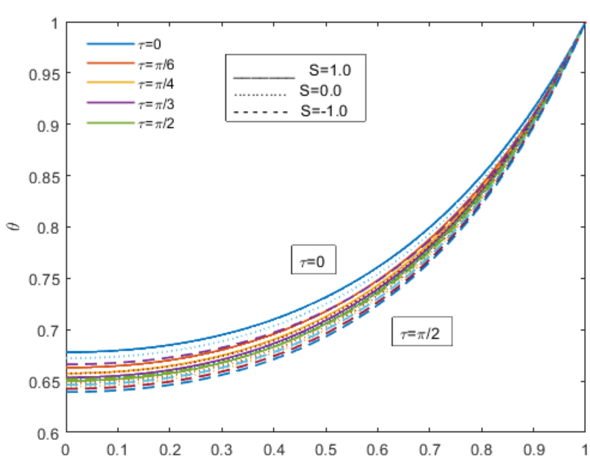

Figure 9. Thermal profiles θ versus x for varying τ.

wards $S = 1$ from $S = -1$. Hence, the shrinking process aids in the cooling process of the magnetized fin and fin rate of heat transfer at the base is deteriorated by the stretching mechanism. The impact of S and N_r on the energy transfer rate Q of a transposed permeable exponential fin is presented in Figure 12. It is clear that as the value of N_r increases the fin energy transfer rate increases proportionately. Also, as the stretching or shrinking parameter S slides from $S = -1$ to $S = 1$, the change is very narrow, implying the strong dependence on N_r than S. Figure 13 depicts the influence of A and S on the heat transfer rate Q of a transposed exponential fin. It is clear that the effect of increasing A is to increase the fin energy transfer rate. Also, when the stretching or shrinking parameter S slides $S = -1$ from $S = 1$ the fin energy transfer rate decreases proportionately for all the values of A. The influence of angle of inclination τ and the stretching/shrinking parameter S on the energy transfer rate Q of an inverted exponential fin is portrayed in Figure 14. It is observed that increasing the parameter τ increases the value of Q considerably in a proportionate manner along the vertical axis. Also, along the horizontal axis as S sweeps through -1 to $+1$ the energy transfer rate decreases relative to τ, indicating higher angle of inclination in a shrinking fin is preferred to achieve the desired cooling.

The combined influence of N_C and S on the energy transfer rate Q of a inverted exponential fin is highlighted in Figure 15. It is evident that as the value of N_C increases the fin energy transfer rate increases proportionately. Also, as the stretching or shrinking parameter S sweeps through $S = -1$ to $S = 1$ the fin energy transfer rate decreases considerably for all the values of N_C, hence the shrinking mechanism with higher value of N_C augments cooling process. The energy transfer rate Q of an inverted exponential fin as a function of wet porous parameter m_2 and stretching or shrinking parameter S is shown in Figure 16. Increasing m_2 increases Q and increasing S decreases Q as evident from Figure 16. Hence, the influence of m_2 is to eliminate more heat from the base at its higher values. It is worth to note that the parameters H, N_r, A, τ, N_C and m_2 exhibit an

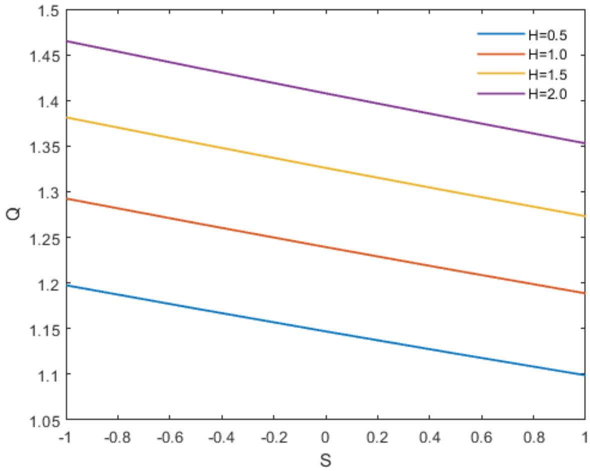

Figure 11. Energy transfer rate at the base Q versus S for various H.

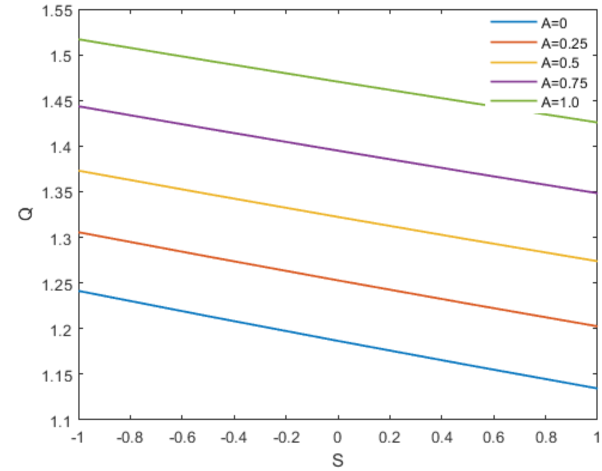

Figure 13. Base energy transfer rate Q versus S for various values of A.

