Abstract: The boundary-layer equations for mass and heat energy transfer with entropy generation are analyzed for the two-dimensional viscoelastic second-grade nanofluid thin film flow in the presence of a uniform magnetic field (MHD) over a vertical stretching sheet. Different factors, such as the thermophoresis effect, Brownian motion, and concentration gradients, are considered in the nanofluid model. The basic time-dependent equations of the nanofluid flow are modeled and transformed to the ordinary differential equations system by using similarity variables. Then the reduced system of equations is treated with the Homotopy Analysis Method to achieve the desire goal. The convergence of the method is prescribed by a numerical survey. The results obtained are more efficient than the available results for the boundary-layer equations, which is the beauty of the Homotopy Analysis Method, and shows the consistency, reliability, and accuracy of our obtained results. The effects of various parameters, such as Nusselt number, skin friction, and Sherwood number, on nanoliquid film flow are examined. Tables are displayed for skin friction, Sherwood number, and Nusselt number, which analyze the sheet surface in interaction with the nanofluid flow and other informative characteristics regarding this flow of the nanofluids. The behavior of the local Nusselt number and the entropy generation is examined numerically with the variations in the non-dimensional numbers. These results are shown with the help of graphs and briefly explained in the discussion. An analytical exploration is described for the unsteadiness parameter on the thin film. The larger values of the unsteadiness parameter increase the velocity profile. The nanofluid film velocity shows decline due the increasing values of the magnetic parameter. Moreover, a survey on the physical embedded parameters is given by graphs and discussed in detail.

Keywords: entropy generation; second-grade fluid; nanofluid; liquid films; thin film; time depending stretching surface; magnetic field; HAM
1. Introduction

In the last few years, thin film flow problems have received great attention. The history behind such a loyalty and importance is the use of thin film flow in various technological disciplines. Thin film flow problems cannot be categorized and classified in a simple way, because they are rooted in particular to broad areas, such as from the analysis of flow in human lungs to industrial problems involving lubricants. Examining thin film flow of liquids and its uses leads us to an important relationship between structural mechanics and fluid mechanics. The polymers and metal extraction, drawing of elastic sheet, exchanges, foodstuff striating, fluidization of the devices, and constant forming are some common uses and applications of liquid film flow. In view of these practical uses of liquid film flow, further advancement and development is observed to be necessary. For this purpose, a variety of attempts have been made with constructive geometries from time to time by many investigators. One such an important geometry is the expanding sheet, which has received great attention and become a problem of interest for the investigators [1,2].

In the beginning, thin liquid film flow was devoted to fluids with some viscosity. Classifications of these fluids based on viscosity have made the area saturated. With the passage of time, the domain was extended to non-Newtonian fluids. Non-Newtonian nano-liquids are studied and are discussed with variations in internal and external agents. The transfer of heat is investigated for non-Newtonian nanoliquid thin film flow by Sandeep et al. [3]. In stretching sheet problems, the geometry of the problem is important, due to its time dependency as well as the nature of the sheet. Wang [4] investigated the liquid thin film flow past a time-dependent expanding sheet. The same geometry with finite thin liquid is investigated by Usha et al. [5]. They analyzed the flow on an unsteady stretching sheet for finite thin liquids. Liu et al. [6] investigated the thin film flow for heat transfer enhancement through an expanding sheet. Aziz et al. [7] described the flow of thin fluid film with generation of heat over an expanding surface. Tawade et al. [8] examined thin film liquid flow for the transfer of heat in the presence of thermal radiations. They implemented the RK-Fehlberg and Newton-Raphson method to tackle the modeled equations. A briefer survey on heat transfer analysis on liquid film flow past an expanding sheet is presented by Andersson et al. [9]. The study of expanding sheet problem is not rare in the literature and a brief survey can be found on its applications and other technological advancements in [10–15]. Besides all these, a variety of fluids are investigated under the same geometry. Megahed [16] studied the impact of heat on thin Casson fluid past an unsteady expanding surface by assuming the slip velocity in the presence of viscous dissipation and heat flux. Shah et al. [17] described the flow of Casson nanofluid in rotating parallel plates in the presence of Hall effect. Jawad et al. [18] studied the MHD flow of the nanofluid thin film by considering the Joule heat loss and Navier’s partial slip by considering Darcy-Forchheimer model. Interested readers are referred to [19–22] for more brief discussion on rotating systems. Some new modifications are made by Khan et al. [23] and Tahir et al. [24] for the thin film flow of nanofluids.

The proficiency in different applications of nanofluids are due to the enormous features (heat transfer enhancement, cooling etc.). From the practical application point of view, nanofluids are used in powered engines, pharmaceutical procedures, micro-electrons, and hybrid fuel cells. Presently, its major use is in the field of nanotechnologies. In industries, the use of electronic equipment and nanoboards are essential presently. These boards and electronic accessories become hot with the passage of time, due to which its efficiency is normally badly affected. To overcome this situation, nanofluids are used as a coolant to reduce heat [25]. A literature survey shows that air is used as a coolant in many processes. In the enhancement of the performance of microchips, projectors and LED nanotechnology coolants are used [26,27]. Non-Newtonian fluid flow is found in abundance in the literature and deeply depends on the mechanism in which it is used. One such a mechanism is the peristaltic mechanism, which plays a vital role in physiological and industrial processes. In this process, along the wall of the channel sinusoidal waves are propagated. The best examples of such waves in practice are dialysis, hose pumps, and the heating of lungs etc. Further investigation of this study leads researchers to examine MHD flows. MHD analysis of peristaltic flows plays a key
role in medicine and bio-engineering. The variations in viscosity for peristaltic flow are examined by Srivastava et al. [28]. The variation of viscosity with temperature is studied by Abbasi et al. [29] for nanofluid flow.

From earlier study, nanofluids have been found to retain dimensions smaller than 100 nm [7,8]. Nanofluids are known to be a mixture of nanoparticles and the general heat transfer fluids, for example oil, ethylene glycol, glycol, and water etc. Nanoparticles can be prepared in laboratories and in industries on a large scale. It can be obtained from metals such as Ag, Al, Au, Cu, and oxides of metals such as Fe$_3$O$_4$, CuO, TiO$_2$, Al$_2$O$_3$, nitrides such as AlN, SiN, carbides (SiC) etc. The nanoparticles obtained from these materials are used in very small amounts for the improvement of heat transfer, due their high thermal conductivity. The enhancement of heat transfer due to thermal systems for augmentation are presently become widespread. Abolbashari et al. [30] described nanofluid flow using Buongiorno’s model through a time-dependent stretching sheet. Hayat et al. [31] discussed the nanoliquid flow in three dimensions by using the Maxwell model. Malik et al. [32] studied a mixed convective MHD nanofluid flow on a stretching surface by considering Erying-Powell fluid. Nadeem et al. [33] discussed the Maxwell liquid film flow of nanoparticles past a perpendicular stretching surface. Raju et al. [34] examined the non-Newtonian nanoliquid MHD flow through a cone with free heat convection and mass transfer. The heat transfer investigations of the nanofluid flow through plates are performed by Rokni et al. [35]. Numerical investigations of the non-Newtonian nanoliquid flow on the stretching surface are presented by Nadeem et al. [36]. Shehzad et al. [37] examined the nanoliquid MHD flow of Jaffrey fluid in the presence of convective-type boundary constraints. Sheikholeslami et al. [38,39] analyzed the heat effects on nanoliquid flow by applying an external magnetic field. Mahmoodi et al. [40] studied the flow of nanofluid for cooling purposes and discussed the heat sink for the flow field. The impact of thermal radiations and Hall current is recently explored by Shah et al. [41,42] for rotating surfaces. A detailed study on rotating surfaces with stretching sheet performed by Shah et al. can be found in [43–49]. CuO containing nanofluid thin film flow inside a semi-annulus region is examined by Sheikholeslami and Bhatti [50] numerically with constant magnetic field. They analyzed the heat transfer enhancement and found some good results. Tube-in-tube analysis of heat exchanger for $\gamma$–ALOOH nanofluid is performed by Monfared et al. [51]. They found both upper and lower boundaries of irreversibility for platelet and spherical shape geometries. A brief and detailed survey on nanofluids of Sheikholeslami with modern applications of dissimilar phenomena with a variety of approaches can be found in [52,53]. Besides the theoretical study, literature is rich with experimental results on nanofluid flow and its use in the heat transfer analysis. A combined effect of the silver and carbon nanotubes by taking water as the base fluid is performed by Munkhbayar [54]. In this study, he used 3% of the nanoparticles by volume as compared with base fluids. The use of these combined nanoparticles enhances the heat transfer up to 14.5% at a very low temperature. The increase in concentration and heat transfer for a hybrid of the copper oxide and titanium nanoparticles is achieved by taking water and ethylene glycol mixture as the base fluid studied by Hemmat et al. [55]. They performed this experiment in a laboratory from (30–60)°C. At the upper bound of the temperature range they found a 41.5% increase in the thermal conductivity. Hybrid base fluid (water-ethylene) and hybrid nanofluids (titanium-MWCNT’s) investigation was carried out by Akhgar et al. [56] for the stability of base fluid and enhancement of thermal conductivity. They observed a 38.7% increase in the thermal conductivity of the nanofluids as compared with the base fluid. Similar experimental results for the enhancement of the thermal conductivity of nanofluids can be found in [57,58].

The free existence of non-Newtonian fluids and its use attracted researchers to construct models and further developments due to its application in industry. Most of the organic compounds came under the umbrella of the non-Newtonian fluids. Food products, molten plastic, wall paints, lubricant oils, drilling mud, and molten plastic are some of the widely used examples non-Newtonian fluids. Surveys suggest that to classify the non-Newtonian fluids in terms of behavior, many models have been introduced and developed. Some of them, Williamson fluid, Walter’s-B fluid, Casson fluid,
Carreau fluid, etc., are very common in use. Carreau fluid model is also known as the Newtonian generalized model [59]. The significance of the Carreau fluid model in the field of melts, water-based polymers, and suspensions attracted investigators. Considering the effectiveness of this model, many researchers investigated the nature of Carreau fluid by using different geometries. Some surveys related to this model are presented here. Kefayati et al. [60] performed a survey on the thermosolutal forced convective flow over two circular cylinders with magnetic effects by taking the Carreau fluid model. They also analyzed the entropy generation in their study. Olajuwon [61] studied the Carreau liquid flow over a perpendicular permeable surface with magnetic effect. Hayat et al. [62] investigated this model for a free convection flow over a non-stationary surface. The study of nanofluids is not just linked to the fluids model used, but purely depends on the nature of the nanomaterial used. The shape of the nanomaterial used is more important in the study of heat transfer processes. To enhance the heat transfer, and to improve thermal and hydraulic properties, the shape of the nanoparticles used is also important. Alsarraf et al. [63] implemented a two-phase mixture model to investigate the double-pipe flow of boehmite alumina nanofluid. They presented the results in the form of percentages for both spherical and platelet-shaped nanoparticles under high Reynolds numbers. Similarly, an experimental study is presented by Azari et al. [64] for alumina nanofluid flow. They successfully analyzed the two-phased model theoretical results with practically obtained information.

Due to its complicated nature, non-Newtonian fluids have been studied by many researchers, just for the purpose of explicitly or implicitly explaining the strain rate. An important type of non-Newtonian fluids is Sisko fluid, which has great significance in engineering as well as in technology. Stretching surface analysis was made by Munir et al. [65] by using Sisko fluid bidirectional flow. Sisko model is used by Olanrewaju et al. [66], for the unsteady non-convective fluid flow over a flat surface by taking into account heat transfer. Khan et al. [67] studied the effect of heat energy transfer in an annular pipe of the Sisko fluid steady state flow. Khan et al. [68] described the Sisko fluid boundary-layer flow over a stretching surface. Similar investigation on the stretching surface for the laminar flow by using Sisko fluid model is carried out by Patel et al. [69]. Darji et al. [70] examined the natural convective time-independent Sisko fluid flow of boundary-layer type. Analytical solutions of the Sisko fluid thin film flow for the drainage down a vertical belt is presented by Siddiqui et al. [71]. The MHD Sisko fluid numerical study for an annular region flow is carried out by Khan et al. [72]. Sar et al. [73] studied both the Lie group and Sisko fluid boundary-layer equations. Hameef et al. [74] investigated the Maxwell nanofluid flow for magnetic and electric effects on a stretching plate. Moallemi et al. [75] studied the flow of Sisko fluid in the pipe and discussed the exact solution. Dawar et al. [76] investigated the CNT Casson fluid flow with MHD in a rotating channel for heat transfer analysis. Shah et al. [77] implemented Cattaneo-Christov model for the heat transfer analysis of MHD micropoler Casson fluid over a stretching sheet. Khan et al. [78] investigated the Eyring-Powell nanoliquid film slip flow by considering nanoparticles of graphene. Recently, Khan and Pop [79] investigated the thermophoresis effect and Brownian motion of a boundary-layer nanofluid flow past a stretching sheet. For the enhancement of heat transfer, researchers started to use impurities. Osiac [80] discussed the electrical and structural properties of nitrogen. Radwan et al. [81] performed the synthesis classification and applications of polystyrene. Coating applications of thin film flow and flexible coating with conductive fillers and applications of thermoelectric materials are discussed [82–85].

The best possible design conduction in the energy system is always the aim of investigators. For this purpose, the role of entropy cannot be ignored in modeling, and other optimization applications of the energy systems. The roots of entropy are connected to the second law of thermodynamics and its irreversible aspects are laid down by Kelvin and Clausius. The theoretical background of entropy was developed very rapidly and has been extended to the new generation. However, in the heat transfer process/thermal radiations, entropy generation cannot be treated by conventional thermodynamic approaches. That is why researchers are compelled to take an interest in the second law of thermodynamics and to investigate its engineering applications. When there is a heat transfer in the system, there must be the generation of entropy. The generation of entropy is
mainly concerned with the irreversibility of thermodynamics. Entropy can be generated from different sources, such as viscous dissipation, mass diffusion, and finite temperature gradients in the transfer of heat. The generation of entropy in thermal engineering has been investigated by Bejan [86,87] from some new aspects. The work already available in the system vanishes due to the generation of entropy. From an engineering point of view, it makes sense to understand the irreversibility and mechanism of the entropy generation in the transfer of heat and other problems in the fluid flow.