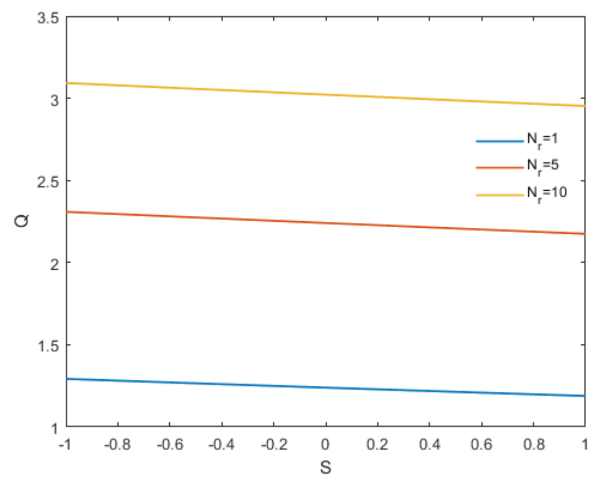

Figure 12. Energy transfer rate at the base Q versus S for various N_r.

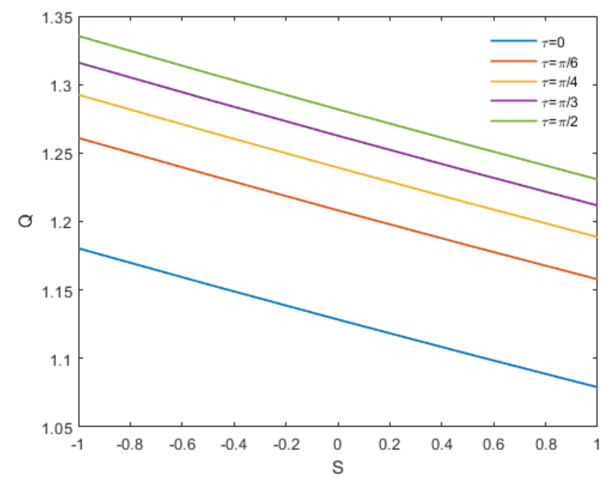

Figure 14. Energy transfer rate at the base Q versus S for various τ.

identical behavior on energy transfer rate Q. Augmenting these parameters would augment the Q proportionately with shrinking process dominating the heat removal from the fin base. Influence of P_e and S on the base energy transfer rate of a transposed exponential fin is depicted in Figure 17. It is clear that as the value of P_e increase from 0 to 1 the energy transfer rate Q decreases considerably. Also, the rate of decrease is very narrow in a shrinking fin and is wide in a stretching fin. Hence, lower values of P_e in a shrinking fin are favorable to enhance the fin cooling. The description of how θ_a and S attribute to the energy transfer rate of a transposed exponential fin is provided in Figure 18. Increasing θ_a decreases Q monotonically along both Q and S axes, which indicate the proportionate influence of θ_a and S on Q. Hence, the minimum value of θ_a is preferred to augment the fin cooling in shrinking, stationary and stretching fins. Figure 19 portraits the effect of power index p and S on the energy transfer rate Q of a transposed permeable exponential fin. The influence of p on Q is to decrease the energy transfer rate monotonically with the increase in p. Also, as S slides from -1 to +1 the energy transfer rate decreases considerably, indicating the strong influence of p and S on Q. The case of condensation in a shrinking is conducive to achieve better cooling.

The parameters P_e, θ_a and p behave alike on rate of energy transfer at the base of a transposed exponential fin. Diminishing these parameters would augment the Q proportionately with the shrinking mechanism dominating the energy removal from the fin base.

6. Conclusion

The performance of a transposed exponential moving wet porous fin attached to the prime surface obliquely with variable energy transfer coefficient and exponential dependency of thermal conductivity on temperature in the presence of an external constraint of an applied magnetic field is investigated numerically. A finite difference based technique of MATLAB software, bvp4c, is employed to solve the second-order non-linear

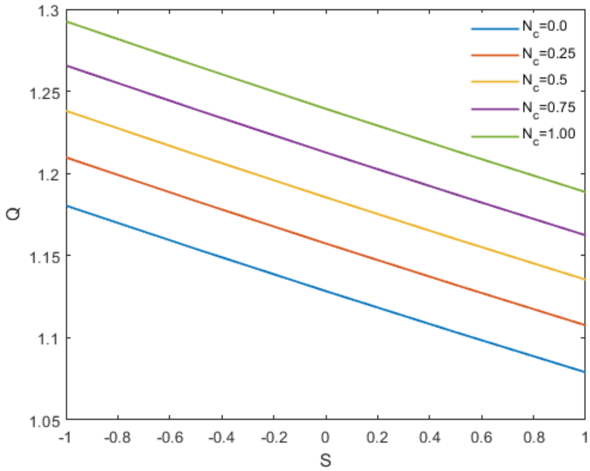

Figure 15. Energy transfer rate at the base Q versus S for various N_c.