The generation of entropy in thermal systems has been discussed by many investigators. Weigand and Birkefeld [88] investigated the laminar flow past a flat plate with entropy generation. Makinde [89] investigated the second law for the hydro-magnetic flow of the boundary layer on a stretching surface along with the heat transfer analysis by using variable viscosity. Makinde reported that with the increasing values of Prandtl number and radiation parameter the entropy generation decreases. Hayat et al. [90] presented Darcy-Forchheimer CNT-based nanomaterial convective flow with heat flux for entropy generation. They analyzed both SWCNTs and MWCNTs for heat transfer enhancement and entropy generation. In another investigation of gravity-driven thin film flow in the direction of the heated inclined plate, Makinde [91] reported that at the liquid-surface, the irreversibility of heat transfer is dominant, while an opposite result is observed at the surface of the plate. A small amount of work is done on the heat transfer analysis, considering the second law of thermodynamics in nano-fluids. This is because of the rarity of the nano-fluids. Recently, Esmaeilpour and Abdollahzadeh [92] investigated the enhancement of heat for nano-fluid free convection flow inside an enclosure with the entropy generation. Dawar et al. [93] presented a semi-analytic solution to the CNT nano-fluid flow inside rotating plates. In this investigation, the effect of magnetic field and entropy generation is deliberated numerically. A further brief survey on entropy generation by investigating different models and geometries can be found in [94,95]. Surveys suggest that the stretching sheet problem has been studied by different researchers for different fluids. Entropy generation of viscoelastic fluid for the second-grade fluid is rare and will be discussed in this article for the first time. In science and engineering majority of the mathematical models are very complicated, and it is also impossible to solve these types of problems for exact solution. For this purpose, researchers are widely using numerical and semi-analytic methods for the approximate solution. Numerical techniques are sometimes difficult to perform in an efficient way for some problems. This happens due to the high non-linearity of the problem. To overcome this situation, Liao [96,97] investigated the solution of these types of problems by implementing a new technique. The method is termed the Homotopy Analysis Method (HAM), due to the use of homotopy, a topological property. He further discussed the convergence of the new implemented method. A solution is a function of single variable in the form of a series.

The foremost aim of discussing this work is to investigate the flow of second-grade thin film flow in the presence heat transfer and magnetic effect with the generation of entropy in a vertical stretching sheet. To the best of our knowledge, we cannot find new work on nano-fluid thin film flow on vertical stretching sheet by considering viscoelastic fluid of second grade. Equations for the generation of entropy and the boundary-layer heat transfer over a vertical stretching sheet are constituted for two-dimensional nano-fluid thin film flow with uniform magnetic field (MHD). These equations are the leading-order mathematical equations constituted from the geometry, keeping in view the assumptions in flow field. Different physical aspects such as thermophoresis, concentration gradients, and Brownian motion of the flow are assumed in the nano-fluid model. The modeled leading-order system in the form of PDEs (partial differential equations) are further transformed into a system of ODEs (ordinary differential equations), with the help of similarity variables. Similarity variables have the property of non-dimensionalization and transforming the system of PDEs to a single independent variable system also known as ODEs. The reduced system of differential equations is tackled by an analytic approach (HAM). HAM is implemented with initial guesswork, as required for the implementation of the technique, due to its fast convergence. The convergence of the implemented technique is discussed numerically and with graphs. The state variables are plotted under the variation of different physical parameters and discussed in detail. Physical quantities such as Sherwood number, Nusselt number,
and skin friction are presented numerically for its significance in the boundary-layer flow. The impact of Brinkman number and Bejan number is discussed by graphs for entropy function. The effect of Reynolds number, Prandtl number, and magnetic parameter is also influential on entropy function, Bejan number, and Brinkman number by graphs.

2. Problem Formulation

Assume an unsteady nanoliquid thin film flow of the second-grade fluid past a stretching sheet. Furthermore, the fluid is assumed to be electrically conducting and the magnetic field effect is also considered inside the flow field. The moving sheet starts its motion from a fixed slit. The arrangement of the geometry is made in the Cartesian system of coordinates in such a way that the plate length is equal to \( ox \), and \( oy \) is flat to the surface. The stretching effects are applied in such a manner to the surface of the flow that the two forces are in opposite direction with an equal magnitude along the \( x \)-axis, and keeps the center motionless. The stretching sheet and \( x \)-axis are taken in such a manner that it is adjacent to each other, and the stress velocity of the sheet is given by [17]:

\[
U_w(x, t) = \gamma x (1 - \zeta t)^{-1},
\]

where \( \zeta \) and \( \gamma \) represents any fix numbers, which are vertical to \( x \)-axis. The wall temperature and capacity of the nanoparticles are given by [17,19]:

\[
T_w(x, t) = T_r \left( \frac{\gamma x^2}{2\nu_f} \right) (1 - \zeta t)^{-1.5} + T_0
\]

\[
C_w(x, t) = C_r \left( \frac{\gamma x^2}{2\nu_f} \right) (1 - \zeta t)^{-1.5} + C_0
\]

where \( \nu_f \) denotes the fluid kinematic viscosity, \( T_0 \) and \( C_0 \) denotes the temperature of the slit and volume friction of the nanoparticles, while \( T_r \) and \( C_r \) represents the reference temperature and reference volume of the nanoparticles, respectively.

The applied magnetic field has the relationship of the form [17]:

\[
B(t) = B_0 (1 - \zeta t)^{-1/2},
\]

here \( B_0 \) is the magnetic field strength.

The mathematical model that illustrates the second-grade fluid is given in the form [23]:

\[
\vec{T} = -p\vec{I} + \vec{S}.
\]

The basic equations of the second-grade fluid can be obtained by using \( \beta_1 = \beta_2 = \beta_3 = 0 \) in the third-grade fluid model i.e.

\[
\vec{S} = \tau = \mu \vec{A}_{(1)} + \alpha_{(2)} \vec{A}_{(2)} + \alpha_{(2)} \vec{A}_{(2)}^2.
\]

Here \( p\vec{I} \) is an isotropic stress, \( \vec{S} \) is an extra tensor of stress, \( \mu \) is the coefficient of viscosity, \( \alpha_{(1)} \) and \( \alpha_{(2)} \) represent the thermal stress moduli, \( \vec{A}_{(1)} \) and \( \vec{A}_{(2)} \) are the stresses of Rivlin Ericksen tensors and have the mathematical structures

\[
\vec{A}_{(1)} = \nabla \vec{V} + (\nabla \vec{V})^T
\]

\[
\vec{A}_{(2)} = \frac{D}{Dt}(\vec{A}_{(1)}) + \vec{A}_{(1)} \nabla \vec{V} + (\nabla \vec{V})^T \vec{A}_{(1)}.
\]

2.1. Continuity Equation:

The equation of continuity under the assumed assumption (in-compressible fluid) for the modeled geometry takes the vectorial form [74]:

\[
\nabla \cdot \vec{V}.
\]
For two-dimensional nanofluids, Equation (7) takes the form:

\[
\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = 0
\]

\[\text{(8)}\]

2.2. Momentum Equation

The momentum equations for the modeled geometry and flow assumptions, are given by [74]:

\[\rho \frac{D}{Dt}(\vec{V}) = \nabla \cdot \vec{P} + \vec{f} + \vec{g}.
\]

\[\text{(9)}\]

Here \(\rho\) denotes the fluid density, \(\vec{V}\) velocity, which can be expressed in components form as: \(\vec{V} = (u, v, 0)\). \(\vec{f}\) Cauchy tensor of stress and \(\vec{g}\) force acts from a distance respectively. \(\vec{f} \times \vec{B}\) represents the famous Lorentz force, in which \(\vec{f}\) is the current density, \(\vec{B}\) is the magnetic field with a magnetic field strength \(B_0\). Furthermore, \(\vec{f}\) can be expressed as: \(\vec{f} = \sigma(\vec{E} + \vec{V} \times \vec{B})\), also known as Ohm’s law, in which \(\sigma\) and \(\vec{E}\) describe the electrical conductivity and electric field respectively, and assume that \(\vec{E} = 0\). \(\frac{D}{Dt}\) represents the substantial derivative. Using all the above assumptions in Equation (9), we get

\[
\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \frac{\alpha_1}{\rho} \left( \frac{\partial}{\partial y} \left( u \frac{\partial u}{\partial y} \right) - \frac{\partial}{\partial x} \left( u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) \right) - \sigma B_0^2 u + g_T \beta_T (T - T_\infty) + g_T \beta_T (C - C_\infty),
\]

\[\text{(10)}\]

where \(B_0\) and \(\alpha_1\) describe the strength the magnetic field and thermal conductivity of the fluid, respectively, \(\beta_T\) is the thermal expansion coefficient, \(C_\infty\) and \(T_\infty\) denotes the concentration and temperature at a distance from the surface, and \(g\) is the gravitational acceleration.

2.3. Equation of Thermal Energy

Thermal energy equation for the unsteady flow field is presented in the form [74]:

\[
\frac{\partial T}{\partial t} + \vec{V} \cdot \nabla T = \nabla \cdot \left( \frac{K(T)}{\rho c_p} \nabla T \right) + \tau \left( D_B \nabla C \cdot \nabla T + \left( \frac{D_T}{T_0} \nabla T \right) \cdot \nabla T \right),
\]

\[\text{(11)}\]

where \(T\) represents the temperature, \(\tau = \frac{\rho_k}{\rho_L}\) illustrates the ratio of the base liquid to thermal capacities of nanoparticles, the heat capacitance of the liquid is represented by \(c_p\), \(D_B\) represents the constant of Brownian diffusion, while \(D_T\) demonstrates the constant of thermophoretic diffusion, \(T_0\) denotes the liquid temperature, which is detached from the sheet.

After implementing the assumptions (two-dimensional, unsteady, viscous, in-compressible, electrically conducting, etc.), Equation (11) is reduced to:

\[
\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \frac{1}{\rho c_p} \frac{\partial}{\partial y} \left( \frac{\partial T}{\partial y} \right) + \tau \left( D_B \left( \frac{\partial C}{\partial y} \right) \frac{\partial T}{\partial y} + \frac{D_T}{T_0} \left( \frac{\partial T}{\partial y} \right)^2 \right).
\]

\[\text{(12)}\]

2.4. Equation of Mass Transfer

The nanofluid concentration can be mathematically described as [14]:

\[
\frac{\partial C}{\partial t} + \vec{V} \cdot \nabla C = D_B \nabla^2 C + \frac{D_T}{T_0} \nabla^2 T.
\]

\[\text{(13)}\]

After applying the assumptions, Equation (13) takes the form:

\[
\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = D_B \frac{\partial^2 C}{\partial y^2} + \frac{D_T}{T_\infty} \left( \frac{\partial^2 T}{\partial y^2} \right).
\]

\[\text{(14)}\]
The pertinent restrictions can be written as:

\[ u = U_w, \quad v = 0, \quad T = T_w, \quad C = C_w \atop \text{at} \quad y = 0, \quad (15) \]

\[ \frac{\partial u}{\partial x} = \frac{\partial T}{\partial x} = \frac{\partial C}{\partial x} = 0, \quad v = \frac{dh(t)}{dt}, \quad C > 0, \quad \text{at} \quad y = h. \quad (16) \]

Introducing the following transformations [14]:

\[ \psi = x, \quad f(\eta), \quad u = \frac{\partial \psi}{\partial y} = \gamma \frac{f'(\eta)}{1 - \zeta t}, \quad v = \frac{\partial \psi}{\partial x} = -\sqrt{\frac{\gamma \psi}{(1 - \zeta t)^2}} f(\eta), \quad (17) \]

Here the stream function is represented by \( \psi \), the thickness of the fluid film is denoted by \( h(t) \), and the kinematic viscosity is represented by \( \nu = \frac{\mu}{\rho} \). The dimensionless film thickness is defined as:

\[ \beta = \sqrt{\frac{\zeta}{v(1 - \zeta t)}} h(t) \quad (18) \]

In other words, Equation (18) becomes:

\[ \frac{dh}{dt} = -\frac{\zeta \beta}{2} \sqrt{\frac{v}{(1 - \zeta t)}}. \quad (19) \]

With the help of the newly introduced variables, Equations (10)–(14) are reduced to the following equations, while the continuity equation is satisfied identically.

\[ f''' + \gamma_1 \left( f''' - (f'')^2 - f f'' \right) + f f'' - (f')^2 - St \left( f' + \frac{\nu}{2} f'' \right) - Gr \theta + G m \phi + M f' = 0, \quad (20) \]

\[ (1 + Rd) \theta'' + f \theta' - 2 f' \theta - \frac{S t}{2} \left( 3 \theta + \eta \theta' \right) + N t (\theta')^2 + N b \theta' \phi' = 0, \quad (21) \]

\[ \phi'' + Sc \left[ f \phi' - 2 f' \phi - \frac{S t}{2} \left( 3 \phi + \eta \phi' \right) \right] + \frac{N t}{N b} \phi'' = 0. \quad (22) \]

The boundary conditions of the problem are:

\[ f(0) = 0, \quad f'(0) = 1, \quad \theta(0) = 1, \quad \phi(0) = 1, \quad f(\beta) = \frac{S \beta}{2}, \quad f''(\beta) = 0, \quad \theta'(\beta) = 0, \quad \phi'(\beta) = 0. \quad (23) \]

After generalization, the physical parameters are defined as: \( St = \frac{\gamma}{2} \) is the measure of the time-dependent non-dimensional parameter, \( \gamma_1 = \frac{a_B^2}{\rho \nu^2} \) is the second-grade stretching parameter, \( M = \frac{\eta B^2}{\nu f} \) represents the magnetic parameter, \( \lambda = m (T - T_0) \) denotes the variable viscosity, \( Pr = \frac{\nu e z}{k} \) represents the Prandtl number, \( N t = \frac{\sigma D_w (T_w - T_0)}{\rho_{\infty} c_{\phi}} \) demonstrates thermophoresis parameter, \( N b = \frac{\sigma D_w (c_w - c_0)}{\nu} \) represents the limitations of Brownian motion, \( G m = \frac{g B^3}{c_{\phi}} \) is the mixing parameter, \( Gr = \frac{g B^3 (T_w - T_0)}{\nu} \) denotes the Grashof number, \( Rd = \frac{16 \sigma T_0^2}{\mu} \) is the radiation parameter, and \( Sc = \frac{\nu}{D_w} \) represents Schmidt number.
3. Parameters of Interest