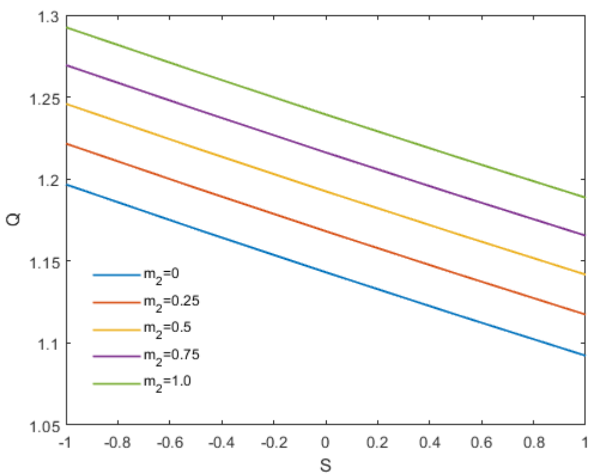

Figure 16. Energy transfer rate at the base Q versus S for various m_2.

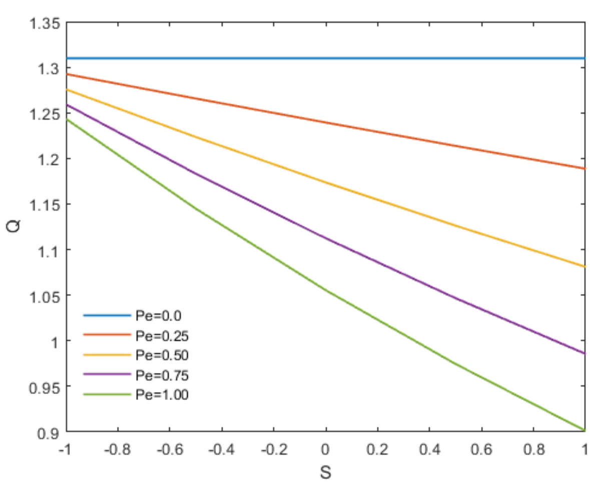

Figure 17. Energy transfer rate at the base Q versus S for various P_e.

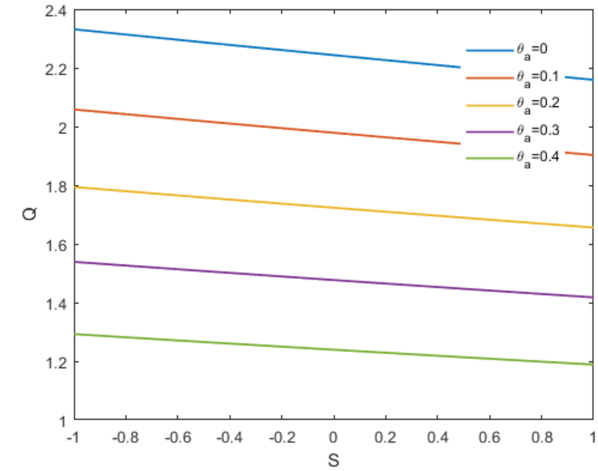

Figure 18. Energy transfer rate at the base Q versus S for various θ_a.

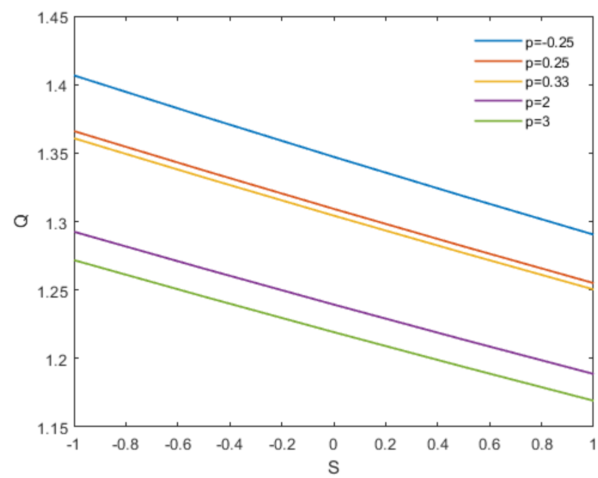

Figure 19. Energy transfer rate at the base Q versus S for various p.

governing ordinary differential equation for temperature, θ. The thermal flow and geometrical parameters that contribute to the temperature distribution and the base energy transfer rate of the fin are explicated graphically. Major findings of this research work are i) Peclet number P_e, thermal conductivity parameter A, convective sink temperature θ_a, and power index p decrease the temperature of the fin hence accelerates the energy transfer. ii) The parameters like wet porous parameter m_2, Hartman number H, radiation parameter N_r, angle of inclination τ, and convective parameter N_C increase the temperature of the fin hence accelerates the energy transfer. iii) The Hartman number H, radiation parameter N_r, thermal conductivity parameter A, angle of inclination τ, convective parameter N_C, and wet porous parameter m_2 would augment the base energy transfer rate. iv) The parameters; Peclet number P_e, convective sink temperature θ_a, and power index p would suppress the base energy transfer rate. v) Shrinking processes intensify fin cooling than stagnant and stretching mechanisms. vi) With the proper choice of flow and geometrical parameters, it is possible to design a fin with better efficiency.

Data Availability

I do not have any research data outside the submitted manuscript file.

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