3.1. Skin Friction

The coefficient of skin friction can be defined in the closed form as:

$$C_f = \frac{(S_{xy})_{y=0}}{\frac{1}{2} \rho U_w^2},$$  \hspace{1cm} (24)

where

$$S_{xy} = \left[ \mu \frac{\partial u}{\partial y} + \rho a_1 \left( 2 \frac{\partial u}{\partial x} \frac{\partial u}{\partial y} + \frac{\partial^2 u}{\partial x \partial y} \right) \right].$$  \hspace{1cm} (25)

A dimensionless description of $C_f$ is demonstrated as:

$$C_f = (Re)^{-\frac{1}{2}} \left( f''(0) + 3 \gamma_1 f''(0) f'(0) \right),$$  \hspace{1cm} (26)

where $Re$ denotes the local Reynolds number, and has the mathematical description given as: $Re = \frac{U_w x}{\nu}$.

3.2. Nusselt Number

Nusselt number has the closed mathematical form given by

$$Nu = \frac{h Q_w}{\hat{k} (T_0 - T_h)}$$

where $Q_w = -\hat{k} \left( \frac{\partial T}{\partial y} \right)_{y=0}$ is the flux of heat. A dimensionless description of $Nu$ is demonstrated as:

$$Nu = -\Theta(0)$$  \hspace{1cm} (27)

3.3. Sherwood Number

Sherwood number can be demonstrated in mathematical form as:

$$Sh = \frac{h J_w}{D_B (C_0 - C_h)}$$

where $J_w = -D_B \left( \frac{\partial C}{\partial y} \right)_{y=0}$ is the flux of mass. The non-dimensional descriptions of $Sh$ is demonstrated as:

$$Sh = -\Phi(0)$$  \hspace{1cm} (28)

4. Entropy Analysis and Its Mathematical Description

Entropy generation of volumetric type of viscous fluids is demonstrated as [87,88]:

$$S'' = \frac{K(T)}{L_0^2 \rho} \left[ \frac{\partial T}{\partial y} \right]^2 + \frac{16c T_0^4}{8k} \left( \frac{\partial T}{\partial y} \right)^2 + \frac{\mu(T)}{C_0} \left( \frac{\partial y}{\partial y} \right)^2 + \frac{Rd \frac{\partial C}{\partial y}}{C_0} \left( \frac{\partial y}{\partial y} \right)^2 + \frac{Rd \frac{\partial T}{\partial y}}{C_0} \left( \frac{\partial C}{\partial y} + \frac{\partial C}{\partial x} \frac{\partial y}{\partial y} \right) + \frac{\sigma B^2 \mu^2}{T_0}$$  \hspace{1cm} (29)

Equation (29) illustrates that the entropy generation has two main features, i.e., the irreversibility of the transmission of heat, and the fluid friction irreversibility. Magnetic and porosity effects are illustrated in the last two terms. The aspects of entropy generation are illustrated by mathematical description, given by

$$S''_0 = \frac{K_0 (\Delta T)^2}{L_0^2 T_0^2},$$  \hspace{1cm} (30)

while $N_G = \frac{S''}{S''_0}$, demonstrates the ratio of the actual entropy generation to the generation rate of characteristic entropy. This number $N_G$ for a non-dimensional system takes the form:

$$N_G = Re (1 + \epsilon \theta + Rd) (\theta')^2 + \frac{R_e Br}{\Omega(1 + \Lambda)} (f')^2 + \frac{R_e Br}{\Omega} M (f')^2 + Re \lambda \left( \frac{\lambda}{\Omega} \right)^2 (\phi')^2 + Re \lambda \left( \frac{\lambda}{\Omega} \right) \theta' \phi',$$  \hspace{1cm} (31)
where \( Br \) is used for the Brinkman number, \( \lambda \) represents the diffusion quantity, \( M \) demonstrates the parameter of the magnetic field, \( \Omega \) and \( \chi \) denotes the dimensionless temperature and concentration change, respectively.

The illustrated mathematical description of each parameter is given as:

\[
R_e = \frac{bl^2}{v}, \quad \Omega = \frac{\Delta T}{T_0}, \quad \chi = \frac{\Delta C}{C_0}, \quad \lambda = \frac{RdC_0}{k}.
\] (32)

The source of the generation of the entropy is an important class for engineers, the Bejan number is responsible for such an important measurement, which is defined as:

\[
Be = \frac{k(T)}{T_0} \left( \left( \frac{\partial T}{\partial y} \right)^2 + \frac{16\nu T}{3k} \left( \frac{\partial T}{\partial y} \right)^2 \right)
\] 
\[
\mu \left( \frac{\partial u}{\partial y} \right)^2 + \sigma B_0^2 \left( \frac{\partial u}{\partial y} \right)^2
\] (33)

The alternative representation of the Bejan number, after using the similarity transformations, is:

\[
Be = \frac{(1 + \epsilon\theta + Rd)(\theta')^2}{\Omega (f'')^2 + \frac{8r}{\Omega} M (f'')^2}
\] (34)

5. Solution by HAM

Numerical methods applied presently uses the concept of linearization and discretization to tackle the nonlinear systems. HAM is the method used for the same purpose, analytically, as the numerical techniques. Its derivation is totally dependent on the topological concept known as homotopy. Liao [97,98] was the first to use this concept successfully. For this purpose, Liao used the idea of homotopy by considering two continuous functions \( \Psi_1 \) and \( \Psi_2 \) defined on the topological spaces \( \bar{X} \) and \( \bar{Y} \). The homotopic idea explained in topological spaces is implemented over a closed unit interval by:

\[ \Psi : \bar{X} \times [0,1] \to \bar{Y} \]

where the relation holds for all \( \bar{x} \in \bar{X} \), together with \( \Psi(\bar{x}, 0) = \bar{\xi}_1(\bar{x}) \) and \( \Psi(\bar{x}, 1) = \bar{\xi}_2(\bar{x}) \). The mapping defined by \( \Psi \) is known as a homotopic function in the literature. Equations (20)–(23) have been tackled by HAM. Solutions are restricted by a new parameter, \( \bar{h} \), which modifies and links the solutions in an appropriate manner.

We guess

\[
f_0(\eta) = \frac{1}{4\beta^2} (4\beta^2 \eta + 3\beta(S - 2)\eta^2 + (2 - S)\eta^3), \quad \theta_0(\eta) = 1, \quad \phi_0(\eta) = 1.
\] (35)

The linear operators represented by \( L_f, L_\theta \) and \( L_\phi \) are defined as:

\[
L_f(f) = f'''' \quad L_\theta(\theta) = \theta'' \quad \text{and} \quad L_\phi(\phi) = \phi''
\] (36)

with the following properties

\[
L_f(a_1 + a_2\eta + a_3\eta^2) = 0, \quad L_\theta(a_4 + a_5\eta) = 0, \quad \text{and} \quad L_\phi(a_6 + a_7\eta) = 0.
\] (37)

6. HAM Solution Convergence

The goal of the HAM solution (series solution) is its convergence, which is always linked to some constraints. The subordinate restrictions \( \bar{h}_f, \bar{h}_\theta, \) and \( \bar{h}_\phi \) are implemented in the HAM procedure. The embedding parameters choice guarantee the solution convergence [99]. In our case, the proposed method shows the performance in the form of results, which are valid and efficient. The probability
sectors of \( h \) are constructed \( h \)-curves of \( \tilde{f}''(0) \), \( \tilde{\theta}'(0) \) and \( \tilde{\phi}'(0) \) for the HAM solution (approximated) of order 25. The effective domains of \( h \) are \(-1.5 < h_f < 0.0 \), \(-1.5 < h_\theta < 0.0 \) and \(-2.5 < h_\phi < 0.0 \). Figure 1 illustrates the HAM technique convergence of \( h \)-curves for the state variables (velocity, temperature, and concentration). The numerical values of HAM solution convergence with the variations of different parameters are presented in Tables 1 and 2. The table illustrates that HAM is a rapidly convergent method.

![Figure 1](image-url)

**Figure 1.** (a,b) \( h \)-curve representation of \( f(\eta) \), \( \theta(\eta) \) and \( \phi(\eta) \).

### Table 1. 25th-order approximation table for HAM convergence, when \( \gamma_1 = Sc = 0.5 \), \( Nt = Gr = \beta = St = 0.1 \), \( h = -0.5 \), \( Pr = Nb = Gm = 0.1 \).

<table>
<thead>
<tr>
<th>Approximation Order</th>
<th>( f''(0) )</th>
<th>( \theta'(0) )</th>
<th>( \phi'(0) )</th>
</tr>
</thead>
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<tr>
<td>1</td>
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<td>0.0537500</td>
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<td>-0.106817</td>
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<td>9</td>
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<td>-0.106809</td>
<td>0.0959997</td>
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<tr>
<td>11</td>
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<td>-0.106807</td>
<td>0.0961163</td>
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<tr>
<td>13</td>
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<td>0.0961457</td>
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<tr>
<td>15</td>
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<td>-0.106806</td>
<td>0.0961530</td>
</tr>
<tr>
<td>17</td>
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<td>0.0961548</td>
</tr>
<tr>
<td>19</td>
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<td>-0.106806</td>
<td>0.0961552</td>
</tr>
<tr>
<td>23</td>
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<td>-0.106806</td>
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<tr>
<td>25</td>
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<td>-0.106806</td>
<td>0.0961554</td>
</tr>
</tbody>
</table>

### 7. Results and Discussion

The objective of our investigation focuses on the interpretation of the thin film flow of nanoliquid flow parameters. Figures 2–23 reveal the comprehension of the parameters involved in our model equations.

#### 7.1. Velocity Profile

The liquid film thickness \( \beta \) along the direction of the fluid flow is illustrated in Figure 2. The flow velocity curve declines with the larger numbers of the film thickness \( \beta \), because the dimensionless thin film thickness is directly related to the fluid thickness \( h(t) \) and is the function of viscosity. As a result, an increase in \( \beta \) further increases the viscosity of the film, which further causes in the decline of the velocity curve. This happens due to the indirect relationship between \( \beta \) and the flow velocity profile, i.e., the increasing values of \( \beta \) decrease the viscosity of the fluid, which as a result decreases the velocity profile.
Figure 2. Impact of $\beta$ on $f'(\eta)$, when $\gamma_1 = 0.2, St = 0.6, Gm = 0.8, Gr = 0.7, M = 0.8$.

Figure 3 reflects the impact of the unsteadiness parameter over the profile of the velocity for dissimilar values of the embedded parameters. A direct variation can be observed in the profile of the velocity with the variations in the unsteadiness parameter $St$ in the figure as demonstrated. These variations are due to the effect of the stretching parameter. The unsteadiness parameter is a function of the liquid film thickness, which further varies directly with the stretching parameter and as a result increases the velocity profile. An increase in $St$ rises the motion of the fluid. Investigation demonstrates that the solution exists for $St \in [0, 2]$ and strongly depends on the parameter $St$.

Figure 4 illustrates the mixed convective effect on the flow. In Figure 4 $Gm$ shows the characteristic of buoyancy forces, which play a favorable behavior for the state variable velocity. The mixing parameter is mainly affected by the length, concentration difference, and the kinematic viscosity of the nanofluid. There is an inverse relation between the velocity and the viscosity of the nanofluid. Therefore, when the mixing parameter increases, the liquid film concentration increases directly, and the viscosity decreases, which further causes increase of the profile of the velocity. The velocity profile shows a direct relation to $Gm$. 
Figure 4. Impact of $Gm$ on $f'(\eta)$, when $\gamma_1 = 0.2, \beta = 0.9, St = 0.3, Gr = 0.7, M = 0.9$.

Figure 5 reveals the effect of the order two-fluid velocity distribution parameter $\gamma_1$. Physically, this parameter is inversely related to the density, keeping the thickness parameter constant. Therefore, an increase in the values of the parameter $\gamma_1$, would decrease the density of the fluid, which further causes in the increase of the velocity profile. In other words, it would make the fluid less dense and as a result the fluid velocity jumps up. Thus, the larger the values of non-Newtonian parameter, the greater the motion of thin film.

Figure 6 illustrates the relation between Grashof parameter $Gr$ and the profile of the velocity. Here $Gr$ shows the characteristics of buoyancy forces, which offers a favorable behavior for the velocity profile. Physically, Grashof number $Gr$ is the ratio of the buoyancy force to the viscous force. Increasing values of the buoyancy forces cause the decrease of the viscous forces, which as a result producing faster motion. In summary, the increasing values of $Gr$ causes a rapid increase in the velocity profile.
Figure 6. Impact of $Gr$ on $f'(\eta)$, for $\gamma_1 = 0.4, \beta = 0.6, St = 0.5, Gm = 0.8, M = 0.7$.

Figure 7 illustrates the variation of the magnetic parameter $M$ over the velocity profile. Since the magnetic parameter is applied horizontally to the surface on which the nanofluid flows, so an increase in the magnetic parameter would increase the strength of the magnetic field that create bending on the surface of the plate. This bending causes the decline of the velocity profile, but does nothing to the magnitude. In short, with the increasing values of the magnetic parameter $M$, a decrease is observed in the velocity profile.

Figure 7. Impact of $M$ on $f'(\eta)$, for $\gamma_1 = 0.2, \beta = 0.6, St = 0.6, Gr = 0.5, Gm = 0.8$.

7.2. Temperature Profile

The effect of thermal radiations $Rd$ on $\theta(\eta)$ is discussed in Figure 8. The figure reveals an inverse relationship between the thermal radiation parameter $Rd$ and the temperature profile. For higher values of $Rd$ a rapid decrease can be observed in the profile of the temperature and vice versa.
Figure 8. Impact of $Rd$ on $\theta(\eta)$, for $\beta = 0.1, St = 0.1, Nt = 0.6, Nb = 0.5$.

Figure 9 reveals the impact on the temperature profile of the thermophoresis parameter $Nt$. The limitations on thermophoresis helps in the increase of a surface temperature. The irregularity in motion (Brownian motion) causes a temperature increase due to the kinetic energy produced by nano-suspended particles; consequently, a thermophoretic force is produced. The fluid starts in the opposite direction of the stretching sheet, due to the intensity produced by this force. As a result, larger values of $Nt$ cause an increase in temperature, due to which the surface temperature also increases.

Figure 9. Impact of $Nt$ on $\theta(\eta)$, for $\beta = 0.1, St = 0.1, Rd = 0.2, Nb = 0.3$.

Figure 10 demonstrates the effect on the profile of a heat $\theta(\eta)$ of the unsteadiness parameter $St$. It is observed that $\theta(\eta)$ directly varies with unsteadiness parameter $St$. The higher numbers of the unsteadiness parameter $St$ increases the temperature, which further causes increase in the kinetic energy of the fluid, the result of which appears in the form of increase in the liquid film.
The impact of thin film thickness $\beta$ on temperature for different values of the embedded parameter is presented in Figure 11. Since the thickness parameter is the function of the kinematic viscosity and fluid thickness, so an increase in $\beta$ would increase the viscosity, which further causes the decline of the temperature profile. Thus, for larger values of $\beta$, the profile of the temperature falls. The same effect can be seen in the profile of the velocity for $\beta$.

Figure 11. Impact of $\beta$ on $\theta(\eta)$, for $St = 0.1$, $Nt = 0.5$, $Rd = 0.6$, $Nb = 0.5$.

Figure 12 illustrates the temperature distribution under Brownian motion parameter $Nb$. In general, due to the irregular motion of particles, a collision is produced between the particles. The figure shows that an increase in heat of the fluid can be observed with the ascending order of the Brownian motion parameter, $Nb$; consequently, free surface nanoparticle volume friction decreases.
7.3. Concentration Profile

Figure 12 illustrates the effects on concentration profile $\phi(\eta)$ of the Brownian motion parameter $Nb$. The irregularity and turbulence in the motion of the fluid particles is normally known as Brownian motion. At molecular level, Brownian motion of micropolar nanofluid leads to the thermal conductivity of nanofluids. The figure illustrates the increase in $Nb$ in the form of a decline in the profile of the concentration. The boundary-layer thicknesses diminish due to the larger values of Brownian motion, which results in reduction of the concentration profile.

Figure 13 shows the concentration profile $\phi(\eta)$ behavior, under the effect of the unsteadiness parameter $St$. A direct relation can be observed between the unsteadiness parameter $St$ and the concentration profile $\phi(\eta)$. Higher values of the unsteadiness parameter $St$ increases the profile of temperature that blows the kinetic energy of the fluid, which further causes an increase in the concentration of the liquid film.
Figure 14. Impact of St on \( \phi(\eta) \), for \( Nt = 0.1, Nb = 1.2, Sc = 0.5, \) and \( \beta = 0.9 \).

Figure 15 illustrates the effect on concentration field of the thermophoresis parameter \( Nt \). The figure demonstrates that the concentration profile rises due to an increase in \( Nt \). This is because of higher values of \( Nt \) increase the nanofluid molecule kinetic energy, as a result of which the concentration increases.

Figure 16 illustrates the thin film thickness \( \beta \) effect on \( \phi(\eta) \) for different values of the embedded parameters. The thickness parameter is inversely related to the kinematic viscosity; we know that kinematic viscosity is inversely proportional to the density of the fluid, so increasing the thickness parameter \( \beta \) causes the decline of the concentration profile. Thus, it is obvious that the concentration profile falls with higher numbers of \( \beta \). The same effect was observed for \( \beta \) in the velocity distribution as well as in temperature distribution.
Figure 16. Impact of $\beta$ on $\phi(\eta)$, when $Nt = 0.1$, $Nb = 0.3$, $Sc = 0.3$, $St = 0.1$.

Figure 17 demonstrates the opposite information as discussed in the temperature distribution under different parameters. The diagram shows that with increasing values of Schmidt number $Sc$, the concentration profile decreases, consequently reducing the thickness of the boundary-layer.

7.4. Entropy Profile

The diagram reflects the variations of Brinkman number $Br$ verses Bejan number $B$. It is observed that with increasing values of $Br$ the Bejan number $B$ declines. There is no variation in the Bejan number, and it remains constant up to 0.8 for the values of $\eta$ in decreasing order for different values of the Brinkman number. Large variations are observed for smaller values of $\eta$ as we increase the values of Brinkman number.

Figure 18 illustrates the variations in Bejan number under dissimilar values of the magnetic parameter $M$. It is clear from the figure that for larger values of $M$, the Bejan number boots up. Similar variations are observed for Brinkman number in Figure 19. The variations here are constant for smaller values of the magnetic parameter in the range of $0.85 < \eta \leq 1.0$. Large variations are investigated for greater values of the magnetic parameter in the range of $0.0 < \eta \leq 0.2$. 
Figure 18. Deviations in Bejan number $B_e$ for dissimilar numbers of $M$, when $Br = 0.1$, $Re = 0.7$, $Rd = 0.6$, and $Pr = 0.6$.

Figure 19. Variations in $B_e$ for dissimilar values of $Br$, when $M = 0.1$, $Re = 0.7$, $Rd = 0.6$, and $Pr = 0.6$.

Figure 20 illustrates the effect of Reynolds number on $N_G(\eta)$. For greater values of $Re$ the entropy regime increases. Consequently, Reynolds number and entropy function variates directly. From the graph it is clear that for large values of $\eta$ the variations in entropy remains constant, while this variation jumps up for large values of the Reynolds number in the range of $0.0 \leq \eta \leq 0.4$.

Figure 20. Variations in the function of entropy $N_G(\eta)$ for dissimilar values of $Re$, when $Br = 0.1$, $Rd = 0.6$, $M = 1.3$. 

Figure 21 demonstrates the variations in entropy number with the variations in Prandtl number $Pr$. The figure demonstrates that for larger values of the Prandtl number $Pr$, the temperature profile rises, and consequently, the entropy function boots up. The variations in the entropy function jumps up throughout inside the interval $0.0 \leq \eta \leq 1.0$. The increasing values of the Prandtl number increases the entropy function exponentially.

![Figure 21: Variations in the function of entropy $N_G(\eta)$ for unlike values of $Pr$, when $Br = 0.3$, $Re = 0.7$, $Rd = 0.7$ and $M = 0.9$.](image)

Figure 22 demonstrates the variations of magnetic parameter on the entropy function $N_G(\eta)$. It is clear from the figure that for larger numbers of $M$, the entropy function reduces, because the Lorentz force in the magnetic field produces the resistance strength. These variations in the entropy function exist in the range of $0.0 \leq \eta \leq 0.65$ for larger values of the magnetic parameter, and remains constant elsewhere.

![Figure 22: Variations in the function of entropy $N_G(\eta)$ for unlike values of $M$, when $Br = 0.3$, $Re = 0.7$, $Rd = 0.7$ and $Pr = 1.2$.](image)

Figure 23 demonstrates the effect of Brickman number $Br$ on the generation function of entropy $N_G(\eta)$. Figure shows that for larger numbers of the Brickman number $N_G(\eta)$ increases. Viscous dissipation produces heat, which as a result raises the generation of entropy due to the lower conduction rate. The figure demonstrates that the variation in the entropy function remains constant between $0.64 < \eta \leq 1.0$, while an increasing tendency is observed for large values of the Brickman number elsewhere.
7.5. Table Discussion

The influence of different parameters is demonstrated in Tables 2–4. Table 2 explains the effect on skin friction of $M$, $Gr$, $\beta$, and $St$. The skin-friction coefficient shows a rapid increase, with larger numbers of the unsteady parameter $St$, while for large values of the magnetic parameter $M$ the Nusselt number decreases. On the other hand, larger values of the Grashof number $Gr$ and thickness parameter $\beta$ cause the decline of the skin-friction coefficient. Physically, Grashof number arises in the natural convection due to density difference. Viscous forces are also the functions of dependence of the Grashof number. Increasing the viscosity coefficient causes a decrease in the Grashof number. Therefore, as a result, the increasing values reduce the skin friction.

Table 3 reveals the effect on $Nu$ of the parameters $M$, $St$, $\beta$, and $Pr$. It is noted that the larger the values of $M$ (magnetic parameter), and the unsteadiness parameter $St$, the smaller the Nusselt number $Nu$. On the other hand, the Nusselt number $Nu$ increases with larger values of unsteadiness parameter $St$ and thickness parameter $\beta$. The increasing values of the Prandtl number decreases $Nu$.

The effects of Brownian motion $Nb$, thermophoretic parameter $Nt$, Schmidt number $Sc$, Prandlt $Pr$, and unsteadiness parameter $St$ on Sherwood number are demonstrated in Table 4. It is clear that the increasing values of the thermophoretic parameter increases the Sherwood number. An inverse relation is observed between the Schmidt number and Sherwood number. The same phenomenon appears in observations for the unsteady parameter $St$ and Prandtl number $Pr$ for the Sherwood number in the form of decline. The larger values of the Prandtl number show an exponential decline in the Sherwood number.

Table 2. Variation in skin-friction coefficient, under dissimilar values of $M$, $Gr$, $\beta$ and $St$.

<table>
<thead>
<tr>
<th>$M$</th>
<th>$Gr$</th>
<th>$\beta$</th>
<th>$St$</th>
<th>$C_f$</th>
</tr>
</thead>
<tbody>
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<td>0.1</td>
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<td>0.1</td>
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Figure 23. Variations in the function of entropy $N_G(\eta)$ for unlike values of $Br$, when $M = 0.7$, $Re = 0.6$, $Rd = 0.8$ and $Pr = 1.5$. 
Table 3. For dissimilar values of $Pr$, $M$, $Rd$ and $St$ variations in $Nu$ (Nusselt Number).

<table>
<thead>
<tr>
<th>$M$</th>
<th>$\beta$</th>
<th>$St$</th>
<th>$Pr$</th>
<th>$Nu$</th>
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Table 4. For dissimilar values of $Nb$, $Nt$, $Sc$, $Pr$, and $St$, variations in Sherwood Number.

<table>
<thead>
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<th>$Nt$</th>
<th>$Sc$</th>
<th>$St$</th>
<th>$Pr$</th>
<th>$Sh$</th>
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8. Conclusions

These reconsideration efforts are worthy enough to categorize the enhancement in heat transfer and thermal conductivity of non-Newtonian fluid with nanoparticle conductive properties. The velocity profile shows an increase with increasing value of the unsteadiness parameter $St$, while the increasing values of the magnetic parameter causes the decline of the velocity profile of the nanofluid film. It is shown that the coefficient of skin friction rises with the larger rates of the magnetic parameter $M$ and the unsteadiness parameter $St$; on the other hand, the coefficient of skin friction decreases with higher values of the stretching and thickness parameters. The temperature profile shows a direct variation with Brownian motion parameter. The thermal boundary-layer thickness decreases with increasing values of the of $Sc$. Nusselt number with increasing values of the radiation parameter increases. The surface temperature of the fluid increases with increasing values of Prandtl number, while an opposite tendency is observed with larger values of the unsteady parameter on the temperature profile. Similar results are investigated for the temperature profile with the variation of the thermophoresis parameter. The mass flux shows a decline with higher numbers of the Brownian motion parameter, while an opposite trend is experienced for the thermophoretic parameter. The implemented technique convergence is shown numerically for the validation of our technique.

Author Contributions: A.U., Z.S. and S.I. modeled the problem and wrote the manuscript. P.K. and M.A. thoroughly checked the mathematical modeling and English corrections. M.J. and A.U. solved the problem using
Mathematica software, and P.K., Z.S., M.J., and M.A. contributed to the results and discussions. All authors finalized the manuscript after its internal evaluation.

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**Conflicts of Interest:** The authors declare no conflict of interest.

**Abbreviations**
The following abbreviations and parameters with their possible dimensions stated here are used in this article:

- \( Sh \) \text{Sherwood number}
- \( \beta \) \text{Film thickness parameter}
- \( Nu \) \text{Nusselt number}
- \( St \) \text{Unsteady parameter}
- \( Re \) \text{Reynolds number}
- \( Pr \) \text{Prandtl number}
- \( \zeta \) \text{Stretching parameter}
- \( Sc \) \text{Schmidt number}
- \( U_w \) \text{Stretching velocity} \( \left( \frac{m}{s} \right) \)
- \( Nt \) \text{Thermophoretic parameter}
- \( C_f \) \text{Skin-friction coefficient}
- \( Nb \) \text{Brownian motion parameter}
- \( T \) \text{Fluid temperature} \( (K) \)
- \( I \) \text{Identity tensor}
- \( v \) \text{Kinematic viscosity} \( \frac{m^2}{s} \)
- \( \rho \) \text{Density} \( \left( \frac{Kg}{m^3} \right) \)
- \( \mu \) \text{Dynamic viscosity} \( mPa \)
- \( c_p \) \text{Specific heat} \( \left( \frac{J}{KgK} \right) \)
- \( h(t) \) \text{Thickness of liquid}
- \( Q_w \) \text{Heat Flux} \( \left( \frac{W}{m^2} \right) \)
- \( j_w \) \text{Mass flux} \( \left( \frac{Kg}{sec.m^2} \right) \)
- \( f \) \text{Dimensionless velocity}
- \( \infty \) \text{Condition at infinity}
- \( \theta \) \text{Reference condition}
- \( \tilde{u} \) \text{Velocity component in} \( x \)-direction \( \left( \frac{m}{s} \right) \)
- \( \tilde{v} \) \text{Velocity component in} \( y \)-direction \( \left( \frac{m}{s} \right) \)
- \( x, y, z \) \text{Coordinates} \( (m) \)
- \( \eta \) \text{Similarity variable}
- \( t \) \text{Time} \( (sec) \)
- \( \omega \) \text{Frequency parameter}
- \( A_1 \) and \( A_2 \) \text{Revilin Erickson Tensor}
- \( E \) \text{Electric Field}
- \( a \) \text{Non-Newtonian Parameter}
- \( u_0 \) \text{Magnetic Permeability}
- \( a_1 \) and \( a_2 \) \text{Material constants}
- \( Gm \) \text{Mixing parameter}
- \( \sigma \) \text{Electric conductivity}
- \( j \) \text{Current density}
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